OPTIMIZATION OF FUSING PROCESS CONDITIONS USING THE RESPONSE SURFACE DESIGN

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Abstract: *In this investigation, optimization of fusing conditions to minimize the shrinkage and maximize the bond strength between a fabric and a fusible interlining before and after the dry-cleaning process has been carried out using the Response Surface Design. To optimize the quality of fused specimens, most important fusing parameters such as fusing time and fusing temperature were selected. Woven interlining was fused on men's shirting fabric by varying fusing time (10 sec, 12 sec, 14 sec, and 16 sec) and temperature (120℃, 130℃). As per the standard, fusing pressure of 1.5 bar was kept constant. After fusing, the fused fabric was characterized for different properties. Obtained results were analysed by factorial analysis method. Findings of this will help garment manufacturers in selecting the optimum fusing conditions so that they can maintain the cost and quality of the product at the same time.*

Keywords: *Response Surface Design, Fusing Conditions, Bond Strength, Shrinkage*

1. Introduction

Interlining is a layer of fabric placed between the shell fabric and facing. One side of the interlining fabric has thermoplastic resin which on heating is responsible for joining shell fabric and facing. Interlinings assume a significant job fit as a fiddle into the detail zones of garments, for example, the fronts of coats, collars, lapels, sleeves, and pocket folds [1]. Additionally, they settle and fortify zones subject to additional wearing pressure, for example, neck areas, facings, fix pockets, belts, plackets, and catch gaps [2][3]. Elements of fusible interlining in articles of clothing can be abridged as the simplicity of piece of clothing fabricating because of dependability of shell texture, blessing of volume because of good formability, outline and shape maintenance of piece of clothing because of reiteration of cleaning, accomplishment of fitting adaptability, improvement of the look, fall and material properties of a delivered piece of clothing [2][3]. Although interlining is an undetectable inside piece of an article of clothing, the interlining development and the combination procedure of interlining and shell texture influence sewability, appearance, toughness, handle, and mechanical properties of the article of clothing [4][5]. A decent fused textile material can be obtained when a privilege fusible interlining is picked for a given fabric and when ideal fusing conditions (fusing time, temperature, and pressure) are resolved. Choosing a correct sort of fusible interlining is still to a great extent dependent on experimentation strategy just as experience. Henceforth it is worth to study the impact of fusing time and temperature on qualities of fused fabric.

2. Experimental

2.1 Material

Woven fusible interlining with polyamide coating was fused on commercially available men's cotton shirting fabric. Properties of fusible interlining and men's shirting fabric are represented in table 1 and table 2 respectively.

Table 1: Properties of fusible interlining

Sr. No.	Specification	Value
01.	Composition	100% Terylene
02.	Coating	PA
03.	Base fabric	Plain
04.	Glue type	Double dot, small.
05.	Areal Density	200 gm/m^2
06.	Thickness	0.35mm
07.	Tensile Strength	53 gmf
08.	Elongation	26.8%
09.	Bending Modulus	341.06 kg/cm^2
10.	Colour	White

Table 2: Properties of men's shirting fabric

Sr. No.	Specification	Value
01.	EPI	60
02.	PPI	46
03.	Areal Density (g/m^2)	160
04.	Thickness (mm)	0.35
05.	Warp Way Tensile Strength (gmf)	64
06.	Warp Way Elongation (%)	20
07.	Weft Way Tensile Strength (gmf)	35
08.	Weft Way Elongation (%)	27.5
09.	Bending Modulus (kg/cm^2)	76.55
10.	Hot Air Shrinkage (%)	1.2
11.	Hot Water Shrinkage (%)	2.01

2.2 Methodology

Woven fusible interlining was fused on commercially available men's cotton shirting fabric by varying fusing conditions like fusing time and temperature at constant fusing pressure of (1.5 bar). Fusing was carried out at two different temperatures viz. (120℃, 130℃) with four different fusing time (10 sec, 12 sec, 14 sec, 16 sec). The experiment was carried out with two factors viz. fusing time having 4 levels and fusing temperature having 2 levels, as shown in table 3.

Table 3: Sample runs

Run/Sample No.	Time (Sec)	Temperature (℃)
S1	10	120
S2	10	130
S3	12	120
S4	12	130
S5	14	120
S6	14	130
S7	16	120
S8	16	130

This orthogonal array is chosen due to its capability to analyze the interactions among factors. Fusing parameters were standardized after preliminary experiments. Selection of the levels is based on the interlinings fusing parameters specifications. The fusing process was carried out in factory conditions, on continuous fusing press.

