



*In the name of Allah the Compassionate, the Merciful
Children of Adam; we have given you clothing with which
to cover your nakedness and garments pleasing to eye, but
the finest of all these is the robe of piety.*

(Al-Quran, Sura "Al-A,raf" Ayat ~ 26, 7)

**SIMULTANEOUS PIGMENT DYEING AND
FUNCTIONAL FINISHING OF
COTTON/POLYESTER BLENDED FABRICS**



SHABANA RAFIQUE

**COLLEGE OF HOME ECONOMICS
UNIVERSITY OF PESHAWAR
(2015)**

SIMULTANEOUS PIGMENT DYEING AND FUNCTIONAL FINISHING OF COTTON/POLYESTER BLENDED FABRICS



SHABANA RAFIQUE

**A dissertation submitted to University of Peshawar for the partial fulfillment of
the requirements for the degree of Doctor of Philosophy in
Home Economics (Textiles & Clothing)**

**COLLEGE OF HOME ECONOMICS
UNIVERSITY OF PESHAWAR
(2015)**

**SIMULTANEOUS PIGMENT DYEING AND
FUNCTIONAL FINISHING OF
COTTON/POLYESTER BLENDED FABRICS**



SHABANA RAFIQUE

Ph.D Scholar

**COLLEGE OF HOME ECONOMICS
UNIVERSITY OF PESHAWAR
(2015)**

CERTIFICATE OF APPROVAL

This dissertation titled “*Simultaneous Pigment Dyeing and Functional Finishing of Polyester/Cotton Blended Fabrics*” submitted to the University of Peshawar by Ms. Shabana Rafique is hereby approved and recommended as partial fulfillment for the award of Degree of Doctor of Philosophy in Home Economics (Textiles & Clothing).

Approved by:

1. _____
Prof. Dr. Bashir Ahmad
Meritorious Professor,
Centre of Biotechnology & Microbiology,
University of Peshawar.
Research Supervisor
2. _____
Prof. Dr. Tanveer Hussain
Dean, Faculty of Engineering & Technology,
National Textile University, Faisalabad
Research Co-Supervisor
3. _____
Prof Dr. Khanzadi Fatima Khattak,
Dean, Faculty of Science,
Abdul Wali Khan University.
Mardan.
Viva Voce Examiner
4. _____
Prof. Dr. Syeda Kaniz Fatima Haider
Principal

COLLEGE OF HOME ECONOMICS
UNIVERSITY OF PESHAWAR
(2015)

DEDICATION

This thesis is dedicated to my mother, without whose prayers my success would not have been possible & my late father, Muhammad Rafique Alamgir whose prompting and cherishing words to pursue the excellence still linger on and lighten my path

TABLE OF CONTENTS

ACKNOWLEDGEMENT	i
LIST OF TABLES	iii
LIST OF FIGURES	vi
LIST OF ABBREVIATIONS	xii
ABSTRACT	xiii
 CHAPTER 1	
INTRODUCTION	1
1.1 Colouration of textiles	1
1.2 Dyes and pigments	1
1.3 Pigments as textile printing materials	2
1.3.1 Historical review	2
1.3.2 Types of pigments	2
1.3.2.1 Organic pigments	3
1.3.2.2 Inorganic pigments	5
1.4 Pigment colouration system	5
1.4.1 Pad dyeing machines/padding mangles for pigment dyeing	6
1.5 Pigment colouration system for various fabric types	7
1.5.1 Pigment dyeing of lyocell fabrics	7
1.5.2 Pigment dyeing of silk fabrics	7
1.5.3 Pigment and reactive dyeing system for cotton	8
1.6 Colouration of cotton and polyester fabrics	8
1.6.1 Cotton polymer system	8

1.6.2	Dyeing of cotton	9
1.6.3	Polyester polymer system	9
1.6.4	Dyeing of polyester	10
1.7	Colouration of polyester/cotton blended fabrics with various dyestuffs	10
1.7.1	Dyeing of P/C blended fabrics with disperse and reactive dyes	10
1.7.2	Dyeing of P/C blended fabrics with direct dyes	11
1.8	Dyeing of P/C blended fabrics with pigment colouration system	12
1.8.1	Binders in the pigment colouration system	13
1.8.2	Binder mechanism	14
1.8.3	Classification of Binders: based on chemical constitution	15
1.8.3.1	Butadiene copolymers	15
1.8.3.2	Acrylic binders	16
1.8.4	Selection of binder	16
1.8.5	Novel approach for synthesis of aqueous binder for pigment printing and dyeing	17
1.8.6	Film forming binders	17
1.9	Incorporation of crosslinkers in the binder system	18
1.9.1	Amino resins	18
1.9.2	Urea formaldehyde resins	19
1.9.2.1	Reaction mechanism of N-methylol with cellulose	20
1.9.2.2	Effect of DMDHEU on tensile, tear and abrasion resistance	22
1.9.3	Melamine resins	22
1.10	Incorporation of softeners in pigment colouration system	24
1.10.1	Definition of softener	24
1.10.2	Types of softeners	24
1.10.2.1	Anionic softeners	25
1.10.2.2	Cationic softeners	25
1.10.2.3	Nonionic softeners	25
1.10.3	Silicon softeners	25

1.10.4 Methyl oils	26
1.10.5 Amino oils	26
1.10.6 Amphoteric softeners	27
1.10.7 Fatty acid amide condensation products	27
1.10.8 Polyethylene emulsions	28
1.11 Functional finishes	28
1.11.1 Flame retardant finishes	28
1.11.1.1 Mechanism of flame retardants	28
1.11.1.2 Type of flame retardant compounds	29
1.11.1.3 Flame retardant finishes on cotton and polyester fabrics	30
1.11.2 Hand Builders	30
1.11.2.1 Type of hand builders	31
1.11.3 Water and oil repellent finishes	32
1.11.3.1 Oil repellency	32
1.11.3.2 Water repellency	32
1.11.3.3 Water-proof fabrics	32
1.11.3.4 Fluorochemical oil and water repellents	32
1.12 Various characteristics of fabrics influenced by dyeing and finishing treatment	33
1.12.1 Colourfastness	33
1.12.2 Rubbing fastness	33
1.12.3 Abrasion resistance	34
1.12.4 Pilling	34
1.12.5 Tearing resistance	35
1.13 Simultaneous dyeing and finishing	35
1.14 Aims and objectives	37

CHAPTER 2

MATERIALS AND METHODS 38

2.1 Materials 38

2.1.1	Fabric	38
2.1.2	Preparation of fabric prior to dyeing and finishing	38
2.1.2.1	De-sizing	38
2.1.2.2	Scouring	38
2.1.2.3	Bleaching	39
2.2	Pigments	39
2.3	Auxiliaries for pigment dyeing	40
2.4	General chemicals for dyeing and finishing	41
2.5	Equipment for dyeing and finishing	44
2.5.1	Padder for dyeing	44
2.5.2	Tenter	45
2.6	Testing	46
2.6.1	Colourfastness	46
2.6.1.1	Colourfastness to washing	46
2.6.1.2	Colourfastness to rubbing (wet & dry)	47
2.6.2	Tear strength of fabrics	49
2.6.3	Tensile strength and elongation	50
2.6.4	Abrasion resistance	50
2.6.5	Pilling assessment	52
2.6.6	Flexural rigidity	52
2.6.7	Standard test method for flame resistance of textiles (vertical flammability test)	53
2.6.8	Mass (weight) per unit area	54
2.7	Application Methods	55
2.7.1	Application of base formulation	55
2.7.2	Two-step dyeing and finishing	55
2.7.3	Meta phase dyeing and finishing	55
2.7.4	Mode of application for pigment dyeing	55
2.7.5	Mode of application for pigment dyeing and finishing	56
2.8	Formulations for Dyeing & Finishing Treatment on Padding Mangle	57

2.8.1	Base formulation for pigment dyeing	57
2.8.2	Incorporation of crosslinkers in optimized binder systems	57
2.8.3	Formulations with softeners	58
2.8.4	Post treatment of pigment dyed fabrics with functional finishes	59
2.8.5	Simultaneous pigment dyeing and functional finishing	59
2.9	Statistical Analysis	59

CHAPTER 3

RESULTS AND DISCUSSIONS	61
3.1	Effect of different binders on the properties of pigment dyed fabrics 61
3.1.1	Colourfastness of the pigment dyed samples 61
3.1.1.1	Dry rubbing fastness 63
3.1.1.2	Wet rubbing fastness 63
3.1.1.3	Washing Fastness (shade change) 68
3.1.1.4	Washing fastness (staining) 68
3.1.2	Tensile strength 75
3.1.3	Tear strength 79
3.1.4	Flexural rigidity 84
3.1.5	Abrasion resistance 88
3.1.6	Pilling resistance 92
3.2	Effect of different crosslinking agents on the properties of pigment dyed fabrics 95
3.2.1	Effect of different crosslinking agents on colourfastness properties 95
3.2.1.1	Effect of different crosslinking agents on dry rubbing fastness 98
3.2.1.2	Effect of different crosslinking agents on wet rubbing fastness 100
3.2.1.3	Effect of different crosslinking agents on washing fastness (shade change) 102
3.2.1.4	Effect of different crosslinking agents on washing fastness (staining) 102
3.2.2	Effect of different crosslinking agents on tensile strength 106

3.2.3	Effect of different cross linking agents on tear strength	109
3.2.5	Effect of different crosslinking agents on flexural rigidity	113
3.2.6	Effect of cross linking agents on abrasion resistance	116
3.2.7	Effect of different crosslinking agents on pilling grades	119
3.3	Effect of Different Softeners on the Properties of Pigment Dyed Fabrics	122
3.3.1	Effect of different softeners on the colourfastness Properties of pigment dyed P/C fabrics	122
3.3.1.1	Effect of different softeners on the dry rubbing fastness	122
3.3.1.2	Effect of different softeners on the wet rubbing fastness	123
3.3.1.3	Effect of different softeners on the washing fastness (shade change)	126
3.3.1.4	Effect of different softeners on the wash fastness(staining)	129
3.3.2	Effect of different softeners on the tensile strength of fabrics	130
3.3.3	Effect of softeners on the tear strength of fabrics	134
3.3.4	Effect of softeners on the flexural rigidity of fabrics	137
3.3.5	Effect of softeners on the abrasion resistance of pigment dyed P/C fabrics	141
3.3.6	Effect of softeners on pilling resistance	144
3.4	Effect of different functional finishes, on the properties of pigment dyed fabrics	147
3.4.1	Effect of different functional finishes on the colourfastness properties	148
3.4.1.1	Effect of different functional finishes on the dry rubbing fastness	152
3.4.1.2	Effect of different functional finishes on the wet rubbing fastness	155
3.4.1.3	Effect of different functional finishes on the wash fastness (shade change)	158
3.4.1.4	Effect of different functional finishes on the wash fastness (Staining)	158
3.4.2	Effect of different functional finishes on the tensile strength	164
3.4.3	Effect of different functional finishes (types, concentrations	172

and application methods) on tear strength	
3.4.4 Effect of different functional finishes on the flexural rigidity	178
3.4.5 Effect of different functional finishes on the abrasion resistance	182
3.4.6 Effect of different functional finishes on the pilling resistance	188
3.4.7 Flame retardant finishes on pigment dyed P/C fabrics	192
CONCLUSION AND RECOMMENDATIONS	194
REFERENCES	206
APPENDICES	213
Appendix A	
Table1: Paired sample T-Test for comparing tensile strength between the means of two selected binders	213
Table 2: Paired sample T-Test for comparing tear strength between the means of two selected binders	213
Appendix B	
Table 3: Paired sample T-test for comparing abrasion resistance between means of two selected binders	214
Table 4: Paired sample T Test for comparing the means between the tensile strength of softener treated and untreated dyed P/C fabrics	214
Appendix C	
Table 5: Paired sample T-Test for comparing the means between the tear strength of softener treated and untreated dyed P/C fabrics	215
Table 6: Paired sample T Test for comparing the means between the flexural rigidity of softener treated and untreated dyed P/C fabrics	215

Appendix D

Table 7: Paired Sample T-Test for comparing the means of tensile strength of P/C fabrics by PFPD &MFPD	216
Table 8: Paired samples T- test for comparing abrasion resistance of P/C fabrics by PFPD &MFPD process	216

Appendix E

Table 9: Paired samples T-Test for comparing tear strength of P/C fabrics by PFPD&MFPD process	217
Table10: Paired samples T- test for comparing flexural rigidity of P/C fabrics by PFPD &MFPD process	217

Appendix F

Exhibit1: Abraded P/C specimens, dyed with incorporated modified DHEU & assorted softeners	218
--	-----

Appendix G

Figure 1: Effect of various softeners on the cumulative colourfastness properties of DHEU treated pigment dyed P/C fabrics	219
--	-----

ACKNOWLEDGEMENTS

First of all, I would like to thank Allah who has given me the strength to take such a challenging task and complete it with constancy of disposition. It is absolutely incumbent upon me to highlight the names of my teachers, well-wishers and friends. I would like to give them their due as they are the ones whose support and encouragement brought this day of success and glory. It is due to their persistent endeavors that I have been able to reach my destination. I owe my heartfelt gratitude to Dr. Bashir Ahmad, Meritorious Professor, who consented to supervise my research. I am grateful to him for his scholastic guidance; his patience and his perpetual encouragement. Besides his academic facilitation his positive criticism enabled me to achieve my goal successfully.

Prof. Dr. Tanveer Hussain, Dean, Faculty of Engineering & Technology, National Textile University, Faisalabad played an instrumental role in the formulation of my experimental work. His assistance and guidance is commendable in this regard. He guided me at every step during the completion of this project.

I am thankful to Prof. Nisar Ahmad Jamil, Ex-Dean, Quality Assurance Cell, NTU, Faisalabad for his compassionate and kind attitude. He facilitated me to utilize the library resources generously and to avail accommodation at NTU. His generosity and hospitality can never be forgotten.

I am grateful to my principal, Prof. Dr. Kaniz-e-Fatima Haider, for her supportive attitude, keen interest and sympathetic facilitation throughout our course work. Prof. Dr. Ghazala Nizam, Prof Dr. Fanila Far, and Ms. Nuzhat Dar, former principals have extended their full cooperation during their tenures for which I am all praise.

My special thanks go out to Ms. Shahnaz Khattak, Head of Deptt, Textiles & Fashion Designing and one of my best friends, for fortifying my courage to overcome the problems that I have confronted during hard times. I am thankful to her for channelizing my thoughts and enriching my ideas.

I also seize this opportunity to thank the technical staff of the Textile processing Laboratory and Textile physical laboratory, N.T.U, Faisalabad, who provided necessary facilities and a good working environment during the research work.

My special thanks to the management of BASF, Clariant and Huntsman Chemical companies for providing dyes, auxiliaries and finishing reagents required for my research work.

I would also like to thank my friends, Faiza Touqeer, Imrana Seemi and Zil-e-Huma, who encouraged me at every step, if any problem arose. Infact, it took us hard to row the boat, but finally we got to the shore. I am profoundly thankful to all my colleagues, teaching and non- teaching staff and my dear students, who have supported me during this period.

My family has contributed enormously to my success. I am indebted to my mother for her prayers and concern. Moreover, the credit of my achievement goes to my husband; Dr. Sajjad; my children, Maham, Moez and Hassaan; my sister, Farah Rafique. They have always been there to revitalize my dropping spirit. It would not have been possible for me to accomplish this difficult task without their support. They relieved me from household chores to focus on my academic pursuits.

I am profoundly thankful to my elder sister, Noshaba Kaleem and my brother in law for their prayers and unconditional support during my research work. I would also like to thank my brothers and their families for the supportive attitude and good wishes. My special thanks are extended to my in-laws, especially my sister-in- law, Rubina Ejaz who has encouraged me throughout this endeavour.

Not less is the role played by my friends, Asiya Sultan and Amena Nudrat, who have always kind enough to understand my fluctuating moods. I greatly value their

friendship for their constant support and love. I am grateful to Asiya, who spare time from her busy schedule to compose my final draft.

Last, but not the least is the contribution of those, who played their bit by remaining off screen. Among them are my friends Dr. Shazia Shah, Dr. Farhat Shahzad and Duaa Mujeeb.

May Allah reward them all.

Shabana Rafique.

LIST OF TABLES

Table #	Title of Table	Page #
Chapter 2		
2.1	The molecular structure of two types of pigments	39
2.2	Types of binders	40
2.3	Type of crosslinkers	41
2.4	Type of softeners	42
2.5	Functional finishing reagents	43
2.6	Pigment binder formulations at various concentrations	57
2.7	Formulations with crosslinkers	58
2.8	Treatment with softeners	58
Chapter 3		
3.1	Physical characteristics of desized, scoured and bleached P/C fabric	61
3.2	Effect of pigment concentration, different binder types and concentrations on colourfastness of the dyed samples	62
3.3	Analysis of variance for dry rubbing fastness	64
3.4	Analysis of variance for wet rubbing fastness	66
3.5	Analysis of variance for washing fastness (shade change)	70



3.6	Analysis of variance for washing fastness (staining)	72
3.7	Effect of pigment concentration, and different binder types and concentrations on tensile strength of the dyed samples	76
3.8	Analysis of variance for tensile strength	77
3.9	Effect of pigment concentration, different binder types and concentrations on tear strength of the dyed samples.	80
3.10	Analysis of variance for tear strength	81

Table #	Title of Table	Page #
3.11	Effect of pigment concentration, and different binder types and concentrations on flexural rigidity of the dyed samples.	84
3.12	Analysis of variance for flexural rigidity	85
3.13	Abrasion resistance and pilling grades of pigment dyed P/C fabrics	88
3.14	Analysis of variance for abrasion resistance	89
3.15	Analysis of variance for pilling resistance	93
3.16	Effect of different crosslinking agents on the colourfastness of dyed P/C fabrics	96
3.17	Analysis of variance for dry rubbing fastness	97
3.18	Analysis of variance for wet rubbing fastness	99
3.19	Analysis of variance for washing fastness (shade change)	101
3.20	Analysis of variance for washing fastness (staining)	103
3.21	Effect of different crosslinking agents on tensile strength of the dyed samples	106
3.22	Analysis of variance for tensile strength	107
3.23	Effect of different cross linking agents on tear strength of the dyed samples	109
3.24	Analysis of variance for tear strength	110
3.25	Effect of different crosslinking agents on flexural rigidity of the dyed samples	113
3.26	Analysis of variance for flexural rigidity	114
3.27	Effect of different crosslinking agents on flexural rigidity of the dyed samples	116
3.28	Analysis of variance for abrasion resistance	117
3.29	Analysis of variance for pilling resistance	120
3.30	Effect of different softeners on colourfastness properties	123
3.31	Effect of different softeners on tensile strength properties	131
3.32	Effect of different softeners on tear strength properties	134
3.33	Effect of different softeners on the flexural rigidity	138

Table #	Title of Table	Page #
3.34	Effect of different softeners on the abrasion resistance and pilling grades	141
3.35	Effect of different functional finishes (types, concentrations and application methods) on the colourfastness properties	149
3.36	Analysis of variance for dry rubbing fastness of dyed & finished P/C fabrics	150
3.37	Analysis of Variance for wet rubbing fastness of dyed/finished Fabrics	153
3.38	Analysis of variance for wash fastness (SC) of dyed/finished fabrics	156
3.39	Analysis of variance for wash fastness (ST) of dyed/finished fabrics	159
3.40	Effect of different functional finishes (types, concentrations and application methods) on the tensile strength	166
3.41	Analysis of variance for tensile strength of dyed/finished fabrics	167
3.42	Effect of different functional finishes (types, concentrations and application methods) on the tear strength	174
3.43	Analysis of Variance for Tear Strength of Dyed/Finished Fabrics	175
3.44	Effect of different functional finishes (types, concentrations and application methods) on flexural rigidity	179
3.45	Analysis of variance for flexural rigidity of dyed/finished fabrics	180
3.46	Effect of different functional finishes (types, concentrations and application methods) on the abrasion resistance and pilling grades	184
3.47	Analysis of variance for abrasion of dyed/finished fabrics	185
3.48	Analysis of variance for pilling of dyed/finished fabric	190

LIST OF FIGURES

Chapter 1

Fig. #	Title of Figure	Page #
1.1	Azo group	3
1.2	CI Pigment Red, 1 Para Red (Shore, 2002)	3
1.3	Pigment orange Bis Chloro ethyl ether ($C_{32}H_{24}N_8O_2$)	4
1.4	Copper Pthalocyanine	4
1.5	Quinacridone red (PV 19)	5
1.6	Structure of Cellulose polymer	8
1.7	Poly (ethylene terephthalate) unit	9
1.8	Carboxy redical as film forming group	13
1.9	Mechanism of Film formation with Cellulose	13
1.10	A copolymer of 3 mols of butyl acrylate & 1 mol of acrylonitrile	14
1.11	Schematic of film formation [Mlynar, 2003]	15
1.12	Butadiene rubber	15
1.13	Acrylic Binder	16
1.14	Structure of Urea or Carbamide (a) & Melamine (b)	18
1.15	Chemical structure of DMDHEU	20
1.16	Chemical structure of modified DMDHEU.	20
1.17	Reaction mechanism of dimethyloldihydroxyethane urea with cellulose molecule	21
1.18	Crosslinking of DMedHEU with cellulose	21
1.19	Tri methoxymethylmelamine	22
1.20	Structure of hexa methoxymethyle melamine.	23
1.21	Amino propyl (Silicon softener)	26

Chapter 2

Fig. #	Title of Figure	Page #
2.1	Laboratory Padder	44
2.2	Tenter Frame	45
2.3	Launder-o-meter for wash Fastness	47
2.4	Wash Fastness Assessment	47
2.5	AATCC Crockmeter	48
2.6	Grey scale	49
2.7	Elmendorf Apparatus for Tear Strength Testing	49
2.8	Testomtric 220 D for Tensile Strength Testing	50
2.9(a)	Martindale Abrasion Tester with specimen holder	51
2.9(b)	Lissajous Figure	52
2.10	I.C.I Pilling Box Tester	52
2.11	Shirley Stiffness Tester	53
2.12	Flame resistance (Vertical flammability test)	54

Chapter 3

Fig. #	Title of Figure	Page #
3.1	Main effects plot for dry rubbing fastness of dyed P/C fabrics	64
3.2	Effect of pigment conc., binder type and binder concentration on the dry rubbing fastness	65
3.3	Main effects plot for wet rubbing fastness of dyed P/C fabrics	66
3.4	Effect of pigment conc., binder type and binder concentration on the wet rubbing fastness	67
3.5	Main effects plot for washing fastness (shade change) of dyed P/C fabrics	70
3.6	Effect of pigment conc., binder type and binder concentration on the washing fastness (shade change)	71

Fig. #	Title of Figure	Page #
3.7	Main effects plot for washing fastness (staining) of dyed P/C fabrics	72
3.8	Effect of pigment conc., binder type and binder concentration on the washing fastness (staining)	73
3.9	Main effects plot for tensile strength of dyed P/C fabrics	77
3.10	Effect of pigment conc., binder type and binder concentration on the tensile strength of dyed P/C fabrics	78
3.11	Main effects plot for tear strength of dyed P/C fabrics	81
3.12	Effect of pigment conc., binder type and binder concentration on the tear strength of dyed P/C fabrics	82
3.13	Main effects plot for flexural rigidity of dyed P/C fabrics	85
3.14	Effect of pigment conc., binder type and binder concentration on the flexural rigidity of dyed P/C fabrics	86
3.15	Main effects plot for abrasion resistance of dyed P/C fabrics	89
3.16	Effect of pigment conc., binder type and binder concentration on the abrasion resistance of dyed P/C fabrics	90
3.17	Main effects plot for pilling performance of dyed P/C fabrics	93
3.18	Effect of pigment conc., binder type and binder concentration on the pilling resistance of P/C fabrics	94
3.19	Main effects plot for dry rubbing fastness	97
3.20	Effect of binder types and crosslinkers on the dry rubbing fastness	98
3.21	Main effects plot for wet rubbing fastness	99
3.22	Effect of binder types and crosslinkers on the dry rubbing fastness	100
3.23	Main effects plot for washing fastness (SC)	101
3.24	Effect of binder types and crosslinkers on the washing	102



	fastness (shade change)	
3.25	Main effects plot for washing fastness (ST)	103
3.26	Effect of binder types and crosslinkers on the washing fastness (staining)	104

Fig. #	Title of Figure	Page #
3.27	Main effects plot for tensile strength (warp and weft)	107
3.28	Effect of binder types and crosslinkers on the tensile strength (warp and weft)	108
3.29	Main effects plot for tear strength (warp and weft)	110
3.30	Effect of binder types and crosslinkers on the tear strength (warp and weft)	111
3.31	Main effects plot for tear strength (warp and weft)	114
3.32	Effect of binder types and crosslinkers on the flexural rigidity (warp and weft)	115
3.33	Main effects plot for abrasion resistance	117
3.34	Effect of crosslinking agents on abrasion resistance	118
3.35	Main effects plot for Pilling grades	120
3.36	Effect of crosslinking agents on pilling performance	121
3.37	Main effects plot for dry rubbing fastness of pigment dyed P/C fabrics	124
3.38	Effect of different softeners on the wet rubbing fastness of pigment dyed P/C fabrics	124
3.39	Main effects plot for wet rubbing fastness of pigment dyed P/C fabrics	125
3.40	Effect of different softeners on the wet rubbing fastness of pigment dyed P/C fabrics	125
3.41	Main effects plot for washing fastness (shade change)	127
3.42	Effect of different softeners on the wash fastness (shade change) of pigment dyed P/C fabrics	127
3.43	Main effects plot for washing fastness (staining)	128
3.44	Effect of different softeners on the wash fastness (staining) of pigment dyed P/C fabrics	128
3.45	Main effects plot for cumulative colourfastness	129

3.46	Main effects plot for tensile strength (warp & weft)	131
3.47	Effect of different softeners on the tensile strength of pigment dyed P/C fabrics	132
3.48	Main effects plot for tear strength (warp & weft)	135

Fig. #	Title of Figure	Page #
3.49	Effect of different softeners on the tear strength of pigment dyed P/C fabrics	135
3.50	Main effects plot for flexural rigidity (warp & weft)	138
3.51	Effect of different softeners on the flexural rigidity of pigment dyed P/C fabrics	139
3.52	Main effects plot for abrasion resistance	142
3.53	Effect of different softeners on the abrasion resistance of pigment dyed P/C fabrics	142
3.54	Main effects plot for pilling grades	145
3.55	Effect of different softeners on the pilling performance of pigment dyed P/C fabrics	146
3.56	Main effects plot for dry rubbing fastness of finished P/C fabric	150
3.57	Effect of functional finishes in different concentrations and application methods on the dry rubbing fastness of P/C fabrics	151
3.58	Main effects plot for we rubbing fastness of finished P/C fabric	153
3.59	Effect of functional finishes in different concentrations and application methods on the wet rubbing fastness of P/C fabrics	154
3.60	Main effects plot for washing fastness (shade change) of finished P/C fabric	156
3.61	Effect of functional finishes in different concentrations and application methods on the wash fastness (shade change) of P/C fabrics	157
3.62	Main effects plot for washing fastness (shade change) of finished P/C fabric	159

- 3.63 Effect of functional finishes in different concentrations and 160
 application methods on the wash fastness (shade change) of
 P/C fabrics

Fig. #	Title of Figure	Page #
3. 64	Main effects plot for tensile strength of dyed/finished fabrics	167
3.65	Effect of functional finishes in different concentrations and application methods on the tensile strength	169
3.66	Main effects plot for tear strength	175
3.67	Effect of functional finishes in different concentrations and application methods on tear strength	176
3.68	Main effects plot for flexural rigidity of fabrics	180
3.69	Effect of functional finishes in different concentrations and application methods on the flexural rigidity of P/C fabrics	181
3.70	Main effects plot for abrasion resistance	185
3.71	Effect of functional finishes in different concentrations and application methods on the abrasion resistance of finished fabrics	186
3.72	Main effects plot for pilling resistance	190
3.73	Effect of functional finishes in different concentrations and application methods on pilling resistance	191

LIST OF ABBREVIATIONS

AATCC	American Association for Textile Chemists and Colourists
Adj MS	Adjusted mean square
Adj SS	Adjusted sum of squares
ASTM	American Society for Testing Materials
CL	Cross linker
Conc.	Concentration
DF	Degrees of freedom
DHEU	Dihydroxyethyleneurea
DMDHEU	Dimethyloldihydroxyethyleneurea
Flame R.	Flame retardant
Flex. Rig	Flexural Rigidity
g/L	grams per litre
MFPD	Meta finished pigment dyeing
OH	Hydroxyl
P/C	Cotton/Polyester
PPDP	Post finished pigment dyeing
PU	Polyurethane
SC	Shade change
St	Staining
Str	Strength
Tg	Glass transition temperature
UVA	Ultra Violet Absorber
Water R.	Water repellent
WP	Warp
WPU	Wet pick up
Wt	Weft
Min	Minute

ABSTRACT

The present study titled, “Simultaneous Pigment Dyeing and Functional Finishing of Polyester/Cotton Blended Fabrics” has been conducted to develop a compatible eco-friendly pigment colorization system for polyester/cotton (P/C) blended fabrics with desirable performance characteristics. In the preliminary phase, the fabrics were padded with conventional aqueous formulations containing pigment colourants, dispersing agents and binders followed by analysis of various physico-mechanical characteristics. The optimized binder systems were applied on P/C fabrics with various cross linkers, softeners and assorted functional finishes. The dyed/finished fabrics were evaluated at constant process parameters and then characterised subsequently, with qualitative and statistical analysis. The properties of pigment dyed P/C fabrics regarding various types of binders demonstrated, that acrylic based, Helizarin binder ET ECO and Helizarin binder CFF at 50:200g/L pigment/binder ratio, showed the best performance regarding wet rubbing fastness, washing fastness, tensile strength, abrasion resistance, pilling resistance, tear strength, and flexural rigidity. The wet rubbing fastness of majority of the softeners showed a consistency in results, indicating no beneficial effects and remained at only the desired level of fastness, while, the dry rubbing fastness with all the softening chemicals, was good, except Ultratex UM new softener, which showed only satisfactory performance. The staining to adjacent cloth for assessing the wash fastness characteristics of P/C fabric was found to be upgraded by the co- application of a softener based on fatty acid amide condensation product and Dihydroxydiethyleneurea (DHEU) in pigment dyeing formulation. The crosslinking agent DHEU, with almost all the softening reagents, appeared to have the best alliance with pigment coloration of P/C fabrics. Keeping in view the importance of value added functional finishes, two modes of application in different concentrations of finishes were used, i.e. post finishing with pigment dyeing and meta-finishing

pigment dyeing. As regards the effect of finishing techniques, the meta finishing treatments of dyed P/C fabrics with pigments, provided maximum dry rubbing fastness, tear strength and abrasion resistance at both high and low concentrations of finish, while wet rubbing fastness, tensile strength at high only, and wash fastness (staining), flexural rigidity at low concentration were found to be better in performance than post finishing method. The most favorable results with respect to wet rubbing were attained by the fabric, treated with NUVA HPU durable oil and water repellent liquid. The wash fastness and staining to adjacent cloth was found to be graded at maximum level of fastness with NUVA FD water repellent and hand building finish. The treatment of soft polyurethane, water repellent (Nuva FD) and the water repellent in combination with oleophilic finish (Nuva 3585) treatment on dyed P/C fabrics had shown a positive impact on wash fastness and maintained at very good level of fastness (shade change). The treatment of Pekoflam 3585 liquid flame retardant and UV absorber on P/C fabric provided maximum tensile strength. As regards the tear strength, the fabrics had shown highest tear strength with the application of both the flame retardant finishes. The fabric stiffness with these finishes was remarkably reduced, providing a soft textural quality as compared to other finishes. The overall performance of Pekoflam OP, a phosphorous based flame retardant finish produced better colourfastness and mechanical stability to the dyed/finished fabric amongst all. Though, desirable crocking fastness was achieved by incorporating fluorine dispersion (water repellent finish) in pigment dyeing formulations, yet, the wet rubbing fastness technically needs to be improved for commercial acceptance. The overall investigation and the result of this study specify that coloration with pigments is best option for P/C fabrics, provided that appropriate selection of process parameters along with auxiliaries and finishing is carried out. The incorporation of an appropriate level of cross linkers, softeners and functional finishing reagents in the same dyeing formulation, would be a feasible option for all those industrialists who are striving for eco-friendly, low energy consuming dyeing systems.

CHAPTER-1

INTRODUCTION

1.1 COLOURATION OF TEXTILES

Dyeing is a method of imparting a coloured substance (whether natural or synthetic) to a textile material like fiber, yarn and fabric. It is generally applied in an aqueous solution, and sometimes requires a mordant; a particular chemical material to improve fastness properties (Board, 2004). The dyes can attach to compatible surfaces by solution, by establishing covalent bond or complexes with salts or by mechanical reaction. Dyeing can also be accomplished by pigment colouration system, that which differ from dyeing by not showing any chemical or physical affinity for the fibers, hence they are attached with binding agents.

The classification of dyes is based on their application and chemical configuration, and is comprised on a group of atoms known as chromophores, responsible for the dye colour. These chromophore-containing centers are based on varied functional groups, such as azo, anthraquinone, methine, nitro, arilmethane, carbonyl and several others. Furthermore, electrons withdrawing or donating substituents that are designated as auxochromes, generate or strengthen the colour of the chromophores. Generally, the common auxochromes consist of amine, carboxyl, sulfonate and hydroxyl group (Chequer et al., 2012).

1.2 DYES AND PIGMENTS

Organic colourants are categorized in to two classes, based on their solubility viz. dyes and pigments. The key difference between the two is that dyes are soluble in water or an organic solvent, whereas pigments are *insoluble* in both types of media. Further, dyes are applied to the substrates for which they have affinity. Despite their insolubility, pigments can be used to dye any polymeric substrate but by a different mechanism unlike dyes. It involves the surface only colouration system unless the

pigment is linked with any polymeric compound prior to the application on textile substrates. Although the pigments consist of small particles but are insoluble in the medium to which they are applied. Despite their small particle size they have to bond to a substrate by the assistance of some additional compounds like by-polymers in paints, plastics, or melts (Zdinger, 2003).

1.3 PIGMENTS AS TEXTILE PRINTING MATERIALS

Printing is the most common method of applying pigment colourants on textile fabrics. It is one of the most versatile and popular technique for introducing colour and design to a textile substrate. Generally, the similar fixation mechanism is used in dyeing and printing, therefore, careful and appropriate selection of dye is very important. Commercially, pigments have key importance as they are most widely applied colourants in textile printing.

1.3.1 Historical review

For almost 3000 years, mineral pigments have been milled with natural binding materials (dried and boiled oils or viscous, aqueous solutions of albumen products and vegetable gums) and used on textile products to develop a pattern. In spite of the fact that pigment printing is an old technique, it could not gain commercial importance until the second world war due to the poor performance such as loss of textural qualities of textiles, dull colours, and poor wear and wash fastness.

Though the fundamental products for modern pigment printing were available in earlier times, but the techniques needed further development. In the 1920s dispersions of beneficial organic pigments (according to the current pigment printing requirements) were available in the market, such as Hansa Yellow. In the 1930s, olefinic substances like butadiene, vinyl esters, acrylonitrile and acrylic acid esters were discovered by emulsion copolymerization; the integral steps in the development of present pigment printing (Miles, 2003).

1.3.2 Types of pigments

Synthetic organic and some inorganic pigments are used for routine colouration of textiles, mostly in the form of pigment dispersion.

1.3.2.1 Organic pigments

Organic pigments have a wide range of industrial application in many coloured products of which the most important is the colouration of textiles. For textile printing generally, the following types of organic pigments are used.

a. Azoic pigments:

These are produced by the coupling of Naphthol dyes and fast colour bases. All Azoic pigments contain at least one nitrogen atom double bonded to another nitrogen atom (Figure 1.1).

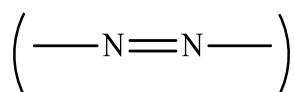


Figure 1.1: Azo group

They are inexpensive and have comparatively good fastness properties. A few types of azoic pigments are azoic scarlet, azoic red and azoic violet (Shore, 2002).

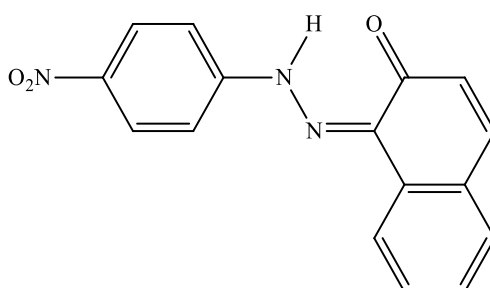


Figure 1.2: CI Pigment Red, 1 Para Red

b. Diarylide (pigment yellow 14)

Diarylide is commonly named as orthotoulidine and has good dry cleaning and light fastness properties in medium and dark shades. Pigment orange 16 is a bright

orange with excellent heat resistance and dry cleaning fastness. The structure of pigment orange 5 is given in Figure 1.3 (Shore, 2002).

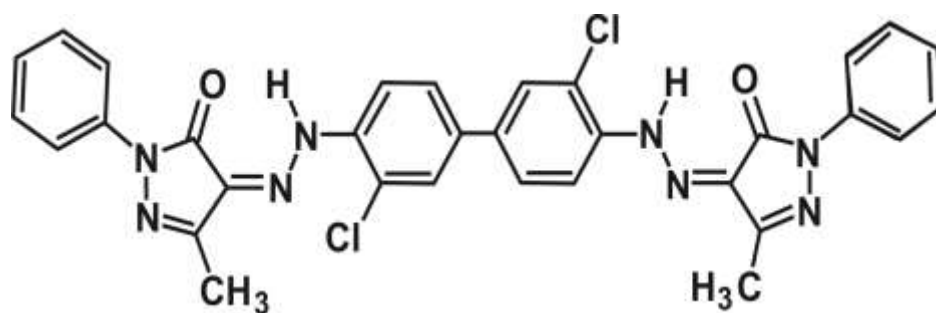


Figure 1.3: Pigment orange Bis Chloro ethyl ether ($C_{32}H_{24}N_8O_2$)

c. Phthalocyanine pigments (pigment blue)

It is a bright, strong and red shade of Phthalocyanine blue (Shore, 2002). Generally, it is known as red shade blue and also includes pigment green.

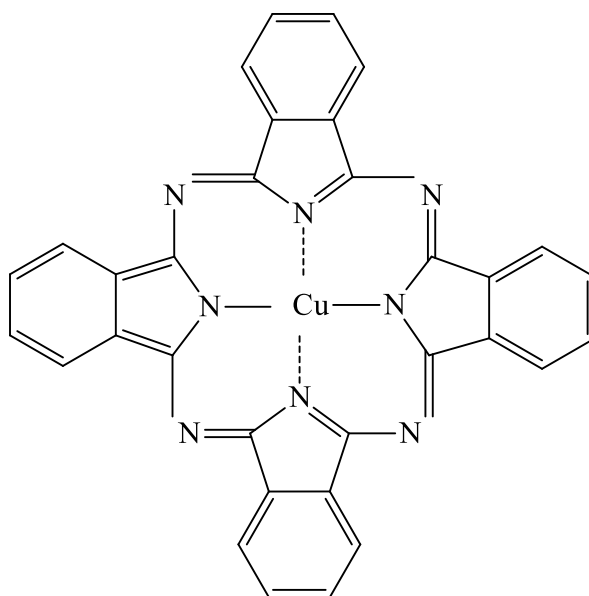


Figure 1.4: Copper Phthalocyanine

d. Quinacridone

It includes pigment violet 19 (Figure 1.5) and pigment red 122, known as bright pink and bright magenta respectively (Shore, 2002). They bear excellent fastness light and dry cleaning.

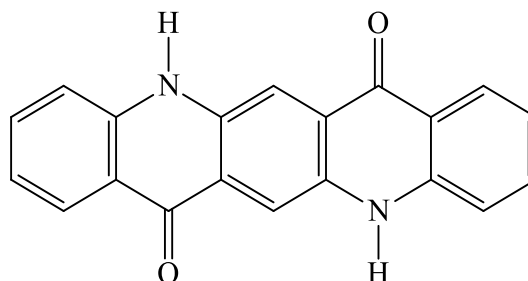


Figure 1.5: Quinacridone red (PV 19)

1.3.2.2 Inorganic pigments

Inorganic pigments have key importance in pigment chemistry due to cultural and historical reasons. These pigments are often used for textile printing due to their hydrophilic nature and their high sensitivity for water needs a high ratio of binder that only induces a low grade wash fastness to fabric.

a. Black & white pigments

Pigment black 7 is generally called “carbon black” and is composed of dispersion of fine carbon particles used for printing inks. It is the most widely used types. It has excellent colourfastness to light, heat and dry cleaning. Pigment white 6 is a dispersion of titanium dioxide with excellent colourfastness properties (Sheldon, 1995).

1.4 PIGMENT COLOURATION SYSTEM

Pigments are used for colouring different materials, including textile substrates. One of the significant physical characteristics of the pigments is their particle size and the distribution of particle size in that medium. The deposition of pigments occurs in dispersion state on the surface of the substrate with the help of an

|

appropriate binding agent. The Polymer binder entraps the pigment particles in the form of a thin coating, bonded to the fiber surface (Aspland, 1993).

Pigments are insoluble neither in water nor in any solvent, and bear no affinity for fibers. They do not have any level of substantivity and are not practicable for exhaust dyeing methods. They are only applicable for fibers and blends with suitable binder system. The stiffness in dyed fabrics increases due to the formation of binder coating.

A conventional pigment dyeing system for cellulose textile materials consists of padding process with a formulation containing pigment dispersion, anionic binders, acid liberating agents and other types of additives. Drying at high temperature of textiles cure film forming binders and pigment colours firmly on textiles (Technical Bulletin, 2004).

The textile industry consumes a considerable amount of water in its production plants particularly in the dyeing and finishing processes. The waste water from such industries cause severe environmental pollution (Chequer et al., 2013). The problem of inappropriate effluents disposal can be resolved by pigment colouration system, as one of the qualities of pigment dyeing is that it does not require the post wash treatment; hence waste water load can be minimized (Chakraborty, 2010 & Cao, 2013).

1.4.1 Pad dyeing machines/padding mangles for pigment dyeing

The pad dyeing machines surmount the deficiency of winch and jigger dyeing machines by overcoming their deficiencies like smaller batch size and discontinuity in dyeing. Padding mangle technique offer continuous process of the fabric such as pretreatment, dyeing or finishing of dyestuffs. The concerned liquor is formulated in the pad dyeing machines with single or multiple immersing in solution. In the padding process, the fabric passes into a solution of chemicals, under a submerged roller and out of the bath followed by squeezing to remove excess solution. The main objective of this process is to mechanically impregnating the fabric with the solution or dispersion of chemicals. Pad immersion is common for the dyeing of fabric and for

|

the application of finishing chemicals. (www.amazon.com/pad-batch-dyeing-plant-fibers-tech)

A comparative study between reactive/disperse dyeing and pigment dyeing on blended P/C fabric was carried out and also different fastness properties determined. For this purpose, pad dry thermosol pad steam process was used to dye the sample by using disperse/reactive dye. The “Thermosol” process for dyeing polyester was developed by the DuPont Company in 1949 for the continuous dyeing of polyester fabrics (Arthur, 2001).

1.5 PIGMENT COLOURATION SYSTEM FOR VARIOUS FABRIC TYPES

1.5.1 Pigment dyeing of lyocell fabrics

Conventional dyes, pigments do not dissolve in water and hence have no affinity for Lyocell fabrics as well. It is observed that at high pH the KS value of the Lyocell fabric can be increased but beyond a certain limit it may slightly reduce the reactivity. Lyocell fabrics could be dyed with pigment dispersion systems in desirable fastness properties, if it has been modified with a cationic reagent. The positively charged Lyocell fabric produced a higher colour yield by nano pigments than conventional pigments, but with reduced rub and wash fastness. The effect of Pigment concentration and the particle size on the shade depth of fabric indicate that both the nano scale and conventional pigment colouring of fabric, revealed a high colour yield with increasing concentration. Further analysis show that colourfastness grading of Lyocell fabric was reduced by nano scale pigment than normal pigment dispersions (Hao et al., 2009).

1.5.2 Pigment Dyeing of silk Fabrics

Anionically surface modified organic pigment/binder inkjet inks were formulated for printing the silk fabrics, pretreated with chitosan. The fabrics were

printed in cyan, magenta, yellow and black pigments that were thermally cured and evaluated afterwards for wash fastness, crock fastness and other characteristics. According to the results, the colourfastness to crocking and washing of the chitosan pretreated, pigment dyed silk fabrics were comparatively better than untreated fabrics. The same printing ink can be recommended for any type of textile that has been given a treatment with protonated chitosan (Chakwattanatham, 2010).

1.5.3 Pigment and reactive dyeing system for cotton

A comparative study has been carried out on cotton fabrics, dyed in light, medium and dark shades using pigment and reactive dyes. The main objective was to compare the recently available reactive dyeing with pigment dyeing system regarding various physical characteristics. No change in colour depth has been observed by increased amount of pigment except for very light tints. The Light fastness of pigment coloured fabrics was better than reactive dye, showing more consistency in obtained results from light to deep shades. Generally, the deteriorating effect in physical properties was observed particularly in tear strength (Hussain & Ali, 2009).

1.6 COLOURATION OF COTTON AND POLYESTER FABRICS

1.6.1 Cotton polymer system

Cotton has linear cellulosic polymer system which consists of cellobiose as repeating units of cellulose. The major constituent of cotton fiber is 65-75 % crystalline and 30-35 % amorphous with cellobiose comprising two glucose units (Figure 1.6).

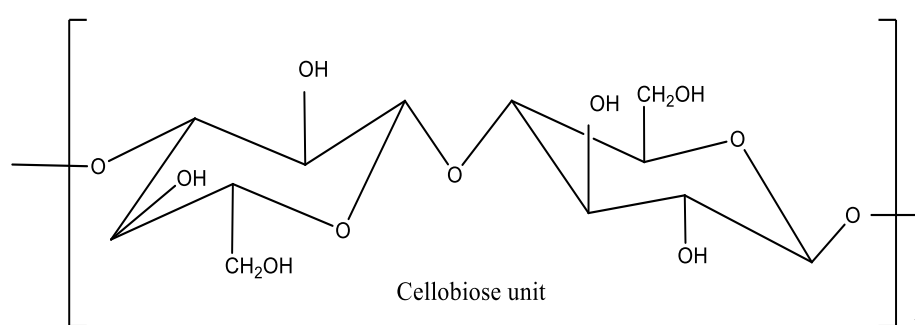


Figure 1.6: Structure of Cellulose polymer

The most important forces of attraction present in polymer system of cotton are hydrogen bonding. The hydrogen bonding has a key role in the moisture absorbing property of this polymer. The polar OH groups in its polymer system attract water molecules due to their polar character. The penetration of water occurs in amorphous regions of the polymers and not in the well oriented crystalline regions.

1.6.2 Dyeing of cotton

Cotton fabrics can be dyed by diverse colouring matters such as direct, reactive, sulphur and azo vat dyes. Presently, reactive dyes are the most widely applied type of dyes on cotton fabric. Reactive dye molecules form a covalent bond with the hydroxyl groups of cotton polymer bearing very good wash fastness properties (Gohl & Vilensky, 2003).

1.6.3 Polyester polymer system

Polyethylene terephthalate, one of the several types of polyester, has a commercial importance (Figure 1.7). The polyester polymer system is 65-85 percent crystalline and 35-15 percent amorphous. It has a hydrophobic character, with very weak hydrogen bonding existing between polyester polymer. These hydrogen bonds occur at the weakly polar carbonyl oxygen atoms, which are considered sufficient for the development of polarity to form very weak hydrogen bonds with the help of any adjacent methylene hydrogen atoms. The significant forces of attraction in the polymer system of polyester filaments are van der waal's forces.

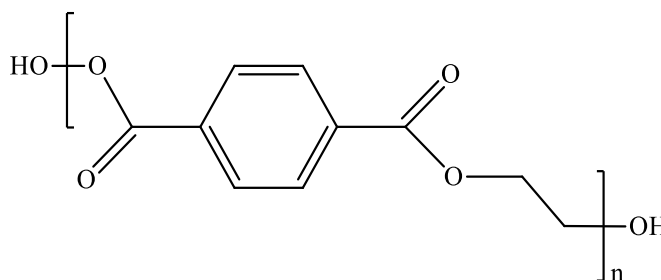


Figure 1.7: Poly (ethylene terephthalate) unit

1.6.4 Dyeing of polyester

The hydrophobicity of the polyester polymer system tends to attract fats, oil and greasy soils. The lack of polarity and crystalline structure of polyester causes resistance against penetration of water molecules into the polymer matrix (Gohl & Vilensky, 2003). This fact, together with an absence of active chemical groups in polyester's macromolecules, makes it difficult to apply the majority of dye stuffs. In order to obtain intensive colour strength of polyester, various fibers and auxiliary agents are often added to the dye bath. These agents, often induce sensitization of the human skin. Moreover, a small amount of them left on the polyester fibers reduces colour fastness to light.

1.7 COLOURATION OF POLYESTER/COTTON BLENDED FABRICS WITH VARIOUS DYESTUFFS

The blends of Polyester/cotton can be ranked among the well recognized textiles by the consumers, both as home furnishings and apparel products. Polyester contributes tensile strength, abrasion resistance and dimensional stability where as cotton induces good pilling resistance, absorbency and comfort during use. Numerous possibilities of colouring polyester/cellulose fabrics batch wise, continuously or semi continuously have been determined. These contain the combined formulations of disperse dyes with azoic, direct, sulphur, vat and particularly reactive dyes (Aspland, 1997). Pigment dyeing of P/C blended fabrics can be an acceptable replacement of single-phase dyeing process with disperse/reactive dyes or disperse/vat dyes (Hussain et al., 2012).

1.7.1 Dyeing of P/C blended fabrics with disperse and reactive dyes

The traditional method of exhaustive dyeing for P/C blends is to dye each component individually under its optimum conditions, i.e. in a two-bath process. In

the past, several attempts have been made to reduce this to a one-bath process with the objectives of tackling the issues of productivity and environment. The Imperial Chemical Industries (ICI) has developed a rapid one-bath method using a selected mixture of disperse and reactive dyes (Lee et al., 2003).

Two chemically different classes of dyes are currently in use namely disperse for polyester and reactive for cotton, in two bath processes. However, the method is comparatively lengthy and complex. On the other hand, single bath, two-step dyeing process is short, but produces a product with reduced dyeability and undesirable reproducibility (Kim et al., 2004).

Various types of dyes, based on their different chemical constitution called disperse for polyester and reactive for cotton, are presently applied in two phase dyeing processes. Experimental work was carried out on investigating the possibility of developing the physical combination of Disperse/Reactive (D/R) dyes for colouring the P/C blends (80/20, 67/33) in one bath process. The study was also conducted to determine the stability of the physical mixture of dyes and it was observed that the dyes were stable in terms of particle size, filtration time and flow rate studies. The physical mixture indicated 'level dyeing' having good fastness properties and offered an alternative, cost effective, eco-friendly one-bath dyeing process (Meena et al., 2013).

1.7.2 Dyeing of P/C blended fabrics with direct dyes

Investigation into the methods of dyeing polyester and cotton-polyester fabrics using direct dyestuffs was determined. In order to enhance the adhesion of chitosan to the surface of polyester fibers, pre-treatment in sodium hydroxide (NaOH) solutions was carried out. It is feasible to eliminate disperse dyestuffs and the deteriorating auxiliary agents by the application of natural polymers such as chitin or chitosan in the textile finishing processes. The colour and rubbing fastness properties of the chitosan-deposited fabrics were evaluated. The colour difference between the dyed untreated samples and the samples dyed after alkaline and/or chitosan treatment was investigated using spectrophotometer evaluation. The data obtained shows that there

is possibility of dyeing polyester and cotton-polyester blended fabrics, finished by chitosan with only one direct dyestuff, which generally presents substantivity to cellulose fibers. The dyed samples exhibited good rubbing and washing colour fastness properties within the standard range of colour change. The colour strength of the dyed samples increased with the high deposition of chitosan on the fabric (Walawska, 2003).

1.8 DYEING OF P/C BLENDED FABRICS WITH PIGMENT COLOURATION SYSTEM

Polyester/cotton blended fabrics, the most commonly accepted textiles by the consumers, offer some challenges to the dyer owing to the hydrophobic character of polyester and the hydrophilic nature of cotton. Polyester fibers resist swelling in the water bath and hence the access of the dye stuff molecules to the interior of the substrate is hard enough as compared to cotton (Arslan, 2001). Conversely, the hydrophilic nature of cellulose fibers (cotton) allows the diffusion of dyestuff molecules into the core of the fibre conveniently (Murlidharan & Laya, 2011, Saber, 2010).

Though various conventional and novel approaches have been used to dye polyester/cotton blended fabric, with its favourable and adverse colouring effects oftenly, yet, it poses a challenge for the textile industry to develop this blend with better dyeability, colour depth and performance properties. The challenges can be met with pigment dyeing, a comparatively recent addition in which the affinity to various fiber types for that colourant is adjustable. Since pigments are not fiber specific, these are applicable to a wide variety of textiles even with different characters and unidentical physico-chemical characteristics like polyester/cotton blends (Smith, 2011). Sometimes, the fabric may need a particular treatment for applying pigment colourant, e.g., the outer covering of resin with adhering properties.

Pigment dyes have been used for printing various textile products like T-shirts, sport wears, waistcoats and trousers for a long time. It is a feasible option for cotton

with a possibility of pretreatment with a cationic auxiliary, as cationization tends to increase affinity of pigment dye for cotton fabric (Fang, et al., 2005).

A comparative study has been conducted on Polyester/Cotton blended fabric for comparing two different dyeing systems and their impact on colour fastness properties. It has been observed that pigment dyed samples possessed higher wash and light fastness grading as compared to the traditional dyed sample. In case of rubbing fastness no gradual decrease from light to deep shade resulted which further induced a harsh texture to the fabric. There was no prominent change in rubbing fastness both the warp and weft way however, dry rubbing fastness was better as compared to wet rubbing fastness (Islam & Akhtar, 2010).

1.8.1 Binders in the pigment colouration system

Pigments are small insoluble particles which have little or no affinity for the fiber or fabrics. To enhance their functionality it is required that pigments be linked with the fiber by a film forming material, called binder (Cardozo, 1995). The basic necessity of pigment dyeing is the binder, a polymeric compound that is used to form a matrix for entrapping the pigment particle with a substrate.

The attachment of pigment between binders and cotton is revealed in an equation (Figure 1.8 & 1.9, Ckraborty, 2010), which is a simple mechanism of film formation.

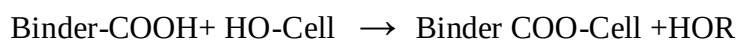


Figure 1.8: Carboxy redical as film forming group

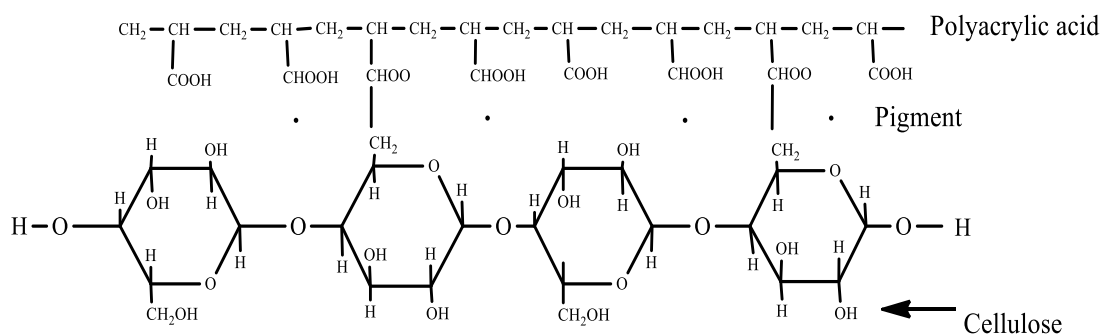


Figure 1.9: Mechanism of Film formation with Cellulose

Binder must be stable enough to external forces like washing and rubbing etc. that would tend to dislodge the pigment from the textile substrate. Besides an additive effect, some other salient characteristics of the binder are to enhance the colouring effect of pigments on the substrate, to provide mechanical stability and re-dispersibility into liquid. The key factor influencing the crock fastness and adhesion of the binder film to the substrate is the cross-linking efficiency of the binder (Iqbal et al., 2010).

1.8.2 Binder mechanism

The binder film in a pigment printed fabric has a three-dimensional structure, the third dimension being rather less significant than the other two. The structure is made up of a long-chain network of macromolecules linked with pigment when applied to the textile, with the pigment. All the binders are addition polymers of which preferable copolymers are more desirable e.g. structure given in Figure 1.10.

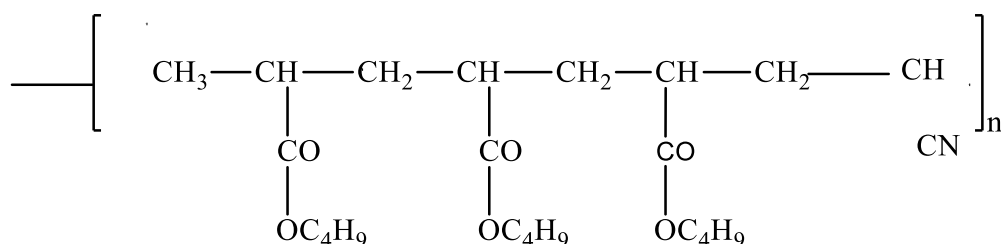


Figure 1.10: A copolymer of 3 mols of butyl acrylate & 1 mol of acrylonitrile

The technique applied for pigment printing is type of emulsion co-polymerization that occurs in an aqueous dispersion medium with binder, followed by drying. During the first phase of film formation, water and surfactants are detached from binder by absorption and evaporation process consecutively. The coagulated disperse solids converted into gelatinous layer with adhesive ability. During the second phase, gel like particles, oriented together to form a continuous binder film as shown in Figure 1.11 (Miles, 2003).

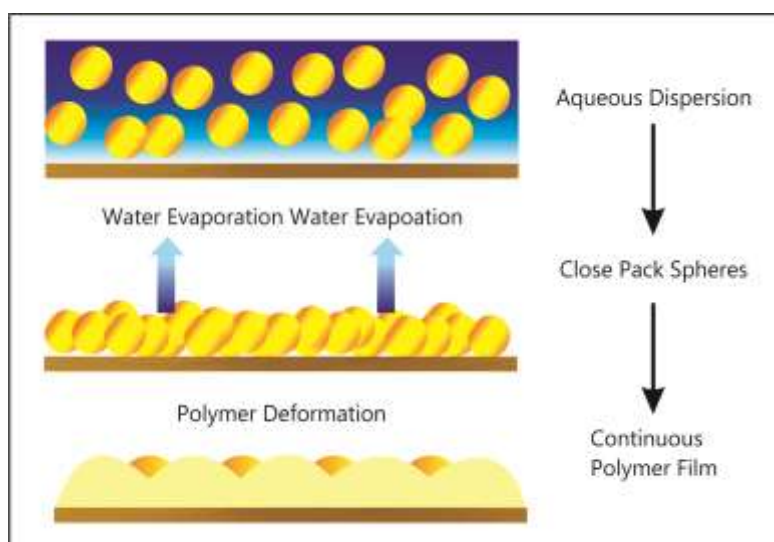


Figure 1.11: Schematic of film formation [Mlynar, 2003]

1.8.3 Classification of binders: based on chemical constitution

The classification of binders that is based on chemical configuration is as following. There are three basic types of binders viz, butadiene, acrylate and vinyl copolymers. The most common lattices are butadiene based and acrylic monomers.

1.8.3.1 Butadiene copolymers

The butadiene polymers have the ability to crosslink by polysulphides and their properties are further enhanced by the addition of different copolymers. The butadiene monomers contribute elasticity while styrene and acrylonitrile provide improvement in tensile strength and resistance for oil and solvents respectively. Their

drawbacks are oxidation and discolouration induced by residual double bonds in their structure. (Figure 1.12)

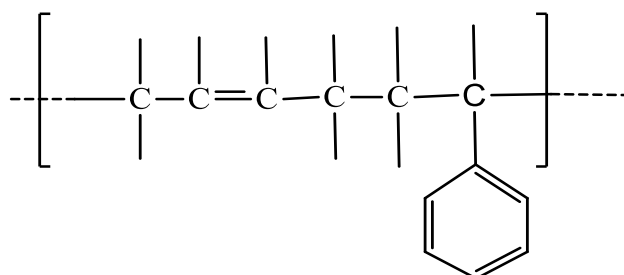


Figure 1.12: Styrene Butadiene Rubber

1.8.3.2 Acrylic binders

These are the most widely used binders due to their versatility and various modified forms. These include acrylic monomers i.e. Methacrylate, Meth methacrylate, ethyl acrylate and so on.

The general molecular structure of one of the acrylic polymers is as following:

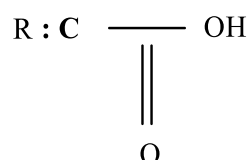


Figure 1.13: Acrylic Binder

The performance of acrylate Polymers is generally excellent due to their resistance against degradation by chemicals, heat and light. Since the functionality of binders is associated with crosslinking ability, therefore, the acrylic binders containing carboxylic acid provides reacting sites for crosslinking with other polymers (Kawath et al., 2004).

