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Pretreatment of Silk for Digital Printing: Identifying influential factors using fractional factorial experiments

Abstract

Purpose

The purpose of this study is to identify most influential factors affecting the printing properties and print quality of digitally printed silk fabrics in terms of colour strength and fixation percentage.

Design/methodology/approach

In this study, five factors (concentration of thickener, concentration of urea, concentration of alkali, pH of pretreatment liquor and steaming duration) were investigated using a blocked 2^{5-1} fractional factorial experiment. The type of thickeners (polyacrylic acid and polyacrylamide) were considered as a blocks.

Findings

Linear models were obtained and statistically tested using both analysis of variance (ANOVA) and coefficient of determination (R^2), and they were found to be accurate at 90% confidence level. It was revealed that concentration of alkali, concentrations of urea and pH of the pretreatment liquor had increasing effect on colour strength whereas concentration of thickener and steaming duration showed decreasing effect on colour strength of digital printed silk fabrics. Furthermore, concentration of alkali, concentrations of urea had increasing effect on dye fixation percentage whereas steaming duration showed decreasing effect on dye fixation percentage of digital printed silk fabrics. In addition, polyacrylamide thickener based pretreatment recipe exhibited better printing properties for the digitally printing of silk fabrics.

Originality/value

The main influences and significant two-factor interactions were discussed in detail to gain a better understanding of the printing properties of digitally printed silk fabrics. The findings of this study are useful for further optimisation of pre- and post-treatment processes for digital printing of silk fabrics.

Keywords: Silk; reactive ink; digital printing; pretreatment; colour strength; dye fixation percentage

Introduction

Coloration of silk by dyeing using reactive dyes is widely used in textile industries (Barker and Johnson, 1973), and the optimum parameters of reactive dyeing on silk are well-known (Burkinshaw and Paraskevas, 2011a ; Burkinshaw and Paraskevas, 2011b ; Agarwal et al., 1996). In comparison to other dyestuffs, the generally acclaimed advantages of using reactive dyes for coloration of silk include the possibility of obtaining bright shades with good wash fastness, light and perspiration fastness (Chakraborty, 2010 ; Uddin and Hossain, 2010). Various type of reactive dyes differ in terms of their characteristics during and/or after application (Mousa, 2007). For instance, it is known that the dye-fiber bond for most of the common type of reactive dyes is sufficiently resistant to hydrolysis (Meyer et al., 1986). MCT dyes are generally known for poor build-up properties when applied to silk and attempts have been made to counter such issues by a variety of techniques (Hosseini et al., 2013 ; Kang et al., 2009 ; Fang et al., 2007 ; Weibin et al., 2007 ; Iriyama et al., 2002 ; Barker and Johnson, 1973). Numerous accounts pertaining to the in-depth analysis of intrinsic characteristics of the fibre, the dye-fibre interactions, the suitability of various type of dyestuffs, application processes and associated parameters, etc., have greatly improved our understanding of the fundamental aspects of coloration of silk using reactive dyes (Burkinshaw, 2016 ; Lewis, 2014 ; Guo and Tang, 2013 ; Zuwang, 1998 ; Agarwal et al., 1997 ; Agarwal et al., 1996).

Silk can also be printed using a number of dyestuffs including reactive dyes. When reactive dyes are used for printing of silk fabrics, while the underlying dye-fibre interactions and processing parameters are essentially similar to that of dyeing of silk using reactive dyes, there are some obvious changes such as the use of a thickener in printing in order to restrict the dye molecules within specific areas on the fabrics. Consequently, the influences of the interactions between the thickener and the reactive dye on the printing qualities need to be taken into account.

Screen printing is by far the most widely used printing technique worldwide for textiles in general. This is due to the numerous advantages of this process including, but not limited to, high productivity, versatility, easier setup, and a broad range of achievable resolutions, etc. Interestingly, high productivity, which is one of the main advantages of screen printing, could potentially become a limitation for printing of expensive and high-value substrates such as silk, in which exclusive short lot sizes are more probable. This makes digital printing particularly suitable for printing of silk as digital printing is well acclaimed suitable for short production runs (Liker, 2004 ; Malachowski, 2004).

For a fabric to be digitally printed, a number of essential chemicals and auxiliaries including thickener are applied to the fabric prior to digital printing in a separate step which is often referred to as the "pre-treatment". In the case of screen printing, the thickener and all other ingredients are added into the printing ink which is then applied to the substrate. In contrast, in the case of digital printing, the addition of polymeric ingredients into the ink which is to be dispensed from very fine nozzles causes problems such as clogging of these nozzles. The pre-treatment of fabrics and corresponding interplay of chemicals and auxiliaries prior to digital printing have a direct effect on the quality of print (Teli, 2015 ; Fan et al., 2002), and the factors affecting colour strength and dye fixation in digital printing on cotton fibres have been studied (Faisal and Tronci, 2018 ; Kaimouz et al., 2010a ; Kaimouz et al., 2010b).

Accounts of digital printing of silk using pigmented inks are available (Kiatkamjornwong et al., 2004 ; Tincher and Yang, 1999). Various aspects of reactive printing on silk have also been studied in details by many researchers. In one such study, the effects of the type of thickeners, the type of reactive dye, the quantities of ingredients were studied and the processing parameters affecting the printing qualities were reported (Ibrahim et al., 2010). In another comprehensive study, droplet diffusion and distribution models were established, and the effect of the amount of urea and thickener on printing accuracy (roundness of the droplet and diffused area) were analysed and the colour performance (CIE Lab values) between the obverse side and the reverse side of fabrics were compared (Li et al., 2018). However, to the best of our knowledge, the effect of pre-treatment on printing qualities such as the colour strength and dye fixation percentage of digital-printed silk fabrics using reactive dyes have hardly been studied .

In this study, we have studies the effects of pre-treatment recipes and steaming duration on the colour strength and fixation percentage obtained in digital printing of reactive dyes on silk. Specifically, the factors that were studied include the concentration of thickener (100 – 200 g/L), the concentration of urea (80 – 150 g/L), the concentration of alkali (30–70 g/L), the pH of pretreatment liquor (6–9) and the duration of steaming (10–15 min) together with the interactions of these factors. Additionally, type of thickeners i.e. polyacrylic acid (PAA) and polyacrylamide (PAM) were treated as blocks.

