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THE INFLUENCE OF ACRYLIC BINDER ON THE QUALITY OF PIGMENT PRINTED KNITTED FABRICS

Moni Sankar Mondal [1,*], *Naimul Hasan*[1]
[1] Department of Textile Engineering, Khulna University of Engineering & Technology, Khulna-9203, BANGLADESH

ABSTRACT
Acrylic size is a copolymer of acrylate and a sizing agent for spun yarns that is easy to remove. The mixture has a high adhesive strength, is homogeneous, and is quite stable. Suitable for spun yarn used in low-count textiles, including cotton, CVC, rayon, and denim. Additionally, to being elastic, its coating is also antistatic. The primary purpose of the research work was to analyze the Viscosity of pigment paste, pigment penetration behavior, a relative color strength of Pigment printed fabric, stiffness, and different fastness properties of pigment printed fabrics for different concentrations of acrylic binder (100gm/L,120 gm/L,140 gm/L, and 160 gm/L) at two percentages (4%, Light shade and 5%, Dark shade). The viscometer determined the Viscosity of each pigment paste. Printing was done at lab scale on single jersey cotton, polyester, and CVC knitted fabrics by hand screen frame. The reflectance of Pigment printed fabrics before and after wash was examined in a reflectance spectrophotometer for this work. The K/S values were calculated to determine pigment penetration and the relative color strength% of these samples. The SEM image of printed fabric was distinguishable about increasing pigment penetration% into the fabric due to binder concentrations. On the other hand, the fixing agent did not show such a noticeable effect on pigment penetration. It has been found that wet and dry rubbing fastness increased up to 4.1 and 4.6, respectively, with the increase in binder concentrations. The stiffness graphs also showed a higher trend with increased binder concentration. Experimental data showed that a higher amount of acrylic-based binder could increase the rubbing fastness, pigment penetration, and stiffness but wash and light fastness were almost constant 4 and 5 ratings on the grey and blue scale, respectively. This study focuses on the optimal usage of acrylic binder, which the pigment printing industries have not previously prioritized. This will help improve the overall pigment printing quality and reduce chemical consumption.

Keywords: Pigment printing; Acrylic Binder; Color strength; Pigment quality; Fastness properties

1. Introduction

Dyeing is an essential part of the textile manufacturing process where dyes are applied for uniform colorization to the substrate along with required colorfastness. In general, Textile colorization is done mainly in two methods through which a fabric acquires the necessary colorization. One is the conventional dyeing process, where dye molecules are fixed to the fibers by absorption, diffusion, or chemical bonding. The other is the printing process, where colorization is done with the help of pigments and different kinds of binders [1]. Pigment printing is one of the most efficient and commonly used techniques due to its reasonable cost, low environmental effect, and versatile use of all kinds of substrates, including glass fibers, PVC, and imitation leather, subject to some limitations in color depth [2]. Also, eliminating washing off after fixation, quick sampling, and high printing speeds enable maximum production rate. However, comparatively higher curing temperature, the stiff hand feel, and poor crock fastness seem to be some of the significant drawbacks of the printing process. Those downsides are closely related to the types of binder used [3,4].

Pigments are organic or inorganic colorants in a particular form, showing no affinity towards textile fibers. Also, pigments are insoluble in an aqueous medium into which they are conjoined and are mechanically dispersed to modify such media's color and light scattering properties [5]. Binders form flexible films that encapsulate pigment particles kept pigment adhered to the fabric surface without swelling during laundering and dry cleaning, through which optimum fastness properties are achieved. Therefore, the choice of binders is essential, which is chosen according to the final fastness requirement of the product as well as the cost requirements of the process [6]. However, the choice of binder may be complicated but critical steps while developing a recipe may satisfy the specific requirements. Depending on the end-use, different polymers are used to achieve the desired result by achieving particular characteristics. All the polymers used in the textile are addition polymerization products, which are copolymer types [7].

Though the binder film in pigment print is a three-dimensional structure, the third dimension is less important than the other two [8]. The binder is a film-forming substance consisting of a long chain of macromolecules applied to the textile substrate along with the pigment forming a three-dimensional network. The links are formed during the fixing process by applying dry heat and variation of pH value bringing about either self-cross-linking or reaction with other suitable cross-linking agents [9,10]. Higher elasticity and improved adhesion of the film to the substrate can be achieved by cross-linking. Covalent bonds are insensitive to hydrolyzing agents (washing liquor, perspiration, industrial atmosphere) produced by the cross-linking reaction.

