Heliyon 9 (2023) e14175

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

The influence of mixed thickeners on printing over lyocell knitted fabric

Nahida Akter [a], Nasrin Akter [a], Mahfuza Pervin [b], Md. Reazuddin Repon [c,d,e,*]

[a] *Department of Textile Engineering, Ahsanullah University of Science and Technology, Tejgaon I/A, Dhaka, 1208, Bangladesh*
[b] *Department of Textile Engineering, Primeasia University, Banani C/A, Dhaka, 1213, Bangladesh*
[c] *ZR Research Institute for Advanced Materials, Sherpur, 2100, Bangladesh*
[d] *Department of Textile Engineering, Khwaja Yunus Ali University, Sirajgang, 6751, Bangladesh*
[e] *Department of Production Engineering, Faculty of Mechanical Engineering and Design, Kaunas University of Technology, Studentų 56, LT-51424, Kaunas, Lithuania*

A R T I C L E I N F O

Keywords:
Lyocell fabric
Textile printing
Sodium alginate
Guar gum
Substituted guar gum
Viscosity

A B S T R A C T

A quest was carried out to print on light weight lyocell knitted fabric with two mono-functional reactive dyes using pure guar gum (GG) or substituted guar gum (SGG) in combination with sodium alginate (Al) at different ratios. For each dyestuff, the print paste was prepared using mixed thickeners, namely GG/Al or SGA/Al at five different ratios. All samples were compared with the recipe containing pure sodium alginate. The empirical data show that the rheological behaviorisms of print paste-like viscosity and its other physical characteristics, such as paste add-on percentage (%) and penetration percentage (%), were dependent on the percentage of GG or SGG present in the thickener combination prepared with sodium Alginate. The combination of thickeners of these types also creates an impact on the final excellence of printed fabric, such as the colour yield, sharpness, stiffness of the fabric and the fastness of the colour. However, a few qualities are also dye dependent. The SGG/A combination gives a superior result when combining all the data with GG/A. Alginate with the small addition of SGG viz. the 80/20 or 60/40 mixture shows an excellent result in terms of printing characteristics. The thickener had no influential effect on the colour fastness rating.

1. Introduction

Textile printing is the most versatile and indispensable method for introducing the colourant to the selected areas of the textile substrate. Analytically considered, printing is a process of composition of a design notion, colourants (single or many hued), and a textile substrate, using a technique through machines to smearing the colourants with some precisions [1]. The most suitable textile printing technique is screen printing due to its simplicity, low cost, and high productivity [2,3]. A successfully printed fabric comprises exact colour, sharpness of mark, degree of penetration, levelness, suppleness, colour yield and retaining white ground, all of these factors heavily rely on the viscosity of the print paste and its rheological behaviour [4,5]. Pseudoplastic nature paste is suitable for screen printing process due to less viscosity while the shear rate increases [6]. Low-viscous printing paste is responsible for spreading, deep penetration, and flushing of the colour [1]. Among all the ingredients of the print paste, the viscosity is dependent on the

* Corresponding author. ZR Research Institute for Advanced Materials, Sherpur-2100, Bangladesh.
E-mail address: reazmbstu.te@gmail.com (Md.R. Repon).

https://doi.org/10.1016/j.heliyon.2023.e14175
Received 22 November 2022; Received in revised form 23 February 2023; Accepted 24 February 2023
Available online 1 March 2023

Table 1
Stock paste recipes.

Ingredients	A	B	C
Al (g)	140	–	–
GG (g)	–	60	–
SGG (g)	–	–	80
Water (g)	860	940	920
Total (g)	**1000**	**1000**	**1000**

thickener. Inevitably, the thickener must be compatible and stable with other ingredients in the printing paste [7]. Leaving aside the property of the dye during fixation, different thickeners transfer different amounts of dye. The procedure was revealed to be significantly influenced by the viscosity of the lubricant because a low viscosity lubricant results in reduced pressure being used to extrude the paste [8,9].

In 1994, Lyocell was introduced as a sustainable and biodegradable regenerated cellulosic fibre, obtained by dry-jet-wet spinning process of dissolved wood pulp in an amine oxide solvent (*N*-methylmorpholin *N*-oxide or NMMO) [10,11]. Lyocells have some beneficial properties over other regenerated cellulosic fibres, such as high wet tenacity, soft and silky handle, luster and startling water imbibition, and enhanced wearer comfort [12]. This fibre can be dyed and printed using analogous dyes, recommended for other cellulosic fibres, such as cotton, viscose, and modal [13,14]. Most of the cellulosic fibres are printed with pigments or reactive dyes. However, pigment printing is not compatible for dark-colour blotch prints as a result of its lower air permeability and stiffer fabric handle [15,16]. Reactive dye print paste comprises the different chemicals, namely, thickening agent, alkali, humectant, etc. Sodium alginate, a derivative of sea weed, is the most widely used thickener in reactive dye printing [17]. Some benefits of sodium alginate thickener are good air permeability, even colour, good plasticity and explicit printing figure. Another advantage of alginate film is that it can be easily washed out after drying and steaming (fixation) and the result is less fabric stiffness [18–20]. However, the unstable price and inadequate resource of alginate tends to reveal and use of alternative thickeners such as guar gum, carboxymethyl cellulose (CMC) and synthetic thickeners [21]. The less expensive guar gum is obtained from the guar plant named *Cyanaposis tetragonolobus.* It is a natural hydrocolloid polysaccharide, composed of galactose and mannose, which may be chemically described as galactomannan. But the native guar gum has an enormous number of hydroxyl groups that cross-link with reactive dyes, alter the stiffness of the printed fabric and diminish the colour yield [22]. Guar gum has stability in the wide range of pH 1–10.5 and above 0.5% concentrated paste shows pseudoplastic nature which is also favourable for printing. Nanotechnology and 3D printing have been integrated for a variety of uses due to their fascinating characteristics. Complex nanoscale structures can be created using 3D printers, and nanoparticles are used to improve the desirable qualities of 3D printed materials [23,24].

