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Sewing Needle Temperature and Fabric Bending Property Correlation

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Key words: Sewing needle, needle heat, fabric bending properties, seams, sewing machine

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Abstract: Sewing needle temperature is one of the main problems during sewing of thermoplastic materials. The needle temperatures can cause fabric and sewing thread damage. Many studies have been carried out to understand the parameters which influence needle temperature. Understanding these parameters will help in minimizing the problem of needle heating. Needle heat is influenced by needle, fabric characteristics and the sewing conditions. In this project an attempt has been made to correlate the bending modulus of three different construction 100% cotton fabrics of the same GSM with varying thickness. The fabrics were sewn in the sewing machine at a constant speed of 3500 rpm without sewing thread in 3 different seams. The needle temperature was recorded with the help of an infrared pyrometer at time intervals of 30 sec for 5 min. The highest sewing needle temperature recorded was for the fabric with highest bending modulus among the three samples. Correlation between the fabric bending modulus and sewing needle temperature was calculated using MINITAB v.16.1. The correlation result obtained was positive and linear thus indicating that the bending modulus of the fabric effect the needle temperature.

INTRODUCTION

High speed industrial sewing machines working above the speed of about 5000 rpm have long been used in apparel, leather, shoe, carpet tufting, needle punching, stitch bonding and many other industries[1]. It has been observed that the friction between the fabric surface and the needle generates excessive heat which are influenced by a number of parameters such as weave, type of fibre, fabric thickness, finish, needle size, shape, surface coating, sewing speed and the interrelationships of these and other factors[2]. Studies have shown that the problem of needle heating can affect fabric and garment performance. With the usage of different types of materials such as synthetic fabrics, synthetic blends, cotton, leather, duck, canvas and other materials of higher areal weight the problem becomes more acute. The needle heat often exceeded the glass transition temperature of many synthetic fabrics and causes melts, melted residue and weakened seams. While natural materials such as cotton, wool and its blend would scorch or burn leading to sewing defects such as; thread breaks, skipped stitches, fabric damage, seam damage, skipped stitch, needle breakage and other quality issues in readymade garment manufacturing[2, 3]. Further, the materials that are sewn range from a simple single ply to more complex multiple ply seam configuration. The high needle temperature can weaken the sewing thread, since, its strength is a function of temperature and cause, thread breaks resulting in intermittent stoppage for rethreading which is time consuming. The heated needle can lead to unwanted crease formation in the sewing thread because of which the loop formed by the sewing thread is improperly shaped and the hook misses the loop, resulting in skipped stitches and all these are severe quality issues leading to higher percentage of rejects. The needle heat can also temper the needle and weaken it, so it may bend or fail by breaking easily. Decreasing the sewing speed can cool the needle but it will decrease the operator's other handling activities; hence the sewing productivity is doubly decreased.

The needle temperature depending on sewing conditions ranges from 100-300°C, part of which is absorbed by fabric along the stitches, some of the heat is lost to radiation but most of the heat is accumulated in the needle as it penetrates and withdraws periodically. Sewing industries have adopted many methods to reduce the magnitude of needle heating problem by using surface finished needles, lubricants, cooling air streams and special shaped needles with limited success[4, 5]. Needle heat is lost by conduction, convection and radiation, the outer surface of the needle that is not in contact with the fabric loose heat by convection and within the needle the conduction of temperature from higher gradient points to lower temperature points occurs, further a small amount of heat is also lost from needle to the environment by way of radiation[5].

In this study, a study is carried out on woven fabric bending property along with the needle heating temperature during the sewing operation. Woven fabrics are produced by interlacements of two sets of yarn called warp yarn and weft yarn. By varying the interlacements different designs like plain, twill, sateen etc are produced. The variations in interlacements influence the mechanical properties of the woven fabric structures[6]. Even though the typical sewing machine is made of hundreds of parts, only few parts come in contact with the fabric. The needle is the only part that goes in and out of the fabric. Clearly, understanding the needle-fabric interactions, optimizing sewing operations, minimizing the penetrating force and the peak temperature can result in significant economic benefit for the apparel industry.