The reaction is accelerated in dry, hot air through the curing process. After drying, a layer of film is formed from the dispersed binder. Initially, absorption and evaporation remove water and surfactants from the binder

* Corresponding author. Tel.: +88-01716335078
E-mail addresses: sankarmondal@te.kuet.ac.bd

at the film formation. The dispersed solids coagulate, forming a gel-like layer of very tightly packed 'balls', with poor solidity and adhesive properties [11,12]. Using mechanically more stable, more re-dispersible dispersion binders, these coagulated particles return to their original form by rubbing in water. The gel particles flow together during the second phase and form a continuous film [13]. The lowest temperature at which a film can be formed depends upon chemical constitution, but for pigment printing, it is usually around 5°C. The acceleration of film formation relies on the range of particle size.

The addition of cross-linking agent increases the crocking, washing, and dry-cleaning fastness properties, but it degrades the fabric handle feel [14]. Therefore, if there are no self-cross-linking groups, an additional cross-linking agent such as urea, formaldehyde, or melamine formaldehyde condensate, methylated urethane compounds, etc., has at least two reactive groups per molecule needs to be added to the binder system [15].

The fastness levels of medium or dark-colored prints on materials made from polyester fibers are, at best, only suitable for articles that will not be subjected to a great deal of wear [16,17]. Dark-colored prints on woven and knitted goods of synthetics are especially susceptible to abrasive wear and a reduction in color strength by use. Pigments are sensitive to crushing during roller, particularly where bulky materials and deep engravings are concerned [18]. The binder film covers the original surface of the textile material. This is occasionally aesthetically effective but usually undesirable [19,20].

The present research demonstrates the effect of different concentrated acrylate-based binders on pigment printing at different qualities such as Viscosity of pigment paste, Penetration behavior of pigment, printed outline sharpness, color strength, stiffness, wash fastness, light fastness, color strength, stiffness, and crocking fastness.

2. Materials and Method

Materials

For this work, single jersey scoured and bleached cotton and CVC fabric was provided by Rapa Knitwear (Pvt.) Ltd., Kunia, Board Bazar, Gazipur, Bangladesh and Polyester fabric was supplied by Biswas Textiles Ltd (Biswas Group). Shokran, Mirza Nagar, Savar, Dhaka. Printofix Blue HBP Pigment of Copper phthalocyanine (CI Pigment Blue 15) and Acrylic Binder (Printofix Binder 77N) were supplied by Archroma (Bangladesh). In addition, other printing assistants such as Acrylic-based thickener (Printofix thickener CLN) mand Antifoaming agent (Antimasul UDF) were collected from Archroma (Bangladesh), Ammonia (Acid-liberating agent) and urea (Hygroscopic agent) were purchased from a local chemical store, Dhaka, Bangladesh.

Methodology

2.1 Recipe formulation

The amount of binder in printing paste is normally determined by Pigment weight in the printing industry. The binder for light shade (4%) and dark shade (5%) are {(g/kg Pigment ×2.5) + 25}gm and {(g/kg Pigment ×3.5) +30}gm, respectively. Recipes of different concentration binders at light shade % for fabrics are given below in **Table1**.

Table 1: Recipe of different concentration binder at light shade % for fabrics.

Shade		Paste ingredients						
	Pigment (gm/L)	Binder (gm/L)	Thickener (Printofix thickener CLN)	Fixing agent (Printofix Fixer WB)	Antimasul UDF (gm/L)	Urea (gm/L)	Ammonia (gm/L)	Water (cc)
Light Shade (4%)	40	100	25gm	10gm	5	10	10	800
		120	"	"	"	"	"	780
		140	"	"	"	"	"	760
		160	"	"	"	"	"	740
Dark shade (5%)	50	200	25gm	10gm	5	10	10	690
		220	"	"	"	"	"	670
		240	"	"	"	"	"	650
		260	"	"	"	"	"	630