Experimental

Materials

Thermacol MIN (polyacrylic acid) was supplied by Huntsman, Pakistan. Diamontex HD-C (polyacrylamide, Diamontex, Italy) was provided by SU & Company. Revatol S (reduction inhibitor) and Ladipur RSK (anionic detergent) were purchased from Archroma, Pakistan. Commercial grade Sodium bicarbonate and urea were used. Antelos R-KY XD (monochlorotriazine, Solunaris GmbH) was used for digital printing. Ready-to-print 100% silk fabric of plain weave without any finish and 34.6 g/m^2 in mass per unit area was obtained from local market.

Methods

Experimental design for screening

The processing factors studied in this work include the concentration of thickener (A, g/L), concentration of urea (B, g/L), the concentration of alkali (C, g/L), the pH of padding liquor (D), the steaming duration (E, min). Each of these factors was set at two levels. The high and low levels defined for the half fractional factorial design are listed in Table I. The levels for each of the factors were selected on the basis of preliminary experiments. The responses considered in the analysis include the colour strength (K/S) and the dye fixation percentage expressed as %F. The average of five values for each response was considered for the analysis.

Table I Factors and levels used in the 2^{5-1} fractional factorial design

Symbol	Factor	Low Level (-1)	Centre Point (0)	High Level (+1)
A	Thickener (g/L)	100	150	200
B	Urea (g/L)	80	115	150

C	Alkali (g/L)	10	17	25
D	pH of liquor	6	7.5	9
E	Steaming Duration (min)	10	12.5	15

To conduct a comprehensive study of the selected factors on the two selected responses, a blocked, 2^{5-1} fractional factorial design (FFD) with four centre points was developed as shown in Table II. The block was used to check for any variation observed on the responses due to different type of thickeners used in the pretreatment recipe. The centre points were added for the analysis of curvature (nonlinearity). It was anticipated that the 2^{5-1} design provide valuable information regarding the main influences and two-factor interactions. For the 2^{5-1} design, every main influence is confounded with a single four-factor interaction, and every two-factor interaction is confounded with a three-factor interaction. The experimental runs and the corresponding results for the responses i.e. colour strength and fixation percentage, for each run are provided in Table II. All statistical analyses were performed using the Minitab software version 17.

Table II Experimental runs and the corresponding results for the responses

Run	Blocks	A	B	C	D	E	K/S	%F
1	1	1	-1	-1	-1	-1	6.56	40.23
2	1	-1	1	-1	1	1	8.16	51.39
3	1	1	-1	-1	1	1	5.80	35.50
4	1	-1	1	1	1	-1	10.96	70.72
5	1	1	-1	1	-1	1	9.61	73.37
6	1	0	0	0	0	0	10.88	69.25

Run	Blocks	A	B	C	D	E	K/S	%F
7	1	0	0	0	0	0	11.98	72.95
8	1	-1	1	1	-1	1	10.47	70.12
9	1	1	-1	1	1	-1	12.40	79.05
10	1	-1	1	-1	-1	-1	9.32	62.04
11	2	1	1	-1	1	-1	10.25	67.41
12	2	-1	-1	1	-1	-1	12.31	86.13
13	2	1	1	1	-1	-1	12.65	80.25
14	2	-1	-1	-1	1	-1	11.66	69.31
15	2	0	0	0	0	0	11.43	81.84
16	2	-1	-1	-1	-1	1	8.50	58.78
17	2	1	1	1	1	1	12.58	81.91
18	2	1	1	-1	-1	1	9.75	64.96
19	2	-1	-1	1	1	1	11.59	76.66
20	2	0	0	0	0	0	11.65	77.22

Block 1 (PAA): runs 1–10, block 2 (PAM): runs 11–20, centre points: runs 6, 7, 15 and 20

Preparation of padding liquor

The required quantities of urea, alkali, reduction inhibitor and thickener were added in 500 mL water with constant stirring to ensure proper dissolution. Remaining amount of water was then added to make up 1 L of padding liquor and the pH was adjusted to the required value using acetic acid. Each formulation contains 15 g/L of Revatol S as reduction inhibitor.

Pretreatment

Padding of fabric samples (20×30 cm) in the prepared padding liquor was carried out on a Mathis laboratory padder at a pressure of 1.7 bar and speed of 1.5 rpm. The pick-up was maintained between 75-80%. After padding, the fabric was dried at 100°C for 5 minutes and then conditioned in an air conditioned room for 24 hours prior to digital printing.

Digital printing

Two passes of digital printing on the pretreated fabrics was carried out on a MS JP5 evo digital printing machine. The resolution of each pass was set at 600 x 600 dpi and a rectangular geometric pattern was printed for colour measurements using spectrophotometer.

Fixation and washing-off

For fixation, the printed fabrics were steamed at 102°C (saturated steam) for the duration as required for each individual experimental run. After steaming, the fabrics were washed in 200 mL of cold water for 10 minutes, subsequently rinsed in 200 mL of water containing 2 g/L of ladipur RSK at 95 °C for 10 min and then rinsed again in 200 mL of cold water for 10 minutes.

Analytical techniques

Assessment of colour strength

Reflectance measurements of printed samples were made using Datacolor spectrophotometer D650 (D65 illuminant and 10° standard observer) to determine the colour strength. The digitally-printed fabric was folded twice and an average of five readings at λ_{max} was calculated for each sample from Kubelka-Munk equation (Equation 1) (Garland, 1997), in which K is the absorption coefficient and S is the scattering coefficient.

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

Assessment of fixation percentage

Dye fixation was calculated by using Equation 2 (El-Shishtawy et al., 2004) in which $(K/S)_B$ and $(K/S)_A$ are colour strength values before and after wash, respectively.

$$\%F = \frac{(K/S)_B}{(K/S)_A} \times 100 \quad (2)$$

Results and discussions

In this section, the influences of pre-treatment recipes and steaming duration on both colour strength and fixation percentage of digital printed silk fabrics using reactive dyes are analysed and discussed based on the resultant colour strength and dye fixation obtained from the 2^{5-1} fractional factorial design, as shown in Table II and Figures 1–6.

