Optimization of Selected Binder Systems for Pigment Colouration of PES/CO Fabrics with Respect to Flexural Rigidity and Colourfastness Characteristics

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Summary: Pigment dyeing of PES/CO fabrics was carried out by a conventional padding method, incorporated with various binders at different concentrations while at constant thermo-fixation and wet pick-up conditions. The pre-dyed fabric was evaluated and compared for their colourfastness and stiffness properties and the formulations optimized. As regards the effect of binders' type and their concentration, the maximum rubbing fastness (wet and dry) and wash fastness (shade change) was induced by two commercially available acrylic and particularly crosslinkable acrylate copolymer binders at 50:200g/L pigment/binder ratio. The improvement at this concentration by both of these binders endorsed to their appropriate ratio with pigment in the dyeing formulation. With the same ratio of binder a desirable flexural rigidity (41.39 µ Joule/M) was reported in the pigment dyed PES/CO fabrics. One of the polyurethane constituted binders was ranked at the lowest wet and dry rubbing grade at higher binder concentration; however, the same type acquired excellent wash fastness (staining) at 20:150 g/L pigment binder concentration. The flexural rigidity of the dyed fabric at 50:150 g/L pigment/binder concentration remained beneficial in contributing a softer feel to the fabric. In general, the excess amount of binder was considered to be one of the several causes of low crocking fastness and deteriorated fabric handle. But, in the present case a general trend in increased fabric stiffness in terms of flexural rigidity has been observed at higher pigment concentration.

Key words: Acrylic binder, Colour fastness, Flexural rigidity, Crosslinkable, Polyurethane dispersion, wet pickup

Introduction

Dyeing is a technique of imparting a coloured substance (whether natural or synthetic) to a textile material like fiber, yarn and fabric. In general it is applied in an aqueous solution, and sometimes requires a mordant; a particular chemical material to improve fastness properties [1]. 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 with pigment colouration system, which differs from conventional dyeing by not presenting any chemical or physical affinity for the fibers, but, they can be attached to the substrates of different compositions with a binding agent. Another quality of pigment dyeing is that it does not require the post wash treatment [2, 3]. As, the textile industry consumes a considerable amount of water in its production plants particularly in the dyeing and finishing processes. The waste water load from such industries cause severe environmental pollution [4] which can be minimized by adopting pigment colouration system.

Despite their insolubility, pigments can be applied to any polymeric substrate but by a diverse mechanism unlike dyes. It comprises the surface only colouration system unless the pigment is allied with any polymeric compound before the application on textile substrates. Regardless of the small particle size pigments have to bond to a substrate by the assistance of some additional compounds like by-polymers in paints, plastics, or melts [5]. 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.

Pigments are small insoluble particles which have little or no affinity for the fiber or fabrics. To boost their functionality it is required that pigments be attached with the fiber by a film forming material, called binder [6]. It is a polymeric compound, 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, Fig-1. [7] which is a simple mechanism of film formation.

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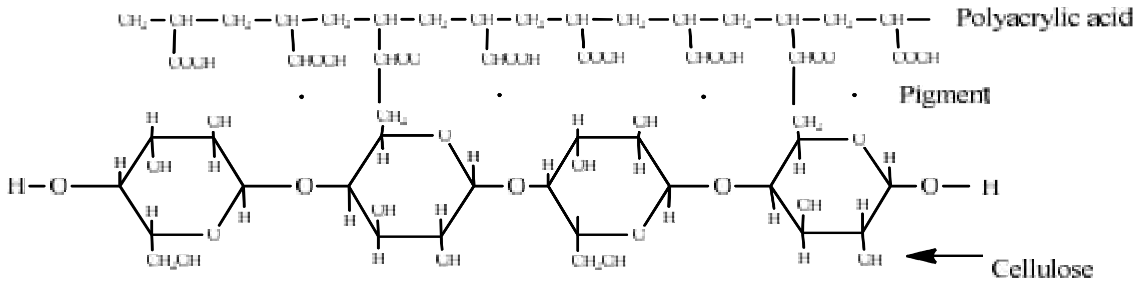


Fig 1: Mechanism of film formation of pigment/binder with cellulose.

A few drawbacks of printing with pigments are curing at relatively high temperature, stiffness and low grades of crock fastness of printed products. As 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 and applied for inks of inkjet printing and pigment dyeing of various fabrics i.e. cotton, viscose, wool, polyester and nylon 6, 6 fabrics. In case of colour fastness to crocking properties of polyester, it was graded as moderate to good level of fastness[10]. 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 significant characteristics of the binder are to enhance the colouring outcome of pigments on the substrate, to deliver mechanical stability and re-dispersibility into liquid. The key factor influencing the crock fastness and adhesion of the binder coating to the substrate is the cross-linking efficacy of the binder [11].

