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Optimizing the Needle - Thread - Fabric Interaction for Enhanced Seam Performance in Clothing Manufacturing

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Abstract

In apparel industry, product quality is always the key factor determining the success of a business. Not only does this create customer satisfaction, but product quality also directly affects the business's reputation, competitiveness, and market expansion opportunities. In this, seam appearance is one of the most important quality requirements, directly determining customer satisfaction. This paper examines the relationship and impact of three most important specifications, including needle-thread compatibility, fabric weight on the quality of seam performance. Through the experiment according to the full factorial design, this paper has determined the influence of each factor, in which the fabric weight is the factor with the most significant impact on the variation of the seam length, followed by the needle size and thread size. Determining the relationship between material parameters (fabric, thread) and equipment parameters (needle) not only helps to minimize errors but also creates the premise for building standardization processes for technical parameters according to each specific product group. These results will support the operator to adjust the machine faster, more accurately and less dependent on manual experience, thereby improving productivity and efficiency of the whole system.

Keywords: clothing industry, seam performance, quality control, design of experiment.

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1. Introduction

The apparel sector is always one of the key industries, holding an important position in the economy, bringing a considerable foreign currency to the country, and creating jobs for millions of workers [1]. In this sector, product quality is always the key factor determining the success of an apparel business. Not only does this create customer satisfaction, but product quality also directly affects the business's reputation, competitiveness, and market expansion opportunities. In the clothing industry, a product that meets high-quality standards ensures not only aesthetic factors but also has high durability, brings comfort to users, and meets strict technical requirements. In this, seam appearance is one of the most important quality requirements, directly determining customer satisfaction.

For optimal seam performance, several key requirements should be considered. These include achieving adequate seam strength and stretch and ensuring strong resistance to chemical and biological influences. Additionally, good color stability is essential, alongside minimal shrinkage during washing and ironing processes. It is also important to consider suitable frictional properties and to maintain an appealing seam appearance.

One of the factors that reduces the aesthetic value and affects the quality of the product is the phenomenon of seam puckering [2]. This problem has been known for a long time and has attracted the attention of many researchers and apparel managers. Due to the increasing demand for quality garment products, businesses have brought this problem to the forefront. There have been many studies to identify and overcome the phenomenon of seam wrinkles, but in practical production, it is still a matter of great concern for businesses. There are some common

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errors in which seam wrinkles often occur when making product codes: shirts, trousers, jackets. Seam puckering is a phenomenon that affects the quality of garment products in general. Many factors affect seam wrinkles, such as fabric composition and structure, sewing thread, processing conditions, technological parameters, and sewing equipment [3]. Moreover, the incompatible needle-thread-fabric combinations are one of the most significant problems in the quality of seam performance.

However, in many apparel enterprises, the selection of needles and threads based on the characteristics of fabrics is still mainly based on the production managers' experience or advice from raw material suppliers. This approach is subjective and does not ensure consistency in production, mainly when producing with many different types of fabrics. This research examines the relationship and impact of three factors: needle-thread compatibility, fabric weight on the quality of seam performance. The final result proposes an optimal set of parameters to ensure high seam quality.

2. Literature review

2.1 Definition of seam performance

Seam performance is important in the clothing industry, affecting product durability, consumer satisfaction, and marketability. Seam quality reflects aesthetics and determines the load-bearing capacity, durability during use, and resistance to mechanical impacts such as washing, stretching, and friction. [2] concluded that a high-quality seam must be durable, flexible, and free of sewing errors while ensuring the aesthetics according to the product's design requirements. Common problems that affect seam quality include seam puckering, skipped stitches, broken threads, fabric damage, needle damage to the fabric, etc. These errors can reduce the productivity and quality of garment products. In these, seam puckering is the phenomenon of unstable seams on the product, which are wrinkled, creating ripples on the surface of the detail. Seam puckering is caused by unstable stitching during or after sewing, shifting of yarn, thread, and shrinkage [4]. Seam puckering causes error shapes along the seam and is considered a serious defect because it dramatically affects the aesthetics and deforms the shape of the product at the seams.

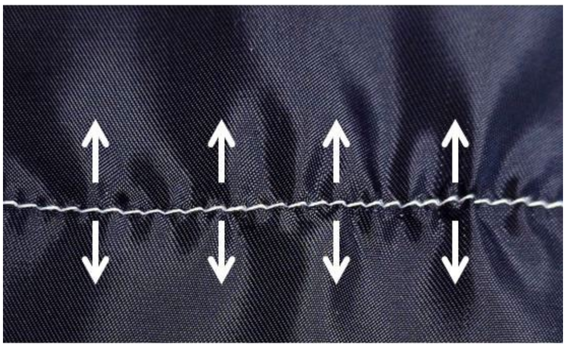

Figure 1. Seam puckering defect on garments.