Sixteen fused samples were produced at each fusing condition. Out of 16 samples, 8 samples were subjected to the dry-cleaning process. Dry cleaning was done using Tetrachloroethylene, which is the most widely used solvent for commercial dry cleaning. The solvent temperature was maintained at 30℃. After cleaning samples were tumbled in a stream of warm air.

2.3 Testing

All specimens were subjected to bending rigidity for fusible interlining, bending rigidity for fused fabric, bond strength, tensile strength, elongation, and shrinkage tests. Details of all these tests are shown in table 4.

Table 4: Details of tests

Sr. No.	Test	Instrument	Standard
01.	Areal Density	GSM Cutter	ASTM D3776
02.	Thickness	Thickness Tester	ASTM D1777
03.	Bending Length	Stiffness Tester	ASTM D1388
04.	Bond Strength	Instron-5565	ASTM D2724
05.	Tensile Strength and Elongation	Instron-5565	ASTM D5035
06.	Hot Air Shrinkage	Oven	ASTM D4974
07.	Hot Water Shrinkage	Boiling Water Pan	ASTM D5104

3. Results and Discussion

This investigation was divided into two parts. In the first part effects of fusing conditions on properties of men's shirting fabric has been identified and in second part optimization of fusing process conditions using the response surface design has been done.

3.1 Effect of Fusing Conditions

3.1.1 Bending Modulus

Bending modulus is the key indicator stiffness of material irrespective of the type of material and its characteristics. After determining the bending length bending modulus of all the specimens had been determined and the results are tabulated in Table 5. Also, the effect of fusing condition on bending characteristics of the normal and dry-cleaned specimen is represented in fig. 1.
From fig. 1 one can depict that fusing time and fusing temperature are directly proportional to bending modulus. Increase in fusing time and fusing temperature significantly increases the fabric stiffness increasing the fabric stability.

Table 5: Bending Modulus (kg/cm^2)

Sr. No.	Time (Sec)	Temperature (°C)	Bending Modulus (kg/cm^2)	
			Normal	Dry Cleaned
S1	10	120	6.8	6.9
S2	10	130	7.3	7.0
S3	12	120	7.4	7.3
S4	12	130	7.6	7.5
S5	14	120	7.7	7.7
S6	14	130	7.7	7.7
S7	16	120	7.9	7.8
S8	16	130	8.0	7.8

This trend is because of increased bending length due to increase in fusing time and temperature. During the process of fusing, because of longer fusing time and higher fusing temperature, the resin melts properly and spreads over the fabric causing the adhesion of the interlining with fabric. As compared to the unfused fabric on fusing bending modulus increased by 568%. Almost 5-6 time raise in bending modulus represents the higher shape retention characteristics of fused fabric. The dry-cleaning process does not affect the fabric stiffness. Even though there is a decrease in bending modulus after dry cleaning, this change is insignificant. S8 represents higher bending modulus in all cases.

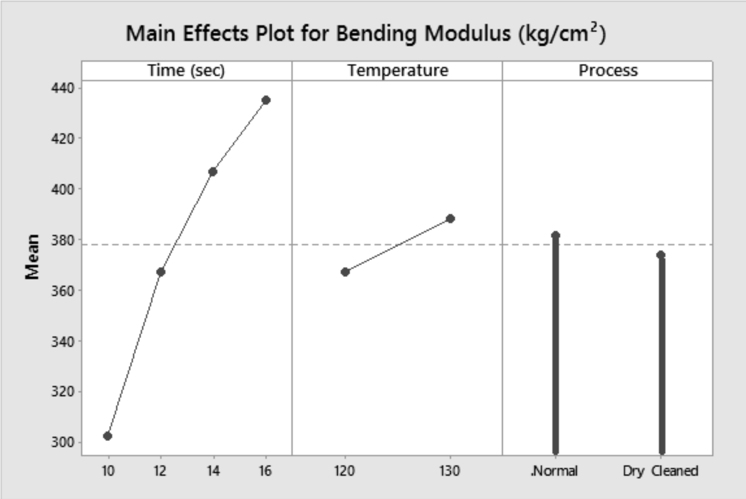

Figure 1: Bending Modulus (kg/cm²)

3.1.2 Bond Strength

Bond strength of fused systems is one of the most important parameters which greatly influence the quality of a garment. The strength of the connection depends on the adhesive forces between the fabric and the adhesive. Table 6 represents the mean values of bond strength of fused fabric in both directions (warp and weft) before and after dry cleaning.