Now-a-days it is the demand to print reactive dyes economically with high quality has led to the printer to induce the mixed thickener concept. However, sodium alginate is compatible with different gums, starch, cellulose ethers, and synthetic thickeners [1,3]. Therefore, it is easy to make binary mixtures using sodium alginate. In this work, the viscosity and quality of print paste, prepared by using mixed thickeners, have been studied to find out the advantages of the mixed thickener without losing the advantages for each that are known. In the literature, there are numerous research articles devoted to the printing process, the characteristics, and the settings for the print paste used to print lyocell fabric [25–30]. However, there are not many studies on the effects of mixed thickeners used for printing on lyocell knitted fabric that have been reported in the literature.

Therefore, the objective of this exploration was to investigate the influence of mixed thickeners on printing over lyocell knitted fabric. The viscosity of the print paste was evaluated to measure the excellency of the printed fabric. The paste add-on percentage, penetration percentage, colour strength, sharpness and drape co-efficient value of printed fabric were likewise evaluated.

2. Experimental

2.1. Materials

A 100% lyocell plain knitted fabric having course and wales density of 21 cm^{-1} and 13 cm^{-1} respectively was used in this study. The linear density of the lyocell yarn was 20 Tex and the areal density of the lyocell fabric was 132 g/m^2. Three types of medium viscous industrial thickeners were used, namely sodium alginate (Al), guar gum (GG), and substituted guar gum (SGG). Two monofunctional reactive dyes namely Novacron Turquoise Blue P-GR (larger molecular size) and Novacron Red P-4B-GR (smaller molecular size) were used to print. Several auxiliary chemicals like; Lab grade sodium bicarbonate, resist salt and urea were supplied by Merck (India) which were used in the printing paste. Optical brightening agent-free ECE detergent (James Heal, UK) and sodium perborate (Merck) were used for the colour fastness to wash test.

2.2. Methods

2.2.1. Preparation of the thickener stock paste and printing paste using binary mixtures of thickeners

On the basis of initial trials, thickeners stock paste concentrations of 140 g/kg for the sodium alginate, 60 g/kg for guar gum (GG) and 80 g/kg for substituted guar gum (SGG) were found to be suitable. The stock paste for each thickener was prepared according to the recipe shown in Table 1. Each variety was mixed for 15 min using a laboratory type mechanical stirrer with 3000 rpm and left to

Table 2
Common print paste recipes.

Ingredients	Amount (g)
Thickener (single/binary mixture of thickener)	750
Dye (Turquoise Blue P-GR/Red P-4B-GR)	30
Sodium bicarbonate	30
Resist salt	10
Urea	150
Water	30
Total	**1000**

Table 3
Combination of thickeners used in the print paste.

Mixture of thickener	Ratio of the thickener	Abbreviation
Pure Na alginate	100%	Al
Na Alginate: Guar gum	80:20	Al: GG (8:2)
Na Alginate: Guar gum	60:40	Al: GG (6:4)
Na Alginate: Guar gum	40:60	Al: GG (4:6)
Na Alginate: Guar gum	20:80	Al: GG (2:8)
Pure guar gum	100%	GG
Na Alginate: Substituted guar gum	80:20	Al: SGG (8:2)
Na Alginate: Substituted guar gum	60:40	Al: SGG (6:4)
Na Alginate: Substituted guar gum	40:60	Al: SGG (4:6)
Na Alginate: Substituted guar gum	20:80	Al: SGG (2:8)
Pure substituted guar gum	100%	SGG

stand it for 24 h at 27 °C to obtain full swelling. The viscosity of the stock pastes was assessed with Brookfield's viscometer (LVT model) using 61 spindles at 6 rpm and the viscosity of the stock pastes was found to be between 68,000 and 75,000 cP.

To prepare the print paste, reactive dye and auxiliaries were added to each thickener mixture and the resulting mixtures were stirred again for another 15 min. The recipe for the common printing paste is given in Table 2. Each series was prepared using two reactive dyes.

For each colourant, a total of 11 types of print pastes were prepared including 3 distinct pure thickeners and two types of binary mixtures of thickeners were prepared according to six different ratios (Table 3). In total, 22 print pastes were prepared for 2 different colourants. Finally, the viscosity of the print pastes was evaluated under the same conditions as that of the stock pastes.

2.2.2. Printing

The printing pastes were applied on light-weight lyocell knitted fabric in the laboratory, using a flat printing screen (200 mesh count), with 2 squeegee passages. The printed fabrics were dried for 2 min at 90 °C and fixation was carried out for 10 min with saturated steam at 110 °C. The printed fabrics were washed first in cold water and formerly twice in hot water. Soaping (Dekol SN, 1 g/L) was carried out at the boil for 15 min, then rinsed and dried. A total of 22 pairs of printings were executed with varying recipe components using 2 different dyes to find the optimum ratio for the binary thickener mixture. Each pair consists of a printing with a motif and a printing without motif (commonly known as a blotch printing). The quality of the sharpness of the print was assessed by the sample containing the motif. The blotch printed samples were used to measure the other printing properties, namely paste add-on%, penetration%, K/S value, stiffness, and colour fastness.