Influences of factors on printing properties

Concentration of thickener

The influence of thickener concentration on the printing properties is shown in Figure 1. Both colour strength (K/S) and dye fixation (%F) values increase drastically upon increasing the thickener concentration from 100 g/L to 150/L and the highest value for both responses are obtained at the concentration of 150 g/L. Sufficient amount of thickener padded onto the fabric plays a crucial role in preserving the sharpness of prints such as outlines and edges by hindering the natural wicking of the fabrics. It also holds moisture and creates a minuscule dye-bath in which dissolution of the dye occurs, followed by diffusion and penetration into the fibres during the subsequent steam curing (Kaimouz et al., 2010b; Yuen et al., 2005). However, further increase in the thickener concentration leads to a sharp decrease in both colour strength (K/S) and dye fixation (%F) regardless of the thickener used. This could be attributed to the fact that the presence of excessive amounts of thickener forming a thick film could act as a barrier for reactive dye migration into fibres, thus limiting the amount of dye that is migrated from thickener film onto the fibre and subsequently fixed (Yuen et al., 2005 ; Schulz, 2002).

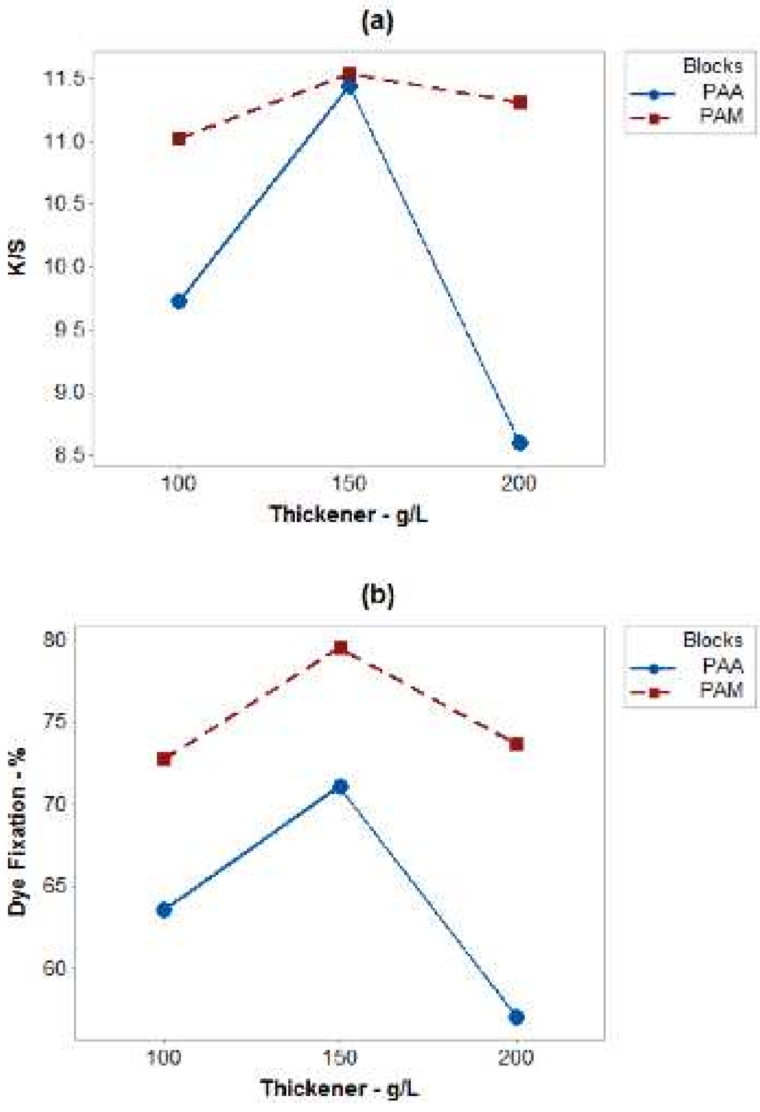


Figure 1

Concentration of urea

Urea is a very common constituent of pre-treatment acting as dye solvent and swelling agent of silk fibres prior to digital printing. As shown in Figure 2, increase in the urea concentration from 80 to 115 g/L resulted in a marked increase in both colour strength and dye fixation value. This could be attributed to the favourable influence of urea on holding moisture thus facilitating the dissolution of dyes that are otherwise in aggregated form (Kaimouz et al., 2010b). In the context of colouration of textiles, urea is known to cause swelling of the fibres. It is also well-known that during steaming, the steam condenses onto the film of thickener which causes swelling of thickener film. This swelling of thickener film and the swelling of the fibre to be dyed accelerates the release of dye from the thickener film while allowing the penetration of dye into the fibre (Yuen et al., 2005 ; Yuen et al., 2004 ; Yuen et al., 2003). These effects thus collectively result in higher colour strength and a higher dye fixation percentage in digital printing. The positive effects of urea on the colour strength and dye fixation diminish when the concentration of urea is increased beyond 115 g/L irrespective of the thickener used. It is probable that when present in excess amounts, urea holds more moisture during steaming process and as a result hydrolysis of reactive dye might occur and reduces the colour strength and dye fixation (Yuen et al., 2005 ; Yuen et al., 2004 ; Yuen et al., 2003).