Table 6: Bond strength (kgf)

Sr. No.	Time (Sec)	Temperature (℃)	Normal		Dry Cleaned	
			Warp Way	Weft Way	Warp Way	Weft Way
S1	10	120	13.76	13.93	13.47	13.64
S2	10	130	14.74	14.15	14.43	13.85
S3	12	120	16.48	16.32	16.13	15.98
S4	12	130	16.87	16.82	16.52	16.47
S5	14	120	18.37	18.65	17.98	18.29
S6	14	130	18.34	18.76	17.95	18.37
S7	16	120	21.48	21.48	21.03	21.03
S8	16	130	21.76	21.53	21.30	21.08

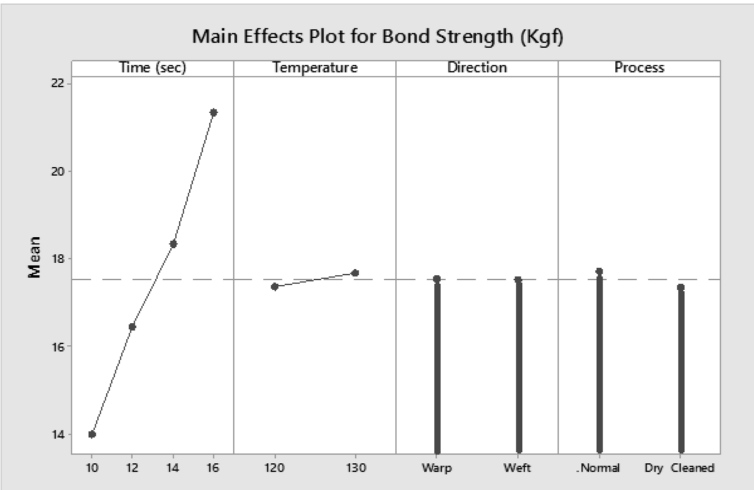

Figure 2: Bond strength (kgf)

From fig. 2 it can be clearly observed that there is a significant increase in bond strength as we increase the fusing time and temperature. During the process of fusing, it has been observed that the adhesive or the resin that is present on the surface of interlining will melt and flow into the interstices of the fabric thus enabling a deeper and a bigger contact area. Therefore, more energy is required in the breaking of bonds and hence the bond strength is high. This rate of melting and flow increases with increase in fusing time and temperature.

In the case of bond strength, directional effects are negligible. Irrespective of other factors all fabric samples show same band strength as far as warp and weft direction is concerned. The fabric onto which the interlining is fused is made up of the same yarns (fibres) in both warp and weft direction. Similar kind of material in both warp and weft direction have the same bonding efficiency in either direction. Hence bond strength is the same in the warp as well as in weft direction. Though there is a decrease in bond strength after dry cleaning the effect is not significant. On multiple washing cycles, there may be a significant reduction in bond strength. This can be attributed to the poor stability of adhesive in dry cleaning solvents. But this needs further investigation, which is out of the scope of the current topic.

3.1.3 Tensile Strength and Elongation

Tensile strength is an important property as it relates to the strength and performance of the material. The results of the measurements of tensile strength and elongation values of fused specimens are given in table 7 and table 8 respectively. Effect of selected factors on tensile strength and elongation of fused fabric has been represented in fig.3 and fig. 4 respectively.

Table 7: Tensile strength (kgf)

Sr. No.	Time (Sec)	Temperature (°C)	Normal		Dry Cleaned	
			Warp Way	Weft Way	Warp Way	Weft Way
S1	10	120	70.20	69.35	68.80	67.96
S2	10	130	89.70	78.26	87.91	76.69
S3	12	120	87.75	74.30	86.00	72.81
S4	12	130	75.40	92.12	73.89	90.28
S5	14	120	101.40	94.10	99.37	92.22
S6	14	130	116.35	99.05	114.02	97.07
S7	16	120	111.80	104.00	109.56	101.92
S8	16	130	124.80	109.94	122.30	107.74