The important crieterian for the performance of a coloured fabric is its colourfastness properties for which the American Association of Textile Chemists and Colourists have developed several procedures of which the wash, light, perspiration, dry cleaning, abrasion and heat fastness are common.[12,13]. The degree of colour transfer from a dyed textile material is affected by several parameters such as the type and concentration of colouring matter, dyeing, fixation process, crosslinking quality, contact parameters including time, temperature and moisture. The problems of pigment dyeing i.e. fair crocking fastness properties, reduced tear strength and deterioration of fabric handle has been reported especially in deep shades [14]. Keeping in view the above parameters the current study was focused on evaluating the effect of different binders in different concentrations on the flexural rigidity and the colourfastness characteristics of pigment coloured PES/CO blended fabrics.

Material and Methods

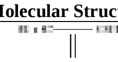
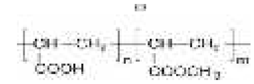
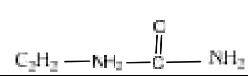
Fabric

The medium weight polyester/cotton fabric, containing 65/35 blend ratio with areal density of 108g/m.^{2} was used in the present research study. The greige fabric was de-sized by industrial pad batch method, while scoured and bleached by pad-steam method prior to further processing.

Pigment and Auxiliaries

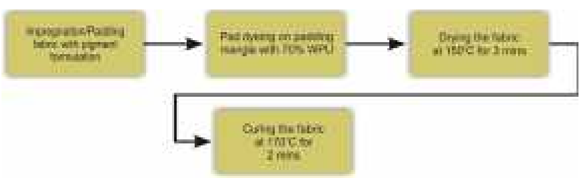
The Pigment Red and the Setamol-BL dispersing agent (sodium salt of a condensation product of naphthalene sulphonic acid and formaldehyde) were obtained from BASF chemical company, Pakistan. The type of binders, applied with dyeing formulations is given in Table-1.

Table -1:Types of binders

Code No	Trade Name/Source	Chemical nature	Molecular Structure
B1	**Helizarine Binder CFF (BASF Chemical Company)**	**Acrylic Dispersion**	
B2	**Helizarine Binder ET ECO (BASF Chemical Company)**	**Crosslinkable acrylatc copolymer**	
B3	**Printofix Binder MTB (Clariant International Limited)**	**Self-crosslinking acrylate co polymer dispersion**	---------
B4	**Printofix Binder 77 N liquid. (Clariant International Limited)**	**Self-cross-linking acrylic dispersion**	--------
B5	**Printofix Fixative WB liquid (Clariant International Limited))**	**Aliphatic Polyurethane dispersion**	

Pad dyeing of Fabric

Pigment dyeing was carried out on laboratory padder model VPM-250, from Nippon-bashi, Japan. The drying and curing was done on an over feed pin tenter of model number OPT-1 from Tsuji dyeing machine manufacturing Helizarin pigment red, binder and setamol dispersing agent(1-2ml /L). The formulations were distributed company, Ltd. All the fabric specimens were padded by double dip double nip technique with a wet pick up of 70% with an aqueous formulation containing in to five sets of binders in different concentrations and applied according to the following scheme.



Scheme 1: Sequence for application of pigment

Testing

Rubbing fastness (wet & dry)

Colourfastness to wet & dry rubbing was assessed on crockmeter according to the standard test method, AATCC-08[15].

Washing fastness (Shade Change and Staining)

Colourfastness to washing was tested on Launder-o-meter in accordance with the AATCC-TM 61[16] standard method. The specimens were evaluated for shade change of dyed fabric and staining against untreated fabric using standard Grey Scal.

Flexural Rigidity

The flexural rigidity test was determined on Shirley Stiffness Tester according to the method given in ASTM. D 1388-08 [17]. The flexural rigidity of the dyed specimens was calculated as following:

$G = (1.241 \times W \times C^3 \times (10^{-5})$,where W = Fabric mass per unit area (g/cm$^{2)}$.and C is bending length (mm)

The statistical analysis of the results was carried out by Minitab 17 software package. The main effects plots of the results were drawn by the ANOVA tables and the same modal was applied (general linear model) to assess the effect of various binders, pigments and binder concentrations on the properties.