1.8.4 Selection of binder

The selection of an appropriate binder for padding of fabric is very important. The binder must have compatibility with all the auxiliaries like anti-migrating agents, wetting agents and resin treatments. Wettability of the binder is a key factor for

complete polymerization. If applied with a non or low rewettable binder, it may lead to incomplete polymerization and hence poor quality of the resultant product. The order of incorporating the auxiliaries in the formulation of a binder system should be dealt carefully. If the set up of formulation is not in an appropriate order, it may result in destabilization of bath liquor. The pH of the binder may range from 7.5-9.5 for providing stable liquor dispersion (Technical Bulletin, 2004).

1.8.5 Novel approach for synthesis of aqueous binder for pigment printing and dyeing:

A few drawbacks of pigment printing are curing at relatively high temperature, stiffness and low grades of crock fastness of printed products. Since the problems are basically influenced by the binder used, therefore, overall binder characteristics must be improved. Keeping into consideration these faults, aqueous UV-curable binder of polyurethane acrylate oligomers, comprised on the polyethylene Glycol 1000 and polyethylene Glycol 2000, has been synthesized. The binder was applied for inks of inkjet printing and pigment dyeing of all types of fabrics i.e. cotton, viscose, wool, polyester and nylon 6, 6 fabrics. In case of colour fastness to crocking properties of cotton /viscose and nylon 66 were rated from good to very good, while polyester was graded as moderate to good level of fastness. It was observed that by increasing the concentration of the binder, colour strength was enhanced (Molla-El, 2006).

Anionic surface modified organic pigment/binder inkjet inks were formulated for printing on silk fabrics, pretreated with chitosan. The fabrics were printed in cyan, magenta, yellow and black pigments that were thermally cured and evaluated afterwards for wash, crock fastness and other characteristics. According to the results, the chitosan pretreated pigment dyed silk fabrics had comparatively better colourfastness to crocking and washing than the untreated fabrics. The ionic affinity between the sulphonate group of the pigment and protonated amino groups of chitosan in combination with polyacrylate binder tend to improve various characteristics like colour strength, washfastness and crock fastness. The same ink can be recommended for any type of textile that has been given a treatment with protonated chitosan. (Chakvattanatham et al., 2010)

1.8.6 Film forming binders

Finishing with film-forming latexes generally tends to improve the pilling performance of all the fabrics. These finishes reduce migration of fibers by attaching the filaments which assist binding them together. It has been reported that latex

binders remarkably improved the pill rating as the finished fabric was better than the base fabric- the one made from conventional polyester fibers alone.

1.9 INCORPORATION OF CROSSLINKERS IN THE BINDER SYSTEM

Various physico-chemical characteristics of the textile products can be upgraded by using additional cross-linking monomers such as resins in the binder system. When dyeing is carried out in conjunction with resin finishing time, cost of production as well as energy consumption can be saved (Raheel, 1998). In case the binder molecules are deficient of self cross-linking groups, the external cross-linkers like urea-formaldehyde or melamine formaldehyde condensate, each containing at least two reactive groups and can be included in the binder system to induce easy care finishing and improved characteristics. The external crosslinkers can be incorporated in the binder system even if it has self cross linking group, because it exists in enhanced fastness grading. The precondensates viz melamine formaldehyde and urea formaldehyde can be applied as cross-linking as well as binding agent (Chakaraborty, 2010).

1.9.1 Amino resins

Amino resins are thermosetting class of polymers, synthesized by combining formaldehyde with a chemical compound including an amino (NH_2) group. Urea formaldehyde (U/F) accounts for almost 80% of amino resins while the rest comprises of melamine formaldehyde.

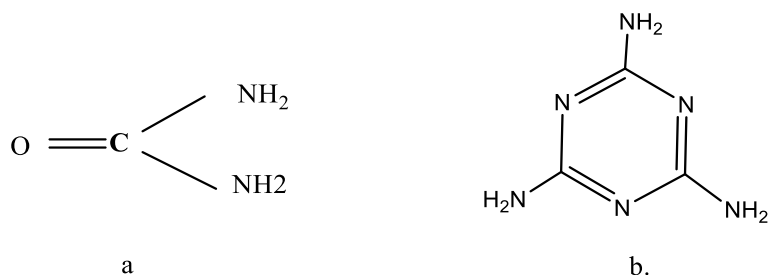


Figure 1.14: Structure of Urea or Carbamide (a) & Melamine (b)

The primary attraction of amino resins and plastics is their characteristic of water solubility, prior to curing, which assists easy application with several materials. Furthermore, its colourlessness allows limitless colourability with dyes and pigments, outstanding solvent resistance in the cured state, extraordinary hardness, good abrasion and heat resistance which increases its efficacy.

A major drawback of these resinous materials is the release of formaldehyde during curing process. Despite this defect amino resins are manufactured throughout the industrialized world to provide a wide variety of useful products. Some amino resins are used as additives to modify the properties of textile materials such as a small amount of amino resin added to textile fabric imparts the desirable wash-and-wear qualities to shirts and dresses (WWW.ASPEAK.NET).

1.9.2 Urea formaldehyde resins

The most effective crosslinking reagents for durable press finishing of cellulose fibres are formaldehyde adducts of urea, which unfortunately release formaldehyde during manufacture and use in clothes so treated. The omission of formaldehyde from durable press (DP) treated fabrics is as hazardous for human health and safety as formaldehyde is suspected to be carcinogenic. The instant effects of exposure to formaldehyde are irritation of eyes and nose, rashes and headaches. Researchers are constantly trying to develop new reagents, such as low formaldehyde-content in durable press finisher and other substitute reagents with no formaldehyde in their structure (Voncina et al., 2000).

Dimethylol dihydroxy ethylene urea (DMDHEU) and modified dimethylol dihydroxy ethylene urea (modified DMDHEU) are compounds which contain N-methylol and mainly N-alkoxymethyl groups. Dihydroxyethyleneurea (DHEU) which is formed by combining glyoxal and urea, further reacts with formaldehyde to form dimethylol dihydroxy ethylene urea (DMDHEU) The chemical structures of both conventional and modified forms are exhibited in Figure 1.15 & 1.16 (Shiqi, 2008).

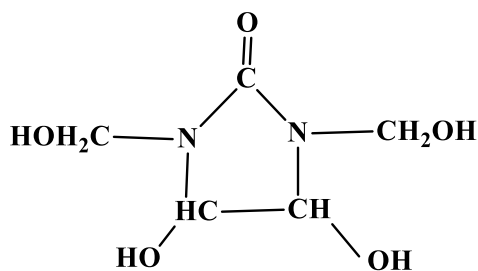


Figure 1.15: Chemical structure of DMDHEU

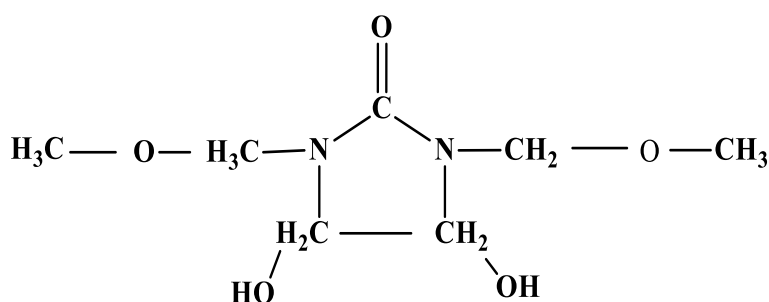


Figure 1.16: Chemical structure of modified DMDHEU.

Both of these crosslinkers are broadly used in textile industry as durable press finishers. During the finishing procedure the N-methylol compounds can react with hydroxyl groups of cellulose, which is the most preferable reaction; they may also react with themselves or with reactive NH groups. Primarily the complete reaction with the hydroxyl groups of cellulose results in a very low free-formaldehyde value in the treated textile product, which is a true indicator of the quality of the crosslinking.

1.9.2.1 Reaction mechanism of N-methylol with cellulose

Dimethylolurea reacts with cellulose molecules to form crosslinkers to induce durable press or wash and wear finish. The reaction of dimethyloldihydroxyethane urea with cellulose molecule is conducted in the presence of a catalyst, which is as following:-

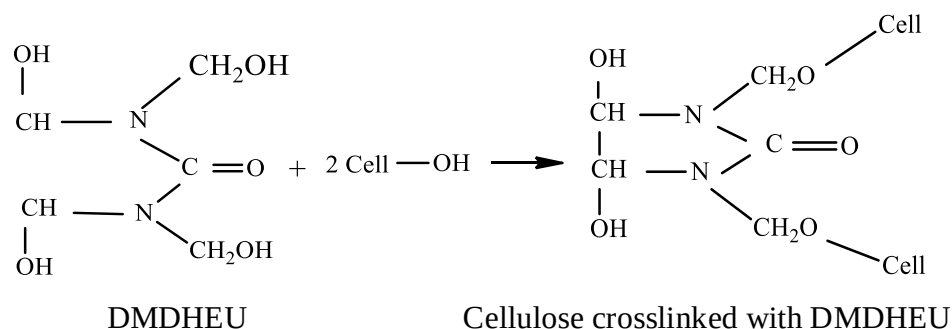


Figure 1.17: Reaction mechanism of dimethyldihydroxyethane urea with cellulose molecule

As formaldehyde is hazardous to health, therefore, the textiles treated with formaldehyde based finishing reagents needs special consideration. Due to the controversy about formaldehyde content, proper regulations have been set for its upper limits. Various low formaldehyde finishing agents along with non formaldehyde agents have been synthesized and used as resin treatments.

1,3 – Dimethyle 4,5 – Dihydroxyethylene urea (DM_eDHEU) is synthesized by reacting glyoxal with N,N- dimethyle urea, which can crosslink cellulose according to the recommended conditions. The reaction is as following.

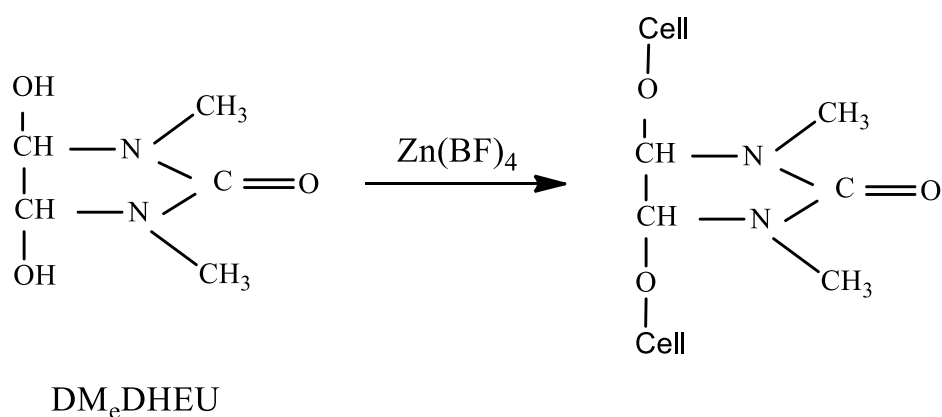


Figure 1.18: Crosslinking of DM_eDHEU with cellulose

In both the earlier mentioned types of dimethyldihydroxyethylene urea there is similarity of structure with a small difference in their constituted groups, such as,

CH₃ for DM_e DHEU and CH₃OH for DHMDHEU which provides reacting sites for cross linking. In case of DH_e DHEU, the OH groups are crosslinked with cellulose molecules, generating no formaldehyde during finishing treatment or consumer use (Li, 2008).

1.9.2.2 Effect of DMDHEU on tensile, tear and abrasion resistance

The loss in tensile, tear and abrasion resistance in 100% cotton are directly related to cross-linking quality. In a study performed with 15 % commercial DMDHEU (7 % bath solids) in the bath, the improvement in DP properties was observed while on the other hand, the strength and abrasion resistance losses exceeded 30 to 60 % of the original fabric values (Tomassino, 1992).

1.9.3 Melamine resins

They form a three dimensional network by crosslinking with other polymers. Melamine resins are characterised by their versatile finishing ability. They provide wash and wear properties to cellulose fabrics. Melamine resins are synthesized by combining melamine (C₃N₆H₆) with formaldehyde (CH₂O) to form methylemelamine molecule which then reacts with methanol to form melamine resin. Its types and properties are affected by a number of reactive groups present in its molecule. One of the commonly applied melamine resin used for fabric modification technique is trimethylol melamine (Figure 1.19) which has a tendency to self polymerize (Tomassino, 1992).

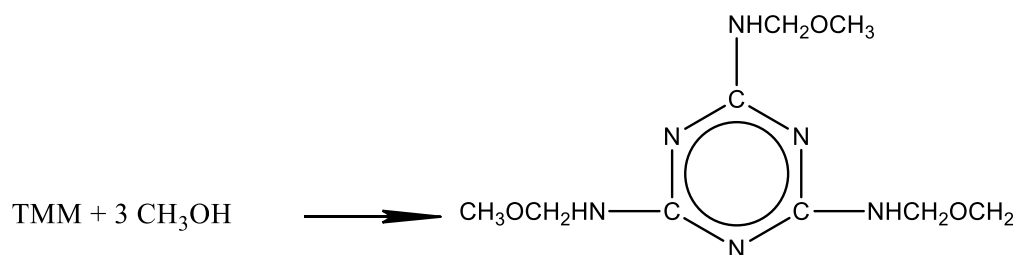


Figure 1.19: Tri methoxymethylmelamine

Another commercially important melamine is named as hexamethoxymethyl melamine (HMMM) which is its highly etherified version, having more reacting sites facilitating in complete crosslinking under proper curing conditions (Figure 1.20). HMMM can react with hydroxyl carboxyl and amide groups, providing stability to coloured materials, (Randy, 1995).

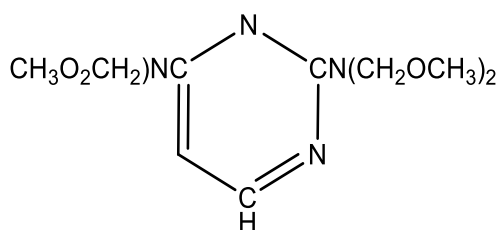


Figure 1.20: Structure of hexa methoxymethyle melamine.

Melamine formaldehyde resin is like urea formaldehyde resins in its synthesis and application techniques, but it exceeds the latter in resistance, toughness and strength. Melamine resins are applied for pigment printing to achieve enhanced crock fastness and wash fastness.

N-methyl acryl amide and melamine cross-linking activity occurs at the final stage of dyeing. This is called the curing process in which the temperature is set for the formation of dried film by actual latex binder with its cross-linking capability. As the formaldehyde release is potentially carcinogenic, there has been a growing demand for low or sometimes formaldehyde free binders and cross-linkers (Mlynar, 2003).

The polymerization is carried out during some appropriate ‘fixing’ process by dry heat at a suitable pH level to generate either self-crosslinking or to react with some external crosslinking agents. The degree of crosslinking should be restricted to some extent, to prevent the macromolecules from becoming too tightly bonded, thus preserving a little extensibility. The performance criteria which make certain that, the pigment within the crosslinked binder film is fast to wear and cleaning is assessed by elasticity, cohesion and adhesion to the substrate and resistance to hydrolysis (Miles, 2003).

1.10 INCORPORATION OF SOFTENERS IN PIGMENT COLOURATION SYSTEM

A few drawbacks of pigment dyeing include fair crocking fastness properties, reduced tear strength and deterioration of fabric handle. The colouring process with additional cross-linkers and binders, link between substrate and pigment and increase in the stiffness level has been reported especially in deep shades (Hussain & Ali, 2009). To overcome these deficiencies, various additives as softening chemicals can be united with a modified fabric appearance and enhanced technical properties like hydrophilicity, rubbing fastness and antistatic properties, comfort and smoothness in synthetic fabrics (Whale & Falkoroski, 2002).

1.10.1 Definition of softener

A softener is a chemical that alters the fabric hand, making it more pleasing to the touch. The more pleasing feel is a combination of a smooth sensation, characteristic of silk, and of the material being less stiff. The softened fabric is fluffier and has better drape i.e. the ability of a fabric to follow the contours of an object. In addition to aesthetics (drape and silkiness), softeners improve abrasion resistance, increase tearing strength and reduce sewing thread breakage.

Softeners are applied on textile fabrics with an aim to achieve soft handle, and to facilitate the various processing techniques. Fabrics are treated with softeners to obtain smooth, supple, elastic and even super soft surface. Moreover it improves various technical properties like, hydrophilicity, sewability, stretchability, antistatic and rubbing fastness properties are improved so on (Tomasino, 1992).

1.10.2 Types of softeners

According to ionicity and molecular configuration, softeners are classified into three main types i.e. cationic, anionic and non ionic (Whale & Falkowoski, 2002).

1.10.2.1 Anionic softeners

Anionic softeners have a negative charge on the molecule, chemically constituted on either carboxylate ($-\text{COO}^-$) sulphate ($-\text{OSO}_3^-$) or phosphate group ($-\text{PO}_4^-$). Mostly these softeners have good heat stability and rewettability properties.

1.10.2.2 Cationic softeners

These softeners have a positive charge on the molecule that are majorly based on nitrogen, either in the form of positively charged or quaternary ammonium salts. At acid pH amines are converted into positively charged molecules and act as cationic softener at pH below 7. These are highly efficient, its ionic affinity resulted in a complete exhaustion than the formulated bath and well oriented on the surface of the fibre/fabric. Its various types include amino functional cationic softener, fatty amino esters, quaternary ammonium salts and so on. Cationic softeners include very soft, fluffy and silky touch to most of the fabrics. They tend to enhance tear strength, abrasion resistance and sewability of fabrics.

1.10.2.3 Nonionic softeners

Nonionic softeners can be divided into three major classes i.e. ethylene oxide derivatives, silicones and hydrocarbon waxes based on polyethylene. Polyethylene emulsion deposits on the surface of the fabric in the form of a hard film thus reducing its coefficient of friction.

1.10.3 Silicon softeners

Silicones are most versatile polymeric softeners having wide spread applications. Silicon is a generic term which refers to a group of manmade polymers based on building blocks of alternating silicon and siloxane bonds with organic substituents linked to the silicon. Majority of the softeners are polydimethyl siloxanes which differentiate them from conventional polymers. Some other types of silicones include amino functional epoxy, hydroxyl and silicone polyethers etc. Some salient

characteristics of the silicones are high compressibility, hydrophilicity, decline fire hazards, soft and supple hand of fabric.

1.10.4 Methyl oils

Polydimethyl siloxanes or methyl oils are the possibility of crosslinking Si-OH or Si-OR on the surface of fabric to achieve elastomeric effects. These are applied in pigment printing of textiles to attain good rubbing fastness, lubricating properties and for the improved handle of fabric.

1.10.5 Amino oils

Aminofunctional organopolysiloxanes are a group of silicones that have a key importance in various types of softeners. One of the most important type of softener include aminopropyl which is represented in Figure 1.21 (Habereeder & Bereck, 2002).

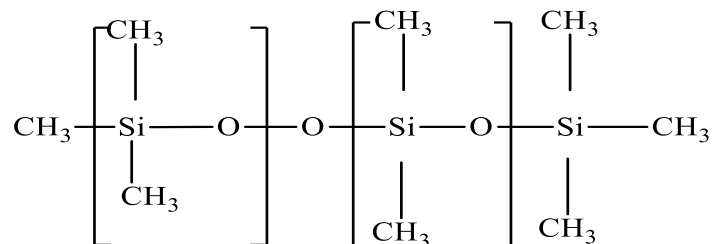


Figure 1.21: Amino propyl (Silicon softener)

Silicones based softeners are resistant to biodegradation system by micro organisms, but they can be degraded via hydrolysis in the presence of a catalyst and oxidation process, which is a natural chemical procedure. Polydimethyl siloxane is ecologically stable and hence silicon chemical for fabric care can be listed under ecofriendly chemicals (Manickam, 2013).

The softening compounds vary in affinity to assorted materials. Some are better for hydrophilic materials like cellulose-based fibers while others have a higher affinity to hydrophobic materials like polyamide (nylon), polyethylene terephthalate

(polyester) and polyacrylonitrile, etc. As the softeners are often of hydrophobic character, they are generally occurring in the form of an emulsion. In the early formulations, soaps were used as emulsifiers that are usually opaque, milky fluids. However there are also microemulsions where the droplets of the hydrophobic phase are substantially smaller (<http://en.wikipedia.org/wiki/Fabric-softeners>).

Silicone finishes are well recognized softening reagents for providing the softness to the fabric as well as improving their handle and pleasing feel. Various types of silicones and their modified types i.e. diethyl silicone, methyl hydrogen silicone, epoxy, carboxyl, amide and amino silicone are available for varying comfort properties. Currently, the amino functional silicon elastomers are considered to be the most effective types of softeners regarding finishing techniques. The cationization of these species increased the affinity particularly for negatively charged cotton fabrics. The process reveals improvement in deposition and enduring softener film.

The effect of nano emulsion softening reagents was investigated for physical properties of cotton fabric in comparison to conventional emulsions. It has been found that nano emulsion softening chemical tends to improve the textural quality like feel, gives a soft surface and crease resistance, remarkably with higher values against the conventional softeners' treatment (Chattopandhay & Vyas, 2010).

1.10.6 Amphoteric softeners

Softeners constituted on amphoteric substance are generally applied for special products. Amphoteric softeners are usually compatible with white and provide the fabric a good hydrophilic and additional antistatic properties.

1.10.7 Fatty acid amide condensation products

There are certain fatty acid amide condensation products that are called multifunctional softening agents satisfying the requirements of modern, fast moving trends. Besides providing the hydrophilic characteristics, they have many other functions like sewability, antistatic, smooth surface textures and shearing stability. (Nostadt & Zyschka, 1997)

1.10.8 Polyethylene emulsions

Polyethylene emulsions form hard, waxy films after drying at suitable temperature. When the emulsion is applied to fibers, a waxy coating deposits on the surface thus, reducing its coefficient of friction. These coatings offer good protection against needle thread breakage and improve abrasion resistance and tearing strength.

1.11 FUNCTIONAL FINISHES

The functional finishing technology is based on textile treatments by directly incorporating functional chemicals to textiles, such as flame retardants, water repellents, oil repellents, anti microbial agents, UV absorbers, soil and stain removals and handle modifiers etc. (Jocic, 2010).

1.11.1 Flame retardant finishes

The term “flame retardant” is used for any additive that allows a polymer to retard a flame or for any polymer that shows the ability to slow fire growth when ignited (Morgan & Wilkie, 2010). Polymers, when burned, can produce volatile fragments which can ignite on exposure to oxygen or form an inert insulating char. This char can act as a barrier to internal components from further heating and prevent combustion. The main objective of the flame resistant substance is to promote char formation (Lawson & Srivastava, 2008).

1.11.1.1 Mechanism of flame retardants

Combustion during particular phases of the fire process e.g. heating, decomposition, ignition, or flame propagation is prevented by flame retardants. Physically, the performance of the flame retardants consists of the following stages:

a. Formation of a protective layer

The chemicals can prevent transfer of heat from a high temperature source and resist oxygen flow to the flammable material as well as the supply of pyrolysis

|

gases to the surface. This mechanism is exhibited by phosphorus compounds, silicon compounds and inorganic borates.

b. Cooling effect

The chemical can heighten the endothermic process, which cools down the substrate's temperature and prevents ignition.

c. Dilution effect

The additives provoke non-flammable decomposition of gases and dilute the fuel in gas and solid phases (Bourbigot & Duquesne, 2007).

1.11.1.2 Type of flame retardant compounds

There are many compounds that function as flame retardant finishes for specific fibers. Most of all, these compounds have some elements in common that provide protection-namely boron, phosphorous, nitrogen and halogens. These elements in the flame retardant compounds function as following.

a. Boron

According to the literature available, many compounds function as flame retardants such as boric acid (H_3BO_3) and borax ($\text{Na}_2\text{B}_4\text{O}_7$). Boron functions in the condensed phase as a lewis acid and coats the fiber as a glassy polymer.

b. Halogens

Combustion occurs by a free radical chain reaction mechanism contributed by chlorine and bromine, of which hydrogen and hydroxyl radicals are major reactants. The halogen radicals deactivate them, causing the chain reaction to break down.

c. Phosphorus and Nitrogen

Phosphorus and nitrogen also function as condensed phase. Phosphorus compounds react with the C(6) hydroxyl of the anhydro glucose unit impeding the

formation of levo glucosan. This tends to decrease the amount of fuel to the flame. In addition, the phosphorous promotes char formation (Tomasino, 1992). Phosphorous as a halogen free alternative, has met with immense market acceptance, and development for these compounds is very promising (Levchik & Wel, 2006).

1.11.1.3 Flame retardant finishes on cotton and polyester fabrics

To prevent cotton from burning, flame retardant treatment is one of the most appropriate methods. It enhances thermal resistance of cotton to ignition, lessens flame propagation rate, raises ignition temperature and resists continuous burning. Textile flame retardancy is principally required in work clothes, protective clothing, children's sleep wear, carpets, military uniforms, furnishings, draping items and beddings (Levchick & Weil, 2006).

Polyester fabrics being thermoplastic, melt and shrink away from the heat source. The best suited flame retardants for polyester are composed of halogenated compounds that function in the vapor phase. One of the best products to serve this purpose was tris (2,3 dibromopropyl) phosphonate. The product offered good flame retardancy, desirable fabric hand and durability to repeated laundering.

It is very difficult to impart flame resistance to polyester/cotton blends because both of the components have varying burning characteristics. Polyester normally melts and shrinks away from the flame, but in cotton blended fabrics, the melt is held in place by the charred backbone. Commercially, the antimony-bromine finish system is often used, which is normally applied by the pad-dry-cure process. However, the fabric becomes stiffer with the increase in finish content (Tomasino, 1992).

1.11.2 Hand builders

Hand or handle describes how a fabric drapes around an object or feels to the touch. When the stiffer or bulkier fabric is developed, the hand of the fabric is said to be built. Chemicals which impart desirable draping quality are called hand builders. When the drape improves further with silkier touch, it means that the fabric has been

|

softened. The chemicals used for that purpose are called softeners. In general several softeners are derived from natural resources of fats, oils and waxes.

1.11.2.1 Type of hand builders

Hand builders are categorized as either durable or nondurable.

a. Non-durable

Non-durable or temporary hand builders impart better textural appearance than many conventional fabrics. Starched fabrics have a greater consumer appeal since stiff fabrics are easier to manipulate than limpy fabrics.

b. Durable hand builders

Thermosetting and thermoplastic polymers as well as various finishing reagents can serve as durable hand builders. Urea/formaldehyde and in particular, melamine/formaldehyde are thermosetting resins that stiffen the fabric. The chemistry of these two have been described earlier in section 1.9.2. While used primarily for crosslinking cellulosic fibers, they can also be used on other fibers as hand builders.

Stable water dispersion of high molecular weight thermoplastic polymers serves as durable hand builders. Vinyl and acrylic polymers are available as latexes or stable water dispersions and come as very high molecular weight materials with a wide range of glass transition (T_g) temperatures. These products are usually engineered for other end-uses, e.g. non-woven binders, pigment binders, adhesives, carpet backing, paint binders etc. so there is an endless variety to choose from. The property of the dried film depends mainly on the combination of monomers used in the polymerization step. Film hardness, stiffness, flexibility, elasticity, adhesiveness, colour, solvent resistance etc. are all functions of the monomers.

As finishing, the film properties of latex can be used to engineer the fabric hand, as the polymers with a very high T_g add stiffness without adding weight. Polymethyl methacrylate latexes dry down to form very stiff films so it does not take much add-on to stiffen a fabric. On the other hand, ethyl or butyl acrylate polymers

dry down into softer, flexible films. They can be used to build-up weight without making the fabric excessively stiff.

1.11.3 Water and oil repellent finishes

1.11.3.1 Oil repellency

It is tested by placing a drop of oil on the fabric and observing whether the drop resides on top of the fabric or penetrating. The hydrocarbon bearing the lowest surface tension to remain on top and not penetrating is a sign of the fabric's repellency. Lower the surface tension of the liquid, better the fabric's resistance to oily stains.

1.11.3.2 Water repellency

Generally speaking, water repellent fabrics are those which resist being wetted by water and water drops. A fabric's resistance to water depends on the nature of the fiber surface, the porosity of the fabric and the dynamic force behind the influencing water spray.

1.11.3.3 Water-Proof fabrics

These are resistant to the penetration of water under much higher hydrostatic pressure than are water-repellent fabrics. These fabrics have fewer open pores and are less permeable to the passage of air and water vapor. The more waterproof a fabric, the less able it is to permit the passage of air or water vapor.

1.11.3.4 Fluorochemical oil and water repellents

Fluorochemical repellents are distinctive in that they confer both oil and water repellency to fabrics. The ability of fluoro chemicals to repel oils is allied to their low surface energy depending upon the structure of the fluorocarbon section, the nonfluorinated segment of the molecule, the orientation of the fluorocarbon and the distribution and the amount of fluorocarbon deposited on the fibers.

Commercially available fluorochemical repellents are fluorine-containing vinyl or acrylic polymers. The acrylate monomer polymerizes to synthesize a high molecular weight polymer that can be converted to an emulsion. The emulsion dries to a continuous film, covering the fiber surface. The perfluoro segment present there as a side chain, linked to the polymer backbone and further, the heat facilitates the orientation by increasing molecular motion.

1.12 VARIOUS CHARACTERISTICS OF FABRICS INFLUENCED BY DYEING AND FINISHING TREATMENT

The performance of textile fabrics is measured by physical and chemical characteristics. Many fabric properties can be modified by the treatment of finishing reagents. Pigment printed fabrics have some intrinsic properties which assure their multiple application in various fields. These properties contain not only the colourfastness but also the durability of a fabric. Generally, change in colourfastness properties are expressed by ratings according to different levels of fastness.

1.12.1 Colourfastness

Colourfastness is an important criterion for the performance of a coloured fabric. “Colourfastness is the resistance of a material to change its colour characteristics, to transfer its colouring matter to adjacent material or both”. The American Association of Textile Chemists and Colourists have developed nearly thirty test procedures to assess the fastness of a coloured item. The commonly used tests consist of wash, light, perspiration, dry cleaning, abrasion and heat (Cotton incorporated Technical Bulletin, 2002, Saville, 1999).

1.12.2 Rubbing fastness

Rubbing fastness is the resistance of a textile material against colour change by rubbing action. The migration of colour from a coloured surface to an accompanying surface is known as crockfastness (Corbman, 1983). The crockfastness

is determined in both dry and wet conditions. The degree of colour transfer from a dyed textile product is influenced by various parameters such as the type and concentration of colouring matter, dyeing, printing techniques, fixation process, post finishing treatments such as softeners, crosslinking agents, intensity of contact parameters including time, temperature and moisture.

1.12.3 Abrasion resistance

Abrasion is caused by the physical destruction of fibres, yarns, and fabrics, resulting from the rubbing of a textile surface over another surface (Abdullah et al., 2006). Several factors are responsible for rendering the textile material unserviceable, abrasion being the main cause. Wearing, cleaning or washing process can cause abrasion which may distort the fabric, cause fibres or yarns to be pulled out or remove fibre ends from the surface (Kadolph, 2007). Abrasion not only results in the loss of performance characteristics, such as strength, but it also influences the appearance of the fabric (Collier & Epps, 1999., Booth, 1996).

The finishing reagents, types of finishes and the concentration are various parameters which influence the abrasion performance of the fabrics. Similarly, single phase dyeing and application of finishes tend to cling the fibers on the fabric surface and restrict the movement of fibers within the yarn. This compactness of fabric can cause an increased abrasion resistance (Manich et al., 2001).

1.12.4 Pilling

The masses of tangled fibres are known as pills which appear on fabric surfaces during wear and laundering. Pills give an unsightly appearance to fabrics and are also unpleasant to handle. Loose fibres that are pulled from yarns form into spherical balls due to frictional forces of abrasion. Longer fibers called anchor fibres hold these balls of tangled fibres to the fabric.

Pilling problems are not common in fabrics made from wool, cotton or rayon as they fall off as soon as they are formed. But Fabrics made of polyester or nylon spun yarns have strong anchor fibres which are not easily broken. The pills thus

formed stick to the fabric and deteriorate its appearance. In fibre blends of cotton and polyester, the weaker cotton fibres easily get entangled while the stronger polyester filaments hold it to the fabric.

Several chemical finishes can reduce pilling tendency. The first approach is to apply polymeric coating to keep loose fibres from forming the basic fuzz. Friction reducing lubricants such as acrylic copolymers minimize abrasion damage, since they can be easily modified to yield tough flexible films with good adhesion to fabric surface. Generally, finishes that lubricate fibers also increase pilling because, frictional forces needed to pull loose fibres from yarn is reduced. A careful combination of softeners and polymeric coating should be used to achieve a soft hand and pilling control (Schindler, 2004).

1.12.5 Tearing resistance

Fabric tearing is a function of breaking yarns, one at a time, when tearing forces are applied to the fabric. Softeners act as fiber lubricants and reduce the coefficient of friction between fibers, yarns, and between a fabric and an object (an abrasive object or a person's hand). Yarns slide past each other more easily, the fabric will be more pliable and have better drape. If some of the lubricant transfers to the skin and the fabric is more pliable, the fabric will feel soft and silky. Tearing resistance, reduce abrasion and improved the yarns to slide past each other more easily therefore several yarns can bunch up at the point of tear. More fiber mass is brought to bear and the force required to break the bunch is greater than the force required to break a single yarn (Tomassino, 1992).

1.13 SIMULTANEOUS DYEING AND FINISHING

Single stage dyeing processes in conjunction with various finishing treatments i.e. non formaldehyde agents, butane tetracarboxylic acid BTCA and citric acid have been reviewed with respect to various performance properties like colour strength, fastness, strength and crease recovery etc on various substrates. Generally, the concurrent dyeing and finishing approach was followed by acid, basic, direct and

reactive dye stuffs inducing improved fabric performance but sometimes adverse effects like strength losses relative to a conventional method being reported. However, the extent of colouration and improved performance is influenced by composition of substrate, concentration and class of dye stuff, surface modification techniques as well as other necessary parameters. Comparatively acceptable performance properties of dyed and finished cotton substrate can be attained with proper tuning of the treating conditions (Cho et al., 1994, Dong et al., 2005, Ibrahim et al., 2011)

Pigment dyeing is more advantageous as compared to other conventional dyeing systems since the former can incorporate various finishes in the same formulation without any ecological hazards. One bath pigment dyeing offers considerable savings in cost, in equipment, and also in time, energy, and water. Another advantage offered by this process is the possibility of obtaining solid shades on all types of fibrous blends with one class of dye, in one operation (Islam & Akhtar, 2010).

A novel approach for pigment dyeing and functional finishing via ester crosslinking of polyamide – 6/ cotton blended fabric have been developed with enhanced qualities. The fabric was treated with a crosslinker based on citric acid and dyed with a conventional basic and pigment colouring formulations. The simultaneously modified and dyed fabric sample produced a significant improvement in the colour depth as well as functional properties such as UV-B protection and antibacterial performance. It has been observed that the higher the concentration of the dye, the darker the colour yield of the received pigment dyeing. The colour fastness to perspiration, washing and rubbing was graded between 4-5 and 5. The extent of improvement in the dyeing characteristics i.e. shade depth, fastness ratings, imparted UV protection and antibacterial performance was influenced by the combined dyeing/finishing formulation, their concentrations and curing temperature (Ibrahim, 2011).

1.14 AIMS AND OBJECTIVES

The present study aims at developing a compatible pigment/finish colouration system for dyeing of polyester/cotton (P/C) blends with better performance characteristics. It is hoped that incorporation of an appropriate level of crosslinkers, softeners and variant functional finishing reagents in the same dyeing formulation, would be a feasible option for all those industrialists who are striving for eco-friendly, low energy consuming dyeing systems.

The aims of the present study were to

- dye cotton-polyester blended fabrics by a conventional pigment colouration system using double-dip double-nip technique at varying concentrations.
- incorporate various crosslinkers with two optimized pigment/binder systems and evaluate their effects on the performance of treated fabrics.
- determine the qualitative analysis of P/C fabrics dyed and treated with assorted softeners in a single bath formulation followed by physical testing of treated fabrics.
- compare the post and meta treated pigment dyed fabrics with commercially available functional finishing reagents and check their feasibility by statistical analysis.

CHAPTER 2

MATERIALS AND METHODS

This chapter contains the description of the materials and standard methods which were followed in undertaking the current research study.

2.1 MATERIALS

2.1.1 Fabric

The fabric specimens of medium weight polyester/cotton comprising 65/35 blend ratio were used in the current research project and were obtained from a leading mill of Pakistan. The fabric areal density was 108g/m.²

2.1.2 Preparation of fabric prior to dyeing and finishing

The greige fabric was de-sized, scoured and bleached according to the following formulations.

2.1.2.1 De-sizing

The solution was prepared with amylases enzyme Bactasol PHC (1-2g/L, from Clariant Pakistan)) at an adjusted pH of 6-6.5 and the fabric was treated for 4 hours at 60°C temperature followed by washing.

2.1.2.2 Scouring

Scouring was carried out with a solution containing 15g/L of sodium hydroxide, 1g/L wetting agent, 2g/L sequestering agent and 1g/L detergent. The fabric was treated at temperature of 80-90°C for a duration of 1 hour.

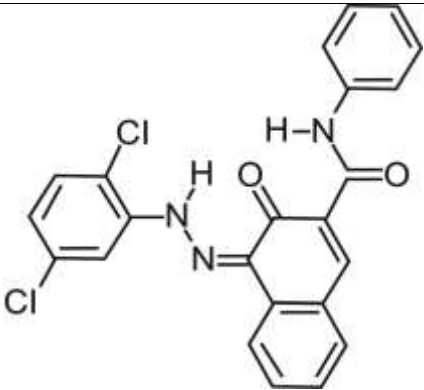
2.1.2.3 Bleaching

The bleaching process was done with Hydrogen peroxide-H₂O₂ (10g/L), sodium hydroxide -NaOH (2g/L), the stabilizer (2g/L), sequestering agent 1g/L, at an adjusted pH of 10-10.5. The fabric was treated at 80-90°C temperature for one hour followed by washing, neutralization, and air drying at room temperature.

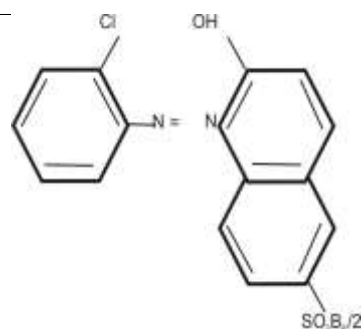
2.2 PIGMENTS

The pigments used in this study, Pigment Red, and Pigment Orange were provided by BASF chemical company. The detail is given in Table 2.1.

Table 2.1 The molecular structure of two types of pigments

Commercial name/Source	Molecular structure
C.I Pigment Red or Fast Red 2	 (C₂₃H₁₅Cl₂N₃O₂)

C.I Pigment Orange 19



Ba salt of (C₁₆H₁₁ClN₂O₄S)

2.3 AUXILIARIES FOR PIGMENT DYEING

The dispersing agent, Setamol BL (sodium salt of condensation product of naphthalene sulphonic acid and formaldehyde) was obtained from BASF Chemical Company. The detail of various binders, crosslinkers and softeners with their trade names and chemical nature is given in Table 2.2, 2.3 & 2.4 respectively.

Table 2.2 Types of binders

Code No	Trade Name/Source	Chemical nature	Molecular Structure
B1	Helizarine Binder CFF (BASF Chemical Company)	Acrylic Dispersion	$\begin{array}{c} \text{R} : \text{C} - \text{OH} \\ \\ \text{O} \end{array}$
B2	Helizarine Binder ET ECO (BASF Chemical Company)	Crosslinkable acrylate copolymer	$\left[\begin{array}{c} \text{CH} - \text{CH}_2 \\ \\ \text{COOH} \end{array} \right]_n \left[\begin{array}{c} \text{CH} - \text{CH}_2 \\ \\ \text{COOCH}_3 \end{array} \right]_m$
B3	Printofix Binder MTB (Clariant International Limited)	Self crosslinking acrylate copolymer dispersion	-----
B4	Printofix Binder 77 N liquid. (Clariant).	Self cross linking acrylic based dispersion	-----
B5	Printofix Fixative WB liquid by Clariant	Aliphatic Polyurethane dispersion	$\text{C}_2\text{H}_2 - \text{NH}_2 - \overset{\text{O}}{\parallel} \text{C} - \text{NH}_2$

Table 2.3 Type of crosslinkers

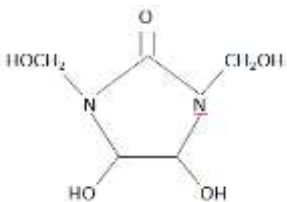
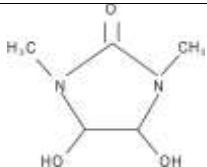
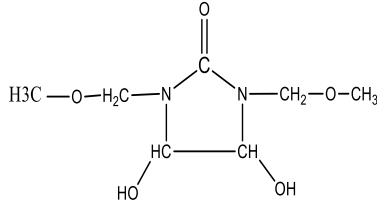
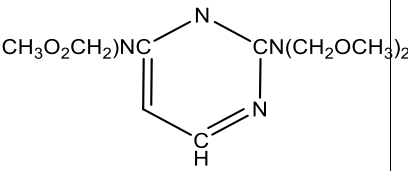
S.No	Commercial Name/Source	Chemical Nature	Molecular Structure
CL1	Fixpret CPF (BASF)	Methylolation product based on Glyoxal monourein (DMDHEU)	
CL2	Fixapret F-ECO (BASF)	Modified Dimethylol dihydroxy ethyleneurea (Formaldehyde free)	 1,3dimethyl- 4,5dihydroxyethyleneurea
CL3	Knittex RCT (Huntsman)	Modified dihydroxy ethylene urea	
CL4	Arkofix New (Clariant)	Modified Dihydroxy ethylene urea (DHEU)	--
CL5	Printofix Fixative WB liquid (Clariant International Ltd)	Highly Etherified Methylol melamine compound (Very low Formaldehyde)	 Hexamethoxy methylemelamine

Table 2.4 Type of softeners

	Commercial name & Source	Chemical Nature	Molecular Structure
S1	Siligen FF-SI (BASF Chemicals)	Amino functional polysiloxane	$\left[\begin{array}{c} \text{CH}_3 \\ \\ \text{---O---Si---} \\ \\ \text{CH}_3 \end{array} \right]$
S2	Siligen SIH Nano (BASF Chemicals)	Modified polysiloxane	-
S3	Ultratex MHT Conc. (Huntsman chemicals)	Micro emulsion concentrate of a quaternary polydimethyle siloxane	-
S4	Ultratex UM New from (Huntsman chemicals)	Macro emulsion of functional Polydimethyle siloxane	$\text{CH}_3 \left[\begin{array}{c} \text{CH}_3 \\ \\ \text{---Si---} \\ \\ \text{CH}_3 \end{array} \right] \text{O} \left[\begin{array}{c} \text{CH}_3 \\ \\ \text{---Si---} \\ \\ \text{CH}_3 \end{array} \right] \text{O} \left[\begin{array}{c} \text{CH}_3 \\ \\ \text{---Si---} \\ \\ \text{CH}_3 \end{array} \right] \text{CH}_3$
S5	Sapamine SFC from (Huntsman chemicals)	Fatty acid amide condensation product	$\text{R} \text{---} \overset{\text{O}}{\parallel} \text{C} \text{---} \text{NH} \text{---} \text{C}_3\text{H}_6 \text{---} \underset{\text{CH}_3}{\overset{\text{CH}_3}{\text{N}}} \text{---} \text{CH}_2 \text{---} \text{COO}$
S6	Perapret F-PEB NEW (BASF Chemicals)	Secondry Polyethylene dispersion	$\begin{array}{ccccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & & \\ & & & & & & \\ \text{H} \text{---} \text{C} & \text{---} \text{C} & \text{---} \text{C} & \text{---} \text{C} & \text{---} \text{C} & \text{---} & \text{H} \\ & & & & & & \\ \text{H} & \text{H} & \text{n} & \text{R} & \text{H} & \text{m} & \text{H} \end{array}$

Various finishing reagents that were used in the current study are given in Table 2.5.

Table 2.5 Functional finishing reagents

	Commercial name & Source	Type of Finish	Chemical Nature
1	Pekoflame HSD Liquid (Clariant International Ltd)	Flame Retardant	Inorganic salts
2	Pekoflame OP liquid (Clariant International Ltd)	Flame Retardant	Organic Phosphorous Compound
3	NUVA F D Liquid (Clariant International Ltd)	Water Repellent Finish	Dispersion of a fluorine compound
4	NUVA 3585 (Clariant International Ltd)	Oil & Water Repellent Finish	Dispersion of a fluoro compound
5	NUVA HPU Liquid (Clariant International Ltd)	Durable Water & Oil Repellent Finish	Dispersion of a fluorine compound
6	UV SUN CEL LIQ (Huntsman chemicals)	UV Absorber	Oxalanilide
7	Dicrylan BSRN (Huntsman chemicals)	Handle Modifier & Stain Release Finish	Soft Polyurethane emulsion
8	Hand building finish (BASF chemicals)	---	Polyurethane

2.4 GENERAL CHEMICALS FOR DYEING AND FINISHING

These include acetic acid (10%), magnesium chloride. $6\text{H}_2\text{O}$, sodium hydroxide, sodium carbonate, enzyme Bactasol PHL, wetting agent, sequestering agent, detergent, hydrogen peroxide and stabilizer.

2.5 EQUIPMENT FOR DYEING AND FINISHING

2.5.1 Padder for dyeing

Application of dyes with various treatments i.e. cross linkers, softeners and functional finishing chemicals was carried out on laboratory padder model VPM-250, from Nippon-bashi, Japan, available at the processing laboratory of National Textile University, Faisalabad. The air pressure of the padder was adjusted to attain 70% wet pick up on the weight of the fabric.

The padding fabric speed was set to the desired value (1.2m /min). The dyeing liquor according to the appropriate proportion was supplied in the fluid beck, the test cloth immersed in it, passed through the nips of mangle, squeezed through rollers. The operation was repeated again, called as double- dip, double-nip technique.



Figure 2.1: Laboratory Padder

2.5.2 Tenter

An over feed pin tenter of model number OPT-1 from Tsuji dyeing machine manufacturing company, limited was used in this study for drying and curing of P/C fabrics after padding. The drying temperature was set at a selected optimal value i.e. 150°C for 3 minutes while for curing 170°C for 2 minutes. The linear fabric speed of the tenter frame was 1.2 m/min.

After switching on the pilot lamp in control panel, the desired drying temperature was set at 150°C and the width of the tentering machine was adjusted according to specimen cloth's width. The duration of thermal drying was set and the padded cloth was fixed evenly on to an overfeed mechanism. The cloth end was taken over to an overfeed roller, and then passed through swivel tension and then delivery rollers. The nip was closed by a slight tightening of the cloth which was then automatically taken out of the drying unit by a cloth remover, operated through a caterpillar system. The same procedure was repeated again for curing of fabric at a constant temperature of 170°C for two minutes. The thermo-fixed dyed fabric was received from thermal chamber within a prescribed time.



Figure 2.2: Tenter Frame

2.6 TESTING

All the fabric specimens, both treated and untreated, were subjected to various physico-mechanical tests according to the following standard methods.

2.6.1 Colourfastness

The American Association of Textile Chemists and Colourists (AATCC) defined the colourfastness as “the resistance of a material to change in any of its colour characteristics, to transfer its colourant(s) to adjacent materials, or both, as a result of the exposure of the material to any environment that might be encountered during the processing, testing, storage, or use of the material” (Cotton Incorporated Technical Bulletin, 2002).

2.6.1.1 Colourfastness to washing

Colourfastness to washing was tested on Launder-o-meter in accordance with the AATCC-TM 61 standard method. The dyed fabric specimens (4x10 cm) were stitched together along with untreated cotton fabric and immersed in a liquor that was prepared with 5g/L of AATCC recommended detergent, 2g/L sodium carbonate in a material to liquor ratio of 1:50 at 60°C. After 30 minutes of washing, the composite specimens were rinsed thoroughly in fresh tap water and dried at room temperature. The fabric was unstitched after drying and evaluated for shade change of dyed fabric and staining against untreated fabric using standard Grey Scale, ranging from 1-5, where ‘1’ denotes maximum change and ‘5’ no change.



Figure 2.3: Launder-o-meter for Wash Fastness



Figure 2.4: Wash Fastness Assessment

2.6.1.2 Colourfastness to rubbing (wet & dry)

Colourfastness to wet & dry rubbing was assessed on crockmeter according to the standard test method, AATCC-08. The base of the crock meter was covered with an abrasive paper to avoid sliding of the test specimen. The specimen was clamped upon the paper to the base, firmly with the specimen holder. The test cloth was

fastened to the rubbing finger with the help of a spring clip. To begin with the finger, resting on the specimen, the meter handle was cranked for the specified number (10) of strokes. The finger with a force of 9 Newtons, traversed the whole path i.e. 4 inches. After completing the strokes the test cloth was removed and the circular image was evaluated with the help of Grey Scale for colour change (Figure 2.6). The grey scale comprises achromatic grey chips in light to dark scale of nine pairs corresponding to grading of 5, 4-5, 4, 3-4, 3, 2, 1-2, & 1, which demonstrates the colour differences. The same test was repeated to determine the wet rubbing fastness of the test cloth too with 65 % wet pickup on the weight of fabric.



Figure 2.5: AATCC Crockmeter

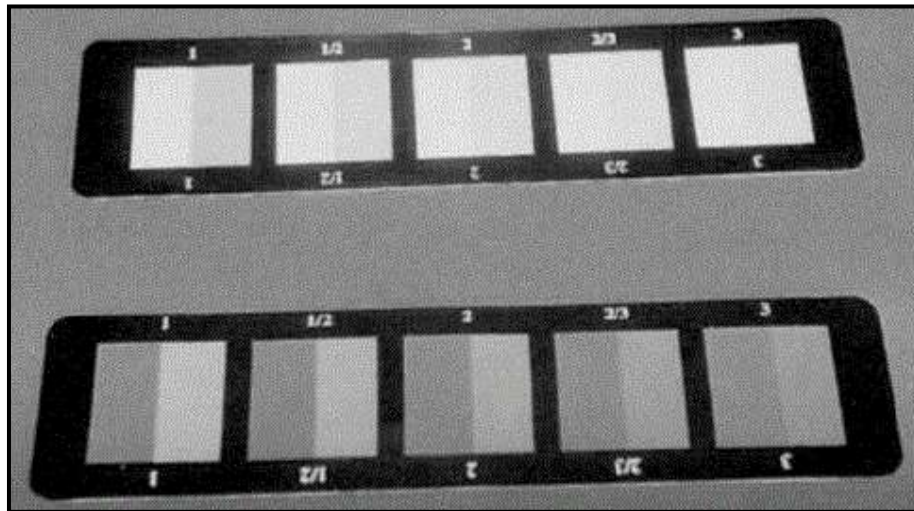


Figure 2.6: Grey scale

2.6.2 Tear strength of fabrics

The tear strength of P/C fabric was conducted on Elmendorf Apparatus according to ASTM. D 1424-96. According to the procedure a slit was made in the centre of test specimen (4x25), (4 inch long by 2.5 inch wide) held between two clamps. The specimen was torn with the help of a knife-edge, mounted on stationary clamp, through a specific distance by instantly releasing the pendulum from raised position. The resistance to tearing of the test specimen was measured in gm force.



Figure 2.7: Elmendorf Apparatus for Tear Strength Testing

2.6.3 Tensile strength and elongation

The tensile strength test of fabric samples was conducted on Testometric 220 D testing machine in accordance with ASTM standard D 6035-06, Breaking Force and Elongation of Textile Fabrics (strip method). The fabric strips (2.5x8 inches) were ravelled by removing equal number of yarns (0.2 inch) on each side in width (1 inch extra length for jaws grip) in both warp and weft direction. The specimens were subjected to test at recommended strain speed (constant lb/inch) and the force required to break the specimen as well as percentage elongation was reported.



Figure 2.8: Testometric 220 D for Tensile Strength Testing

2.6.4 Abrasion resistance

Abrasion behavior of fabric specimens the P/C fabric was evaluated on the Martindale abrasion tester (Abrasion machine mark II) in accordance ASTM D4966-98(Reapproved 2007). Four circular specimens of fabric, 38mm in diameter were subjected to rubbing action under pressure of 14 ounces against a standard cross-bred worsted fabric on the apparatus. The specimens were inspected at regular intervals till

abraded and the visual examination reveals the breakdown of two or more threads. The total number of movements required to break the threads in the form of lissajous figure (a geometrical shape) Figure 2.9(b) was recorded for the four specimens and average calculated.



Figure 2.9(a): Martindale Abrasion Tester with Specimen Holder

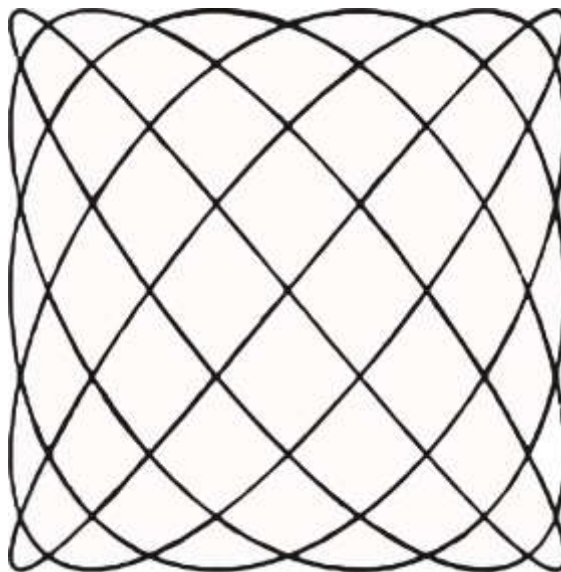


Figure 2.9(b): Lissajous Figure

2.6.5 Pilling assessment

The pilling resistance of P/C fabrics, was determined on I.C.I. Pilling-Box tester according to the recommended procedure described in British Standard -5811. Fabric specimens were mounted on polyurethane tubes with a secured fastening device and then tumbled randomly in cork-lined cubic wooden boxes. After 5 hours (equivalent to 18000 revolutions), the degree of pilling of the samples was evaluated by comparing their visual appearance against standard photographs of pilled fabrics or ASTM light box as a subjective grading. The samples were rated on a scale of 1-5, with 1 representing severe pilling and 5 for no pills.



Figure 2.10: I.C.I Pilling Box Tester

2.6.6 Flexural rigidity

The flexural rigidity test was carried out on Shirley Stiffness Tester according to the method given in ASTM. D 1388-08. The bending stiffness of a fabric was measured by allowing a narrow strip of the fabric to bend to a fixed angle (41.5°) under its own weight. The length of the fabric required to bend to this angle was measured, known as the bending length and the method called Cantilever bending fabric principle. The test specimens in both warp and weft directions each 25 mm

wide and 200 mm measurement were tested according to the recommended procedure. Four readings were taken from each specimen, one face up and one face down on the first end, and then the same for the second end. After taking the mean bending length for warp and weft, the flexural rigidity was calculated as following

$$G = (1.241 \times W \times C^3 \times 10^{-5}), \text{ where}$$

G = Flexural Rigidity (μ joule/m)

W = Fabric mass per unit area (g/cm^2).

C = Bending length (mm)



Figure 2.11: Shirley Stiffness Tester

2.6.7 Standard test method for flame resistance of textiles (vertical test)

The flame resistance of fabric was determined according to the method described in ASTM D6413-99. This test measures the flame resistance of textiles in vertical position. A specimen measuring 76mm (30 in) by 300mm (12 in) was mounted and exposed to the flame for a specific period of time. The specimen was clamped between the two halves of the holder with the bottom of the specimen. With the holder held vertically the specimen was secured in the holder with the minimum

of four clamps, near the top and the bottom on each side. The specimen was transferred into the test cabinet in a stable position. The burner was set in the middle position of the specimen and exposed to the flame for 12 ± 0.28 . During flame exposure, the after flame and afterglow time was recorded. The specimen was allowed to cool after removing it from flame. The char length was determined along the undamaged edge of specimen to the nearest 3mm (0.12 in). The average after-flame time, after-glow time and the char length was calculated.

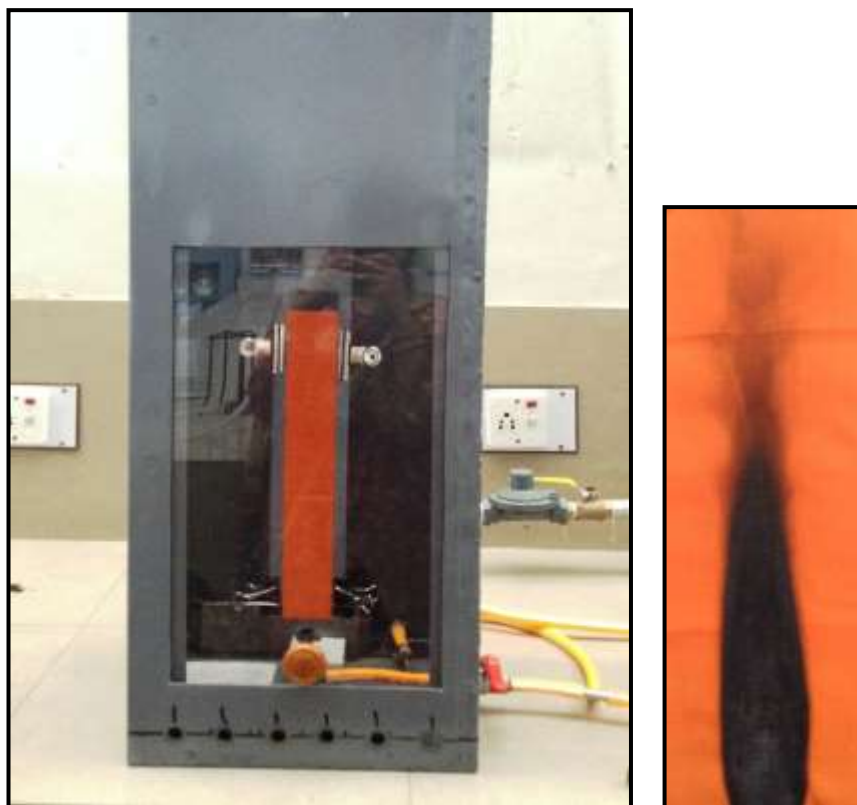


Figure 2.12: Flame Resistance (Vertical Flammability Test)

2.6.8 Mass per unit area

The mass per unit area (weight) of fabric was determined in accordance with test procedure described in ASTM D766–07. The test specimen measuring 10 cm^2 was cut using a cutting die provided with apparatus. The cloth balance was adjusted to its zero position by a revolving screw and the sample was set on the balance. The

weight per unit area was read directly from the scale graduated in grams per square meter.

2.7 APPLICATION METHODS

The whole scheme of investigation was divided into the following five phases:

2.7.1 Application of base formulation

In the first phase, Helizarin red pigment was applied on P/C blend with five different binders in four concentrations.

2.7.2 Two-step dyeing and finishing

It consisted of two steps,

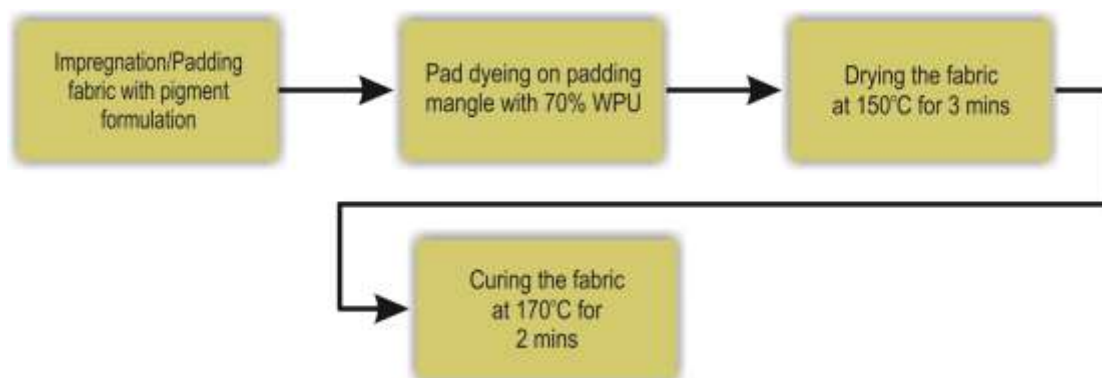
- i) Pigment dyeing of P/C fabrics in a conventional method.
- ii) Post treatment of some commercially available functional finishing chemicals on dyed specimens.

