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Analysing The Effects of Knitted Fabrics Physical Properties to The Heating of Sewing Machine Needles

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Abstract

Due to the increasing demand in the clothing industry, industrial sewing machines operate at high speeds ranging from 2000 to 3000 revolutions per minute. One of the most significant problems that adversely affect the stitching quality and efficiency is the needle temperature, which reaches up to 300 °C and is influenced by various parameters such as machine speed, thread tension, and fabric properties. In this study, the heat generated from the friction between the needle and the textile surface in knitted fabrics and the fabric properties affecting heat are examined. Four different knitting techniques and twelve different knitted fabrics with varying weights, thicknesses, and blend properties were used. An Optris CT3M pyrometer was employed to measure the temperature on the needle. The results can be summarized as follows: in all knitted fabrics, an increase in fabric weight and thickness was observed to correspond to an increase in needle temperature values. The highest needle temperature values above 90 °C were obtained in TF2-coded three-thread fleece fabric with a fabric thickness of 1.31 mm and a fabric weight of 340 g/m^2, while the lowest needle temperatures of 66 °C and below were achieved in the lightest and thinnest fabric with a fabric weight of 100 g/m^2 and a thickness of 0.39 mm. Additionally, no significant relationship was found between fabric stitching density and needle temperature.

Keywords: Sewing machine needle, Heating, Knitted fabric, Physical properties

Örme Kumaşların Fiziksel Özelliklerinin Dikiş Makinesi İğnelerinin Isınmasına Etkilerinin Analizi

Öz

Hazır giyim sanayisinde artan talep dolayısıyla endüstriyel dikiş makineleri 2000-3000 devirlerde varan yüksek hızlarda çalışmaktadır. İğne sıcaklığı makine hızı, iplik tansiyonu, kumaş özellikleri gibi birçok parametreden etkilenerek 300 °C sıcaklıklara ulaşarak dikiş kalitesi ve verimliliğini olumsuz yönde

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etkileyen en önemli problemlerden birisidir. Bu çalışmada, örme kumaşlarda iğne ile tekstil yüzeyi arasındaki sürtünmeden kaynaklanan ısı ve ısıyı etkileyen kumaş özellikleri incelenmektedir. Çalışmada dört farklı örgü tekniğine ve on iki farklı ağırlık, kalınlık, karışım özelliğine sahip örme kumaşlar kullanılmıştır. İğne üzerindeki ısıyı ölçmek için Optris CT3M pirometre kullanılmıştır. Sonuçlar şöyle özetlenebilir: tüm örme kumaşlarda, kumaş ağırlığı ve kalınlığındaki artışın iğne sıcaklığı değerleri ile bağlantılı bir artışa neden olduğu gözlemlenmiştir. 90 ºC üzerindeki iğne sıcaklık değerleri en yüksek sıcaklık değerleri 1.31 mm kumaş kalınlığı ve 340 g/m^2 kumaş ağırlığı ile TF2 kodlu üç iplik kumaşta elde edilirken, 100 g/m^2 kumaş ağırlığı ve 0.39 mm ile en hafif ve en ince kumaş türünde 66 ºC ve altındaki en düşük iğne sıcaklıkları elde edilmiştir. Bunların yanında kumaş dikiş yoğunluğu ile iğne ısısı arasında anlamlı bir ilişki bulunmamıştır..

Anahtar Kelimeler: Dikiş makinesi iğnesi, Isınma, Örme kumaş, Fiziksel özellikler

1. INTRODUCTION

The basic process in clothing industry is sewing. Sewing is an assembling technique that comprises of needle, thread, fabric, and machine that follows certain methods and with this method people produce millions of products such as apparel, medical textiles, automotive textiles, shoes, bags etc. [1].

With the increase in consumption, the demand has increased so companies have started to produce more products by using high-speed sewing machines and capacity usage rates. The sewing machine speeds vary from 2000 to 6000 r/min. During the sewing operation, the needle penetrates the fabric and moves very fast, causing the needle heating due to friction between the needle and fabric. Sewing speed is one of the main factors in the needle heating, but other factors also contribute, such as sewing needle design, coating, material sewn, thread tension, thread lubricants and fabric finishing. Due to these factors, the temperature of needle can change from 100 ºC~300 ºC during the sewing operation depending on the sewing conditions [2-5].