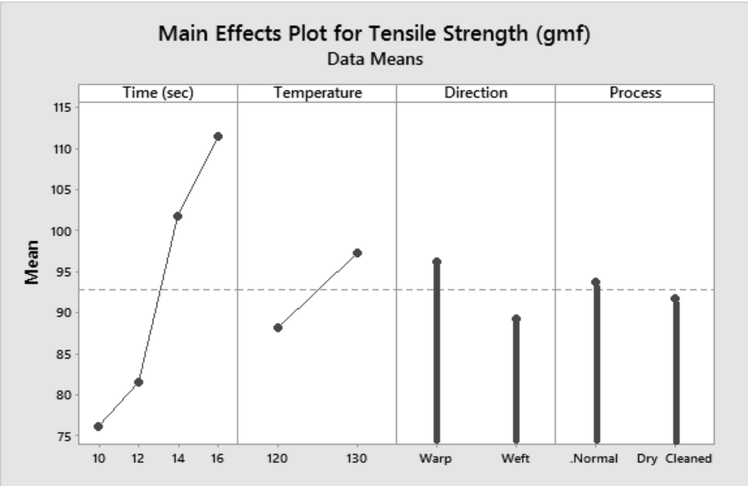

Figure 3: Tensile strength (kgf)

Among the fused samples, S8 has the highest tensile strength compared to other samples. As compared to unfused sample, the tensile strength of the fused sample in warp direction increases by 194% and by 311% in the weft direction. These results are enough to explain the reinforcing effect of interlining on fabric.

When the load is applied on the fabric, initially the load is carried by both interlining and fabric. When applied reaches maximum bond strength or holding the power of interlining polymer, delamination starts. Because of delamination, there is a nonuniform distribution of load on both on interlining and fabric. Further loading results in rupture of either interlining or fabric. Then there is a fracture in fused fabric. Therefore, the load required to cause breakage of fused fabric is high compared to that of unfused fabric.

As fusing time and temperature increases, the tensile strength of fused specimen increases. The same reason can be given for these trends as given for bond strength. Warp way tensile strength is significantly higher than that of weft way strength. Inherent weft way strength of the fabric is lesser than that of warp way strength. The same trend is observed for fused fabric samples as well. There is no significant impact of dry cleaning on tensile properties of fused samples.

Table 8: Elongation (%)

Sr. No.	Time (Sec)	Temperature (°C)	Normal		Dry Cleaned	
			Warp Way	Weft Way	Warp Way	Weft Way
S1	10	120	32.45	33.21	33.10	33.87
S2	10	130	30.40	31.11	31.01	31.73
S3	12	120	31.52	32.26	32.15	32.90
S4	12	130	29.40	30.09	29.99	30.69
S5	14	120	28.25	28.91	28.82	29.49
S6	14	130	27.60	28.24	28.15	28.81
S7	16	120	26.34	26.95	26.87	27.49
S8	16	130	26.04	26.65	26.56	27.18

It is clearly visible from fig. 4 that, with the increase in fusing time and temperature there is a reduction in fabric elongation. This reduction in elongation is significant.

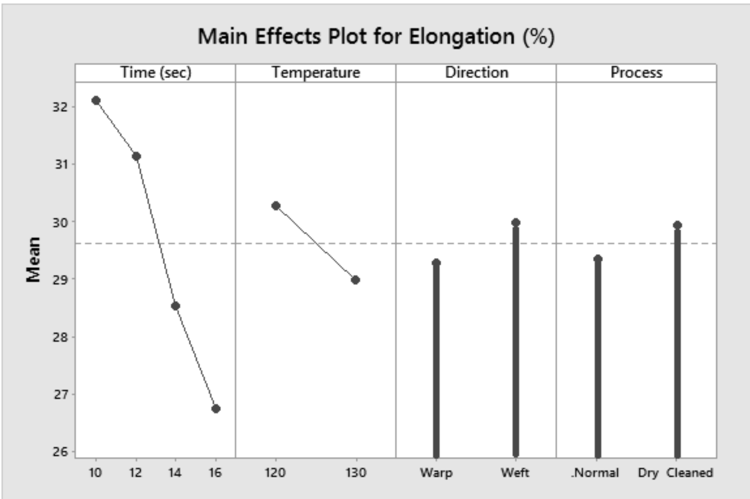

Figure 4: Elongation (%)

This trend in elongation of fabric is observed due to the deposition of polymer/adhesive on fabric after fusing. Interlining adhesive/polymer gets diffused inside the yarn structure, coating the component yarn and fibres of the fabric. This coating is rigid and creates hindrance in natural elongation of component yarn and fibres of the fabric.

Inherent weft way elongation of fabric is higher than that of warp way elongation. The same trend is reflected in the fused sample as well. Weft way elongation is significantly higher than that of warp way elongation. There is no significant effect of dry-cleaning agents on fabric elongation.