2.7.3 Meta phase dyeing and finishing

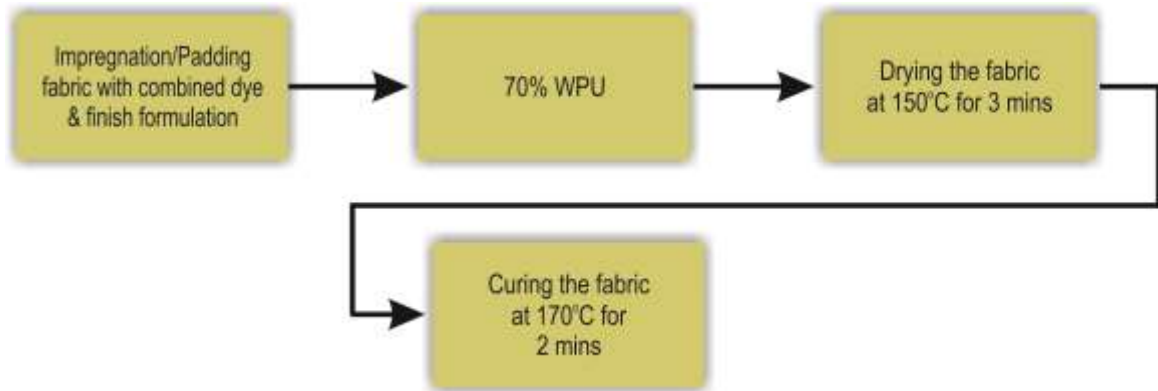
In this section dyeing and finishing of fabrics was carried out simultaneously in single bath formulations at various concentrations.

2.7.4 Mode of Application for pigment dyeing

Throughout the study the mode of application, was pad dyeing.

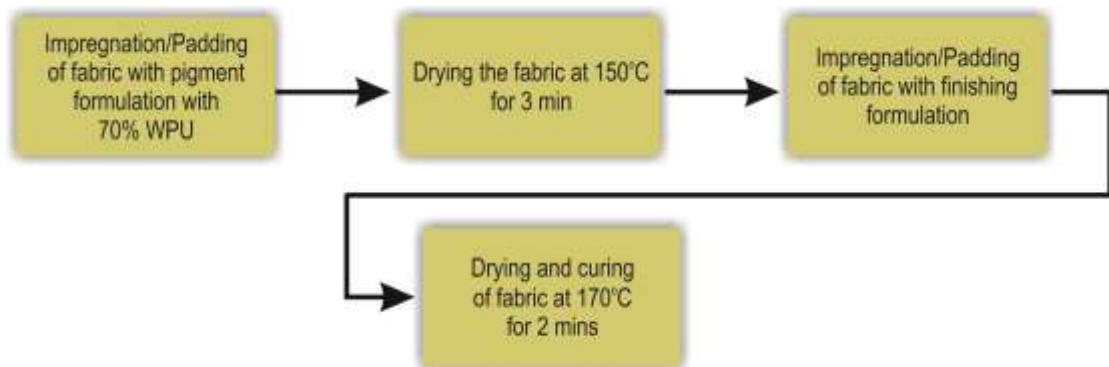


For the first three phases it was adopted and accomplished according to the following sequence.

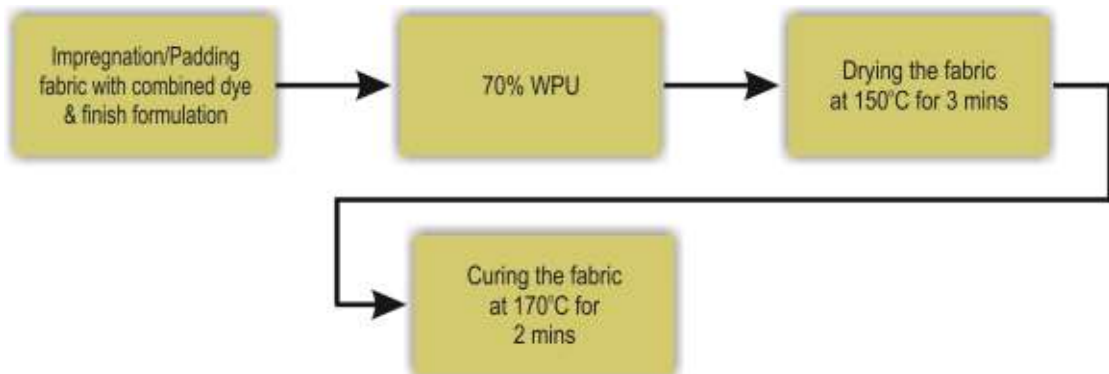


2.7.5 Mode of application for pigment dyeing and functional finishing

- a. The application of two-step, two-bath pigment dyeing and finishing technique of fabrics was followed in accordance with the sequence given below.



- b. The approach for application of simultaneous pigment dyeing and finishing of fabrics was modified a little in the order represented as,



2.8 FORMULATIONS FOR DYEING & FINISHING TREATMENT ON PADDING MANGLE

In this study padding technique was used as the main application system for dyeing and finishing, therefore the preparation of formulation, the first step of this technique was as following.

2.8.1 Base formulation for pigment dyeing

According to earlier mentioned scheme, the formulations were distributed in five sets. The base formulation for dyeing consisted of pigment, binder and dispersing agent. A small quantity of dispersing agent (1 gm/L) was included to prevent agglomeration of the pigment particles in the liquor. The formulations mentioned in Table 3.6 were followed accurately unless specified differently.

Table 2.6 Pigment Binder Formulations at Various Concentrations

Pigment conc. (g/L)	Binder conc. (g/L)	Type of Binders				
20	100	Helizarin Binder ET Eco	Helizarin Binder CFF	Printofix BindeMTB	Printofix 77Nliquor	Poly Urethane Binder
20	150					
50	150					
50	200					

Following the 1000 ml stock formulation this way, five sub sets were prepared using various binders that are listed in Table 2.2.

2.8.2 Incorporation of crosslinkers in optimized binder systems

In this set various crosslinkers were incorporated with the two optimized binder systems for dyeing of P/C fabric. For this purpose 1000ml of stock solution

was prepared using 50g/L pigment, 200gm/L binder, 1g/L dispersing agent, 20 gm/L of magnesium chloride and 100g/L of cross linker.

Table 2.7 Formulations with Crosslinkers

Pigment Conc.	Catalyst Conc.	Binders (200g/L)	Crosslinkers (100g/L)each				
Pigment red (50g/L)	Magnesium Chloride (20g/L)	Helizarin Binder CFF	CL1	CL2	CL3	CL4	CL5
		Helizarin Binder ET ECO	CL1	CL2	CL3	CL4	CL5

The formulations were prepared at constant parameters with the only difference being in the type of cross linker (enlisted in Table 2.3) substituted each time with the specific type of binder.

2.8.3 Formulations with softeners

Table 2.8 Treatment with Softeners

Pigment conc.	Cross linker conc.	Catalyst conc.	Binder conc.	Softeners (30g/L)each					
Pigment red (50g/L)	Knittex RCT (100g/L)	Magnesium chloride (20g/L)	Helizarin Binder CFF (200g/L)	S1	S2	S3	S4	S5	S6

Keeping all the parameters constant (a cross linker with catalyst, acrylic binder, & pigment orange), the fabrics were pad dyed and treated with various softeners according to the formulation mentioned in Table 2.8. The stock formulations were prepared separately with all types of softeners (Table 2.4) with the exception of

only one recipe, in which 0.5 ml/L acetic acid (60%) was mixed with Ultratex MHT conc. softening agent.

2.8.4 Post treatment of pigment dyed fabrics with functional finishes

This set contained two steps:

In the first stage P/C fabrics were dyed according to the conventional stock formulation i.e. 50g/L pigment, 200g/L of binder and 1g/L of dispersing agent.

In the second stage, post treatment of dyed fabric was carried out with some commercially available functional finishing chemicals (Table 2.5) according to the following two concentrations.

Pekoflame HSD Liquid	500g/L	&	300g/L
Pekoflame OP liquid	300g/L	&	200g/L
Nuva F D Liquid	50g/L	&	20g/L
Nuva 3585	50g/L	&	30g/L
Nuva HPU Liquid	50g/L	&	30g/L
UV SUN CEL LIQ	50g/L	&	15g/L
Dicrylan BSRN	40g/L	&	20g/L
Hand building finish	40g/L	&	20g/L

2.8.5 Simultaneous pigment dyeing and functional finishing

Functional finishes were incorporated with pigment dyeing formulation at exactly the same concentrations as mentioned in the previous scheme. All the treatments were applied twice, simultaneously with dyeing solution at both maximum and minimum concentrations.

2.9 Statistical analysis

The data was statistically analysed by using Minitab 17 software package. The effect of various binders, finishes, pigments and finish concentrations on various

characteristics was statistically analysed by the general linear model. The main effects plots of the results were drawn by the ANOVA tables and the same modal was applied also for assessing the significant or non-significant effect of the application methods on physico-chemical properties.

CHAPTER 3

RESULTS AND DISCUSSIONS

3.1 EFFECT OF DIFFERENT BINDERS ON THE PROPERTIES OF PIGMENT DYED FABRICS

In the first phase of the current project, Helizarin Pigment Red was applied with five different binders in varying amounts. The performance of dyed fabrics analyzed with respect to their colour fastness as well various other physico-mechanical properties and the results are tabulated. The physical properties of the control sample are listed in Table 3.1.

Table 3.1 Physical characteristics of desized, scoured and bleached P/C fabric

Weight per unit area (gm/m ²)	Threads per inch	Tensile Str. (lb)		Elongation (%)		Tear Str. (gm.force)		Flexural Rig. (μ joule/M)	
		Wp	Wt	Wp	Wt	Wp	Wt	Wp	Wt
108	83×53	137.01	47.0	0.96	2.06	1526	2320	10.36	3.99

¹ASTM (D 5035-06)

²ASTM (D1424 – 96)

³ ASTM (D1388 – 08)

3.1.1 Colourfastness of the pigment dyed samples

A summary of the colourfastness results of polyester /cotton fabrics dyed with different pigment concentrations, different binder types and concentrations is given in Table 3.2.

Table 3.2 Effect of pigment concentration, different binder types and concentrations on colourfastness of the dyed samples

Sample No.	Factors			Responses			
	Pigment Conc. g/L	Binder Type	Binder Conc. g/L	Dry Rubbing Fastness	Wet Rubbing Fastness	Washing Fastness SC	Washing Fastness ST
1	20	B1	100	3.0	2.5	3	3
2			150	4.0	3.5	4	4.5
3		B2	100	3.5	3	4.5	4.5
4			150	4.0	3	4	4
5		B3	100	4.0	2.5	3.5	3.5
6			150	4.0	2.5	5	4.5
7		B4	100	3.5	2.5	3.5	4.5
8			150	3.5	2.5	4.5	4.5
9		B5	100	2.5	2	3.5	4.5
10			150	3.5	2.5	4	4.5
11	50	B1	150	3.5	2.5	4.5	3
12			200	3.0	3.5	4.5	3
13		B2	150	3.0	2.5	4.5	4
14			200	3.5	3	4.5	3.5
15		B3	150	1.5	1	2	3
16			200	1.5	1	3	2
17		B4	150	2.5	2	4.5	4.5
18			200	3.5	2.5	4.5	4.5
19		B5	150	3.0	2.5	4.5	4.5
20			200	4.0	3	3.5	4.5

B1: Helizarin Binder ET ECO

B2: Helizarin Binder CFF

B3: Printofix Binder MTB

B4: Printofix Binder 77N

B5: Printofix Fixative WB Binder

3.1.1.1 Dry rubbing fastness

The detail of the results, regarding rubbing fastness properties of P/C fabrics applied with various binders and Helizarin Pigment Red are as following. The analysis of variance (ANOVA) of the dry rubbing fastness results, given in Table 3.3, shows that only the effect of pigment concentration is statistically significant on the dry rubbing fastness of the dyed samples (P -value < 0.05). The effect of binder type and concentration was not found statistically significant on the dry rubbing fastness. The main effect plot for dry rubbing fastness is given in Figure 3.1, which shows a decreasing trend in the dry rubbing fastness with increase in pigment concentration, and an increasing trend in dry rubbing fastness with increase in the binder concentration.

Figure 3.2 shows results of the individual samples treated with different types and concentration of binders at different concentrations of the pigment. The pictorial representation shows that, at 20 g/L pigment concentration, the best performance of dyed fabrics was contributed by the binder B1, B2 and B3 maintaining the good rubbing fastness level with the corresponding concentration of 150g/L of pigment, whereas, the maximum degradation in the values for dry rubbing fastness was induced by the binder B3 at higher pigment/binder concentration.

3.1.1.2 Wet rubbing fastness

The analysis of variance (ANOVA) of the wet rubbing fastness results (Table 3.4), shows that the effect of pigment concentration and binder type is statistically significant on the wet rubbing fastness of the dyed samples (P -value < 0.05). The effect of binder concentration was not found statistically significant on the wet rubbing fastness.

The main effect plot for wet rubbing fastness is given in Figure 3.3, which shows a decreasing trend in the wet rubbing fastness with increase in pigment concentration, and an increasing trend in wet rubbing fastness with increase in the binder concentration. Binder B3's wet rubbing performance was found to be significantly poor as compared to other binders, whereas Binder B1 gave the best, mean wet rubbing fastness results.

Table 3.3 Analysis of variance for dry rubbing fastness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	4.438	0.6339	1.21	0.369
Pigment conc.	1	3.025	3.0250	5.76	0.033*

Binder Type	4	1.300	0.3250	0.65	0.657
Binder conc.	2	1.025	0.5125	0.98	0.405
Error	12	6.300	0.525		
Total	19	10.738	-		
*Statistically significant at P value 0.05					

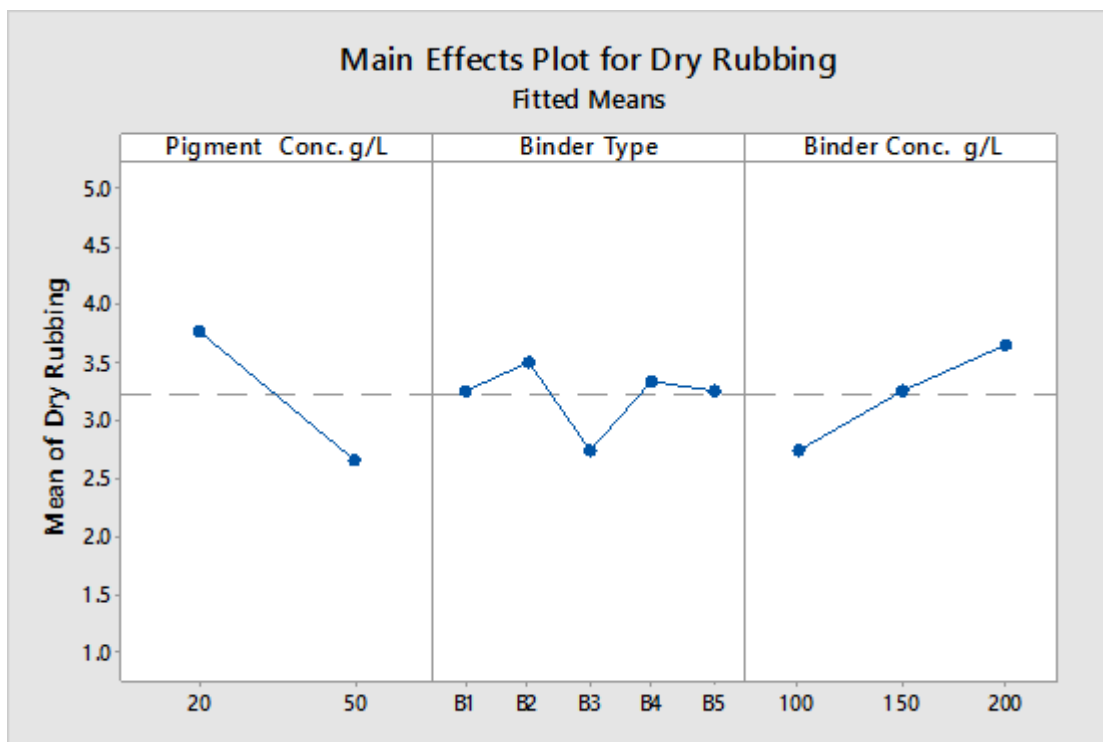


Figure 3.1: Main effects plot for dry rubbing fastness of dyed P/C fabrics

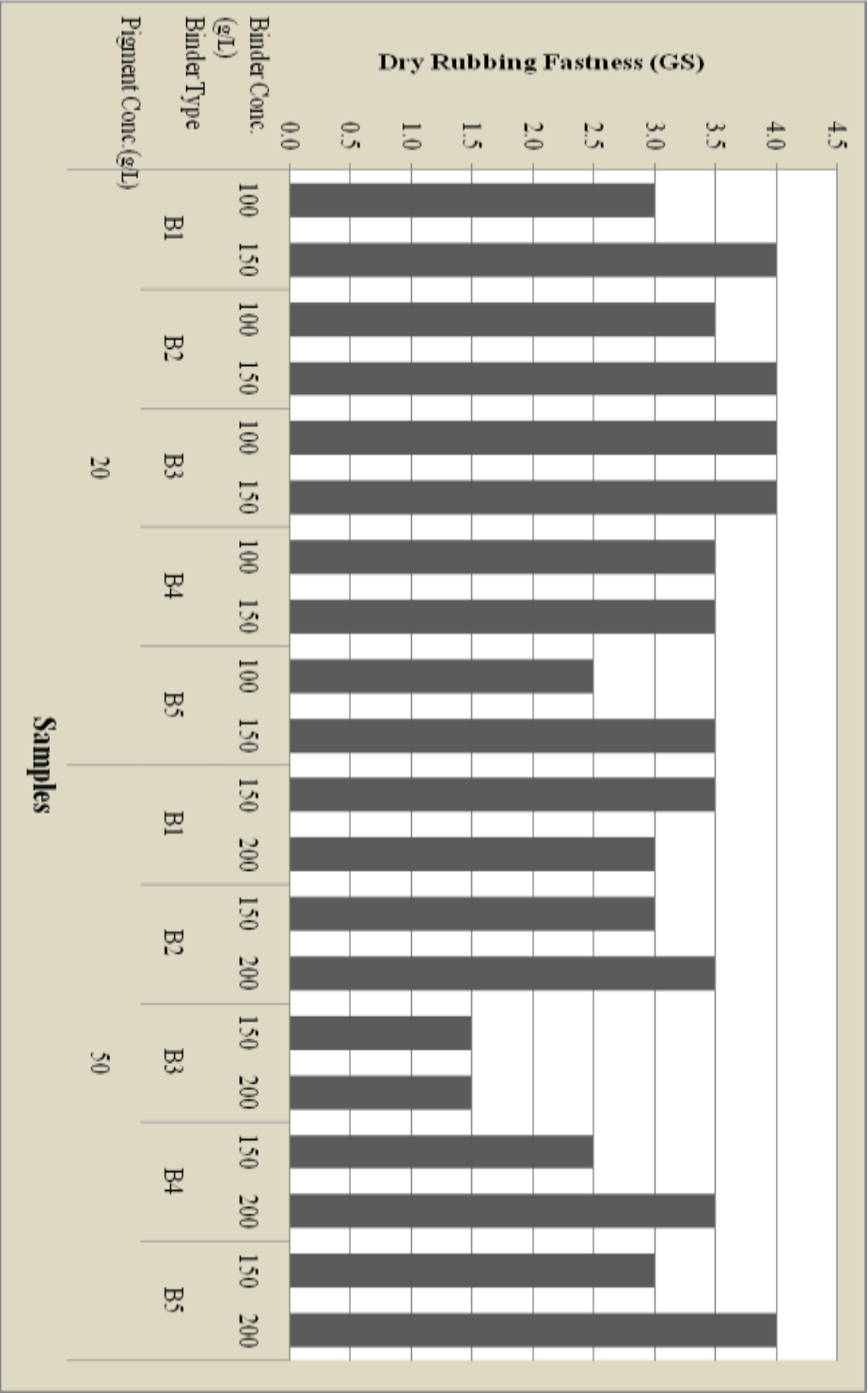


Figure 3.2: Effect of pigment conc., binder type and binder concentration on the dry rubbing fastness

Table 3.4 Analysis of variance for wet rubbing fastness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	5.175	0.7393	3.14	0.040
Pigment conc.	1	1.225	1.225	5.20	0.042*
Binder Type	4	3.875	0.9687	4.12	0.025*
Binder conc.	2	0.85	0.425	1.81	0.206
Error	12	2.825	0.2354	-	-
Total	19	8.0	-		-

*Statistically significant at P value 0.05

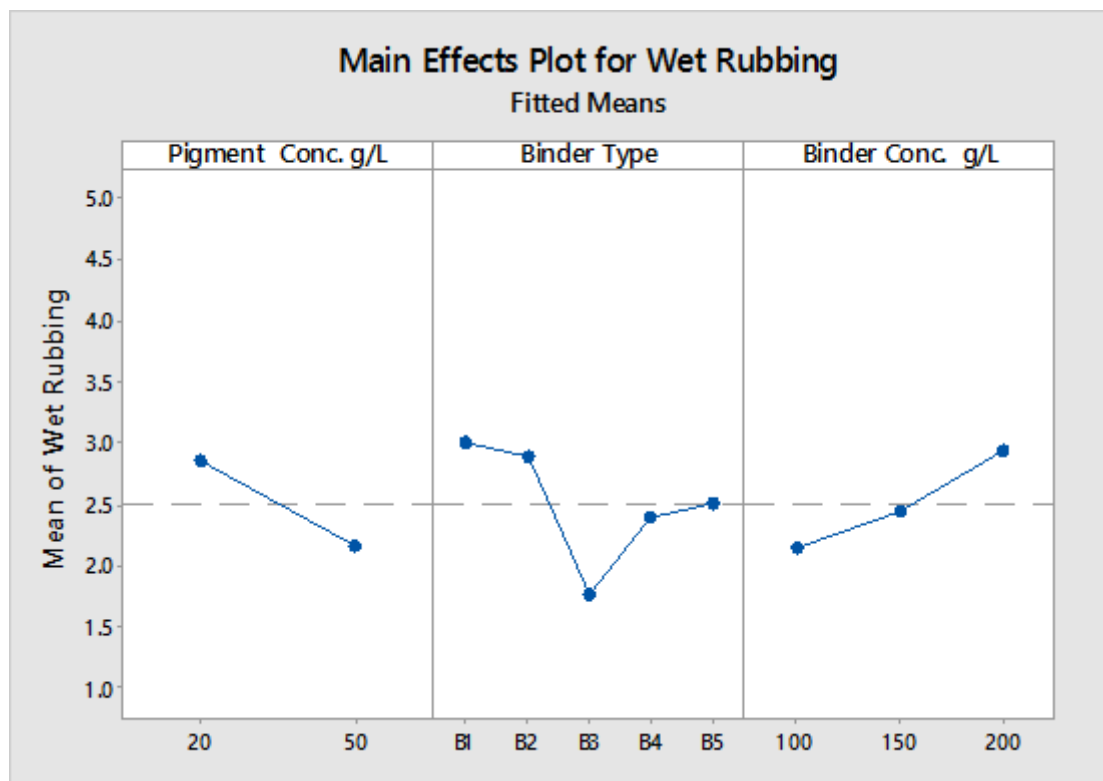


Figure 3.3: Main effects plot for wet rubbing fastness of dyed P/C fabrics

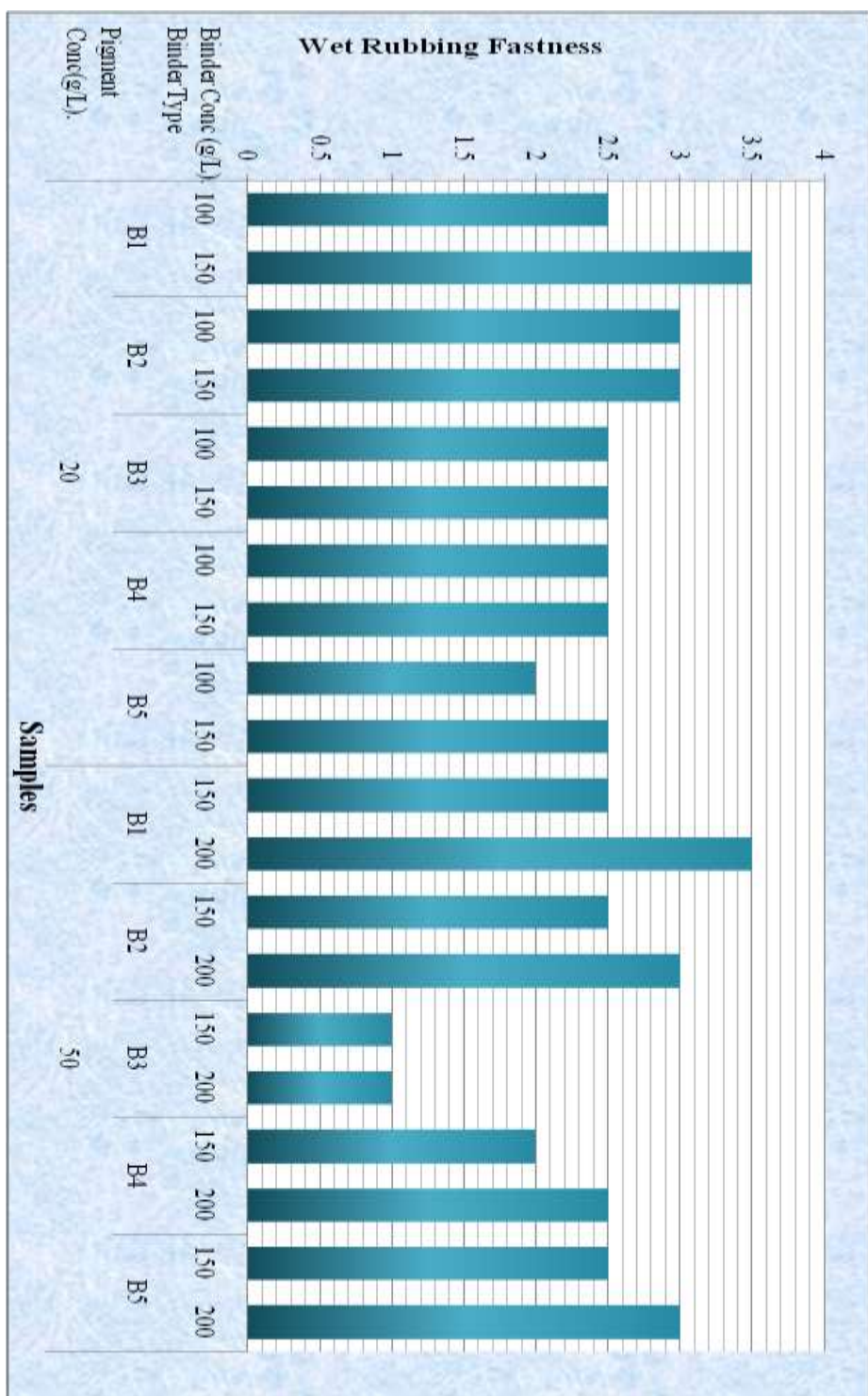


Figure 3.3 shows results of the individual samples treated with different types and concentration of binders along different concentrations of the pigment. It is evident from the findings that, the binder B1 again showed highest wet rubbing fastness of fabric as its grades were gradually increased with maximum concentration i.e. 200 g/L at both the 20 and 50 g/L of pigment. As far as the individual performance of the other fabrics are concerned, again the B3 at high binder concentration was ranked at the lowest rubbing grade i.e. '1', signifying a prominent change towards the worst level of fastness.

3.1.1.3 Washing fastness (shade change)

The analysis of variance (ANOVA) of the washing fastness results regarding change in colour are presented in Table 3.5. The tabulated values reveal that the effect of pigment concentration, binder type and binder concentration are statistically non significant, on the washing fastness of the dyed samples (P -value < 0.05). The main effects plot for shade change due to washing treatment shows a slight decline in fastness level with an increase in pigment concentration (Figure 3.5). The binder B2 exhibited lesser change in shade while the washing fastness of B5 was found to be statistically least affected.

In case of effect of binder concentration a directly proportional relation was found with the mean wash fastness values of fabrics. The shade change grading was increased gradually with binder concentration and then stabilized at maximum value.

The results of the individual samples treated with different types and concentration of binders at different concentrations of the pigment regarding wash fastness (shade change) are exhibited in Figure 3.6. An astonishing difference in the wash fastness results were obtained by the dyed P/C fabric by the utilization of binder B3 at low pigment concentration with higher binder concentration. Though, it had given poor rubbing fastness, yet after washing treatment it had exhibited the highest grade (5) representing no change in fabric shade at all.

3.1.1.4 Washing fastness (staining)

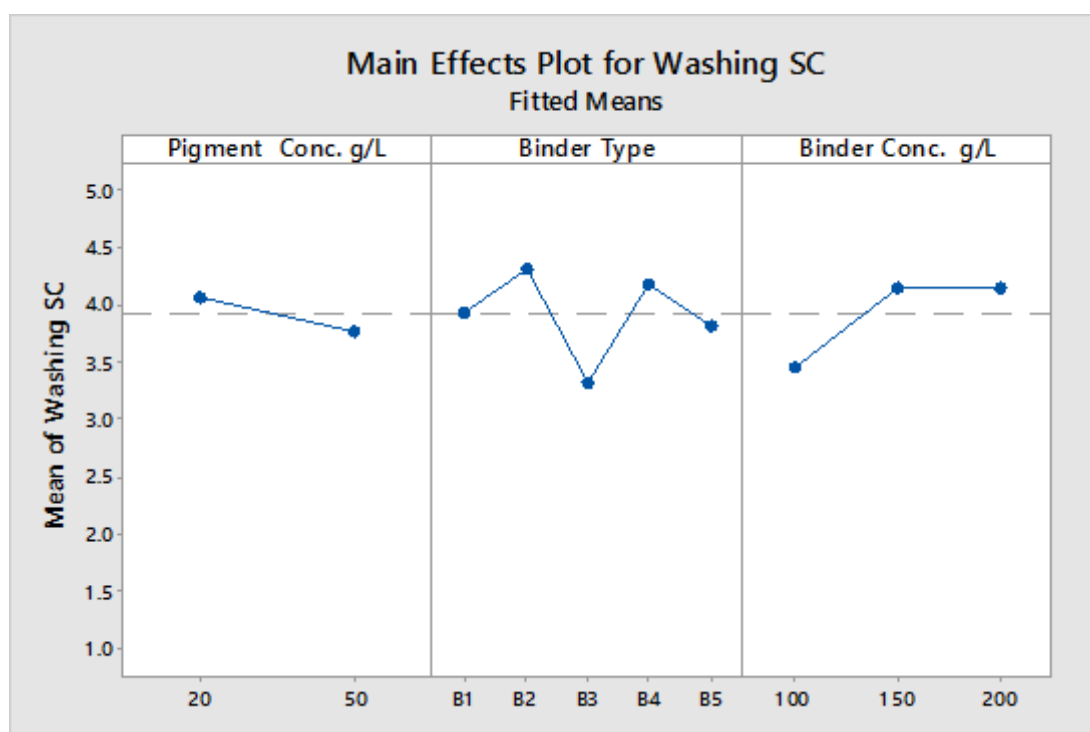
Table 3.6 presents the analysis of the variance of the staining to adjacent cloth occurs due to washing treatment of dyed P/C fabrics. As regards the pigment and binder concentration, the effect on colour change to adjacent cloth was statistically non significant. The binder type effected the same property with a significant difference in the mean values of dyed P/C fabrics obtained after wash treatment.

The main effects plot for ANOVA of washing fastness with respect to staining on adjacent cloth is given in Figure 3.7, according to which a decreasing trend in wash fastness grading was found with an increase in pigment concentration. Two of the binders, B4 and B5 revealed the best washing fastness on P/C fabrics, while B3 presented the less resistance regarding staining to adjacent cloth. The effect of binder concentration showed an increased resistance for staining on adjacent cloth after washing treatment at first and then decreased slightly with further increase in binder ratio. The individual comparison of treated samples with different types and concentration of binders at different concentrations of the pigment regarding wash fastness (staining) are shown in Figure 3.8.

Table 3.5 Analysis of variance for washing fastness (shade change)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	3.6625	0.5232	0.95	0.503
Pigment conc.	1	0.2250	0.2250	0.41	0.534
Binder Type	4	2.4250	0.6063	1.11	0.398
Binder conc.	2	1.2250	0.6125	1.12	0.359
Error	12	6.5750	0.5479	-	-
Total	19	10.2375	-	-	-

*Statistically significant at P value 0.05

**Figure 3.5: Main effects plot for washing fastness (shade change) of dyed P/C fabrics**

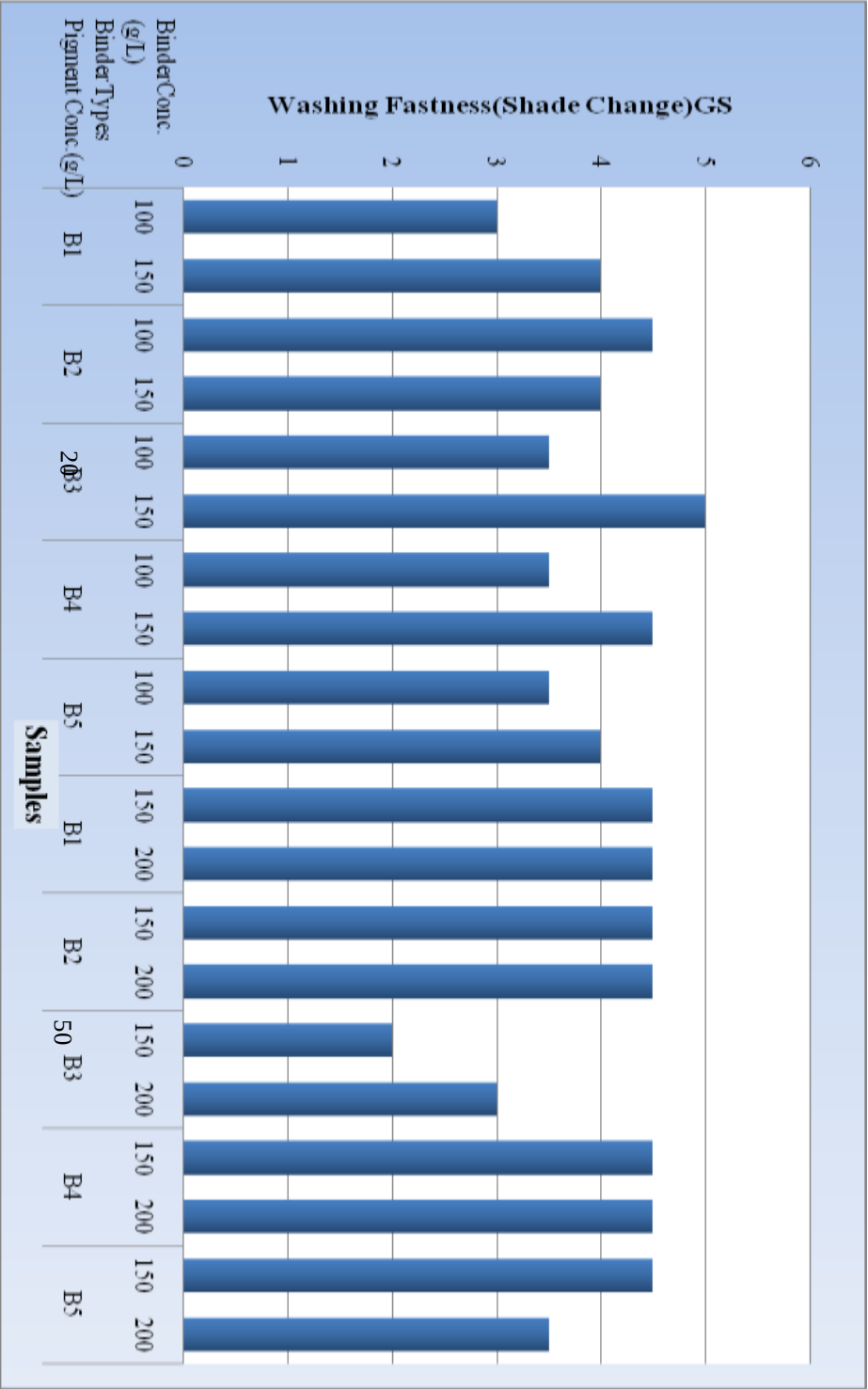


Figure 3.6: Effect of pigment conc., binder type and binder concentration on the washing fastness (shade change)

Table 3.6 Analysis of variance for washing fastness (staining)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	7.8375	1.1196	4.07	0.016
Pigment conc.	1	0.9000	0.9000	3.27	0.096
Binder Type	4	5.7000	1.4250	5.18	0.012*
Binder conc.	2	0.6250	0.3125	1.14	0.353
Error	12	3.3000	0.3125	-	-
Total	19	11.1375	0.02750		

*Statistically significant at P value 0.05

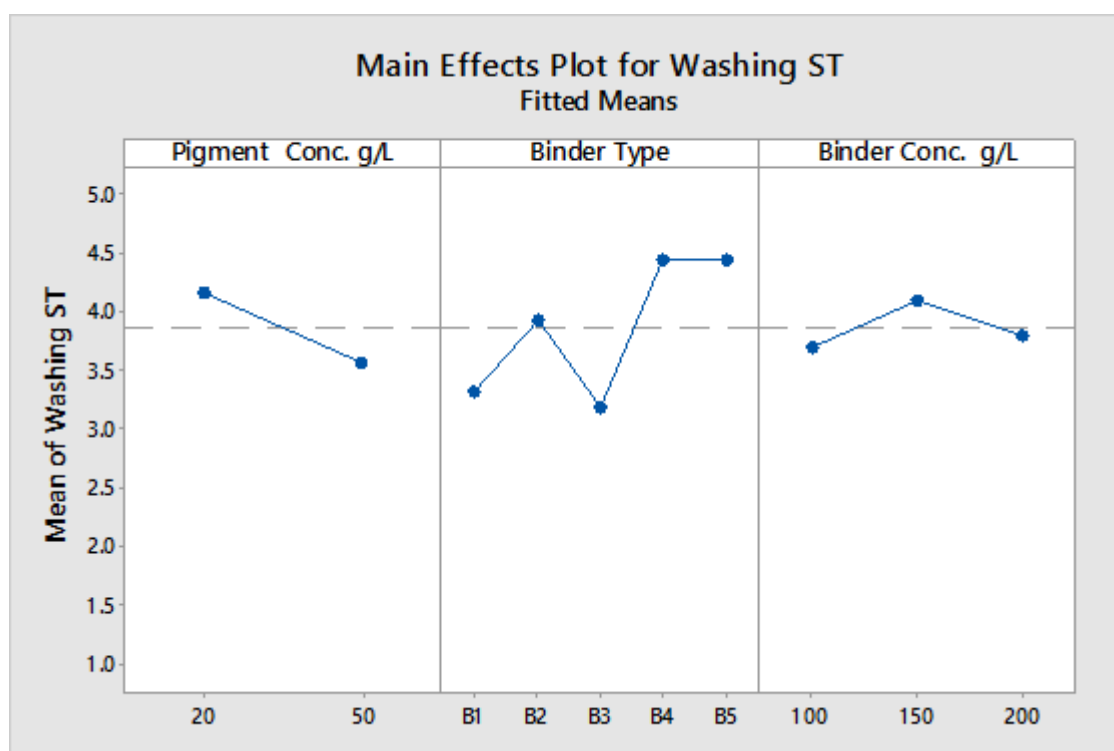
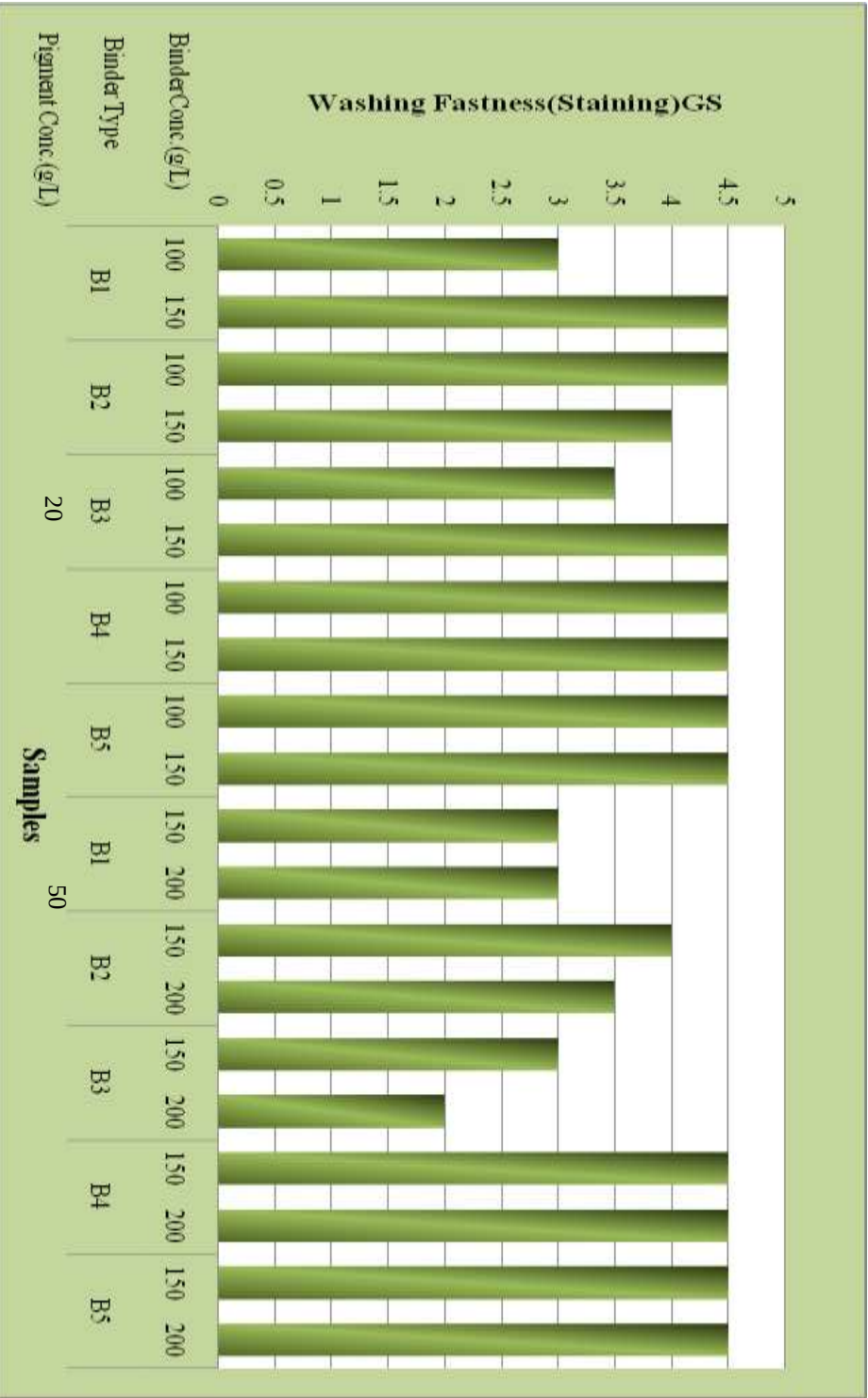


Figure 3.7: Main effects plot for washing fastness (staining) of dyed P/C fabrics



The results of cumulative colourfastness properties of pigment dyed P/C fabrics regarding various types of binders show that the optimum rubbing fastness was obtained by Helizarin binder ET ECO and Helizarin binder CCF at 50:200g/L pigment/binder ratio, with the constant process parameters. The improvement at this concentration by both of these acrylic based binders can be attributed to their appropriate ratio with pigment in the dyeing formulation for P/C fabrics. The same binder was found to be beneficial at 20/150g/L pigment and binder concentration for rubbing fastness test whereas the level of wash fastness was slightly reduced. Such an influence of pigment/binder ratio on fastness grading was reported by Islam and Akhter (2012), who conducted a study on 50:50 P/C blended fabrics, dyed with red, yellow and blue pigments. It was observed that with same binder type, the fastness to wet and dry rubbing grades were de-valued gradually from lighter to deeper shades. The degradation of the colour fastness of P/C fabric at high concentration (50:200g/L) was probably due to the high binder ratio. They further pointed out that wet rubbing fastness was better than dry rubbing grades, which are partly in agreement with our study in which the similar difference in wet and dry rubbing fastness of dyed P/C fabric was noticed. It is evident that P/C fabric that was dyed with the Helizarin binder ET Eco formulation, attained the highest wet rubbing fastness with an acceptable level of 3.5 GS, conforming to the BS 2543 (Textile guide Testing). According to their criteria, the fabrics for end use must possess, maximum grade of '3 – 4' for dry rubbing and '3' for wet rubbing.

Another type which induced very good colourfastness properties in the dyed P/C fabric, was a polyurethane based binder called Appretan PU, liquid. The maximum value of polyurethane treated P/C fabrics suggests that it had developed a good pad/liquor stability in the formulation, yielding an increased resistance in fabric against wash and rubbing fastness tests. A consistent and uniform film formation tended to strengthen the binding force between polyurethane dispersion and pigment/fabric matrix. The results are supported by the report given by (Agosta, 2002) according to which polyurethane dispersions have excellent chemical and scrubbing resistance as coating materials in several products.

In the current study it was observed that Printofix MTB tended to reduce the colour fastness properties of the dyed P/C fabric. The performance of fabrics was poor; particularly the wet rubbing fastness had shown worst grading scale i.e. '1'. Similarly wash fastness was also found to be degraded at varying concentration of the binder. This adverse response is related to the incomplete polymerization of the binder due to some reasons which might fit here in the present case. According to Chakraborty (2010), the stronger the reaction of the

binder is, the better the stability of the thermo set binder film on the substrate. Incomplete crosslinking of the applied binder resulted in an inappropriate reaction with textile, hence inducing poor wash fastness. The problem may arise due to other related parameters, like polymerization time, unsuitable temperature, inappropriate binder selection and the catalyst.

3.1.2 Tensile strength

The tensile strength results of polyester/cotton fabrics dyed with different pigment concentrations, and different binder types and concentrations are summarized in Table 3.7.

The analysis of variance (ANOVA) of the tensile strength results presented in Table 3.8 indicates a statistically non significant effect on the tensile strength of fabrics regarding pigment/binder concentrations. The tabulated values show the highly significant effect of binder type only on the tensile strength of pigment dyed P/C fabrics.

Figure 3.9 exhibits the main effects plot for tensile strength (warp and weft). It is evident that the increase in pigment concentration has a statistically significant effect on the slight increasing trend of the tensile strength of dyed P/C fabrics. Similarly a gradual decreasing and increasing trend is shown by the tensile strength of fabrics with the rise in binder concentration. As far as the binder type is concerned, B1 and B2 exhibit the highest and B5, the lowest tensile strength according to the statistical analysis.

Figure 3.10 shows the tensile strength results of the individual samples, dyed with different types and concentration of pigment/binders. It is evident from the findings that Binder 1 showed outstanding performance regarding tensile strength of pigment dyed fabrics. According to the results, the tensile strength was enhanced by increasing the concentration of binder in the dye bath (50:200 g/L) but on the other hand, a few values got a little bit deviated by showing decline in tensile strength of fabric. The tensile strength of fabrics with B2 gave almost the same results as exhibited by B1. In this case too, generally an ascending trend in tensile strength was observed irrespective of the binder concentration.

Table 3.7 Effect of pigment concentration, and different binder types and concentrations on tensile strength of the dyed samples

Sample No.	Factors			Responses		
	Pigment Conc. g/L	Binder Type	Binder Conc.	Tensile Warp, lb	Tensile Weft, lb	Tensile (Wp+Wt), lb

			g/L			
1	20	B1	100	165.0	84.5	249.5
2			150	105.1	39.5	144.6
3		B2	100	177.1	56	233.1
4			150	167.0	43	210.0
5		B3	100	143.0	37	180.0
6			150	69.0	16	85.0
7		B4	100	74.5	69	143.5
8			150	163.0	25	188.0
9		B5	100	80.0	42	122.0
10			150	78.5	34	112.5
11	50	B1	150	145.3	22	167.3
12			200	179.5	73	252.5
13		B2	150	117.0	27	144.0
14			200	173.0	57	230.0
15		B3	150	150.0	57	207.0
16			200	94.0	79	173.0
17		B4	150	127.0	38.5	165.5
18			200	137.0	37	174.0
19		B5	150	71.0	30	101.0
20			200	68.0	51	119.0

Table 3.8 Analysis of variance for tensile strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	28646.4	4092.3	2.77	0.058
Pigment conc.	1	199.8	199.8	0.14	0.719
Binder Type	4	22220.4	5555.1	3.76	0.033*
Binder conc.	2	6214.2	3107.1	2.10	0.165
Error	12	17727.8	1477.3	--	--
Total	19	46374.2	--	--	--
*Statistically significant at P value 0.05					

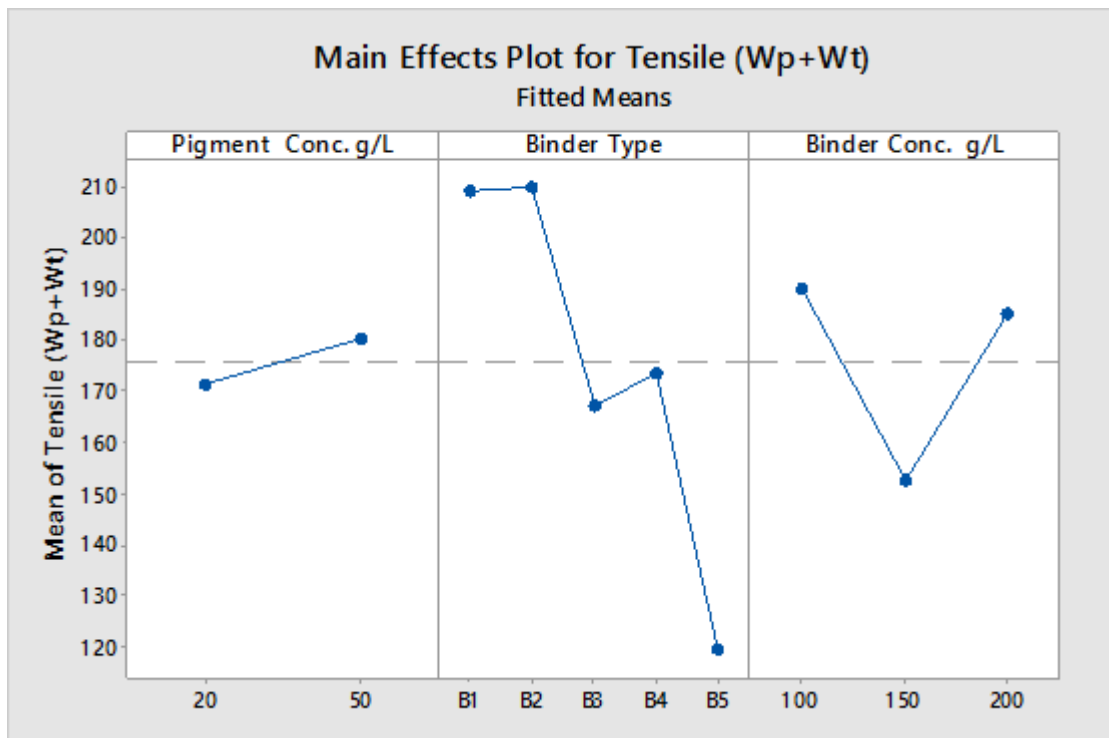


Figure 3.9: Main effects plot for tensile strength of dyed P/C fabrics

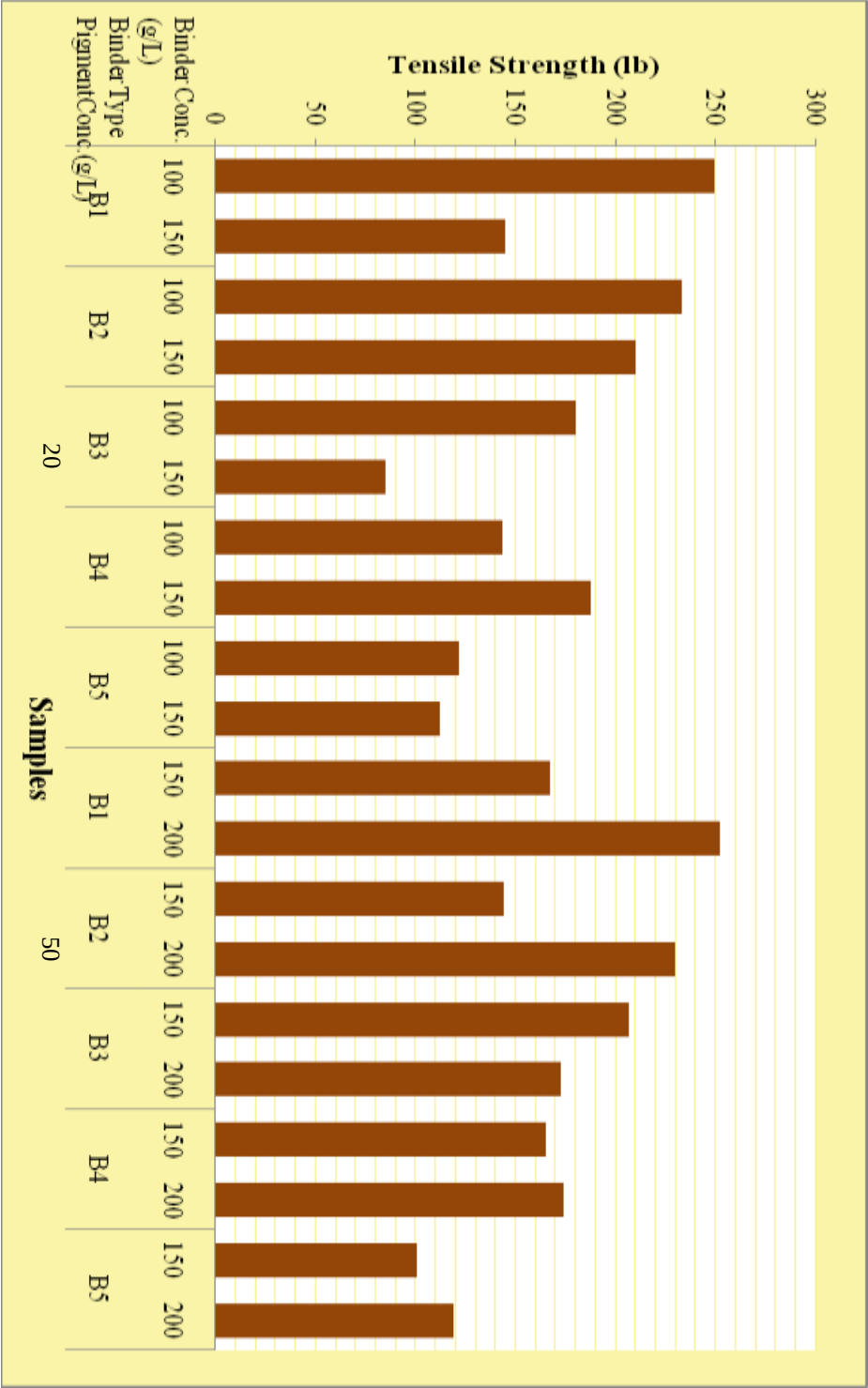


Figure 3.10: Effect of pigment conc., binder type and binder concentration on the tensile strength of dyed P/C fabrics

According to the results, the tensile strength was augmented by increasing the concentration of binder in the dye bath but on the other hand, some values deviated a little bit by indicating a percentage decline in tensile strength of fabric. It was observed that, when binder concentration was increased by 150g/L with 20 gm of dye the strength was reduced. These results suggest that, a compromise must be made between pigment and binder concentration when dye formulation is prepared. The decline in tensile strength may be attributed to excess amount of binder in proportion to dye.

The overall performance of Helizarin binder ET ECO and CFF exhibited a handsome increase in tensile strength after pigment dyeing at varying concentrations. The optimum strength in both warp and weft direction was attained by the dyed P/C applied with B 1 at 50:200g/L pigment, binder concentration. Almost the same trend in improvement was observed in weft direction too, with the only exception at 50:150g/L dye/binder ratio in which tensile strength declined with a striking difference of 53 percent in comparison to the control fabric. The strengthening of P/C dyed fabric probably contributed by the internal crosslinking of acrylate copolymer system of Helizarin binder ET ECO. The results are supported by Patel (1995) who stated that internal crosslinking of the acrylate polymer resist elongation (1.83% <0.96) (reference fabric) beyond a certain point resulting in high strength.

3.1.3 Tear strength

Table 3.9 indicates the tear strength results of pigment dyed cotton/Polyester fabrics with different binder types at different pigment and binder concentrations.

The analysis of variance (ANOVA) of the tear strength results is given in Table 3.10. The tabulated values clearly reveals a statistically non significant effect of the pigment concentration, binder type and binder concentration on the mean tear strength of dyed P/C fabrics.

Table 3.9 Effect of pigment concentration, different binder types and concentrations on tear strength of the dyed samples.

Sample No.	Factors			Responses		
	Pigment Conc. g/L	Binder Type	Binder Conc. g/L	Tear St. Warp, lb	Tear St. Weft, lb	Tear St. (Wp+Wt), lb
1	20	B1	100	1000	2000	3000
2			150	940	1960	2900
3		B2	100	920	1760	2680
4			150	1040	2000	3040
5		B3	100	1320	1880	3200
6			150	780	1920	2700
7		B4	100	1200	1680	2880
8			150	1060	1720	2780
9		B5	100	880	1600	2480
10			150	920	1200	2120
11	50	B1	150	960	1500	2460
12			200	1160	1600	2760
13		B2	150	800	1760	2560
14			200	880	1540	2420
15		B3	150	1160	2040	3200
16			200	1000	1480	2480
17		B4	150	930	1800	2730
18			200	1160	1680	2840
19		B5	150	1060	1600	2660
20			200	800	1440	2240

Table 3.10 Analysis of variance for tear strength

Source	DF	Adj. SS	Adj. MS	F-Value	P-Value
Model	7	875015	125002	2.04	0.133
Pigment conc.	1	490	490	0.01	0.930
Binder Type	4	648080	162020	2.65	0.086
Binder conc.	2	124690	62345	1.02	0.391
Error	12	735040	61253	-	-
Total	19	2383315		-	-
*Statistically significant at P value 0.05					

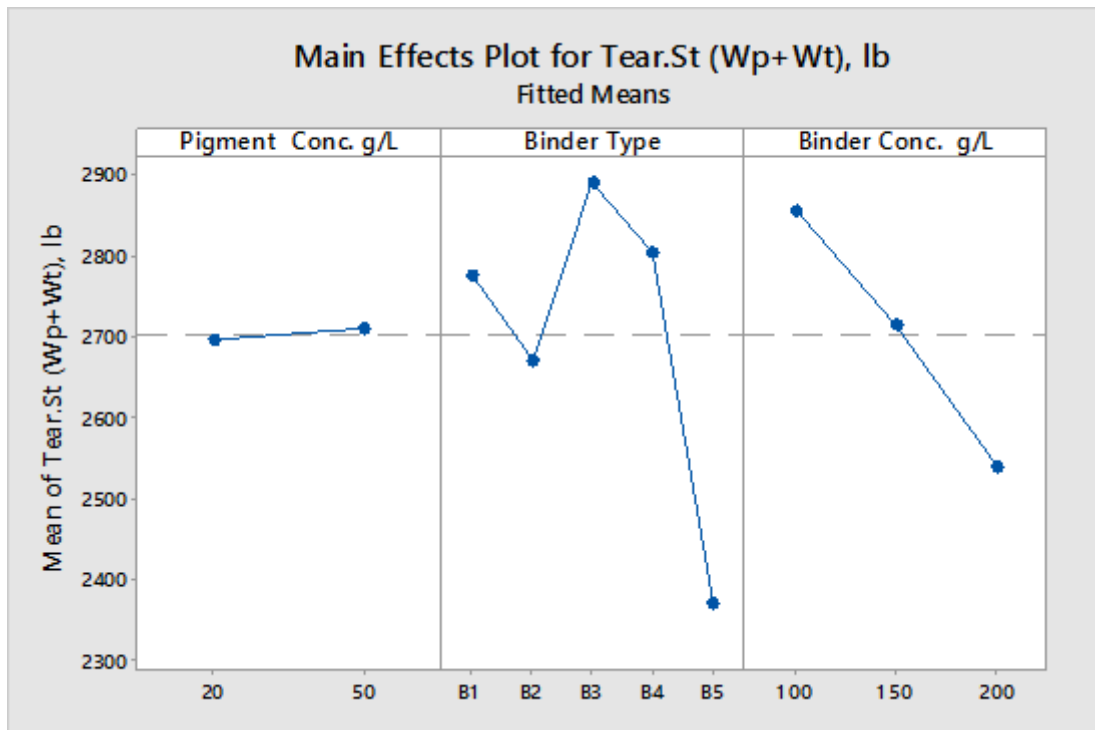


Figure 3.11: Main effects plot for tear strength of dyed P/C fabrics



Figure 3.12: Effect of pigment conc., binder type and binder concentration on the tear strength of dyed P/C fabrics

The main effects plot for the tear strength results is shown in Figure in 3.11. As regards the binder type, B5 gave significantly lower fabric tear strength as compared to other binders. Increase in pigment concentration does not seem to have any noticeable effect on fabric tear strength. Whereas, increase in binder concentration shows a decreasing trend in fabrics tear strength.

An overview of the individual samples results for the tear strength of dyed fabrics with different types and concentration of pigment, and binders can be taken from Figure 3.12. From the graphical representation it can be clearly depicted that majority of the fabrics showed a decline in tear strength.

