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A study on dimensional changes in the fused shirt components

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ABSTRACT

Shirt manufacturing involves fusing the cut parts with an interlining. Shrinkage in these components leads to puckering, mismatched design between fused and non-fused components, and increased fabric consumption. The study aims to explain the effect of ten factors – fabric (content, weight, weave structure, cover, and finish), interlining (weight, finish), fusing time, temperature and pressure – on thermal and relaxation shrinkage of the fused plackets. The results show that the thermal shrinkage in the placket is influenced by three factors (interlining finish, weight and temperature), and relaxation shrinkage of placket samples is influenced by three factors (fabric fiber content, temperature and pressure). The lower weight interlining with a raised finish used for shirt plackets is found to shrink when fused. After washing, the cotton placket shrunk more than the polycotton plackets. The optimized process condition for a specific fabric and interlining is proposed in the study.

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KEYWORDS
Design of experiment, Fused fabric composites, Interlining, Placket, Thermal shrinkage

1. INTRODUCTION

The fusing process is an important stage of shirt manufacturing wherein a fusible interlining is fused to shirt cut components that include the collar, collar stand, placket and cuff. The fusible interlinings are performance textiles coated with a heat-sensitive thermoplastic adhesive. Fabric and interlining cut components are placed with the coated side of interlining touching the fabric reverse side. This fabric composite is then exposed to a specific temperature and pressure for a specific time on a fusing machine. Fabric cut components are fused to impart the desired hand, volume, stiffness and stability [1].

The fusing process is carried out at a high temperature to ensure that the resin reaches the right viscosity level. The temperature at which the adhesive softens is called the fuse-line temperature [2,3]. A slight pressure exerted on the composites enables the molten resin to enter the interstices of the fabric. This leads to a good bond between the interlining and fabric components. A suitable adhesive should have a lower fuse-line temperature range to optimize the fusing process cost. This temperature range should be higher than the temperature maintained in pressing, and finishing during subsequent garment manufacturing and end-use garment care. Application of high temperature during fusing causes thermal shrinkage in many fused shirt components, and maximum changes can be as high as 30 mm [4]. Thermal shrinkage in collars and plackets are critical defects that can be corrected only by changing the parts with newly cut parts.

All three components of a fused composite (namely fabric, resin, and the interlining base fabric) behave independently when exposed to heat and pressure. The weave type of the fabric affects its shrinkage [5]. Three main reasons cause dimensional changes in the fused composites. The reasons include (a) effect of external stresses, (b) fusing process setting of time, temperature and pressure, and (c) release of internal stresses in fabric present before fusing and internal stresses formed during fusing due to fiber swelling [6]. The maximum acceptable change in dimensions caused in

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fabrics after fusing in commercial applications is ± 3%. Studies have established a fair amount of shrinkage in shirting fabrics in this range and few that are more than the acceptable range [7]. Shirting fabrics are subjected to various finishes to reduce the extent of shrinkage. The chemical finishing reduces the incidence of shrinkage caused due to stress [8]. In the case of checked and striped shirting fabric, even a 1% change in dimensions can pose a significant problem in check matching (Figure 1) [9]. Weft way shrinkage affects the width of the shirt component, and warp way shrinkage affects the length of the shirt component. The extent of shrinkage in the warp way and weft way are rarely the same [4]. Warp way shrinkage leads to quality and size issues in the fused shirt components [10]. The weft way relaxation shrinkage of fused woolen fabrics is higher than the warp way shrinkage [11]. The differential shrinkage in woolen fabric and interlining in warp direction caused rippling in the weft direction. The rippling is more in double fusing, where two interlinings are fused to the shell fabric [12]. In shirts, double fusing is done in the collar and stand. Rippling in the fused parts can lead to a bad fit and fall [10]. Extra allowance is added to the shirt patterns to counter the effect of shrinkage after fusing. This allowance increases marker consumption [4]. The literature pertaining to thermal shrinkage in fused shirting is scarce and causal factors are unknown. The factors known to influence the fused composite quality are properties of the component fabrics and fusing process parameters [13]. The woven interlinings are subjected to raising treatment to add bulk or volume to the fused composites. Interlinings with and without the raised finish are included in this study. Raising is a mechanical finish given to the interlining for achieving a brushed or napped appearance, giving higher volume and fullness [14]. This study aims to understand the factors that influence thermal and relaxation shrinkage caused after fusing shirting fabrics with interlinings used for plackets. An attempt has been made to explain the relation with a statistical regression model.