The needle heating can lead problems for productivity and seam quality such as sewing thread breaks, creased threads, seam damage, fabric damage and decrease of production [6-13].

According to literature there are various studies evaluating the problem of needle heating. Experimental techniques such as usage of thermocouple (touch, inserted method), IR pyrometers, temperature sensitive materials like waxes are commonly used for measuring the needle temperature [6,7,14].

While various studies have measured and predicted the needle temperature using different methods, designs, or materials, this research focuses on studying the fabric parameters causing needle heating.

Mazari et. al. predicted needle temperature using theoretical models and verified their results using the inserted thermocouple method. They concluded that needle temperature increases with machine speed according to theoretical and the experimental results [15]. Liasi et. al. used finite element analysis to predict and compare the needle temperature with experimental results [16].

Dal, et. al. studied needle coating design studied needle coating design and concluded that coating the needle with TiN can reduce needle temperature by reducing friction [17]. Other studies, e.g., Mazari et. al., have also analysed different coatings for needle heating, with some concluding that DLC (Diamond-like carbon) coating has a positive effect on reducing needle temperature by reducing friction [18].

Additionally, needle size and point shape have been analysed as factors affecting needle heating [7]. Moreover, the literature has analysed the effect of sewing thread lubrication on reducing friction [19]. Some studies have examined seam and fabric damages and the impact of fabric properties on needle heating. For instance, Muge et. al.

investigated different woven polyester upholstery fabrics with varying sewing machine speeds, and needle temperature was measured using thermal cameras [20]. They found that needle temperature increases with increasing machine speed and sewing thread count.

Similarly, Dal et. al. analysed the impact of woven fabric properties on needle heating and concluded that it is a critical issue for sewing quality and production efficiency [21]. While many studies have investigated woven fabrics, there are fewer studies on the effect of knitted fabric properties on needle heating, despite the widespread use of knitted fabrics in daily clothing, outerwear, sportswear, medical textiles, and shoes with synthetic or other natural fabrics. Sewing damage is particularly critical in knitted fabrics because ruptures in the thread may result in knots being pulled off or even the knitting pattern coming undone entirely. Some sewing errors are not noticeable during the sewing process but become apparent during wear or washing due to stretching and movement [2].

This paper presents an experimental study on needle heating and the effect of knitted fabric properties to the needle heating. The primary objective of this study is to understand how knitted fabric properties affect needle temperature. This research aims to contribute to the literature on sewing problems and their causes.

2. MATERIAL AND METHOD

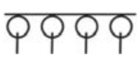
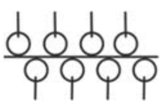
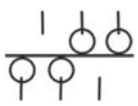
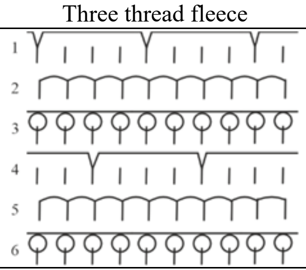
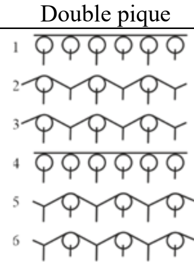
2.1. Material

In this study, twelve knitted fabrics with four different knitting types, varying fabric weights, and thicknesses, all made from 100% cotton, were utilized. The physical characteristics and knitting notations of each fabric are displayed in Table 1 and Table 2.

Table 1. Properties of the fabrics

Fabric code	Fabric type	Fabric weight (g/m^2)	Fabric thickness (mm)	Average yarn count (tex)	Course density (Loop/cm)	Wale density (Loop/cm)
S1	Single Jersey	100	0.39	14.75/1	15	18
S2	Single Jersey	110	0.45	14.75/1	15	20
S3	Single Jersey	155	0.54	19.67/1	12	21
S4	Single Jersey	175	0.59	21.85/1	11	14
R1	Rib (1*1)	195	0.71	19.67/1	24	21
R2	Rib (2*2)	210	0.73	19.67/1	20	18
R3	Rib (1*1)	280	0.77	19.67/1	20	20
R4	Rib (1*1)	380	1.18	19.67/2	16	18
TF1	Three Thread Fleece	270	1.50	19.67/19.67/29.50	9	11
TF2	Three Thread Fleece	340	1.31	19.67/29.50/59	10	13
DP1	Double Pique	190	0.74	24.58/1	12	36
DP2	Double Pique	210	0.82	24.58/1	11	44