It can be clearly depicted from the earlier mentioned results, that majority of the fabrics showed a reduction in tear strength as compared to the control fabric. The loss in tear strength was more apparent in warp direction in comparison to the weft direction of fabric, regardless of binder type and the concentrations. Only one of the binder i.e. Printofix MTB (B.3) surprisingly remained productive, showing an increase in percentage tear strength at 50:150g/L. A study conducted by (Hussain, 2008) revealed that tear strength of pigment dyed cotton fabrics in deep colours decreased, which might be attributed to the higher ratio of binder applied in the formulation to harmonize with the pigment colourant. This resulted in lowered yarn slippage of alliance of yarns during tearing process. The present results concur with the same findings but here the dyeing specimen was 70:30 cotton/polyester blend instead of 100% cotton.

3.1.4 Flexural rigidity

The stiffness as bending length and flexural rigidity was determined for dyed P/C fabrics with Helizarin Pigment Red and different binders in different concentrations and the results are given in Table 3.11.

The analysis of variance (ANOVA) with respect to flexural rigidity results is presented in Table 3.12. It shows that the effect of binder type is statistically significant on the flexural rigidity of the dyed P/C fabrics. The effect of pigment and binder concentration is found to be non significant regarding flexural rigidity of fabrics.

Table 3.11 Effect of pigment concentration, and different binder types and concentrations on flexural rigidity of the dyed samples.

Sample No.	Factors			Responses		
	Pigment Conc. g/L	Binder Type	Binder Conc. g/L	Flex. Rig Warp, μ Joule/M	Flex. Rig Weft, μ Joule/M	Flex. Rig (Wp+Wt) μ Joule/M
1	20	B1	100	33	11.5	44.5
2			150	15.53	9.78	25.31
3		B2	100	18.16	6.98	25.14
4			150	17.89	13.41	31.3
5		B3	100	21.39	13.19	34.58
6			150	21.95	9.86	31.81
7		B4	100	16.95	12.73	29.68
8			150	19.42	11.69	31.11
9		B5	100	52.55	14.74	67.29
10			150	25.09	13.83	38.92
11	50	B1	150	20.75	14.69	35.44
12			200	29.22	15.39	44.61
13		B2	150	27.09	11.89	38.98
14			200	23.38	18.01	41.39
15		B3	150	10.53	8.17	18.7
16			200	9.28	10.08	19.36
17		B4	150	30.29	12.01	42.3
18			200	29.47	12.43	41.9
19		B5	150	56.04	38.82	94.86
20			200	63.57	39.14	102.71

Table 3.12 Analysis of variance for flexural rigidity

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	7025.3	1003.6	5.17	0.007
Pigment conc.	1	516.0	516.0	2.66	0.129
Binder Type	4	6076.5	1519.1	7.82	0.002

Binder conc.	2	221.4	110.7	0.57	0.580
Error	12	2331.4	194.3	-	-
Total	27	16170.6	-	-	-
*Statistically significant at P value 0.05					

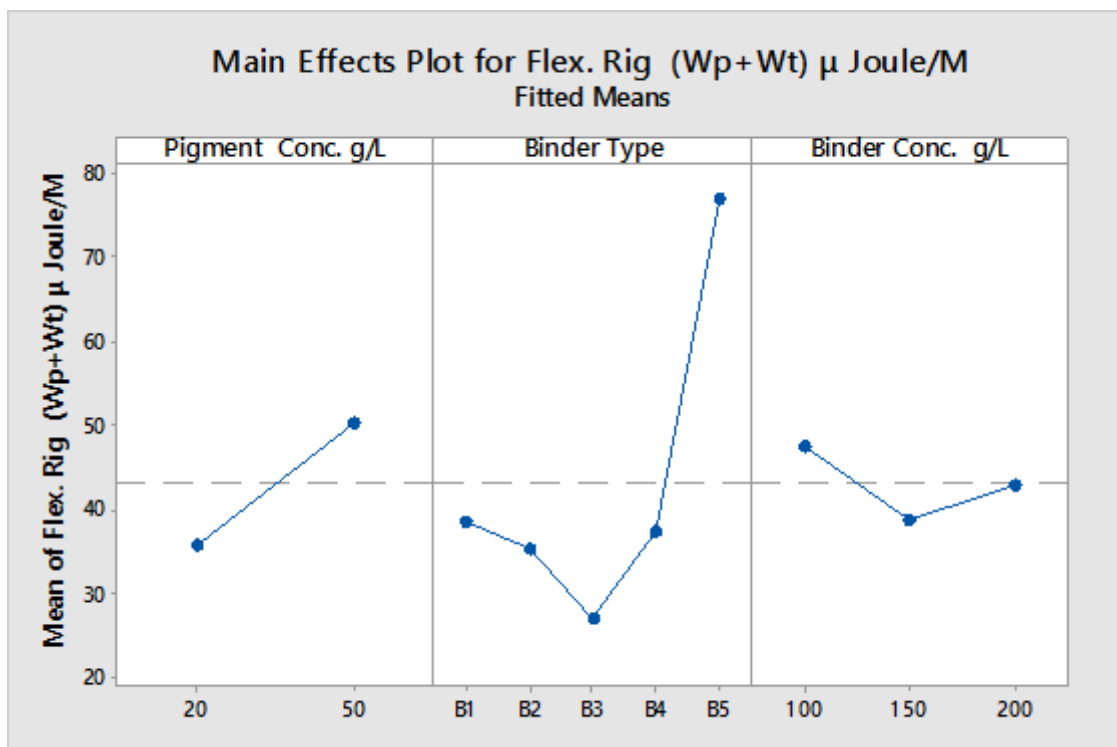


Figure 3.13: Main effects plot for flexural rigidity of dyed P/C fabrics

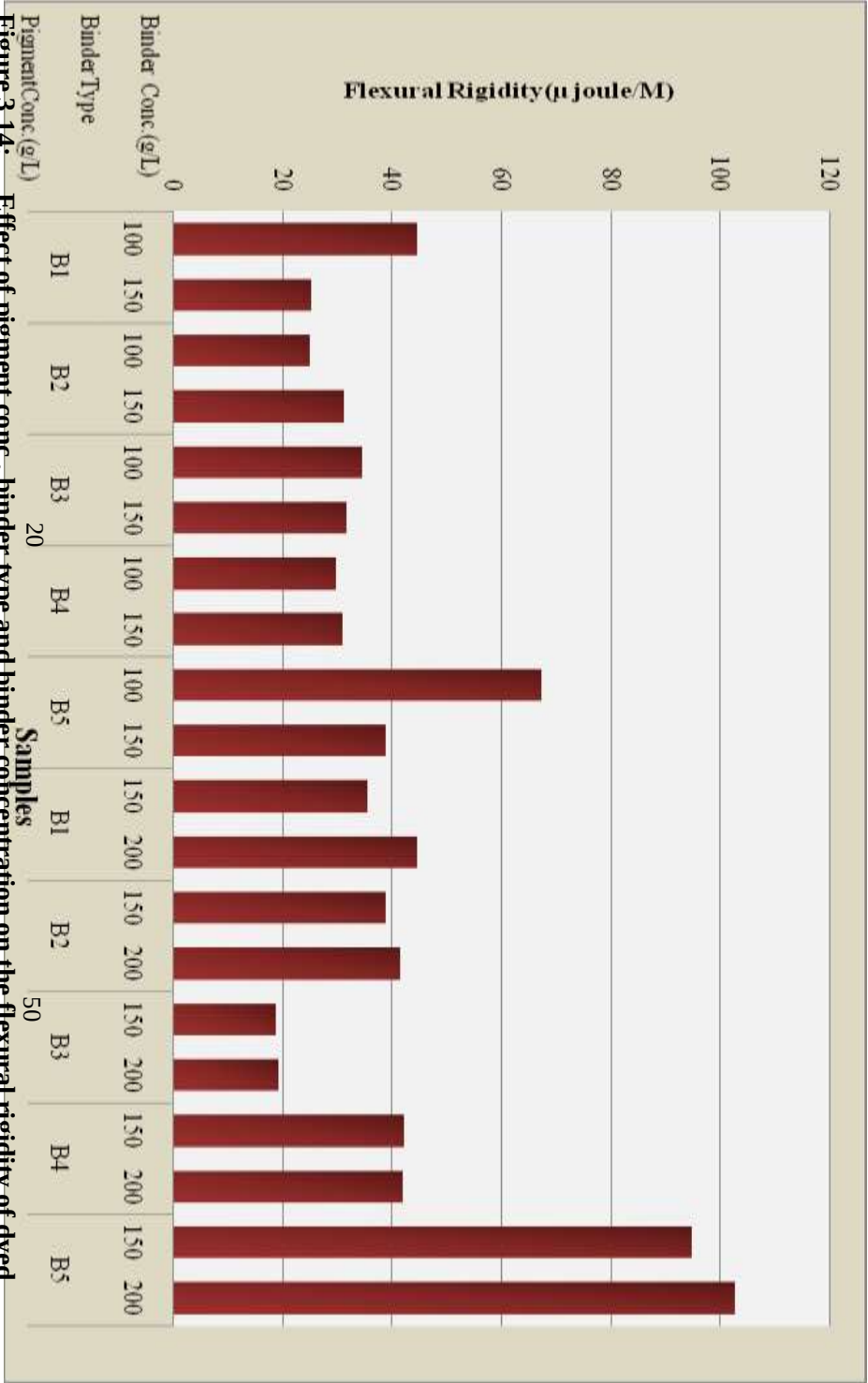


Figure 3.14: Effect of pigment conc., binder type and binder concentration on the flexural rigidity of dyed

P/C fabrics

The main effects plot for flexural rigidity of fabrics is exhibited in Figure 3.13. The increasing trend in flexural rigidity of fabrics with increase in pigment concentration is evident in the figure. The binder B 5 results in significantly highest flexural rigidity as compared to other binders. Figure 3.14 shows the effect of pigment concentration binder type and different concentrations of binders on the individual results, regarding flexural rigidity of P/C fabrics.

Pigment to binder ratio needs special consideration in the formulation of padding liquor for dyeing, as excess amount of binder may produce an adverse effect on the handle of fabric. The major cause of increased fabric stiffness for deep shades particularly, is the application of binders and cross linkers in pigment dyeing. However, improvement in the chemistry of pigments and binders tend to reduce the deteriorating effects (Hussain, 2009). The current investigation has revealed that different binders produced variant stiffness levels, though the proportion of binder and pigment remained the same in each padding liquor formulation.

One of the binders with the usual recipe at 150g/L binder induced only a negligible rise in fabric stiffness thus providing a softer handle. Though, it was expected that the results would be in accordance with the other findings, yet the flexural rigidity was slightly reduced. Here, the difference in the expected results might have been caused by the self crosslinking acrylate copolymer dispersion, which decreased the stiffness level of fabrics due to its low glass transition temperature (T_g). The results are supported by Mlynar (2003) who mentioned the directly proportional relationship of T_g with softness. According his statement, the lower the T_g, the softer is the polymer. In another study, carried out by Patel (1995), it was quoted that the resultant polymer is very important in determining the various characteristics of the fabrics especially the handle of fabric. The lower the T_g, the lesser tightening of the polymer chain packing and softer will be the fabric. Keeping in view the above mentioned results, it seems that if the dye bath is formulated with appropriate binder type and pigment/binder ratio, an acceptable stiffness level can be achieved. (BS 2543 Textile Guide – Testing, www.holdsworthusa.com/Downloads/).

3.1.5 Abrasion resistance

The abrasion resistance results of the dyed P/C fabrics with respect to the effect of various binder types in different concentrations as well as different pigment concentrations are summed up in Table 3.13.

Table 3.13 Abrasion resistance and pilling grades of pigment dyed p/c fabrics

Sample No.	Factors			Responses	
	Pigment Conc. g/L	Binder Type	Binder Conc. g/L	Abrasion. Res (no. of cycles)	Pilling grades
1	20	B1	100	26,200	4.5
2			150	63,400	4
3		B2	100	17,200	4
4			150	15,335	4
5		B3	100	42,080	4.5
6			150	25,045	4
7		B4	100	20,995	4
8			150	20,405	4
9		B5	100	24,200	3
10			150	43,450	3
11	50	B1	150	24,455	4
12			200	46,100	4
13		B2	150	57,480	4
14			200	39,300	4
15		B3	150	23,575	4
16			200	25,640	3
17		B4	150	20,500	3
18			200	20,505	3
19		B5	150	30,225	3
20			200	29,890	4

Table 3.14 Analysis of variance for abrasion resistance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
--------	----	--------	--------	---------	---------

Model	7	941847645	134549664	0.65	0.709
Pigment conc.	1	12996000	12996000	0.06	0.806
Binder Type	4	783799005	195949751	0.95	0.471
Binder conc.	2	139308160	69654080	0.34	0.721
Error	12	2484816935	207068078	-	-
Total	27	4362767745	620217573		
*Statistically significant at P value 0.05					

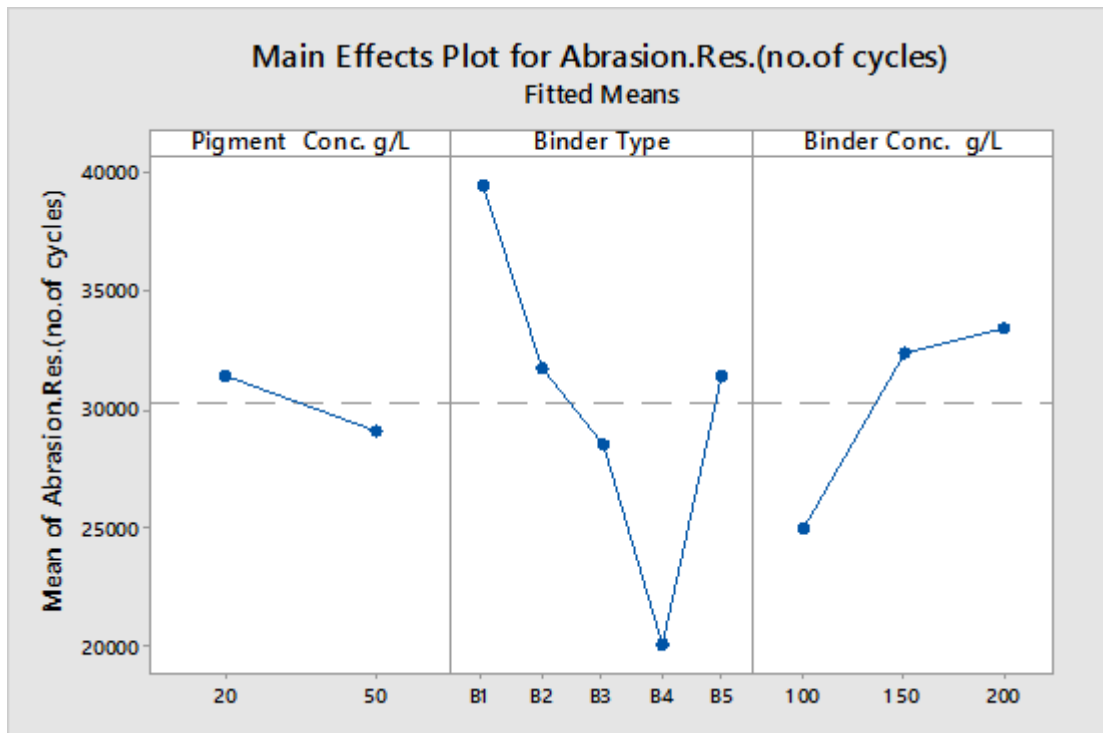


Figure 3.15: Main effects plot for abrasion resistance of dyed P/C fabrics

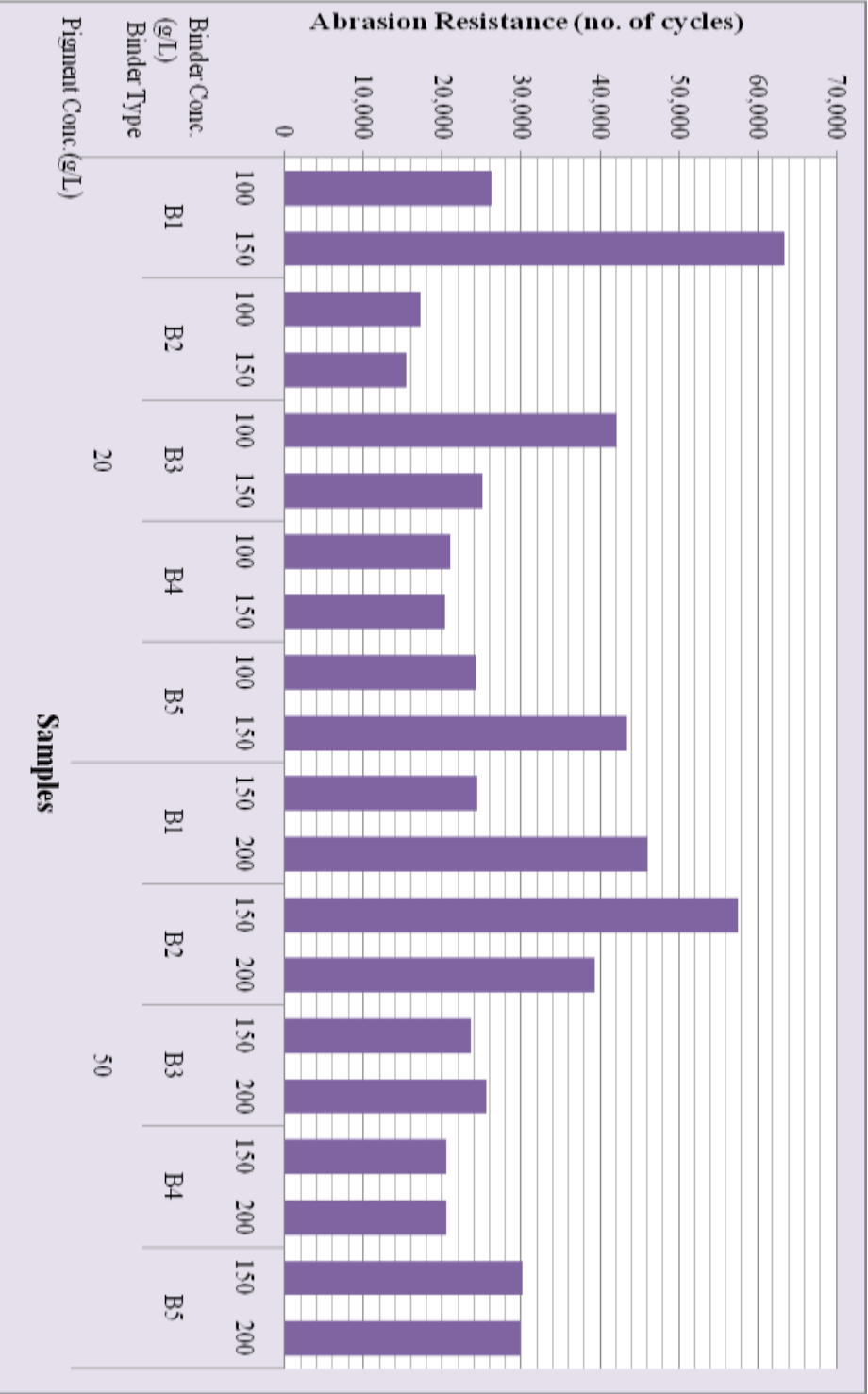


Figure 3.16: Effect of pigment conc., binder type and binder concentration on the abrasion resistance of dyed P/C fabrics

Table 3.14 displays the ANOVA of the abrasion resistance of the obtained results according to which a statistically non significant effect is found in the abrasion values. The main effect plot given in Figure 3.15 clearly shows a declining trend in abrasion resistance of the dyed fabrics with an increase in pigment concentration. On the other hand, an increase in binder concentration exhibits an increasing trend in the abrasion resistance of fabrics. As far as the binder type is concerned, B1 displays the highest and B4 the lowest abrasion resistance respectively. The abrasion resistance results with respect to individual performance of fabrics has been displayed in Figure 3.16. The figure clearly reveals the highest abrasion resistance of B1 at 20:150g/L and B2 at 50:150g/L pigment/binder concentrations respectively.

The abrasion resistance of pigment dyed P/C fabric, according to earlier mentioned results represented both an increasing and decreasing trend in the abrasion cycles. Generally, it was observed that loss was more obvious at high concentration of binder. However, a few of the fabrics abraded at same number of rubs with all concentrations. As far as the Helizarin Binder ET Eco (B1) is concerned, the amount of binder remarkably influenced the abrasion resistance of pigment dyed P/C fabrics by showing an increment in number of cycles proportionally with the higher binder ratio. The fabric that was abraded at 26,200 number of rubs at 20:100g/L pigment binder ratio showed an almost 50 percent increase in numbers of rubs at 150g/L binder with the same proportions of pigment. Helizarin Binder CFF significantly resisted abrasive motion at 50/150g/L pigment, binder concentration.

The results suggest that improvement in abrasion resistance was achieved actually by the application of crosslinkable acrylate copolymer in favourable amount. Usually, a reduced abrasion resistance is associated with acrylate binder (Hammonds, 1995), but in the current study, the results showed a different behavior with increased resistance to abrasion cycles. The suitable amount of binder in conjunction with the pigment rendered to form a protective film on P/C fabric, which had developed high resistance to the abrasion of fabric.

3.1.6 Pilling resistance

Table 3.13 displays the effect of pigment concentration, different binder types and concentrations on pilling grades of the dyed samples. The analysis of variance (ANOVA) of the pilling resistance is given in Table 3.15. In this case also, the effect of binder concentration, pigment concentration and the binder type was statistically non significant for the pilling grades of dyed P/C fabrics. The main effects plot for pilling resistance is given in Figure 3.17, which clearly shows a decreasing trend in the pilling grades with increase in pigment concentration. In case of binder concentration, the pilling resistance is slightly decreased while the binder B1 shows maximum grade amongst all the binder types. The individual results regarding pilling performance with same variables are exhibited in Figure 3.18. Binder B1 gave significantly better abrasion and pilling resistance as compared to other binders.

Overall, binder B1 showed the best performance including best wet rubbing fastness, acceptable washing fastness, best tensile strength, abrasion resistance, pilling resistance, good tear strength, and low flexural rigidity of P/C fabrics. The second best performer binder B2 was found to be good regarding colourfastness and mechanical properties. It exhibited very good dry rubbing fastness, desirable wet rubbing fastness, excellent wash fastness, attaining maximum tensile and tear strength, less stiffness, good pilling resistance and fair abrasion resistance. This binder was selected for further experimentation with different types of crosslinking agents.

Table 3.15 Analysis of variance for pilling resistance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	2.6750	0.38214	1.78	0.181
Pigment conc.	1	0.1000	0.10000	0.47	0.508
Binder Type	4	2.1250	0.53125	2.48	0.100
Binder conc.	2	0.1000	0.05000	0.23	0.796
Error	12	2.5750	0.21458		
Total	19	5.2500	1.27797		
*Statistically significant at P value 0.05					

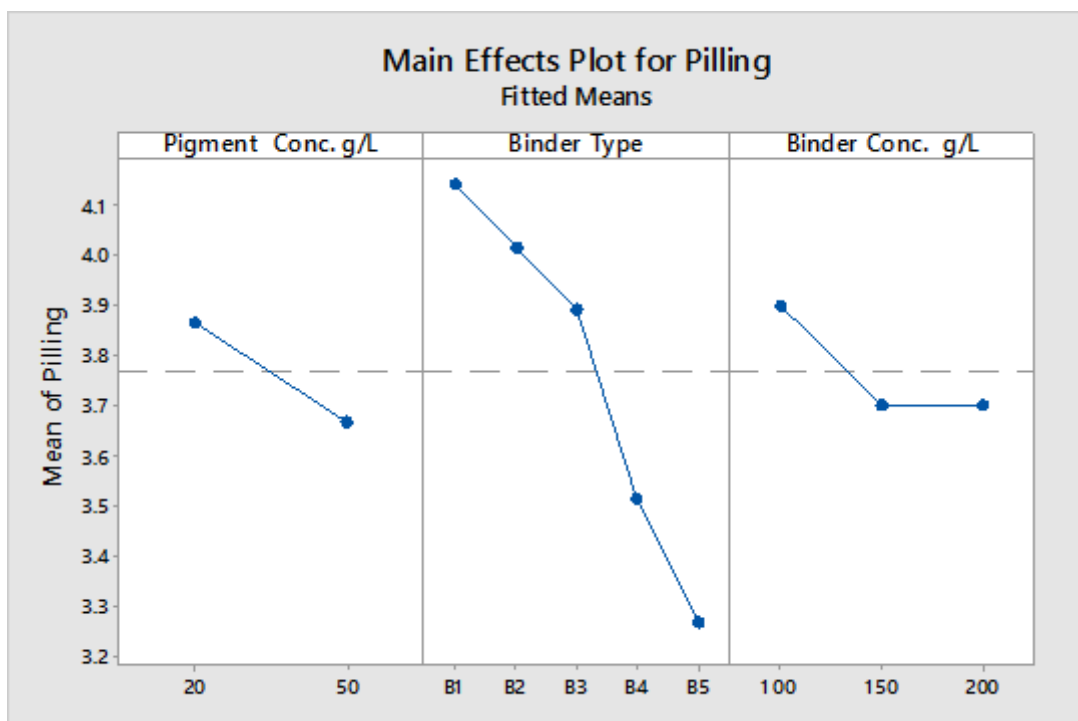


Figure 3.17: Main effects plot for pilling performance of dyed P/C fabrics

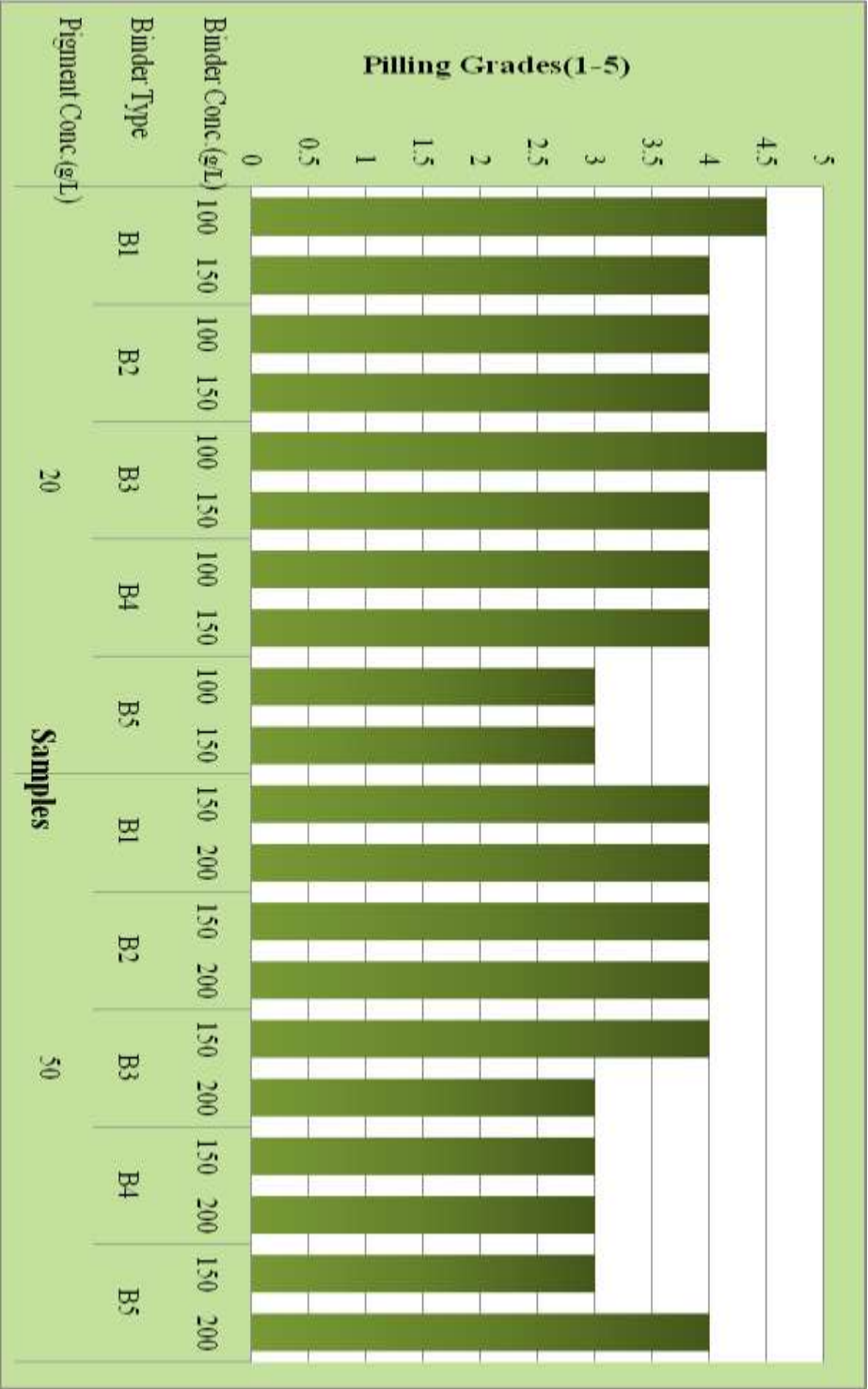


Figure 3.18: Effect of pigment conc., binder type and binder concentration on the pilling resistance of P/C fabrics

3.2 EFFECT OF DIFFERENT CROSSLINKING AGENTS ON THE PROPERTIES OF PIGMENT DYED P/C FABRICS

On the basis of individual performance of all the binders regarding physico-mechanical characteristics, the best two binders from BASF chemical company were selected for application with various crosslinkers and the pigment red on P/C fabrics simultaneously. Though both have self crosslinking quality but various external crosslinkers were used with the binder systems to further improve the characteristics of the dyed P/C fabrics. Five different cross linkers were applied in a recommended proportionate amount, separately, with two optimised binder systems on P/C fabric specimens at constant concentrations of pigment and the binder. The post treated fabrics were subjected to various physical tests and the results were analysed.

3.2.1 Effect of different crosslinking agents on colourfastness properties

A summary of the colour fastness results of P/C fabrics dyed with different binder types and various crosslinkers is given in Table 3.16.

3.2.1.1 Effect of different Crosslinking agents on dry rubbing fastness

The analysis of variance (ANOVA) of the dry rubbing fastness results is presented in Table 3.17, which shows that the effect of crosslinkers on the dry rubbing grades of fabric was found to be statistically non significant. As far as the binder types are concerned in this case also, the effect was not found statistically significant on the rubbing fastness.

Table 3.16 Effect of different crosslinking agents on the colourfastness of dyed P/C fabrics

Sample no.	Factors		Responses			
	Type of Cross linker	Type of Binder	Dry Rubbing Fastness	Wet Rubbing Fastness	Washing Fastness SC	Washing Fastness ST
1	CL1	B1	3.5	2	4	3.5
2		B2	3.5	2	4.5	4
3	CL2	B1	3	2	4	3.5
4		B2	3	2.5	4	3.5
5	CL3	B1	3.5	2.5	4	3.5
6		B2	3.5	2.5	4.5	4
7	CL4	B1	3	2	4	3.5
8		B2	3.5	2.5	4	4
9	CL5	B1	3	2.5	4	3.5
10		B2	2.5	2.5	4	3.5

CL.1. Fixapret CPF

CL.2. Fixapret F-ECO

CL.3. Knittex RCT

CL.4 Arkofix NZF New liq

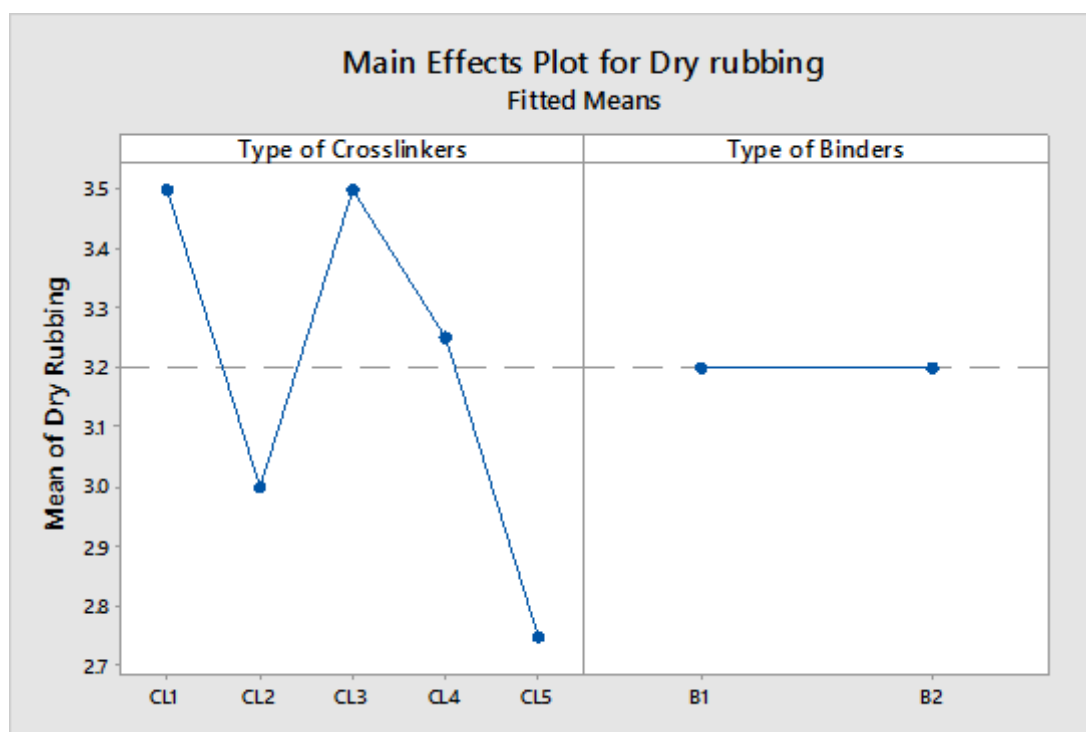
CL.5. Printofix Fixative WB Liqui

The main effects plot for dry rubbing fastness of fabrics is given in Figure 3.19 which represents the maximum grading by cross linking agents, CL1 and CL3. A statistically significant adverse effect of crosslinker CL5 on the mean dry rubbing fastness is apparent in the plot. The binder type has no effect on the dry rubbing fastness of cross linker's treated fabrics.

Table 3.17 Analysis of variance for dry rubbing fastness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	0.85000	0.170000	2.72	0.177
Type of Crosslinkers	4	0.85000	0.212500	3.40	0.13
Type of Binders	1	0.00000	0.000000	0.00	1.000
Error	4	0.25000	0.062500		
Total	9	1.10000			

*Statistically significant at P value 0.05

**Figure 3.19:** Main effects plot for dry rubbing fastness

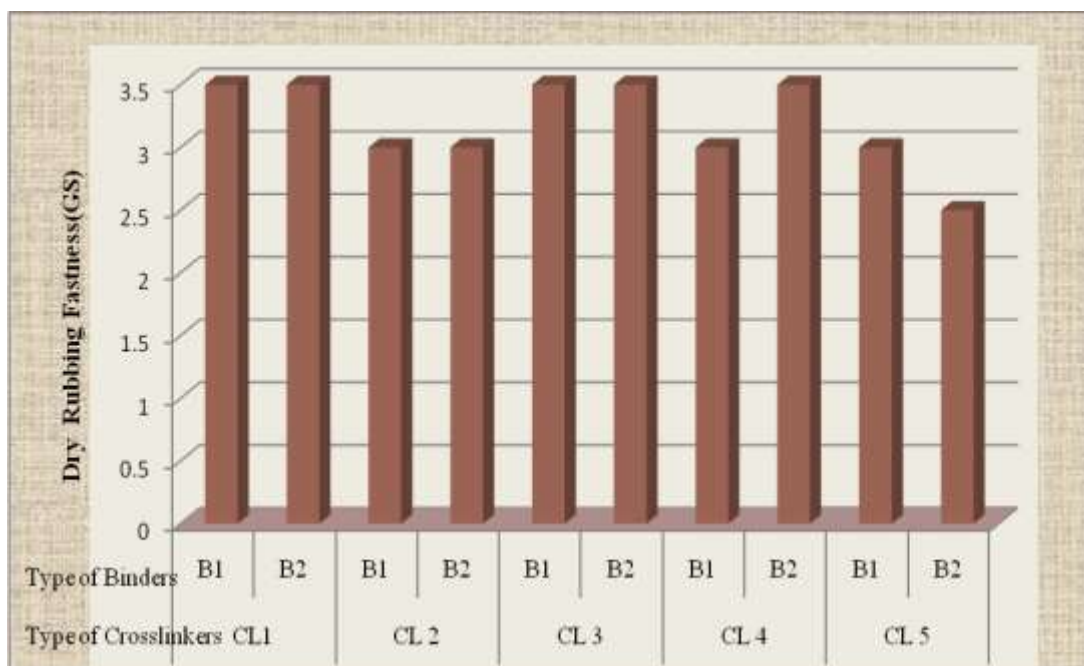


Figure 3.20: Effect of binder types and crosslinkers on the dry rubbing fastness

Figure 3.20 represents the dry rubbing fastness characteristics of simultaneously dyed and crosslinked P/C fabrics with different binders. It is evident that crosslinking agents CL1 and CL3 were found to be ranked at the highest grade of colourfastness to dry rubbing amongst all the fabrics.

3.2.1.2 Effect of different crosslinking agents on wet rubbing fastness

Table 3.18 shows the results regarding analysis of variance for wet rubbing fastness of crosslinked P/C fabrics. The data shows that effect of crosslinkers and binder type was found to be statistically non significant. The main effect plot for the results of wet rubbing fastness is exhibited in Figure 3.20, according to which a decreasing trend in the wet rubbing fastness with various crosslinking agents, was noticed. The binder B3's wet rubbing performance was found to be significantly poor as compared to other binders, whereas B1 gave the best mean wet rubbing fastness. The data plotted for individual performance of crosslinked P/C fabrics is given in Figure 3.21. The crosslinking agents, CL3 and CL5 with both the binders, induced maximum wet rubbing fastness in P/C fabrics.

Table 3.18 Analysis of variance for wet rubbing fastness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	0.4500	0.09000	2.40	0.208
Type of Crosslinkers	4	0.3500	0.08750	2.33	0.216
Type of Binders	1	0.1000	0.10000	2.67	0.178
Error	4	0.1500	0.03750		
Total	9	0.6000			

*Statistically significant at P value 0.05

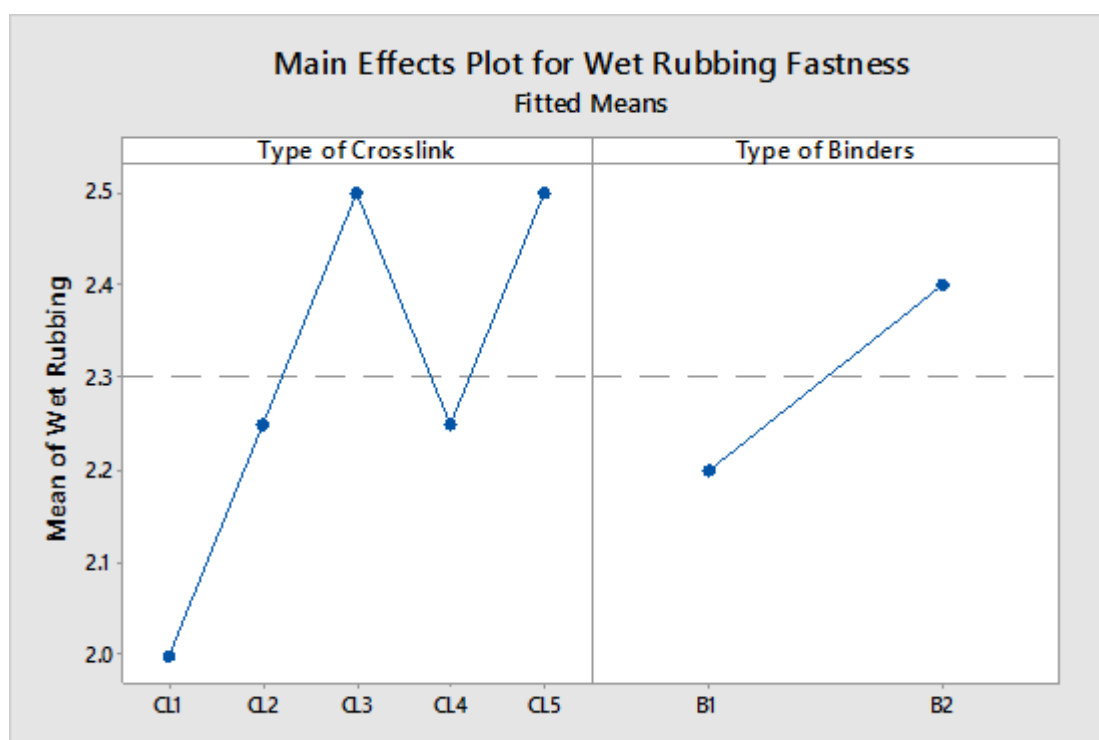


Figure 3.21: Main effects plot for wet rubbing fastness

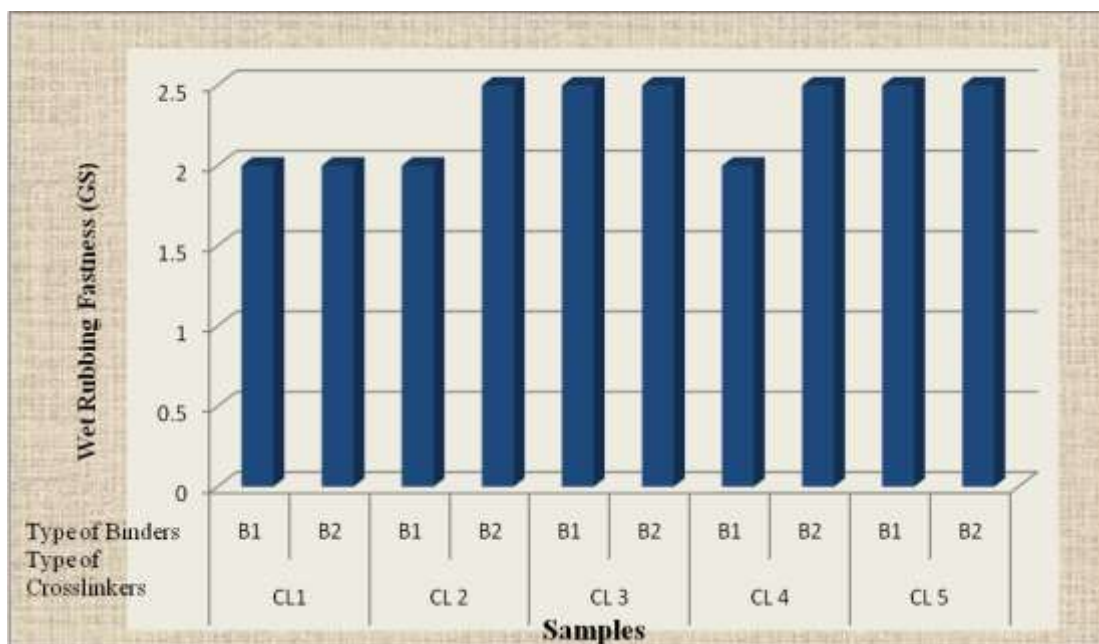


Figure 3.22: Effect of binder types and crosslinkers on the wet rubbing fastness

3.2.1.3 Effect of different crosslinking agents on washing fastness (shade change)

Table 3.19 comprises analysis of variance for washing fastness results of P/C fabrics. The data shows that non significant effect of crosslinking agents and binder types was found on the shade change of fabrics. The main effects plot for washing fastness (shade change) of crosslinked P/C fabrics is displayed in Figure 3.23. The crosslinking agents i.e. CL1 and CL3 show a higher shade change gradings as compared to other cross linkers. The colour change of fabrics after washing treatment was adversely affected by cross linkers CL2, CL4 and CL5 which is clearly evident from the plotted figure. As regards the performance of binders, B2 seems good, while B1 showed low resistance against washing test after cross linking treatment.

As regards the individual performance of fabrics with respect to shade change is concerned, the effect of crosslinking agents is exhibited in Figure 3.24. All the crosslinkers showed a consistency in wash fastness performance with different binders except the cross linker CL3, which induced maximum grading.

Table 3.19: Analysis of variance for washing fastness (change in colour)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	0.2500	0.05000	1.33	0.402
Type of Crosslinkers	4	0.1500	0.03750	1.00	0.500
Type of Binders	1	0.1000	0.10000	2.67	0.178
Error	4	0.1500	0.03750		
Total	9	0.4000	0.225		

*Statistically significant at P value 0.05

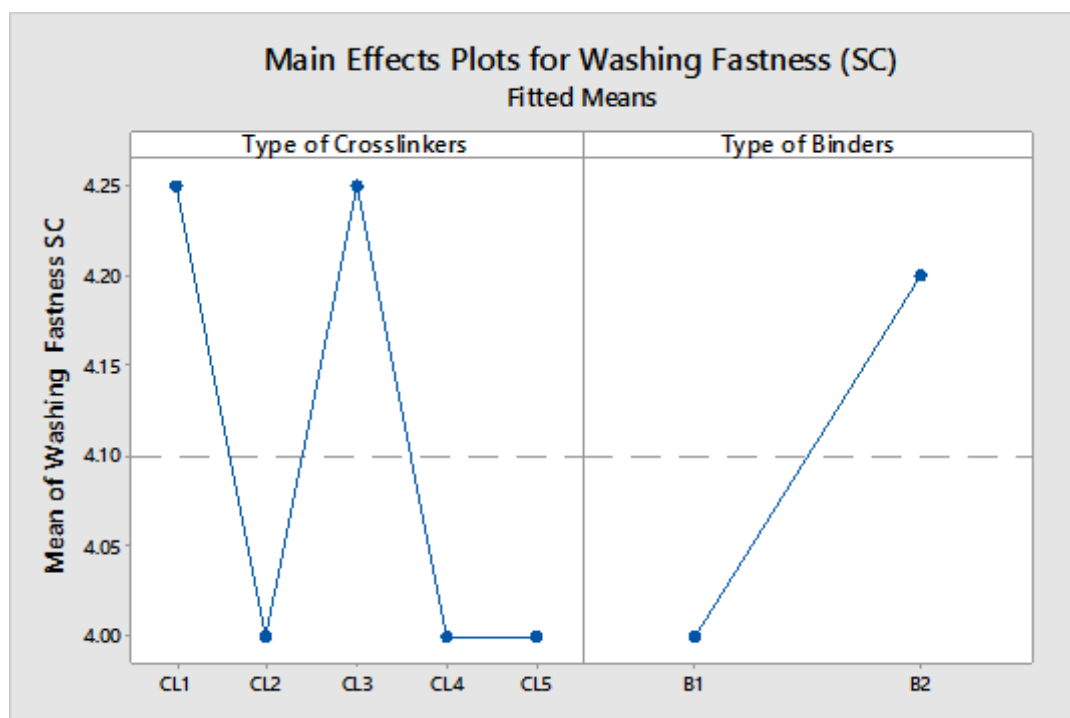


Figure 3.23: Main effects plot for washing fastness (SC)

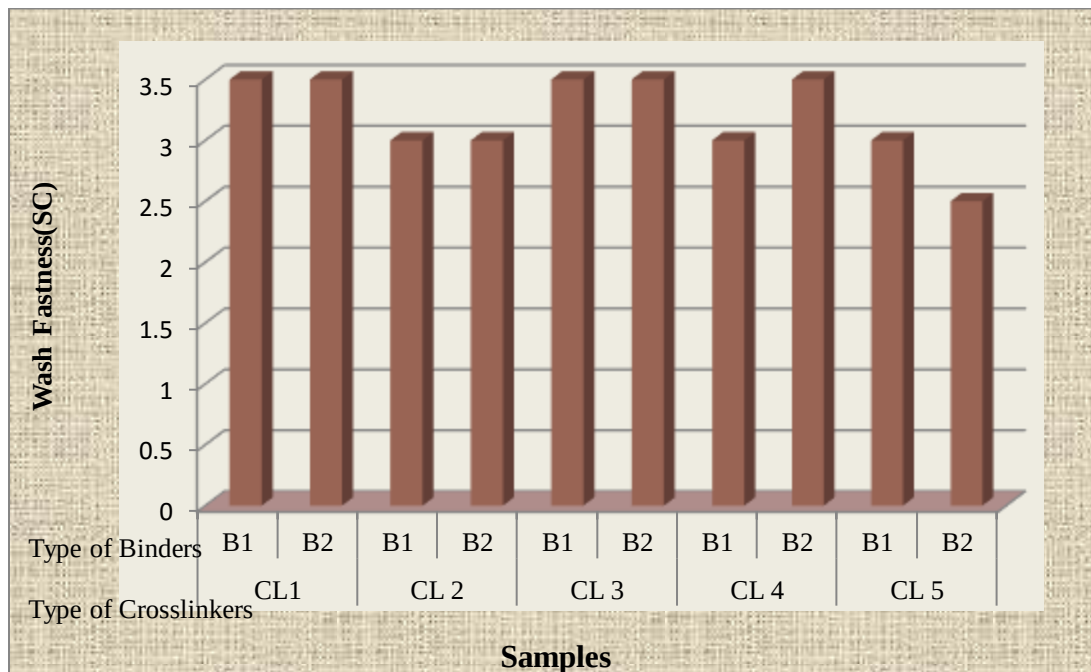


Figure 3.24: Effect of binder types and crosslinkers on the washing fastness (shade change)

3.2.1.4 Effect of different crosslinking agents on washing fastness (staining)

Table 3.20 contains the analysis of variance for the staining to adjacent cloth after washing treatment of dyed P/C fabrics. As regards the type of cross linker, the effect on colour change of treated fabric was statistically non significant. However, the binder types effected the staining of fabric with a significant difference in the mean values of dyed P/C fabrics.

The main effects plot for staining to adjacent cloth after wash treatment is given in Figure 3.25. The figure reveals that the results of crosslinkers CL1, CL3, CL5 reveal better performance than the remaining two crosslinkers i.e. CL2 and CL5. The overall performance of B2 was excellent with respect to staining on accompanying cloth and is apparent in Figure 3.25 while B1 presents poor level of washing fastness grades.

Figure 3.26 displays the individual performance of fabrics concerning wash fastness (staining) taken from one step dyed and crosslinked P/C fabrics. The same findings were observed here too, i.e. the highest grades for staining to adjacent cloth was imparted by cross linker CL3. The striking similarity of fastness with both of the binders, with Knittex

crosslinker, suggests a compatible stock formulation for dyeing of P/C fabrics with acceptable performance.

Table 3.20 Analysis of variance for washing fastness (staining)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	0.3750	0.07500	2.00	0.261
Type of Crosslinkers	4	0.1500	0.03750	1.00	0.500
Type of Binders	1	0.2250	0.22500	6.00	0.070*
Error	4	0.1500	0.03750		
Total	9	0.5250			

*Statistically significant at P value 0.05

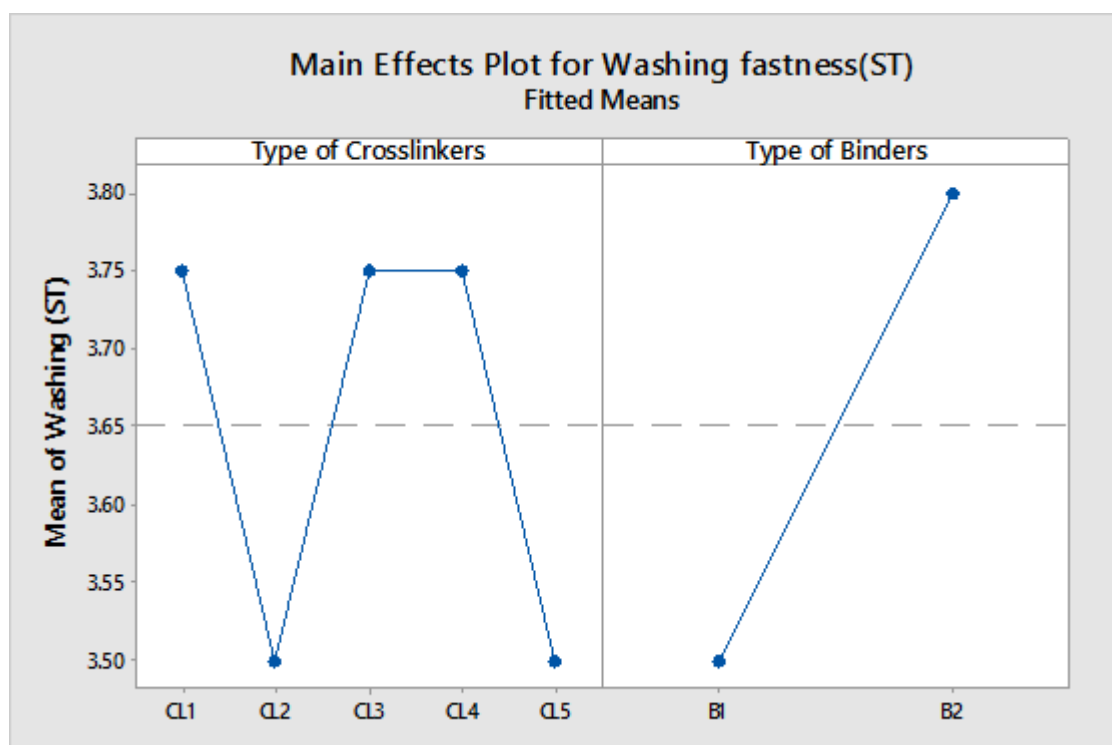


Figure 3.25: Main effects plot for washing fastness (ST)

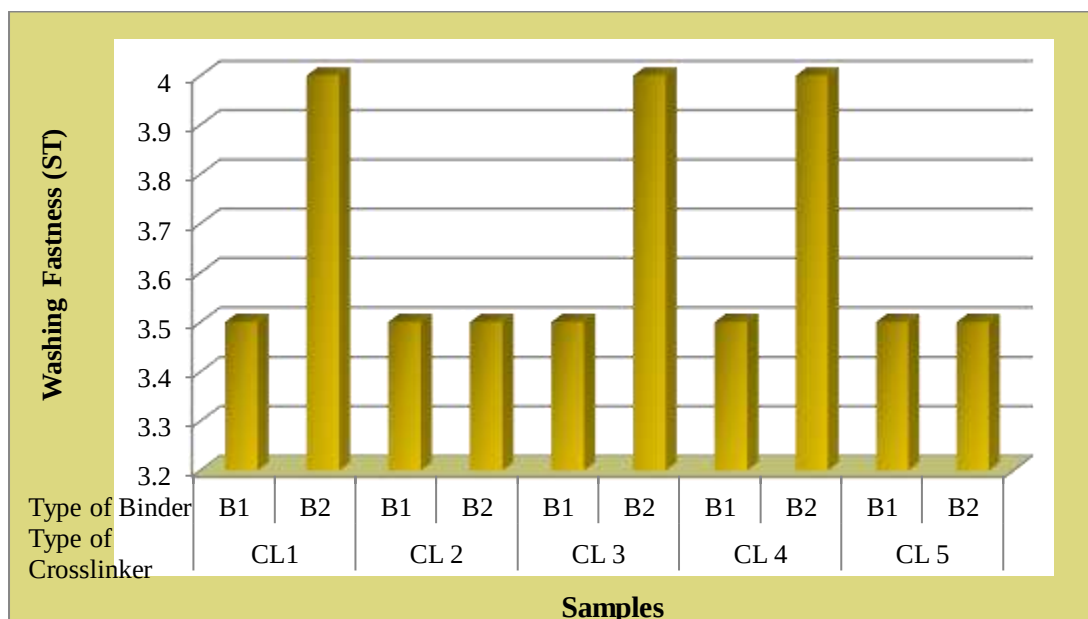


Figure 3.26: Effect of binder types and crosslinkers on the washing fastness (staining)

All the binders have self crosslinking quality, but in the current study some external crosslinkers were used with the optimized binder systems to further improve the characteristics of the dyed P/C fabrics. The improvement in the performance of a polymer can be achieved by applying another group of monomers, called functional or cross linking monomers. The optimized binder systems, Helizarin binder CFF and Helazarin binder ET ECO, when crosslinked with Fixapert CPF and ArkofixNZF in separate formulations, reduced the fastness grading to a difference of 0.5 unit. The other results with the same crosslinker showed striking similarity in fastness grades especially in shade change and staining on cloth. There were insignificant differences in fastness ratings of both dyed/crosslinked and untreated fabric.

Generally, the results were equivalent to or slightly less than the colour fastness ratings of treated (dyed/crosslinked) and untreated fabrics particularly wet and dry rubbing fastness. The findings are comparable to the results reported by Uddin & Lomas (2005) who conducted a study on one step printing and finishing with pigment dye and DMDHEU as crosslinker on cotton fabrics.

The concurrent pigment printing and finishing with DMDHEU was conducted on cotton fabrics, using pigment red and pigment blue along with polyacrylate binder and other necessary auxiliaries. The sequence for application technique was print- dry- cure comprises,

60 °C for drying of 7 minutes and 160 °C curing of 3 minnutes. Regardless of catalyst type and processing sequence, all the fabric specimens showed excellent wash fastness obtaining grade 4-5 for colour change and '5' for stainig. The formation of the binder film and level of crosslinking within it was seemed to be unimpaired by the co-application of pigment dyeing and DMDHEU finishing in both studies. In our study the technique was same with an exception of small difference in thermofixation conditions and application method was dyeing with pigment colourants, instead of printing on P/C fabrics.

The wash fastness with respect to colour staining on adjacent fabric and shade change of dyed fabric remained at higher grades but the wet and dry rubbing fastness of melamine formaldehyde (Printofix WB liquid) treated fabrics was found to be reduced with both of the binder systems. In each case the external crosslinking provoked no beneficial effects in rubbing fastness of P/C fabrics. In the present study the wet and dry rubbing fastness grades were de valued by 0.5 to 1 units. The results are in fair agreement with Thomson (2006) who claimed that the melamine resin as crosslinkers provide additional bonding to the pigment coloured substrate. The external crosslinking in conjunction with acrylic binder improved the colour resistance, especially the wet fastness.

The usage level of crosslinker is recommended as 0.5 % to 1% by him but in present study, the quantity was 10% a with a conventional pigment dyeing formulation. It seemed that high usage level of chemical with acrylic binder CFF, formed a hard film on the surface of the fabric due to increased amount of crosslinker and the binders. The binders film could not resisted the abrasive action and the dye crocked off from a hard coated substrate thereby lowering the fastness level.

3.2.2 Effect of different crosslinking agents on tensile strength

The results with respect to the effect of crosslinking agents on the tensile strength (warp and weft) of P/C fabrics is given in Table 3.21. The summary also contains the effect of binders, coupled with crosslinking agents on the tensile strength of fabrics.

Table 3.21 Effect of different crosslinking agents on tensile strength of the dyed samples

Sample No.	Factors		Responses		
	Type of Cross linker	Type of Binder	Tensile St, Warp (lb)	Tensile St ,Weft(lb)	Tensile St (Wp+Wt), lb
1	CL1	B1	137.3	35.61	172.91
2		B2	142.8	35.2	178
3	CL2	B1	139.41	43.61	183.02
4		B2	123.5	21.5	145
5	CL3	B1	160.0	72.05	232 .05
6		B2	160.6	91.01	251.61
7	CL4	B1	153.01	37.61	190.2
8		B2	168.8	27.71	196.51
9	CL5	B1	123.2	36.5	159.7
10		B2	150.71	54.25	204.96

The analysis of variance (ANOVA) of the tensile strength results is given in Table 3.22. The tabulated values clearly show a statistically non significant effect of the crosslinking agents on the mean tensile strength of dyed P/C fabrics. The overall performance of binder B2 was slightly better than B1. The main effects plot for the tensile strength of fabric is displayed in Figure 3.27, in which the excellent performance of CL3 is obvious with an increasing trend of tensile strength.

The individual performance of P/C fabrics in Figure 3.28 showed, that the tensile strength with one of the crosslinking agent (CL2) was adversely affected, while mean strength of fabrics with CL4 was slightly better than the others.