Figure 1. Check mismatch in shirt placket due to thermal shrinkage during fusing process

2. MATERIAL AND METHOD

2.1 Material

Medium weight cotton and polyester/cotton shirting fabrics and 100% cotton woven fusible interlinings with HDPE (high-density polyethylene) resin were selected for the study. The fabric properties are given in Table 1. The interlining weight selected was 65 g/ m^2 and 145 g/m^2, both raised and flat. This gives four different combinations of interlinings based on two levels of weight and finish.

2.2 Method

Screening design was used in the first stage to select the factors that significantly affect the shrinkage in the fused shirt components. The second stage of analysis used the full factorial design formed with the screened factors. The fabric properties considered for this study are fiber content, weight (grams per square meter), weave structure, fabric cover factor, and finish. The interlining properties considered as factors were weight and finish. The fusing process parameters were time, temperature and pressure applied during fusing. All the ten factors were considered in two levels, as shown in Table 2. The initial screening design was based on a ten factor – twenty run Plackett Burman design (Table 3), considering the properties of shirting fabric and interlining and fusing process parameters.

Two replicates of samples were prepared (a total of 40 samples) and marked for shrinkage testing as per standard ASTM D 2724-19. The samples were fused on a continuous fusing machine as per the screening design given in Table 3. After fusing and cooling, the markings were measured again in the warp direction for dimensional changes. The percentage change as both shrinkage and expansion was noted. The samples were washed for five cycles as per the standard ASTM D 2724-19 and the relaxation shrinkage was noted. The dimensional changes in the samples due to fusing (thermal shrinkage) and washing (relaxation shrinkage) were initially analyzed by stepwise regression analysis considering all the ten factors. The factors that showed a significant main effect (P-value < 0.05) on the thermal and relaxation shrinkage of the samples respectively were considered for a full factorial analysis in the second stage of analysis. The best-fit regression model was validated by the ANOVA [15]. The DOE formulation and analysis were done using the statistical software Minitab.

Table 1. Fabric properties

Fabric code	Fabric structure	Fabric finish	Areal weight (g/m^2)	Fabric cover factor	Fabric code	Fabric structure	Fabric finish	Areal weight (g/m^2)	Fabric cover factor
50-50 polyester cotton fabrics					**100% cotton fabrics**				
F_1	Plain	Yes	130	24	F_3	2/2 Matt	No	110	25
F_2	1/1 & 3/1 twill	No	132	21	F_6	2/2 matt & 3/1twill	No	145	21
F_4	Plain	Yes	118	24	F_7	1/1 & 2/1 twill	Yes	136	24
F_5	Plain	No	130	21	F_{12}	Plain	No	134	25
F_8	2/1 Twill	Yes	145	26	F_{14}	Plain	No	109	25
F_9	7/7 matt & plain	No	114	25	F_{16}	Plain	No	116	17
F_{10}	Plain	No	132	25	F_{17}	Plain	Yes	135	20
F_{11}	1/1 & 3/1 twill	No	101	21	F_{18}	1/1 & 2/1 Twill	Yes	133	21
F_{13}	2/1 Herringbone	Yes	115	21	F_{19}	2/2 Matt	Yes	109	24
F_{15}	Plain	Yes	124	19	F_{20}	Plain	Yes	111	21

Table 2. Factors and levels used in the design of the experiment

No	Factor	Factor code	Level 1	Level 2
1	Fabric areal weight	Fgsm	100-120	130-145
2	Fabric weave structure	FS	Plain	Twill/Matt
3	Fabric cover factor	FC	18-21	23-26
4	Fabric fiber content	FFC	Cotton	50-50 Polyester/cotton blend
5	Fabric finish	FF	Silicon finish	None
6	Interlining areal weight Collar	Igsm	135 g/m^2	160 g/m^2
	Stand		150 g/m^2	240 g/m^2
	Cuff		110 g/m^2	140 g/m^2
	Placket		65 g/m^2	145 g/m^2
7	Interlining finish	IF	Raised	Flat
8	Time	T	15 Seconds	20 Seconds
9	Temperature	Te	150ºC	170ºC
10	Pressure	P	1.5 kp/cm^2	3 kp/cm^2