3.1.4 Shrinkage

Shrinkage of fused garment patterns is an exceptionally normal and significant issue. This issue could emerge from improper selection of fusing parameters, non-uniform pressure, temperature, and imperfections in interlining [5]. Abundance shrinkage may cause measuring issues as the completed article of clothing will be smaller than it was planned. It additionally prompts the arrangement of puckered creases [4].

Mechanical action during garment manufacturing can cause intemperate shrinkage of fused fabric and results in lesser bond strength. Shrinkage was resolved in two distinct ways. The initial one is hot air shrinkage and the second one is hot water shrinkage.

The mean values of hot air shrinkage and hot water shrinkage of fused fabric in both direction (warp and weft) before and after dry cleaning are given in table 9 and table 10 respectively. Fig. 5 and fig. 6 represent the effect of fusing time, temperature and dry cleaning on hot air and hot water shrinkage behaviour of fabric respectively.

Table 9: Hot air shrinkage (%)

Sr. No.	Time (Sec)	Temperature (°C)	Normal		Dry Cleaned	
			Warp Way	Weft Way	Warp Way	Weft Way
S1	10	120	1.92	1.06	1.89	1.04
S2	10	130	1.82	1.00	1.79	0.98
S3	12	120	1.79	0.95	1.76	0.93
S4	12	130	1.66	0.93	1.63	0.91
S5	14	120	1.16	0.88	1.14	0.86
S6	14	130	1.45	0.80	1.42	0.79
S7	16	120	1.38	0.74	1.36	0.73
S8	16	130	1.18	0.65	1.16	0.64

Hot water shrinkage test of all the specimens was calculated by immersing the samples in boiling water for 15 minutes and determining the distance between the gauge marks before and after the test.

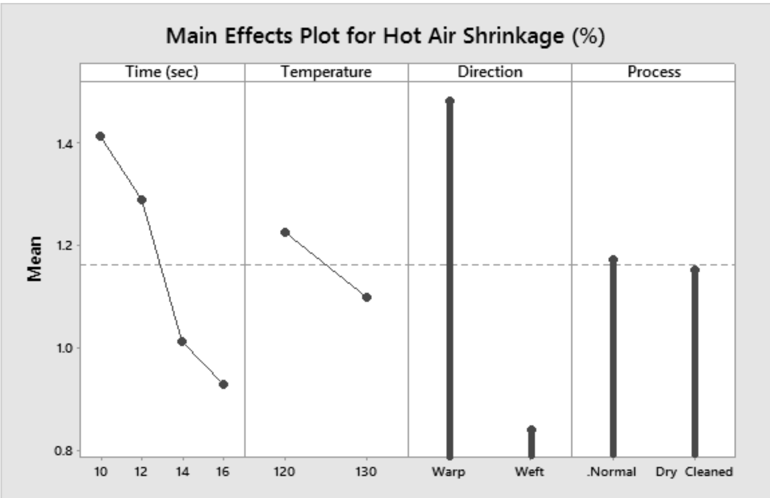

Figure 5: Hot air shrinkage (%)

From fig.5 and fig.6, all the fabric specimens exhibit similar shrinkage behaviour for both hot air shrinkage and hot water shrinkage tests. However, irrespective of all the factors boiling water shrinkage is more than that of hot air shrinkage. Since fabric specimen in water undergoes more relaxation than that of in the air.

Table 10: Hot water shrinkage (%)

Sr. No.	Time (Sec)	Temperature (℃)	Normal		Dry Cleaned	
			Warp Way	Weft Way	Warp Way	Weft Way
S1	10	120	2.96	1.67	2.93	1.65
S2	10	130	2.23	1.34	2.21	1.33
S3	12	120	2.78	1.49	2.75	1.47
S4	12	130	2.18	1.24	2.16	1.23
S5	14	120	1.80	1.37	1.78	1.35
S6	14	130	1.15	1.11	1.14	1.10
S7	16	120	1.15	1.15	1.14	1.14
S8	16	130	1.03	0.98	1.02	0.97