Table 3.22 Analysis of variance for tensile strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	7408.7	1481.7	3.25	0.139
Type of Crosslinkers	4	7262.4	1815.6	3.98	0.105
Type of Binders	1	146.3	146.3	0.32	0.602
Error	4	1825.8	456.5		
Total	9	9234.5	3900.1		

*Statistically significant at P value 0.05

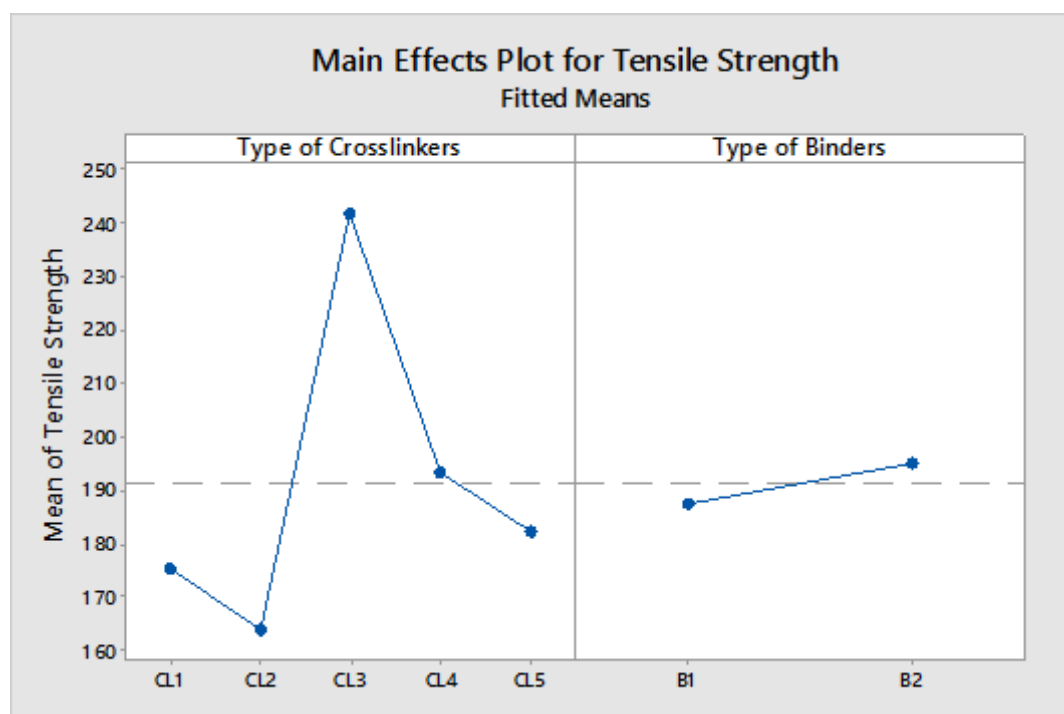


Figure 3.27: Main effects plot for tensile strength (warp and weft)

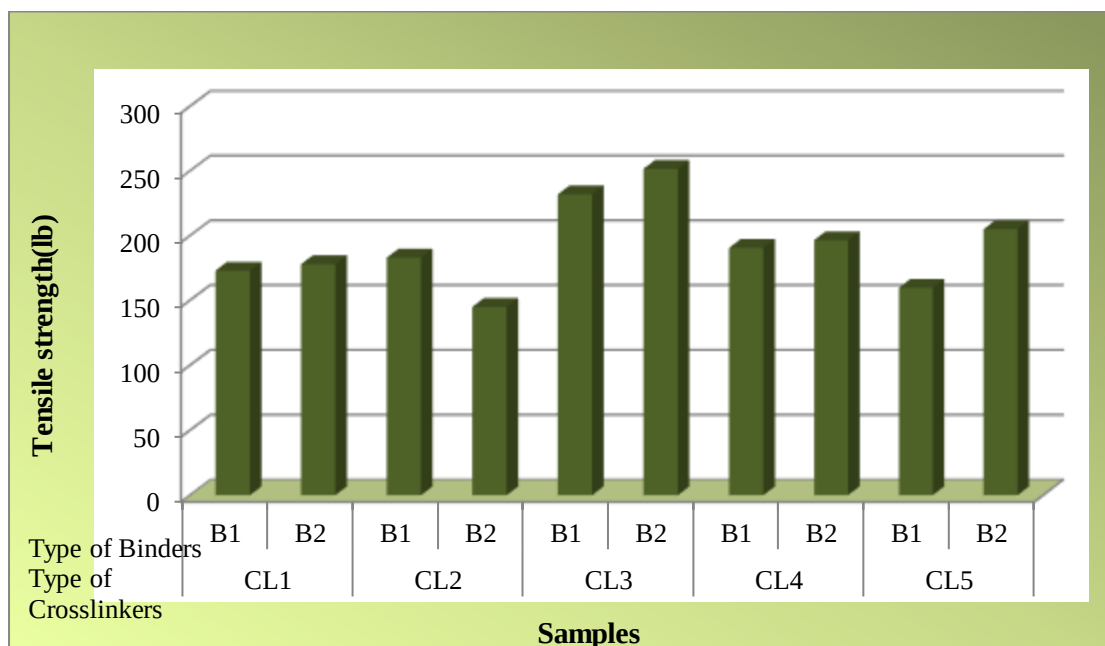


Figure 3.28 Effect of binder types and crosslinkers on the tensile strength (warp and weft)

In general the effect of cross linker on the tensile strength of P/C fabrics was considered to be harmful. However, in current investigation it sometimes remained beneficial, though the performance was not as good as the pre treated fabric. The combined dyeing and crosslinking with dimethyloldihydroxy ethylene urea rendered low tensile strength. The reason for this decline may be the cross linking mechanism of DMDHEU with adjacent molecules which was described by (Schindler & Hausar, 2004). In DMDHEU finishing chemical the cross linking of adjacent molecules restrict movement of fibres under stress, which leads to loss in tensile and tear strength. Without resin treatment cellulose chains are not cross linked and stress can be distributed over neighbouring molecules, minimizing strength loss. Contradictory to these findings the incorporation of modified DHEU with pigment stock formulation, rendered very good tensile strength to P/C fabric. The extent of improvement in the earlier mentioned parameters was determined by the type of binder and the cross linker used for finishing. The treatment of knitted RCT (modified DHEU) with two optimized binder systems brought a positive impact on the tensile strength of P/C fabric. The increase in strength was observed with Helizarin binder CFF and Helizarin binder ET ECO, respectively.

In this case the cross linked chains formed by resin treatment were not in a stable position. There was a moderate increase in flexibility with an increase in percentage extension

values in weft as compared to warp of fabric. Such a mechanism can be understood by the investigation of (Lickfield et al., 2000) on various crosslinkers which were applied on cotton fabric. The cross link chains formed by DHEU treatment were mutually displaced in order to resist the applied load uniformly, thus strengthening the fabric.

The overall results indicate that the process of cross linking could overcome the low strength problems by the application of a formaldehyde free cross linker, such as knittex RCT. It can be a feasible option for imparting crease resistance or durable press finishing to P/C fabrics without disturbing their durability.

3.2.3 Effect of different cross linking agents on tear strength

The summary of tear strength results are given in Table 3.23, representing the effect of cross linking agents on the warp and weft tear way strength of fabrics.

Table 3.23 Effect of different cross linking agents on tear strength of the dyed samples

Sample No.	Factors		Responses		
	Type of Cross linker	Type of Binder	Tear St, Warp (lb)	Tear St , Weft(lb)	Tear St (Wp + Wt), lb
1	CL1	B1	680	1480	2160
2		B2	960	1400	2360
3	CL2	B1	720	1440	2160
4		B2	800	1780	2580
5	CL3	B1	740	1200	1940
6		B2	840	1480	2320
7	CL4	B1	800	1320	2120
8		B2	1000	1600	2600
9	CL5	B1	1000	1840	2840
10		B2	1120	1960	3080

Table 3.24 Analysis of variance for tear strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	110480	222096	31.11	0.003

Type of Crosslinkers	4	814640	203660	28.52	0.003*
Type of Binders	1	295840	295840	41.43	0.003*
Error	4	28560	7140		
Total	9	1139040	728736		
*Statistically significant at P value 0.05					

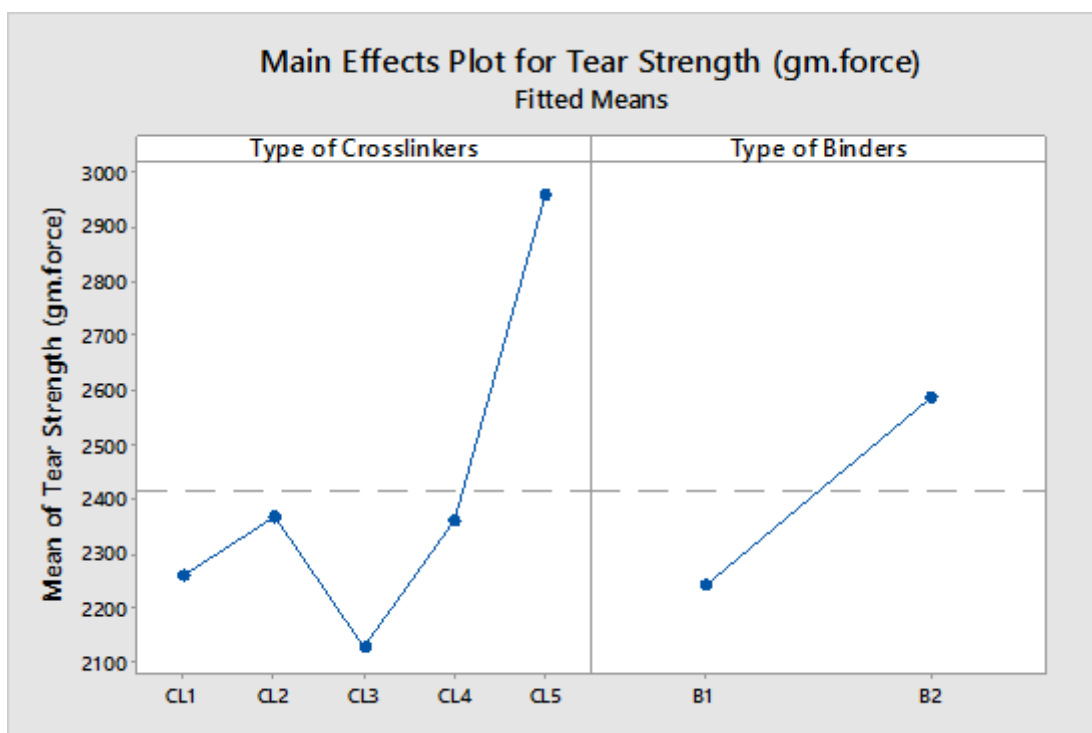


Figure 3.29: Main effects plot for tear strength (warp and weft)

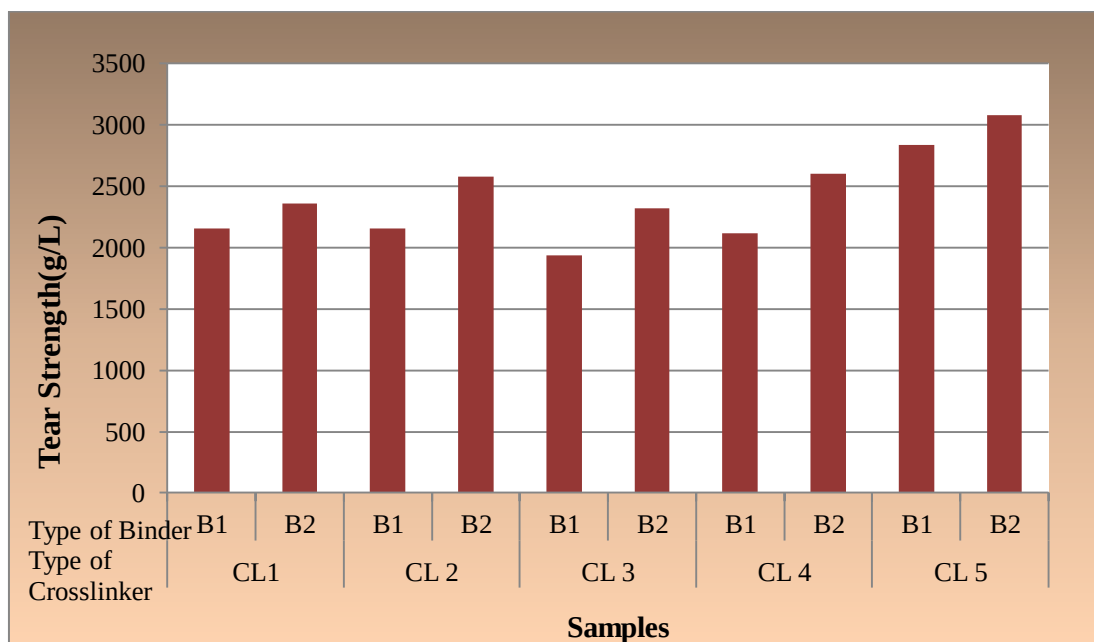


Figure 3.30: Effect of binder types and crosslinkers on the tear strength (warp and weft)

Table 3.24 contains the ANOVA of results for the tear strength of simultaneously dyed and crosslinked P/C fabrics. The effect of crosslinking agents as well as the type of binders were found to be highly significant on the tear strength properties.

Figure 3.29 illustrates the main effects plot for the results of tear strength, obtained after crosslinking treatments on fabrics. The figure shows an overall decreasing trend in the tear strength of fabrics with the exception of one crosslinking agent, CL5 which had least affected the strength in a negligible manner. As regards the binder types, B2 has proved to be better than B1, with respect to the effect of crosslinking agents on tear strength.

The results of tear strength of simultaneously pigment dyed and finished P/C fabrics with various cross linkers have been displayed in Figure 3.30. According to the findings, CL5 was found to be the best in enhancing the tear strength of treated fabrics. The minimum tear strength was possessed by the fabric treated with crosslinking agent, CL1 coupled with both the binders, individually.

In general, it was observed that, the P/C fabrics showed a decrease in tear strength with pigment colourants, but, when the same formulation was applied with various resin or crosslinking chemicals, the performance of fabrics was found to be upgraded. Few of the dyed and DMDHEU treated fabrics recovered the loss in tear strength, indicated by the raised

values. The results are supported by the investigation carried out by (Li Shiqi, 2007) who quoted the enhanced properties of DMDHEU finished fabric that was treated with procion-resin method. The tear strength was found to have increased 4 to 6% in warp and weft directions respectively. In this study Fixapret CPF and Arkofix NZF, both conventional and modified DMDHEU had induced the higher tear strength as compared to the control fabric that was dyed only with pigment colourant.

In the same set of cross linking treatment, the next highest value of tear strength corresponded to Printofix fixative WB liquid, a highly etherified melamine compound. Its combined treatment with pigment stock formulation strengthened the tearing tendency of the dyed fabric, in comparison to the control fabric. The present findings are in agreement with that of (Yorston, 1995), who reported that hexamethoxy melamine creasing agents had more reactive sites which resulted in a complete cross linking with OH groups on cellulose, under appropriate post curing conditions. That's why the fabrics treated with this chemical had excellent durability, as observed in our study and also the optimal strength ratio with this cross linker.

The result of two crosslinkers with very low formaldehyde content i.e. Fixapret F-Eco and knittex RCT, showed a slight deviation in the tear strength values. The same formulations with Helizarin binder ET ECO provided surprising results regarding tear strength of P/C fabric. The cross linkers were applied at constant process parameters but in this case, the loss in tear strength was more obvious in warp direction of P/C fabrics, except with the one treated with printofix fixative WB liquid. The chemical that was applied to cross link resin finishing, indicated minimum loss to the fabric regarding tear strength. Furthermore a handsome increase of 15% was contributed in strength level by the same cross linker.

3.2.5 Effect of different crosslinking agents on flexural rigidity

The summary of results for the flexural rigidity are given in Table 3.25, representing the effect of cross linking agents on the treated fabrics.

The analysis of variance for the results regarding flexural rigidity of fabrics is displayed in Table 3.26, according to which the type of crosslinkers had non significant effect on the flexural rigidity of fabrics. The binder types had a different response on fabric's texture, indicated by a significant effect on flexural rigidity.

Table 3.25 Effect of different crosslinking agents on flexural rigidity of the dyed samples

Sample No.	Factors		Responses		
	Type of Cross linker	Type of Binder	Flex. Rig Warp, μ Joule/M	Flex. Rig Weft, μ Joule/M	Flex. Rig (Wp+Wt) μ Joule/M
1	CL1	B1	15.79	7.66	23.45
2		B2	19.42	11.24	30.66
3	CL2	B1	16.81	9.06	25.87
4		B2	21.27	7.85	29.12
5	CL3	B1	16.66	8.99	25.65
6		B2	33.56	11.24	44.8
7	CL4	B1	17.85	7.53	25.38
8		B2	30.47	7.79	38.26
9	CL5	B1	15.66	9.06	24.72
10		B2	20.4	8.24	28.64

The main effects plot for flexural rigidity of fabrics is given in Figure 3.31. From the pictographic representation, it can be clearly seen that flexural rigidity of all the fabrics was reduced by crosslinkers irrespective of the binder types. The results of individual fabric performance is exhibited in Figure 3.32, in which all the fabrics depicted a reduced level of stiffness. However, one of the fabric, which revealed the highest stiffness level of fabric, was induced by CL3 in combination with B2. The crosslinking agents, CL1, CL2 and CL5 gave low mean flexural rigidity results, hence it can be inferred that the effect of crosslinking treatment on the stiffness of fabrics was insignificant.

Table 3.26 Analysis of variance for flexural rigidity

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	327.37	65.47	2.91	0.161

Type of Crosslinkers	4	111.98	27.99	1.25	0.418
Type of Binders	1	215.39	215.39	9.59	0.036*
Error	4	89.88	22.47		
Total	9	417.24	331.32		
*Statistically significant at P value 0.05					

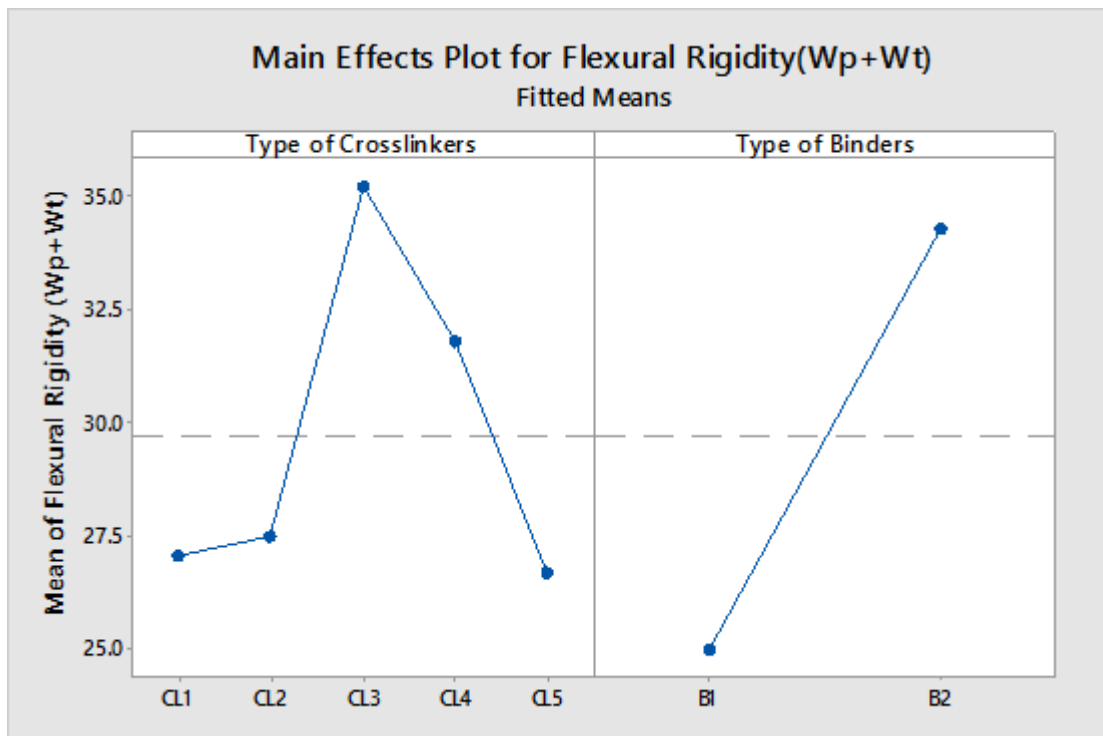


Figure 3.31: Main effects plot for flexural rigidity (warp and weft)

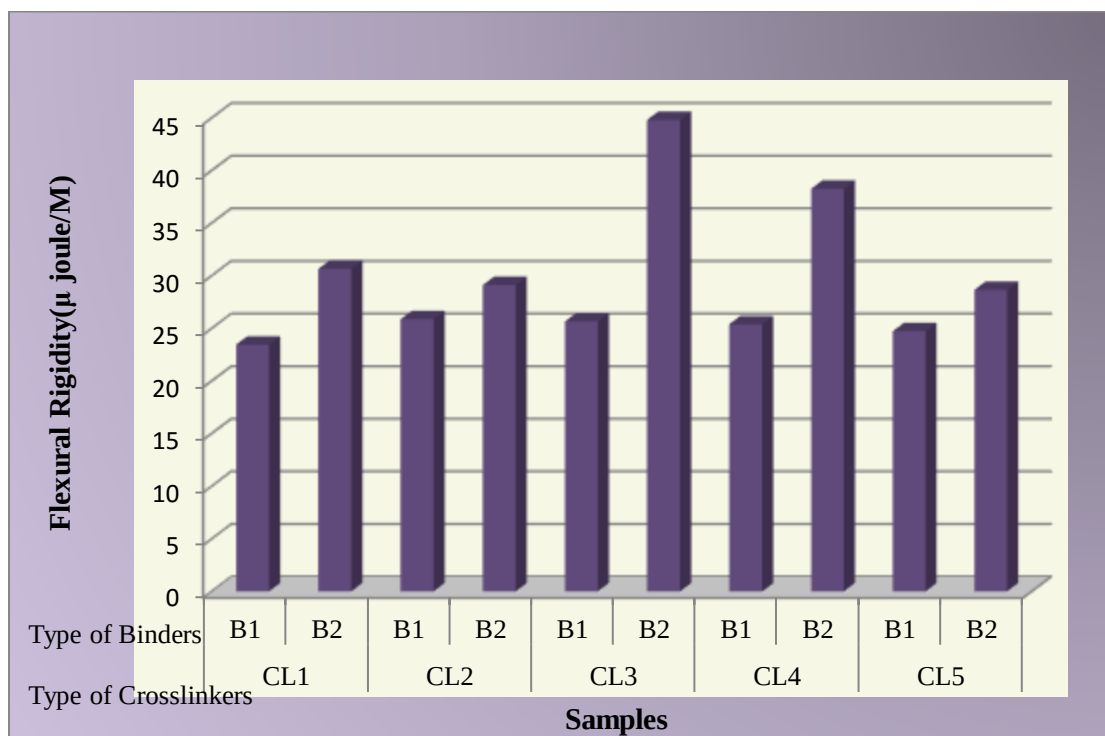


Figure 3.32: Effect of binder types and crosslinkers on the flexural rigidity (warp and weft)

The flexural rigidity of dyed crosslinked P/C fabric with Helizarin binder CFF and Helizarin binder ET ECO have been displayed in Table 3.13. The flexural rigidity, which in turn is an indication of stiffness of fabric was found to be decreased with almost all the crosslinkers in both the directions of fabric i.e. warp and weft. Since weft way fabrics were more flexible and pliable than warp, they were declared to be softer in handle. The control fabric, dyed only with a conventional pigment formulation was assessed to be stiffer due to high binder ratio, however, with cross linking the textural qualities of the fabric had been altered. The modified surface produced low flexural rigidity particularly in warp direction compared to the weft of fabric. The results are in line with the study conducted by (Li Shiqi, 2008) on durable press finishing of cotton.

3.2.6 Effect of crosslinking agents on abrasion resistance

The effect of various crosslinkers, combined with pigment colouration on P/C fabrics was analyzed for their abrasion resistance property and the results are given in Table 3.27.

Table 3.27 Effect of different crosslinking agents on abrasion resistance and Pilling of the dyed samples

Samples	Factors		Responses	
	Type of Cross linker	Type of Binder	Abrasion res. (no. of cycles)	Pilling
1	CL1	B1	14,600	3
2		B2	30,710	5
3	CL2	B1	16,220	4
4		B2	27,635	5
5	CL3	B1	23,160	3
6		B2	17,270	4
7	CL4	B1	24,000	3
8		B2	37,160	4
9	CL5	B1	28,000	3
10		B2	18,275	3

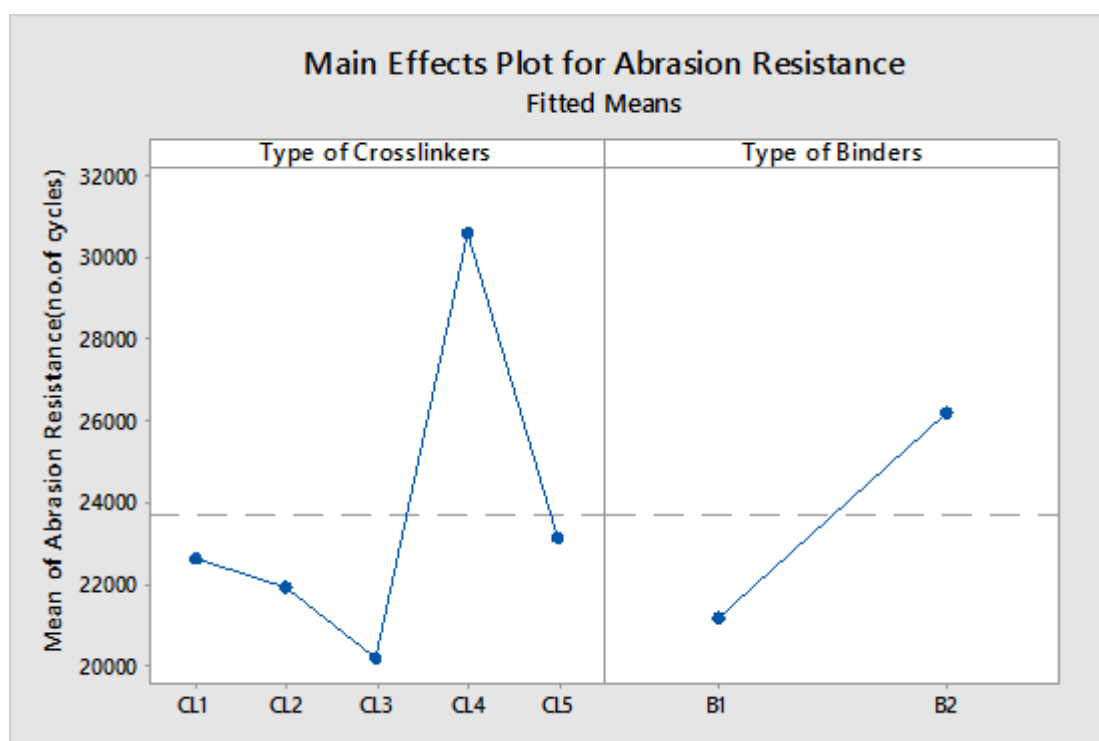
The analysis of variance for the results of the abrasion resistance of fabrics is given in Table 3.28, according to which the type of crosslinkers used, had non significant effect on the abrasion resistance of fabrics. The data regarding binder types was also found to be statistically in significant.

Figure 3.33 displays the main effects plot for the abrasion resistance of fabrics, induced by different crosslinking agents and binders. The majority of cross linking agents were found to be low abrasion resistant, hence indicating a statistically adverse effect on abrasion response. Figure 3.34 represents the abrasion behavior of all the fabrics treated with different crosslinking agents and different binder types, as well. The treatment with cross linker CL4 needed maximum number of cycles to abrade the specimen. As regards the performance of binders, the effect of B2 on the abrasion resistance statistically seemed to be less intense than B1.

Table 3.28 Analysis of variance for abrasion resistance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	190910025	38182005	0.54	0.744
Type of Crosslinkers	4	128059535	32014884	0.45	0.770
Type of Binders	1	62850490	62850490	0.89	0.400
Error	4	283293335	70823334		
Total	9	474203360	665113855		

*Statistically significant at P value 0.05

**Figure 3.33:** Main effects plot for abrasion resistance

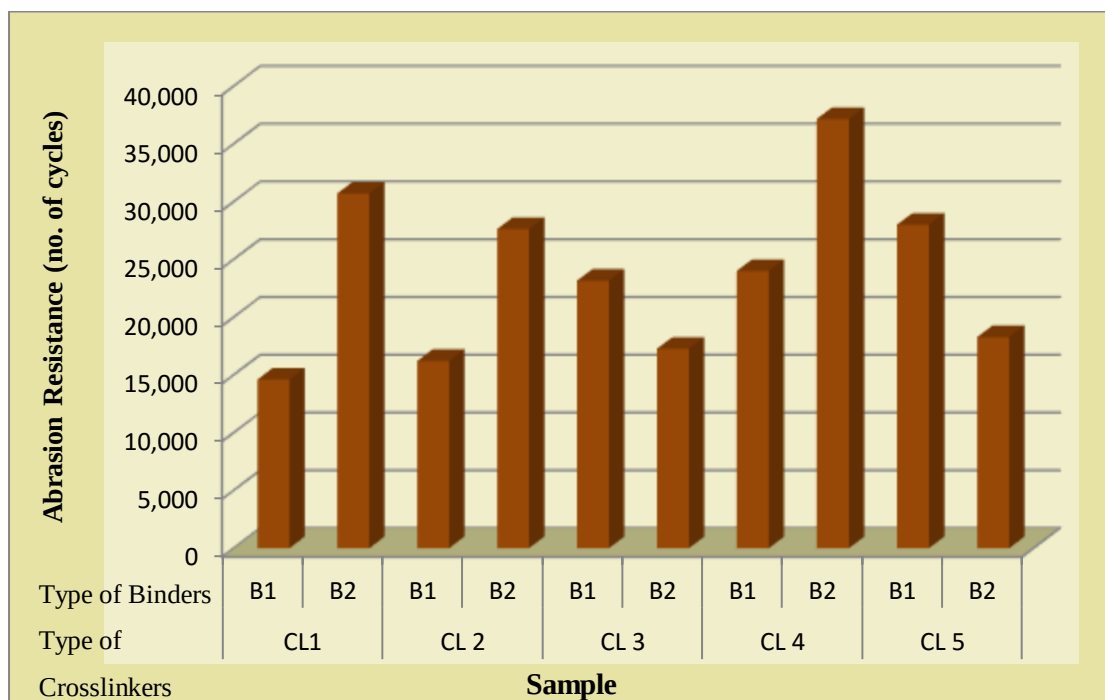


Figure 3.34: Effect of crosslinking agents on abrasion resistance

Abrasion is the physical destruction of fibers, yarns and fabrics, resulting from the rubbing of a textile surface over another surface (Abdullah, 2006). In this study the abrasion resistance of cross linked P/C fabrics was adversely effected irrespective of the binder systems. In an investigation carried out by (Lickfield et al., 2000) the significant loss in mechanical strength and abrasion performance of cross linked fabrics with multifunctional DMDHEU and DHEU have been obtained. The reduction in abrasion resistance was attributed to the rigidity of crosslinks on the surface of fabrics, formed and inhibited the movement within the fiber microstructure. The same mechanism worked here in this study causing embrittlement due to the formation of binder film and combined cross linking of cellulose molecules with DMDHEU both conventional and modified, thus leading to bad abrasion performance. The treated fabric could not withstand the rubbing action and wore off at an early stage of testing as compared to the control fabric.

The visual comparison of the fabric's abrasion resistance can be interpreted by the Figure 3.25. The maximum change in decreasing order of abrasion value is dominated by printofix fixative WB liquid, a methyl melamine compound. The white area on the specimen indicated that the binder film on the surface of the fabric was removed by rubbing action thus exposing the outer

layer and distorting its appearance. The difference was more promising with binder B2, compared to B1 with various crosslinkers.

Cotton fabric is reduced in the flexibility by post treatment of durable press finishing which further lowers the strength and stiffness of the fabrics. The mechanism was further reviewed by (Patel (1995) according to which, upon cross linking several linear flexible polymer molecules converted into a single molecule of a complex polymer network, provoked significant improvements in physical properties with minimal loss in flexibility. The difference in flexural rigidity of non crosslinked and crosslinked pigment dyed P/C fabric with B1 can be observed in this study (Table 3.11). However, the behavior of external cross linkers with B-2 was slightly different since in that set two of the cross linkers, knittex RCT and arkofix NZF, both with dihydroxyethylene urea component yielded an increased flexural rigidity. The high stiffness level might be attributed to a thin, film forming tendency that was analyzed by (Thomson, 2006) and can be correlated to this study. Both ureaformaldehyde and melamine formaldehyde have a serious drawback as a finishing reagent for cotton. They enhance the durable press properties simultaneously with increased stiffness. A coating or film can be formed around the fibers if appropriate application conditions are not followed. In the same study concluded by the researcher that, “the bending rigidity of carboxymethylated and ionically cross linked fabrics is strongly influenced by the procedures used to treat the fabrics.”

3.2.7 Effect of different crosslinking agents on pilling grades

The results with respect to the effect of pilling performance are summarized in Table 3.27. The fabrics treated with CL2 attained the maximum value of grade 5, indicating no signs of pilling or fuzzing on the surface of the fabric. Two of the cross linkers, CL3 and CL4, both modified DHEU, tended to create partially formed pills, rated under grade “4”. The results in this case were found to be in close agreement with the reference fabric.

The main effects plot for pilling resistance of fabrics is given in Figure 3.35, which illustrates a highly significant effect of cross linking agent, CL2 on the P/C fabrics. The overall pilling performance of CL5 showed adverse response on pilling property with a statistically significant change. Again the mean pilling grade of B2 was at higher grading level as compare to B1. Figure 3.36 demonstrates the individual performance of pilling of

dyed/crosslinked P/C fabrics according to which, the highest grades were gained by crosslinking agent, CL 2 with B2.

Table 3.29 Analysis of variance for pilling resistance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	5.100	1.0200	4.08	0.099
Type of Crosslinkers	4	2.600	0.6500	2.60	0.189
Type of Binders	1	2.500	2.5000	10.00	0.034
Error	4	1.000	0.2500		
Total	9	6.100	3.4		

*Statistically significant at P value 0.05

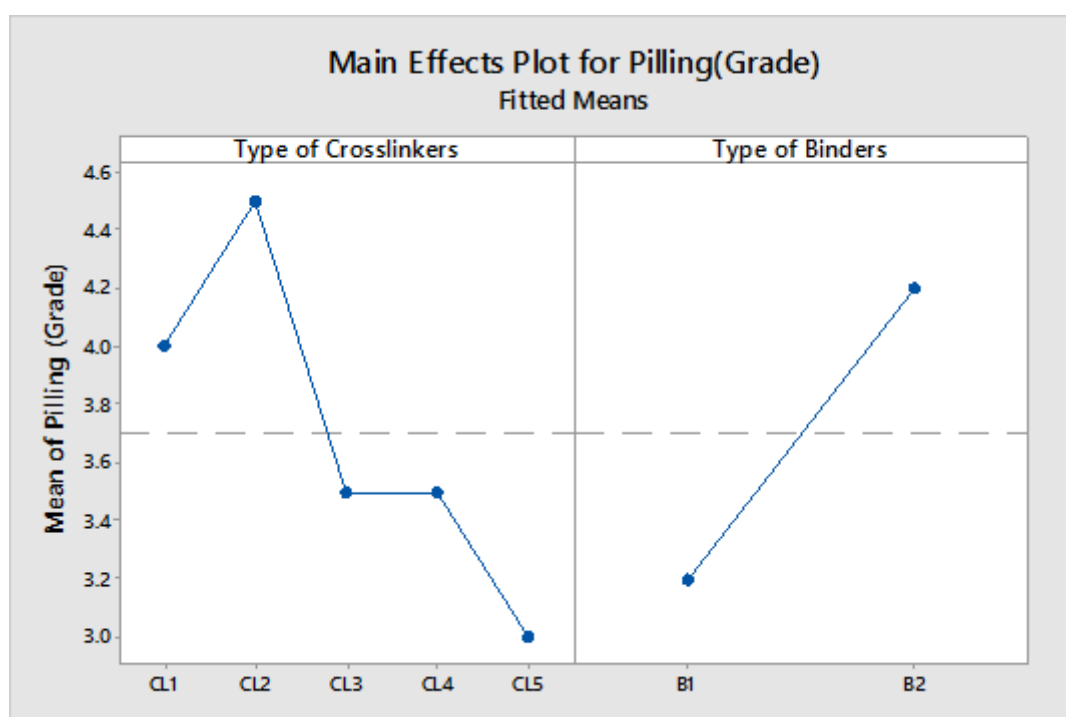


Figure 3.35: Main effects plot for Pilling grades

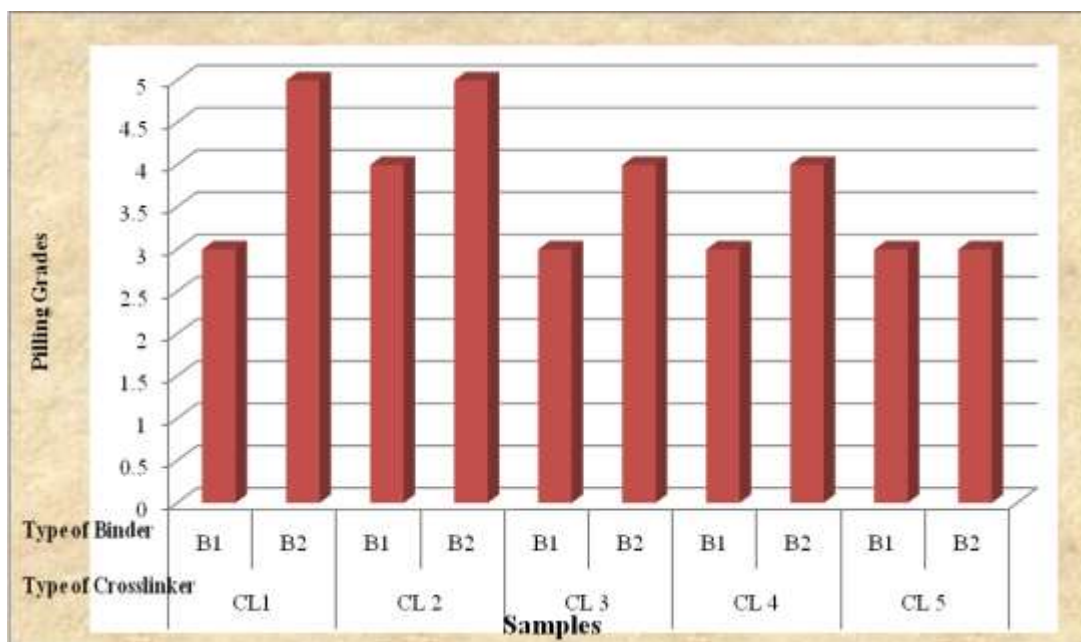


Figure 3.36: Effect of crosslinking agents on pilling performance

The pilling test results of dyed and cross linked P/C fabric have been enclosed in table x. The cross linking with binder B1 resulted in decreased pilling resistance of fabrics exceptionally with the fixapret F-Eco (DHEU). This crosslinked fabric developed only a partially formed pills indicating negligible difference with control fabric. Figure 3.38 represents the visual appearance of the pilled fabric in which a marginal difference in pilling resistance is evident. The low resistance of pilling in remaining fabrics was induced by the other crease resistant chemicals i.e. DMDHEU, DHEU and melamine formaldehyde respectively. The reason might be the strong cross linking effects of these chemicals which assisted the protruding pills to cling on the surface of the substrate by strong polyester filaments.

Another fact for moderate pilling tendency fabric might be attributed to the reaction of certain finishes applied with stock formulations. Certainly there are various types of finishes that can lubricate fibers with improved pilling grades by lowering the frictional forces. But, in this investigation various cross linkers were applied on fabrics with pigment colourant which might have increased the frictional forces between fibers and yarn structure, converting them into small fuzzy pills. Contrary to first group with binder 1, the combination of cross linking agent with acrylate copolymer binder in pigment dyeing formulations resulted in very good pilling resistance properties to P/C fabric. The excellent pilling grades were

attained by fabrics that were dyed and treated with DMDHEU and modified DHEU while the other kinds of same crosslinkers were also found to be beneficial regarding pilling behavior. The results concur with those of Schindler & Hausar (2004) according to which the pilling of resin treated polyester/cotton fabric can be scrubbed off after a specific period of time due to weakening of crosslinked fibers. The present findings somehow concur with the description about the application of durable press finishes on cotton fabric which not only provide wrinkle recovery properties but also reduce the pilling tendency. It happened presently with P/C fabrics due to the low fiber strength, obtained by DHEU crosslinking for easy care finishing.

3.3 EFFECT OF DIFFERENT SOFTENERS ON THE PROPERTIES OF PIGMENT DYED FABRICS

3.3.1 Effect of different softeners on the colourfastness properties of pigment dyed P/C fabrics

In the third phase, the P/C fabrics were pigment dyed in combination with assorted softeners, an acrylate binder, and a crosslinker (modified DHEU) with optimized performance characteristics. The results of the colourfastness properties of treated fabrics are summarized in Table 3.30.

3.3.1.1 Effect of different softeners on the dry rubbing fastness

The main effects plot for the results of dry rubbing fastness of P/C fabrics is shown in Figure 3.37, according to which the simultaneously dyed, crosslinked and finished P/C fabrics with different softeners showed a similar trend. All the softening chemicals exhibited a desirable level of fastness, except S6 (polyethylene softener), which had satisfactory performance. Figure 3.38 shows the individual results of softeners' performance for the dry rubbing fastness of dyed fabrics.

3.3.1.2 Effect of different softeners on the wet rubbing fastness

The data with respect to wet rubbing fastness was statistically analyzed by (ANOVA) and the results of the main effects plot are displayed in Figure 3.39, majority of the softeners showed a consistency in results with respect to wet rubbing fastness by indicating maximum grade '2.5'.

According to the plotted Figure 3.40, the individual performance showed the same trend i.e. a slight decline in wet rubbing of fabrics, treated with S6.

Table 3.30 Effect of different softeners on colourfastness properties

Samples No.	Factors	Responses			
	Type of Softeners	Dry Rubbing Fastness	Wet Rubbing Fastness	Washing Fastness SC	Washing Fastness ST
1	S1	3.5	2	4	3.5
2	S2	3.5	2.5	4	3.5
3	S3	3.5	2	4	4
4	S4	3.5	2.5	4.5	4
5	S5	3.5	2.5	4.5	4.5
6	S6	3	2.5	4.5	4.5

S1: Siligen FF-SI

S2: Siligen SIH Nano

S3: Ultratex MHT

S4: Ultratex UM NEW

S5: Sapamine SFC

S6: Perapret F PEB

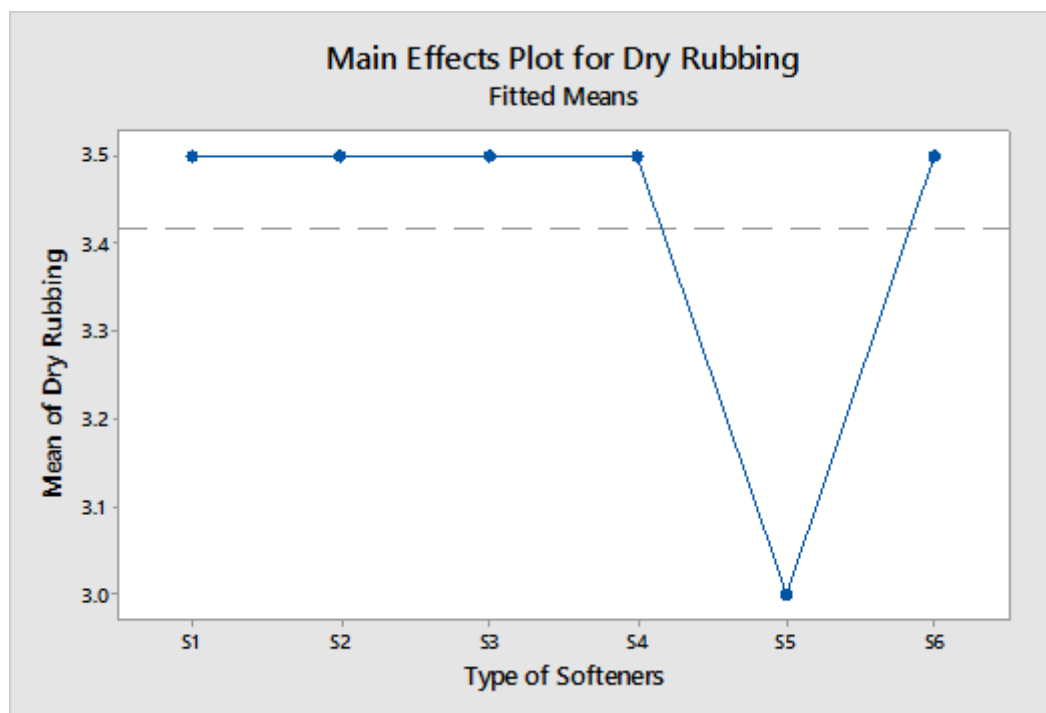


Figure 3.37: Main effects plot for dry rubbing fastness of pigment dyed P/C fabrics

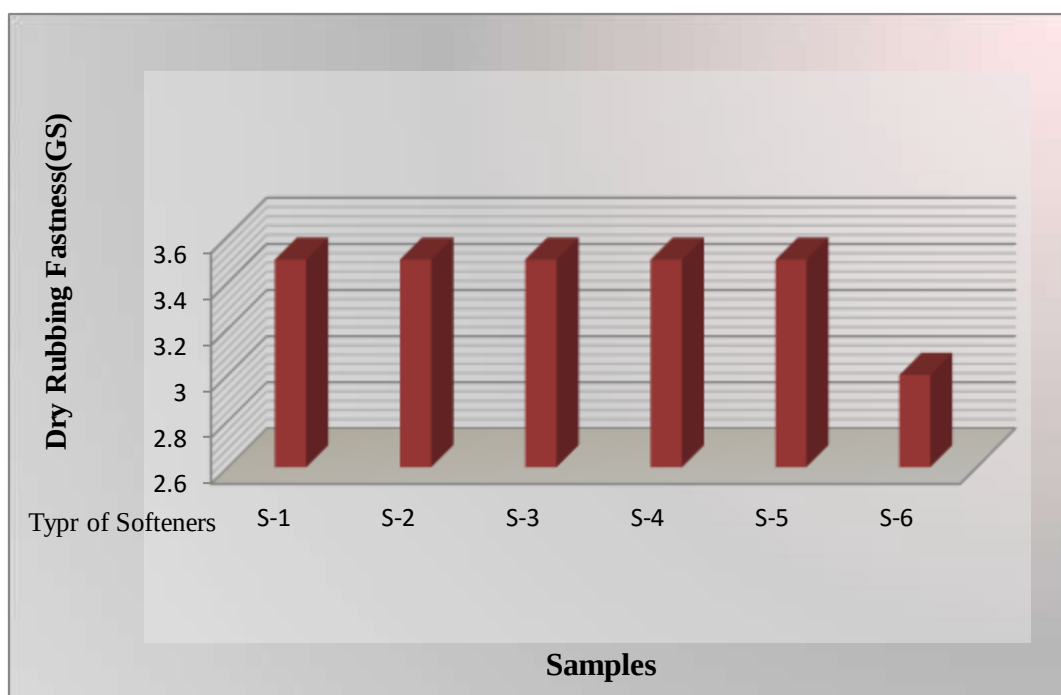


Figure 3.38: Effect of different softeners on the dry rubbing fastness of pigment dyed P/C fabrics

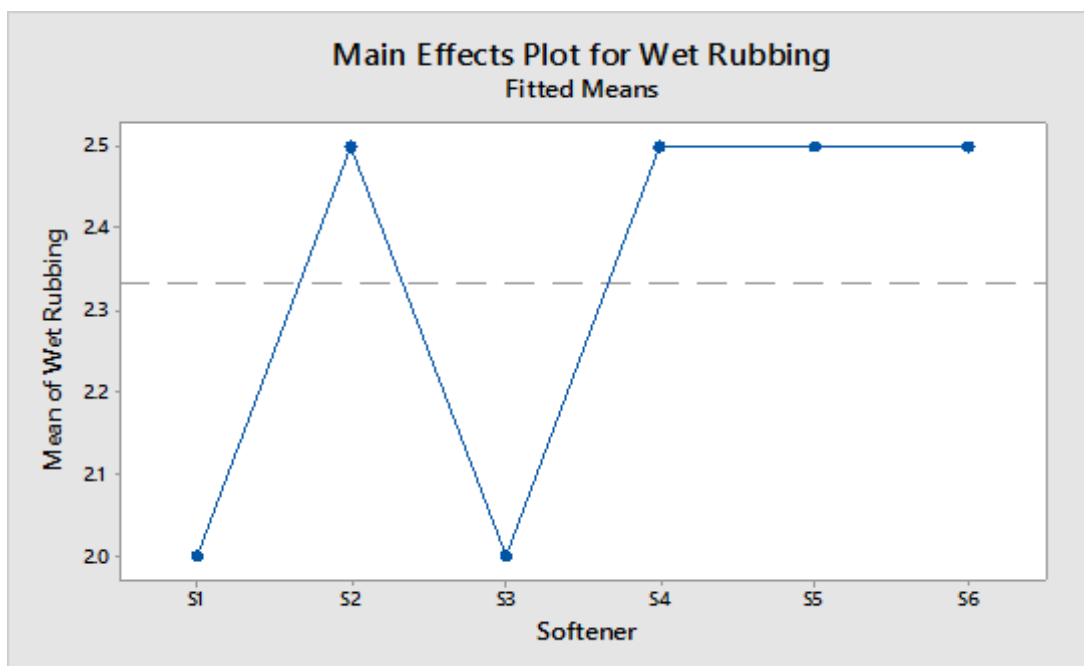


Figure 3.39: Main effects plot for wet rubbing fastness of pigment dyed P/C fabrics

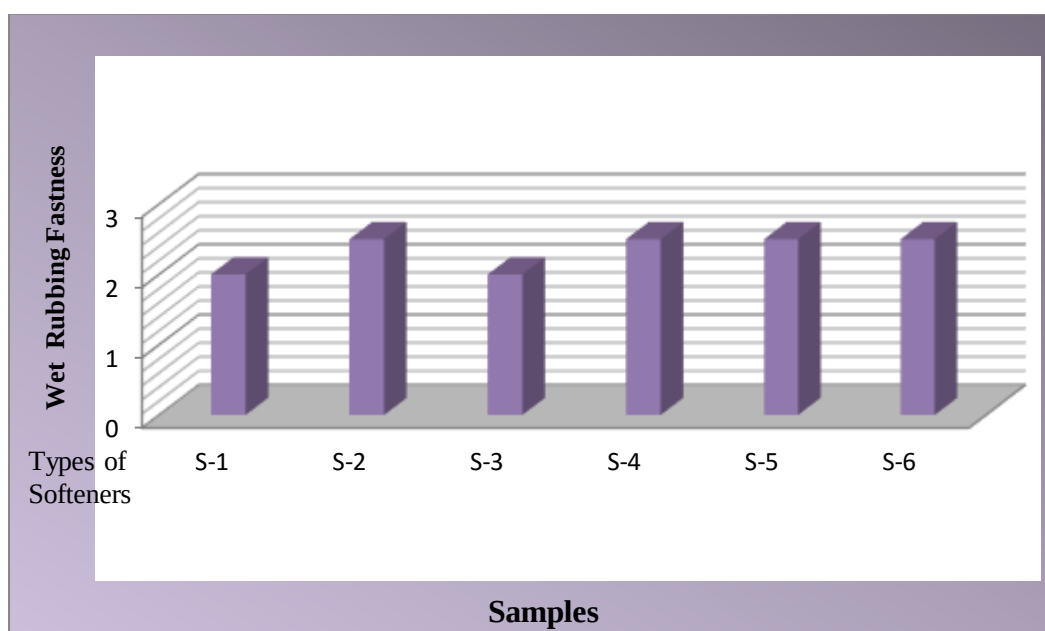


Figure 3.40: Effect of different softeners on the wet rubbing fastness of pigment dyed P/C fabrics

3.3.1.3 Effect of different softeners on the washing fastness (shade change)

The colourfastness results with respect to wash fastness, indicating shade change of treated fabrics are statistically analyzed and displayed in Figure 3.41. It is obvious that few of the softeners, incredibly improved the colourfastness of the simultaneously pigment dyed and cross linked P/C fabrics represented by an increasing trend in mean values. On the other hand a slight decline in shade change according to standard grey scale was observed in some fabrics. The results of wash fastness (shade change) for exhibiting individual performance are given in Figure 3.42. It is evident that S4, S5 and S6 induced excellent wash fastness with a negligible change in colour after wash treatment.

3.3.1.4 Effect of different softeners on the wash fastness (staining)

The results for wash fastness (staining) were analyzed statistically and displayed in Figure 3.43. The main effects plot shows that a non significant signs of staining on adjacent specimens were reported with S2 and S3 treatments. The decreasing trend in the mean wash fastness with the application of two of the softeners i.e. S1 and S2 are apparent in the plot. The individual results of wash fastness test of dyed and finished P/C fabrics with different softeners can be viewed from Figure 3.44. According to the finding the maximum wash fastness was attained by Sapamine SFC (S5) and Perapret F-PEB NEW (S6) as compared to other fabrics.

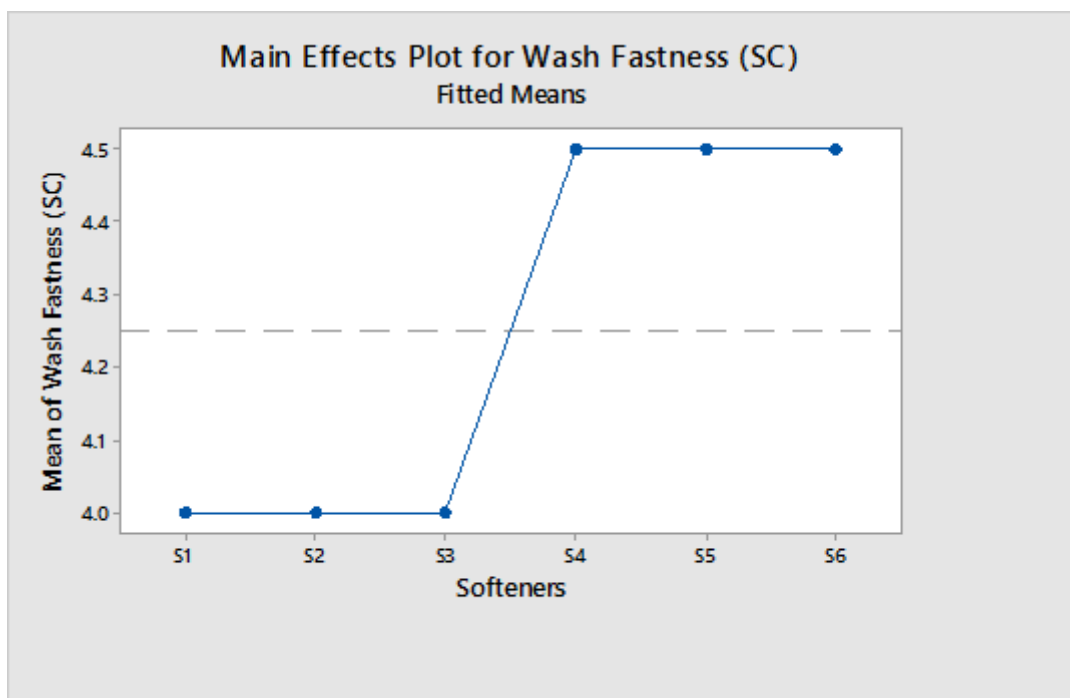


Figure 3.41: Main effects plot for washing fastness (shade change)

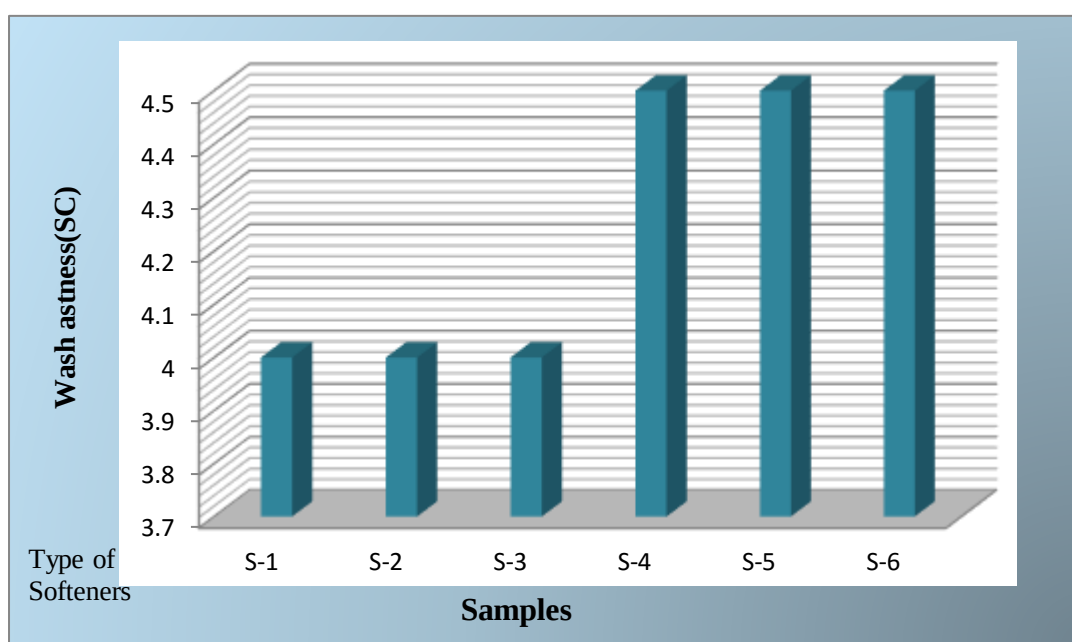


Figure 3.42: Effect of different softeners on the wash fastness (shade change) of pigment dyed P/C fabrics

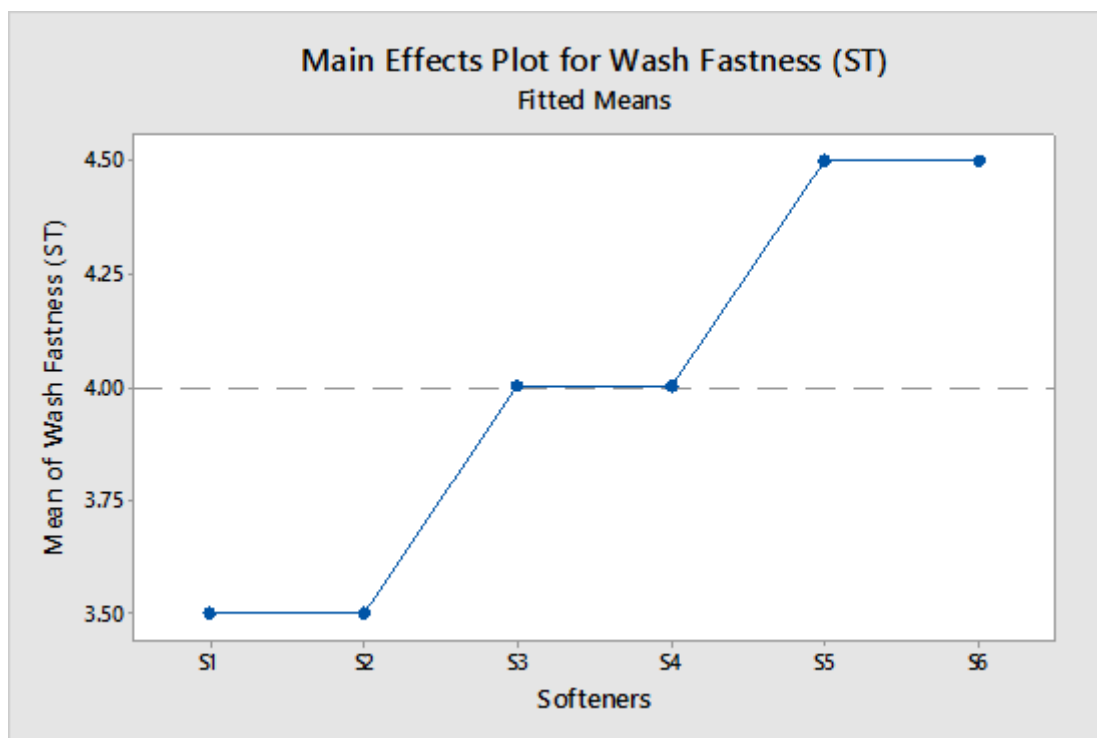


Figure 3.43: Main effects plot for washing fastness (staining)

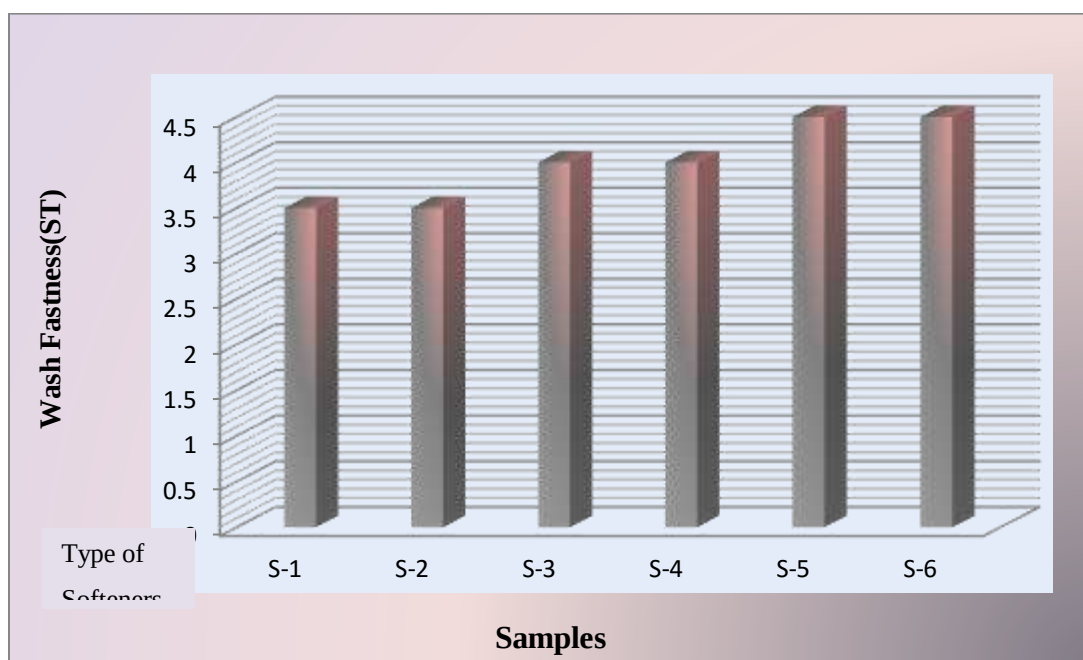


Figure 3.44: Effect of different softeners on the wash fastness (staining) of pigment dyed P/C fabrics

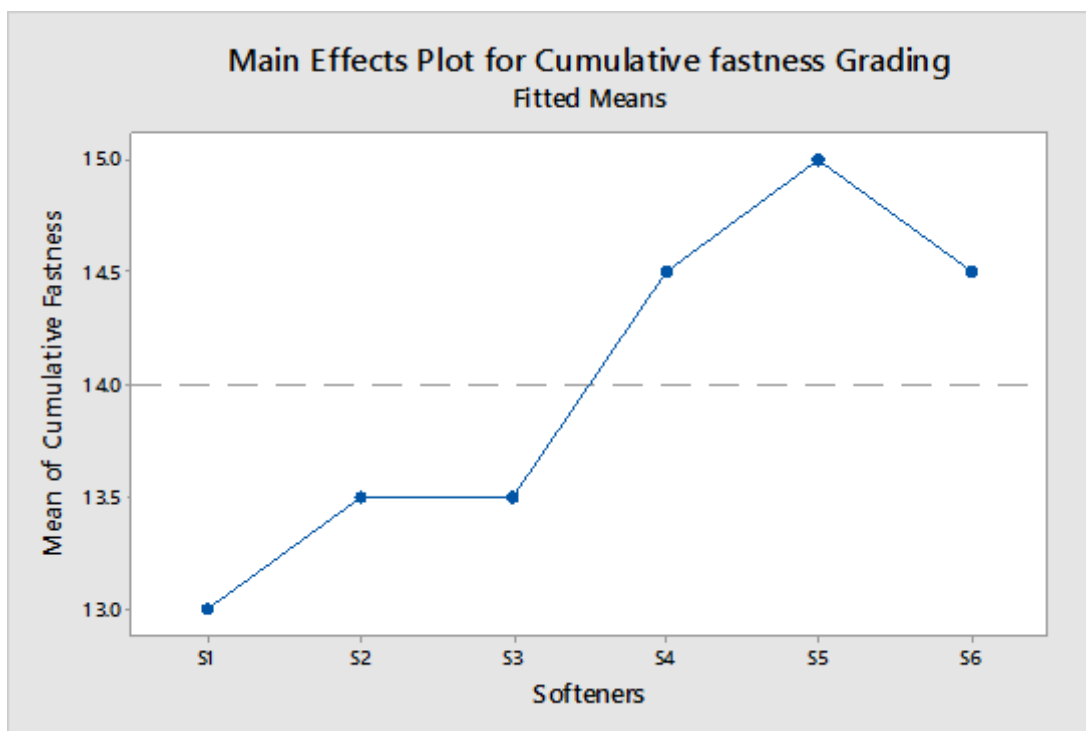


Figure 3.45: Main effects plot for cumulative fastness (staining)

Figure 3.45 shows the main effects plot for the results of cumulative colourfastness. It is evident from results that, the effect of softeners on the cumulative fastness grading of P/C fabrics showed an increasing trend, with the maximum value attained by S6 and minimum S1 (Appendix G).