Results and Discussion

Effect of Different Binders on the Colour fastness Properties of Pigment Dyed Fabrics

Dry Rubbing Fastness

A summary of the colourfastness results of polyester /cotton fabrics dyed with different pigment concentrations, different binder types and concentrations is given in Table-2. The analysis of variance (ANOVA) of the results, given in Table-3 indicates that only the effect of pigment concentration is statistically significant on the dry rubbing fastness of the dyed samples (P-value < 0.05). The main effect plot for dry rubbing fastness is given in Fig-2, which shows a decreasing trend in the fastness with increase in pigment concentration and an increasing trend with high binder concentration. Fig-3 display results of the individual samples treated with different types and concentration of binders at different concentrations of the pigment. The best performance of dyed fabrics was contributed by the binder B1, B2 and B3 maintaining the good rubbing fastness level at 20:150 g/L pigment/binder ratio, whereas, the maximum degradation in the values for dry rubbing fastness was induced by the binder B3 at higher pigment/binder concentration.

Wet rubbing fastness

The analysis of variance (ANOVA) of the results (Table-4), shows that the effect of pigment concentration and binder type is statistically significant on the wet rubbing fastness of the dyed samples. 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 Fig-4, which shows a decreasing trend in the wet rubbing fastness with increase in pigment concentration, and an increasing trend in 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. Fig-5 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 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.

Washing fastness (shade change)

The analysis of variance (ANOVA) of the washing fastness regarding change in colour are presented in Table-5 which reveal that the effect of pigment concentration, binder type and binder concentration are statistically non-significant on the washing fastness of the dyed samples. The main effects plot for shade change shows a slight decline in fastness level with an increase in pigment concentration (Fig-6). The binder B2 and B5 exhibited slight change in shade and was found to be statistically least affected by washing. In case of effect of binder concentration a directly proportional relation occurred with the mean wash fastness values of fabrics. The shade change grading was raised gradually with binder concentration and then stabilized at optimum 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 Fig-7. Though, B3 had poor rubbing fastness, yet it exhibited the highest wash fastness grade (5) denoting no change in fabric shade at all.

Table-2: Effect of pigment, different binder types and their concentrations on colourfastness of the dyed samples.

Sample No.	Factors: Pigment Conc. g/L	Binder Type	Binder Conc. g/L	Responses: 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

Table-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

Table 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

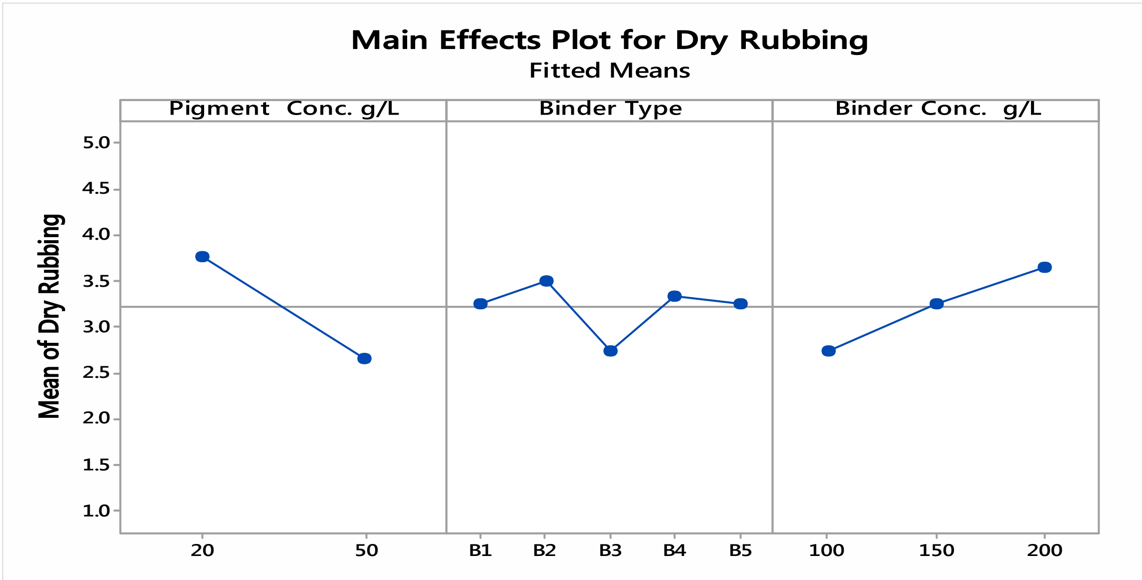


Fig. 2: Main Effect Plot for dry rubbing fastness of dyed PES/CO fabrics.

