

Effect of Process Parameters on Tensile Properties of Threads during High Speed Lockstitch Sewing

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Abstract—During high speed sewing, the needle thread is exposed to dynamic loading, short strike loading, inertia forces, friction, rubbing, force of check spring, bending, pressure, friction, impact, shock and thermal influence. These stresses act on the thread repeatedly for 50-80 times before the thread gets incorporated into the seam, which has a negative influence on the properties of sewing threads and situation becomes worse when the heavy fabrics are sewn. In this study, the effect of various parameters viz number of fabric layers, stitch density and needle size on tensile properties of threads has been studied using Box-Behnken design. Contrary to the general expectation, the loss in tenacity and breaking elongation was found to decrease initially or remain unchanged as the number of fabric layers increased. As the needle size increased, the loss in tenacity and breaking elongation increased for polyester threads and remained unchanged for cotton thread.

Keywords—Box-Behnken design, breaking elongation, initial modulus, tenacity

I. INTRODUCTION

DURING the passage of sewing thread through the machine, the needle thread is exposed to various stresses and strains at different guides, tension discs, tension spring, take up lever, needle eye and the fabric assembly. In the beginning, compression force of the tension discs, force of tension spring and the action of take up lever cause tensile loading of the thread. The thread is also subjected to the inertia forces due to rapid acceleration in forward and backward direction, besides friction at various guides. Further, during the formation of stitch, it passes through the needle and fabric assembly and exposed to high tensile forces, frictional contact with the needle and fabric assembly, thermal loading due to heating of the needle, and bending through small radius of curvature. In the process of stitch formation, it also interacts with the bobbin thread and is subjected to bending, abrasion and tensile deformation before getting incorporated into the seam [1]-[4]. The greatest tensile force occurs at the moment of stitch stretching, when the take up lever pulls for required thread length through the tension regulator. These stresses act on the thread repeatedly and the thread passes 50-80 times through the fabric, the needle eye and the

bobbin case mechanism, before getting incorporated into the seam, which has a negative influence on the properties of sewing threads and situation becomes worse when the heavy fabrics are sewn.

In practice, the stitch density is carefully determined for the material so as to avoid excess tension which will unbalance the elasticity and cause puckering. At higher stitch density, the thread is subjected to higher number of loading cycles before getting incorporated into the seam and the loss in tensile properties is expected to increase. The force applied to a sewing needle while penetrating a woven fabric affects the important features of the sewing process, such as needle temperature, fabric and thread damage, and needle breakage. There has been good amount of experimental data on the needle penetration force and needle temperature [5]-[9] but fewer attempts [3], [4], [10] to study the effect of needle temperature on the thread damage and strength loss. Use of finer needles has been recommended [11] to avoid the fabric damage; however at excessively high speeds the fine needles tend to flutter, leading to faulty seams and frequent needle breakages. Higher needle size avoids these problems but is expected to increase the needle penetration force, resulting in higher needle temperature.

In this paper, the number of fabric layers, stitch density and needle size are changed at three levels and the effect on change in the tensile properties (tenacity, breaking elongation, and initial modulus) of the needle thread has been studied using Box Behnken experimental design.

II. EXPERIMENTAL

A. Materials & Methods

Mercerized cotton and polyester staple spun threads of 40 tex were used for the study. The physical properties of the threads have been shown in Table I.

Standard denim fabric of heavy construction, 3/1 twill, 355 g/m² weight, 27 ends/cm and 17 picks/cm was used for sewing. The samples were prepared by changing the parameters, i.e. number of fabric layers, stitch density and needle size at three levels as per Box-Behnken Design on Juki industrial lockstitch sewing machine (Table II).

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TABLE I
PHYSICAL PROPERTIES OF SEWING THREADS

Thread Type	Characteristics						
	Fineness (Tex)	Twist (tpm)	Twist direction (ply/single)	Friction coefficient	Tenacity (cN/tex)	Breaking elongation (%)	Initial modulus (cN/tex)
Cotton	14.2 × 3	704	Z/S	0.15	32.85	6.31	445.67
Polyester staple	22.6 × 2	567	Z/S	0.12	35.87	18.59	291.91

TABLE II
BOX-BEHNKEN DESIGN

Factors		Levels		
		-1	0	+1
Number of fabric layers	X ₁	3	4	5
Stitch density (Stitches/25mm)	X ₂	7	9	11
Needle size	X ₃	14	16	18

Tensile testing of the needle threads before and after sewing was performed at a gauge length of 250 mm on Zwick tensile testing machine as per ASTM standard D2256. Thirty tests were carried out for each sample and the error was found to be less than 4% at 95% confidence level. The change in tensile properties was calculated from the following expression [12]:

$$\text{Change (\%)} = \frac{\text{Tensile property after sewing} - \text{Tensile property before sewing}}{\text{Tensile property before sewing}} \times 100$$

In order to study the individual and interactive effect of each parameter on the tensile properties, response surface regression equations were developed for loss in tensile properties on number of fabric layers, stitch density and needle size by backward elimination method.