Table 3. Plackett Burman experiment design and shrinkage (%) of fused samples

Std order	Fgsm	FS	FC	FFC	FF	Igsm	IF	T	Te	P	Thermal shrinkage (%)	Relaxation Shrinkage (%)
1	1	-1	1	1	-1	-1	-1	1	1	-1	-0.5	0.475
2	1	1	-1	1	1	-1	-1	1	-1	1	-0.125	0
3	-1	1	1	-1	1	1	-1	1	-1	-1	0	0.525
4	-1	-1	1	1	-1	1	1	1	-1	-1	0.5	0.375
5	1	-1	-1	1	1	-1	1	1	-1	-1	0.25	0.375
6	1	1	-1	-1	1	1	-1	1	1	-1	-0.5	0.875
7	1	1	1	-1	-1	1	1	1	1	1	-0.25	0
8	1	1	1	1	-1	-1	1	1	-1	1	0.25	1.05
9	-1	1	1	1	1	-1	-1	1	1	-1	-0.25	0
10	1	-1	1	1	1	1	-1	1	1	1	-0.5	0
11	-1	1	-1	1	1	1	1	1	-1	1	0.5	0
12	1	-1	1	-1	1	1	1	1	-1	-1	0.25	1.45
13	-1	1	-1	1	-1	1	1	1	1	-1	-0.5	1.05
14	-1	-1	1	-1	1	-1	1	1	1	1	-0.25	0
15	-1	-1	-1	1	-1	1	-1	1	1	1	0	0.375
16	-1	-1	-1	-1	1	-1	1	1	1	1	-0.25	0
17	1	-1	-1	-1	-1	1	-1	1	-1	1	0.25	0.875
18	1	1	-1	-1	-1	-1	1	1	1	-1	-0.5	0.875
19	-1	1	1	-1	-1	-1	-1	1	-1	1	0.125	0.375
20	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	0	0.875

3. RESULTS AND DISCUSSION

The extent of shrinkage in the placket samples is between -0.5 to 0.5 % after fusing (Figure 2). This level of shrinkage can lead to a dimensional change of about 0.30 cm (placket length- 60 cms). The relaxation shrinkage (measured between 0- 1.5 %) causes a dimensional change of about 0.9 cm in the finished placket.

3.1 Thermal shrinkage in placket samples

The factors that significantly affect the warp way shrinkage are temperature, interlining finish and interlining weight (Table 4). The full-factorial experiment (Table 5) was formulated with interlining finish and temperature and analyzed (Table 6). The model and the two factors (Te and IF) are statistically significant with P-value < 0.05. The individual effect of interlining weight (Igsm) and interaction effect of IF*Igsm were found statistically insignificant and hence removed from the model to derive the best fit model. The adjusted coefficient of determination squared (Adj. R^2) for the model is 85.15%. This implies that 85.15% of the variability in the data is considered in the model. The lack of fit has a P-value of 0.414, implying that the model is adequately capable of predicting shrinkage. The contribution to the total effect by the interlining finish is 73.89% and by temperature is 16.23%. The two-way interaction contributes 30.96% to the total effect, and the three-way interaction contributes 18.01% to the total effect. The regression equation from the analysis of the full-factorial design for thermal shrinkage in placket samples is given in Equation (1).

Thermal shrinkage of placket samples (reduced factor design)

$$= -0.1053 - 0.1358\,Te + 0.1682\,IF + 0.0769\,Te*IF - 0.1711\,Te*Igsm - 0.1431\,Te*IF*Igsm \quad (1)$$

