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Effects of industrial ironing on mechanical and dimensional properties of cotton, wool and polyester fabrics

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The influence of industrial ironing cycle on low-stress mechanical properties and on dimensional changes in three selected weave fabrics has been studied. The experimental results are statistically analyzed using ANOVA. It is observed that the compressional properties measured by FAST system are the most influenced by the process of ironing. Cotton and wool fabrics show much variation in mechanical and dimensional changes compared to polyester fabric.

Keywords: Cotton, Dimensional changes, Dry ironing, Ironing paths, Low- stress mechanical properties, Polyester, Steam ironing, Wool

1 Introduction

Ironing or pressing are processes carried out on a textile fabric or garment to eliminate undesirable wrinkles and to restore its shape and appearance by applying mechanical pressure with heat, either in dry state or in the presence of steam [1]. In industry, there are three general pressing operations, viz under pressing of garment during making up, molding to give a three dimensional shape and top-pressing to finish the fully assembled item [2].

Hand irons and buck press are extensively used in garment manufacturing [2,3]. Industrial iron is a heating device providing even heat transfer to the specimen from the top by close contact at a controlled temperature and giving a pressure on the specimen[1]. The pressing action is frequently enhanced with the presence of steam discharged through holes in the iron sole plate. In order to make iron sliding easier and to reduce weight, the sole plate are made of aluminium and/or coated with a low friction polymeric material such as teflon. Ironing table has a temperature regulated heating element incorporated into the table top which rapidly evaporates the humidity that may penetrate the garment being ironed. A foot operated fan assists vacuum chamber in order to draw the steam away from an ironed garment in order to minimize garment distortion after pressing[2].

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The ironing consists of five main processes, namely handling, flattening, ironing, removing, and folding/hanging[4,5]. Hand stroking action or iron path/profile on the item is the sliding action needed to remove wrinkles and creases. The profile of sliding may be a straight line profile, a triangular periodic profile or a curved profile according to the type of garment and the region in the garment[5].

The ironing temperature depends to a large extent on the type of fibre, its thermal properties and on the construction of fabric or garment. The safe ironing temperature of a fabric is determined by the softening and/or decomposition temperature of the fibre and must be significantly below this temperature[6]. The following temperatures for various fibres are always used[1-7]:

- For polyamide, acrylic and acetate fibres— 110±2°C.
- For wool, silk, polyester and viscose fibres— 150±2°C.
- For linen and cotton— 200±2°C.

Ironing shall be avoided if it affects garment appearance (i.e. shining marks, sticking and modification of finishing appearance of printed fabric, wrinkled denim). Steam is a basic medium to transmit thermal energy to the fabric. It is a fast effective method to transmit significant heat quantity to the fabric. This not only makes the fabric to achieve definite temperature but also it can make it to obtain certain humidity[8].

As a result, a hand smooth is wanted after ironing, unavoidable or even desirable dimensional changes may occur during industrial ironing due to temperature and humidity.

Many ancient studies[3] have investigated the pressing conditions in order to optimize steam pressing, such as by Kopke and Lindberg (1966), Baird (1968), Kalecki *et al.*(1974), Rosenblad-Wallin and Cednas (1974), Pharo and Munden (1978), and Dhingra and Postle (1980).

Wang *et al.*[3] evaluated the pressing performance of light weight wool and wool blend fabrics using the crease angle measurement after ironing with a domestic hand iron. Fan[9] reported an experimental investigation concerning the relationship between the crease recovery and the pressing performance of wool fabrics after press finishing.

Ji˘rí and Vladimier[7] described the influence of washing/ironing cycles on hand, shrinkage and surface roughness of cotton weaves. Wrinkle recovery measured by the CSIRO multiple pleat test have been used by Hayes and Philips[10] for the improvement of wrinkling behaviour of annealed wool fabrics after steam pressing. Jue-Won[11] have studied changes in dimensional and mechanical properties by KES-FB system of wool blended fused fabrics after pressing and /or dry cleaning. Conflicting results on the dependence of fabric pressing performance on fabric mechanical properties have been reported. The answer to this conflict may lie in the difference in pressing conditions and the specific behaviour of the fibres[12]. The study on industrial hand ironing has not been approached in recent past.