2.2.3. Measurement of print paste add-on%

The printing paste add-on was calculated gravimetrically from the differences between the mass before printing the lyocell samples and immediately after making an impression of the paste on the samples [18]. To measure the print paste add-on%, the blotch printed fabrics were weighted instantly after the printing paste is smeared through the screen openings at higher shear rates. Then the paste add-on was calculated in g/m^2 with the help of the lyocell samples printed before printing by Equation (1).

$$Paste\ add-on,\% = \frac{E_2 - E_1}{A} \times 100 \tag{1}$$

Where, E_2 (g) = Weight immediately after making an impression of the paste on the sample, E_1 (g) = Weight before applying the printing paste on the lyocell sample and A (m^2) is the area where the paste is transferred.

2.2.4. Measurement of colour depth and penetration%

Colour yield (K/S) and the extent of dye penetration of the printed samples were determined by measuring the reflectance value of the sample using a Datacolor 650™ spectrophotometer (Datacolor, USA) with diffuse illumination and 8° viewing geometry under the following measurement conditions: wavelength ranges from 400 nm to 700 nm, aperture area 20 mm in diameter (MAV- medium area view), and SIN (specular included) mode. The colour depth value (K/S) of the samples at the maximum absorbed wavelength was

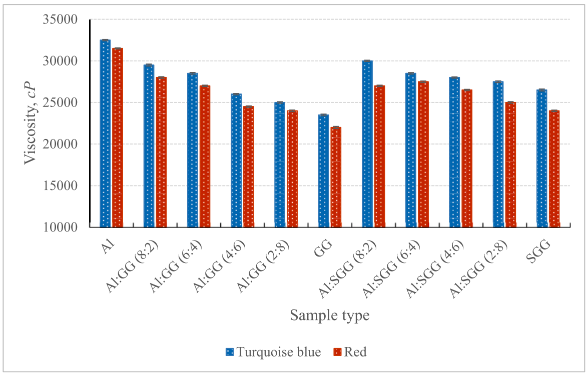

Fig. 1. Effect of mixed thickener on print paste viscosity.

calculated using the KubelkaMunk hypothesis, which provides the correlation between K/S and R as shown in Equation (2) [31].

$$\frac{K}{S} = \frac{(1-R)^2}{2R} \tag{2}$$

Where, R is the reflectance of incident light from the dyed material, whereas K and S denote the dyed fabric's absorption and scattering co-efficient, individually.

The penetration level of the paste into the lyocell fabrics was calculated using the following Equation (3).

$$Penetration\ Percentage = \frac{100 \times \left(\frac{K}{S}\right)_b}{0.5\left\{\left(\frac{K}{S}\right)_f + \left(\frac{K}{S}\right)_b\right\}} \tag{3}$$

Where $(K/S)_b$ and $(K/S)_f$ are the colour yield on the back and that on the face side of the printed sample, respectively.

2.2.5. Sharpness of prints

The sharpness of the printed samples was visually assessed under D65 illuminant using a colour-matching cabinet (VeriVide Light Box, UK). Three types of ratings were given to the samples for sharpness measurement, depending on the sharpness of the motif around the printed area. To improve the sharpness of the print, samples were represented by the symbols Δ for poor, ΔΔ for good and ΔΔΔ for the excellent rating, respectively. The 'poor' rating means worst sharpness, the 'good' rating means moderate sharpness, and the 'excellent' rating means the superior quality of print sharpness. Ten professionals were employed to assess all the printed samples, and the maximum rating given by the evaluators for each sample was taken. All of the evaluators' educational backgrounds were in Textile Engineering, and their educational levels were at least master's. At least five years of experience were required to determine printing quality.

2.2.6. Drape co-efficient

The drape co-efficient values of the blotch printed samples were calculated to determine the softness or stiffness of the printed area followed by the test standard ISO 9073–9:2008 [32]. This test was carried out with the Cusick drape tester (James H & Heal) using a template diameter of 24 cm and a translucent paper annular ring [33]. Equation (4) was used to calculate the drape co-efficient value.

$$\text{Drape co-efficient} = \frac{\text{Mass of shaded area}}{\text{Total mass of the paper ring}} \times 100 \tag{4}$$

2.2.7. Fastness properties

The colour fastness to wash and rubbing (dry and wet) were evaluated according to ISO 105-C06:2010 [34] and ISO 105- X12:2016 [35] standard respectively. The grey scale assessment for the change in colour of printed fabrics and the staining of adjacent samples was carried out according to visual assessment using ISO 105-A02:1993 [36] and ISO 105-A03:2019 [37], respectively.

2.2.8. Standard atmosphere

All experiments were carried out under a standard atmosphere (20 °C ± 2 °C temperature and 65% ± 4% humidity) according to the standard LST EN ISO 139:2005 [38]. Each data has been taken minimum three times and average results have been presented.

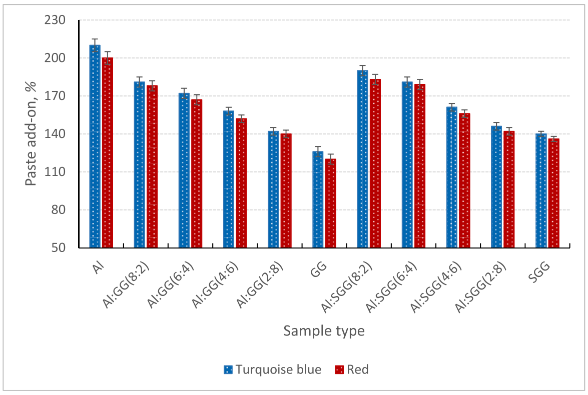

Fig. 2. Effect of mixed thickener on paste add-on%.