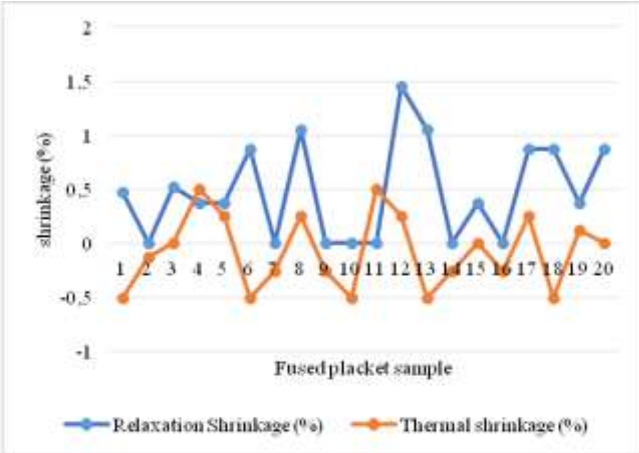


Figure 2. Shrinkage in placket samples

Table 4. Result of factorial analysis of shrinkage in placket samples

Model	Factors influencing response	Adj. R^2
Thermal shrinkage		
Screening design	All 10	69.85%
Full-factorial design	Temperature, Interlining finish and interlining weight	85.15%
Relaxation shrinkage		
Screening design	All 10	28.60%
Full-factorial design	Fabric fiber content, temperature and pressure	88.04%

Table 5. Full-factorial design for thermal shrinkage % in placket samples

Std order	Igsm	IF	Te	Shrinkage % Replicate 1	Std order	Igsm	T	Te	Shrinkage % Replicate 2
1	-1	-1	-1	-0.243	9	-1	-1	-1	0.000
2	+1	-1	-1	-0.500	10	+1	-1	-1	-0.482
3	-1	+1	-1	-0.260	11	-1	+1	-1	-0.241
4	+1	+1	-1	0.499	12	+1	+1	-1	0.021
5	-1	-1	+1	0.000	13	-1	-1	+1	0.000
6	+1	-1	+1	-0.471	14	+1	-1	+1	-0.492
7	-1	+1	+1	0.500	15	-1	+1	+1	0.488
8	+1	+1	+1	-0.255	16	+1	+1	+1	-0.249

The main effects of the factors seen in Figure 3a shows that raised interlinings are prone to negative shrinkage (about -0.27%), and the flat interlinings show negligible positive shrinkage (about 0.06%). Further, the negative shrinkage is higher (-0.24%) in the case of samples fused at 170ºC than the ones fused at 150ºC (0.03%). Interlinings for placket comprises the base fabrics of low-weight and low cover compared to interlinings used for collars and cuffs. As seen in the interaction effect of Te*Igsm (Figure 3b), the use of lower weight (65 g/m^{2,} reed count 50*50) interlining has led to slight negative shrinkage when fused at both levels of temperature (150 & 170 ºC). The use of interlining with the weight of 145 g/m^2 (reed count 75*55) shows positive shrinkage of 0.2 % at a lower temperature (150ºC) and negative shrinkage (0.41%) when fused at 170ºC. The extension (negative shrinkage) in samples with lower weight interlining can be due to the lower resistance offered against the pulling force of the conveyor belt during the fusing process. The higher weight interlining has been observed to provide higher stability in the fused composites at a lower temperature, but at a higher temperature, it allows an extension. The resin becomes highly viscous and pliable when heated to a high temperature of 170ºC [16]. At this stage, the placket interlining base fabric, which has low ends and picks per inch, provides less resistance to the pull exerted by the moving conveyor belt against the pressure rollers in the fusing machine as the fabric composite is pulled in the fusing machine direction. The exposure to high temperature further sets the fabric in an extended state. The influence of the interlining finish is stronger than the temperature on the thermal shrinkage of fused plackets (Table 6). Negative shrinkage is higher in the fused components having raised interlining than the samples fused with flat interlinings. This effect is due to the instability in the base fabric of the interlining caused by mechanical raising [14]. Hence the lower weight interlinings (65 g/m^2) should be subjected to mechanical raising finish with great caution.

Results imply that minimum shrinkage is expected at a fusing temperature of 150 ºC when using the interlining weight of 145 g/m^2 with the raised finish. The higher weight interlining with raised finish fused at 170ºC leads to higher negative shrinkage. At a lower temperature (150ºC), the flat interlining of higher weight shows positive shrinkage. The interlinings of a weight of 65 g/m^2 should be fused at a lower temperature to avoid shrinkage (Figure 3c). The negative shrinkage can be avoided if fused at a lower temperature of 150 ºC in raised interlinings (Figure 3d).