The results of colourfastness properties of single step dyed and finished P/C fabrics with assorted softeners have been mentioned earlier in Table 3.30. According to the results Perapret F-PEB NEW was rated at high fastness level that was fundamentally contributed by wash fastness scale. The staining to adjacent cloth for assessing the wash fastness characteristics of P/C fabric was found to be upgraded by the application of Sapamine SFC, a fatty acid amide condensation product, together with DHEU in pigment dyeing formulation. The pH of this amphoteric softener was adjusted with the addition of acetic acid to increase its substantivity for simultaneous dyed and finished P/C fabric. Cartwright & Columbini (1993) in an investigation emphasized the significance of monitoring the pH of washing solution throughout different stages of the washing process.

In the current investigation, the overall wash fastness rating was ranged between 4 and 4-5 for colour change, indicating good to very good fastness grading. One of the several

reasons of very good wash fastness grading was the incorporation of crosslinkers in the stock formulation. Patel (1995) recommended the co-application of external crosslinkers with the binder formulation to improve the fastness of coloured fabrics and hence, this study justified the same, where DHEU was used for the purpose of easy care finishing and improvement in fastness rating with softeners.

Contrary to above mentioned results, two of silicone softening agents i.e. Siligen FFSI and Siligen SIH Nano, constituted on amino functional polysiloxane and modified polysiloxane, had decreased in wash fastness level. They could not resist the staining and resulted fair performance due to the transfer of colour on the adjacent cloth. It was probably due to thermo migration of the dye that dissolved in silicon emulsion at high temperature and to the substrate. An acceptable standard of grading with wet rubbing is relatively bad performance and should be undertaken for future exploration.

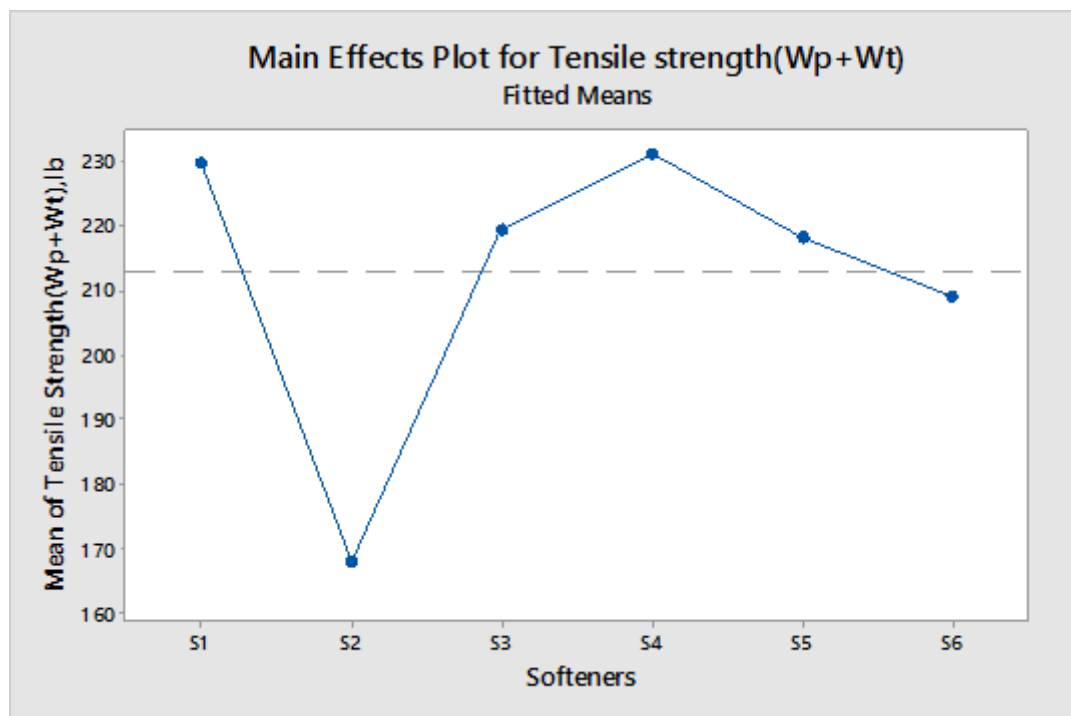
The current study reveals that a micro emulsion concentrate of polydimethyl siloxane (S4) induced a slight change in colour fastness grades of which wash fastness remained unchanged. A similar study was performed by Chattopandhay (2006) on dyed cotton fabric samples treated with both conventional and silicon nano emulsions and the results were then compared for colourfastness properties such as washing and sunlight exposure. The treatment of nano emulsion produced a slight decline in the fastness rating of the dyed samples as compared to normal emulsion silicon. Perhaps, the reason being the small particle size of softening emulsion, bearing good bonding with dyed substrate. The results in respect to dry and wet rubbing fastness were found to be satisfactory, as compared to the fastness level of reference fabric.

3.3.2 Effect of different softeners on the tensile strength of fabrics

The effect of softeners in one-step dyeing process with Helizarin Pigment Orange, and a cross linker on P/C fabrics was investigated for tensile strength and the results displayed in Table 3.31. The effect of softeners on the mean tensile strength of treated fabrics is exhibited in Figure 3.46. According to the plotted data in of the main effects plot, it was found that, generally an increasing trend in the tensile strength of P/C fabrics was found with the treatment of various softeners except, one of the softening chemical which caused a reduction in strength.

Table 3.31 Effect of different softeners on tensile strength properties

Sample No.	Factors	Responses		
	Type of Softeners	Tensile Strength, Wp, lb	Tensile Strength, Wt, lb	Tensile Strength, lb (Wp+Wt)
1	S1	157.52	72.44	229.96
2	S2	138.01	30.01	168.02
3	S3	137.05	82.5	187.09
4	S4	138.01	93.2	220.51
5	S5	168.4	50.04	261.6
6	S6	144.0	65.1	209.1

**Figure 3.46:** Main effects plot for tensile strength

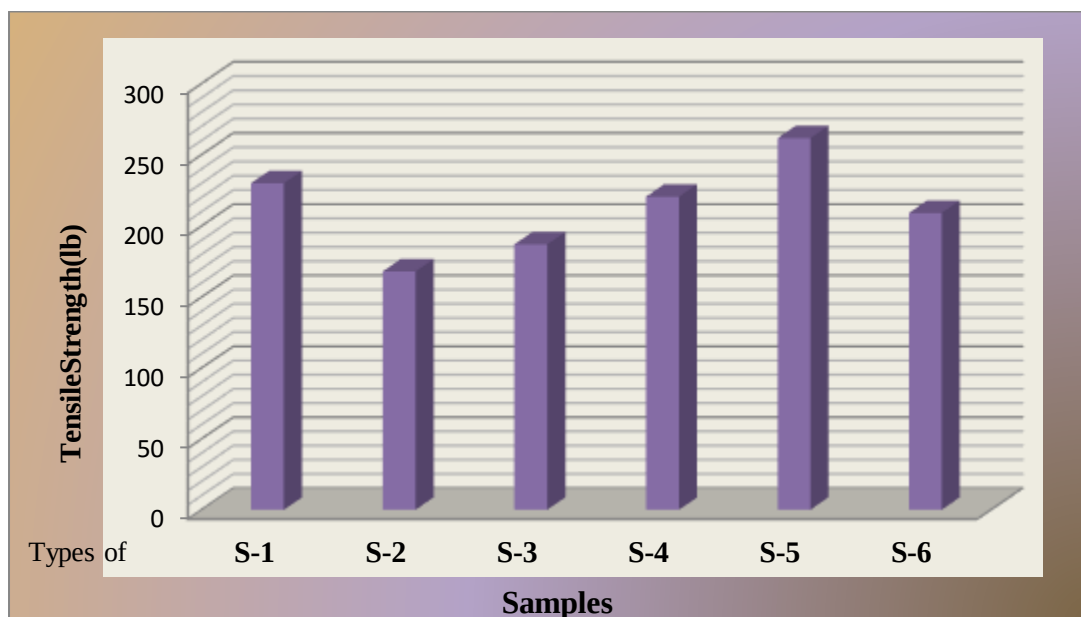


Figure 3.47: Effect of different softeners on the tensile strength of pigment dyed P/C fabrics

The plotted data (Figure 3.47) of individual results of the tensile strength (warp and weft direction) of treated fabrics showed that the highest strength was induced by Sapamine SFC softener (S5). The P/C fabrics treated with Siligen Softener FFSI (S1) and a crosslinkable silicon elastomer (S4) were also found to be reinforced by these softeners. The upper limit of tensile strength was attained by S3 a fatty acid amide condensation product that can be clearly depicted by Figure 3.47. The Siligen softener Nano (S2) and a micro emulsion concentrate of quaternary ammonium polydimethyl siloxane (S3) tended to reduce the tensile strength of P/C fabric as compared to other reagents.

In the present study the maximum increase in tensile strength was attained by the fabrics treated with S1, S3 and S4, composed of amino functional polysiloxane microemulsions and macroemulsions polydimethyl siloxane respectively. In all cases, the strength was enhanced with increased extension percentage at the ultimate breaking load. In an another study conducted by Chattopandhay & Vyas (2010) the physical properties of cotton fabric have been compared with respect to conventional and nano emulsion softening chemicals. The various types of dyes applied on substrate were direct, azoic and reactive instead of pigment colourant, however, the nature of softeners and application techniques was the same like in this study. The reason for the high tensile strength of S3, the microemulsion

polydimethyl siloxane might be the reduction in friction among the fibers of yarn and within the yarn used in fabric, which further resulted in more slippage of these units and increased the rate of extension. The reduction in breaking load with increased extension induced by silicon softeners on cotton fabric was investigated by Cheng et al., (2009). According to their findings, the nano emulsion softeners due to its excellent penetration in the core of the textiles and higher cover factor had emphasized their effect on physical stability. However, in present investigation the effect of modified polysiloxane, a nano emulsion softener, showed adverse response with respect to fabric strength. The yield point was shifted towards lower level in both warp and weft directions of fabric regarding breaking load and the extension percentage. It seemed that the combination of DHEU with incorporating softeners in the pigment formulation was found to be incompatible for tensile strength retention and weakened the fabric due to its non-ionic nature. The results concur with Wahle and Falkowski (2002) according to which the non-ionic softeners exhibited no remarkable substantivity. In the weft direction also, the increasing trend in strength was dominant as the maximum strength in P/C fabric was enhanced by the treatment of S-3 with 73.91% remarkable increase as compared to the control fabric. One of the fabric indicated lowered tensile strength induced by Ultratex MHT softening chemical, bearing 4.34% loss in strength, a negligible difference with untreated fabric.

Generally speaking, from the above results it can be deduced that the amalgamation of acrylate copolymer binder with pigment colourant, the crosslinker (modified dihydroxy diethyleneurea) and the earlier mentioned varied softeners in the dye bath formulation represented a compatibility with each other. Thus crosslinking capability of dihydroxy ethyleneurea with cellulose resulted in a handsome improvement in durability, especially in the tensile strength of P/C fabrics. Though the strength had been lowered by the treatment of various softeners in weft direction but the percent change was negligible.

3.3.3 Effect of softeners on the tear strength of fabrics

The results with respect to the effect of softeners on the tear strength of resin bonded/pigment dyed P/C fabrics are given in Table 3.32.

The main effects plot for tear strength results of fabrics is given in Figure 3.48. It is obviously illustrated from figure that, in general, the strength was improved tremendously at first by the application of softeners and then decreased with one of the softener. The individual performance of treated fabrics is evident in graphical representation (Figure 3.49). According to the results the

crosslinkable silicon elastomer (S3) reinforced the tearing capacity of pigment dyed P/C fabric significantly, by inducing a high strength value as compared to other fabrics. The Siligen FF-SI (S1) and Siligen MHT (S1) softeners presented more or less the same results in average.

Table 3.32 Effect of different softeners on tear strength properties

Sample no.	Factors	Responses		
	Type of Softeners	Tensile Strength, Wp, lb	Tear Strength, Wt, lb	Tear Strength, lb(Wp+Wt)
1	S1	1000	1840	2840
2	S2	1000	1960	2960
3	S3	1400	2400	3800
4	S4	880	1320	3290
5	S5	960	1680	2200
6	S6	920	2330	2600

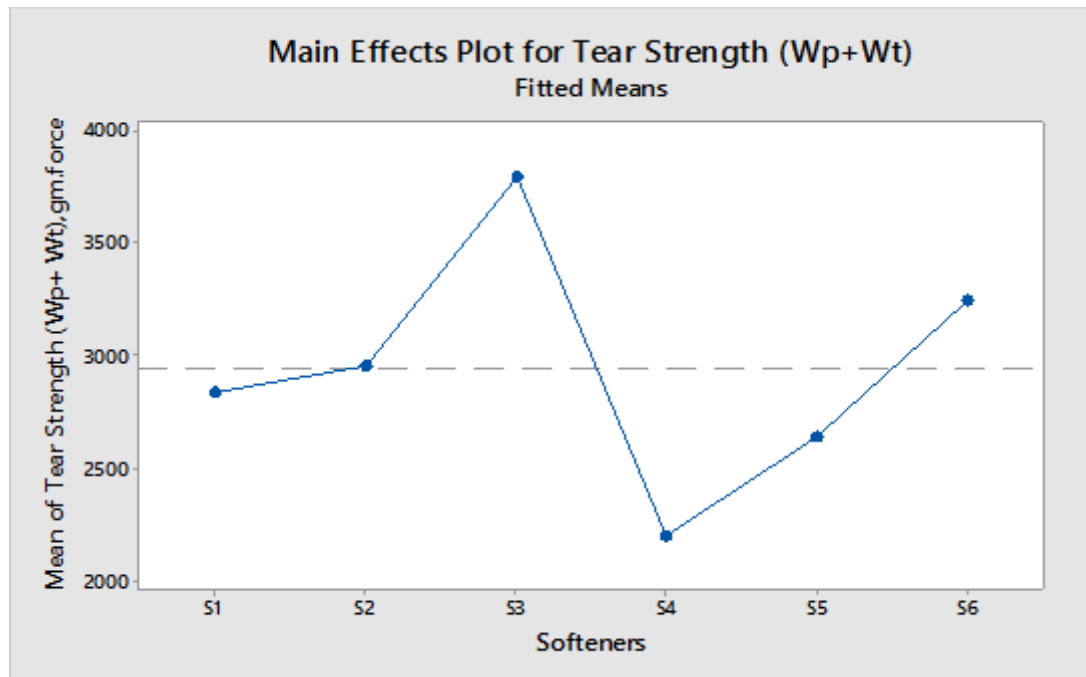


Figure 3.48: Main effects plot for tear strength

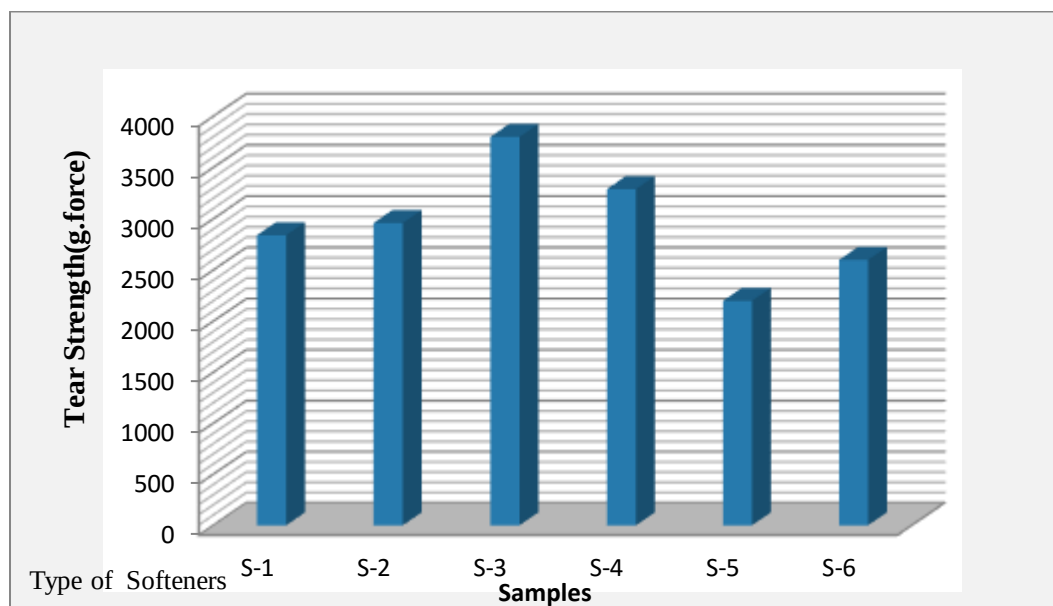


Figure 3.49: Effect of different softeners on the tear strength of pigment dyed P/C fabrics

The results obtained for the tear strength property of P/C fabric with incorporated softeners were analyzed and expressed in Table 3.30. In this study the cross linker DHEU with almost all the softening chemicals appeared to be the best alliance with pigment colouration of P/C fabrics particularly in weft direction. The findings concur with an investigation conducted by Li Shiqi, (2007), who mentioned that, harsh handle and strength loss can be avoided or minimized by the application of hydrocarbon and silicon softeners with durable press finishing formulation.

In the current study, Ultratex UM new, a crosslinkable silicon elastomer and parapret F-PEB new, a polyethylene dispersion remarkably enhanced the tear strength of P/C fabric. The resin treated P/C fabrics with modified dihydroxyethyleneurea and conventional pigment dyeing formulation reduced in tear strength. The tear strength of dyed/crosslinked P/C fabrics was being reduced with resin treatment but the inclusion of softeners in the same formulation imparted significant improvement in the strength. In this study the co-application of micro emulsion concentrate of polydimethyl siloxane and polyethylene dispersion was approached towards higher tear strength retention of treated fabrics. The results are at par with the investigations carried out by Hussain et al., (2010) on cotton fabric using modified n-methylol dihydroxyethyleneurea reactant and polyethylene softeners in the presence of magnesium

chloride. The tear strength declined as a result of cross linking being recovered with polyethylene softeners due to increased lubricity and hence improved chain slippage.

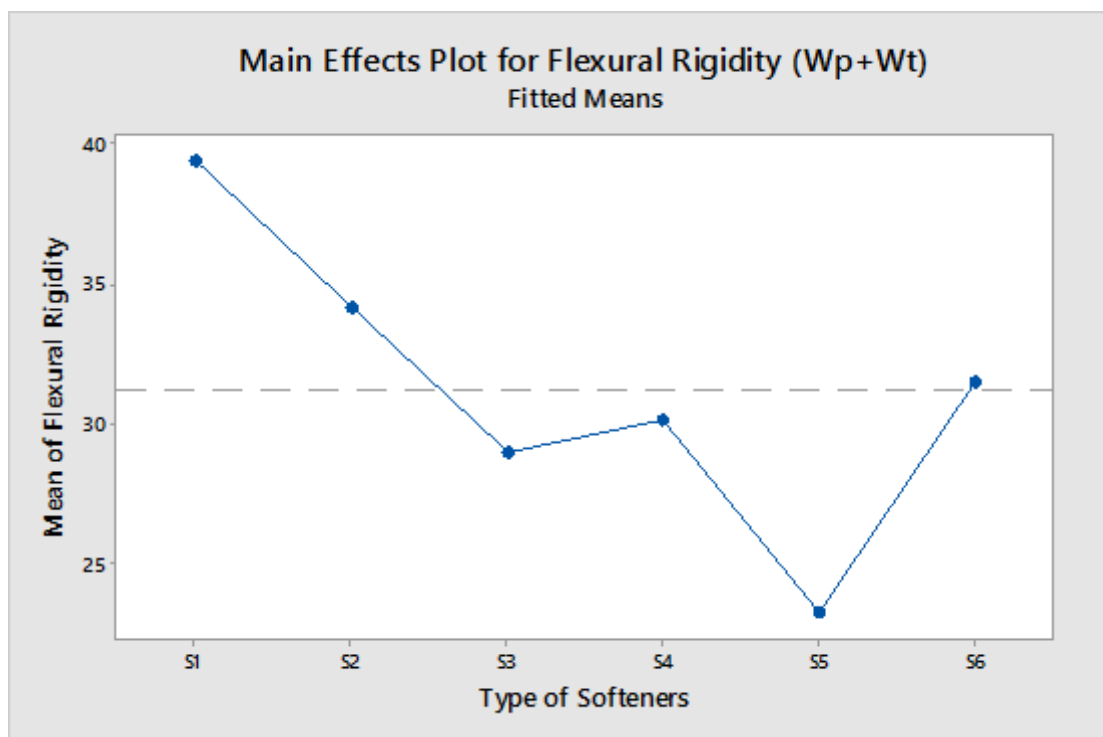
Among all the additives applied as softeners, the second highest tear strength retention was attained by the fabric, treated with Ultratex MHT conc. softener. The excellent tearing resistance of this specimen can be related to its small particle size and emulsifying mechanism. Nostadt and Zyschka (1997) focused on the advantages of silicon micro emulsions by stating that the low particle size of microemulsions $<0.01\ \mu$ and semi macroemulsions $<0.1\ \mu$ allow the softeners to penetrate into the fibre core thus facilitating the excellent product distribution. Their deep penetrating quality gives textiles excellent softness stability along with improved technological properties. Furthermore its remarkable performance is based on its chemical constitution. The micro emulsion concentrate of polydimethyl siloxane is generally quaternized to cationic species (NH^+_3) which have strong affinity for negatively charged fabric, particularly cotton based fabrics which carry anionic charges on their surface. This way the improved deposition, good performance and durability of softeners' coating is delivered to fabric (Chattopandhay & Vyas, 2006). The present findings are supported by the similar mechanism because the percentage of cotton in P/C blended fabric was higher than polyester content, hence anionically charged fabric surface attracted by the quaternary PDMS and resulted in high tear strength. The acrylic binder, DHEU and softeners treatment was interlinked with the surface of fabric to provide initial softness and then increase its resistance against tearing forces (Li Shiqi, 2007).

3.3.4 Effect of softeners on the flexural rigidity of fabrics

The flexural rigidity of the concurrently dyed, cross linked and softeners' treated P/C fabrics was assessed and presented in Table 3.33. The treated fabrics presented a slight modification in the flexural rigidity of all the fabrics, though the rate of change appears to be reduced or enhanced sometimes. Figure 3.50 illustrates the main effects plot for the results of flexural rigidity after treatments on fabrics. The Figure shows an overall decreasing trend in the stiffness of fabrics with different softeners of which S3 softeners build up a good resisting behavior against the flexural rigidity of fabrics.

Table 3.33 Effect of different softeners on the flexural rigidity

Sample no.	Factors	Responses		
	Type of Softeners	Flex. Rig Warp, μ Joule/M	Flex. Rig Weft, μ Joule/M	Flex. Rig (Wp+Wt) μ Joule/M
1	S1	21.87	17.53	39.4
2	S2	22.25	11.89	34.14
3	S3	21.25	7.72	28.24
4	S4	22.5	7.61	30.97
5	S5	17.25	5.99	23.11
6	S6	23.12	8.39	31.51

**Figure 3.50:** Main effects plot for flexural rigidity

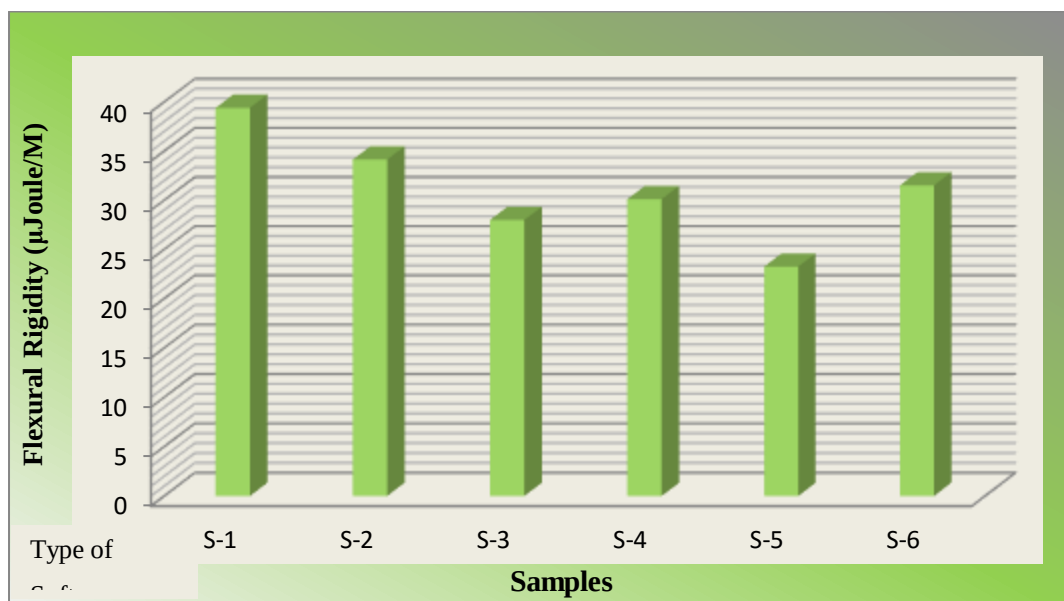


Figure 3.51: Effect of different softeners on the flexural rigidity of pigment dyed P/C fabrics

Figure 3.51 shows the individual performance with respect to flexural rigidity. It is self apparent that amongst all the assorted softeners, the Ultratex MHT silicon concentrate of a quaternary polydimethyl siloxane, (S3) resulted in the decreased stiffness of pigment dyed P/C fabrics as compared to the other fabrics. Figure 3.51 indicates the reduction in flexural rigidity of fabrics by various softening chemicals corresponding to Sapamine SFC (S5), Ultratex UM new silicone softener (S4) and polyethylene dispersion (S6) in the decreasing order of flexural rigidity respectively. Though it was expected, that the softener treatment influenced the flexural rigidity positively, giving a softer to all of pigment dyed fabrics the observation turned to be reversed with one fabric. In this case the application of Siligen FFSI (S1) contributed a stiffer handle to the P/C fabric with the increase in flexural rigidity.

One of the index of excellent softness, is the reduced flexural rigidity level of fabrics. In this study the flexural rigidity of the concurrently dyed, cross linked and softener treated P/C fabrics was assessed and presented earlier in Table 3.33. The treated fabrics presented a slight modification in the flexural rigidity of all the fabrics, though the rate of change sometimes appeared to be reduced or enhanced. A few of the softeners increased the flexural rigidity of fabrics, though the change was not so obvious. It is self apparent that amongst all the assorted softeners, S-5, a fatty acid amide condensation product resulted in the decreased

stiffness of pigment dyed P/C fabric. Here the effect of softening chemical was found to be constructive in the sense that it produced effectively a softer handle in the fabric by reducing the stiffness levels to almost 45.19 percent as compared to the reference fabric.

The next higher value was attained by Ultratex UM New and Polyethylene dispersion in the decreasing order of flexural rigidity respectively. A few results of the study conducted by Chattopandhay, (2010) on the effect of softeners on physical properties of cotton fabric, supported the present findings. According to the results the silicon emulsion acted as a lubricating agent within the fibres of the yarn, and the yarns of fabric, hence inducing a soft and supple texture to the fabric. Since the bending length and rigidity are interdependent properties therefore, drop in bending length is the sign of reduced rigidity or enhanced softness of the textile product.

Though, it was expected that all the softeners would reduce the high stiffness levels of P/C fabrics that were actually exposed to the application of crosslinker and the acrylic binder in the previous formulations, however, few results in warp direction of the fabric did not meet the expectations. Fabrics treated with Siligen FFSI (amino functional polysiloxane) Ultratex MHT concentrate (micro emulsion concentrate of quarternary polydimethyle siloxane and Ultratex UM New (macro emulsion), exhibited only a slight increase in stiffness values. The results are comparable with the investigation of Beal et al., (1990) in which 100% polyester fabrics were treated with various softeners. It was found that durable press finishing with DMDHEU and acrylic finish, even with the high ratio of softeners could not decrease the stiffness of level of fabrics. The softening chemical Ultratex MHT concentrate had shown no change in flexural rigidity of treated fabrics.

3.3.5 Effect of softeners on the abrasion resistance of pigment dyed P/C fabrics

In one phase pigment dyeing and crosslinking, an additional treatment with softeners was given to P/C fabrics followed by analysis of abrasion resistance. The treated fabrics were subjected to abrasive experiment according to the recommended procedure and the change in abrasion behavior is presented in Table 3.34.

Table 3.34 Effect of different softeners on the abrasion resistance and pilling grades

Sample No.	Factors	Responses	
	Type of Softeners	Abrasion Res. (no. of cycles)	Pilling Grades
1	S1	70,000	4
2	S2	27,900	4
3	S3	48,800	4.5
4	S4	66,600	3
5	S5	27,750	3
6	S6	22,350	4

The main effects plot for the results is given in Figure 3.52. The plot showed a remarkable increasing trend in abrasion resistance of fabrics with S1 and S4, while some other types caused a reduction in abrasion resistance.

Figure 3.53 presents the effect of individual performance of P/C fabrics, treated with softeners according to which Siligen FFSI softener imparted a handsome increase in abrasion resistance. The P/C fabric treated with Sapamine SFC, a fatty acid amide condensation took the brunt of abrasive action adversely and reduced the abrasion resistance.

The photographs of abraded specimens determined by the breakage of yarns after a specific rubbing action are shown in Exhibit (Appendix F). The numbers of cycles, the criteria for the assessment of abrasion resistance, were ranged from 22,350 to 70,000 number of cycles of which the maximum value corresponded to the fabric treated with siligen softener FFSI, based on aminofunctional polysiloxane. A slight discolouration can be observed with Ultratex UM new.

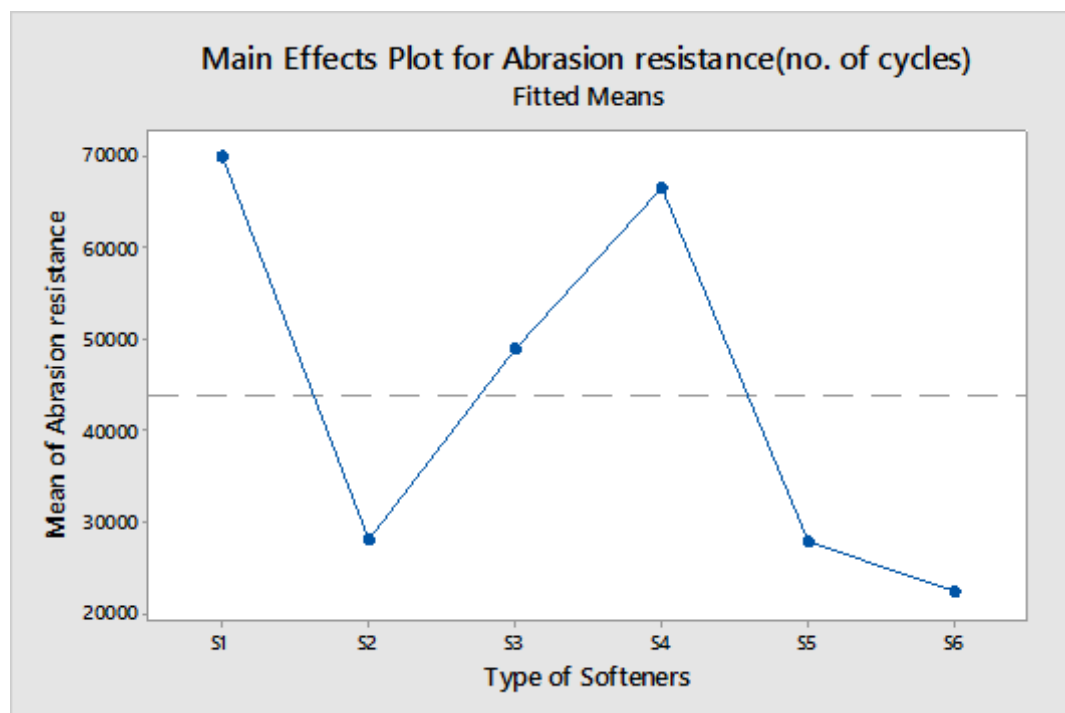


Figure 3.52: Main effects plot for abrasion resistance

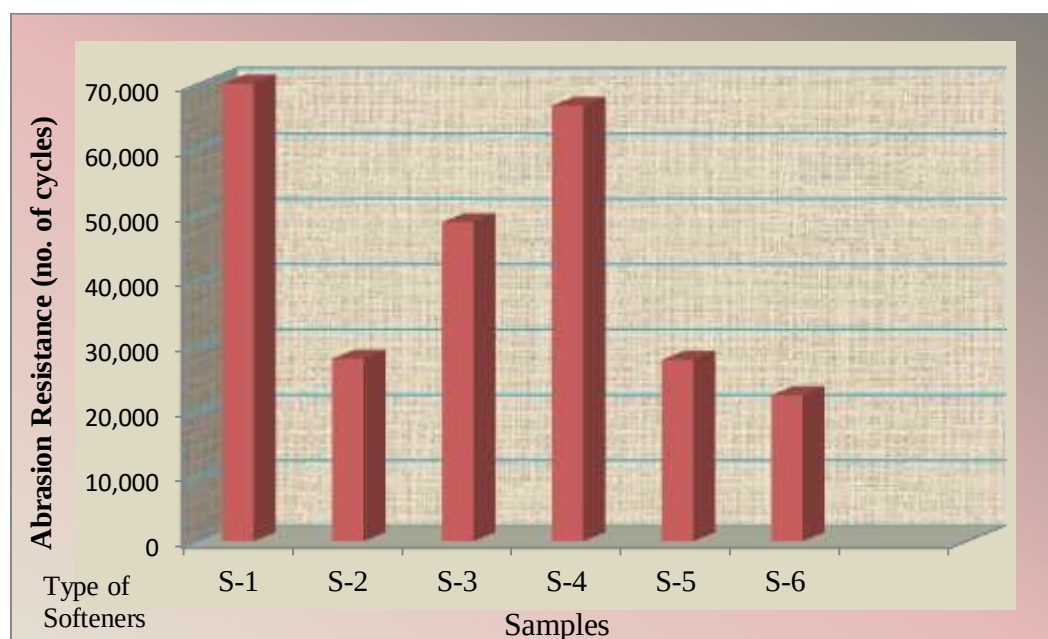


Figure 3.53 Effect of different softeners on the abrasion resistance of pigment dyed P/C fabrics

Abrasion is a vital index to determine the performance of a fabric and was observed by visual examination in which the number of cycles were determined for the first yarn breakage. In one phase pigment dyeing and cross linking, an additional treatment with softeners was given to P/C fabrics followed by analysis of abrasion resistance. As mentioned earlier that most of the crosslinked fabrics responded unfavorably to the abrasion test, but, with the application of softeners the trend was found to be reverted as few of the fabrics revealed high percentage increase in abrasion cycles.

In this study majority of the fabrics attained excellent abrasion resistance in combined dyeing and softener treatment. Two of the softening chemicals i.e. siligen softener 1, an amino functional polysiloxane and S4, macroemulsion concentrate of polydimethyl siloxane, induced almost a cent per cent increase in number of cycles. The results were in close agreement with the conclusions drawn by (Lickfield et al., 2000) who had emphasized the importance of softeners in relation to their deposition and orientation on the crosslinked fabric surface. The treatment of cotton with DMDHEU crosslinking agents block the surface of the cellulosic fibre to restrict crosslinking at the fabric surface, making it mechanically stable.

The use of softener in our study served to improve the abrasion performance of P/C fabric just like afore mentioned mechanism. The reason might be, the rigid cross links formed by DHEU had reacted with softener to prevent the movement within the fibre microstructure which in turn resisted the brunt of abrasive action on fabric surface, leading to excellent abrasion performance by fabric. Another possible reason for outstanding wear resistance of simultaneously crosslinked and softener treated fabric might be related to the reduction in the friction within fibers so that initial fuzz could be controlled. According to Schindler & Hausar (2004) there are certain lubricants which can reduce friction to minimize abrasion damage. In current study the silicon softener were applied with a cross linker in pigment stock formulation in a conventional way on P/C fabrics which had lessened the abrasion damage.

The Siligen Softener FF SI is nano-silicon softener which caused a tremendous increase in abrasion cycles to break down the yarn. Contrary to these results, a decrease in abrasion resistance occurred when the fabrics were treated with nano-silicone softeners in a study conducted by Celik et al., (2010). The mass loss ratio of samples treated with nano-silicone softeners was higher than the mass loss ratio of the fabric without this treatment. It was probably due to the increase in fibre mobility caused by nano silicone softeners. On the

other hand for 100% cotton woven fabric, silicone softeners induce better wrinkle recovery, tear strength, and abrasion resistance than the cationic softener. The nano-silicon softener restricted the possibility of pulling the loose fibers from the fabric matrix to cause abrasion damage.

The same formulations with some remaining softeners rendered adverse effect on the abrasion property of P/C fabrics. The fabrics treated with S2 (modified polysiloxane) wore off at an early stage of testing as compared to the control fabric. Again the findings are consistent with the Celik et al., (2010), according to him the reason for the low abrasion resistance of silicon treated fabric might be the possibility of increased fibre mobility due to the deep penetration of nano emulsifier inside the fabric structure. In this way the fibers quickly released from the surface of substrate, took the force of abrasive action adversely and abraded the substrate at less number of cycles.

3.3.6 Effect of softeners on pilling resistance

The effect of softeners on the pilling grades of treated P/C fabrics is displayed in Table 3.34. The main effects plot for the results of pilling resistance of softener treated fabrics is given in Figure 3.54, which shows that trend remained constant with fifty percent of the softening chemicals, while others showed (S4, S5) an increased pilling tendency of fabrics. One of the softener induced excellent pilling resistance in P/C fabrics, treated with S3.

The treated P/C fabrics assessed for their pilling performance regarding softeners' effect and were graded accordingly. Figure 3.55 shows that siligen softener FFSl, an amino functional polysiloxane exhibited a moderate performance on P/C fabrics and thus rated at 3rd grade. The application of ultratex UM New silicon concentrate (S4) upgraded with a slight difference in pilling value. The grade remained constant with S3 (Ultratex MHT concentrate) when compared with photographic pilling standards, however in this case another change was occurred i.e., a fuzzy appearance develop on the fabric. The findings indicate that tendency of pilling was found to be increased with the application of softeners. The other softeners responded differently i.e. partially formed pills were being observed on the P/C fabrics treated with S2, S5 and S6 indicating no change in the pilling performance, graded as standard 4.

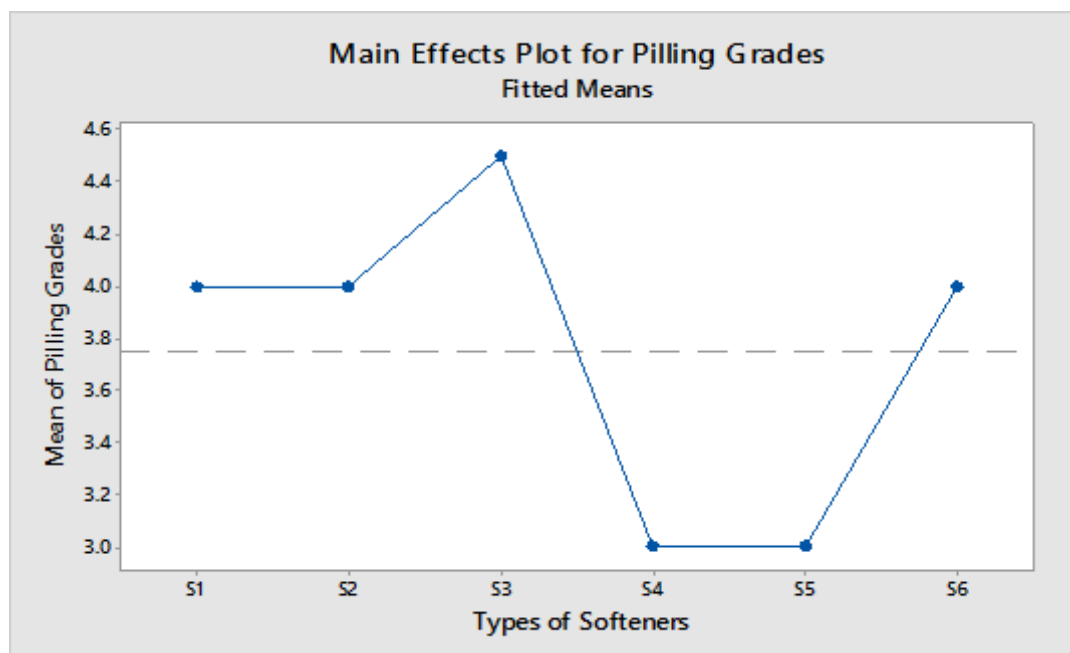


Figure 3.54 Main effects plot for pilling grades

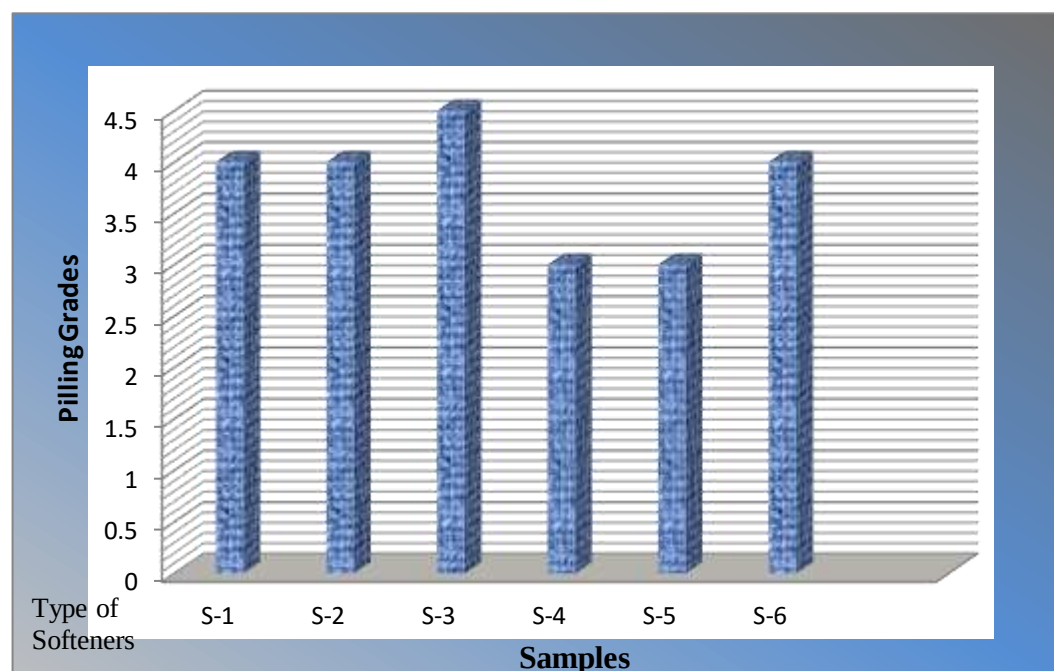


Figure 3.55: Effect of different softeners on the pilling performance of pigment dyed P/C fabrics

The pilling tests of dyed/crosslinked P/C fabrics in different combinations of softeners have been displayed earlier in table 3.34. In the current investigation the overall results revealed that the application of softeners generally produced no change in pilling behavior with the exception of Ultratex UM New silicon softener and sapamine SFC softener. These two softeners reduced the pilling grades from 4 to 3, converting partially formed pills into moderate pilling.

The treatment of Ultratex MHT, a micro emulsion concentrate of polydimethyl siloxane along with conventional pigment dyeing system tended to improve pilling performance of fabric. It was probably due to the well penetrated softening chemicals in the interior of substrate which did not allow entanglement of loose fibres and thus developed resistance against pilling mechanism. It was further recommended that combined treatment of softeners and polymeric coatings can be applied on fabric to develop soft hand and prevention from pilling (Schindler & Hausar, 2004).

The fabrics treated with Ultratex UM, macroemulsion of polydimethyl siloxane and Sapamine SFC, a fatty acid amide condensation product were found to be adversely effected regarding pilling performance. The degradation of pilling from 4-3 in these fabrics could be attributed to the ability of these softeners to decrease surface friction. The coating of macro emulsion of polydimethyl siloxane attached the amino- functional groups on the surface of the fabric for better orientation and lubrication. This resulted in reduced friction in fibers which came out of the main body of the fabric and converted into pills. Hussain et al., (2008) assessed in a study that, non-ionic organo-modified, silicon micro emulsion and amino functional polysiloxane softeners resulted remarkable decrease in the pilling resistance of the cotton/viscose fabrics. The reason behind was, that softeners had reduced the fibre-to-fibre friction by internal lubrication. In the same investigation fatty acid amide softening reagent did not induce a significant decline in pilling performance.

3.4 EFFECT OF DIFFERENT FUNCTIONAL FINISHES, ON THE PROPERTIES OF PIGMENT DYED P/C FABRICS

In this set the P/C fabrics were pad dyed with two dips two nips technique, with an optimized acrylate copolymer binder and Helizarin Pigment Orange at a fixed pigment/binder concentration i.e. 50:200g/L. The process was further preceded by the application of various finishing reagents in different concentrations according to a specific recommended range. The

application of post finishing pigment dyeing, and simultaneous pigment dyeing and finishing technique of fabrics was followed by the determination of various properties.

3.4.1 Effect of different functional finishes on the colourfastness properties

The summary of the colourfastness properties of the post and meta finished P/C fabrics is given in Table 3.35

3.4.1.1 Effect of different functional finishes on the dry rubbing fastness

The analysis of variance (ANOVA) for results of dry rubbing fastness of finished fabrics is given in Table 3.36, which shows that the effect of application methods of finishes on the dry rubbing grades of treated fabric was found to be statistically non significant. As far as the finish types and their concentrations are concerned, yet again the effect was not found statistically significant on the dry rubbing fastness of treated fabrics.

The main effects plot for dry rubbing fastness is given in Figure 3.56 which represents an increasing trend in dry rubbing fastness of meta finished, dyed P/C fabrics. As far as the type of functional finishes is concerned, an increasing and decreasing trend in fastness rating was observed. Overall, the rubbing fastness of Pekoflam OP liquid flame retardant (F2) and a hand building finish (F8) produced the highest rubbing grades. The effect of concentration of finishes showed a highly significant effect on the dry rubbing fastness of treated fabrics. At high concentration generally, the fastness was found to be up graded as compared to low concentration.

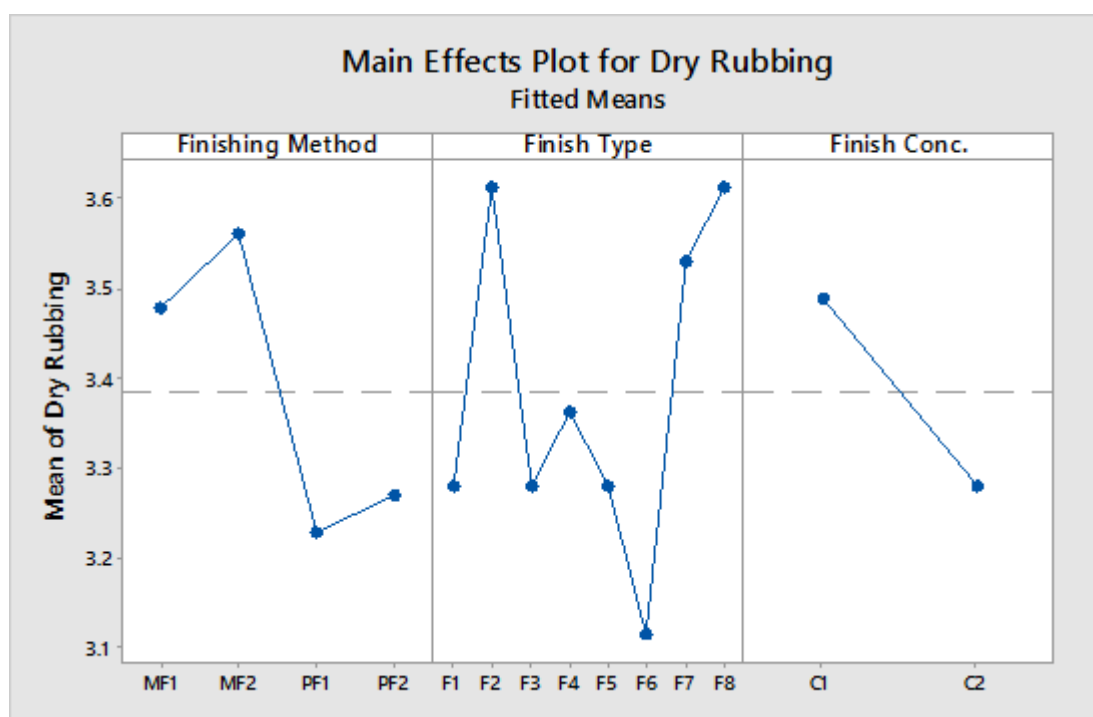
Table 3.35 Effect of different functional finishes (types, concentrations and application methods) on the colourfastness properties

Sample	Factors			Responses			
	Application Technique	Type of Finish	Finish Conc. g/L	Dry Rubbing Fastness	Wet Rubbing Fastness	Washing Fastness SC	Washing Fastness ST
1	Post Finish. Method	F1	500	3.5	2.0	4.0	4.0
2			300	3.0	2.0	4.0	4.0
3		F2	300	4.0	2.0	4.0	4.0
4			200	3.5	2.0	3.5	4.0
5		F3	50	3.0	2.5	4.0	4.5
6			20	3.0	2.5	4.5	4.0
7		F4	50	3.5	2.5	3.5	4.5
8			30	3.0	2.5	4.0	4.5
9		F5	50	3.0	3.0	4.0	4.0
10			30	3.0	2.5	4.5	4.5
11		F6	50	3.5	2.0	3.5	4.5
12			15	2.0	3.0	3.5	4.5
13		F7	40	3.5	2.5	4.0	4.5
14			20	3.5	3.0	4.0	4.0
15		F8	40	3.5	2.0	4.0	4.0
16			20	3.5	2.0	4.0	4.0
17	Meta Finish Method	F1	500	3.0	2.5	4.0	4.0
18			300	3.5	2.5	4.0	4.0
19		F2	300	3.5	2.5	4.0	4.0
20			200	3.5	2.0	4.0	4.0
21		F3	50	3.5	2.0	4.5	4.5
22			20	3.5	2.5	4.0	4.0
23		F4	50	3.5	2.0	3.5	4.0
24			30	3.5	2.0	3.5	4.5
25		F5	50	3.5	2.5	4.0	4.0
26			30	3.5	3.5	3.5	4.0
27		F6	50	3.5	2.0	3.5	4.5
28			15	3.5	2.0	3.5	4.5
29		F7	40	3.5	2.5	4.0	4.0
30			20	3.5	2.0	4.0	4.5
31		F8	40	4.0	2.0	4.0	4.0
32			20	3.5	2.5	4.0	4.5

Table 3.36 Analysis of variance for dry rubbing fastness of dyed & finished P/C fabrics

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	11	1.7917	0.1629	1.48	0.217
Finishing method	3	0.5104	0.1701	1.54	0.235
Finish type	7	0.8917	0.1274	1.15	0.371
Finish conc.	1	0.2604	0.2604	2.36	0.140
Error	20	2.2083	0.1104		
Total	31	4.0000	0.8312		

*Statistically significant at P value 0.05

**Figure 3.56:** Main effects plot for dry rubbing fastness of finished P/C fabric

MF. Meta finishing pigment dyeing

PF. Post finishing pigment dyeing

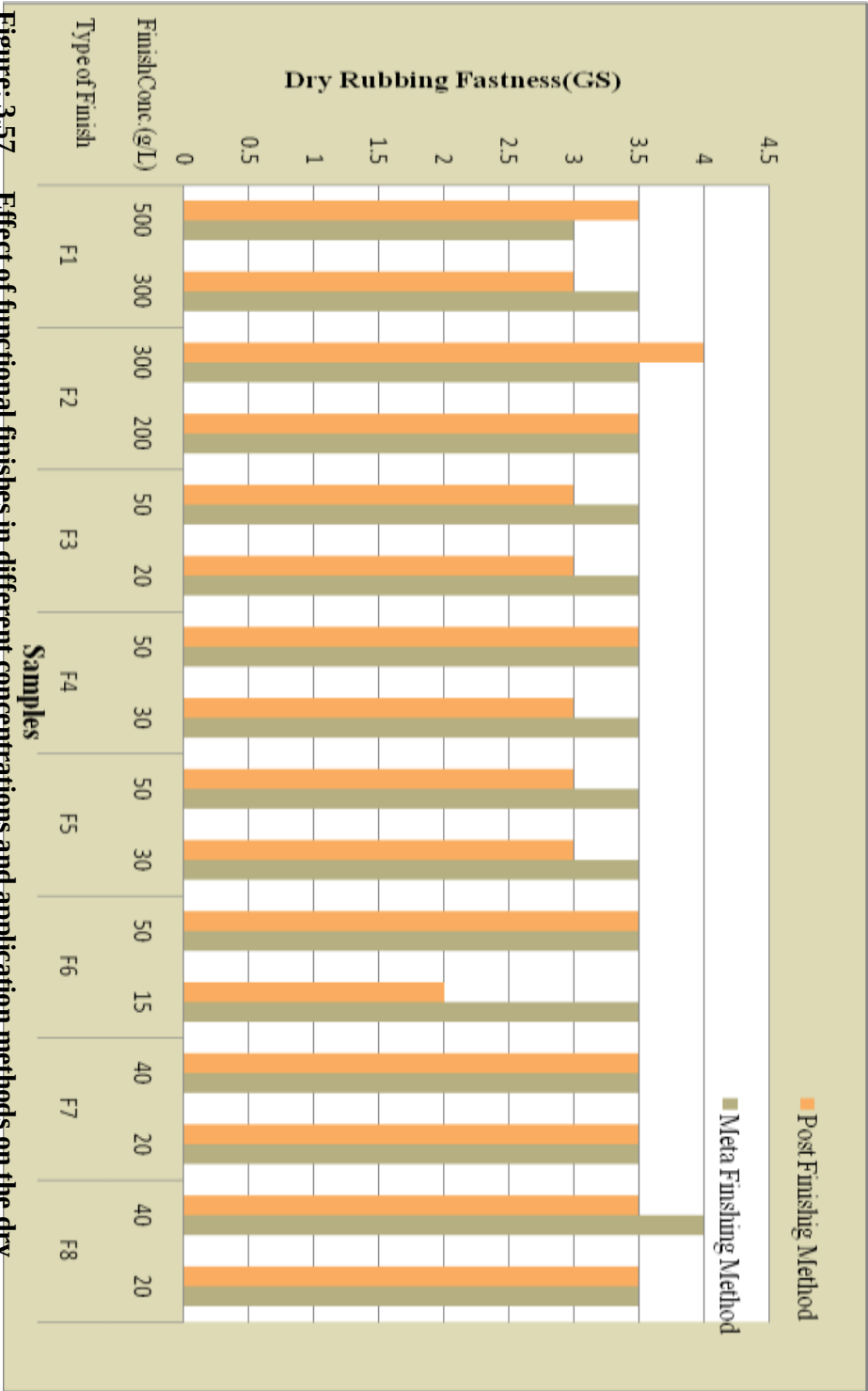


Figure: 3.57 Effect of functional finishes in different concentrations and application methods on the dry rubbing fastness of P/C fabrics

F1. Pekoflam HSD Flame R. F2. Pekoflam OP Flame R. F3. Nuva F D Water R. F4. Nuva 3585 Oil & Water R.
F5. Nuva HPU Oil & Water R. F6. UV SUN CEL LIQ F7. Dicylan Polyurethane F8. Hand building Finish

Figure 3.57 shows dry rubbing fastness data of the individual samples, treated with different types and concentration of finishes and different methods of application. The post treatment of Pekoflam OP Liquid flame retardant finish at high concentration induced better dry rubbing fastness than low concentration. Whereas, by the same finishing reagent at lower range i.e. at 300g/L the fastness value of tested specimen was found to be 4.0 GS bearing a very good dry rubbing fastness. The overall performance of fabrics with meta finishing treatment was found to be better with an exceptional result in which the P/C fabric rendered a very good rubbing fastness at 40g/L of the hand building chemical.

3.4.1.2 Effect of different functional finishes on the wet rubbing fastness

Table 3.35 shows the results of colour fastness to wet crocking of P/C fabrics obtained through post and meta finishing pigment dyeing with various types of reagents.

The data with respect to wet rubbing fastness was statistically analyzed by (ANOVA) and the results are displayed in Table 3.37 the results indicated that the effect of different methods, types and concentrations of finishes, used for P/C fabrics was found to be statistically insignificant on wet rubbing fastness.

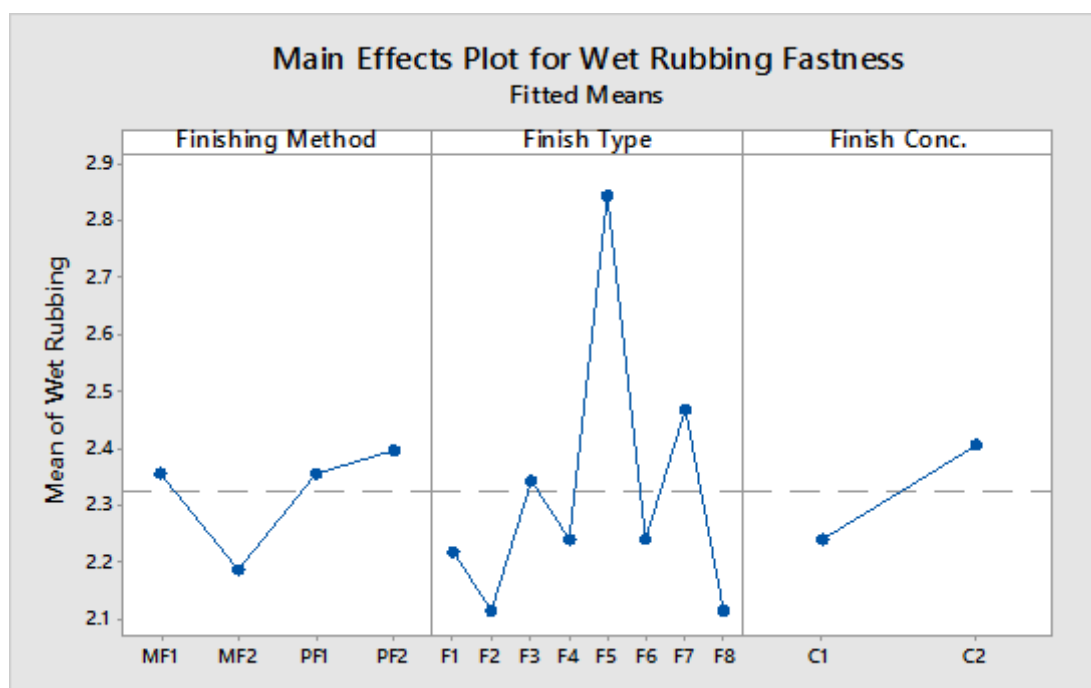
The main effects plot for wet rubbing fastness of P/C fabrics is shown in Figure 3.58, according to which the simultaneously dyed and finished P/C fabrics had better fastness grades than post finishing method at high concentration. However, at low concentration an adverse effect on rubbing fastness was observed. The wet rubbing fastness of post treated dyed fabrics was found to be slightly good as compared to the meta finished fabrics. The most favourable result with respect to wet rubbing was attained by the fabric, that was treated with NUVA HPU durable oil and water repellent liquid (F5). The effect of concentration on wet rubbing fastness was statistically significant at lower range.