2.2 Printing Process

2.2.1 Pretreatment of textile material

The grey fabric's pretreatment process was done to remove the dirt, dust and impurities from the grey fabric. The liquor ratio for the pretreatment process was 1:20. Detergent (ECE A Non-Phosphate, UK) was used at the rate of 2gm/L and sequestering agent (SARAQUEST-AO, India) was used at the rate of 1gm/L. H_2O_2 (Modern Chemical, Dhaka, Bangladesh) was used as the oxidizing agent, and the amount of H_2O_2 was 0.5 gm/L. In order to keep the functionality of H_2O_2 intact, a stabilizer was used at the rate of 1 gm/L. The amount of NaOH (Modern Chemical, Dhaka, Bangladesh) was 1 gm/L. The grey fabric, water, chemicals and auxiliaries were taken into a nozzle at room temperature and then put into a pretreatment machine. The pretreatment process began, and the temperature increased gradually to 85°C. After that, the pretreatment process ran for 30 minutes at that 85°C. The nozzle was cooled down and removed from the machine when the process was over. A hot wash followed by a cold-water wash was done to the fabric, and they were then treated with a 1% solution of Acetic acid (Modern Chemical, Dhaka, Bangladesh) for the neutralization process.

2.2.2. Printing procedure

Various machines are used for printing, but the fabric was printed by hand screen frame at the lab scale. For this study, the local hand screen frame used was 125 circles/square inch and made from Nylon fabric. At first printing, the paste was done and maintained its Viscosity, put the paste on the screen, wiped it with a doctor blade with accurate pressure, and got the printed cloth for drying and fixation.

2.2.3 After-treatment

After printing, the specimens were brought for drying and fixation at a lab curing machine (Werner Mathis AG, Textilmaschinen, Switzerland). The temperature of the curing machine was set at 120ºC, and drying was done for one minute. The machine temperature was set at 150ºC for fixation because pigments are not soluble in water and do not fix. Fixation was done for 5 minutes at 150ºC, and fixed the sample.

2.3. Characterization and Measurements

2.3.1 Viscosity of printing paste

To calculate Viscosity, a Viscometer manufactured by Brookfield, Massachusetts, USA, was used and the ASTM D2196 testing method was used for the test. The Viscosity is calculated according to the following **Eq. 1.**

Dial reading ×Factor = Viscosity in cP (mPa*s) … (Eq.1)
Example: LVT Viscometer with #4 spindle 30 rpm
Dial Reading: 62   Factor: 200
So, Viscosity = 62×200= 12400cP (mPa*s)

2.3.2 Scanning electron microscope (SEM) analysis of cross-sectional layer of print

The microstructure of Knitted fabric after pigment was printed was characterized by using SEM (Scanning Electron Microscopy) Model Hitachi S-3400N (Bangladesh Council of Scientific and Industrial Research, Dhaka) with digital microscopy. First, cut the sample along the cross-section to carry out the pigment penetration test. Then operate the machine by starting the SE detectors because we need only cross-sectional images. For this experiment, a 15kV energy beam was used to gather better surface information.

SEM test was done for those samples to better understand the binder concentration effect. There are two ways for SEM test by using BSE (Backscattered electron image) and SE (Secondary electron image). SE was used here due to the demand for the surface view to better compare pigment penetration. The beam energy was 15KV with different magnifications such as 200µm,300µm and 500µm. One important thing is that the image's appearance depends on the same beam energy, not different magnification. From analyzing the table (Table 2) built up by experiment values using a standard equation of color strength at the face and backside, pigment penetration was proportional to binder concentration. For better comparison, six samples of 100gm and 160 gm binder-treated cotton, polyester, and CVC fabric (two samples of each fabric) were taken for the SEM test, and the test results are shown in **Fig.1.** These SEM test results in **Fig.1** show that pigment penetration depended on the binder concentration, i.e., pigment penetration increased with the increase of binder concentration. SEM images delineate more pigment penetration at high concentrations than low binder concentrations, and our equation-based results represented the same behavior. So, it can be concluded from both our experiments that pigment penetration is proportional to binder concentration. Therefore, for better printing quality, low pigment penetration is preferred.