3.2 Relaxation shrinkage in placket samples

The extent of shrinkage measured after washing the placket samples is positive shrinkage in the range of 0 - 1.5% (Figure 2). The factors affecting the relaxation shrinkage in the fused samples are fabric fiber content, temperature and pressure (Table 4). In the master model, the factors namely the fabric fiber content, pressure and interactions FFC*Te and FCC*Te*P were statistically significant (P-value < 0.05). The best fit model was analyzed after removing the insignificant terms Te & FFC*P (Table 7). The adj. R^2 for the best fit model is 88.04%, and the lack of fit has a P-value above 0.05 (0.102), indicating the adequacy of the model. The regression equation of this reduced design is given in Equation 2. The factor- temperature does not significantly affect the relaxation shrinkage in the final model, whereas its interactions significantly affect relaxation shrinkage.

Table 6. Analysis of variance for thermal shrinkage in placket samples

Source	Master Model		Predictive Model				
	DF	P-Value	DF	Cr	Adj SS	Adj MS	P-Value
Model	7	0.001	5	90.10%	1.63809	0.32762	0.000
Linear	3	0.001	2	41.13%	0.74771	0.37386	0.000
Te	1	0.004	1	16.23%	0.29512	0.29512	0.002
IF	1	0.001	1	24.89%	0.45259	0.45259	0.001
Igsm	1	0.213	-	-	-	-	-
2-Way Interactions	3	0.004	2	30.96%	0.56291	0.28145	0.001
Te*IF	1	0.051	1	5.21%	0.09471	0.09471	0.045
Te*Igsm	1	0.001	1	25.75%	0.4682	0.4682	0.000
IF*Igsm	1	0.715	-	-	-	-	-
3-Way Interactions	1	0.003	1	18.01%	0.32747	0.32747	0.002
Te*IF*Igsm	1	0.003	1	18.01%	0.32747	0.32747	0.002
Error	8		10	9.90%	0.18003	0.018	
Lack-of-Fit			2	1.96%	0.03561	0.0178	0.414
Pure Error			8	7.94%	0.14442	0.01805	
Total	15		15	100.00%			