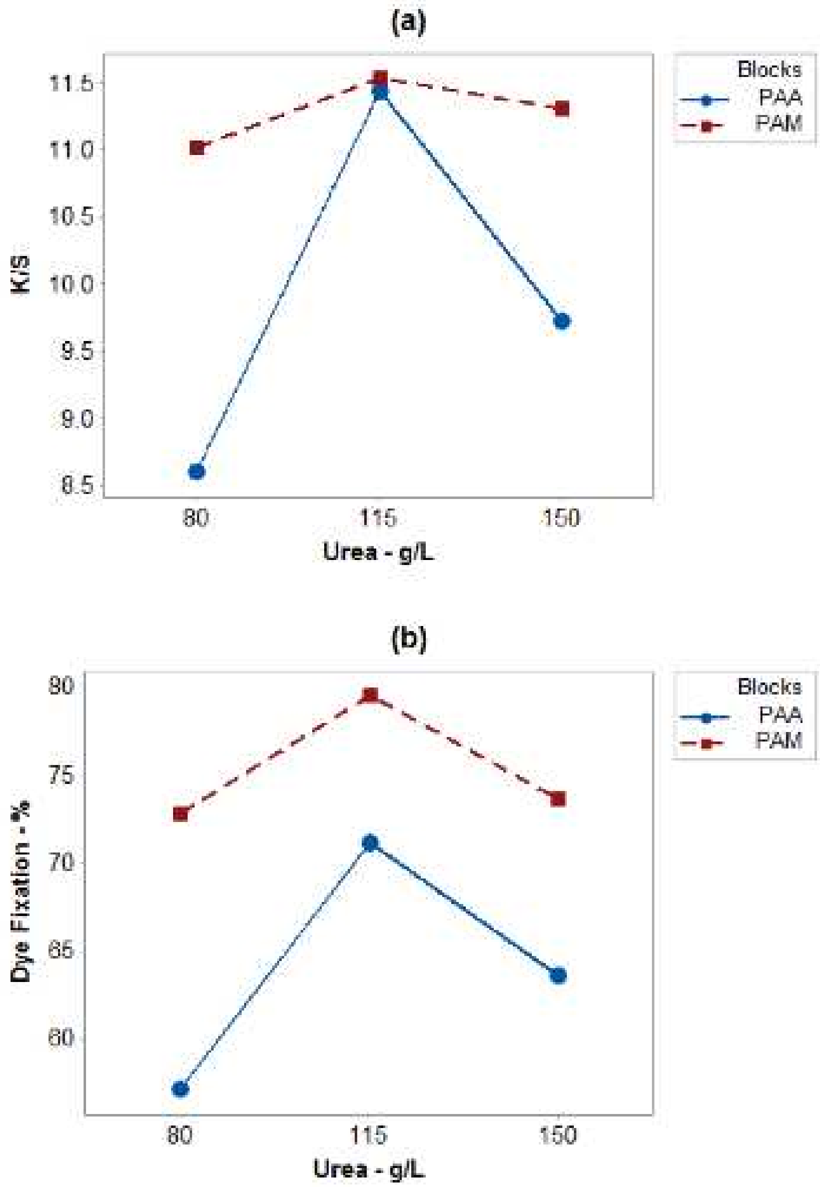


Figure 2

Concentration of alkali

Reactive dyes react with silk under alkaline conditions to form covalent bonds with the fibre. As shown in Figure. 3, increasing alkali concentration from 10 g/L up to 17.5 g/L leads to a remarkable improvement in the colour strength (K/S) and the dye fixation (%F) values, irrespective of which thickener used. However, Figure 3 also shows that the colour strength (K/S) of silk fabrics pre-treated with PAA based pretreatment recipe decreases with further increase in alkali concentration beyond 17.5 g/L. This could be attributed to the potential lack of stability of PAA based pretreatment recipe at higher concentration of alkali. It is also found that, while further increase in concentration of alkali from 17.5 to 25 g/L leads to the increases of dye fixation, such increases is limited. Amount of alkali is the key factor in fixation of reactive dye. Higher alkali concentration favours the formation of active sites and improves the reactivity of silk, thereby promoting the dye-fibre interaction in the fixation stage (Burkinshaw, 2016).