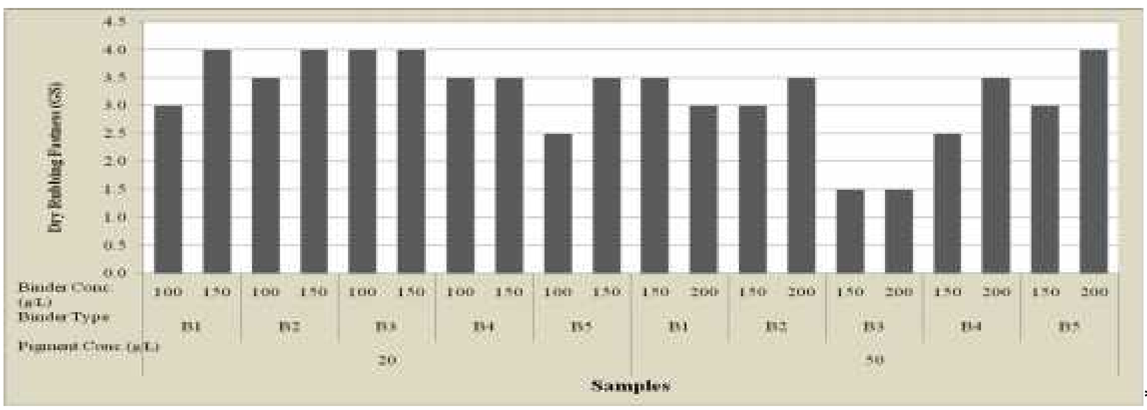


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Fig. 3: Effect of pigment concentration, binder type and binder concentration on the dry rubbing fastness.