Table 2. Knitting notations of fabrics

Single Jersey	Rib (1*1)	Rib (2*2)	Three thread fleece	Double pique
				

2.2. Method

The standards used to analyse the fabric properties were TS 251-Determination of Mass Per Unit Length and Mass Per Unit Area of knitted fabrics to determine the fabric weight; TS EN 14971 Textiles-Knitted fabrics-Determination of number of stitches per unit length and unit area to determine the density of knitted fabrics; and TS EN 14970 Textiles-Knitted fabrics-Determination of stitch length and yarn linear density in weft knitted fabrics. The tests were conducted under laboratory conditions of 20±2 ºC and 65%±2 humidity.

All objects with a temperature above absolute zero (-273.15 ºC) emit electromagnetic radiation from their surface that is proportional to their internal temperature. Electromagnetic radiation is a form of energy that moves through space in the form of electromagnetic waves.

It is defined by its wavelength, frequency, and energy, and follows the principles of diffraction, refraction, reflection, and polarization.

The electromagnetic radiation spectrum is the range of all types of electromagnetic radiation, including radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays. Each type of electromagnetic radiation has a unique wavelength, frequency, and energy, and together they form the electromagnetic spectrum. The pyrometer uses infrared area in the electromagnetic spectrum. (Figure 1) [22].

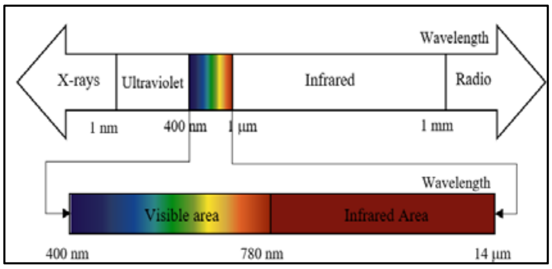


Figure 1. Electromagnetic spectrum

Pyrometer, a type of non-contact temperature measuring device, measures the temperature of the object by detecting the infrared radiation emitted. The device consists of a lens that focuses infrared radiation on the infrared detector that generates analogue signal corresponds to the radiation. An analogue to digital convertor converts analogue signal to digital. Digital signal is processed by the processor to determine the temperature of the object and converted into an output signal proportional to the temperature of the object.

A thermal pyrometer uses four laws which explain radiation, Planck's law, Stefan-Boltzmann law, Wien's Displacement law and Kirchhoff's law.

Planck's law to measure the temperature of an object. Black body is an idealized object that perfectly absorbs all incoming radiation. Planck's law (1) describes the spectral distribution of the radiation emitted by a black body at a specific temperature. This law states that the radiant energy emitted at a given wavelength is directly proportional to the frequency of the radiation and the temperature of the black body. describes the relationship between the spectral radiance of a black body and its temperature: (Equation 1)

$$R(\lambda, T) = \frac{2\pi hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda k T} - 1}, = \frac{c_1}{\lambda^5} \frac{1}{e^{c_2/\lambda T} - 1} \tag{1}$$

where $h = 6.63\ x\ 10^{-34}\ J\ s,$

$c = 3.00\ x\ 10^{8}\ m/s,\ k = 1.38\ x\ 10^{-23}\ J/K$

c: speed of light,

$c_1 = 3.74x10^{-16}\ W/m^2,$

$c_2 = 1.44x10^{-2}\ m\ K,$

$h: Planck's\ constant,$

$k: Boltzmann\ constant,$ [23,24]

The Stefan-Boltzmann law (2) describes the total thermal radiation energy emitted by a blackbody is proportional to the fourth power of its temperature, meaning that as the temperature increases, the amount of thermal radiation emitted by the blackbody increases dramatically. (Equation 2)

$$P = \sigma T^4 \tag{2}$$

where P is the total power emitted by the blackbody, σ $= 5.67x10^{-8} W\ m^{-2} K^{-4}$, (Stefan-Boltzmann Constant) and T is the temperature of the blackbody in Kelvin [25-27].

Wien's Displacement Law, states that the wavelength of maximum radiation emitted by a black body is inversely proportional to its temperature. (Equation 3) This law is expressed mathematically as

$$\lambda_{max} = b/T \quad (3)$$

where λ_{max} is the wavelength of maximum radiation, b is Wien shift constant,
T is the black body temperature [28].