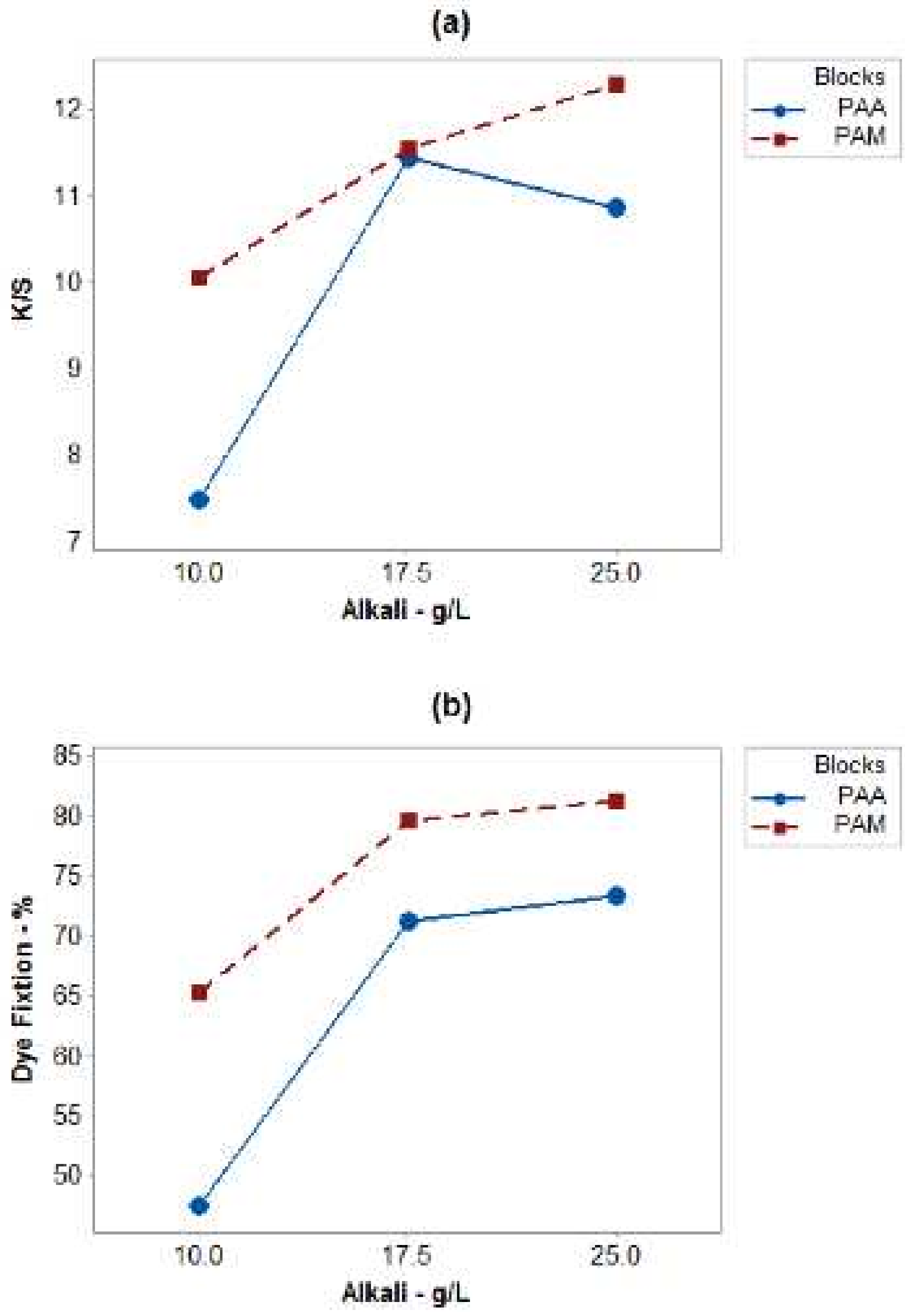


Figure 3

pH of pretreatment liquor

For dye fixation, the nucleophilic groups in silk namely the amino groups in histidine, lysine and arginine are important for reaction under acidic, neutral and alkaline pH conditions. In addition, both the phenolic hydroxyl (tyrosine) and alcoholic hydroxyl (serine) groups contribute under alkaline conditions (Burkinshaw and Paraskevas, 2011a). Figure 4 shows that both colour strength and fixation percentage increase with the increase of pH up to 7.5 and decrease when pH reaches to 9. It is interesting to underline that, while using PAM based pretreatment recipe, the effect of pH>7.5 on colour strength is negligible and it maintains the maximum value. The dye fixation results shown in Figure 4 are generally in-line with known processing parameters for dyeing/printing of silk (Zuwang, 1998). The dye-fibre reaction can only occur at nucleophilic (i.e. non-protonated) amino groups (Burkinshaw and Paraskevas, 2011b), because protonation of the $-NH_2$ groups decreases with the increase of pH from 6 to 7.5 and the number of nucleophilic amino groups which are available for dye-fibre reaction also increase, this effect is believed to result in the dye-fibre reactions which leads to the increased colour strength and dye fixation percentage. The highest level for pH was set at 9 and the decrease in dye fixation percentage might be due to hydrolysis of reactive dye at this pH.

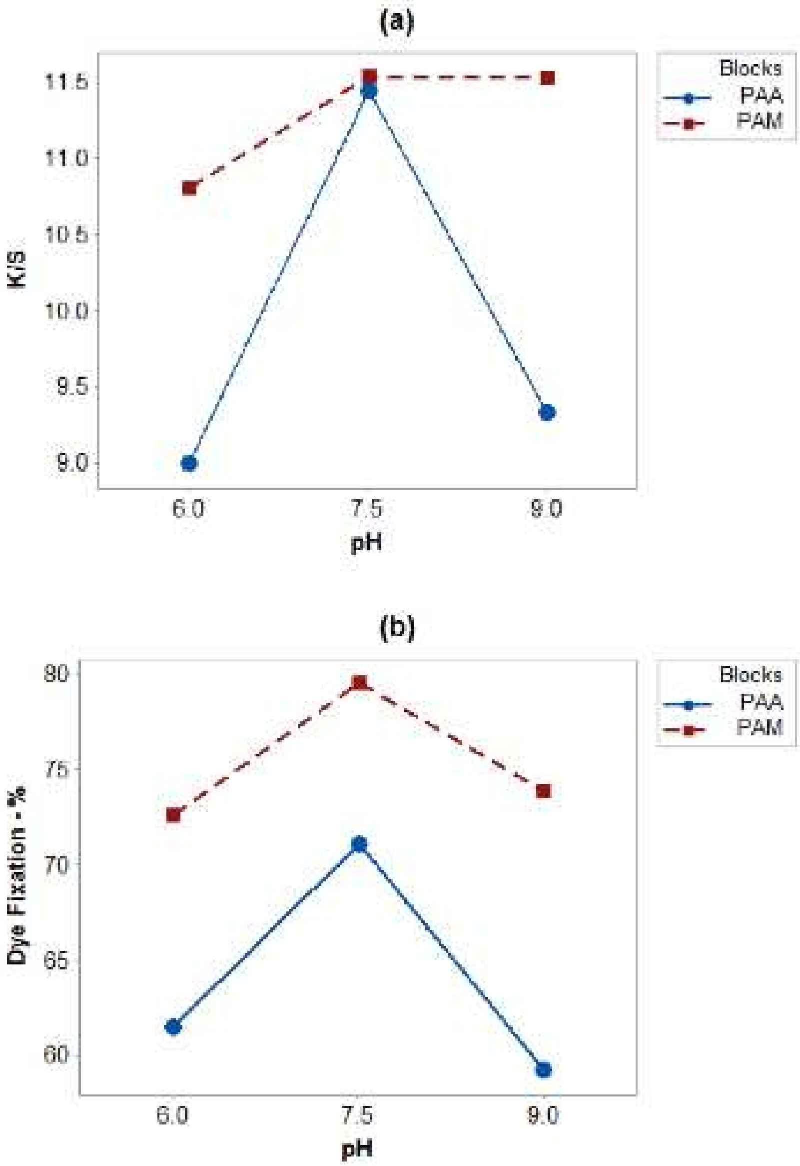


Figure 4

Steaming duration

Figure 5 shows the influence of steaming duration on the printing properties considered in this study. It is apparent that influence of steaming duration on colour strength of digitally-printed silk fabric is dependent on the thickeners used. For PAA based pretreatment recipe, increasing the steaming duration up to 12.5 min results in a considerable increase in the colour strength, whereas, further increase in steaming time decreases the colour strength sharply. In addition, for PAM based pretreatment recipe, increase in steaming time from 10 to 15 min brings a gradual decrease in colour strength. It is also found that, for both thickeners, increasing the steaming duration up to 12.5 min results in a considerable increase in dye fixation irrespective of thickener used. It is understood that longer steaming duration also provide excessive moisture which causes hydrolysis of reactive dye thereby reducing the colour strength and dye fixation (Kaimouz et al., 2010b ; Yuen et al., 2005 ; Yuen et al., 2004 ; Yuen et al., 2003).