III. RESULTS AND DISCUSSION

The average of 30 readings for each sample was used to develop regression equation by using statistical software (STASTICA 8). The linear and polynomial equations were tried along with the interaction of the parameters, at 95% confidence level. The best fit equations for tenacity loss, breaking elongation loss and initial modulus loss were generated. The equations are given in Table III.

A. Tenacity and Breaking Elongation

It was observed that as number of fabric layers increase, the tenacity loss for cotton thread first decreases and then increases slightly, whereas it remains unchanged for polyester staple spun threads. Similar trend was observed for breaking elongation loss.

TABLE III
REGRESSION EQUATIONS OF TENSILE PROPERTIES

Property	Thread type	Regression equations	R ²
Tenacity loss (%)	Cotton thread	$Y_1 = 24.58 - 3.68X_1 + 6.0X_1^2 + 1.04X_2 + 4.16X_2^2 + 0.93X_3^2 - 1.43X_1X_3 + 1.94X_2X_3$	0.99
	Polyester staple	$Y_1 = 17.32 - 1.98X_1 + 2.2X_2 + 5.58X_3 + 3.46X_3^2$	0.92
Breaking elongation loss (%)	Cotton thread	$Y_2 = 17.75 + 6.10X_1^2 + 4.12X_2^2 + 2.16X_3^2 - 2.06X_1X_3 + 2.77X_2X_3$	0.90
	Polyester staple	$Y_2 = 4.64 + 1.81X_1^2 + 1.58X_2 + 3.97X_2^2 + 3.69X_3 + 1.44X_3^2 + 2.11X_1X_3 + 1.80X_2X_3$	0.96
Initial modulus loss (%)	Cotton thread	$Y_3 = 11.46 - 4.26X_1 - 4.18X_3^2 - 2.89X_2X_3$	0.82
	Polyester staple	$Y_3 = 28.86 - 2.61X_1 + 1.76X_2 - 3.39X_2^2 + 0.94X_3$	0.93

Where, X₁ = Number of fabric layers, X₂ = Stitch density, and X₃ = Needle size.

Fig. 1 shows the effect of number of fabric layers and needle size on tenacity of cotton threads during sewing. With the increase in number of fabric layers, the needle penetration

force and hence needle temperature increase, leading to

increased thermal damage to the thread [3], [5], [6], [8]-[10].

Moreover, the thread is subjected to more abrasive damage

through higher number of fabric layers. On the other hand, with the increase in fabric layers, the thread consumption per stitch increases and needle thread is subjected to lower number of loading cycles before getting incorporated into the seam, which in turn leads to lower damage to the threads. As the number of fabric layers increase, less number of loading cycles and insensitiveness of cotton fibres to thermal damage cause lower loss in tenacity, and breaking elongation during sewing. However, as the number of fabric layers increase from four to five, the abrasive damage of cotton fibres outweighs the effect of lower loading cycles and therefore a slight increase in tenacity and elongation loss is observed.

Although polyester staple spun thread experiences higher temperature at the needle, but the number of cycles of passage through the needle before a thread gets incorporated into the seam decreases with increase in fabric layers. The threads are exposed to the heat generated at the needle for lesser number of times, which cause polyester threads to be less affected. Therefore, the tenacity loss for polyester staple spun threads remains unchanged as the number of fabric layers increase.

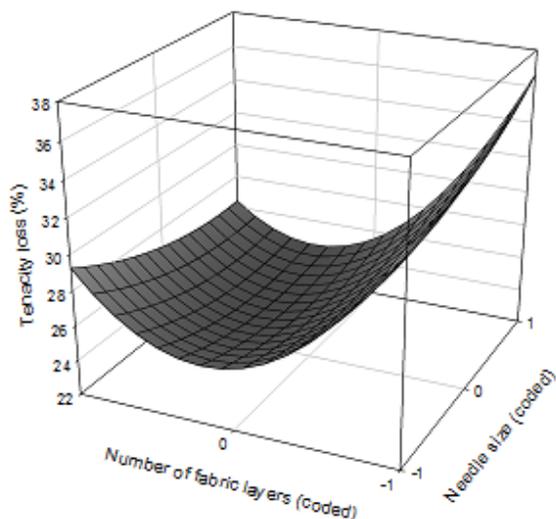


Fig. 1 Effect of number of fabric layers and needle size on tenacity loss of cotton thread after sewing

Fig. 2 shows the effect of stitch density and needle size on tenacity loss of cotton threads. It is observed that tenacity loss first decreases and then increase with increase in stitch density for all threads. However the change in these properties is statistically insignificant for polyester staple spun threads. Therefore, the stitch density influences only the tensile properties of cotton thread. Similar results were observed for the breaking elongation also. The increased stitch density is obtained by decreasing the fabric feed, with frequency of needle penetration per unit time remaining same. Increased level of stitch density causes decrease in stitch length, thereby decreasing thread consumption per stitch. The thread experiences more number of dynamic loading and abrasion cycles before getting incorporated into the fabric. Higher number of dynamic loading and abrasive cycles cause more damage to the threads. On the other hand, higher stitch density decreases the thread consumption per stitch and therefore the strain level experienced by the thread during stitch tightening, decreases accordingly, the thread is subjected to lower tension

levels and therefore experiences lower damage.