In this paper, the influence of some industrial hand ironing conditions, such as steam or dry ironing and ironing action referred by the number of iron paths on the properties of cotton, wool and polyester fabrics has been reported. The ironing temperature has been kept limited within a narrow range. The evaluation is based on the FAST system (fabric assurance by simple testing) and on the dimensional changes in light weight cotton, wool and polyester fabrics.

2 Materials and Methods

2.1 Materials

The investigation has been carried out with three kinds of plain weaves. Basic characteristics of the selected fabrics are shown in Table 1.

Table 1–Basic structural parameters of unwashed fabrics

Properties				Standard
Fibre composition	Cotton	Wool	Polyester	ISO 2076
Weave design	Plain	Plain	Plain	ISO 2959:1973
Density, cm^{-1}				
Warp	35	21.8	35	ISO 7211-2:1984
Weft	32	21.2	26	ISO 7211-2:1984
Area density, g/m^2	138.41	146.5	124.1	ISO 3801:1977
Linear density, tex				
Warp	19.4	38.7	21.5	ISO 2060:1994
Weft	20.2	30.4	17.1	ISO 2060:1994
Thickness, mm	0.322	0.326	0.300	ISO 5084:1996

2.2 Methods

Over-sewed specimens of each fabric (60cm×60cm) were processed by an industrial washing to eliminate any possible impurities. Fabric specimens were then ironed, on one side, on a straight line profile by a continuous movement in the straight on grain of the fabric with a common industrial steam hand iron (Macpi model 028, 2kg) on a vacuum ironing table with electrically heated board (Macpi model 166). Pressure was carefully applied by the weight of iron itself. The temperature of the sole plate was controlled by an IR sensor thermocouple. Ironing table has a temperature regulated heating element incorporated into the table top which rapidly evaporates the humidity that may penetrate the garment being ironed, the temperature is fixed at 90°C. A foot operated fan assisted vacuum to draw the steam away from the ironed fabric. Vacuuming was activated in every passage. The sole plate of aluminium was used.

The factors studied are the ironing mode and the number of iron paths on the fabric. The temperature was maintained almost constant at 200°C for cotton and at 150°C for wool and polyester fabrics.

The tests were conducted according to the FAST instruction manual. FAST is a simple fabric objective measurement system for assessing aspects of the appearance, handle and performance properties of fabrics[13]. The details of three FAST systems used for this study are discussed hereunder:

(i) FAST-1 is a compression meter enabling the measurement of fabric thickness and surface thickness at two predetermined loads. The fabric thickness is measured on a 10 cm² area at two different pressures, namely 2 gf/cm² (0.196 kPa) and 100 gf/cm² (9.81 kPa). This gives a measure of the thickness of the surface layer (ST), which is defined as the difference between these two values[14, 15].

(ii) FAST-2 is a bending meter, which measures the bending length of the fabric which is related to the fabric's ability to drape. From this measurement, the bending rigidity of the fabric can be calculated. The instrument uses the cantilever bending principle described in BS: 3356. However, in FAST 2, the edge of the fabric is detected using a photocell. The bending rigidity, which is related to the perceived stiffness is calculated from the bending length and mass/unit area. Bending rigidity is the couple required to bend the fabric to unit curvature. It is calculated using the following relationship:

$$B = W \times (C^3 \times 9.807 \times 10^{-6}) \quad \ldots (1)$$

where bending rigidity of warp is B-1 and that of weft is B-2 (µNm); bending length of warp is C-1 and that of weft is C-2 (mm); and *w* is fabric weight in g/m² (refs 14-16).

(iii) FAST-3 is an extension meter. The extension of the fabric is measured in the warp and weft directions at three fixed forces of 5, 20 and 100 gf/cm. The following parameters were investigated:

- E5-1 (%) and E5-2 (%) – The extension in warp and weft directions respectively at 5gf/cm.
- E20-1 (%) and E20-2 (%) –The extension in warp and weft directions respectively at 20 gf/cm.
- E100-1 (%) and E100-2 – (%) The extensions in warp and weft directions respectively at 100 gf/cm.