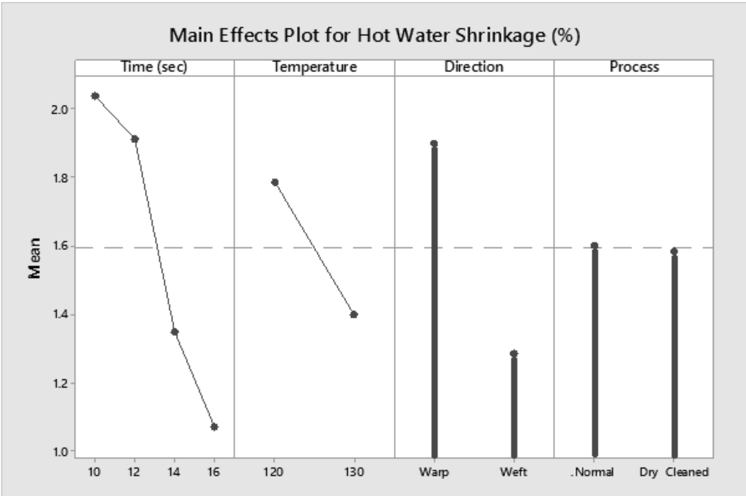

Figure 6: Hot water shrinkage (%)

In both cases, with an increase in fusing time and fusing temperature, there is a reduction in shrinkage significantly. This trend is may be due to shrinkage in fusible interlining during the fusing process. Interlining fabrics are coated with polyamide resin/polymer whose glass transition temperature is 47-60℃ [6] which is well below the fusing temperature. Hence there is a maximum chance for shrinkage during fusing.

From the results, it has been observed that there seems to be no significant shrinkage on dry cleaning. With the increase in fusing time and temperature, there is a significant reduction in fabric shrinkage. This is because of high residual shrinkage of fabric during fusing. Since already shrunk portion is being subjected to shrinkage, fabrics show reduced shrinkage after fusing.

Irrespective of other factors warp way shrinkage is more than that of weft way shrinkage. Since warp yarns are under much strain due to interlacement than the weft yarns. Hence when a fabric can shrink, the warp yarn shrinks more than that of the weft.

3.2 Response Surface Optimization

After studying the effect of fusing time and temperature on the properties of fused textiles, it is essential to optimize the fusing conditions. Keeping this in view, response surface design has been formed for available set of variables with the goal to increase bond strength, formability i.e. bending modulus, tensile strength and to minimize the shrinkage and elongation. Table 11 exhibits the response surface design for optimizing fixing conditions. Table 12 is the solution to the response surface design. From table 12 we can clearly get the idea about optimum fusing conditions. If the selected interlining is fused of shirting fabric with 130℃ temperature for 16 seconds one can achieve the desired goals.

Table 11: Response surface design

Response	Goal	Lower	Target	Upper	Weight	Importance
Elongation (%)	Minimum		26.040	33.8715	1	1
Tensile Strength (kgf)	Maximum	67.9630	124.800		1	1
Hot Water Shrinkage (%)	Minimum		0.969	2.9600	1	1
Hot Air Shrinkage (%)	Minimum		0.540	1.9200	1	1
Bond Strength (Kgf)	Maximum	13.4710	21.760		1	1
Bending Length (cm)	Maximum	6.7535	8.000		1	1

Table 12: Solution of Response Surface Optimization

Solution	Time (sec)	Temperature (℃)	Process	Elongation (%) Fit	Tensile Strength (kgf) Fit	Hot Water Shrinkage (%) Fit	Hot Air Shrinkage (%) Fit	Bond Strength (Kgf) Fit	Bending Length (cm) Fit	Composite Desirability (D)
1	16	130	Regular	26.2413	117.912	0.931121	0.841543	21.5056	7.91459	0.919493

Composite desirability has a range from zero to one. If composite desirability is near to one then it will be the ideal case and model achieves the set goals for all the properties. The Composite desirability (D) of the model is 0.92 which indicates the fusing conditions obtained seem to achieve the desired goal for all the properties as a whole.

4. Conclusion

1. Of all the aspects of performance investigated, it is evident that fusible interlinings fused at with 16 seconds of fusing time performed well in the areas of bending, bond strength, tensile strength, and shrinkage both in warp and weft direction.
2. Fusing time and fusing temperature is directly proportional to the rate of melting and flow of melt of polymer/adhesive/resin used on interlining.
3. Longer fusing time and higher fusing temperature significantly increase bending length, bending modulus, bond strength and tensile strength.
4. As far as the fusing process is concerned, bond strength shows isotropic behaviour.
5. Dry cleaning has a negative influence on several characteristics of fused fabric indicating the unsuitability of either solvent or interlining polymer.
6. To avoid shrinkage in either direction after fusing, fusing temperature must be kept lower than glass transition temperature interlining fabric material as well as shell fabric.
7. Findings of this investigation will help garment manufacturers in selecting the optimum fusing conditions so that they can maintain the cost and quality of the product at the same time.

5. References

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