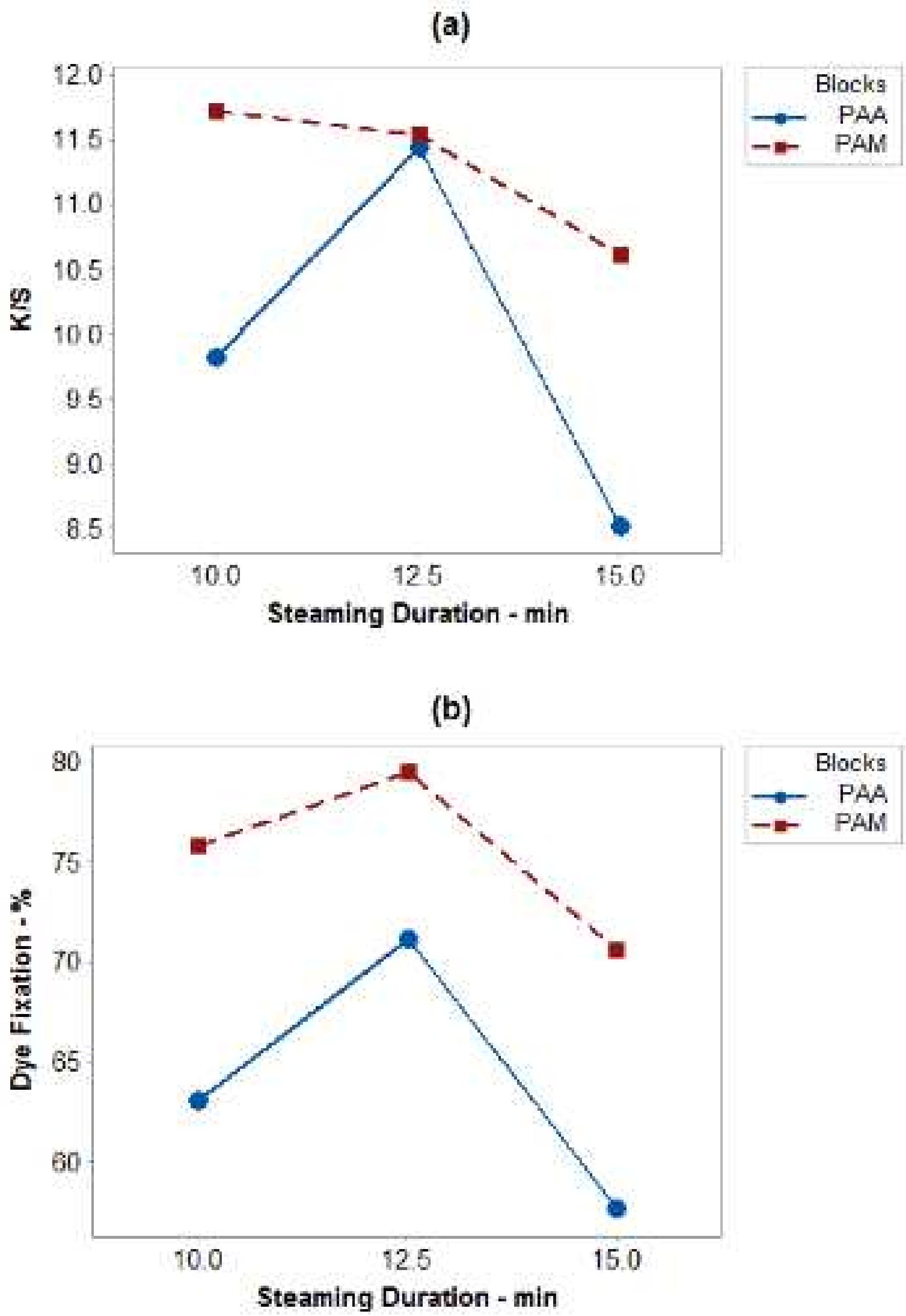


Figure 5

Type of thickeners

In this study, two type of thickeners namely polyacrylic acid (PAA) and polyacrylamide (PAM) were used. The box plot in Figure 6 shows that the higher values of colour strength and dye fixation were obtained when silk fabrics were pre-treated with PAM based pretreatment recipe than those of PAA. These results can be rationalized based on dye/thickener compatibility as well as dye reactivity towards silk fabric. PAM is a non-ionic water soluble polymer containing acrylamide groups (Gooch, 2011 ; Kiatkamjornwong et al., 2004 ; Tincher and Yang, 1999 ; Morris and Penzenstadler, 1978). It is well documented (Uranta et al., 2018a ; Uranta et al., 2018b) that PAM hydrolyses when mixed with alkaline solution or when subjected to elevated temperatures (>90°C), and its amide groups are converted into negatively charged carboxylate groups (Zeynali and Rabiei, 2002), thus the reaction and/or interaction between thickener film and dye is limited by mutual anion repulsion of the carboxylate groups of thickener and the sulphonic acid groups of dye. The repulsion additionally promotes migration of the dye from the thickener film into the fabric during steaming, giving rise to high colour strength and dye fixation percent (Miles, 2003). On the other hand, due to the side reaction of PAA with silk the number of carboxyl groups available on silk increases (Teli et al., 2015) which in turn increases repulsion between sulphonic acid groups of dye and silk fabric and thus producing prints with lower values of colour strength and dye fixation.