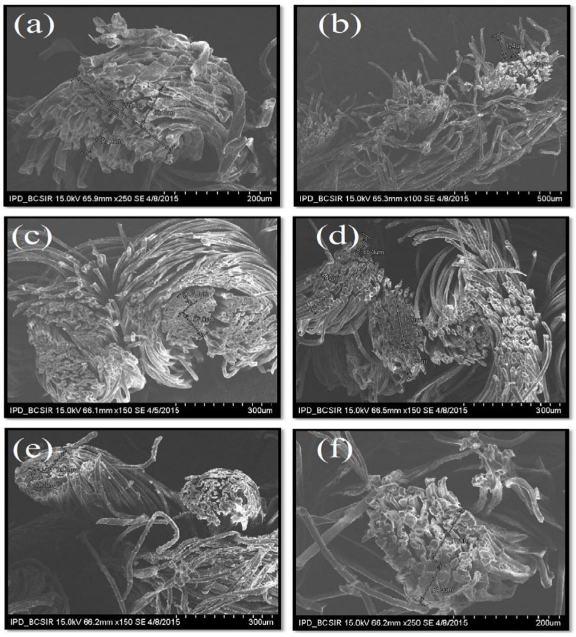

Fig. 1: SEM image of pigment printed Cotton fabric for (a) 100gm and (b)160gm; Polyester fabric for (c) 100gm and (d)160gm binder; CVC fabric for (e) 100gm and (f)160gm binder.

2.3.3 Microscopic observation of printed outline sharpness

The sharpness of the printed outline was checked by Trinocular Microscope BLS-114 (BL Scientific Instruments CO. India) at Textile Engineering Department, KUET. Then, by cutting the knitted fabrics of cotton, polyester and CVC according to the width size of the slide holder and the fabrics containing color and white portion side by side, set color-coded DIN Objectives len at- 4x/0.10. Finally, adjusting the coarse and fine focus knob and closing the eyepiece tube, take the sample image on the computer screen where suitable software was pre-installed. The output results are shown below in **Fig.2**.

From **Fig.2**, it is clear that the binder had no noticeable effect on the sharpness of the printed borderline. However, from the microscopic image of the border line, some deviations were noticed, such as 120gm/L & 240gm/L treated CVC fabric showing some bleeding at the border line as like 220gm/L binder treated polyester fabric. Moreover, 100gm/L binder-treated polyester fabric indicated total deviation from others. Therefore, although some microscopic images have fluctuated from an expected printed outline, it can be said that binder concentration has no mentionable effect on the sharpness of printed borderline.

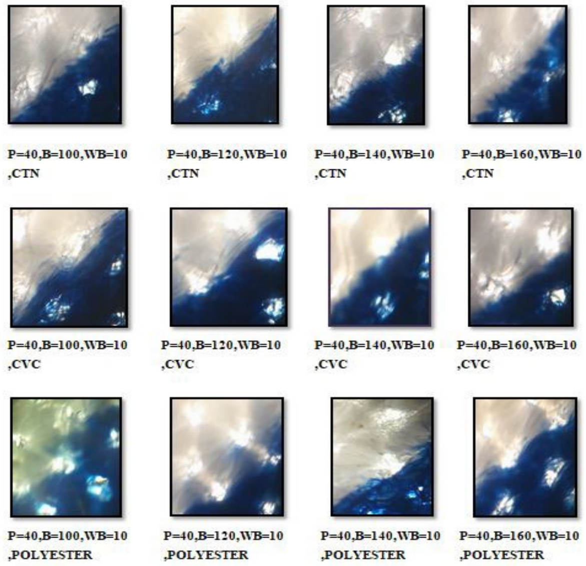

Fig.2: Outline sharpness for different concentration binder on Cotton, Polyester & CVC fabric at light & dark shade%

2.3.2 Assessment of pigment penetration by color strength of the printed fabric

Pigment penetration is one of the essential factors for pigment printing in the screen frame. Some parameters have been present to control pigment penetration in the industrial field, such as pressure between magnet and rod. If the mélange effect or over-penetration is created, then magnetic bed pressure has been modified or magnetic printing rod diameter has been changed. Another factor is binder concentration for pigment penetration. To understand the effect of acrylic-based binder on pigment penetration for Cotton, Polyester and CVC, the penetration or reflectance ratio % of printed fabric was determined using **Eq. (2)** on the difference in reflectance between reflectance on the face and backside of the printed area.

The penetration of pigment pastes through the fabric was determined using **Eq. (2)**, which assessed the printed fabric based on the difference in reflectance between the face and back of the printed area, measured on the spectrophotometer, using the derived (k/s) values for the front and the back of the fabric as reported.

$$\text{Penetration/reflectance ratio \%} = \frac{100\left(\frac{k}{s}\right)b}{.5\left[\left(\frac{k}{s}\right)f + \left(\frac{k}{s}\right)b\right]} \quad (2)$$

The $(k/s)_f$ and $(k/s)_b$ values are for the front and back sides of the fabric, respectively. K is the absorption coefficient of the printed color on the surface, and S is the scattering coefficient caused by the colored substrate. Basically, reflectance from the backside of printed fabric is more than face sides. So, if the values of reflectance ratio are lower, i.e., paste penetration through the fabric is higher.