The extensions are also measured on the bias in both directions but at a force of 5 gf/ cm, this enables the shear rigidity to be calculated. Shear rigidity (G) is calculated from the bias extensibility (%) of the fabric under a load of 5gf/cm [14], as shown below:

$$G\ (\text{N/m}) = \frac{123}{\text{EBS}} \quad \ldots (2)$$

- EB5 (%) – The extension in the bias direction (45° to warp or weft) at 5gf/cm.

The tests are performed in the order FAST-1, FAST-2 and FAST-3, this avoids deformation that would affect later results. Five replicates are recommended for compression measures, three in warp and three in weft directions for bending length and three in warp direction, three in weft direction and six bias replicates (three left-bias, three right-bias) for extension. The dimension of a replicate is 20mm×5mm (refs 14 ,15).

The dimensional changes in washed and ironed specimens were measured according to ISO 3759: 2007: Textiles- preparation, marking and measuring of fabric specimens and garments in tests for determination of dimensional change. One specimen of dimension 600 mm×600 mm was tested. Three pairs of reference points were made in each direction on the fabric, keeping a distance of 350 mm apart, having placed not nearer than 35 mm to the edge. All specimens were then conditioned under a standard atmosphere and then measured. The percentage of change in dimension *Y* is calculated using the following formula:

$$Y\,(\%) = \frac{x(\text{t})-(\text{o})}{x(0)} \times 100 \quad \ldots (3)$$

where x_0 is the original dimension and x_t, the dimension measured after treatment in mm. The minus sign (-) indicates shrinkage and the plus sign (+) indicates an extension. All measurements were carried out under standard testing conditions in accordance to the ISO 139: 2005.

3 Results and Discussion

To assess the influence of ironing conditions on fabric properties, changes in mechanical and dimensional properties are evaluated. The mean values of the FAST test measurement of cotton, wool and polyester fabrics are summarized in Table 2. One-way variance analysis (ANOVA) with two levels using MiniTab® package program is performed in order to determine the difference between means of measurement. The level represents the treatment applied (i.e washing and dry ironing). According to this test, the significant value (P value) is α=0.05. If the P value is greater than α, there is no difference within the group, whereas in case P value is lower than α, there is a significant difference between the groups.

3.1 Compressibility

Compression may be defined as a decrease in intrinsic thickness with an appropriate increase in pressure[17]. Surface thickness (ST) shows roughness of fabric surface and structural stability of a surface layer. The finish imparted to a fabric must be stable to ensure the consistency of its handle and appearance. The stability of a finish can be estimated by comparing the thickness of the surface layer of the fabric before and after it has been released by steaming. The bigger the difference, the less stable is the finish.

The statistical analysis shows that washing treatment leads to an increase in both T2 and T100. This may be due to the fact that in woven structure, "wet relaxation" caused by fibres swelling leads to a thickening of yarn cross-section. For polyester, the increase is slight but significant due to the slight swelling of the fibre after washing. As a result, an increase in surface thickness (ST) shows the rough washed and dried appearance of fabrics.

On the contrary, the statistical analysis reveals that ironing process leads to a decrease in thicknesses T2 and T100 of all fabrics. So, ironing process is found

Table 2–Mean values of FAST test results of unwashed, washed and ironed cotton, wool and polyester fabrics

[Ironing temparature 200 ˚C (cotton), and 150° C (wool & polyester)]