Many efforts have been taken to analyze the needle heating problems, Frederick *et al*.[1] in their study on blends of nylon and wool have observed that the use of sewing finishes on fabrics can effectively reduce needle temperature preventing needle encrustation and nylon melts. Studies carried out by Galuszynski[2] on the effect of fabric structure on needle piercing have shown that there is a definite correlation between fabric resistance to needle piercing and the product of fabric tightness and fabric mass. The penetration force was found to be higher without the sewing thread and lessen with sewing thread because the sewing thread would act as an absorber. Howard and Parsons[3] have described an experimental method to determine the needle temperature by infrared flux and have discussed variables influencing needle temperature such as, emissivity, frequency, geometrical view and signal shapes. They have observed that the needle heat depended on the surface thermal properties of the needle and the cloth. Also a steady state condition was reached when the amount of heat generated by friction exactly equals the amount of heat lost by the needle. Needle temperature was observed to be cyclic, increasing immediately after passing through the cloth and decreasing while exposed to the air. In another study by Khan *et al*.[6] the authors have observed that fabric parameters are one of the important parameters influencing needle heat. However, the study does not detail into the specific fabric properties that directly influence the needle temperature.

Thus, we can say that needle heating is a function which is influenced by fabric, needle and sewing parameters. Among fabric parameters, fabric structure and fabric weight offer resistance to needle penetration. Among the needle parameters, needle finish has the greatest influence on the needle heat and then comes needle diameter. Among sewing parameters, sewing speed influences the peak temperature attained in the needle. Sewing thread acts as a heat sink and therefore absorbs heat. Moreover, fabric handle, aesthetics and end use applications largely depends on their bending behaviour[7, 8]. Fabric stiffness which is characterised by the bending rigidity and bending modulus is a parameter that does not take the fabric content and construction into consideration. It does not focus on the micro properties such as the fibre characteristics and takes only fabric weight and thickness into consideration. Thus, bending property can be taken as a parameter to compare many different fabrics without going into the finer details of the fabric, such as its composition, weave, finish, etc. As such the objective of this study is to elucidate correlation between the bending stiffness of the fabric and the sewing needle temperature developed during sewing.

MATERIALS AND METHODS

Fabrics used for study: All the fabric test specimen, have been tested in a standard testing atmosphere of 65±2% relative humidity and temperature of 27±°C. Since, the study requires fabric in different bending stiffness, three different fabric constructions in 100% cotton sized with native starch were developed, so that they had the same areal weight of about 170 GSM. The linear density of warp yarn was 30^S English cotton (Ne) and the weft densities were wide-ranging as 20^S, 30^S and 40^SNe, so as to vary the thickness of the fabric which will in turn give us three different fabric samples with

Table 1: Construction details of fabric specimens

Test specimens	Warp count (Ne)	Weft count (Ne)	Weave type	Ends/inch (EPI)	Picks/inch (PPI)	Grams/Meter^2 (GSM)
Sample 1	30	30	2/1 Twill	124	66	170
Sample 2	30	40	2/1 Twill	124	88	170
Sample 3	30	20	2/1 Twill	124	46	170

different stiffness values. This selection helps us to compare the bending values of the fabric, while all other fabric parameters were kept constant. All the fabrics were developed in one weaving machine settings, the weave pattern was 2/1 Twill. The samples are listed as sample 1, 2 and 3 throughout. The fabric construction details are given in Table 1. Three different variations of superimposed seam types with increasing number of fabric layers such as SSa (2-ply), SSc (4-ply) and SSp (6-ply) were used in this study. The seam configuration are given in Fig. 1.

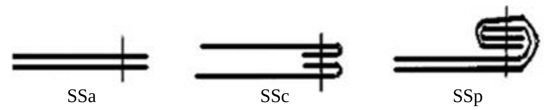

Fig. 1: Super imposed seam configurations SSa, SSc and SSp

Sewing machine and needle: High speed, single needle lock stitch industrial sewing machine model-Zuki DDL 8300N was use in this study. The machine was fitted with size 14/90, Beissel chrome-plated needle, cloth point with round shank and double groove and the stitch length was set at 1 mm. The machine was run at constant speed of 3500 rpm.