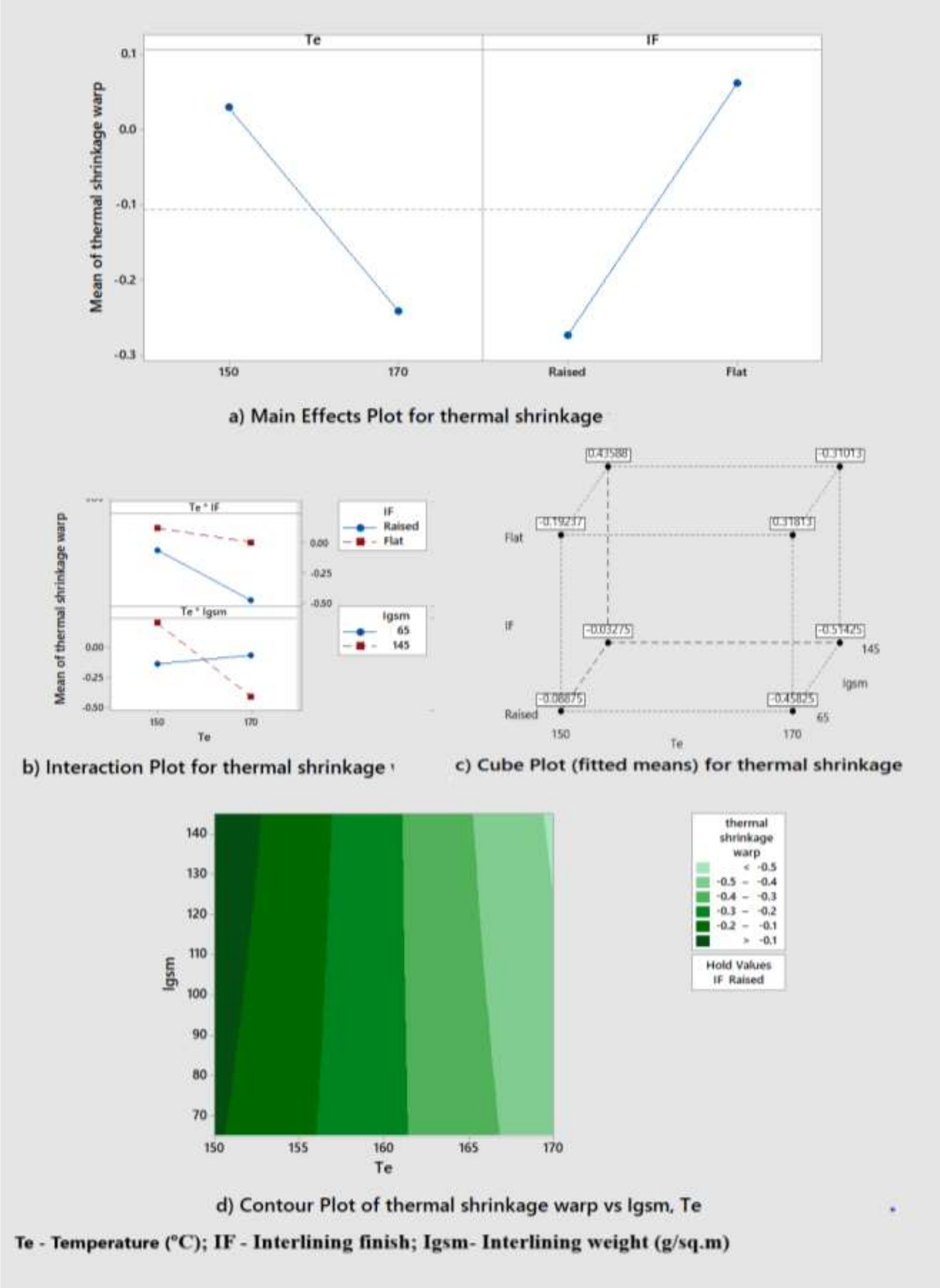


Figure 3. Effect plots for thermal shrinkage in placket samples

Table 7. Full-factorial design for relaxation shrinkage in placket samples

Std Order	FFC	Te	P	Shrinkage % Replicate 1	Std Order	FFC	Te	P	Shrinkage % Replicate 2
1	-1	-1	-1	0.520	9	-1	-1	-1	0.550
2	+1	-1	-1	0.490	10	+1	-1	-1	0.253
3	-1	+1	-1	0.750	11	-1	+1	-1	1.000
4	+1	+1	-1	0.500	12	+1	+1	-1	0.449
5	-1	-1	+1	0.990	13	-1	-1	+1	0.751
6	+1	-1	+1	0.000	14	+1	-1	+1	0.000
7	-1	+1	+1	0.000	15	-1	+1	+1	0.000
8	+1	+1	+1	0.000	16	+1	+1	+1	0.000

The regression equation (Equation (2)) for predicting the relaxation shrinkage in placket samples is as follows:

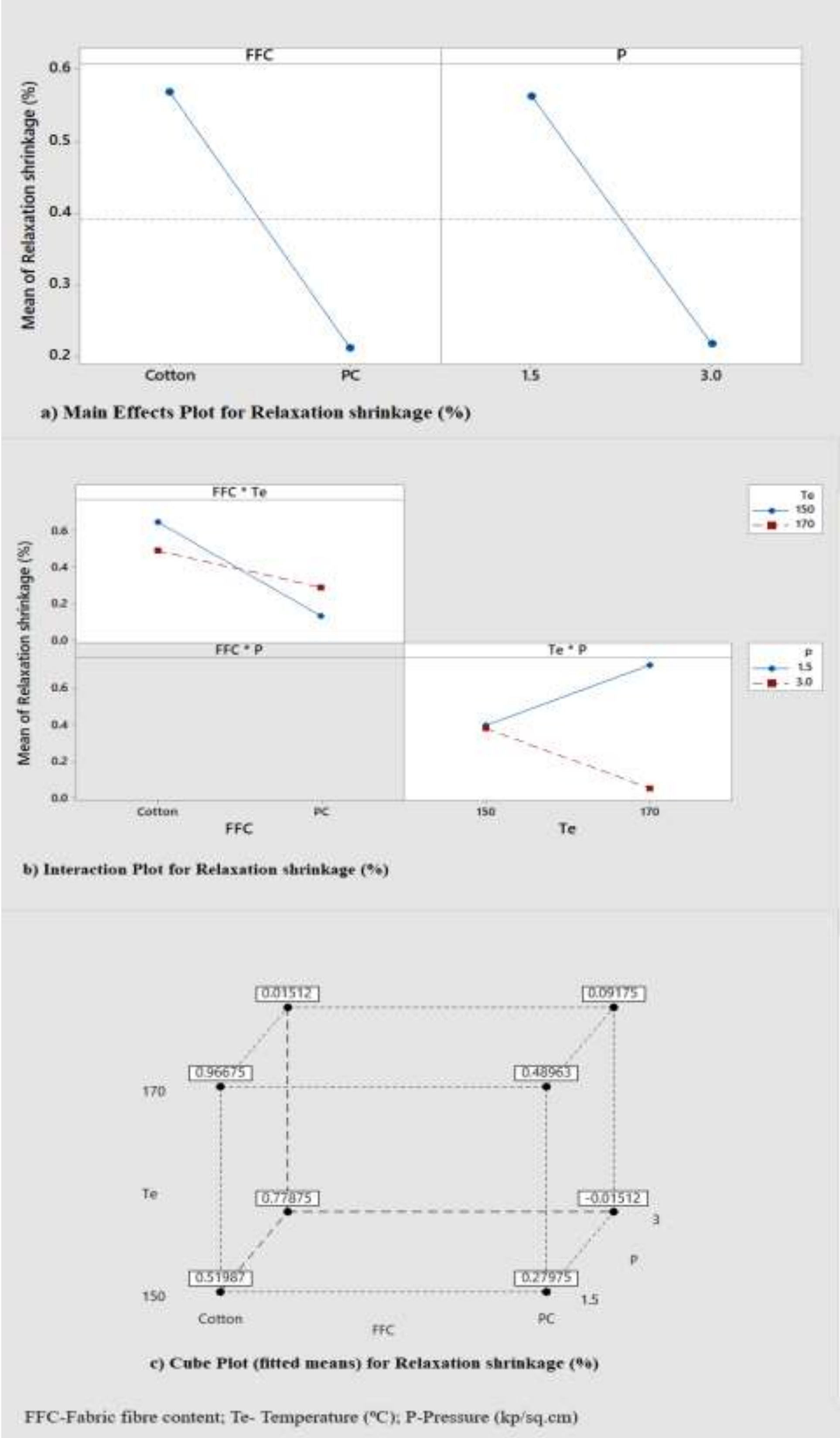
Relaxation shrinkage of placket sample (reduced factor design)

$$= 0.3908 - 0.1793\ FFC - 0.1732\ P + 0.0792\ FFC*Te - 0.1642\ Te*P + 0.1384\ FFC*Te*P \qquad (2)$$

Table 8. Analysis of variance for relaxation shrinkage in placket samples

Source	Master Model		Predictive Model				
	DF	P-Value	DF	Cr	Adj SS	Adj MS	P-Value
Model	7	0.000	5	92.02%	1.83264	0.36653	0.000
Linear	3	0.000	2	49.93%	0.99435	0.49718	0.000
FFC	1	0.000	1	25.83%	0.51445	0.51445	0.000
Te	1	0.078	-	-	-	-	-
P	1	0.000	1	24.10%	0.47990	0.47990	0.000
2-Way Interactions	3	0.001	2	26.70%	0.53165	0.26583	0.001
FFC*Te	1	0.017	1	5.04%	0.10033	0.10033	0.031
FFC*P	1	0.186	-	-	-	-	-
Te*P	1	0.000	1	21.66%	0.43132	0.43132	0.000
3-Way Interactions	1	0.001	1	15.40%	0.30664	0.30664	0.001
FFC*Te*P	1	0.001	1	15.40%	0.30664	0.30664	0.001
Error	8		10	7.98%	0.15882	0.01588	
Lack-of-Fit			2	3.47%	0.06917	0.03459	0.102
Pure Error			8	4.50%	0.08965	0.01121	
Total	15		15	100.00%			