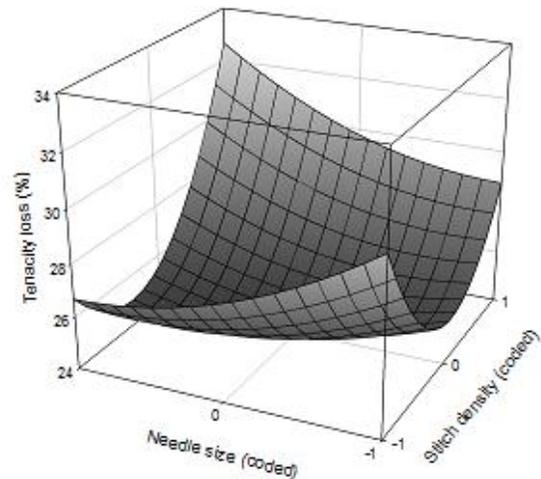


Fig. 2 Effect of stitch density and needle size on tenacity loss of cotton thread after sewing

The effect of both factors is opposite and therefore compensates each other. As stitch density increases further, the effect of higher number of loading and abrasive cycles outweighs the effect of decreased tension. Therefore, the loss in tenacity and breaking elongation increases. Since cotton thread is more susceptible to fatigue and abrasive damage, as compared to polyester thread, and experiences large variation in tension levels (because of higher slope in load elongation behavior), the effect of stitch density is significant in cotton threads only.

Further, it is observed that at lower level of needle size, as stitch density increases tenacity loss first decreases and then increases, which has been discussed earlier. But at higher level of needle size, as stitch density increases the tenacity loss decreases slightly and then increases sharply. Higher level of needle leads to higher needle penetration force and therefore higher temperature. The dynamic loading, abrasive damage is also accompanied by thermal damage. Therefore higher loss in tenacity is observed.

It is observed that, as the needle size increases, the loss in tenacity and breaking elongation increases for polyester staple spun threads, whereas these properties remain unchanged for cotton thread. As needle size increases, the needle penetration force and hence needle temperature increases [7]-[9], leading to higher thermal damage to the threads. Since cotton fibres are insensitive to thermal damage, the tenacity and breaking elongation loss in cotton thread remains unaffected with increase in needle size, whereas the increased needle temperature causes higher loss in tensile properties of polyester staple spun threads. Moreover, the flat cross section of polyester threads (2 ply) as compared to circular cross section of cotton thread (3 ply) (Table 1) increases the frictional contact with the needle, leading to higher damage.

B. Initial Modulus Loss

It is observed from the regression equations that as number of fabric layers increase, the loss in initial modulus decreases for all threads. The loss in initial modulus occurs due to the non-contribution of surface fibres to thread tension. More

number of abrasive cycles cause fraying of thread surface and pullout of fibres, leading to loss in initial modulus of threads. As the number of fabric layers increase, the number of abrasive cycles decrease and therefore lower loss in initial modulus is observed for all the threads. The decrease in initial modulus loss is sharp for cotton threads as compared to polyester threads, because cotton fibres, being shorter in length and poor in abrasion resistance are prone to more abrasive damage.

Further, it is observed that the loss in initial modulus increases as stitch density increases for all threads. However, the increase is significant for cotton threads only. Higher stitch density results in greater number of dynamic loading and abrasive cycles and therefore more pullout of fibers, leading to higher loss in initial modulus. With the increase in needle size, the loss in initial modulus does not show any significant change except a slight change in case of cotton threads. Since there is no change in dynamic loading and abrasive cycles, there is no change in the fibre pullout and therefore the loss in initial modulus remains unaffected for polyester staple spun threads.

IV. CONCLUSION

In the present investigation, the effect of number of fabric layers, stitch density and needle size on the loss in tensile properties of cotton and polyester sewing threads has been studied. The extent of loss in tenacity, breaking elongation, breaking energy and initial modulus primarily depends on the sewing thread type such as cotton or polyester staple spun. As the number of fabric layers increase, tenacity and breaking elongation first decreases and then increases for cotton thread. In polyester threads the loss in these properties remains unaffected with increase in number of fabric layers. However, loss in initial modulus decreases with the increase in number of fabric layers for all threads. Stitch density does not show any significant influence on tenacity and breaking elongation of polyester threads. Loss in initial modulus slightly increases with increase in stitch density. As the needle size increases, increased needle temperature leads to higher loss in tenacity, and breaking elongation of polyester staple spun threads. Since cotton thread is insensitive to needle heating, the tenacity and breaking elongation loss remains unchanged. However, at higher levels of needle size, it has been found that the tenacity loss increases for cotton threads also.

The regression equations for various responses agree well with the experimental data as indicated by higher values of coefficient of determination. Therefore, these equations can be used to predict the loss in tensile properties of threads during sewing.

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