2.3.5Assessment of stiffness of printed fabric

Stiffness is generally regarded as an ability of a material to resist deformation(elongation). It is measured in terms of the bending length in the Shirley stiffness tester (SDL Atlas, England) that was carried in the Textile Testing &Quality Lab at the Bangladesh University of Textiles. There are different methods of fabric stiffness testing. Among these methods, ASTM D138 was used to measure the stiffness of the printed sample [21].

The stiffness in printing is measured by hand feel in the industry, but there are many ways of measuring the stiffness for both woven and knitted fabric. For this study, one standard process for each fabric was used, and got satisfactory results. The stiffness measured at bending length of cotton, polyester, and CVC fabrics and values found for different concentrations of Printofix Binder 77N is plotted on Y-axis against the binder concentration on X-axis.

2.3.6 Measurement of Colorfastness to washing, light and rubbing

Wash fastness testing was carried out in a Gyro-wash (Gyro-wash 815, James, H Heal& Co Ltd, Halifax, England) using standard testing procedure ISO 105-C06 C2S in Rapa Knitwear limited. ISO 105 C06 C2S is the maximum buyers' first choice, and this procedure was followed in the work [22]. The fastness to light was tested in Air Cooled Xenon by following the international standard test procedure ISO-105-B02:2000 [23]. The rubbing fastness of the printed fabric was evaluated using an SDL Atlas Crock-meter- M238A (SDL Atlas, England) by standard testing procedure ISO 105-X12. The grading for rubbing was done with the help of Minolta Spectrophotometer (CM-3220d) QC software at Clarichem Limited [24].

The rubbing fastness values of cotton, polyester, and CVC fabric were found for different concentrations of Printofix Binder 77Nare inserted in the line graph. This comparison is made by plotting the rubbing fastness values on the Y-axis and concentration of binder on the X-axis, where rubbing fastness at light & dark shade% are presented by solid and dotted lines, respectively, for better comparison.

2.3.8 Measurement of color strength & relative color strength

Datacolor SF600PLUS-CT at Square measured the color strength & relative color strength of printed fabric knitted Ltd. Individually. Then, all printed samples were placed on a reflectance spectrophotometer. The values of Reflectance% were recorded at 500 nm. for printed samples. Basically, for the measurement of relative strength, the reflectance percentage of the sample was measured by Datacolor SF600PLUS-CT at Square knitted Ltd. Finally, to find out the (k/s) value of the printed sample before and after washing, the reflectance percentage was used in the Kubelka-Munk equation.

Relative color strength (%) is important for assessing printing quality. Relative color strength (%) is calculated by **Eq. (2)** of the reflectance ratio % of the face side before and after wash.

In this study, the relative color strength %of cotton, polyester, and CVC fabrics for both light and dark shade combinations are plotted on the Y-axis against the binder concentration and fixing agent on the X-axis. In the bar graph relative color strength of each treated fabric at both light and dark shade combinations are placed side by side.

3. Results & Discussion

ratio% will be low, and penetration of pigment will be high. So, pigment penetration was more with the increase of binder concentration. This result was almost true for cotton and CVC, but polyester did not show the same behavior at binder concentration of 220gm or 260 gm for dark shade combination.

Table 2: Pigment penetration (%) for different concentration binder through fabrics at light & dark shade%

Pigment %	Binder conc. (gm/L)	Cotton fabric			Polyester fabric			CVC fabric		
		Color strength		Penetration /Reflectance ratio%	Color strength		Penetration /Reflectance ratio%	Color strength		Penetration /Reflectance ratio%
		F. Side	B. Side		F. Side	B. Side		F. Side	B. Side	
4%	100	2.03	.568	43.70	1.87	1.13	75.33	2.03	.48	38.25
	120	2.03	.54	42	1.87	.986	69.05	2.21	.51	37.5
	140	2.03	.54	42	1.87	.82	60.97	2.21	.45	33.83
	160	2.03	.45	36.30	1.87	.723	55.62	2.03	.38	31.54
5%	200	2.03	.26	22.70	2.03	.68	50.18	2.21	.60	42.70
	220	2.03	.27	23.48	2.03	.82	57.54	1.87	.45	38.80
	240	1.87	.25	23.48	1.87	.60	48.58	2.03	.45	36.30
	260	2.03	.22	19.56	1.73	.77	61.5	2.03	.42	34.29

3.1 Effect of binder on the print paste viscosity

The viscosity values of pigment paste found for different concentrations of Printofix Binder 77N in light and dark shade% by using **Eq. (1)**, were inserted into the bar graph shown in **Fig. 3**.