Kirchhoff's law states that a given material has the same ratio of emissivity to absorptivity at a given temperature and wavelength. In other words, a good radiation emitter is also a good radiation absorber. (Equation 4)

$$\varepsilon = \alpha \quad (4)$$

where α is absorptivity, ε is emissivity [28].

Emissivity is a measure of the ability of a surface to emit thermal radiation. It is a dimensionless value between 0 and 1. An emissivity of 1 represents a perfect emitter, or a black body, which absorbs all incoming radiation and emits radiation according to Planck's law at a given temperature. On the other hand, an emissivity of 0 represents a perfect reflector, which does not emit any radiation [27].

Most objects are not perfect black bodies or white bodies, but rather have intermediate emissivity's that depend on the material, surface finish, and temperature of the object. These objects are referred to as grey bodies.

The concept of a grey body is important in the study of thermal radiation and temperature measurement because it allows for the calculation of the temperature of an object based on the emitted thermal radiation, considering the effect of the object's emissivity. The emissivity of a grey body can be measured experimentally, and then used to correct temperature measurements made using thermal imaging cameras or pyrometers to ensure accurate results [22].

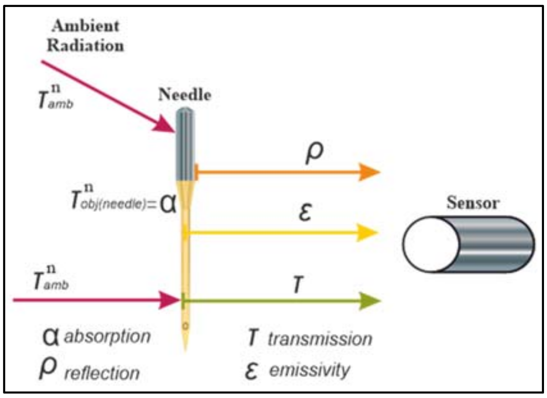


Figure 2. Ambient influences

Infrared sensors receive radiation emitted from the surface of an object, but also reflected radiation from the environment and possibly transmitted infrared radiation through a black body.

$$\varepsilon + \rho + \tau = 1 \quad (5)$$

Where
$\varepsilon: emissivity, \rho: reflection, \tau: transmissivity,$

Most bodies do not exhibit infrared transmission. So:

$$\varepsilon + \rho = 1 \quad (6)$$

Since according to Stefan Boltzmann law, the electrical signal of the detector is as follows:

$$U \sim \varepsilon T^4 \quad (7)$$

Since reflected ambient radiation and the intrinsic radiation of the infrared thermometer must also be considered, the formula is:

$$U = C[\varepsilon T^4_{obj} + (1-\varepsilon)\, T^4_{amb} - T^4_{pyr}] \quad (8)$$

U: Detector signal, Tobj: Object (needle) temperature, Tamb Temperature of background radiation, Tpyr Temperature of the device, C: Device-specific constant, $\rho = 1 - \varepsilon$ Reflection of object (needle).

Since infrared thermometers do not cover entire wavelength range, the exponent n depends on the wavelength λ. In the wavelength range from 1 to 14 µm, n is between 17 and 2 (at long wavelengths between 2 and 3, short wavelengths between 15 and 17).

$$U = C[\varepsilon T_{obj}^{n} + (1-\varepsilon)\, T_{amb}^{n} - T_{pyr}^{n}] \tag{9}$$

Therefore, the object (needle) temperature is determined as follows [22]:

$$T_{obj} = \sqrt[n]{\frac{U - C.T_{amb}^{n} + C.\varepsilon T_{amb}^{n} + C.T_{pyr}^{n}}{C\varepsilon}} \tag{10}$$

An Optris CT3M pyrometer shown in Figure 3 was utilized to measure the needle temperature. To achieve this, the experimental setup seen in Figure 4 was established.

Figure 3. The Pyrometer (Optris CT3M)

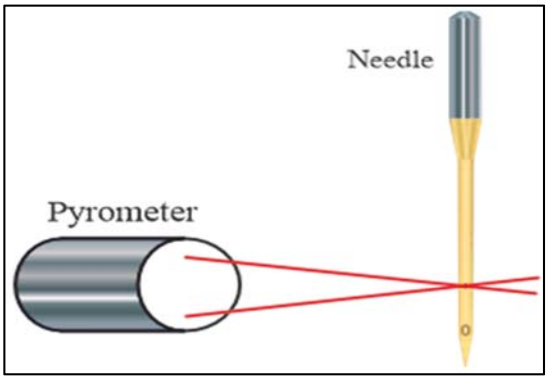


Figure 4. Focus of the laser lights on the needle

Laser beams of pyrometer were focused on the sewing needle, and the emissivity of the needle that made of chromium was assumed to be 0.8 for the thermal images.