Testing methods

Pyrometer: A Pyrometer measures the heat radiated from the surface of the needle. Infrared pyrometers does not require physical contact between the goods and the detecting element. It works on the principle that all the matter above absolute zero continuously emits energy in the form of Infrared Radiation (IR). This emitted energy is measurable and quantified as an object’s temperature through the technique of infrared thermography. This method has been used for some time in high-temperature pyrometry but it has only recently been adapted to the temperature range encountered in the textile industry. The pyrometer used for this study is METRAVI MT 5 infrared non-contact pyrometer, with the temperature range of -5 and 550°C calibrated by the manufacturer. The focus diameter to the distance (between the pyrometer and the heat emitting source) ratio is 1:8. The instrument was hand held and focused on the object to record its temperature.

Tachometer: Digital handy tachometer model ONA SAKKI was used to measure the rotating speed of the sewing machine motor. The sewing machine was worked at a constant speed of 3500 rpm. The tachometer has a measuring range of 50-15,000 rpm. Its accuracy is +/- 1 rpm for 50-15,000 rpm.

Desizing: Desizing process is carried out using hydrochloric acid (2 cc/L) in the liquor ratio of 1:40 at room temperature for 3-4 h to remove the size material applied on the warp yarns during weaving. The mineral acid reduced the molecular weight of the size and reduced starch to glucose, followed by rinsing with hot water at 60°C to remove the reduced starch. The desizing efficiency was carried out by Iodine test, in which. 0.01 N iodine solution was prepared and then few drops of iodine solution along with 1 drop of borax solution are placed on the fabric. If the colour changes to blue, then the presence of size in the fabric was confirmed. On performing the iodine test, the colour did not change to blue indicating that the size has been efficiently removed from the fabric.

Determination of fabric thickness: The fabric thickness is measured on a Shirley thickness gauge machine in accordance with ASTM D1777 standard. This instrument uses a standard load of (5 g/cm^2) that is applied onto the fabric, then the fabric is allowed to relax for about 5 sec thereafter the thickness readings in millimetres are noted from the graduated circular scale. Fabric thickness is measured at different places on the fabric and the mean thickness is reported.

Determination of fabric bending stiffness: Stiffness is the rigidity offered by material to a force tending to bend the material, it is measured using cantilever principle. The bending stiffness test was performed according to the ASTM D1388 standard using a Shirley Stiffness Tester.

This tester measures the bending stiffness of a fabric by allowing a narrow strip of the fabric to bend to a fixed angle (41.5°) under its own weight. The length of the fabric required to bend to this angle is measured and is known as the bending length. Specimen size were 25×200 mm, cut diagonally across the fabric width for warp direction tests and diagonally along the fabric length for weft direction specimens, to ensure that no two specimen contained the same series of warp and weft yarns. Four specimens each in warp way and weft way direction (face and back) were tested on both ends and readings noted. The higher the bending length, stiffer is the fabric.

Flexural rigidity: The flexural rigidity is the ratio of the small change in bending moment per unit width of the material to the corresponding small change in curvature:

Flexural rigidity (G):

$$G = M \times C^3 \times 9.807 \times 10^{-6}\, \mu Nm \quad (1)$$

Where:
C = Bending length (mm)
M = Fabric mass per unit area (g/m^2)

Bending modulus: The stiffness of a fabric in bending is very dependent on its thickness, the thicker the fabric, the stiffer it is if all other factors remain the same. The bending modulus is independent of the dimensions of the strip tested so that by analogy with solid materials it is a measure of 'intrinsic stiffnes's.

Bending modulus (B):

$$B = \frac{12 \times G \times 10^3}{T^3} N/m^2 \quad (2)$$

where, T is fabric thickness (mm); since the bending modulus value does not consider the sample size and takes only thickness into consideration, it serves as a better quantity for correlation.

Design of experimental setup: A special housing was prepared to cover the sewing machine head and needle bed to prevent air flow and radiation, with provision to place the pyrometer at a distance of 8 cm from the sewing machine needle and all the readings were recorded from this point. This experimental setup was designed for accuracy of test results. The flow of air was restricted into the experimental setup. The machine speed was measured using a digital tachometer. In this experimental the sewing machine was run at a constant speed of 3500 rpm.

Recording of needle temperature during sewing operation: The fabric test specimen were cut in the dimensions of 145×10 CM (lengthwise x width way). Each samples was sewn end-to-end with a lap seam to make the sample into a continuous belt. This type of belt arrangement enables continuous sewing so that temperature developed could be measured for a continuous period of time. It was noted that in the trail test that the temperature increases significantly till 5 minutes and after that it is found to be almost constant. As such, the sewing machine was run only till 5 min.