Property	Test parameter	Unwashed fabric	Washed fabric	Dry iron		Steam iron	
				1 path	2 paths	1 path	2 paths
Cotton							
Compression, mm	T2	0.489	0.970	0.713	0.662	0.545	0.464
	T100	0.253	0.291	0.291	0.29	0.290	0.225
	ST	0.236	0.679	0.422	0.373	0.256	0.240
Bending length, mm	C-1	21	19.1	19	18.1	19.6	18.5
	C-2	21.3	21.5	20.1	20.3	20.6	20.5
Bending rigidity, µN.m	B-1	12.5	9.5	9.2	8.1	10	8.5
	B-2	13.1	13.5	11.1	11.3	11.9	11.6
Shear rigidity, N/m	G	175.7	123	139	134	147.6	123.3
Extension,%	E5-1	0.4	0.5	0.5	0.5	0.5	0.4
	E5-2	0.3	0.4	0.4	0.4	0.3	0.3
	E20-1	1.3	1.6	0.9	1.1	0.7	0.7
	E20-2	0.5	1	0.7	0.5	0.5	0.5
	E100-1	5	5.3	3.6	4.2	3.5	3.8
	E100-2	1.3	2.9	2.5	2.5	2.3	2
Wool							
Compression, mm	T2	0.345	0.673	0.615	0.597	0.545	0.489
	T100	0.261	0.365	0.358	0.337	0.336	0.325
	ST	0.084	0.307	0.257	0.26	0.208	0.164
Bending length, mm	C-1	15.3	12.8	14	12.8	13	13.8
	C-2	15.6	13.8	13.3	13.5	13.3	13.1
Bending rigidity, µN.m	B-1	5.1	2.9	3.9	3	3.1	3.7
	B-2	5.4	3.6	3.3	3.4	3.3	3.2
Shear rigidity, N/m	G	37.6	19.8	20.8	21.9	24.6	26.7
Extension, %	E5-1	0.5	0.8	0.5	0.4	0.4	0.5
	E5-2	0.5	0.5	0.5	0.6	0.4	0.5
	E20-1	1	1.2	1.2	1.2	1	1
	E20-2	1.3	2.5	2.7	2.5	2.3	2.1
	E100-1	2.9	3.5	3.4	3.5	3.3	3.1
	E100-2	3.6	7.1	7.5	6.8	7	6.6
Polyester							
Compression,mm	T2	0.271	0.281	0.277	0.273	0.274	0.275
	T100	0.246	0.253	0.248	0.247	0.244	0.244
	ST	0.025	0.029	0.029	0.026	0.03	0.031
Bending length, mm	C-1	17	16.3	14.1	15.1	20	20.8
	C-2	23.5	22	21	21.1	20.6	21.6
Bending rigidity, µN.m	B-1	6	5.3	3.4	4.2	9.7	10.9
	B-2	15.8	12.9	11.3	11.4	10.6	12.3
Shear rigidity, N/m	G	47.3	42.4	42.65	42.41	42.17	41.34
Extension, %	E5-1	0.3	0.5	0.6	0.6	0.6	0.5
	E5-2	0.1	0.2	0.3	0.2	0.2	0.2
	E20-1	0.8	1	1.2	0.9	1	0,9
	E20-2	0.2	0.3	0.3	0.3	0.2	0.2
	E100-1	2.2	2.6	2.8	2.4	2.5	2.3
	E100-2	0.4	0.7	0.7	0.7	0.73	0.7

to decrease the surface thickness of cotton, wool and polyester fabrics giving flattened surfaces. The compressive force given by the sliding motion and the increase in temperature allow the yarn to undergo deformation nonlinearly, resulting in a change in thickness[17].

The increase in ironing paths is found to decrease the thickness of fabrics giving more flattened surfaces. In fact, sliding motion enhances the relaxation of fibres being pressed between the sole plate and the ironing table. It should last sufficiently long to allow fibres to recover from the plastic deformation.

The minimum decrease in thickness and in surface thickness is noted after two steam iron paths. This result can be attributed to the effect of moisture on glass transition temperature of wool and cotton fibres. The glass transition temperature decreases with increasing the fibre moisture content or regain [3]. Therefore, the segmental motion of fibres molecules and so the recovery from plastic deformation caused by washing becomes easier.