The setup was configured to perform 100 measurements per second, with the laser beams continually focused on the sewing needle, as shown in Figure 5, to collect measurements from the entire needle surface that interacts with the fabric while the sewing machine is in operation.

Sewing threads were not used in this study, as they may absorb heat from the needle. Instead, 20 cm x 100 cm pieces of 12 different knitted fabrics, each with four different knitting types, different weights, and thicknesses, were cut into 10 pieces for each fabric type.

Each fabric variant underwent five sewing trials using the Juki DDL 9000A-SS Lock Stitch Machine, a commonly utilized sewing machine model in the industry. The prevailing stitch type, 302 lock sewing type, was employed, and a seam density of 5 seams per 1 cm was maintained throughout the experiments. The sewing process utilized a Nm 80 (12) sewing needle, with two plies of fabric being sewn together. Each sewing operation lasted approximately 10 seconds for a 1-meter fabric piece, during which the pyrometer recorded around 1000 temperature measurements at a rate of 100 measurements per second. To conduct a statistical analysis on the influence of knitted fabric parameters on needle heating, the MINITAB software was employed.

Figure 5. Needle temperature measurement setup

3. RESULTS

The data collected was subjected to analysis, focusing solely on the maximum temperature values. The obtained findings were then interpreted in relation to the different types of knitted fabrics. Figure 6 highlights the maximum temperature values of the sewing machine needle for the various knitted fabric samples after five sewing operations, highlighting the impact of fabric weight on needle temperature. The conducted tests, utilizing 100% cotton single jersey, rib, fleece, and double pique fabrics, revealed a proportional increase in the temperature values of the sewing machine needle with the fabric weight.

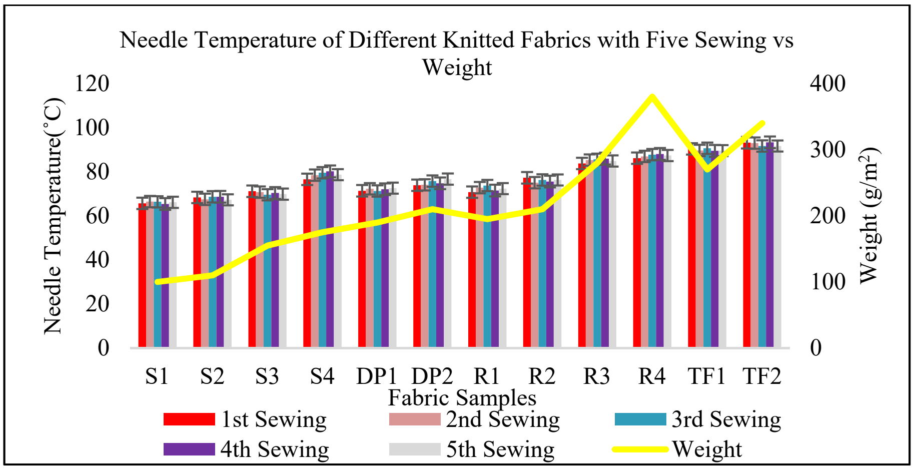


Figure 6. Temperature values of knitted fabrics after sewing vs fabric weight

The physical properties of the single jersey fabrics SJ1, SJ2, SJ3 and SJ4, rib fabrics R1, R2, R3 and R4, fleece fabrics TF1 and TF2, and double pique fabrics DP1 and DP2, including thickness, fabric weight, and course density, were studied, and the results are shown in Table 1. The increase in fabric thickness leads to heightened friction between the needle and fabric during the sewing operation, thereby causing an increase in needle temperature.

The results for TF1, TF2, R3, and R4 samples indicate the highest needle temperature values (Figure 7), which can be attributed to their fabric properties. TF1 has a high fabric weight (270 g/m^2) and thickness (1.31 mm), while TF2 has a higher fabric weight (340 g/m^2) but less thickness (1.31 mm). Rib fabric samples R4 and R3 have high fabric weight values (380 g/m^2 and 280 g/m^2, respectively), which is why their results are close to those of three-thread fleece fabric samples.