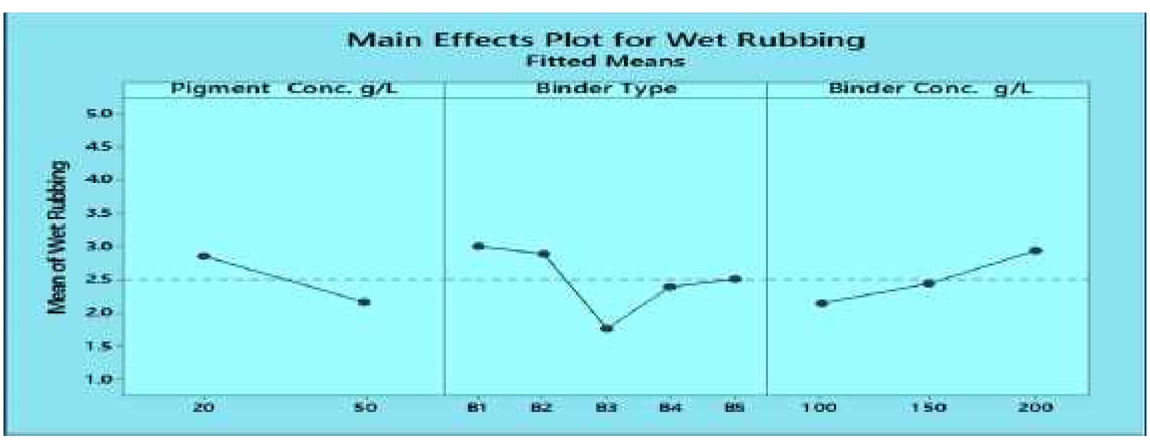


Fig. 4: Main effects plot for wet rubbing fastness of dyed PES/CO fabrics

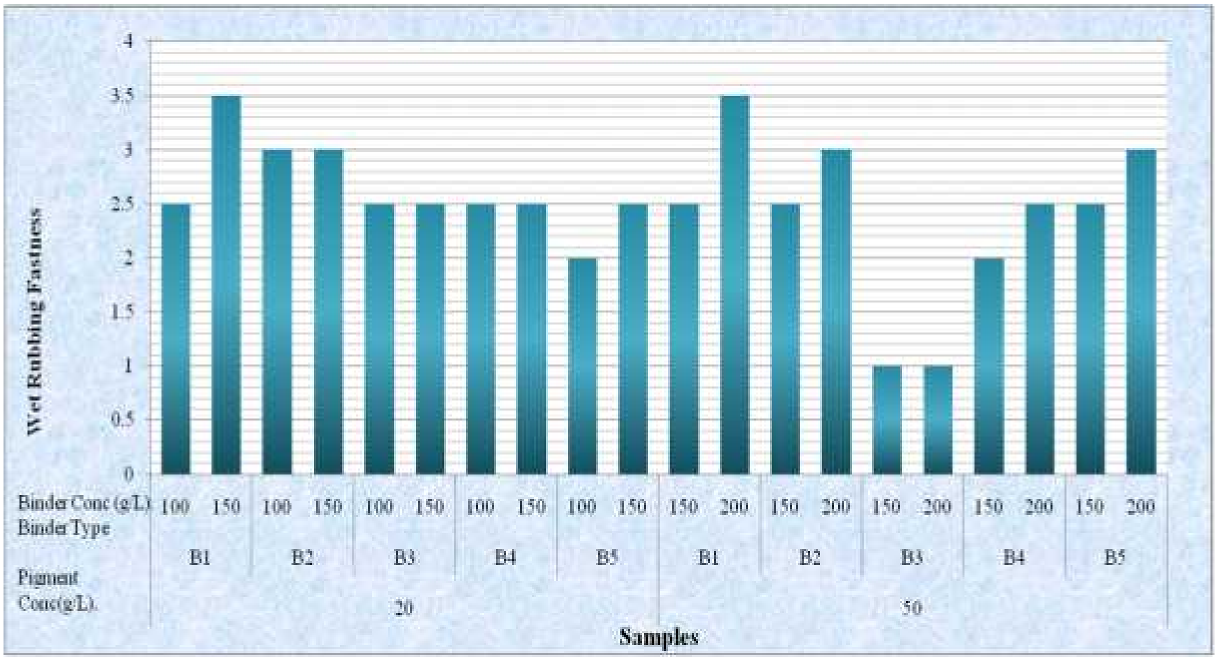


Fig. 5: Effect of pigment concentration, binder type and binder concentration on the wet rubbing fastness.

Table 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

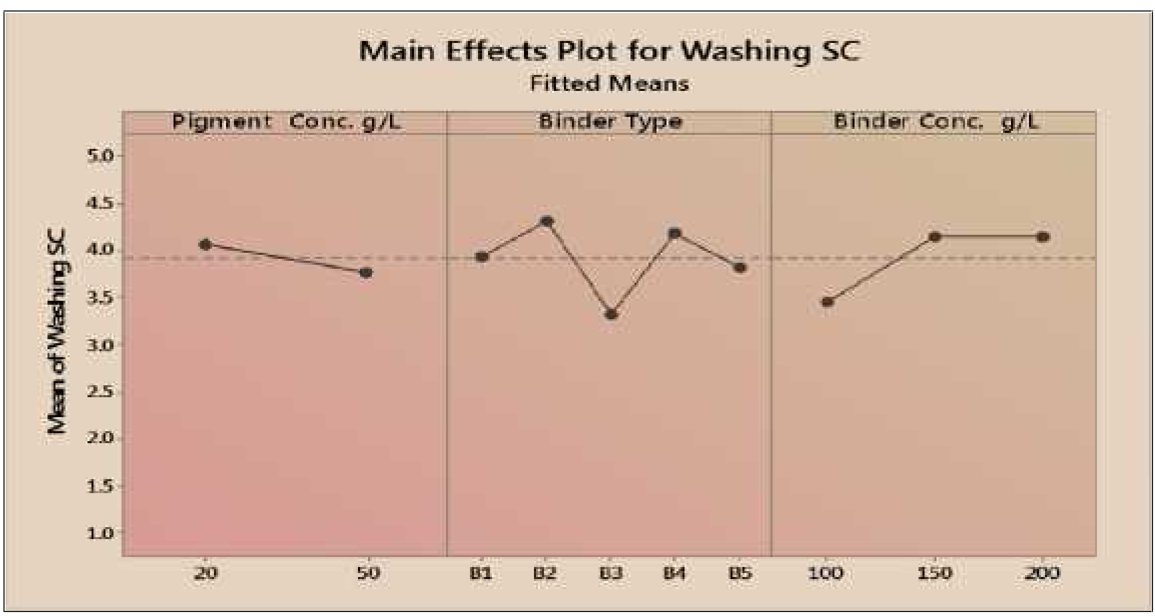


Fig. 6: Main effects plot for washing fastness (shade change) of dyed PES/CO fabrics.