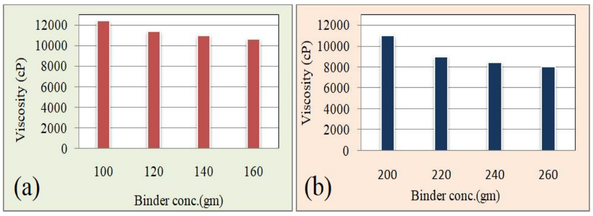

Fig.3: Effect of binder conc. on the print paste viscosity at (a) light and (b) dark shade%

This comparison was done by plotting binder concentration on X-axis and Viscosity (Cp/mPa•s) on Y-axis. The graph (**Fig.3**) shows that Viscosity had fallen when the binder concentration was increased for both shades, whether light or dark. However, this graph shows that this downward is not the same for both portions. Viscosity decreased almost linearly for light shade combination, but the falling behavior of Viscosity for dark shade combination did not show such a relationship as light shade. It is because, in case of dark shade, the overall concentration is less deferred with the change of binder concentration. However, the binder concentration can easily affect the overall concentration as the amount of dye molecule is much lesser.

3.2 Penetration behavior of pigment

Table 2 shows a significant effect of binder concentration on the pigment penetration for Cotton, CVC and polyester fabrics. Basically, bleached/undyed fabric reflectance is more than dyed fabric, so if the face side color strength is the same but back side color strength/ reflectance decreases, i.e., color strength

3.3 Stiffness of Pigment printed fabrics

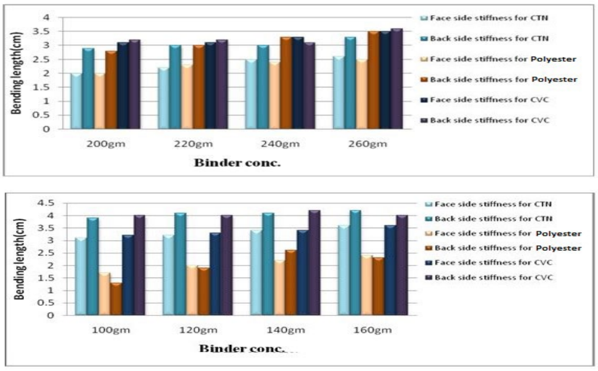

Fig.4: Effect of binder concentration on the stiffness of printed fabrics at (a) light shade 4%, (b) dark shade 5%

Fig. 4 shows that back side stiffness was higher than face-side stiffness for both shade combinations because of printing on the face side. The effect of binder concentration on the stiffness was positive, i.e., stiffness in cotton, polyester, and CVC fabric increased with the increase of binder concentration for light and dark shade combinations. Another fact is clear that polyester stiffness due to binder concentration was not increased similarly to Cotton and CVC as the binder material attacks the (-OH) bond and make new linkage which is present in cellulose. As there is no (-OH) bond present in the polyester fabric, so it does not get stiffer. This binder 77N is acrylate copolymer dispersion which contains 38% solid content, i.e., acrylonitrile monomer. So, it can be said that if the binder concentration is increased, stiffness will be increased, which was proved clearly from research work.

3.4 Wash & light fastness properties of pigment printed fabrics

The wash-fastness and light fastness values of cotton, polyester, and CVC fabrics found for different concentrations of Printofix Binder 77N are presented in **Table 3** for light & dark shade combinations.