The experiment was conducted with fabric samples 1, 2 and 3. The fabric sample 1 belt was sewn without sewing thread in seam type SSa (2 layers) and the temperature raise for every 30 sec up to 5 min were noted down. Then the machine was allowed to rest for 15 min. Since, the needle was heated up in this process and took a long time for it to return to the normal temperature, a new needle of the same specification was used for every run. Then with the use of a seam folder, seam type SSc (4 layers) and seam type SSp (6 layers) were made and sewn as above. This ensured that the seam formation remained intact throughout the sewing process. The needle temperatures were noted down with the help of the pyrometer in °C. Likewise the needle temperature were recorded for test specimens, sample 2 and sample 3 respectively.

RESULTS AND DISCUSSION

Fabric bending stiffness and thickness values: The fabric bending and thickness values are given in the Table 2. From the data, it is observed that sample 2 with a construction of 30s×40s Ne by 124 EPI X 88 PPI has the highest bending rigidity (124.38×10^{-6} Nm) and highest bending modulus (22.47×10^{6} N/m^2) with a thickness of 0.408 mm. Whereas sample 3 with a construction of 30s×20s Ne by 124 EPI X 46 PPI has lower bending rigidity (80.349×10^{-6} Nm) and lowest bending modulus (5.43×10^{6} N/m^2) with a thickness of 0.562 mm among the three test specimens. Implying that the bending stiffness is independent of thickness.

Needle temperatures obtained: The needle temperatures attained is plotted into a graph between time and needle temperature as represented in Fig. 2a and b. It is observed that the highest needle temperatures were recorded for Sample 2 which has the highest bending stiffness. Also, the difference in temperatures among the three fabric test specimens were significant. Thus, it can be determined that there is a definite and positive relationship between needle temperature and fabric bending stiffness. In Fig. 2b, it is seen that the needle temperature rises almost linearly until 0.5 min and there after reaches a steady state. After reaching its steady state, there is no rapid increase in the temperature, while the increase is still significant. Further, test sample 2 has recorded the highest temperature of all the three seam configuration studied. The highest being with seam configuration SSp with six layers of fabrics, followed by SSc and SSa seam configurations with four and two layers of fabrics respectively. Suggesting that the needle temperature increased with the increase in number of fabric plies. Reiterating that number of fabric plies had a significant influence on needle temperature However, this fact cannot be concluded due to the limited samples used in this study.

Correlation between bending modulus and needle temperature: Using the statistical software MINITAB v.16.1, correlation between the needle temperature sand

Table 2: Fabric Bending and thickness values

Test specimens	Sample No.	Bending rigidity×10^{-6} Nm	Bending modulus×10^{6} N/m^2	Thickness (mm)
Sample 1	1	91.8284	11.93	0.452
Sample 2	2	124.38	22.47	0.408
Sample 3	3	80.349	5.43	0.562

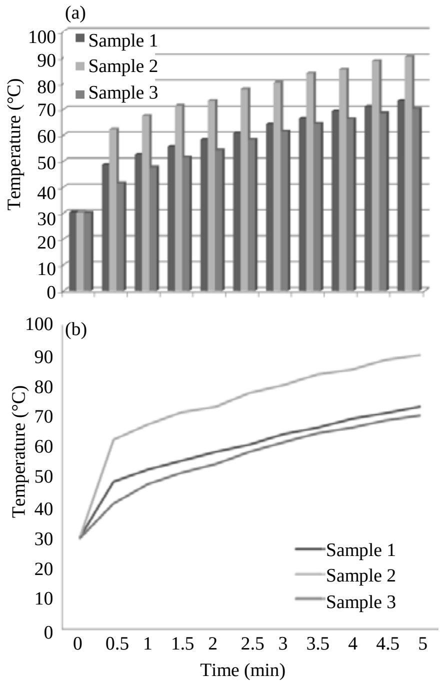

Fig. 2(a, b): (a) Plot showing needle temperatures among the samples and (b) Plot showing needle temperatures among the samples