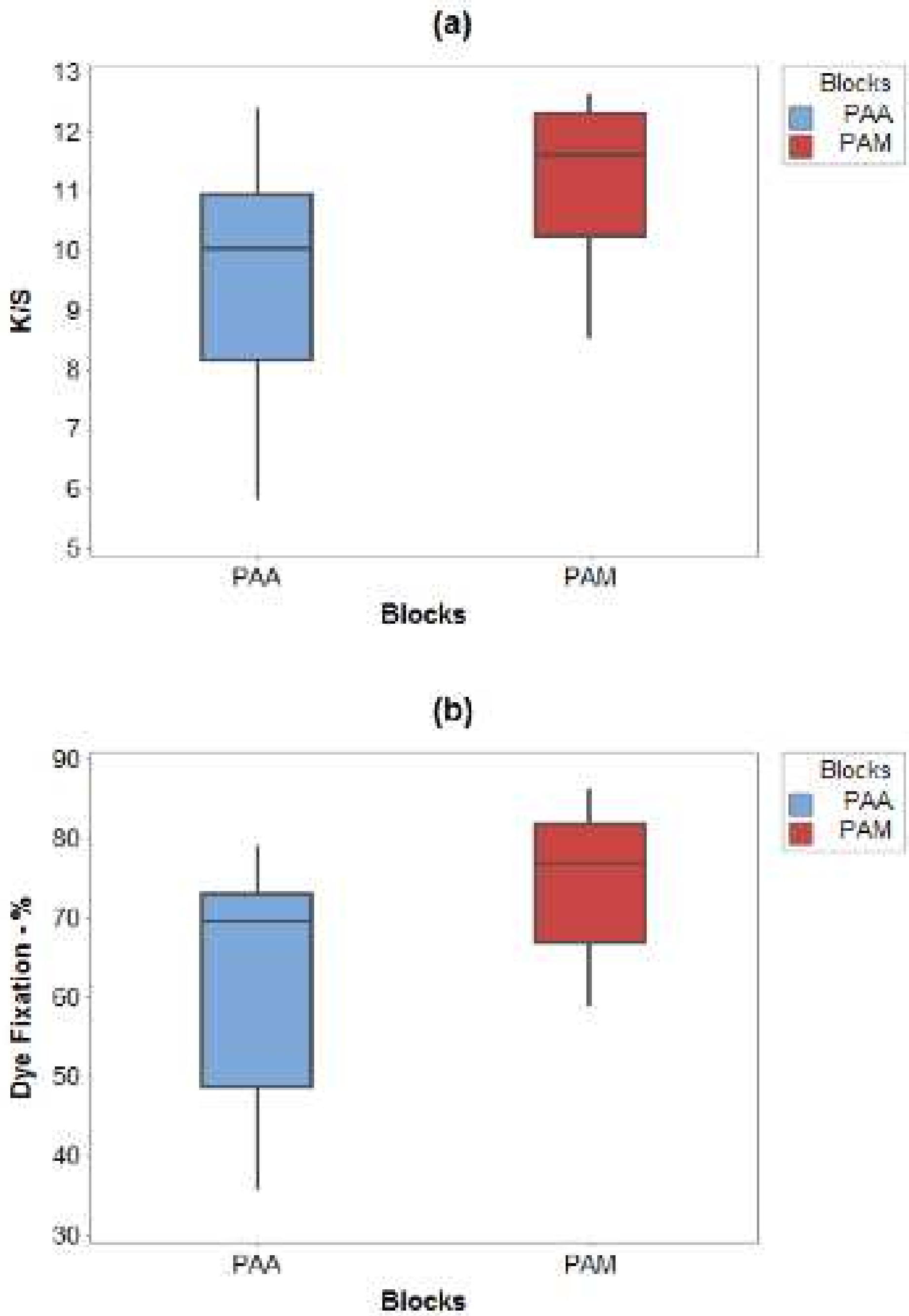


Figure 6

Statistical analysis

First order polynomial models (prediction or fitted model) between significant factors and responses were developed to illustrate the dependence of each response on the significant factors. These models were established by using forward selection regression technique. Adequacy of the regression models was statistically evaluated by analysis of variance

(ANOVA) and is presented in Table III and visualized by using Pareto charts shown in Figure 7.

Table III Analysis of variance (ANOVA) for Colour Strength and Dye Fixation

Source	**DF**	**SS**	**MS**	**F-value**	**P-value**
			Colour Strength		
Model	12	71.99	6.00	43.03	0.000*
Linear	5	41.55	8.31	59.60	0.000*
A: Thickener	1	0.71	0.71	5.07	0.059*
B: Urea	1	2.04	2.04	14.62	0.007*
C: Alkali	1	31.85	31.85	228.45	0.000*
D: pH	1	1.12	1.12	8.07	0.025*
E: Steaming Duration	1	5.83	5.83	41.82	0.000*
2-Way Interactions	6	24.80	4.13	29.65	0.000*
AB	1	16.04	16.04	115.08	0.000*
AC	1	3.23	3.23	23.18	0.002*
BC	1	1.10	1.10	7.90	0.026*
BD	1	1.38	1.38	9.92	0.016*
BE	1	1.71	1.71	12.23	0.010*
DE	1	1.34	1.34	9.60	0.017*
Curvature	1	5.64	5.64	40.45	0.000*
Error	7	0.98	0.14		
Lack-of-Fit	5	0.34	0.07	0.21	0.929
Pure Error	2	0.64	0.32		

Source	DF	SS	MS	F-value	P-value
Total	19				
R^2 = 0.9866; R^2 (adj) = 0.9637; R^2 (pred) = 0.9121					
Dye Fixation					
Model	10	3335.69	333.57	27.67	0.000*
Blocks	1	718.49	718.49	59.59	0.000*
Linear	5	1977.29	395.46	32.8	0.000*
A: Thickener	1	31.61	31.61	2.62	0.140
B: Urea	1	55.41	55.41	4.6	0.061*
C: Alkali	1	1776.68	1776.68	147.36	0.000*
D: pH	1	0.96	0.96	0.08	0.784
E: Steaming Duration	1	112.63	112.63	9.34	0.014*
2-Way Interactions	3	404.53	134.84	11.18	0.002*
AC	1	122.88	122.88	10.19	0.011*
BC	1	183.57	183.57	15.22	0.004*
DE	1	98.08	98.08	8.13	0.019*
Curvature	1	235.38	235.38	19.52	0.002*
Error	9	108.51	12.06		
Lack-of-Fit	7	91	13	1.48	0.460
Pure Error	2	17.51	8.75		
Total	19				
R^2 = 0.9685; R^2 (adj) = 0.9335; R^2 (pred) = 0.8306					

(*) statistically significant at $p<0.1$; DF: Degree of Freedom; SS: Sum of Squares; MS: Mean Square