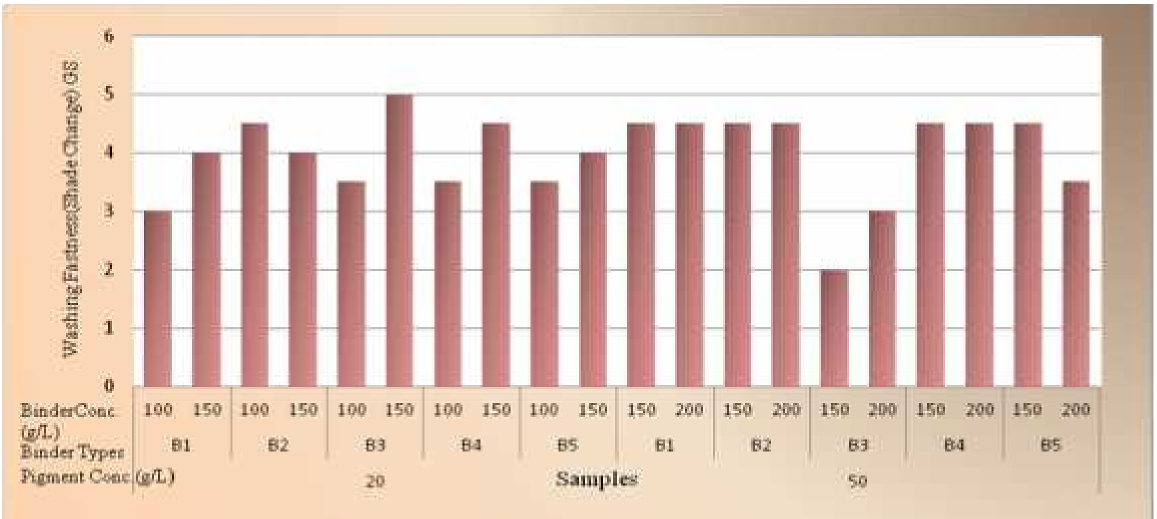


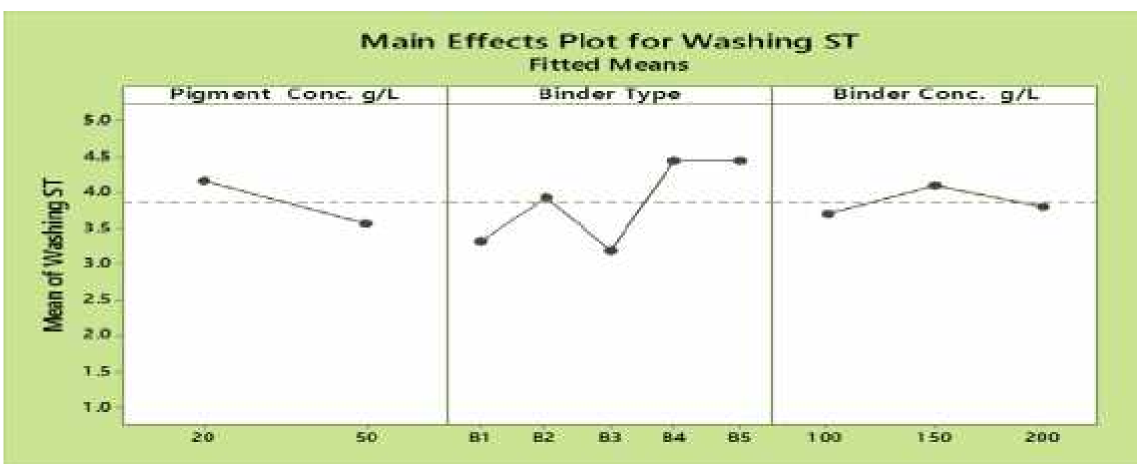
Fig. 7: Effect of pigment concentration, binder type and binder concentration on the washing fastness (shade change)

Washing fastness (staining)

Table-6 presents the analysis of the variance of the staining to adjacent cloth occured due to washing treatment of dyed PES/CO fabrics. As regards the pigment and binder concentration, the effect on colour change was statistically non-significant while the binder type affected the same with a significant difference in the mean values. The main effects plot for ANOVA of washing fastness with respect to staining on adjacent cloth is given in Fig-8, 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 fastness on PES/CO 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 earlier 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 9.

Table-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**	**3.300**	**0.3125**	**-**	**-**
Total	**19**	**11.1375**	**0.02750**		



*Statistically significant at P value 0.05

Fig. 8: Main effects plot for washing fastness (staining) of dyed PES/CO fabric.