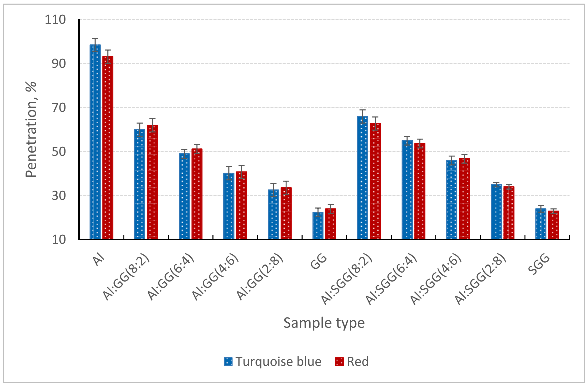

Fig. 3. Effect of mixed thickener on penetration percentage (%).

3. Results and discussion

3.1. Viscosity

The excellence of the screen-printed fabric is highly dependent on the viscosity of the print paste and its rheological behaviour at high shear rate. The viscosity of the thickener is closely related to its chemical structure, concentration, and interaction with other components present within the print paste. The print paste made with pure sodium alginate shows higher viscosity than pure guar gum and substituted guar gum at a certain rate of shear (Fig. 1). This is because the solid content affects the visco-elastic properties of the printing pastes, which means that a higher viscosity of a thickener can be achieved by the higher molecular mass of the polymer [39]. Sodium alginate mixes with pure guar gum or substituted guar gum show positive results, and the high amount of alginate in the binary mixture increases the viscosity of that blend. Henceforth, alginate acts as a viscosity modifier for the mixed thickener print paste (both for turquoise blue and red reactive dyes). However, turquoise blue-colour print pastes have consistently higher apparent viscosities than red. The molecular size, chemical configuration, and substituted groups of the dye are liable for it [22].

In the case of turquoise blue reactive dyes, viscosity increases with decreasing amount of guar gum when mixed with sodium alginate. When Al:GG (2:8), Al:GG (4:6), Al:GG (6:4), Al:GG (8:2) and Al were compared to pure guar gum (GG), their viscosities were 6.38%, 10.64%, 21.28%, 25.53% and 38.29% higher. On the other hand, the viscosity was observed to be 1.89%, 3.78%, 7.55%, 13.21% and 22.64% higher for Al:SGG (2:8), Al:SGG (4:6), Al:SGG (6:4), Al:SGG (8:2) and Al compared to substituted guar gum (SGG).

Turquoise red reactive dyes displayed the same tendency when guar gum was mixed with sodium alginate. According to the results, the viscosities were 9.09%, 11.36%, 22.73%, 31.82%, and 43.18% higher for Al:GG (2:8), Al:GG (4:6), Al:GG (6:4), Al:GG (8:2), and Al when compared to pure guar gum (GG). Comparing Al:SGG (2:8), Al:SGG (4:6), Al:SGG (6:4), Al:SGG (8:2) and Al with substituted guar gum (SGG), the viscosity was 2.04%, 6.12%, 10.20%, 8.16% and 28.57% higher.

3.2. Paste add-on% and penetration%

It is a challenge for printers to print a fabric having a lower paste add-on% and a minimum penetration%, particularly for light-weight knitted fabric. A lower paste add-on onto the substrate is possible when the printing paste shows shear thinning behaviour at a

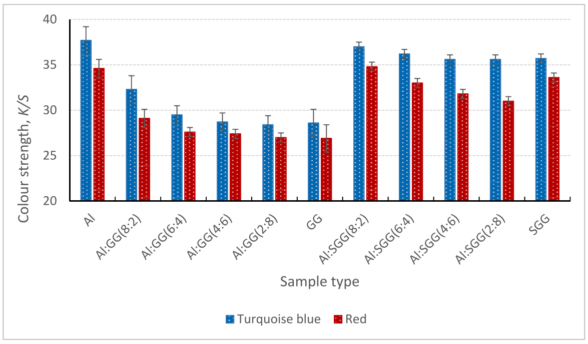

Fig. 4. Effect of mixed thickener on colour strength. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 4
Sharpness of the design printed fabric.

Thickener combination	Sharpness	
	Red colour	Turquoise colour
Al	ΔΔΔ	ΔΔΔ
Al: GG (8:2)	ΔΔΔ	ΔΔΔ
Al: GG (6:4)	ΔΔΔ	ΔΔΔ
Al: GG (4:6)	ΔΔΔ	ΔΔΔ
Al: GG (2:8)	ΔΔΔ	ΔΔΔ
GG	ΔΔΔ	ΔΔΔ
Al: SGG (8:2)	ΔΔΔ	ΔΔΔ
Al: SGG (6:4)	ΔΔΔ	ΔΔΔ
Al: SGG (4:6)	ΔΔΔ	ΔΔΔ
Al: SGG (2:8)	ΔΔΔ	ΔΔΔ
SGG	ΔΔΔ	ΔΔΔ

higher shear rate. And after releasing the squeeze pressure, the onset of lower stresses hinders the passage of the printing paste through the fabric openings, resulting in a lower percentage of penetration into the lyocell fabric [22]. Fig. 2 indicates the effect of mixed thickener on paste add-on% and Fig. 3 indicates the effect of mixed thickener on penetration percentage (%) of printed fabric.