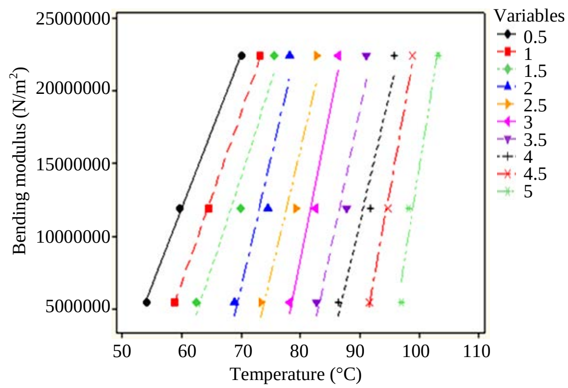

Fig. 3: Scatter plot between modulus and temperature

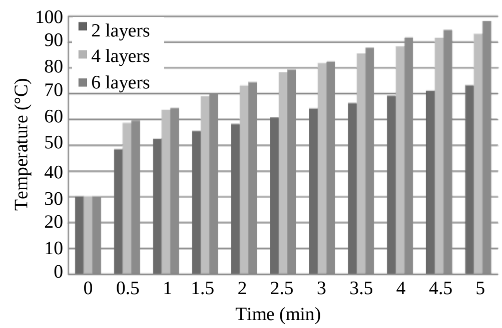

Fig. 4: Plot showing temperature variations among number of layers of fabric

the bending modulus of the three sample fabrics was calculated. The Pearson correlation is defined only if both of the standard deviations are finite and both of them are non-zero. The Pearson correlation is +1 in the case of a perfect positive (increasing) linear relationship (correlation), -1 in the case of a perfect decreasing (negative) linear relationship (anti correlation) and some value between -1 and 1 in all other cases, indicating the degree of linear dependence between the variables. As it approaches zero there is less of a relationship (closer to uncorrelated). The closer the coefficient is to either -1 or 1, the stronger the correlation between the variables. The correlation coefficients for all the samples at different points of time is positive, significant and above 0.9. The p-value is the probability of obtaining a test statistic at least as extreme as the one that was actually observed, assuming that the null hypothesis is true. One often "rejects the null hypothesis" when the p-value is less than the a level of 0.1, corresponding respectively to a 10% chance of rejecting the null hypothesis when it is true (Type I error). When the null hypothesis is rejected, the result is said to be statistically significant. The p-values obtained indicate that the correlation is significantly different from zero showing that there is a positive linear relationship between the two variables, namely, the needle temperature and bending modulus of the fabric.

In Fig. 3, the scatter plot of the correlation data indicates that the relationship between the needle temperature and the bending modulus of the fabric is positively linear because the scatter points are very close to the regression line which gives the 'best fit'.

From the needle temperature data and Fig. 4, it is observed that, as the number of layers of fabric increases, the difference in the temperatures obtained becomes lesser. Although the needle penetration force increases linearly with the number of fabric plies, the temperature need not necessarily raise linearly, since the rate of heat dissipation increases with temperature. Thus, it is established that an equilibrium temperature is reached which does not increase directly with increase in number of plies of fabric.

CONCLUSION

A study has been made to correlate the bending stiff of the fabric and the sewing needle temperature. The samples taken for study were three different construction, 100% cotton fabrics with same areal weight of 170 GSM and differing thickness. The samples were sewn in a single needle lockstitch machine at a speed of 3500 rpm, without sewing thread. The machine was fitted with size 14/90 chrome plated needle. The fabric samples 1, 2 and 3 were sewn in three different seams configurations namely, SSa, SSc and SSp. The corresponding needle temperatures developed during sewing were recorded using an infrared pyrometer at intervals of 30 sec up to 5 min. The needle temperatures obtained were then correlated with the corresponding bending modulus value of the fabrics using the statistical software, MINITAB v16.1.

It is observed that fabric bending property is one of the major factors that influence the needle temperature. The bending modulus of the fabric is positively and linearly correlated to the needle temperature. Thus a strong relationship exists between the bending modulus of the fabric and needle temperature. An increase in the bending stiffness of the fabric will cause an increase in the needle temperature.

The needle temperature does not rise linearly with increase in the number of layers of the fabric as it would be expected due to the rate of heat dissipation. This is because, the needle temperature reaches an equilibrium state and thereafter the increase does not correspond to the increase in number of plies of fabric.

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