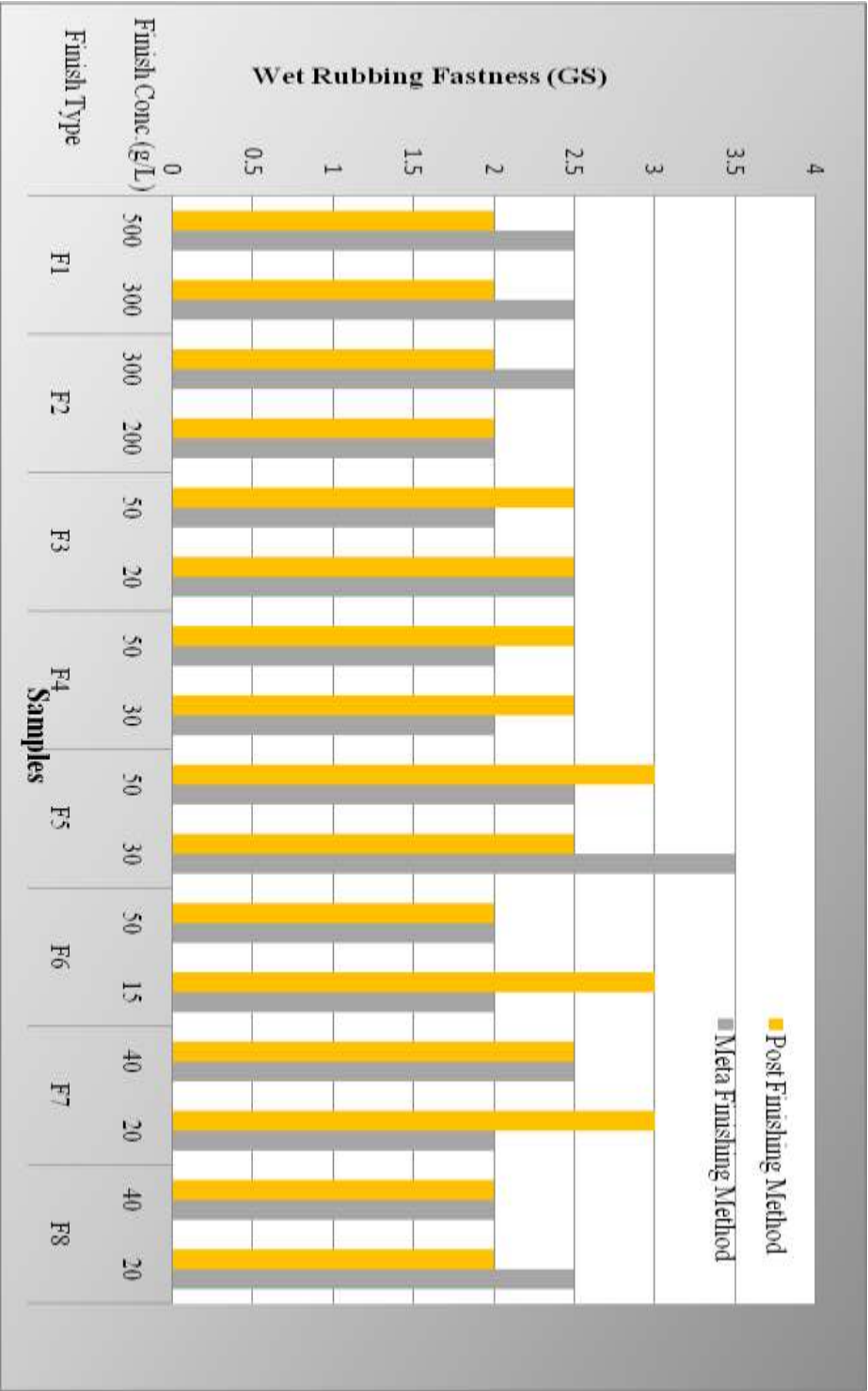
As far as the individual assessment is concerned, the wet crock fastness of P/C fabric varied from 2.5-3.5 indicating a good performance. It can be clearly depicted from Figure 3.59, that fastness of pigment dyed P/C fabrics with durable water and oil repellent reagents by meta finishing method remained at the highest fastness level. Another observation noticed in the individual performance of UV treated(F6) fabrics was, that the wet rubbing fastness upgraded from 2 to 3 G S with meta and post finishing method respectively at low concentration. Similarly, the combined application of polyurethane finish (F7) with pigment dyeing on P/C fabric was rated at the maximum fastness level. The results were better at low concentration as compared to the high concentration as shown in Figure 3.59

Table 3.37 Analysis of Variance for wet rubbing fastness of dyed/finished Fabrics

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	11	1.9479	0.17708	1.28	0.305
Finishing Method	3	0.1042	0.03472	0.25	0.860
Finish Type	7	1.1417	0.16310	1.18	0.359
Finish Conc.	1	0.1667	0.16667	1.20	0.286
Error	20	2.7708	0.13854		
Total	31	4.7188	0.68011		

*Statistically significant at P value 0.05

**Figure 3.58: Main effects plot for we rubbing fastness of finished P/C fabric****Figure 3.59: Effect of functional finishes on wet rubbing fastness of P/C fabric**



3.4.1.3 Effect of different functional finishes on the wash fastness (shade change)

Table 3.38 comprises the results, regarding the analysis of variance (ANOVA) of washing fastness results (change in colour). The data reveals that only the effect of finish type was found statistically significant, while the finishing methods and different concentrations had no effect on the shade change after washing treatment.

The main effects plot for washfastness (shade change) of finished P/C fabrics is shown in Figure 3.60. The methods of finish application differ slightly from each other with respect to their wash fastness results. The post finishing of fabrics produced better results at high concentration than meta finishing method, whereas, the remaining observations were found to be consistent with an acceptable performance of wash fastness level. As regards the effect of assorted functional finishes on colour change of treated fabrics, the minimum shade change occurred with Pekoflam OP liquid flame retardant (F2) and maximum change by Polyurethane finish. The level of wash fastness remained the same irrespective of the different concentration of finishes

The effect of functional finishing reagents with pigment colourants on the wash fastness (shade change) properties of P/C fabrics is given in Figure 3.61. The data plotted in the figure represents that wash fastness grading of P/C fabrics decreased at high concentration of finish, while at lesser concentration it was found to be increased with post treatment of F3 (NUVA FD liquid water repellent) finish. As far as the meta finishing method is concerned, the results revealed that at high concentration the shade change grading showed improvement as compared to the low finish concentration which was quite a different response from the afore mentioned findings. In case of individual performance of another durable water repellent finish (F5), the shade change after one step dyeing and finishing process was visually inspected as 4.5, equivalent to a very slight colour variation.

Table 3.38 Analysis of variance for wash fastness (SC) of dyed/finished fabrics

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	11	1.65625	0.150568	2.83	0.021
Finishing Method	3	0.06250	0.020833	0.39	0.760
Finish Type	7	0.96250	0.137500	2.59	0.045*
Finish Conc.	1	0.00000	0.000000	0.00	1.000
Error	20	1.06250	0.053125		
Total	31	2.71875			

*Statistically significant at P value 0.05

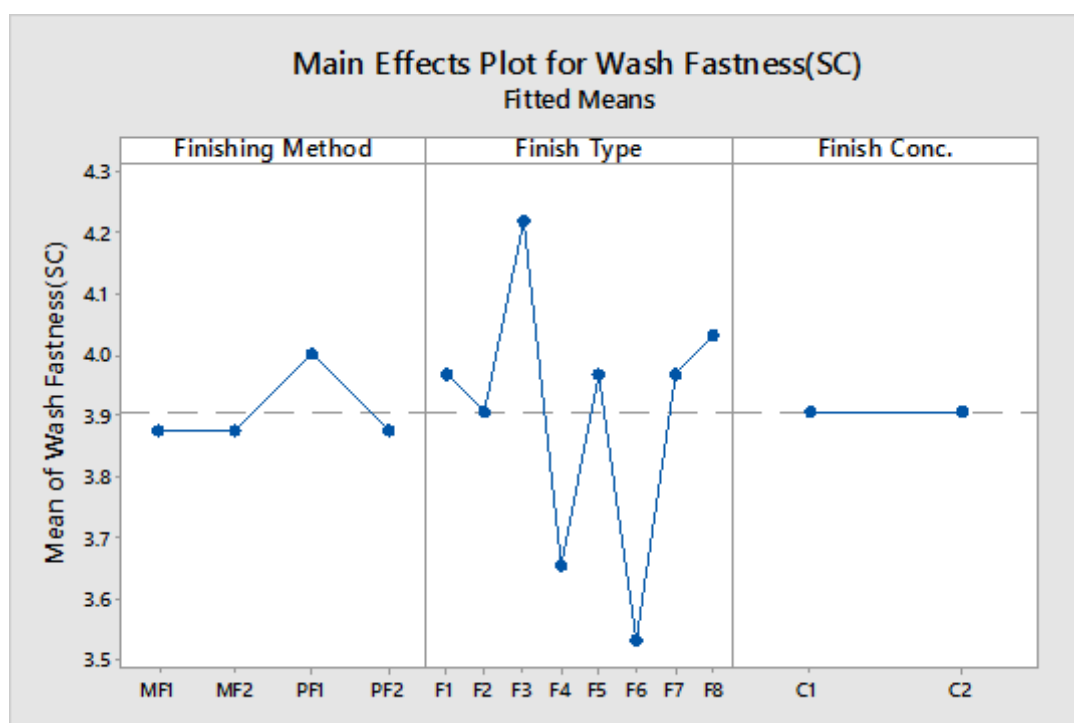


Figure 3.60: Main effects plot for washing fastness (shade change) of finished P/C fabric

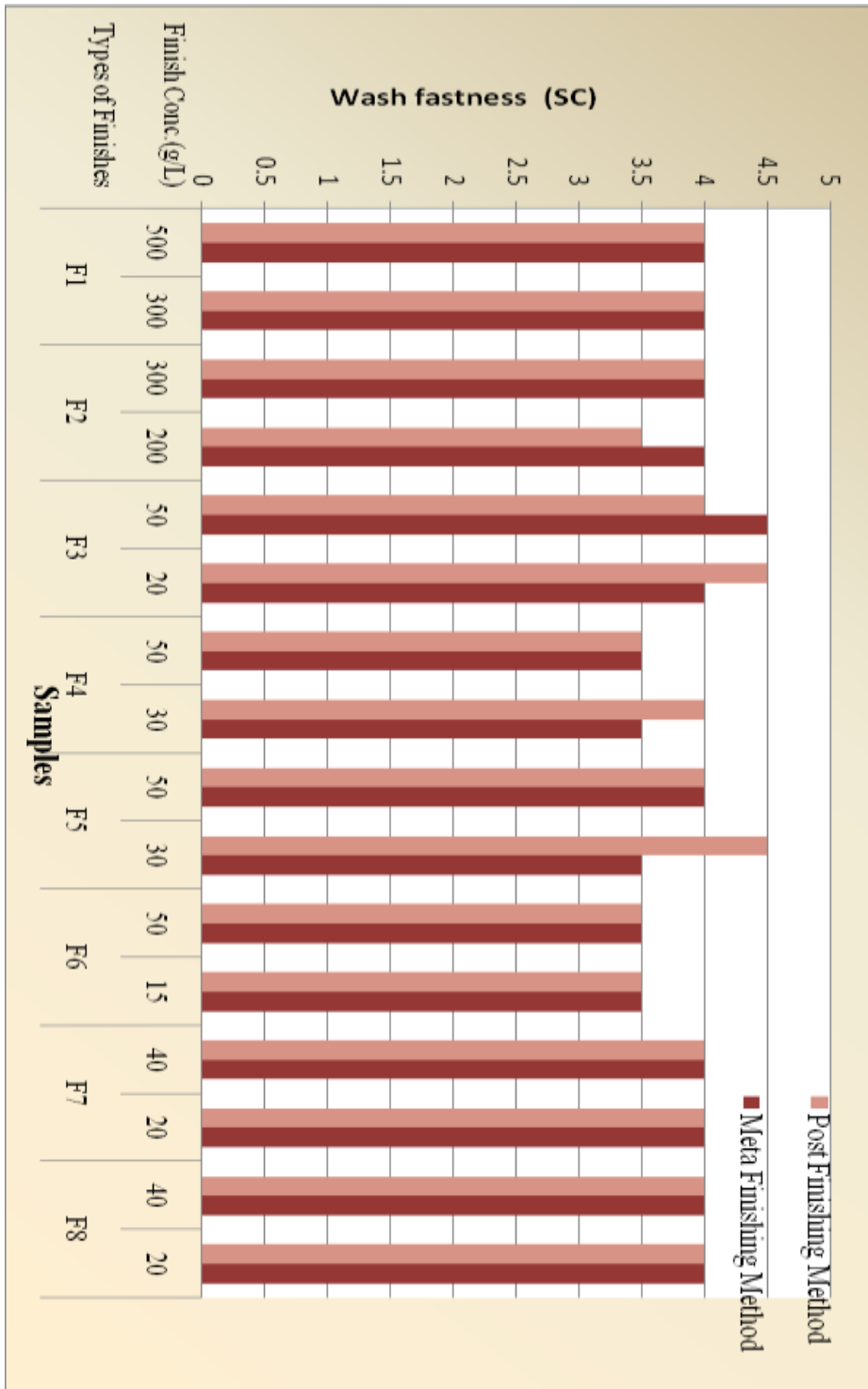


Figure 3.61: Effect of functional finishes in different concentrations and application methods on the wash fastness (shade change) of P/C fabrics

3.4.1.4 Effect of different functional finishes on the wash fastness (Staining)

The analysis of variance of the data for wash fastness (staining) to adjacent specimen is mentioned in Table 3.39. According to the computation there was statistically non significant effect on the wash fastness grading, obtained by two different techniques of finishing. However, type of finishes had an effect on wash fastness results for which there is no clear evidence of statistical significance.(P- value 0.05 equals to tabulated value). As regards the finish concentration again a non significant effect was noticed on wash fastness results, particularly the staining on adjacent fabric. The main effects plot for wash fastness (shade change) property are given in Figure 3.62 according to which meta finishing method produced average results. Post finishing method was found to be better than meta finishing method. As regards the concentration of finishing chemicals no difference was assessed in the fastness grades.

Figure 3.63 displays individual results with respect to wash fastness (staining) results of P/C fabric in which a steady GS value (4-4.5) was obtained with post and meta finishing methods at both concentrations. Thus the application of finishes showed better fastness results for staining on adjacent specimen irrespective of the mode of application. One of the post finished fabric at high concentration exhibited staining after washing by F3.

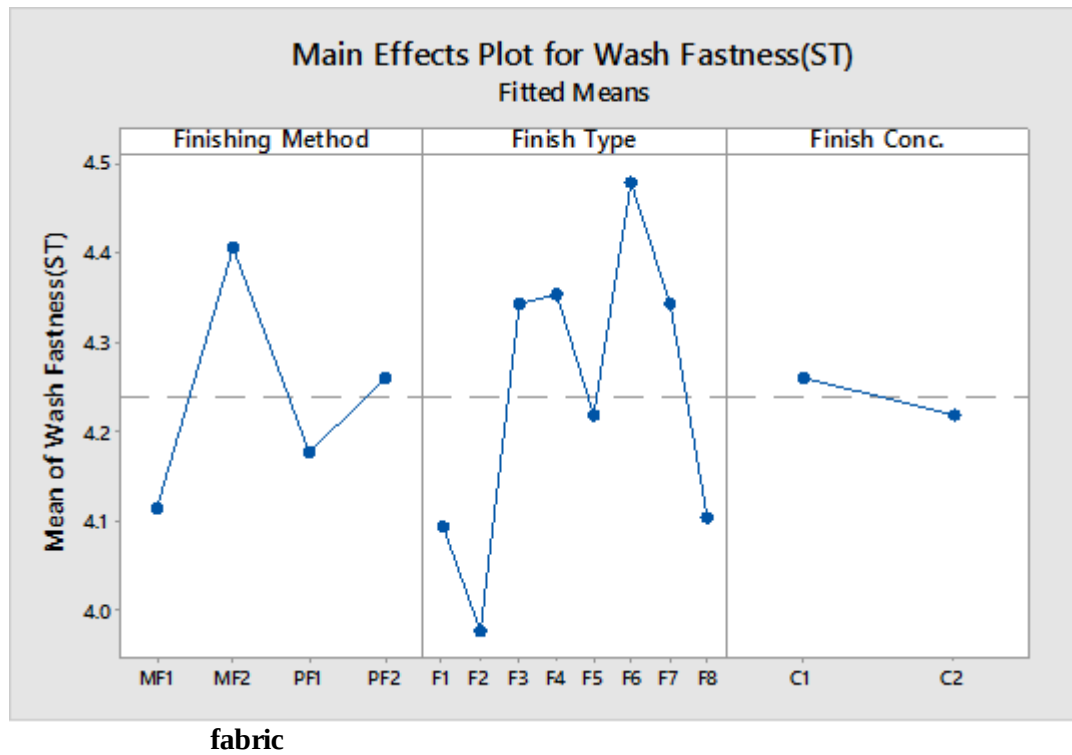
The overall effect of post applied finishing reagents on pigment dyed P/C fabrics showed that best results were obtained with NUVA- HPU liquid, a durable water and oil repellent finish and polyurethane, the handle modifying treatment, as these fabrics were ranked at highest cumulative fastness grades amongst all.

Table 3.39 Analysis of variance for wash fastness (ST) of dyed/finished fabrics

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	11	1.01823	0.09257	2.03	0.081

Finishing Method	3	0.14323	0.04774	1.05	0.393
Finish Type	7	0.79792	0.11399	2.50	0.051*
Finish Conc	1	0.01042	0.01042	0.23	0.638
Error	20	0.91146	0.04557		
Total	31	1.92969	0.31029		
*Statistically significant at P value 0.05					

Figure 3.62: Main effects plot for washing fastness (shade change) of finished P/C



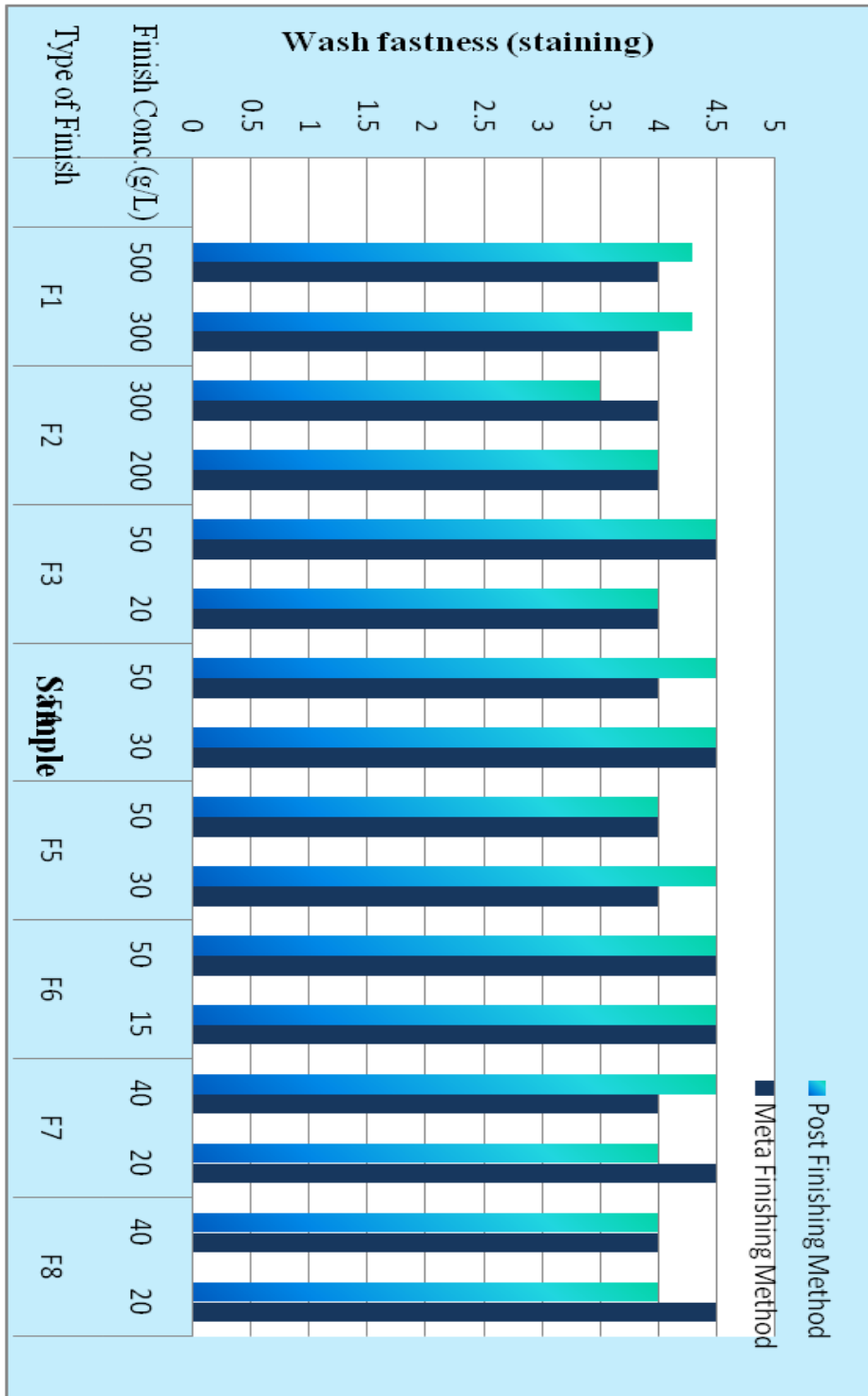


Figure 3.63: Effect of functional finishes in different concentrations and application methods on the wash fastness (shade change) of P/C fabrics

a. Flame retardant finishes

The meta finishing treatment on dyed P/C fabrics with flame retardant finishes rendered a slight reduction in the colourfastness grades at high concentration. As far as the individual performance, the Pekoflam HSD and Pekoflam OP liquid flame retardant had a beneficial effect on the dry rubbing fastness amazingly, at high concentration. The improvement was more obvious in the dry rubbing fastness of Pekoflam OP, a phosphorous based flame retardant finish on P/C fabric. Certainly, the finishing reagent in combination with acrylic binder and pigment formed a network of protective layer on the substrate and provided the resistance against rubbing action. The application of organo-phosphorus compound on pigment dyed P/C fabric could not withstand wet treatment, therefore, it is eminently suitable for those products which did not require frequent washing. The dry rubbing grades were according to commercial requirement.

As regards the wet rubbing fastness, the simultaneously dyed and finished or meta finished P/C fabric gave better response than post finishing treatment of flame retardants on P/C fabrics. In case of rubbing fastness low concentration of Pekoflam OP liquid flame retardant had improved the resistance as compared to other fabrics. It seemed that increasing the concentration of finish in combined formulation could not develop an appropriate binder film on the finished P/C fabric. However, the same formulation at low concentration imparted maximum dry rubbing fastness to the dyed/finished P/C fabric.

b. Water repellent finishes

The comparative analysis of cumulative colour fastness of post and meta treated P/C fabrics with water repellents were found to be maintained at the same level of performance. Though, NUVA FD and NUVA HPU with extremely durable water and oil repellent properties had improved the colour fastness grading but, not with a significant difference. In case of wash fastness, a negligible shade change and staining to adjacent cloth was observed with NUVA 3585 water repellent treatment on dyed P/C fabric. It was observed that by increasing the binder along the pigment proportionately, had also resulted colour loss during wet and dry rubbing assessment. The reason was excess amount of pigment deposited on the surface that crocked off by rubbing action (Cao, 2013). In the current study NUVA FD, a fluorine compound with extremely durable water repellent quality, enhanced the dry rubbing fastness at high concentration. The results were further improved by changing the mode of application with the same formulation. A commercially desirable crocking fastness was

achieved by incorporating fluorine dispersion in pigment dyeing formulations. In a study conducted by Cao, (2013) the wet rubbing fastness was better than dry rubbing with fluorocarbon water repellent finishing on P/C blended fabric. These beneficial effects suggest that an appropriate liquor stability can be maintained by using an appropriate ratio of finishing chemical with pigment formulation to resist rubbing strokes.

c. Polyurethane

The results of simultaneous pigment dyed and finished P/C fabric with assorted chemicals have been displayed in Table 3.44 in previous section. The visual assessment of grey scale indicated minor difference in colourfastness properties. The dry rubbing fastness of polyurethane treated fabric was found to be improved irrespective of the concentration as compared to the reference fabric. However, at low concentration, the level of wet rubbing fastness was better than high concentration which is an evidence of the fact that the degree of improvement from any of the finishing technique is strongly dependent on the appropriate amount of the finishing chemical in particular formulation.

d. UV absorber

Ultraviolet sun absorber is applied on apparels as well as technical textiles to improve the sun screening properties. The excessive exposure of ultraviolet radiation of sun has detrimental effects on humans; some of the hazards of bright sunlight are skin cancer, accelerated aging etc. The method to improve the protection from sunlight is the appreciation of UV absorbing agents that can absorb the UV radiation and prevent it from reaching the skin (Textile Bulletin, 2004). In the previous studies, UV absorber had been applied on fabrics for surface modification and improvement in dyeability (Carr, 1995).

In the current study UV, sun reagent was applied on P/C fabrics by padding technique and its impact on various physico-mechanical characteristics were determined. The results revealed that the colour fastness properties of UV absorber treated fabrics at the recommended range of concentration imparted low fastness grades, particularly the shade change after wash treatment was remarkably effected. It was observed that with both the application techniques i.e. post treatment of finish with pigment dyeing or incorporation in the same stock formulation, the results remained consistent. These findings are in agreement with Cao qing, (2013) who conducted a study to assess the effect of UV absorber treatment on pigment dyed cotton fabrics in which UV absorber treatment had reduced the fastness grades

with respect to wash and wet rubbing tests of dyed cotton fabrics. The shade change was prominent in dark coloured fabric and the reason for its poor performance might be related to the change in their adhesive quality, following surface oxidation. As far as the staining to adjacent cloth is concerned, the results were found to be very good. The study indicated that the colour that was bled had no affinity for the tested specimen and hence showed no signs of colour transfer. In one case, the decreased rating of staining on the adjacent cloth for UV absorber treatment at 50g/L was observed. The degradation in fastness probably occurred due to the high quantity of finishing reagent and the binder on the substrate. The colour crocked off due to thick polymer film and caused staining. In another study conducted by Xin et al., (2004) a novel approach for UV blocking of cotton fabric was developed using sol-gel method. The formation of a thin layer of a compound of titanium (UV absorber) on the cotton surface enhanced UV protection properties. The wash fastness grading of UV protected fabric was assessed to be at excellent level. These findings are consistent with our study to some extent, because in present case the staining to accompanying cloth was graded as 4.5, while the shade change as 3.5, corresponding to excellent and fair performance at 50g/ L of UV concentration.

The wet and dry rubbing fastness of the simultaneously dyed and finished P/C fabric was found to be the same, irrespective of the concentration. In comparison with post finishing process of the dyed fabric, the same treatment of UV sun protection produced the varying results. The dry rubbing fastness of one-step dyed and finished P/C fabric was better than wet rubbing test. In wet condition, the rating of fastness level was found to be improved at 15g/L of UV absorber. Similar findings with respect to rubbing mechanism of the dyed cellulose fibers have been reported by Schindler & Hauser, (2004). According to them, the wet cellulose fibers partly scrubbed by rubbing action, led to staining on adjacent substrate. The rubbing force for the wet testing procedure is about double the rubbing force in dry state. Therefore, wet rubbing grade of the same specimen will be reduced than dry rubbing. Contrary to that, the wet rubbing grade of UV absorber finished fabric was enhanced with only a small quantity of finishing reagent. The reason was probably the coating of the finish coupled with the film formation by acrylic binder as well as the hydrophobation. The finishing chemical acted like lubricants here in wet condition, which inhibited the crocking of colour from dyed material and migrated on to the substrate.

Colourfastness to crocking is a complex phenomena which needs special consideration. Many times, the apparent loss of colour can be attributed to the surface

modification in the fabric, resulting from abrasion action during laundering, gentle rubbing, instead of vigorous rubbing action can minimize the colour loss to both simultaneously, dyed and finished or only dyed fabrics. (CITB, ISP1001, 2002)

3.4.2 Effect of different functional finishes on the tensile strength

The durability characteristic of post and incorporated finishing treatment on dyed P/C fabrics was remarkably influenced by various finishing reagents. The concentration of various finishing chemicals in the impregnating bath was an important variable which enhanced the durability characteristics positively and sometimes adversely. The results of tensile are tabulated considering both the warp and weft directions are given in Table 3.40. The analysis of variance of the data of tensile strength of dyed/finished fabric is given in Table 3.41 which indicates a statistically non significant effect of different application methods, concentrations and type of finishes on the mentioned property.

Figure 3.64 demonstrates the main effects plot for the data of mean tensile strength of fabrics, taking into consideration the different variables. It is obvious that simultaneously dyed and finished fabrics induced good tensile strength at high concentration but with the same finishing reagents and conditions, the post finishing method gave comparatively better response. Different types of finishes showed an increasing and decreasing trend in mean tensile strength of treated fabrics of which the maximum strength was provoked by F4 (oil and water repellent finish). A slightly lower than this was attained by F6, F7 and F3 treated fabrics in the decreasing order of strength. One of the finishing chemicals F1 (Pekoflam HSD liquid flame retardant) had weakened the strength of fabrics remarkably.

Table 3.40 Effect of different functional finishes (types, concentrations and application methods) on the tensile strength

Samples	Factors			Responses		
	Application Technique	Type of Finish	Finish Conc. g/L	Tensile.S Warp, lb	Tensile.S Weft, lb	Tensile.S (Wp+Wt),lb
1	Post Finish. Method	F1	500	141.5	64.7	206.2
2			300	92.4	47.05	139.4
3		F2	300	125.3	75.1	200.4
4			200	132.0	79.0	211.0
5		F3	50	126.6	79.0	205.6
6			20	127.0	79.6	206.6
7		F4	50	152.0	92.3	244.3
8			30	160.7	69.1	229.8
9		F5	50	116.7	86.3	203.0
10			30	124.0	86.0	210.0
11		F6	50	125.1	55.1	180.2
12			15	137.0	51.3	188.3
13		F7	40	128.2	15.2	143.4
14			20	131.6	26.0	157.6
15		F8	40	137.0	74.2	211.2
16			20	110.5	57.01	167.51
17	Meta Finish Method	F1	500	110.02	48.2	158.22
18			300	115.0	46.5	161.5
19		F2	300	115.8	99.3	215.1
20			200	151.9	25.1	177.0
21		F3	50	117.01	23.0	140.0
22			20	159.7	19.4	179.1
23		F4	50	123.5	38.4	161.9
24			30	167.0	58.6	225.6

25		F5	50	83.9	23.0	106.9
26			30	163.3	76.6	239.9
27		F6	50	158.0	92.9	250.9
28			15	164.6	39.8	204.4
29		F7	40	176.2	58.4	234.6
30			20	141.7	27.1	168.8
31		F8	40	182.9	26.5	209.4
32			20	106.8	99.1	205.9

Table 3.41 Analysis of variance for tensile strength of dyed/finished fabrics

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	11	8000.1	727.28	0.50	0.878
Finishing Method	3	549.4	183.12	0.13	0.943
Finish Type	7	5127.9	732.55	0.51	0.817
Finish Conc	1	27.2	27.16	0.02	0.892
Error	20	28811.2	1440.56	-	-
Total	31	36811.2	3110.67	-	-

*Statistically significant at P value 0.05

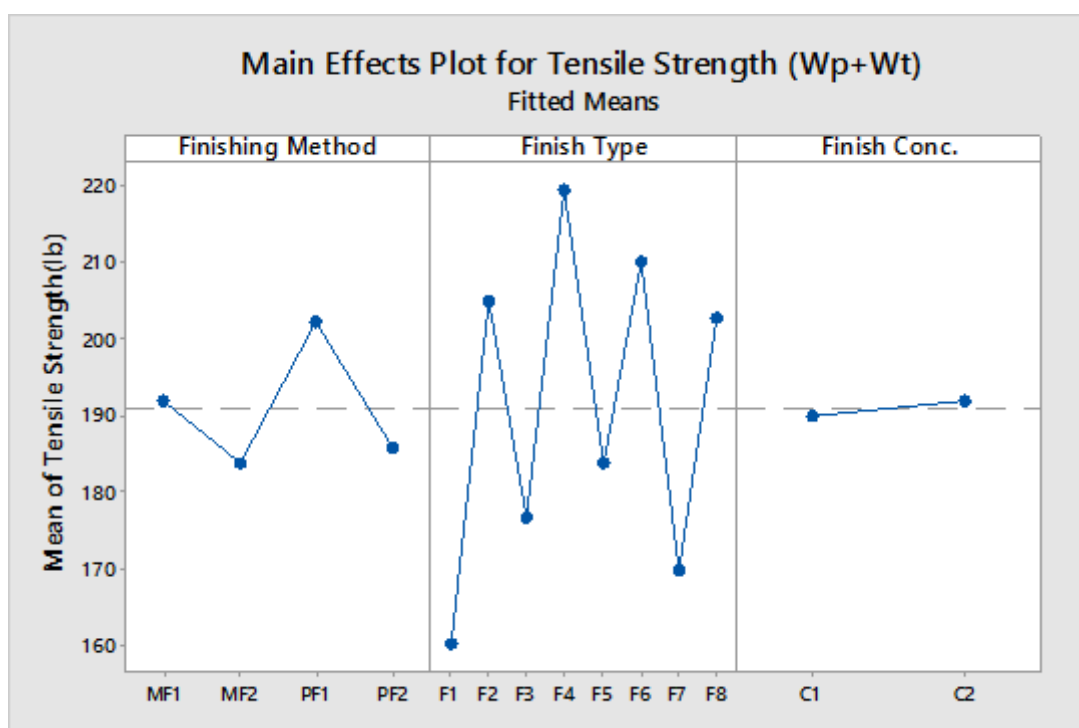
**Figure 3.64: Main effects plot for tensile strength of dyed/finished fabrics**

Figure 3.65 shows that simultaneous treatment of Pekoflam HSD liquid flame retardant with pigment colourant on P/C fabrics showed an improvement in the tensile strength at high concentration while at low ratio a reduction trend was observed. The loss was more obvious at low concentration irrespective of the mode of application.

The response of durable water repellent finish (F3) for pigment dyeing of P/C fabric showed similarity in results with this finishing chemical. Though, the fabric was generally weakened by incorporated finishing reagent. However, an increasing trend in tensile strength was observed by the simultaneously dyed and finished P/C fabric at high and low range of NUVA FD water repellent finish. The impact of durable oil and water repellent finish (F4) on tensile strength with meta treatment was found to be better at high concentration, whereas, with post finishing method at the same concentration, the strength had been reduced.

Though, the durable water and oil repellent (F4) surface treatment of P/C fabrics at higher concentration produced the same results in the aforementioned property, yet at low concentration the fabric was found to be weakened after treatment. As regards the tensile strength of single step pigment dyed and finished P/C fabric with UV absorber, an amazingly improved effect on tensile strength was reported, irrespective of the high or low concentration of the applied finish. At high concentration, the fabric had endured the tensile force very well, and resulted in raised strength with the post finishing method (Figure 3.65).

The results regarding tensile strength of after finished P/C fabric with Dicrylan BSRN, polyurethane (F6) was generally reduced with both application methods. But the effect of same reagent with modified surface withstood the maximum tensile force when applied on pre-dyed fabric.

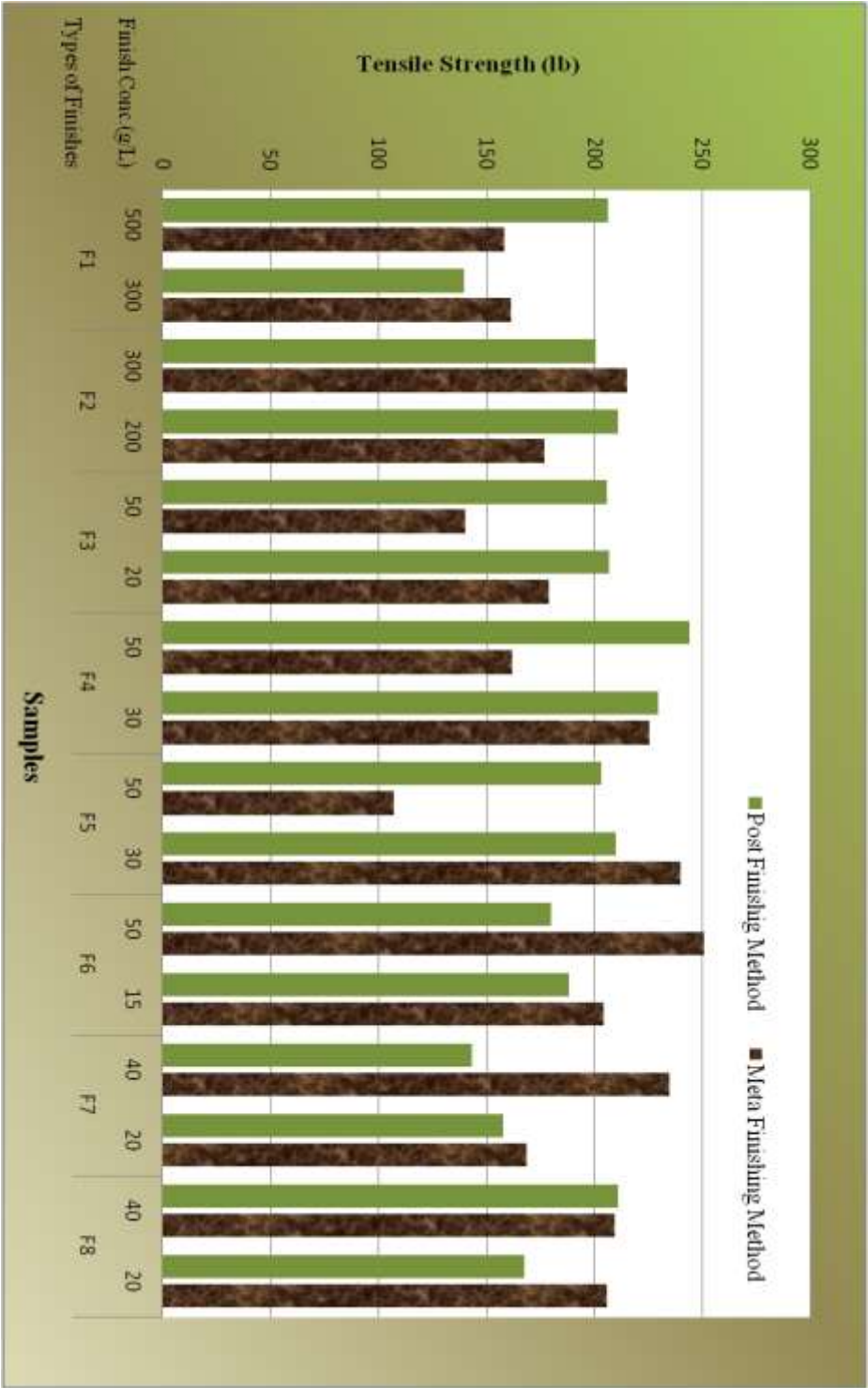


Figure 3.65: Effect of functional finishes in different concentrations and application methods on the tensile strength

a. Flame retardant finishes

The effect of flame retardant finishes on the tensile strength of pigment dyed P/C fabric have been displayed earlier in Table 3.40. Both the flame retardants, that were applied either by post treatment on dyed fabric or by meta finished in the same bath had adversely affected the P/C fabric in warp direction. However, the same finishing treatment had beneficial effects in weft direction of fabrics. The loss in the strength was less severe with Pekoflam OP liquid flame retardant irrespective of the concentration. Its chemical composition was based on organic phosphorous compound and its drawbacks have been discussed by Gohal & Vilensky (2003); which are a little bit controversial with our results. They mentioned that organo phosphorous compounds can be applied on acrylic, acetate, polypropylene, viscose and polyester to induce fire retardancy. However, the resultant product may lose tenacity, depending upon more or less the proportion of the organo-phosphorous compound added in the solution. It was observed that the same finish provoked high tensile strength in weft of fabrics, exceeding more than 100 percent at 300g/L concentration of the finishing reagent. The difference in tensile strength possibly occurred due to fabric construction which is influenced by the interlacing of yarns at initial stage of weaving operation. The existing findings can be related to the study of Malik, et al., (2010) who stated that warp yarns remain under high tension than weft yarns. This difference produce varied amount of crimp in individual directions even with similar yarn fineness and threads per inch of fabric which leads to differences in yarn strength. Furthermore, the final quality also depends upon the appropriate application of the finishing solution on the substrate. In present case the well oriented finishing reagent might have resulted a high mechanical stability in weft as compared to warp of fabric.

The treatment of Pekoflam OP liquid flame retardant on P/C fabrics had slightly reduced the tensile strength at high concentration. It happened probably due to high concentration that imparted stiffness and in turn reduced the inter fibre friction leading to lowered tensile strength of fabrics. In general the effect of flame retardants on priorly dyed fabrics was found to be more beneficial as compared to the simultaneously dyed and finished P/C fabric.

b. UV absorber

The effect of UV absorber on the tensile strength of P/C fabrics has been mentioned earlier in Table x. It was observed that tensile strength of P/C fabric was generally improved by the UV protecting reagent. However, in one of the treatment at 15g/L concentration, the same finish had slightly weakened the fabric in weft direction. In two step dyeing and post finishing treatment of P/C fabric with UV absorber, the degree of loss in strength was higher than single phase method. The dyed fabric was already coated with the binder film which provided a well-oriented surface for further treatment of finish. Despite the fact that pigment dyed fabric was post treated with UV absorber, it resulted in slight degradation; however, the loss was not very significant. The results are supported by the study of El Zaher and Kishk (1996) who concluded that penetration of UV radiations caused photo oxidation and resulted in decreased elasticity and tensile strength of fabric. In an another investigation quoted by Saravanan (2007) it was explored that without UV filters, reduction in tensile strength was computed to be approximately 100%, 23%, 34% and 44% corresponding to nylon, wool, cotton, and polyester after 30 days of exposure. The result in our study was ranged from approximately 9–17% loss in tensile strength of UV absorber treated P/C fabric. These results were in partial agreement with our study because the absorber was enhanced in strength at 15g/L. In weft direction at 50g/L, negligible difference in strength occurred with the same treatment. The improvement in this property was actually imparted by the UV absorbent, which resisted UV radiation to harm the material. Another mechanism of UV sun protection to avoid strength loss is quoted by Saravanan (2007) which supports our findings. UV radiation is one of the key reasons of degradation of textile material which occurs due to excitation in few parts of the polymer molecules and steady loss of integrity. UV blocking restricts the higher energy state and prevents degradations like strength loss. The incorporating finishing chemical with conventional pigment formulation increases the penetration quality of fabric, thus forming a smooth binder film providing mechanical stability to the fabric.

c. Polyurethane

The results with respect to tensile strength of post finished P/C fabric with Dicrylan BSRN and hand building chemicals is given in Table. Generally both of the finishing treatments had reduced the tensile strength of fabric slightly at high concentration. As far as the weft direction is concerned, the pigment dyed P/C fabrics showed remarkable performance regarding tensile strength after the application of polyurethane and hand building

finish. The treatment was found to be harmful for pigment dyed P/C fabric as the strength was tremendously reduced i.e. from 40 to 65 percent at low and high concentrations respectively.

The effect of simultaneously dyed and finished P/C fabrics with polyurethane finish and another hand building finish on tensile strength indicates that the fabric was being strengthened at high concentration of finish. But, at low concentration the fabric could not retain its original strength and weakened by a marginal difference with control fabric. The surface modification with hand building finish caused a weakening tendency with a noticeable percentage of 39.08. At low concentration the fabric had endured the tensile force very well, and resulted more than 100 percent raised strength.

3.4.3 Effect of different functional finishes (types, concentrations and application methods) on tear strength

The effect of post and meta finishing methods, different concentrations and types of finishes were analyzed for tear strength of fabrics and the results are given in Table 3.42

The analysis of variance for the tear strength property of dyed/finished fabrics is exhibited in Table 3.43. It is evident from the results that a highly significant effect on the tear strength of treated fabrics was found by different application techniques. As far as the other variables is concerned i.e. type of finishes and different concentrations, a statistically non significant effect was found in their results.

Figure 3.66 displays the main effects plot of tear strength results which is influenced by the mode of finish application, type and concentration of finish. As regards the first variable, meta finishing method at high concentration induced maximum tear strength in P/C fabrics. The after treatment of various types of finishes on dyed P/C fabric adversely affected the tear strength. However, at low concentration the results were found to be favorable for treated fabrics. The data plotted in Figure 3.67 with respect to individual responses, reveals that the highest mean tear strength was attained by the F-2 (Pekoflam OP flame retardant) treated fabric. As regards the effect of finish concentration, no effect on the fabric tear strength was determined. The individual performance plot showed that, the tear strength of Pekoflam OP liquid flame retardant (F2) treated fabrics was found to be tremendously increased by the simultaneous application of finish with dyeing formulation as compared to post treated fabric. Generally, an increasing trend in the tear strength of treated P/C fabrics

was exhibited by meta finishing method as compared to the post finishing method. Pekoflam HSD liquid finishing chemical (F1) weakened the fabric at high concentration, irrespective of the mode of finish application.

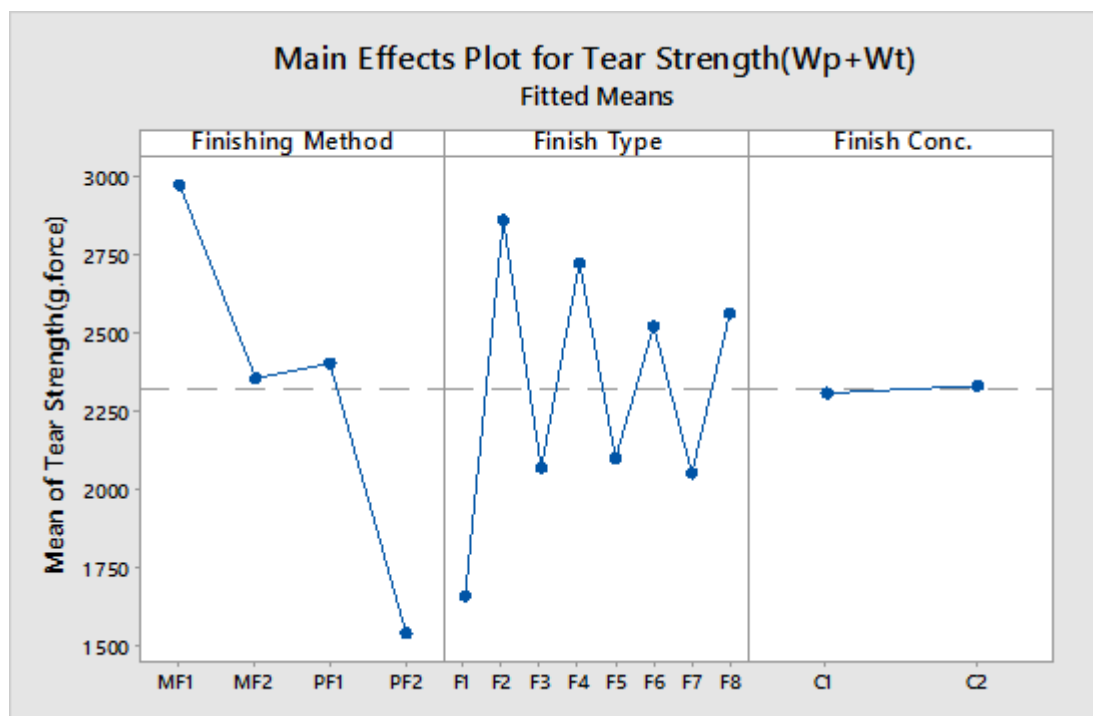
Table 3.42 Effect of different functional finishes (types, concentrations and application methods) on the tear strength

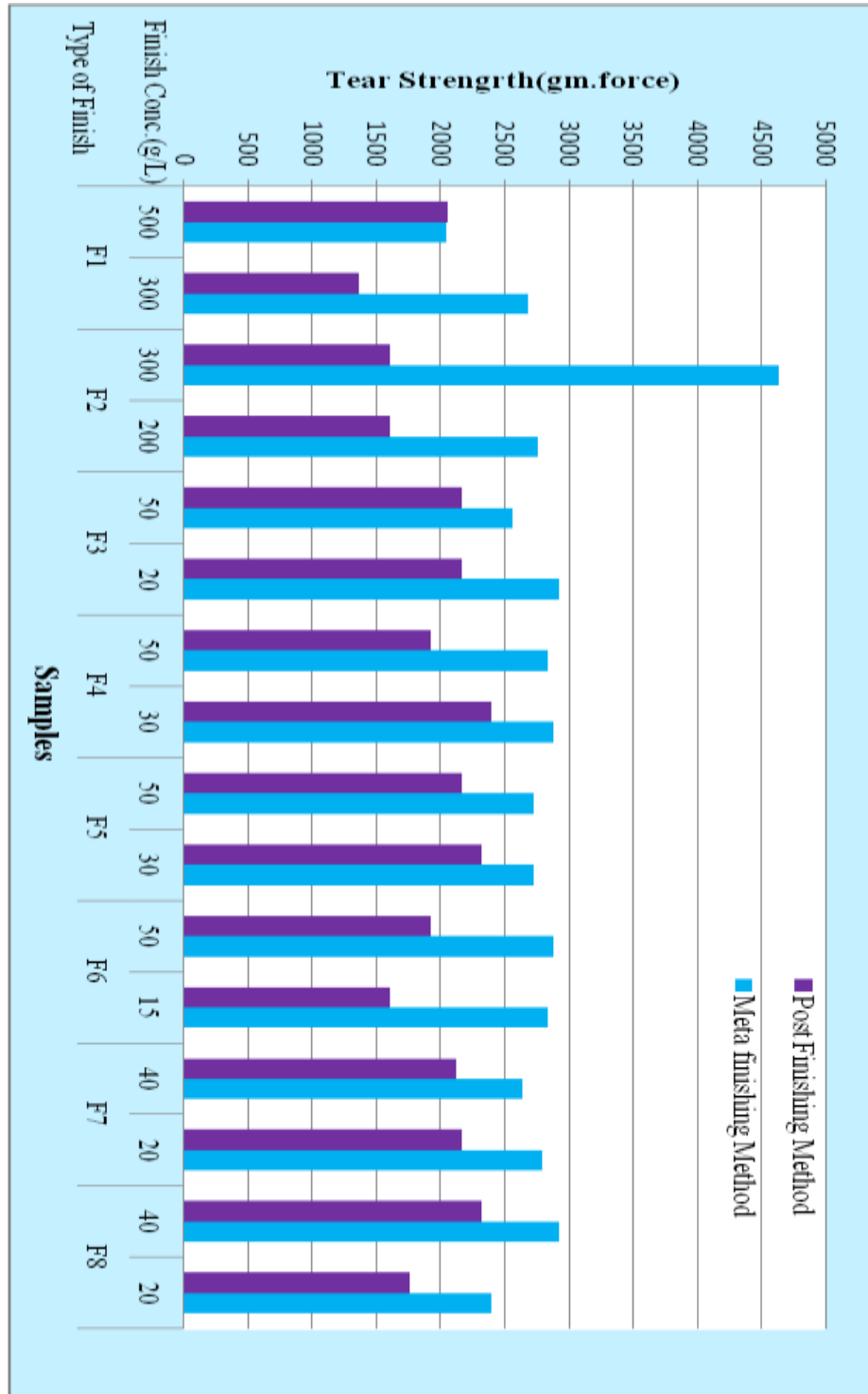
Samples	Factors			Responses		
	Application Technique	Type of Finish	Finish Conc. g/L	Tear.S Warp, g. force	Tear.S Weft, g. force	Tear.S (Wp+Wt), g. Force
1	Post Finish. Method	F1	500	980	1080	2060
2			300	680	680	1360
3		F2	300	800	800	1600
4			200	800	800	1600
5		F3	50	1080	1080	2160
6			20	1080	1080	2160
7		F4	50	960	960	1920
8			30	1200	1200	2400
9		F5	50	1080	1080	2160
10			30	1160	1160	2320
11		F6	50	960	960	1920
12			15	800	800	1600
13		F7	40	1060	1060	2120
14			20	1080	1080	2160
15		F8	40	1160	1160	2320
16			20	880	880	1760
17	Meta Finish Method	F1	500	680	1360	2040
18			300	1080	1600	2680
19		F2	300	1760	2880	4640
20			200	1040	1720	2760
21		F3	50	800	1760	2560
22			20	960	1960	2920
23		F4	50	880	1960	2840
24			30	960	1920	2880
25		F5	50	1040	1680	2720
26			30	1120	1600	2720
27		F6	50	1200	1680	2880
28			15	1200	1640	2840
29		F7	40	960	1680	2640
30			20	1040	1750	2790
31		F8	40	1000	1920	2920
32			20	800	1600	2400

Table 3.43 Analysis of Variance for Tear Strength of Dyed/Finished Fabrics

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	11	8047757	731614	4.25	0.002
Finishing Method	3	6991057	2330352	13.53	0.000*
Finish Type	7	1985695	283671	1.65	0.180
Finish Conc	1	2604	2604	0.02	0.903
Error	20	3445465	172273	-	-
Total	31	11493222	3520514	-	-

*Statistically significant at P value 0.05

**Figure 3.66: Main effects plot for tear strength**



a. Flame retardant finishes

Since the application of flame retardants on P/C fabrics showed the same behavior with respect to tear strength, therefore, all the results have not been discussed here individually. At both the high and low concentrations, majority of the fabrics had shown improvement in tear strength with an outstanding response in warp direction and fair increase in weft direction. A slight decline in tear strength was recorded with the application of flame retardant finishes.

The tearing strength results of treated P/C fabrics with flame retardant finishes have been displayed earlier. In accordance with the results of Table 3.42, a general trend of increased strength has been explored, irrespective of the finish concentration. The meta finished pigment dyed P/C fabric with Pekoflam OP Liquid flame retardant increased in strength as compared to other dyed fabrics. In another application method, when the finishing chemical was applied on conventionally stock formulated pigment dyeing, the tearing strength of fabrics was found to be reduced. One of the reasons for high tear strength of fabric has been explained by Zurich (2011) who assessed various characteristics of fabrics after giving flame retardant treatment. According to his investigation, the spun yarns that were priorly stressed fibers on the outer edges start to break under tension. On the contrary, in present study it seems that the application of flame retardant chemical had well covered the fibers with the polymer film (binder/finish) and hence the outer edges of fibers were being protected and gained higher strength by the polymeric layer.

b. UV absorber

The impact of UV absorber on the tearing strength of P/C fabric has been presented in Table 3.42. The results from meta-dyeing and finishing were reported to be beneficial regarding UV absorber treatment, irrespective of the concentration of finish employed. A handsome increase in tearing strength was induced by UV absorber on P/C fabric, though with 15g/L ratio in stock formulation only a slightly higher strength was observed. The factors which influenced the tensile strength at variant proportions on the fabric were also applicable to the tear strength property of UV treated specimens.

3.4.4 Effect of different functional finishes on the flexural rigidity

The effect of various functional finishing treatments, concentration of finishes and different application methods on the flexural rigidity of dyed P/C fabrics was determined and the results tabulated (Table 3.44) for warp and weft directions of fabric. The data revealed that stiffness of all the treated fabrics increased tremendously in warp direction as compared to un-treated fabric

Table 3.45 comprises the analysis of variance of the flexural rigidity of the dyed/finished fabrics. The results were found to be non significant ($P\text{-value} > 0.05$) for all the variables mentioned in the tabulated values. The main effects plot of the flexural rigidity results in Figure 3.68 shows that the rate of stiffness was the highest with post application method at high concentration. The same trend was observed with the other method also but here the degree of change was not as drastic, produced by post treatment of finishes.

The data plotted in Figure 3.69 revealed the individual performance of fabrics for the flexural rigidity that was induced by the finishes on pre-dyed fabrics verses simultaneously dyed and finished P/C fabrics. The overall results showed that the rate of stiffness of all the treated fabrics was lowered with meta finishing as compared to the post finishing technique.

A directly proportional relation between finishing treatment with F1, F3, F5 and flexural rigidity of P/C fabric was noticed. It was found that, by increasing finish concentration within specified range, the fabric stiffness tended to decrease significantly particularly after treatment of NUVA 3585, oil and water repellent finish(F4) and hence, a softer texture developed.