The results presented in Figs. 2 and 3, independent of dye, the printed samples of GG and SGG show a lower percentage of paste add-ons and a lower percentage of penetration than sodium alginate. This is because GG and SGG show pseudoplastic behavior, while in presence of alginate the system loses its pseudoplastic characteristics and behaves like a Newtonian flow.

3.3. Colour depth (K/S)

Fig. 4 Illustrates the effect of mixed thickeners on the colour strength (K/S) values of the printed samples. As presented in Fig. 4, the lower paste add-on SGG printed sample shows a similar colour depth to that of the higher paste add-on alginate sample. Truly, these properties are attributed to the relative relation of paste add-on% and penetration%. Although the SGG printed sample has a lower paste add-on%, it also has a lower penetration% which facilitates the development of the K/S value. However, for pure guar gum, another factor may also be altered with the K/S value, that is, the interaction between free hydroxyl groups and reactive dye, which cannot be omitted [4]. As a result, GG printed samples exhibited the lowest K/S value among the three thickeners.

In the case of turquoise blue reactive dyes, the order of samples was found as Al:GG (2:8)<GG<Al:GG (4:6)<Al:GG (6:4)<Al:GG (8:2)<Al when guar gum (GG) mixed with sodium alginate (Al) and the order of samples was found as Al:SGG (2:8) = Al:SGG (4:6)<SGG<Al:SGG (6:4)<Al:SGG (8:2)<Al when substituted guar gum (SGG) mixed with sodium alginate (Al). When Al:GG (2:8), Al:GG (4:6), Al:GG (6:4), Al:GG (8:2) and Al were compared to pure guar gum (GG), their K/S values were −0.69%, 0.35%, 3.15%, 12.94% and 31.82% higher. On the other hand, the K/S was found to be −0.28%, −0.28%, 1.40%, 3.64% and 5.60% higher for Al:SGG (2:8), Al:SGG (4:6), Al:SGG (6:4), Al:SGG (8:2) and Al compared to substituted guar gum (SGG).

In the case of turquoise red reactive dyes, the order of samples was found as GG<Al:GG (2:8)<Al:GG (4:6)<Al:GG (6:4)<Al:GG (8:2)<Al when guar gum (GG) mixed with sodium alginate (Al) and the order of samples was found as Al:SGG (2:8)<Al:SGG (4:6)<Al:SGG (6:4)<SGG<Al<Al:SGG (8:2) when substituted guar gum (SGG) mixed with sodium alginate (Al). The K/S values of Al:GG (2:8), Al:GG (4:6), Al:GG (6:4), Al:GG (8:2) and Al were higher than those of pure guar gum (GG) by 0.37%, 1.89%, 2.60%, 8.18% and 28.62%, respectively. On the other hand, the K/S was observed to be −7.74%, −5.36%, −1.79%, 3.57% and 2.98% higher for Al:SGG (2:8), Al:SGG (4:6), Al:SGG (6:4), Al:SGG (8:2) and Al compared to substituted guar gum (SGG).

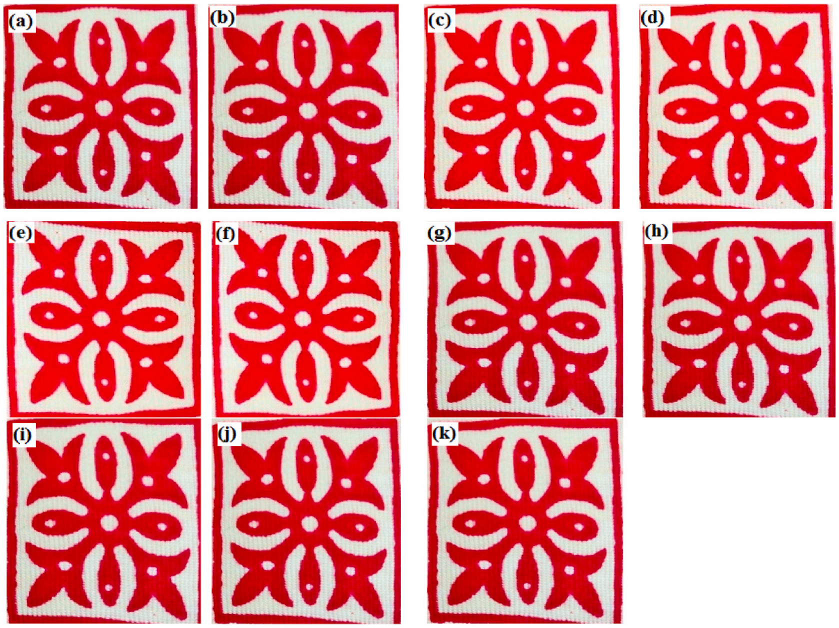

Fig. 5. Digital photograph of printing containing design of red reactive dye: (a) A; (b) A:GG [8:2]; (c) A:GG [6:4]; (d) A:GG [4:6]; (e) A:GG [2:8]; (f) GG; (g) A:SGG [8:2]; (h) A:GG [6:4]; (i) A:GG [4:6]; (j) A:GG [2:8]; (k) SGG. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