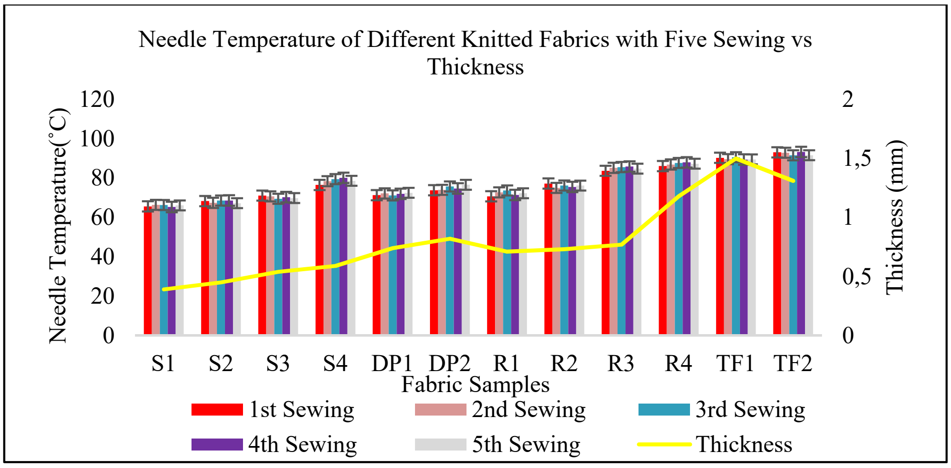


Figure 7. Needle temperature values of knitted fabrics after sewing vs fabric thickness

3.1. Statistical Analysis of the Effect of Fabric Weight on Needle Temperature

During this stage, a statistical analysis was conducted to examine the correlation between the needle temperature and the weight of knitted fabrics. As depicted in Figure 8, a linear model was fitted, providing an equation that describes the relationship between the maximum temperature and the fabric weight: Y=58.01+0.09477X. If the model adequately captures the data, this equation can be used to predict the maximum temperature for a given fabric weight or determine the settings that correspond to a desired maximum temperature value or range.

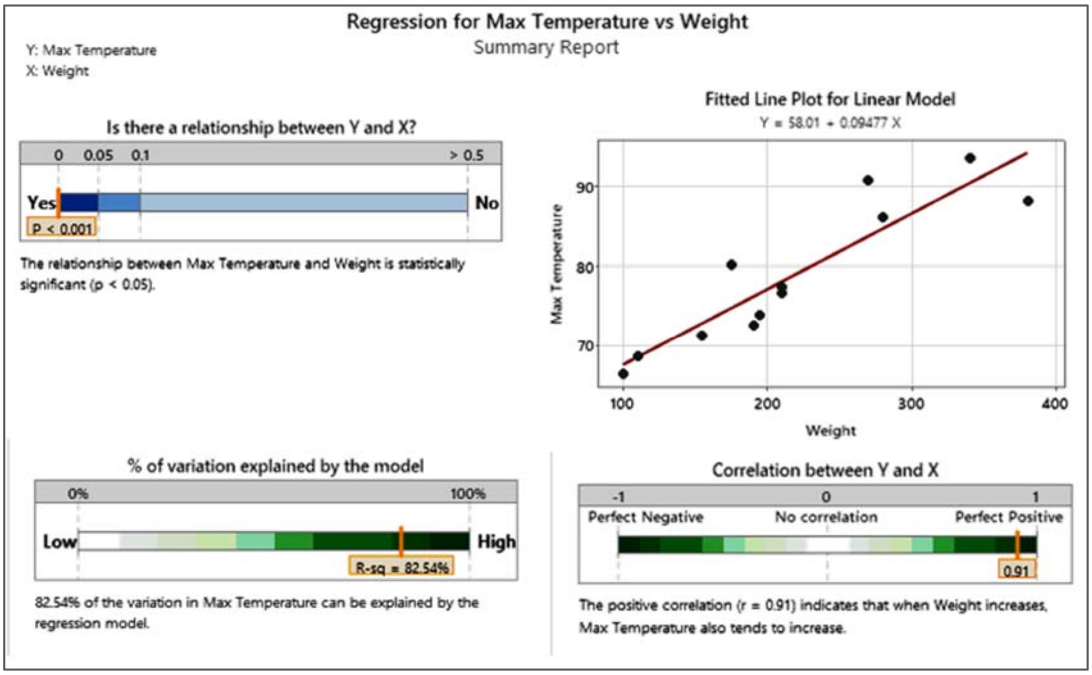


Figure 8. Statistical Analysis of the Effect of Fabric Weight on Needle Temperature