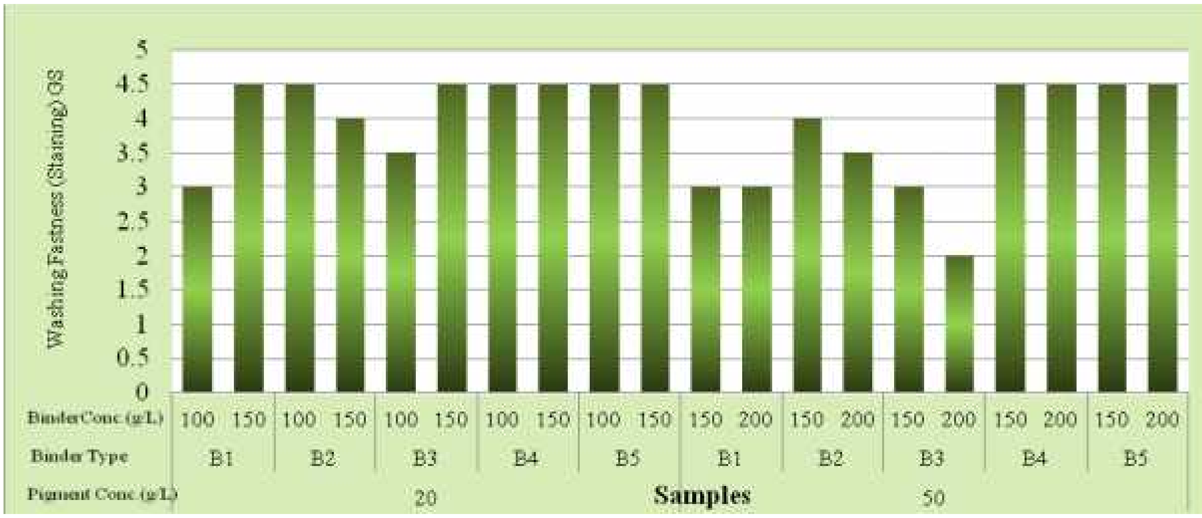


Fig. 9: Effect of pigment concentration, binder type and binder concentration on the washing fastness (staining)

The results of colourfastness properties of dyed fabrics regarding various types of binders show that the optimum rubbing fastness was obtained by acrylic binders 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 PES/CO fabrics. Such an influence of pigment/binder ratio on fastness grading was reported by Islam and Akhter [18], who conducted a study on 50:50 Polyester/Cotton 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 de-gradation of the colour fastness of 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 partially in agreement with our study in which the similar difference in wet and dry rubbing fastness of dyed PES/CO fabric was noticed. Another crosslinkable acrylate co-polymer (Helizarin binder ET- ECO) which induced the highest wet rubbing fastness with an acceptable level of 3.5 GS, conformed to the BS 2543 (Textile guide Testing). Furthermore, the performance of acrylate polymers mentioned by Kawath et al [19] supports our finding according to which these binders are generally excellent due to their resistance against degradation by chemicals, heat and light. Since the functionality of binders is related with crosslinking ability, therefore, the acrylic binders, comprising carboxylic acid provides reacting sites for crosslinking with other polymers. Another polyurethane based binder called Appretan PU, imparted very good colourfastness properties in the dyed PES/CO fabric. A consistent and even film formation tended to reinforce the binding force between polyurethane dispersion and pigment/fabric matrix. The results seemed in accordance with the report given by Agosta, M [20] according to which polyurethane dispersions have excellent chemical and scrubbing resistance as coating materials in several products.

Flexural rigidity

The effect of pigment concentration, and binder types in different concentrations on flexural rigidity of the dyed samples is summarized in Table 7. The analysis of variance (ANOVA) of the aforementioned results is presented in Table.8 which shows the statistically significant effect of binder types on the flexural rigidity of the dyed PES/CO fabrics. As regards the pigment and binder concentration it exhibited a non-significant effect on the flexural rigidity of 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.

In current study the binders produced variant stiffness levels in dyed fabrics, though the process conditions remained unchanged along different ratio of pigment/binder in each padding liquor. One of the binders with the typical recipe at 150g/L binder induced only an insignificant increase in fabric stiffness and hence a minor effect on its handle. Though, it was estimated that the flexural rigidity would be increased, yet, here the difference in the expected results might have been occured by the self crosslinking acrylate copolymer dispersion, which reduced the stiffening level of fabrics due to its low glass transition temperature (Tg). The results are supported by Mlynar [21] who stated an inversly proportional relationship of Tg with softness, the lower the Tg, the softer is the polymer. Keeping in view the above mentioned results, it appears 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/Dowloads/).

Table-7: Effect of pigment concentration, and different binder types and concentrations on flexural rigidity of the dyed samples.

Samples	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-8: 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