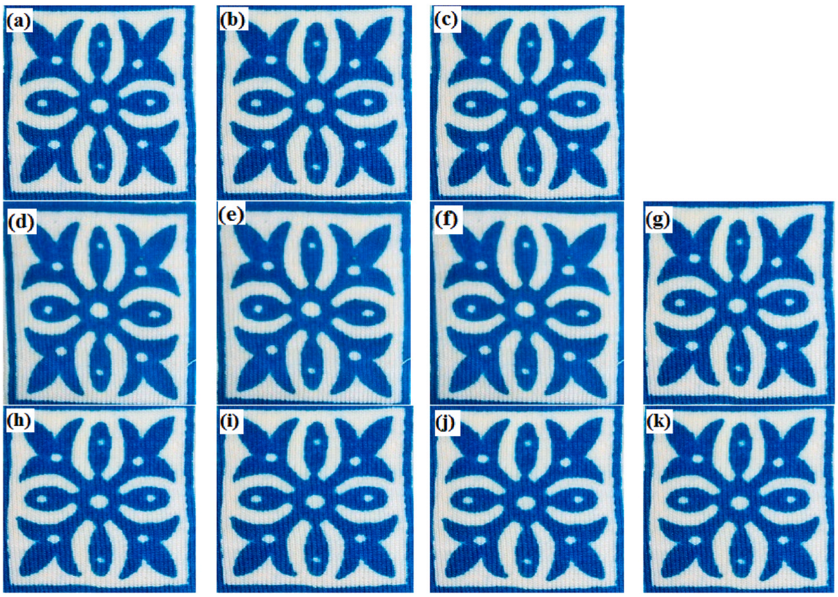

Fig. 6. Digital photograph of printing containing design turquoise blue reactive dye: (a) A; (b) A:GG [8:2]; (c) A:GG [6:4]; (d) A:GG [4:6]; (e) A:GG [2:8]; (f) GG; (g) A:SGG [8:2]; (h) A:GG [6:4]; (i) A:GG [4:6]; (j) A:GG [2:8]; (k) SGG. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.4. Sharpness of the print

The sharpness of the different thickener combination printed samples is shown in Table 4. Sharpness of the printed fabrics was assessed by the neck eye. The result of sharpness is dye independent and all types of thickener combination show a similar rating. The digital photographs in Fig. 5(a–k) show the effect of mixed thickeners on printed lyocell knitted fabrics with red reactive dye. Additionally, Fig. 6(a–k) illustrates the influence of mixed thickeners on the printing of lyocell knitted fabrics with turquoise blue reactive dye.

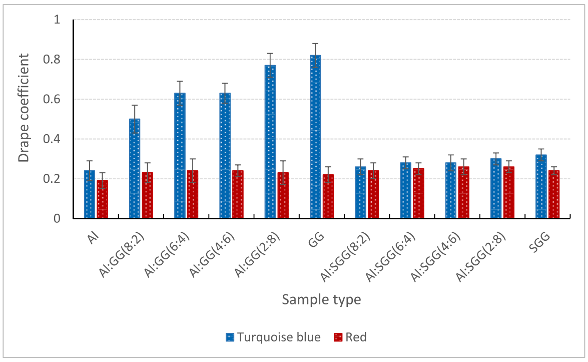

Fig. 7. Effect of mixed thickener on drape co-efficient.

Table 5
Colour fastness to dry and wet rubbing.

Colour fastness rating to dry and wet rubbing								
Thickener Composition	Dry rubbing				Wet rubbing			
	Turquoise blue		Red		Turquoise blue		Red	
	S	C	S	C	S	C	S	C
Al	5	5	5	5	5	5	5	5
Al: GG (8:2)	5	5	5	5	5	5	5	5
Al: GG (6:4)	5	5	5	5	5	5	5	5
Al: GG (4:6)	5	5	5	5	5	5	5	5
Al: GG (2:8)	5	5	5	5	5	5	5	5
GG	5	5	5	5	5	5	5	5
Al: SGG (8:2)	5	5	5	5	5	5	5	5
Al: SGG (6:4)	5	5	5	5	5	5	5	5
Al: SGG (4:6)	5	5	5	5	5	5	5	5
Al: SGG (2:8)	5	5	5	5	5	5	5	5
SGG	5	5	5	5	5	5	5	5

S= Sample, C= Crocking cloth.

Table 6
Colour fastness to wash.

Thickener composition	For red colour			For turquoise blue colour		
	Change in colour	Colour staining		Change in colour	Colour staining	
		Cotton	Wool		Cotton	Wool
Al	5	4/5	5	4/5	4/5	5
Al: GG (8:2)	5	4/5	5	4	4/5	5
Al: GG (6:4)	4/5	5	5	4	4/5	5
Al: GG (4:6)	4/5	4/5	5	4	4/5	5
Al: GG (2:8)	4/5	5	5	4	4/5	5
GG	4/5	5	5	4/5	4/5	5
Al: SGG (8:2)	5	4/5	5	4/5	4/5	5
Al: SGG (6:4)	5	5	5	4/5	4/5	5
Al: SGG (4:6)	5	4/5	5	4/5	4/5	5
Al: SGG (2:8)	5	5	5	4/5	4/5	5
SGG	5	5	5	4/5	4/5	5

3.5. *Stiffness*

Fig. 7 Illustrates the effect of mixed thickeners on the drape co-efficient value of printed fabric. After wash-off, the remaining thickener is responsible for a stiffer handle of the final product. From Fig. 7, it can be concluded that the fabric handle is both dye and thickener dependent. The samples printed with pure GG have higher drape co-efficient values among others. This may be correlated with earlier findings (K/S value). Hydroxyl groups of pure guar gum cross-linked with dye molecules are difficult to remove after the treatment stage [4]. Again, all the turquoise blue colour printed samples showed higher drape co-efficient values than red. This is attributed to turquoise blue dye being cross-linked with GG and SGG which is difficult to remove after treatment. Specifically, it is difficult to use pure GG thickener or their mixture with alginate for turquoise blue colour.