The relationship between maximum temperature and weight is statistically significant (p-value = 0.001<0.05 at 95% confidence interval) with an R^2 -value of 0.8254 indicating that the maximum temperature data depends on weight about 82.54%. The regression model includes the y-intercept (58.01) and slope value (0.09477) coefficients, which explain the regression line's nature and trend. The y-intercept value indicates that the regression line intersects the y-axis at 0.09477, which is very close to the origin of the axis. The slope gives the rate at which the dependent variable is explained by the independent variable. The correlation between the maximum temperature and weight was also measured using MINITAB software (r=0.91), indicating a direct positive relationship between the two parameters.

3.2. Statistical Analysis of the Effect of Fabric Thickness on Needle Temperature

During this stage, a statistical analysis was performed to examine the correlation between needle temperature and the thickness of knitted fabrics. Figure 9 presents the equation derived from the linear model, which accurately represents the connection between maximum temperature and thickness as Y= 61.22 + 21.51X. If the model effectively captures the data, this equation can be employed to forecast the maximum temperature for a specific thickness or determine the thickness settings that yield a desired value or range of values for the maximum temperature.

The relationship between maximum temperature and fabric thickness is statistically significant (p-value=0.001<0.05 at a 95% confidence interval). The coefficient of determination (R^2-value=0.6938) indicates that approximately 69.38% of the variation in needle maximum temperature can be attributed to fabric thickness. The regression model includes the y-intercept (61.22) and slope value (21.51), which provide insights into the nature and trend of the regression line. The y-intercept value (61.22) suggests that the regression line intersects the y-axis at a value of 61.22, which is close to the origin. The slope value (21.51) indicates the rate at which the dependent variable (maximum temperature) changes in relation to the independent variable (fabric thickness). Furthermore, the correlation value calculated using MINITAB software (r=0.83) indicates a strong positive relationship between maximum temperature and fabric thickness.

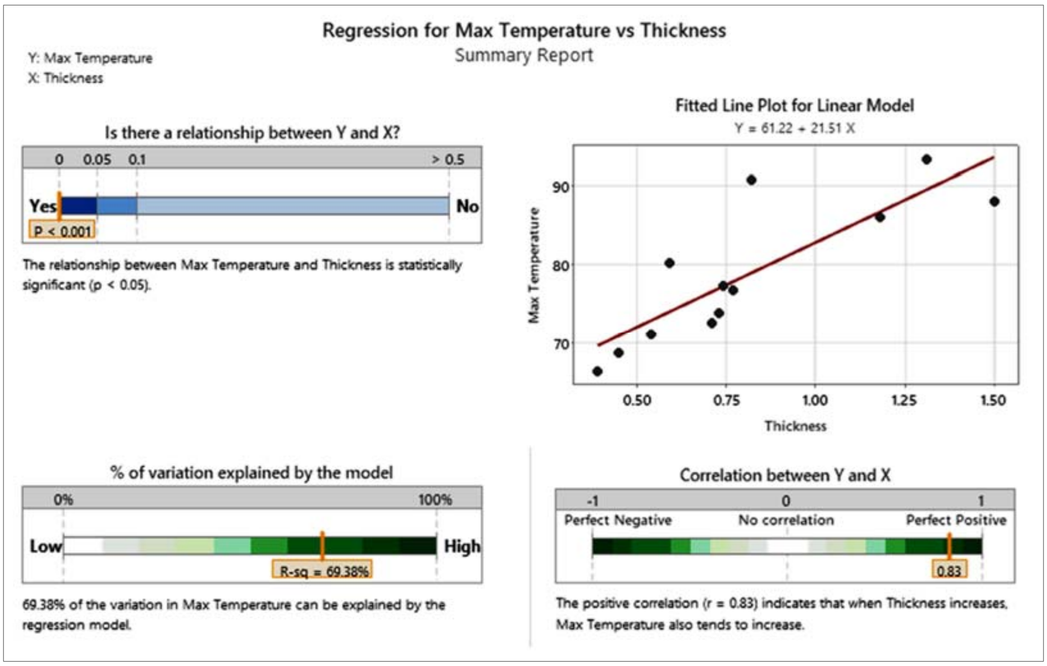


Figure 9. Statistical Analysis of the Effect of Fabric Thickness on Needle Temperature