Pigment (%)	Binder conc.(gm/L)	Cotton fabric		Polyester fabric		CVC fabric	
		Wash fastness value	Light fastness value	Wash fastness value	Light fastness value	Wash fastness value	Light fastness value
4%	100	4	5	4	5	4	5
	120	4	5	4	5	4	5
	140	4	5	4	5	4	5
	160	4	5	4	5	4	5
5%	200	4	5	4	5	4	5
	220	4	5	4	5	4	5
	240	4	5	4	5	4	5
	260	4	5	4	5	4	5

Table 3: Wash and light fastness of binder treated fabrics at light & dark shade%

Table 3 above shows that wash fastness and light fastness were constant with the changing of binder concentration for dark shade combinations like light shade combinations. From analyzing the data, we can say that wash fastness and light fastness values are not usually influenced by increased binder concentration. Although our pigment was constant and the fastness was constant with an increase in binder concentration so it can be concluded that wash and light fastness are dependent on the pigment composition, and there is no need to increase the concentration of binder to get a better wash and light fastness values in the industrial field if the pigment is same.

3.5 Rubbing fastness of printed fabrics for different concentration of binder

From **Fig.5**, dry rubbing was higher than wet rubbing for both shade combinations. In addition, the wet and dry rubbing increased with the concentration of binder, whatever fabric was cotton, polyester and CVC in both light and dark shade combinations. This increase for dry and wet rubbing was clearly noticeable, a significant factor in our printing industry to control the quality.

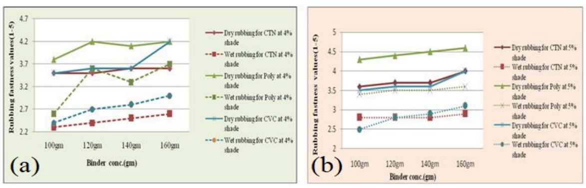

Fig.5: Rubbing fastness values for different conc. of binder at (a) light and (b) dark shade%

3.6 The effect of binder on the relative color strength (%) of printed fabrics

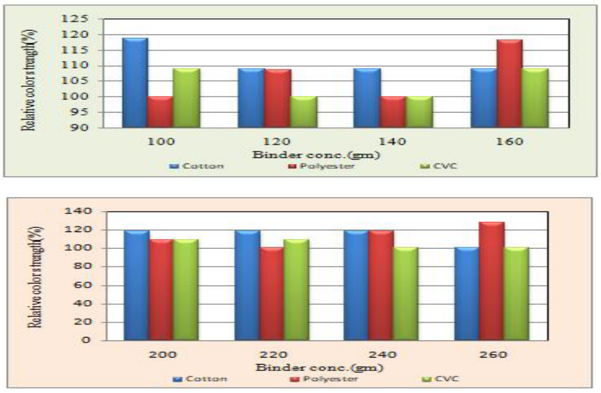

Fig. 6: Relative color strength (%) of printed fabrics for different conc. binder.

Fig. 6 shows that the relative color strength of Pigment printed cotton, polyester and CVC treated fabrics at different concentrated binders for light and dark shades varied randomly. However, relative color strength% was greater in dark shade combinations than in light shade combinations. So, it can be concluded that binder concentration does not affect the relative color strength%. Therefore, to get higher relative color strength%, a dark shade combination can be preferred.

4. Conclusion

Viscosity decreased with the addition of binder in printing paste due to the Penetration of Pigment through the fabric increasing with the increase of binder concentration, which was proved in the research work by reflectance value of printed fabric and SEM test. At microscopic observation of color bleeding and printed outline sharpness, it was found that the sharpness of the printed borderline was almost uniform for different binder concentrations. In stiffness measurement, it was found that binder concentration had a significant effect on the stiffness of the printed portion, i.e., stiffness was increased with the increase of binder conc. The stiffness of polyester fabric due to the binder was not similar to Cotton and CVC fabric. The relative color strength (%) of acrylic binder-treated fabrics was almost the same, so it can be claimed that excess binder will not increase the wash fastness values. Wash fastness and light fastness values were almost uniform for the acrylic binder. Rubbing fastness of wet and dry was increased with the increase of binder concentration for cotton, polyester and CVC fabric. The printed fabrics without fixing agents represented the average printing quality with slightly decreasing values for wash fastness. However, this study was limited within a certain type (acrylic) of binder used for pigment process. With the use of a binder and fixing agents, the viscosity of printing paste was reduced in this study. By lowering the ionization of the COOH group, it is known that electrolytes or salts applied externally to printing paste containing an acrylic-based thickener reduce the paste's viscosity. In a later stage, it will be feasible to investigate the potential existence of reactive electrolyte in binder or fixing agents for thickening and to determine the percentage of viscosity decrease for the same binder to various thickener combination printing paste.

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