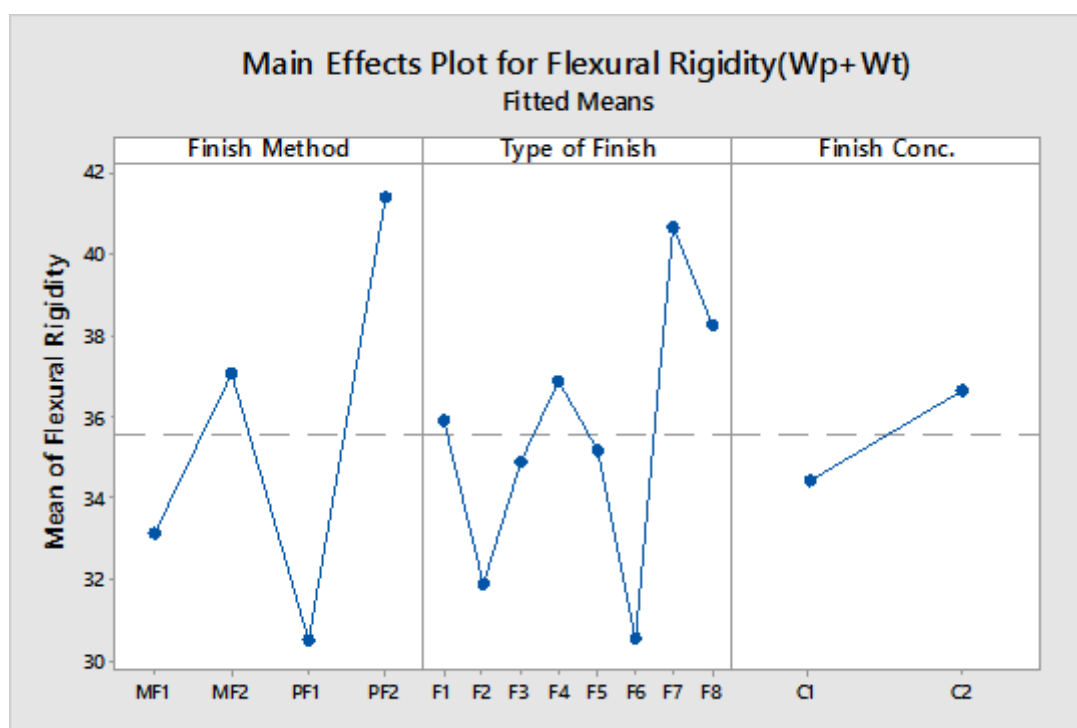
Table 3.44 Effect of different functional finishes (types, concentrations and application methods) on flexural rigidity

Samples	Factors			Responses		
	Application Technique	Type of Finish	Finish Conc. g/L	Flex. Rig (Warp), μ Joule/M	Flex. Rig (Weft), μ Joule/M	Flex. Rig (Wp+Wt) μ Joule/M
1	Post Finish. Method	F1	500	23.02	12.38	35.4
2			300	21.07	11.69	32.76
3		F2	300	26.71	12.81	39.52
4			200	20.39	12.09	32.48
5		F3	50	20.4	3.08	23.48
6			20	19.74	7.19	26.93
7		F4	50	26.23	13.14	39.37
8			30	40.13	13.14	53.27
9		F5	50	18.78	11.89	30.67
10			30	16.95	12.45	29.4
11		F6	50	21.22	9.19	30.41
12			15	30.59	11.62	42.21
13		F7	40	25.79	11.42	37.21
14			20	25.42	11.96	37.38
15		F8	40	23.03	11.27	34.3
16			20	27.38	23.38	50.76
17	Meta Finish Method	F1	500	23.02	14.2	37.22
18			300	10.14	13.38	23.52
19		F2	300	17.38	11.79	29.17
20			200	23.38	14.01	37.39
21		F3	50	20.04	10.88	30.90
22			20	32.91	10.66	43.57
23		F4	50	18.16	11.79	30.03
24			30	0820.	12.39	35.83
25		F5	50	18.47	11.72	37.51
26			30	18.15	10.19	28.34
27		F6	50	18.47	12.43	30.50
28			15	19.41	10.62	30.03
29		F7	40	23.19	12.64	35.83
30			20	24.66	12.85	37.51
31		F8	40	19.09	14.98	34.07
32			20	31.27	13.64	44.91

Table 3.45 Analysis of variance for flexural rigidity of dyed/finished fabrics

Source	DF	Adj SS.	Adj MS.	F-Value	P-Value
Model	11	685.33	62.30	1.61	0.171
Finishing Method	3	209.58	69.86	1.81	0.179
Finish Type	7	269.00	38.43	0.99	0.464
Finish Conc	1	28.84	28.84	0.75	0.398
Error	20	773.55	38.68	-	-
Total	31	1458.88	238.11	-	-

*Statistically significant at P value 0.05

**Figure 3.68: Main effects plot for flexural rigidity of fabrics**

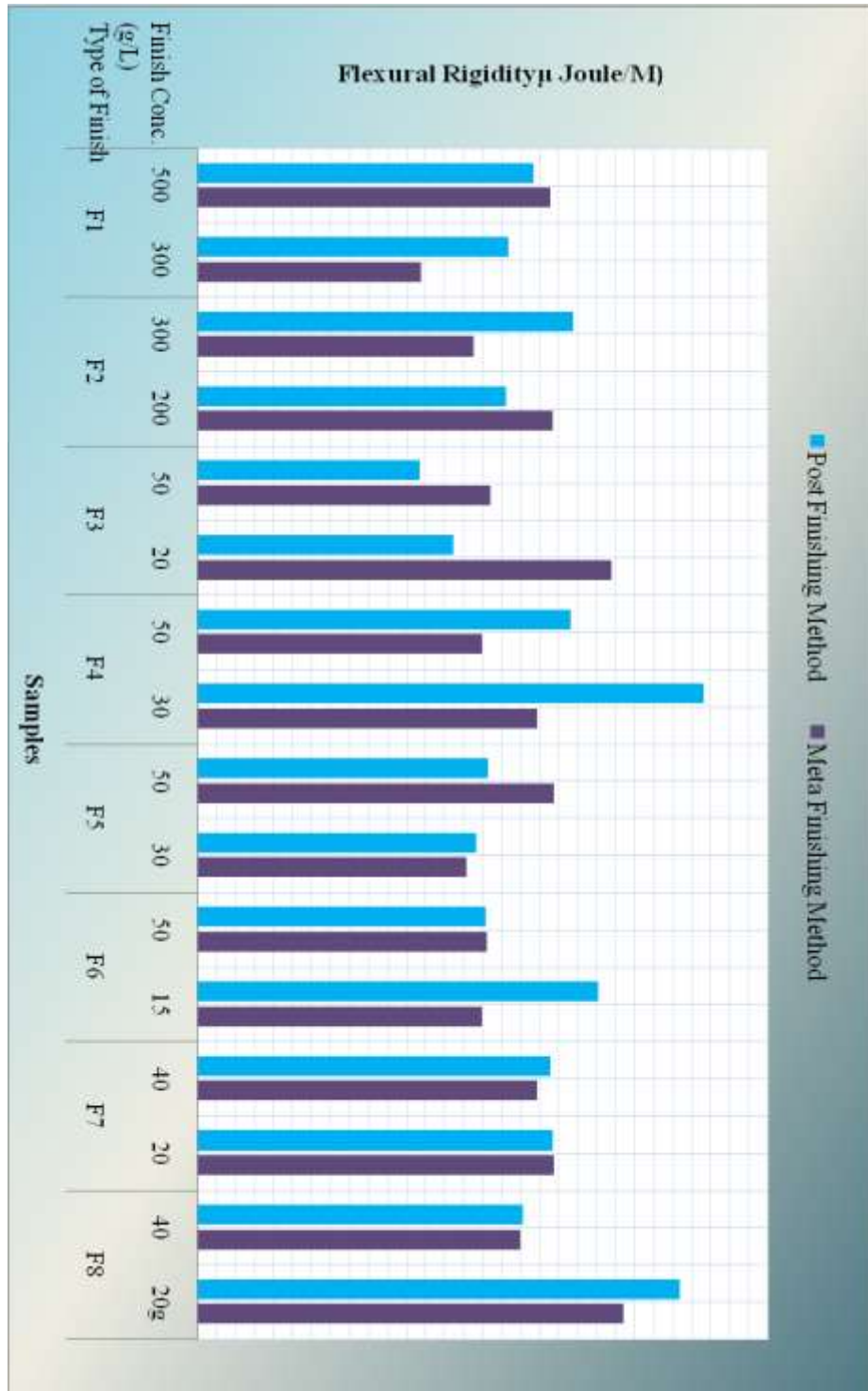


Figure 3.69: Effect of functional finishes in different concentrations and application methods on the flexural rigidity of P/C fabrics

3.4.5 Effect of different functional finishes on the abrasion resistance

Table 3.46 shows the data with respect to the effect of various finishes on the abrasion resistance of P /C fabric in different concentrations and different application methods.

The ANOVA of the results with respect to abrasion resistance of the treated fabrics is displayed in Table 3.47, according to which a statistically non significant effect was found in the mean values. All the variables i.e. different application methods of finishing, types and concentrations were found statistically insignificant.

The main effect plot is displayed in Figure 3.70 which shows the better performance of combined dyed and finished fabrics with various chemicals. The overall abrasion resistance of post treatment method of P/C fabrics was quite low as compared to the other method. As far as the type of finishes is concerned, F3 (NUVA FD water repellent) rendered the highest abrasion resistant to the fabrics while the lowest mean value corresponded to F5, the durable oil and water repellent finish. A small difference in abrasion values was observed between the high and low concentrations of the finishing chemicals used on the sample fabrics. As mentioned above in this case too, the application of Pekoe flame OP liquid (flame retardant finish) on P/C fabric, showed an increase in the number of rubs as compared to the untreated fabric.

Figure 3.71 presents the individual performance of treated P/C fabrics with respect to abrasion resistance. According to the plotted data the post treatment of pekoe HSD liquid (F1) brought about positive change in P/C fabric in the increasing order of abrasion cycles at 300 and 500g/L concentration in the finishing bath. Conversely, the abrasion resistance of meta finished pigment dyed P/C fabric with the same flame retardant was adversely affected irrespective of the concentration of finish. The fabric wore off at an early stage of testing on martindale abrasion machine. Figure 3.71 shows that the post application of Pekoe flame OP liquid (flame retardant finish) on P/C fabric, showed an increase in the number of rubs as compared to the meta finished fabric.

The data with respect to abrasion behavior of P/C fabric dyed and reacted afterwards with water repellent finish showed that when the concentration of NUVA FD liquid (F2) was increased from 20 to 50g/L, the performance was found to be improved. At high concentration, dyed P/C fabric abraded with an increase number of rubs. However, at 20g/L it was adversely affected thus exhibiting the devaluation in the number of abrasion cycles. As

regards the meta finishing, effect of NUVA FD durable water repellent finish had showed a beneficial effect on abrasion resistance of P/C fabric. Almost similar findings were obtained with the application of NUVA 3585 oil and water repellent finish, too, but here the improvement in abrasion resistance of P/C fabric was more pronounced. The meta finished fabric resisted the abrasive motion at more number of cycles which was a very good response as compared to the pre dyed fabric. The low concentration of finish had provoked excellent abrasion resistance to P/C fabric and the fabric bare the brunt of abrasive motion with a remarkable increase. The abrasion resistance behavior of dyed and NUVA HPU treated P/C fabrics is shown in table 3.53. The fabric after treatment had significantly boosted the abrasion resistance of fabric at high concentration.

The effect of post treatment of UV absorber (F6) on the abrasion resistance of treated P/C fabric is given in Table 3.46. The results displayed in Figure 3.71 indicated that, when the concentration of finishing chemicals increased there was less resistance of P/C fabric for abrasion and hence the fabric wore off at an early stage of abrasion operation. In case of low range i.e. 15g/L of UV absorber, excellent abrasion resistance was exhibited by the dyed specimen. It shows that at this level of concentration UV absorber is very beneficial for the pigment dyed P/C fabrics and provides the best option for improving the abrasion resistance.

As regards the application of soft polyurethane and another hand building finish by meta finishing method, the dyed P/C fabric showed a similarity in their results regarding abrasion behavior. An increased finish concentration tended to lower down the abrasion resistance, as represented in Table 3.48, where an increased output in abrasion rubs was observed. When treated at lesser concentration (20g/L) of polyurethane and hand building finish the dyed P/C fabrics exhibited a pretty good abrasion resistance. It is clear that both the finishing chemicals in an appropriate amount could induce a desirable rubbing resistance in dyed P/C fabrics but when it exceeded beyond a certain limit it couldn't take the brunt of abrasive action and reduced the number of cycles.

Table 3.46 Effect of different functional finishes (types, concentrations and application methods) on the abrasion resistance and pilling grades

Samples	Factors			Responses	
	Application Technique	Type of Finish	Finish Conc. g/L	Abrasion Resis (no. of cycles)	Pilling Grades
1	Post Finish. Method	F1	500	42,200	4
2			300	40,390	3
3		F2	300	41,000	3

4	Meta Finish Method	F3	200	40,350	4
5			50	39,040	3
6			20	21,080	4
7		F4	50	45,285	3
8			30	21,770	3
9		F5	50	24,080	3
10			30	16,425	3
11		F6	50	32,570	4
12			15	49,320	4
13		F7	40	17,710	4
14			20	36,900	3-4
15		F8	40	31,265	3
16			20	41,085	3
17	Meta Finish Method	F1	500	23,500	3
18			300	22,500	3
19		F2	300	26,000	3
20			200	68,300	3
21		F3	50	55,335	2
22			20	42,400	4
23		F4	50	42,400	4
24			30	56,440	3
25		F5	50	49,950	5
26			30	31,650	3
27		F6	50	50,000	3-4
28			15	28,600	4
29		F7	40	41,500	4
30			20	50,000	2
31		F8	40	52,690	3
32			20	52,200	3

Table 3.47 Analysis of variance for abrasion of dyed/finished fabrics

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	11	1965564535	178687685	0.86	0.590
Finishing Method	3	1172863498	390954499	1.88	0.166
Finish Type	7	139102167	19871738	0.10	0.998
Finish Conc	1	139102167	99344635	0.48	0.498
Error	20	4162612738	208130637		
Total	31	6128177273	896989194		
*Statistically significant at P value 0.05					

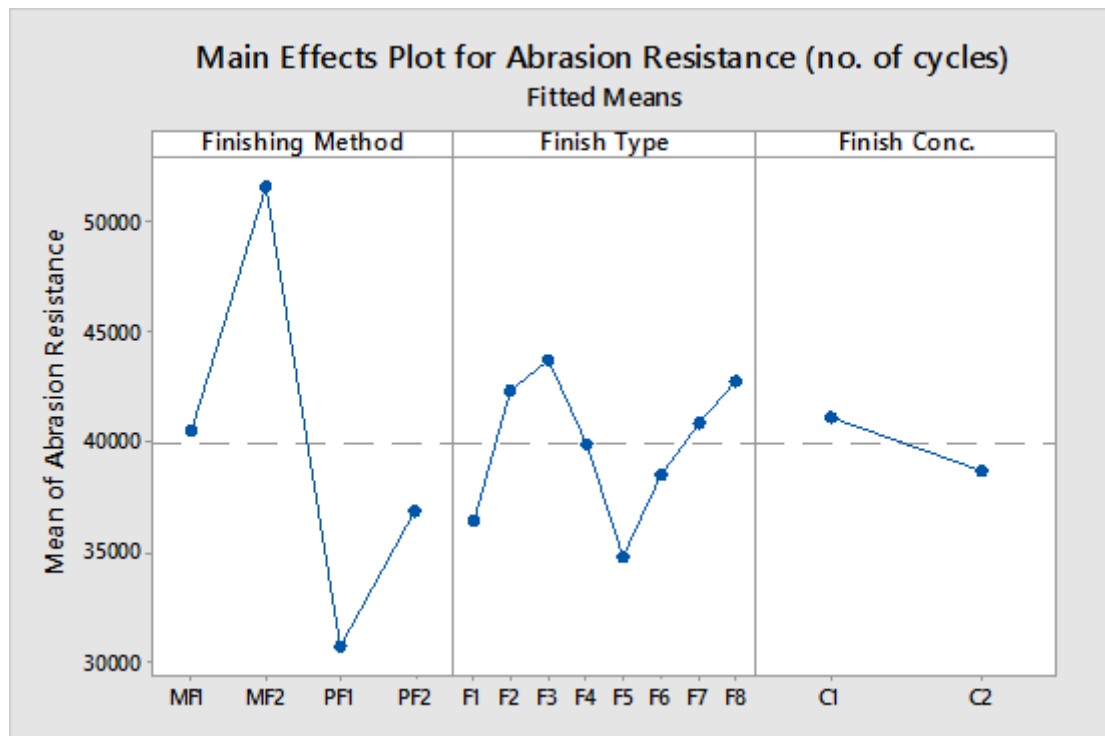


Figure 3.70: Main effects plot for abrasion resistance

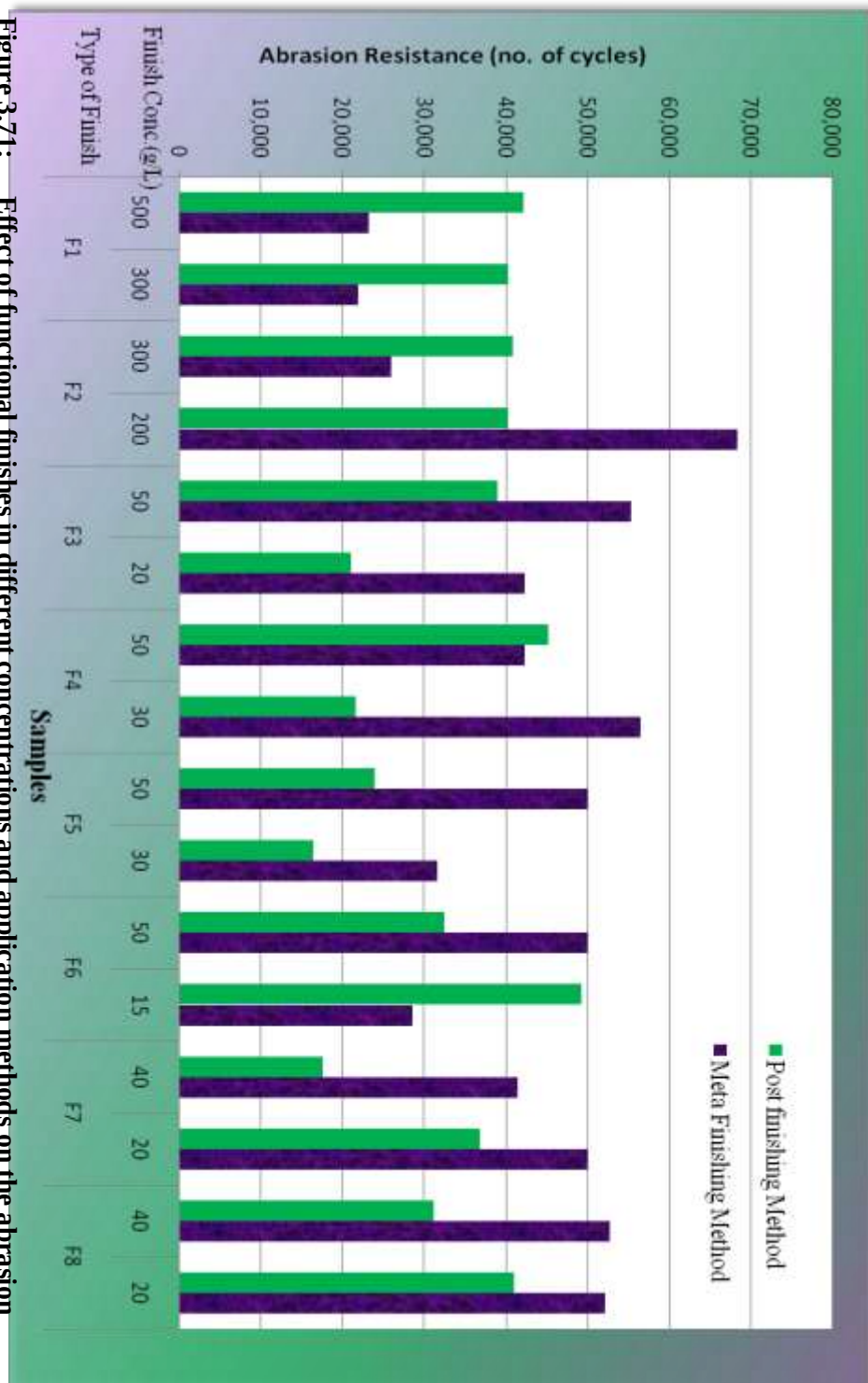


Figure 3.7.1: Effect of functional finishes in different concentrations and application methods on the abrasion resistance of finished fabrics

a. Flame retardant finishes

The results with respect to abrasion resistance of post treated pigment dyed P/C fabric with flame retardant finishes have been displayed earlier in Table 3.48. In the recommended concentration ranges, the abrasion behavior of treated fabrics was found to be positive. However, the combination of finishing reagent with pigment stock formulation produced some fabrics with lowered abrasion resistance, too. The basic reason for decrease in percentage resulted due to a convenient removal of yarns from the fabric structure. The binder film in combination with finish could not resist the abrasive force and broke the yarns at an early stage of testing. However, the Pekoflame OP flame retardant at low concentration resisted abrasion damage. The strong protection was provided by organo phosphorus polymer-matrix to the cellulose component of this blend, due to which the rubbing action could not abrade the specimen even at 68,300 numbers of cycles. The statement given by Zurich (2011) in his study on flame redundancy of cellulose fabrics partially supports our findings. According to him the cotton fiber-ends protrude from spun yarn and are not firmly incorporated in the fabric as filament yarns hence the polymer film (of finish/binder) can cover the surface of fibers and the yarns, giving protection to the treated fabrics against abrasion. The same finish at high concentration decreased the number of rubs to abrade the specimen indicating that fabric was being damaged by increased stiffness. In one-step dyeing and finishing the distribution of the chemical did not have enough time to diffuse in fabric completely and deposited on the surface. The rubbing action removed the over layer and resulted in low abrasion resistance. The present results are supported by another investigation on flame retardant finishes. In a study conducted by Alaei & Wenning (2002) it was determined that sometimes adverse effects on the mechanical properties of cotton fabrics have been observed by the application of these chemicals. The decrease in tensile and tear strength, loss in abrasion cycles, harsh handle and shade change of coloured fabrics are few of the drawbacks induced by flame retardants.

b. UV absorber

The effect of UV absorber on the abrasion resistance of treated pigment dyed P/C fabric with respect to concentration has been mentioned earlier. As far as the application technique is concerned, the post finishing of UV absorber on P/C fabric induced excellent abrasion resistance at 15g/L as compared to untreated fabric. The UV absorber treated fabric after conventional pigment dyeing being prevented by the polymer coating over -layer. In this study the acrylic binder, utilized for pigment colouration of P/C fabric, assisted to retain the post treatment of UV absorber chemical reagent and enhanced the abrasion resistance. According to Thiagaraj & Nankalli (2014) acrylate, based binder helped to retain the applied chemical on the surface of the fabric as in this investigation the UV radiation chemical was applied on an already pigment/binder coated fabric. This coating was firm enough to resist the fibers being pulled out from substrate, leading to yarn breakage or abrasion. On the other hand two-step dyeing and finishing with 50g/L concentration of UV absorber could not bear excess amount of chemical and indicated degradation by reducing the resistance against abrasive motions.

The same concentration of finish in conjunction with pigment stock formulation provoked excellent abrasion resistance of P/C fabrics. The combined solution well penetrated in the fabric structure, reduced friction and enabled the fabric to develop an outstanding performance regarding abrasion behavior. The low concentration in combined application of UV absorber on P/C fabric could not resist the strokes of abrasion machine and remained non-beneficial.

3.4.6 Effect of different functional finishes on the pilling resistance

The summary of pilling results of post and meta treated P/C fabric with various functional finishing reagents at various concentrations is exhibited in Table 3.46

The analysis of variance (Table 3.48) for the data of pilling performance of the finished P/C fabrics show that there was a non significant effect on treated fabrics regarding application procedure, different concentrations of finishes as well as different types.

Figure 3.72 show the main effects plot for results, regarding pilling performance of simultaneously pigment dyed and finished P/C fabrics with various finishing chemicals according which, post finishing technique was found to be better than meta finishing method. The data displayed that concurrent application of F1(liquid flame retardant HSD) with

pigment dyeing, produced a more fuzzy structure of P/C fabrics at 300g/L concentration, but when it reduced to 200g/L with the same conditions, pilling resistance was improved a little by a slight difference in standard grades. Overall, the high concentration was found to be beneficial regarding pilling behavior of fabrics.

Figure 3.73 presented that by raising the NUVA FD water repellent finish from 20-50g/L, the rate of pilling was increased, while with post treatment no change in pilling grade was observed at all. At high concentration, distinct pilling was appeared on the fabric but at low concentration it was controlled by finishing treatment and the fabric attained grade 4 (slight pilling). The similar findings were observed with durable oil and water repellent finish (F5) which induced the optimum pilling grade to the fabric with the meta finishing method.

According to the data, at both low and high concentrations and different methods of application of UV absorber(F6), the pilling grade was found to be the same (4) indicated by slight surface fuzz on the fabric. This analogy of results was also noticed in the fabrics with hand building finish at high and low concentrations. With the same treatment, the specimen developed small fuzz protruded from the fabric at 40g/L content while at low range (20g/L) the pilling grade was devaluated from 4 to 3.5 units.

The effect of crosslinkers, softeners and functional finishing reagents on some important characteristics of the treated and untreated P/C fabrics was statistically analyzed also by paired sample T-Tests and the results displayed in Appendix A-E.

Table 3.48: Analysis of variance for pilling of dyed/finished fabric

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	11	2.1250	0.19318	0.36	0.956
Finishing Method	3	0.1563	0.05208	0.10	0.960
Finish Type	7	1.8531	0.26473	0.50	0.824
Finish Conc	1	0.0938	0.09375	0.18	0.678
Error	20	10.5938	0.52969		
Total		14.822	1.13343		

*Statistically significant at P value 0.05

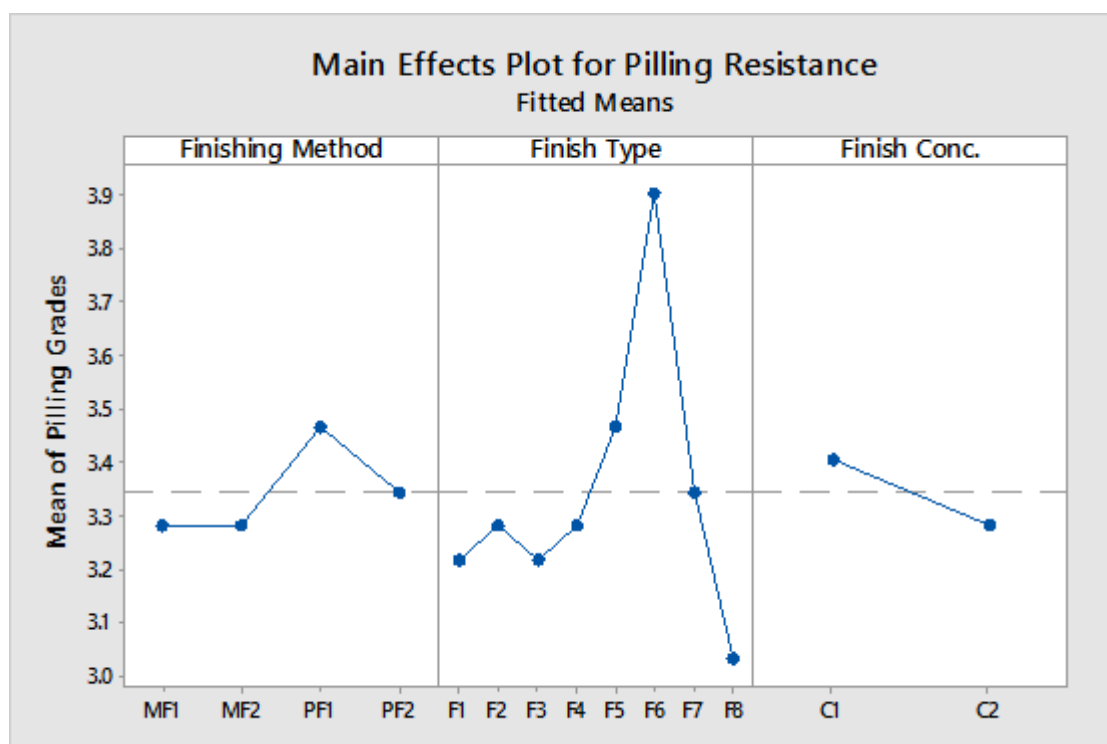


Figure 3.72: Main effects plot for pilling resistance



Figure 3.73: Effect of functional finishes in different concentrations and application methods on pilling resistance

3.4.7 Flame retardant finishes on pigment dyed P/C fabrics

Fire is a serious cause of suffering injuries due to cooking, smoking and other accidents. Flame retardant finishes principally for clothes and furnishing items can offer better protection against these fire damages. Keeping in view the importance of this area, the flame retardants finishes were assessed further for their resistance against flammability test.

The vertical flammability test was carried out on P/C fabrics in two concentrations each by using post and finishing technique. The pre-dyed fabric produced better results than simultaneously dyed and finished P/c fabric. At low concentration i.e. 200g/l Pekoflam OP liquid flame retardant produced beneficial effects while at high concentration it produced unsatisfactory results. According to the results the following burning characteristics were measured to assess the performance.

Flame time	(0 sec.)
After Glow	(22sec.)
Char Length	(6.9 inches)
Occurrence of melting	(nil)

Cotton products are often coated with finishing chemicals, which is a convenient and effective approach to produce flame retardancy (Sirivirynam et al., 2008). In the current study two types of flame retardant chemicals were applied on P/C fabrics by post and meta finishing technique with pigment colouration system Pekoflam OP liquid flame retardant at low concentration tended to produce char formation (6.9 inches) on P/C fabric after vertical flammability test. The finish composed of organic phosphorous compound which was found to be effective in reducing the flame propagation. The results are supported by the investigation of Horrocks & Price (2001) on flammability mechanism. According to them an effective mechanism of flame retardancy is to reduce the synthesis of flammable volatile materials which in turn increase the char formation by endothermic dehydration. In another study conducted by Lewin & Weil (2008) it has been described that at high temperature the phosphorous compounds react to give a polymeric type of phosphoric acid, which causes the material to char by the formation of glassy coating. In this way the pyrolysis process is inhibited which may otherwise promote the burning process.

At high concentration of finish no beneficial effects have been observed, because the specimen could not resist the flame after removal from flammability testing cabinet. Since, char formation is an evidence of a good flame retardant characteristic, (Prinz, 2011) our results are not in agreement with this statement. However, the same finish performed well with low concentration of finish. There is a possibility that the difference in results was due to the excess amount of finishing reagent.

CONCLUSIONS

Pigment dyeing is more advantageous than other conventional dyeing systems, since the former can incorporate various finishes in the same formulation without any ecological hazards. P/C blended fabrics were pigment dyed with conventional post finishing technique as well as by incorporating various functional finishes in the common dyeing formulations. After determining preliminary tests the performance of dyed fabrics was evaluated before and after treatments with respect to their physico-mechanical properties and the results are summarized under various sections.

Optimization of binder systems for pigment dyeing

The results of colourfastness properties of pigment dyed P/C fabrics regarding various types of binders show that the optimum rubbing fastness was obtained by Helizarin Binder ET ECO and Helizarin Binder CCF. The P/C fabrics that were dyed with the Helizarin Binder ET ECO formulation, attained the highest wet rubbing fastness conforming to an acceptable level of 3.5 GS. Polyurethane based binder called appretan PU, liquid was another type which induced very good colourfastness properties in the dyed P/C fabric. The maximum value of polyurethane treated P/C fabrics suggests that it had developed a good pad /liquor stability in the formulation, yielding an increased resistance in fabric against wash and rubbing fastness tests.

The pigment dyed specimens, achieved better dry and wet rubbing fastness as well as the wash fastness (shade change and staining) at higher pigment concentration. As regards the effect of binder concentrations both an increasing and decreasing trend in the level of fastness was observed. However, optimum results of properties of dyed specimens were obtained at 50:200g/L pigment/binder concentration.

It is apparent that the increase in pigment concentration has a statistically significant effect on the slight increasing trend of the tensile strength of dyed P/C fabrics. According to the results, the tensile strength of fabrics was augmented by increasing the concentration of binder in the dye bath but on the other hand, some values deviated a little bit by indicating a percentage decrease in tensile strength of fabric. As far as the binder type is concerned, Helizarin Binder ET ECO and CCF

exhibited the highest and B5, the lowest tensile strength according to the statistical analysis. The optimum strength in both warp and weft direction was attained by the dyed P/C fabric with an acrylate based binder ET ECO at 50:200g/L pigment, binder concentration.

It can be clearly inferred from the earlier mentioned results, that majority of the fabrics showed a reduction in tear strength as compared to the control fabric. The loss in tear strength was more apparent in warp direction in comparison to the weft direction of fabric, regardless of binder type and the concentrations. As regards the binder type, Printofix MTB, (B3) an acrylate copolymer, gave significantly higher fabric tear strength as compared to other binders. The increase in pigment concentration had not any noticeable effect on fabric's tear strength, whereas, increase in binder concentration showed a decreasing trend in tear strength.

The overall results indicate that effect of binder type with respect to the flexural rigidity of the dyed P/C fabrics was significant, while the effect of pigment and binder concentrations were found to be non significant. It is concluded that pigment to binder ratio needs special consideration in the formulation of padding liquor for dyeing, as excess amount of binder may generate an adverse effect on the handle of fabric

The abrasion and pilling performance clearly illustrated a declining trend in resistance of the dyed fabrics with an increase in pigment concentration. As far as the binder type is concerned, Helizarin Binder ET ECO and Helizarin Binder CFF offered the maximum abrasion resistance at 20:150g/L and 50:150g/L pigment/binder concentrations respectively. The pilling resistance of acrylic based, Helizarin binder ET ECO was found to be at upper limits, amongst all the binder types.

Applications of various cross linkers with optimized binder systems

Generally the colour fastness results were equivalent to or slightly less than the ratings of treated (dyed/cross-linked) and untreated fabrics, particularly the wet and dry rubbing fastness. The results represented, that the fabrics, treated with crosslinking agents, Fixapret CPF based on glyoxalmonourein, and Knittex RCT (modified DHEU) were ranked at the highest grade of colourfastness to dry rubbing amongst all the fabrics. The assessment of wet rubbing fastness of dyed/crosslinked fabrics showed that treatment with Fixapret CPF and Printofix WB liquid produced better results, as compared to other crosslinking agents. The overall wash fastness

rating ranged between 4 and 5 for colour change, indicating good to very good fastness grading.

The treatment of knitted RCT (modified DHEU) brought a positive impact on the tensile strength of P/C fabric with two optimized binder systems i.e. Helizarin Binder CFF and Helizarin ET ECO respectively. The crosslinkers, Fixapret CPF and Arkofix NZF, both conventional and modified DMDHEU offered higher tear strength. In the same set of cross linking treatment, the next highest value of tear strength was attained by Printofix fixative WB liquid, a highly etherified melamine compound. On the contrary, the abrasion resistance and pilling of cross linked P/C fabrics was adversely effected by the same cross linker. As regards the binder types, B2 was found to be better than B1, in fabrics' tear strength.

The flexural rigidity of treated fabrics was reduced by the all cross-linkers, irrespective of the binder types which is in agreement with one of our objectives. However, one of the fabrics, revealed the highest stiffness level of fabric which was induced by Knittex RCT, a modified DHEU, coupled with acrylic binder, Helizarin ET ECO.

Incorporation of softeners

The dry rubbing fastness of simultaneously dyed and finished P/C fabrics with all the softening chemicals was good except Ultratex UM new softener, which showed only satisfactory performance. The wet rubbing fastness of majority of the softeners showed a consistency in results, indicating no beneficial effects and remained at only the desired level of fastness. As regards the wash fastness (shade change) Ultratex UM new (polydimethyl siloxane), Sapamine SFC (Fatty acid amide condensation product and Perapret F PEB new (polyethylene) induced grade“4.5”with excellent results. The staining to adjacent cloth for assessing the wash fastness characteristics of P/C fabric was found to be upgraded by the co-application of sapamine SFC, a fatty acid amide condensation product and DHEU in pigment dyeing formulation.

The maximum increase in tensile strength of the fabrics was accomplished by treatment with S1 and S4, composed of amino functional polysiloxane and macro emulsions polydimethyl siloxane respectively. However, the effect of modified polysiloxane, a nano emulsion softener, showed adverse response with respect to

fabric strength. The yielding point was shifted towards lower level in both warp and weft directions of fabric regarding breaking load and the extension percentage.

According to the results the crosslinkable silicon elastomer (S3) treated fabric, possessed significantly higher tear strength value as compared to other fabrics. Among all the additives applied as softeners, the second highest tear strength retention was attained by the fabric, treated with Ultratex MHT conc. softener.

The control fabric, dyed only with a conventional pigment formulation was assessed to be stiffer due to high binder ratio. However, with cross-linking the textural qualities of the fabric were altered. The modified surface produced low flexural rigidity particularly in warp direction as compared to the weft.

It is concluded that majority of the fabrics attained excellent abrasion resistance with a combined dyeing and softener treatment. Two of the softening chemicals i.e. siligen softener 1, an amino functional polysiloxane and S4, macroemulsion concentrate of polydimethyle siloxane, induced a handsome increase in number of cycles to abrade the specimen.

The treated fabrics presented a slight modification in the flexural rigidity of all the fabrics, though the rate of change sometimes appeared to be reduced or enhanced. A few of the softeners' stability increased the flexural rigidity of fabrics, but, the change was not so obvious. It is self apparent that amongst all the assorted softeners, S5, a fatty acid amide condensation product resulted in the decreased stiffness of pigment dyed P/C fabric. The next higher value was attained by Ultratex UM New and polyethylene in the decreasing order of flexural rigidity. The overall results revealed that the application of softeners generally produced no change in pilling behavior with the exception of Ultratex UM New silicon softener and sapamine SFC softener.

Generally speaking, from the above results it can be deduced that the amalgamation of acrylate copolymer binder with pigment colourant, the cross-linker (modified dihydroxy diethyleneurea) and the earlier mentioned varied softeners in the dye bath formulation represented a compatibility with each other. The cross linker DHEU with fatty acid amide based softening chemical (S5), appeared to be the best alliance for pigment colouration of P/C fabrics as it induced best cumulative fastness properties, highest tensile strength and soft textural qualities to the fabric. However, the fabrics wore off at an earlier stage of testing and adversely affected the tear strength also, as compared to the control fabric.

Effect of functional finishes (types, concentrations and post, and meta treatment) on the properties of dyed fabrics

In the last phase of study, the properties of treated specimens were evaluated on the basis of effect of different types of finishes, concentrations and methods of finish application. As far as the effect of finish type is concerned, the fabrics treated with Pekoflam OP liquid flame retardant and hand building finish, showed the best performance regarding dry and wet rubbing fastness. The wash fastness and staining to adjacent cloth was found to be graded at maximum level of fastness with NUVA FD water repellent and hand building finish. The treatment of soft polyurethane, water repellent (NUVA FD) and the water repellent in combination with oleophillic finish (NUVA 3585) treatment on dyed P/C fabrics had shown a positive impact on wash fastness and maintained at very good level of fastness(shade change).

The treatment of Pekoflam 3585 liquid flame retardant and UV absorber on P/C fabric provided maximum tensile strength. As regards the tear strength, the fabrics had shown highest tear strength with the application of both the flame retardant finishes. The effect of UV absorber and Pekoflam OP flame retardant on the flexural rigidity was found to be beneficial. The fabric stiffness with these finishes was remarkably reduced, providing a soft textural quality as compared to other finishes. The results conformed to one of the initial objectives which were formulated to achieve desirable softness in pigment coloured fabrics. The P/C fabrics finished with Pekoflam OP flame retardant and water repellent (NUVA FD), abraded at the highest number of cycles.

The overall performance of Pekoflam OP, a phosphorous based flame retardant finish produced better colourfastness and mechanical stability to the dyed/finished fabric amongst all.

Effect of different concentrations of finishes

The effect of higher level of finish concentration, induced an improvement in the dry rubbing fastness, wash fastness (staining on adjacent cloth), abrasion resistance, pilling resistance and acceptable stiffness of finished fabrics. As far as the wet rubbing fastness is concerned, the lower concentration had more beneficial effects on the performance of fabrics as compared to other finishing reagents. It was apparent from the overall results, that the shade change after washing treatment,

tensile strength and tear strength offered no change in results, regarding finish concentration.

Effect of mode of finish application on the properties of pigment coloured fabrics.

The colourfastness evaluation on the basis of different methods of applications revealed that, generally the meta finishing pigment dyeing of P/C fabrics, rendered maximum dry rubbing fastness, wet rubbing fastness and negligible staining on the accompanying cloth after wash treatment. The same method provoked the higher tensile strength, tear strength and less stiffness at high concentration, whereas at lower recommended ratio excellent abrasion resistance was achieved. These findings are conformed to the initial objectives of our study.

The results from post finishing method had positive effects on the wet rubbing fastness of P/C fabrics, while for wash fastness (shade change), the process was favorable only at high concentration. The visual assessment of grayscale indicated minor difference in colourfastness properties with polyurethane treatment on P/C fabrics. The dry rubbing fastness of resultant specimen was found to be improved irrespective of the concentration as compared to the reference fabric. At low concentration the level of fastness was better than at high concentration which supports the fact that the degree of improvement from any of the finishing technique is strongly dependent on the appropriate amount of the finishing chemical in particular formulation.

Similarly the average tensile strength enhanced after treatment of increased quantity of finish. A slight improvement in tear strength of tested specimen was also recorded with the post application of various functional finishes as compared to the other method. Generally, the application of various finishes on the pre-dyed fabrics provided less resistance against abrasion test and flexural rigidity.

The post application of NUVA FD liquid at high concentration abraded the PC fabric at more number of rubs. When the concentration was increased from 20 to 50g/L the performance improved. Water repellent finishes induced better response regarding abrasion resistance in comparison to post finishing method. Similarly the same composition with oil repellent NUVA HPU remained non beneficial while simultaneous dyeing and finishing provided resistance against heavy brunt of abrasive action.

The effect of meta finishing with polyurethane finish and hand building finish on tensile strength indicated that the fabric was being strengthened at high concentration of finish whereas, at low concentrations the fabric could not retain its

original strength and weakened by a marginal difference with control fabric. The application of soft polyurethane and another hand building finish on pigment dyed P/C indicated that an increased finish concentration tended to lower down the abrasion resistance. However, when the same were treated at lesser concentration (20g/L) of polyurethane and hand building finish the dyed P/C fabrics exhibited a pretty good abrasion resistance.

In most of the finishing chemicals, no appreciable difference was observed in the pilling properties of the P/C fabrics, before and after treatments, while in some cases combined dyeing and finishing was equal to or better than the finishing on pre-dyed fabrics. The overall investigation reveals that colouration with pigments is the best option for P/C fabrics if an appropriate selection of process parameters along with auxilliarues and finishing is carried out. It will certainly help to achieve the desirable characteristics.

RECOMMENDATIONS

The acrylic based, optimized binder system with good rubbing fastness (wet& dry), washing fastness, maximum tensile strength, abrasion resistance, pilling resistance, good tear strength, and low flexural rigidity of P/C fabrics can be achieved at 50:200g/L pigment/binder ratios, hence this concentration is recommended for P/C fabrics, if dyeing is carried out with eco-friendly pigment colourants. Polyurethane constituted binder is also recommended to be a good binder with respect to wash fastness and dry rubbing fastness, however strength would be sacrificed in this regard.

The results indicated that the process of cross linking could overcome the low strength problems by the application of formaldehyde free cross linker (DHEU) based such as knittex RCT. It is recommended to be feasible option for imparting crease resistance or durable press finishing to P/C fabrics without disturbing their durability.

It is observed that the hard binders film cannot resist the abrasive action and the dye easily crocked off from a hard coated substrate thereby lowering the fastness level, therefore a suitable softener is recommended to be applied with pigment dyeing to reduce the stiffness with minimal adverse effects on fastness and texture.

Softeners constituted on amino functional polysiloxane and macroemulsion concentrate of polydimethyl siloxane are beneficial in enhancing a tremendous increase in abrasion resistance with knittex crosslinker. Fatty acid amide condensation product resulted in the decreased stiffness of pigment dyed P/C fabric.

As regards the mode of application, the meta finishing pigment dyeing is recommended to be an appropriate method for P/C fabrics, as it rendered maximum dry rubbing fastness, wet rubbing fastness and negligible staining on the accompanying cloth after wash treatment. The same method provoked the higher tensile strength, tear strength and less stiffness at high concentration, whereas at lower recommended ratio excellent abrasion resistance was achieved.

Fluorocarbon water repellent finishing can have beneficial effects in developing the resistance against wet rubbing strokes on P/C blended fabrics, if an appropriate liquor stability is maintained by using a suitable ratio of finishing chemical. Similarly, the treatment with liquid flame retardant and hand building

finish, showed the best performance regarding dry and wet rubbing fastness and are applicable on P/C blended fabrics.

The finish composed of organic phosphorous compound can be effective treatment in reducing the flame propagation at low concentration of finish. The application of organo-phosphorus compound on pigment dyed P/C fabric could not well sustain the wet treatment, therefore it is eminently suitable for those products which did not require frequent washing.

In the current study NUVA FD, a fluorine compound with extremely durable water repellent quality, enhanced the dry rubbing fastness at high concentration. The results were further improved by changing the mode of application with the same formulation. So a commercially desirable crocking fastness can be achieved by incorporating fluorine dispersion in pigment dyeing formulations.

Colourfastness to crocking is a multifarious phenomena which needs special consideration. In many instances the apparent loss of colour can be attributed to the surface modification in the fabric, resulting from rubbing action during laundering. Mild rubbing, instead of vigorous rubbing action can minimize the colour loss with simultaneously dyed / finished or dyed- only fabrics.

Keeping in view the impermanency of colours and harsh handle, the undertaken research was focused on the afore mentioned fact, namely, adverse effects of pigment colouration such as higher stiffness and low wet rubbing and these effects can be minimized by applying suitable functional finishes, softeners and crosslinkers.

The overall investigation specify that colouration with pigments in conjunction assorted finishes is best option for P/C fabrics provided that appropriate selection of process parameters along with auxiliaries and finishing is carried out. It is hoped that incorporation of an appropriate level of cross linkers, softeners and variant functional finishing reagents in the same dyeing formulation, would be a feasible option for all those industrialists who are striving for eco-friendly, low energy consuming dyeing systems.

FUTURE PROSPECTS

Although at present scenario market is flooded with numerous colouring materials, there is still dire need for search of an ecologically accepted colourant. Nowadays, functional finishing technology is specifically considered as a technical

link for achieving the 21st century's textile requirements. The technique of pigment dyeing has prospects for providing an environmentally friendly dyeing system, well suited to all fabric types such as polyester/cotton blends. In order to achieve the desired, quality product, the co-application of pigment dyeing and functional finishing reagents on cotton/polyester blended fabric would be of great help. Moreover, the problem of inappropriate effluents disposal will be resolved too, that commonly occurs in conventional dyeing methods.

This research will not only open a new vista of avenues for commercialization of pigment colouration in the market place but also widen the prospects of our country's economy in the world market.

REFERENCES

- American Association for Textile Chemists and Colourists 08. (2005). Standard Test Method for Colour Fastness to Wet and Dry Rubbing.
- AATCC.TM 61. (2006). Colour Fastness to Washing for Shade Change & Staining.
- Abdullah, I., Blackburn, R.S., Taylor, J. (2006). Abrasion phenomena in twill tencel fabric, *Journal of Applied Polymer Science*, 1391-1398.
- Adamiak, M. (2012). Abrasion Resistance of Materials. ISBN:978-953-51-0300-
<http://www.intechopen.com/books/abrasion-resistance-of-materials/analysis-of-abrasion-characteristics-in-textiles>.
- Akaydin, M. (2010). Pilling performance and abrasion characteristics of selected basic weft knitted fabrics, *Fibers & Textiles in Eastern Europe*, Vol. 18, No, 2 (79).
- Alae, M. & Wenning, R.J (2002). The significance of brominated flame retardants in the environment, current understanding issues and challenges, *Chemosphere*, 46, 579-582.
- Arsalan, I. (2001). Treatability of a simulated disperses dye-bath by ferrous iron by coagulation, ozonation, and ferrous iron-catalyzed ozonation. *Journal of Hazardous Material*, 85(B), 229-241.

- Arther, (2001). Basic Principles of Textile Colouration Society of Dyers & Colourists, 327.
- Aspland, J. R. (1997). Textile Dyeing and Coloration AATCC. <http://book.Google.com.pk>. BCIN No: 144768, 315-329.
- Aspland, J.R. (1993), Pigments as Textile Colorants, AATCC, Vol 25, 31 – 37.
- ASTM, D. 3776-07. Standard Test Methods for Mass Per Area (Weight) of Fabric ASTM.D766-07 WTPUAREA.
- ASTM. D. 3775-03 a Standard Test Method for Warp End Count and Filling Pick Count of Woven Fabric.
- ASTM. D1388-08. (2006). Standard Test Method for Stiffness of Fabrics.
- ASTM. D1424-96. (Reapproved 2004). Standard Test method for Tearing Strength of Fabrics by Falling-Pendulum Type (Elmendorf Apparatus).
- ASTM. D4966-98 (Reapproved 2007). Standard Test Method for Abrasion resistance of Textile Fabrics.
- ASTM. D5035-06. (2006). Standard Test method for Breaking Force and Elongation of Textile Fabrics (Strip Method).
- ASTM. D6413-99 Standard Test Method for Flame Resistance of Textiles. (Vertical test) 1-11.
- Board, N. (2004). The Complete Technology Book on Dyes and Dye Intermediates. New Delhi, India. National Institute of Industrial Research Publication, 1-5.
- Booth, J.E.(1996), Principles of Textile Testing.CBS Publishers&Distributors,India. 298.
- Bourbigot, S., Duquesne, S. (2007). Fire retardant polymers: recent developments and Opportunities. *Journal of Materials Chemistry*, 17, 2283-2300.
- British Standards.5811 (1986). Determination of the Resistance to Pilling and Change of Appearance of Fabrics. British Standards Institution.
- British Standards 2543 Textile Guide–Testing, www.holdsworthusa.com/Downloads/).
- Ca, Q. (2013). An Investigation into Development of Environmentally Friendly Pigment Colouration. Ph.D Thesis. Faculty of Engineering and Physical Sciences. School of Materials. University of Manchester, 66.
- Car, C.M. (1995). Chemistry of Textile industry. London. Blackie, Academi and Professional. xiii, 361.

- Cardozo, B. (1995). A problematic approach to pigment printing. *Pigment Printing Handbook*, American Association of Textile Chemists and Colorists Committee RA88, Printing Technology. Research Triangle Park, NC, 31.
- Chakarborty, J. N. (2010). Colouration with pigments, *Fundamentals and Practices in Colouration of Textiles*, Woodhead publishing India Pvt. Ltd, 202-204, 208.
- Chakvattanatham, K., Phattananrudee, S., & Kiatkamjornwong, S. (2010). Anionically surface-modified pigment/binder ink jet inks for silk fabric printing. *Pigment & Resin Technology*, 39 Iss: Emerald Group Publishing Limited, 6, 327 – 341.
- Chattopanday, D. P. (2006). Effect of silicon nano emulsion softener on dyed cotton fabric. *Colourage*: 21-24.
- Chattopandhay, D. P., & Vyas, D. D. (2010) Effect of silicone nano-emulsion softener on physical properties of cotton fabric, *Indian Journal of Fiber and Textile Research*, V.35, 68-71.
- Cheng, S.Y., Yuen, C.W., M Khan, C.W., Cheuk, K. L., Tang, J.C.O., & Li, S.Y. (2009). A comprehensive study of silicone –based cosmetic textile agent. *Fibers and Polymers*, 10 (1), 132-140.
- Chequer, F.M.D., Oliveira, G.A.R., Cardoso, J.C., Carvalho, Zanoni., M.V. & Oliveira, D.P. (2013) Eco-Friendly Textile Dyeing and Finishing, In Tech open access company.
- Cho, H.M., Srinivasan, M., & Nancy., M. (1994). Single–step dyeing and treatment of cotton with 1, 2, 3, 4–Butanetetracarboxylic acid. *Journal of Applied Polymer Science*, 54, 2107–2118.
- Cleik, N., Degermenci, Z., Kaynak, H. K. (2010). Effect of nano silicon softeners on abrasion and pilling resistance and colourfastness of knitted fabrics .*Textil ve Konfeksiyon*, V.1,41-47.
- Collier, B. J., Epps, H. H., (1999). *Textile Testing and Analysis*, Prentice Hall, New Jersey.
- Colorfastness of Cotton Textile (2002). Cotton incorporated Technical Bulletin, ISP 1001. 6399 Weston Parkway, Cary, North Carolina , 1-7.
- Corbman, B.P. (1983). *Textles, Fiber to Fabric*. Mc Grawhill Publishing Company. 221
- Cotton Incorporated Technical Bulletin.ISP 1001.Functional finishes for cotton (2004).. 6399 Weston Parkway, Cary, North Carolina. 5.

- Dong, Y.C., Wang, J., & Liu, P. (2005). Dyeing and finishing of cotton fabric in a single bath with reactive dyes and citric acid. *Colouration Technology. Society of Dyers and Colourists*, 12, 138-163.
- El Zaher, N.A., KishK., S.S.(1996). Study of the effect of UVR on the chemical structure, mechanical properties and crystallinity of Nylon-6 films. *Colourage* . (11) 25-30.
- Fang, K., Wang, C., Zhang, X., & Xu, Y. (2005). Dyeing of cationized cotton using nano scale pigment, dispersions. *Coloration Technology*, 121(6): 325 –328.
- Gohl E.P.J., Vilensky, L.D. (2003). Textile Science, An Explanation of Fibre Properties, 2nd. ed. CBS publishers, 112-115.
- Habereeder, P., Bereck, A. (2002). Silicone Softeners part 2: *Review of progress in Coloration. Colouration Technology* (32): 125-136.
- Hammonds, A.G. (1995). Introduction to binders. *Pigment Printing Handbook*, AATCC Committee RA88, Printing Technology. Research Triangle Park, NC, 31.57-61.
- Hao, L., Cai, Y., & Fang, K. (2009). Dyeing of lyocell fabrics with pigment dispersion systems, *Journal of Dispersion Science and Technology, Taylor and Francis* 30(3), 332 – 335.
- Horrocks, A. R., & Price, D. (2001). Fire Retardant Material. Woodhead Publishing ltd, 32.
- http://en.wikipedia.org/wiki/Fabric_softener, retrieved 27 April, 2012
- Hu, T. (2008). Fabric Testing. Woodhead Publishing series in textiles no.76.
- Hussain, T. Marij, A., Rashid, M. (2013). Modeling the properties of pigment dyed polyester -cotton by response surface methodology. *Colouration Technology*, 129(4). 274-278.
- Hussain, T., & Ali, R. (2009). Comparison of properties of cotton fabric dyed with pigment and reactive dye. *The Journal of the Textile Institute* ,100, 95-98.
- Hussain, T., Ahmad, S., & Qayum, A. (2008). Effect of different softeners and sanforizing treatment on pilling performance of polyester/viscose blended fabrics. *Coloration Technology*. 124. 375-378.
- Hussain, T., Ali, S., Qaisar, F.(2010). Predicting the crease recovery performance and tear strength of cotton fabric treated with modified N-methylol dihydroxy ethylene urea and polyethylene softener. *Coloration Technology. Society of Dyers and Colorists* 2010 (126): 257

- I.S.O. 105-10. (2006). Textiles Tests for Colourfastness-Colourfastness to washing with soap and soda.
- Ibrahim, N.A., El-Zairy., W.M., El-Zairy., M.R., Eid., B.M., & Ghazal, H.A. (2011). A smart approach for enhancing dyeing and functional finishing properties of cotton cellulose/polyamide-6 fabric blend, *Carbohydrate Polymers*, 1068-1074.
- Iqbal, M., Mughal, J., Sohail, M., Moiz, A., Ahmad, K., & Ahmad, K. (2012). Comparison between pigment printing system with acrylate and butadiene based binders. *Journal of Analytical Sciences, Methods and Instrumentation*, 2, 87-91.
- Islam, S., & Akhtar, N. (2012). Comparative study between pigment dyeing and reactive/disperse dyeing on polyester/cotton blend fabric, *Journal of Innovation and Development Strategy*, 6, 40-48.
- Jocic, D. (2010). Functional Finishing of Textiles with Responsive Polymeric System. World Textile Conference retrieved from www.utwente.nl/ctw/efsm/advanbiotex/excellenteam/djocic/proceedings .37-54
- Kadolf, S. J. (2007). Quality Assurance for Textiles and Apparel, ISBN: 156367 144-1, Fairchild.
- Kawath, M.G., Dahiya Atul., Raghavendra, R. H., Kannadaguli, M., & Kotra, R. Chemical Bonding, retrieve 29th March (Updated. April, 2004).
- Kim, S.D., Ahn, J.L.,C.H., Kim, K.S., Lee, K.S. (2004). Dyeing of N/P union fabric with reactive disperse dyes. *Journal of Korean society of Dyers and Finishers*, vol.16 (1), 26
- Lawson, J. W., Srivastava, D. (2008). Formation and structure of amorphous carbon char from polymer materials, *Physical Review .Condensed Matter and Material Physics B* 77:144209.
- Lee, J. J., Han, N. K., Lee, W. J., Choi, J. H, & Kim, J. P. (2003). One bath dyeing of blend polyester/cotton with reactive disperse dyes from 2 hydroxyprid-6-one derivatives. *Coloration Technology*.119.134-139.
- Levchick, S.V & Weil, E.D. (2006). A review of recent progress in phosphorous based flame retardants, *Journal of Fire Sciences*, 24. 345.
- Li, S. (2008). One Step Dyeing and Durable Press Finishing of Cotton. *Fiber and Polymer Science*. Raleigh. North Carolina State University. PhD Thesis, 29-31.

- Lickfield, G. C., Yang, C.Q., Drews, M.J., & Aspland, J.R. (2000). Abrasion Resistance of Durable Press Finish Cotton. National Textile Center: Annual Reporter. C00-C0. 2.
- Malik, Z. A., Malik, M. H., Hussain, T., & Tamuri, A. (2010). Predicting strength transfer efficiency of warp and weft yarns in woven fabrics using adaptive neuro-fuzzy inference system. *Indian Journal of Fibre and Textile Research*. V. 35, 310–316.
- Manich, A. M., Castellar, M. D.D., Suri, R. M., Miguel R. A. Bacella, A. (2001). Abrasion kinetics of wool and blended fabrics. *Textile Research Journal* (71). 469-47.
- Manickam, M.M. Silicon chemistry for fabric care .retrieved from www.bevafinish.com June, 2013, 1-8.
- Meena, C. R., Nathany,. A. Adivarekar, R.V. & Sekar, N (2013). One-bath dyeing process for polyester/cotton blend using physical mixtures of disperse/reactive dyes. *European International Journal of Science & Technology*. 2, 6-16.
- Mike, Agosta. (2002). Polyurethane technology: because of its---, *Coatings World*, 1-6.
- Miles, W.C.L (2003). Textile Printing, 2nd Ed. Society of Dyers and Colourists. Bradford. England. 143, 139-140.
- Mlynar, M. (2003). Chemical Binders and Auxiliaries, Rohm and Haas company, Spring House, PA 19477. 1-15.
- Mlynar. M. (2003). Chemical Binders and Auxiliaries, Rohm and Haas Company, Spring House, PA 19477. retrieved from (mmlynar@rohmmaas.com), 3.
- Molla El, M.M. (2007). Synthesis and characterization of aqueous UV-curable binder for ink preparation in ink-jet printing and pigment dyeing of fabrics, *Indian Journal of Fibre & Textile Research*, 32,105-11.
- Muralidharan, B., & Laya, S. (2011). A new approach to dyeing of 80:20 Polyester/Cotton blended fabric using disperse and reactive dyes. *International Scholarly Research Network Material Science*, 2011, 1-12.
- Nostadt, K & Zyschka, R (1997). Softeners in the textile finishing industry, *Colourage* 144 (1): 53-58.
- Patel. (1995). The use of melamine resin in pigment printing. *Pigment Printing Handbook*, American Association of Textile Chemists and Colorists Committee RA88, Printing Technology. Research Triangle Park, NC. 63-68.

- Prinz, K. (2011). Flame retardant and dyeing treatment of cellulose fabrics using a combined “grafting form” and P/G process. Ph. D thesis. E collection library ethz ch/eserv/ eth 4588/eth 4588 02.
- Raheel, M., & Gua, C. (1998). Single step dyeing and formaldehyde free durable press finishing of cotton fabric, *Textile Research Journal*, 68, 571-577.
- Saber, A.M. (2010). An economical dyeing process for cotton/polyester blended fabrics, *Journal of Textiles & Apparel Technology & Management*.6 (4).1-11.
- Sarvanan, D. (2007). UV protection textile material. *Autex Research Journal*, 7(1)53 - 61.
- Saville, B.P (1999), *Physical Testing of Textiles*. Wood head Publishing Ltd. England.244-245
- Schindler,W.D., & Hauser, P.J. (2004). *Chemical Finishing of Textiles, Antipilling Finishes* Wood head Publishing Ltd, P. 129,132,153.
- Sheldon, F. (1995). A history of pigment printing. *Pigment Printing Handbook*, American Association of Textile Chemists and Colorists Committee RA88, Printing Technology. Research Triangle Park. NC, 45-48.
- Shore, J. (2002). *Colourants and Auxiliaries, Organic Chemistry and Application Properties*, 2nd ed. Society of Dyers and Colourists. 10-19, 408.
- Sir Viryanum,. A, O’ Rear, E. A., Yanumet, N. (2008). Self extinguishing cotton fabric with minimal phosphorous deposition. *Cellulose*. 15 (5), 731-737.
- Smith, S.E. (2011). Pigment dyeing, Conjecture Corporation 2003-2011, Retrieved February 12, 2012 from [http:// www.wisegeek.com.hotmail](http://www.wisegeek.com.hotmail).
- Spencer, T, 2006. Thesis on optimization of ionic cross linking, North Carolina State. 7, 66.
- Thiagarajan, P & Nankalli, G., (2014). Effect of combined application ultra violet absorbers and antioxidant of light fastness of reactive dye cotton fabric. *Science .International*. Lahore. 26(1), 253-256.
- Tomassino, C. (1992). *Chemistry & Technology of Fabric Preparation & Printing*, Department of Textile Engineering, Chemistry and Science College of Technology, North Carolina State University. Raleigh, North Carolina 105, 137-144, 212.
- Uddin, F., & Lomas, M. (2005). Combined crease recovery finishing and printing. *Coloration Technology*. Society of Dyers and Colorist, 121, 138-163.
- Voncina, B., Bezek, D., Marechal, A.M. (2002).Eco-Friendly Durable Press Finishing of Textile Interlinings. *Fibres & Textiles in Eastern Europe*, 68-71.

- Walawska, A., Filipowska, B., Rybicki, E. (2003). Dyeing polyester and cotton-polyester fabrics by means of direct dyestuffs after chitosan treatment. *Fibers & Textiles. In Eastern Europe*. Vol. 11.No.2 (41).
- Wei, Q. (2009). Surface Modification of Textiles, Cambridge, Wood head publishers XX, 37.
- Weil, E. D., Levchick, S.V. (2008). Flame retardant in commercial use for development for textile, *Journal of Fire Sciences*, 26(3). 243-281.
- Whale, B., & Falkoroski, J.R. (2002). Softeners in the textile processing part I: an overview, *Review of Progress in Coloration*, 118-123.
- WWW.ASPEAK.NET. Amino Resins and Plastics, Vol. 1, *Encyclopedia of Polymer Science and Technology*. Copyright John Wiley & Sons, Inc.340-345.
- Xin, J.H., Daud, W.A. Kong, Y.Y. (2004). Anew approach to UV blocking treatment. *Textile Research Journal*.(74).93-96.
- Yorston, R. (1995). The use of melamine resin in pigment printing. *Pigment Printing Handbook*, AATCC. Committee RA88, Printing Technology. Research Triangle Park, NC.101-102.
- Zdinger, H. (2003). Color chemistry, synthesis, properties and application of organic dyes and pigments, John Wiley and sons, 3rd revised edition, 1-2.
- Zurich. (2011). Flame retardant and dyeing treatment of cellulose fabrics using a combined “grafting from” in PIGP process. Ph. D thesis. 1-43.