3.6. Colour fastness to wash and rubbing

Colour fastness is one of the important parameters for assessing the quality of printed fabric in terms of serviceability, which also indicates the fixity of the dye-fibre system.

The results of the relevant colour fastness tests are presented in Tables 5 and 6. From these tables, it can be concluded that GG and SGG offer the same fastness rating as alginate. It is evident from the results of the testing of colour fastness to wash, and rubbing that the colour fastness using guar gum compares to the colour fastness using alginates, and that no decrease of quality is observed.

4. Conclusion

This work has focused on the application of native guar gum and modified guar gum as a thickening agent in combination with regular alginate for reactive printing on lightweight lyocell knitted fabric. Based on the experimental outcomes of different tests on the printed paste and printed samples, modified guar gum (SGG) can be used as a thickening agent for reactive printing. Compared to alginate, SGG thickener print paste has a lower viscosity, paste add-on percentage and penetration percentage. On the other hand, SGG printed fabric shows almost similar K/S value, sharpness and fabric handle. Nevertheless, the addition of alginate in the SGG paste changes the characteristics of the mixture which minimize the drawbacks (colour strength and fabric stiffness) and maximizes the beneficial behaviour (paste add-on% and penetration %). Therefore, the ideal combination could be 80%–60% alginate with 20%–40% SGG, respectively. Appreciable good colour yield, sharpness unaffected white ground, and good colour fastness rating to wash and rub with soft handle as well as elastic print paste were achieved by using these combinations. In broad, some properties are dye dependent. SGGs containing turquoise blue printed fabrics exhibit similar colour depth and white ground by losing their handle with minimum diminution of colour fastness rating.

Author contribution statement

Nahida Akter: Conceived and designed the experiments; Performed the experiments; Wrote the paper. Nasrin Akter: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data. Mahfuza Pervin: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Md. Reazuddin Repon: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interest's statement

The authors declare no conflict of interest.

Acknowledgments

Technical supports from the "ZR Research Institute for Advanced Materials", Sherpur-2100, Bangladesh are gratefully acknowledged.

References

[1] M. Mrad, Transfer Printing and Cellulose Based Substrates for Modern Textile Printing, Linköping University, 2019.
[2] N. Kasikovic, G. Vladic, D. Novakovic, Textile printing–past, present, future, Glas. Hemičara, Tehnol. i Ekol. Republike Srp. (2016) 35–46.
[3] E.P.A. Kumbasar, Mixture printing pastes from high substitued guar gum and alginates on reactive printing of viscose, J. Appl. Polym. Sci. 103 (2007) 745–751.
[4] E. Perrin Akcakoca Kumbasar, M. Bide, Reactive dye printing with mixed thickeners on viscose, Dyes Pigm. 47 (2000) 189–199.
[5] B.N. Bandyopadhyay, A.K. Mukhopadhyay, A.V. Afini, N.R. Salaskar, S.B. Acharekar, A new insight into the rheological properties of alginates and carboxymethyl starches for printing of reactive colours, Indian J. Fibre Text. Res. 24 (1999) 49–57.
[6] H.W. Lin, C.P. Chang, W.H. Hwu, M. Der Ger, The rheological behaviors of screen-printing pastes, J. Mater. Process. Technol. 197 (2008) 284–291.
[7] M.M.E. Molla, Innovative technologies for enhancing the printing performance of textile fabrics : a review, Int. J. Innov. Sci. Res. Technol. 4 (2019) 163–172.
[8] W. Xu, C. Li, Y. Zhang, H.M. Ali, S. Sharma, R. Li, M. Yang, T. Gao, M. Liu, X. Wang, Z. Said, X. Liu, Z. Zhou, Electrostatic atomization minimum quantity lubrication machining: from mechanism to application, Int. J. Extrem. Manuf. 4 (2022) 1–43.
[9] Z. Duan, C. Li, Y. Zhang, M. Yang, T. Gao, X. Liu, R. Li, Z. Said, S. Debnath, S. Sharma, Mechanical behavior and Semiempirical force model of aerospace aluminum alloy milling using nano biological lubricant, Front. Mech. Eng. 12 (2022) 6–16.
[10] X. Jiang, Y. Bai, X. Chen, W. Liu, A review on raw materials, commercial production and properties of lyocell fiber, J. Bioresour. Bioprod. 5 (2020) 16–25.