3.3. Statistical Analysis of the Effect of Fabric Stitch Density on Needle Temperature

Figure 10 presents the fitted equation for the linear model that characterizes the relationship between maximum temperature and fabric stitch density as Y=87.92+0.03024X. However, it is important to note that the relationship between maximum temperature and fabric stitch density is not statistically significant (p-value=0.135>0.05 at a 95% confidence interval). The coefficient of determination (R^2-value=0.2087) indicates that approximately 20.87% of the variation in needle maximum temperature can be explained by the fabric thickness. The regression model also includes two significant coefficients: the y-intercept (87.92) and the slope value (0.03024), which provide insights into the nature and trend of the regression line.

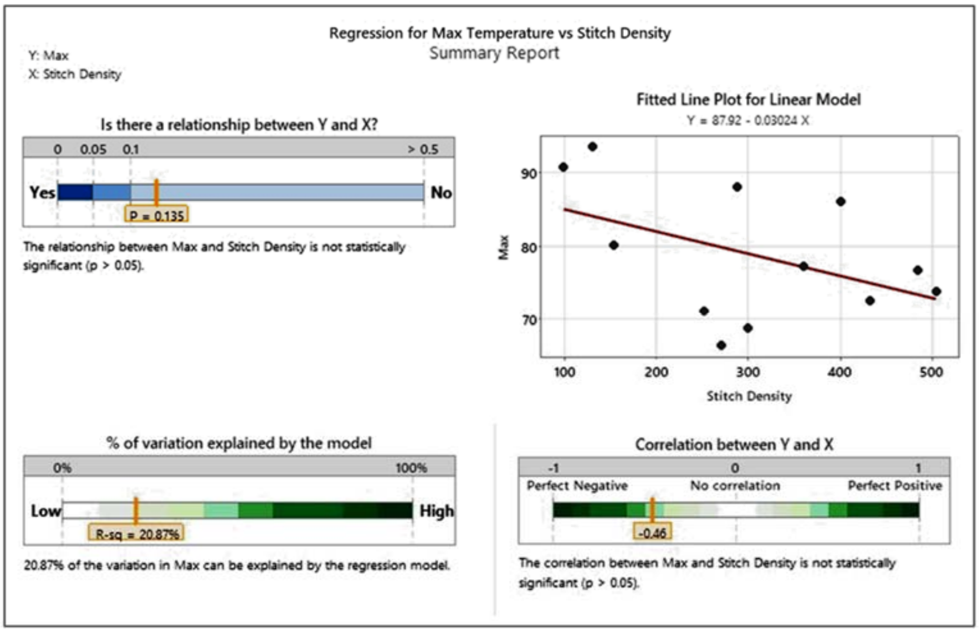


Figure 10. Statistical Analysis of the Effect of Fabric Stitch Density on Needle Temperature

4. CONCLUSION

The objective of the current research was to examine the impact of knit fabric characteristics on the heat generated in sewing machine needles. Needle heating can be attributed to the friction between the needle and sewing thread, which was identified as a significant factor [15]. A comprehensive study was conducted, involving sixty sewing processes using diverse knit fabrics with different densities and weights. Non-invasive temperature measurements were carried out using a pyrometer, focusing solely on the maximum temperature values attained.

The findings of the study revealed a positive relationship between needle temperature and the weight and thickness of various knit fabrics, including single jersey, rib, fleece, and double pique. Notably, the TF2 fabric, characterized by a three-thread fleece structure, exhibited the highest needle temperature values among the tested fabrics, with a fabric thickness of 1.31 mm and a fabric weight of 340g/m^2. The results also demonstrated a strong correlation between fabric weight and needle heating, as well as between fabric thickness and needle heating. These findings align with previous studies conducted on woven fabrics, indicating that similar patterns emerge in the context of knitted fabrics [5,20,21]. The intensification of friction between the needle and the fabric with increasing thickness and weight can be attributed to the elevated needle temperature. Conversely, no significant correlation was observed between fabric stitch density and needle temperature. These findings provide valuable insights into addressing the issue of needle heating in knit fabric research.

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