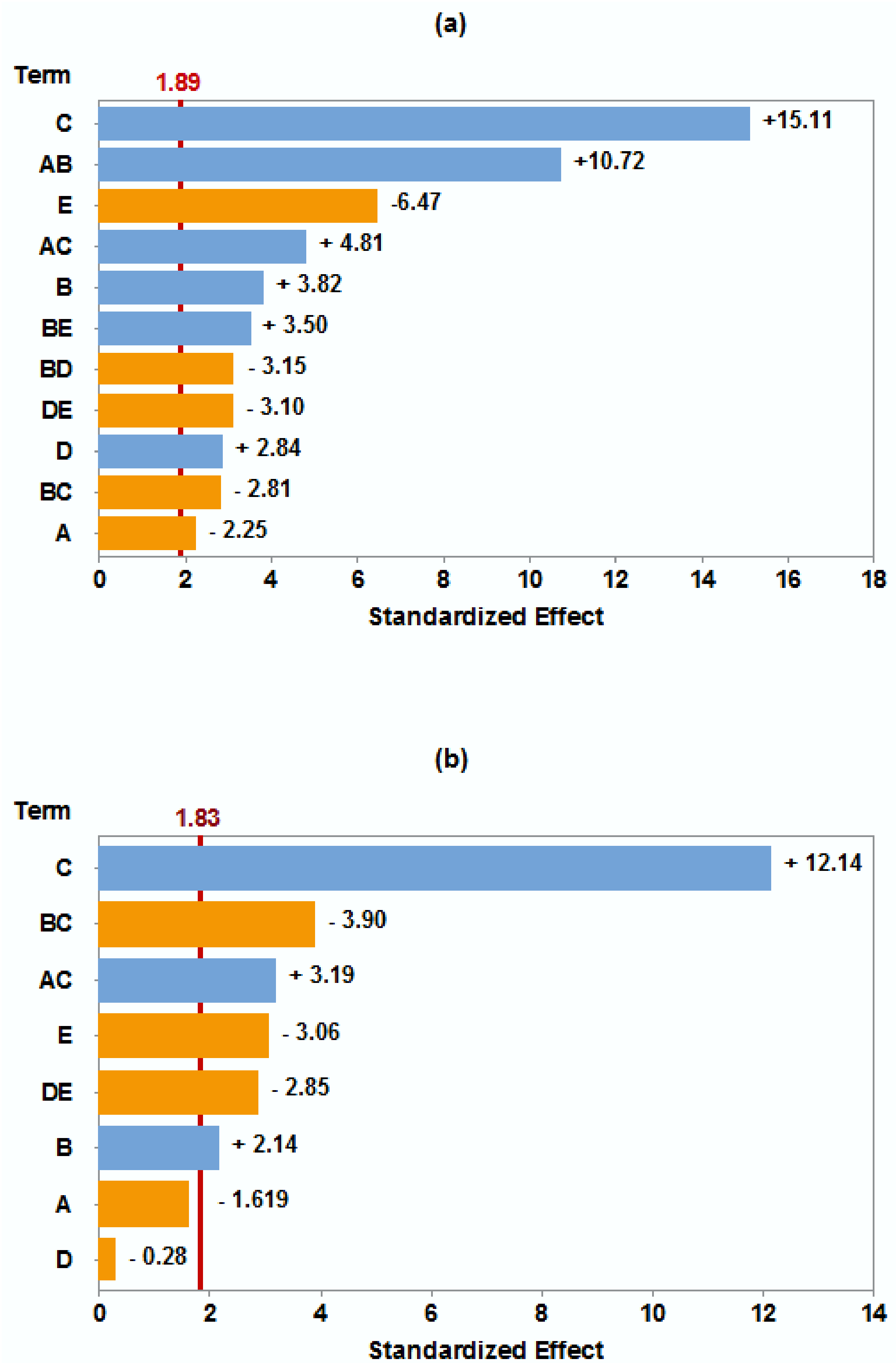
Statistical significance of the models was evaluated by F-test. Summaries of ANOVA for the models are presented in Table 3. The F-value of the regression models are 43.03 for colour strength (K/S) and 27.67 for dye fixation (%F); and the corresponding p-value, which indicates he significance of each model term, are very low (<0.0001) for both models, indicating that the models are significantly accurate. The smaller the p-value and correspondingly the larger the F-value, the more significant is the term. For colour strength, the p-values lower than 0.1 implies that the main influences A, B, C, D, E and the interactions of AB, AC, BC, BD, BE and DE were found to be statistically significant.

Similarly for the dye fixation percentage (%F), the p-value less than 0.1 for the main factors B, C, E imply that these factors have a statistically significant influence on the response. The interactions of AC, BC and DE were also found to be statistically significant. For the main factors A, D the p-values were greater than 0.1. However, these factors were also included in the model in order to obtain a hierarchic model.

The lack-of-fit p-values of 0.929 and 0.460, respectively, for colour strength and dye fixation reveal that they are not significant compared to the pure errors. The block effect appears to be significant only for dye fixation (F-value = 27.67). The curvature F-value for colour strength and dye fixation was 40.45 and 19.52, respectively. This implies that there is significant curvature in the design space. However, for screening of factors, it was assumed the linearity holds approximately. Since obtained models (Table III) contain interaction terms, the models are, therefore, capable of representing some curvature in the response (Montgomery, 2017). However, when significant curvature is detected further experimentation would be required to determine which factor(s) is responsible (Laures et al., 2007). Therefore, a different design such as central composite design and Box–Behnken design (Anderson and Whitcomb, 2016) should be carried out in future studies.

Pareto charts

Pareto charts shown in Figure 7 depicted the relative importance of factors for colour strength and dye fixation of digitally printed silk fabrics. In these charts, the bar lengths are proportional to the absolute value of the estimated main effect. In addition, all bars that are located to the right of the vertical dashed line represent significant factors, which mean that the corresponding factors and/or their interactions influenced the response above a statistically significant level of 90% confidence. Moreover, the positive or negative sign corresponding to each bar reveals that these factors must be kept at high or low levels in order to maximise the responses, respectively. According to Figure 7a, in this study, the main effect of concentration of alkali (C), followed by the interaction effect of concentration of thickener and concentration of urea (AB) have a considerable positive influence, whereas, the main effect of steaming duration (E) has a significant negative influence on the colour strength of digitally printed silk fabrics. It can be further seen that there is a significant positive interaction between concentration of thickener and alkali (AC) and concentration of urea and steaming time (BE); whereas, significant negative interaction between concentration of urea and alkali (BC), concentration of urea and pH of pretreatment liquor (BD) and pH of liquor and steaming time (DE). From Figure 7b, it is evident that once again main effect of concentration of alkali (C), followed by the interaction effect of concentration of urea and concentration of alkali (BC), and the concentration of thickener and concentration of alkali (AC) have significant influence on the dye fixation percentage of digitally printed silk fabrics.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8
10
12
14
16
18
Standardized Effect
(b)
Term
1.83
C
BC
AC
E
DE
B
A
D
+ 12.14
- 3.90
+ 3.19
- 3.06
- 2.85
+ 2.14
- 1.619
- 0.28
0
2
4
6
8
10
12
14
Standardized Effect

Figure 7

Conclusions

The screening of significant factors affecting the fabrication of digitally printed silk fabrics using polyacrylic acid and polyacrylamide as thickeners was performed using blocked 2^{5-1} fractional factorial experiments. Linear models were obtained and statistically tested using both analysis of variance and coefficient of determination, and they were found to be accurate at 90% confidence level. It was revealed that concentration of alkali, concentrations of urea and pH of the pretreatment liquor had increasing effect on colour strength whereas concentration of thickener and steaming duration showed decreasing effect on colour strength of digital printed silk fabrics. Furthermore, concentration of alkali, concentrations of urea had increasing effect on dye fixation percentage whereas steaming duration showed decreasing effect on dye fixation percentage of digital printed silk fabrics. In addition, polyacrylamide thickener based pretreatment recipe exhibited better printing properties for the digital printing of silk fabrics. Moreover, ANOVA analysis indicated that there is significant curvature in the design space. Therefore, a different design such as central composite design and Box–Behnken design will be carried out in future studies.

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