Figure 4a shows the main effects of factors on relaxation shrinkage in samples. Placket samples made of cotton fabrics have a higher shrinkage (0.57%) than the PC blend fabrics (0.2%). The interaction is very high between factors- fabric fiber content and temperature. Cotton fabrics shrink more at lower temperatures, and PC fabrics shrink higher at higher temperatures. Maintaining higher temperatures of 170ºC and high pressure of 3 kp/cm^2 has helped reduce shrinkage in cotton fabrics. The interaction plot in Figure 4b shows that the samples fused at 150ºC have no significant difference in shrinkage level between the two levels of pressure (1.5 & 3 kp/cm^2). However, at 170ºC, it is seen that maintaining 1.5 kp/cm^2 pressure gives rise to high positive shrinkage (0.6%), whereas maintaining a pressure of 3 kp/cm^2 shows the least shrinkage (0.05%) (Figure 4c). Relaxation shrinkage is minimum in cotton fabrics when fused at 170ºC temperature and 3 kp/cm^2 pressure, as shown in the contour plot in Figure 5a. In PC fabrics, the relaxation shrinkage is minimum when fused at 150ºC and 3 kp/cm^2 (Figure 5b).



a) Main Effects Plot for Relaxation shrinkage (%)

b) Interaction Plot for Relaxation shrinkage (%)

c) Cube Plot (fitted means) for Relaxation shrinkage (%)

FFC-Fabric fibre content; Te- Temperature (°C); P-Pressure (kp/sq.cm)

Figure 4. Effect plots for relaxation shrinkage in placket samples

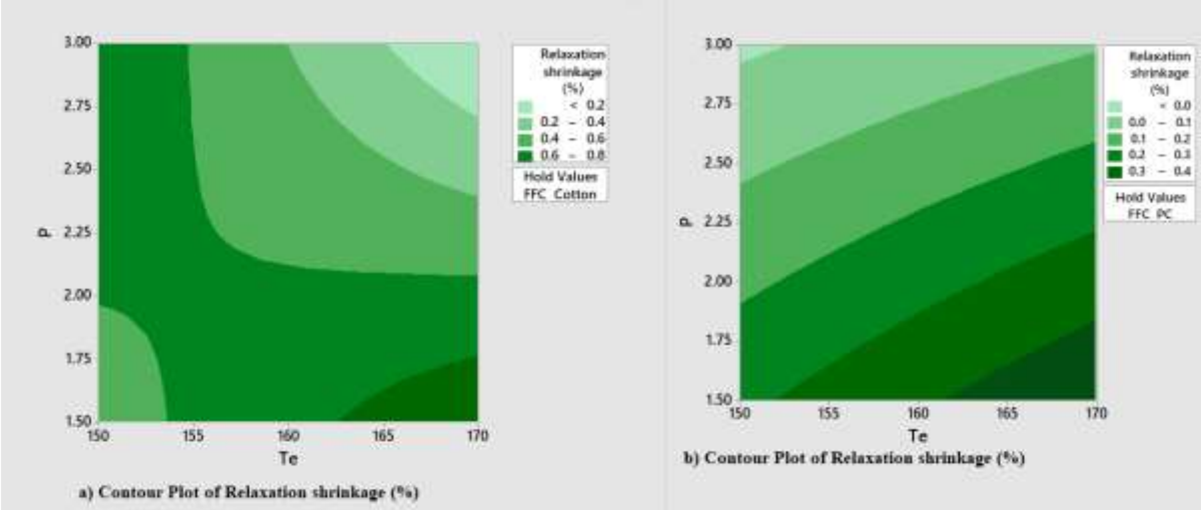


Figure 5. Contour plot for relaxation shrinkage in placket samples

4. CONCLUSION

Cotton and polyester/cotton shirting fabrics were fused with two weights of woven fusible interlinings. The study concluded that after fusing, negative shrinkage increased with increasing temperature due to the combined effect of increasing viscosity of the adhesive and low stability of the interlining weave structure. Further, raised finish on the lower weight interlining leads to a further reduction in its stability, causing higher negative shrinkage. The higher weight interlinings fused at high temperatures can lead to higher negative shrinkage. Notably, the shell fabrics' resin finish or fiber content shows no significant influence on the thermal shrinkage in the fused components. After washing the samples, it was found that cotton fabrics shrink more than the PC blend fabrics. Relaxation shrinkage can be minimized in cotton fabrics by fusing at higher temperatures and pressure. Polyester/cotton blend fabrics should be fused at a lower temperature to reduce shrinkage. The study throws light on the causes of thermal and relaxation shrinkage in fused shirting components, and the learning can be applied in selecting the right interlining and fusing process parameters for improved dimensional stability in the fused components. Further work can include the study of rippling in the fused components.

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