The statistical analysis also reveals that the use of steam hand iron leads to a decrease of T2 by - 52 % and of T100 by -23 % in cotton fabric; a decrease of T2 by - 28.67 % and T100 by -11 % in wool fabric; a decrease of T2 by - 2 % and of T100 by -3.5 % in polyester fabric, as compared to only washed fabrics. So, cotton fabric is able to tolerate greater variation in thickness than a wool fabric which may be due to the difference between the ironing temperatures. Wool fabric is able to tolerate greater variation in thickness than polyester fabric after ironing and this can be due to the fabric construction and fibre nature.

3.2 Bending Rigidity

Bending length is related to the ability of a fabric to drape and bending rigidity is related more to the quality of stiffness felt when the fabric is touched and handled. No significant influence of ironing treatment has been noted on bending length and rigidity of the selected fabrics. This may be due to the fact that the treatment lasts a short time at a constant and safe temperature.

3 3 Shear Rigidity

The statistical analysis proves that washing reduces shear rigidity of the selected fabrics. For cotton and wool fabrics, it may be due to the fact that yarns swell and are set with a higher crimp. When the fabric is dried the crimp remains and the inter-yarn friction is reduced, producing a fabric with lower shear rigidity. For polyester, it may be related to the decrease in inter-yarn friction, so the interlaced yarns can glide over each other more easily.

Table 3– Dimensional changes of cotton, wool and polyester fabrics after ironing

[Ironing temperature 200°C for cotton; and 150°C for wool & polyester]

Fabric	Direction	Washed fabric	Dry iron		Steam iron	
			1 path	2 paths	1 path	2 paths
Cotton	Y(%), Warp	-5.75	-5.25	-5.5	-4.5	-4.25
	Y(%), Weft	-2.5	-2.2	-2.5	-2	-2
Wool	Y(%), Warp	-2.5	-2.25	-2.5	-2	-1.75
	Y(%), Weft	-5.5	-5	-5.25	-5	-5
Polyester	Y(%), Warp	0	0	0	0	0
	Y(%), Weft	0	0	0	0	0

Shear rigidity increases again mainly after the steam ironing in the case of wool fabric. This result is consistent with the observation of Finnimore during steam pressing [18]. Shear rigidity is averagely constant under different ironing conditions in the case of polyester and cotton fabrics.

3.4 Extensibility

The ability of a fabric to stretch at low loads is critical to garment and other sewn product's making up procedures. The statistical analysis proves that washing treatment gives higher extensibility of fabrics in warp and weft directions mainly at high load (100gf/cm) and this may be due to the increase in fibre and yarn crimp as a consequence of relaxation from weaving tension and more freedom for fibres and yarn movement. Significant decrease in extension properties especially at high loads are noted, in case of cotton and wool fabrics. The decrease is higher after steam ironing showing that the heated steam has set the movement of fibres and yarns. No significant change is observed in extension properties after ironing treatment in the case of polyester fabric, either with a dry or a steam iron.

3.5 Dimensional Changes

The results of the dimensional change in each specimen measured after a first wash and after ironing in warp and weft directions are represented in Table 3 for cotton, wool and polyester fabrics. The dimensional changes are quite influenced by the steam ironing at 200°C in the case of cotton fabric compared to that of washed fabric. Shrinkage significantly decreases in the warp and weft direction especially after two paths of a steam iron. Shrinkage of the wool fabric in warp direction decreases mainly after two paths of a steam iron. So, the high temperature and moisture relax the strain in wool and cotton fibres and in conjunction with the iron pressure, set the yarns and fibres in a new conformation [15]. No changes in dimension of the polyester fabric is observed neither after washing nor after ironing along with the changes in structure of polyester fabric after washing and ironing process, because the fibre is hydrophobic.

4 Conclusion

It is inferred that the compression is a primary surface fabric modification after ironing process in cotton, wool and polyester fabric. Extension properties are also affected especially at high load showing a set state of fabrics after ironing at a safe temperature. Shrinkage of cotton and wool fabrics decreases after ironing compared to the wash shrinkage. The use of steam is an effective factor in ironing especially for cotton and wool fabrics. Other structural, physical and thermal properties shall be studied to assess ironing effects on fabrics, which may allow the optimization of the process.

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