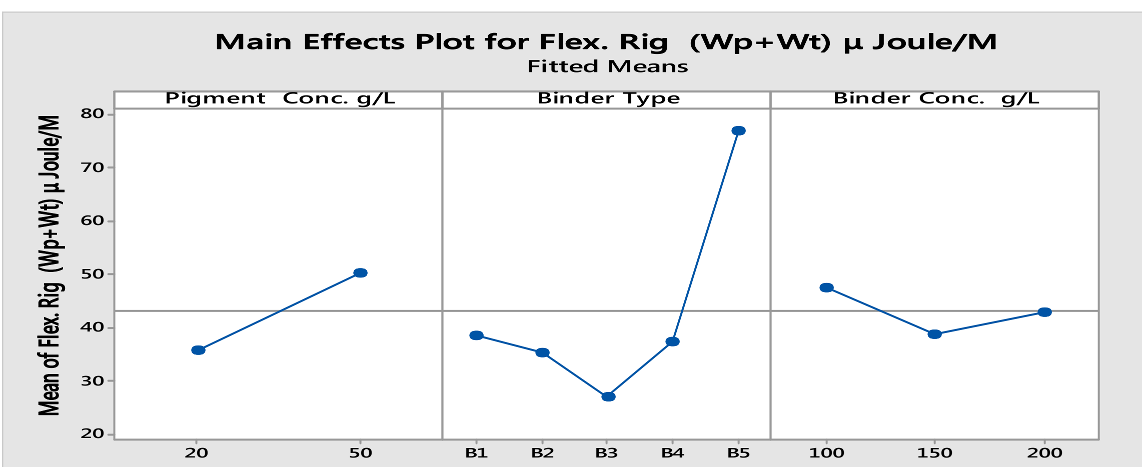


Fig 10: Main effects plot for flexural rigidity of dyed P/C fabric.

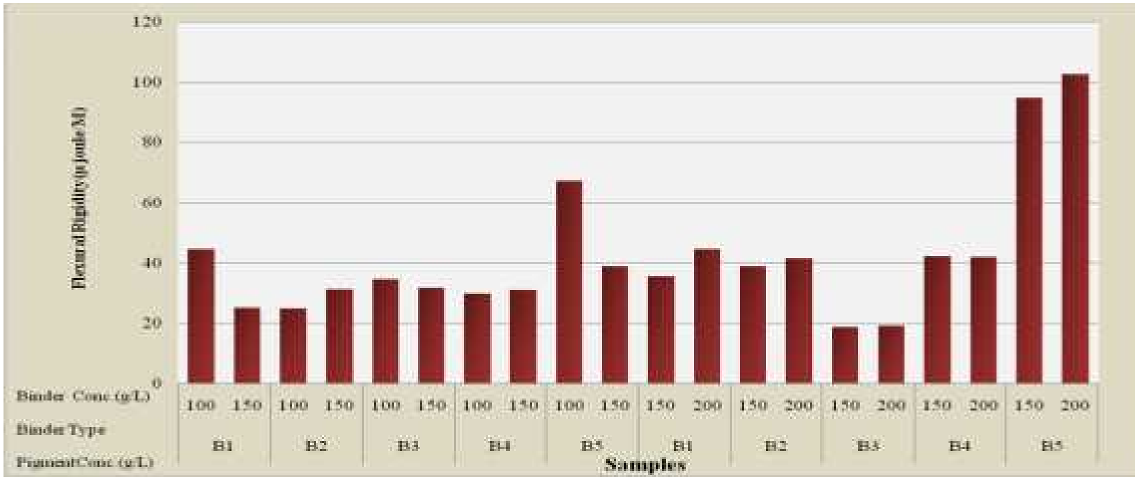


Fig. 11: Effect of pigment concentration, binder type and binder concentration on the flexural rigidity,

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Conclusions

The colourfastness properties of pigment dyed PES/CO blended fabrics regarding various types of binders show that optimum rubbing fastness was obtained by acrylic binders i.e. Helizarin Binder CFF and Helizarin Binder ET ECO, of which the highest wet rubbing fastness conformed to the later one. Polyurethane based binder called (Appretan PU) was another type responsible for the induction of very good wash fastness properties in the dyed fabric. The maximum value of polyurethane treated fabrics suggests that it had developed a good pad /liquor stability in the formulation, yielding an increased resistance in fabric against wash and dry rubbing fastness tests. At higher pigment concentration the dyed specimens, achieved better dry and wet rubbing fastness as well as the wash fastness (shade change and staining). As regards the effect of binder concentrations both an increasing and decreasing trend in the level of fastness was observed, however, the optimum results were obtained at 50:200g/L pigment/binder concentration. The self-crosslinking acrylate copolymer constituted binder is recommended to be a suitable option for pigment dyeing of PES/CO fabrics particularly with respect to its softer handle, however, wet rubbing fastness would be sacrificed in this regard. Though the high binder concentration in pigment formulation resulted in low crocking fastness and deteriorated fabric handle. But, in the present case a general trend with increased flexural rigidity of the dyed fabric has been observed at higher pigment, instead of binder concentration. It is concluded that the technique of pigment fixation has prospects for providing a friendly environment dyeing system, well suited to PES/CO fabric blends. Further it is more beneficial if incorporation of binders and pigments be carried out with an appropriate selection, chemical constitution and concentration of the commercially available binders in the pigment formulation along with the thermos-fixation parameters.

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