[11] B.U. Nergis, Y. Beceren, Visual evaluation of the surface of tencel/cotton blend fabrics in production and cleaning processes, Fibres Text. East. Eur. 16 (2008) 39–43.
[12] T. Li, C. Chen, A.H. Brozena, J.Y. Zhu, L. Xu, C. Driemeier, J. Dai, O.J. Rojas, A. Isogai, L. Wagberg, L. Hu, Developing fibrillated cellulose as a sustainable technological material, Nature 590 (2021) 47–56.
[13] M. Berradi, R. Hsissou, M. Khudhair, M. Assouag, O. Cherkaoui, A. El Bachiri, A. El Harfi, Textile finishing dyes and their impact on aquatic environs, Heliyon 5 (2019).
[14] S. Benkhaya, S. Mrabet, A. El Harfi, A review on classifications, recent synthesis and applications of textile dyes, Inorg. Chem. Commun. 115 (2020), 107891.
[15] E. Kumpikaite, I. Tautkute-Stankuviene, D. Milasiene, S. Petraitiene, Analysis of color fastness and shrinkage of dyed and printed linen/silk fabrics, Coatings 12 (2022) 1–14.
[16] M. Kanik, P.J. Hauser, Printing of cationised cotton with reactive dyes, Color. Technol. 118 (2002) 300–306.
[17] A. Hassabo, D. Hamdy, H. Othman, Recent use of natural thickeners in the printing process (a mini review), J. Text. Color. Polym. Sci. 18 (2021) 75–81.
[18] R. Fijan, M. Basile, R. Lapasin, S. Šostar-Turk, Rheological properties of printing pastes and their influence on quality-determining parameters in screen printing of cotton with reactive dyes using recycled polysaccharide thickeners, Carbohydr. Polym. 78 (2009) 25–35.
[19] Y. Yang, Y. Gong, C. Li, X. Wen, J. Sun, Mechanical performance of 316 L stainless steel by hybrid directed energy deposition and thermal milling process, J. Mater. Process. Technol. 291 (2021), 117023.
[20] T. Gao, Y. Zhang, C. Li, Y. Wang, Y. Chen, Q. An, S. Zhang, H.N. Li, H. Cao, H.M. Ali, Z. Zhou, S. Sharma, Fiber-reinforced Composites in Milling and Grinding: Machining Bottlenecks and Advanced Strategies, 2022.
[21] P. Bajaj, M. Goyal, R.B. Chavan, Synthetic thickeners in textile printing: a critique, J. Macromol. Sci. Part C 33 (1993) 321–348.
[22] S.H. Samaha, Printing properties of carbamoylethyl guar and its mixture with alginate, J. Text. Assoc. 64 (2004) 327–333.
[23] Z. Li, H. Li, X. Zhu, Z. Peng, G. Zhang, J. Yang, F. Wang, Y.F. Zhang, L. Sun, R. Wang, J. Zhang, Z. Yang, H. Yi, H. Lan, Directly printed embedded metal mesh for flexible transparent electrode via liquid substrate electric-field-driven jet, Adv. Sci. 9 (2022) 1–10.
[24] S.B. Khan, S. Irfan, S.S. Lam, X. Sun, S. Chen, 3D printed nanofiltration membrane technology for waste water distillation, J. Water Proc. Eng. 49 (2022) 1–21.
[25] A.A. Babar, N. ul ain Bughio, M.H. Peerzada, T. Naveed, A.Q. Dayo, Exhaust reactive dyeing of lyocell fabric with ultrasonic energy, Ultrason. Sonochem. 58 (2019) 1–8.
[26] C. Fitz-Binder, T. Bechtold, One-sided surface modification of cellulose fabric by printing a modified TEMPO-mediated oxidant, Carbohydr. Polym. 106 (2014) 142–147.
[27] D. Ojha, S. Deodiya, R. Purwar, Printing of lyocell fabric with rubia cordifolia and acacia catechu using guar gum and chitosan as thickening agent, Indian J. Tradit. Knowl. 18 (2019) 615–620.
[28] A.W. Kaimouz, R.H. Wardman, R.M. Christie, Ink-jet printing process for lyocell and cotton fibres. Part 2: the relationship of colour strength and dye fixation to ink penetration, Color. Technol. 126 (2010) 342–347.
[29] D.L. Ellams, R.M. Christie, S. Robertson, An approach to sustainable coloration of lyocell fabrics by screen printing using extracts of leaves and bark from eucalyptus, Color. Technol. 130 (2014) 48–53.
[30] A.W. Kaimouz, R.H. Wardman, R.M. Christie, The inkjet printing process for Lyocell and cotton fibres. Part 1: the significance of pre-treatment chemicals and their relationship with colour strength, absorbed dye fixation and ink penetration, Dyes Pigm. 84 (2010) 79–87.
[31] M.R. Repon, T. Islam, H.T. Sadia, D. Mikucionienė, S. Hossain, G. Kibria, M. Kaseem, Development of antimicrobial cotton fabric impregnating AgNPs utilizing contemporary practice, Coatings 11 (2021) 1–14.
[32] ISO 9073-9:2008, Textiles — Test methods for nonwovens — Part 9: Determination of drapability including drape coefficient, 2008, https://www.iso.org/standard/41375.html.
[33] R. Repon, N.A. Shiddique, R. Al Mamun, M. Quayum, Analysis of drape co-efficient, bending length, flexural rigidity and tightness factor of 4 × 1 rib, 4 × 4 rib, half cardigan and full cardigan knit structure fabric, J. Text. Eng. Fash. Technol. 5 (2019) 119–124.
[34] ISO 105-C06:2010, Textiles — Tests for colour fastness — Part C06: Colour Fastness to Domestic and Commercial Laundering, 2010, https://www.iso.org/standard/51276.html.
[35] ISO 105-X12:2016, Textiles — Tests for colour fastness — Part X12: Colour fastness to rubbing, 2016, https://www.iso.org/standard/65207.html.
[36] ISO 105-A02:1993, Textiles — Tests for colour fastness — Part A02: Grey Scale for Assessing Change in Colour, 1993, https://www.iso.org/standard/3785.html.
[37] ISO 105-A03:2019, Textiles — Tests for colour fastness — Part A03: Grey Scale for Assessing Staining, 2019, https://www.iso.org/standard/75985.html.
[38] ISO 139:2005, Textiles — Standard atmospheres for conditioning and testing, 2005, https://www.iso.org/standard/35179.html.
[39] S. Šostar, R. Schneider, Guar gum as an environment-friendly alternative Thickener in printing with reactive dyes, Dyes Pigm. 39 (1998) 211–221.