The phenomenon of seam puckering has the characteristics that the wrinkle wave graph has a sinusoidal shape, and the wrinkle waves are three-dimensional spatial waves starting from the center points along the seam and spreading to the fabric edge in a direction perpendicular to the seam (***Figure 1***). Seam puckering refers to a change in the length of the seam as specified. Seam puckering is one of the most serious defects frequently encountered in processing products from woven or knitted fabrics [5]. Therefore, it has become a frequently evaluated criterion in the clothing industry to control the quality of garments and evaluate the workers' skill level in the sewing assembly line.

2.2. Factors affecting the seam performance

The seam performance is affected by many factors, which can be divided into three main groups: sewing machine parameters, sewing thread quality, and fabric properties. These factors have a complex interaction, determining the durability and appearance of the seam.

2.2.1 Sewing machine parameters

Many previous studies have shown that the machine's technical parameters will directly affect the seam performance. [6] demonstrated that the density of stitches affects the seam's strength and flexibility. If the stitch density is low, the seam may be weak and unable to withstand the force, leading to thread unraveling. On the contrary, a density that is too high increases the tension on the thread, which can easily cause shrinkage and deformation of the seam structure or even damage the fabric surface. In addition, the pressure on the presser foot is also one of the factors affecting seam performance. According to the study of [7], during the sewing process, if the presser foot pressure is too high, it can cause the fabric to stretch, deform the seam, or cause the fabric to pucker. However, if the pressure is too low, it can cause the fabric to slip, causing uneven stitches or misaligned seams.

Adjusting the presser foot pressure to suit each type of fabric will significantly improve the stability of the seam.

Moreover, the size and type of sewing needle are crucial specifications for achieving quality stitching. Using a needle that is too large can damage delicate fabrics by tearing them as the needle passes through. Conversely, a needle that is too small may lack the strength needed to penetrate thick layers of fabric, which can result in the needle breaking, skipping stitches, or weakening the seam. Additionally, using an inappropriate needle for the specific type of thread can cause excessive friction during sewing [6].

2.2.2 Fabric properties

Depending on the knitting or weaving structure, the fabric will have different thicknesses and surfaces. The friction between the fabric, the feeder, and the presser foot depends a lot on the above two factors [8]. The magnitude of the friction is proportional to the thickness of the fabric; the thicker the fabric, the greater the friction, and it helps the fabric move in line with the presser foot, reducing seam wrinkles. In addition, for fabrics with smoother, shinier surfaces, the friction will be negligible, causing more seam wrinkles than fabrics with rougher surfaces. [9] demonstrated the correlation between fabric thickness and seam puckering. On the other hand, it also showed the correlation between seam puckering and weave type. Additionally, the study conducted by [10] revealed that the characteristics of the fabric, the type of seam, the sewing thread, and the stitch densities all affect seam performance. Among these factors, it was identified that the fabric characteristics have the greatest impact on seam pucker, which includes aspects such as fabric thickness, weight, and warp density.

2.2.3 Sewing thread quality

During the processing and assembly of parts in the sewing process, the mechanical and physical properties of the thread directly affect the seam puckering, including elasticity, fineness, friction resistance, uniformity, dimensional stability, etc. In the research of [11], the influence of the mechanical properties of sewing thread on seam quality was analyzed. The hysteresis curve graph representing the mechanical properties of sewing thread - showing the relationship between tensile force and deformation of the thread during sewing - was used to compare the deformation of three fabric samples with fiber compositions of 100% cotton, 100% polyester, and 100% viscose sewn with cotton thread and polyester thread. After washing and drying, the frequency of seam puckering defects obtained had the highest value in the sample sewn with cotton thread compared to the sample sewn with polyester thread.

From the factors affecting the seam performance, as presented in the above section, the seam quality depends on many factors, of which the three most significant components are needle, thread, and fabric. The relationship between these three factors directly impacts the ability to form stitches and the durability and stability of the seam.

2.3. Needle – Thread – Fabric Characteristics

2.3.1 Needle characteristics and their effects on seam performance

The sewing needle is an important part of the sewing machine, which creates holes in the material to thread through without damaging the fabric. In addition, the sewing needle also helps create loops of thread, supporting the process of forming stitches by coordinating with the thread hook or other parts of the sewing machine [12]. A sewing machine needle consists of various components that enable it to connect to the sewing machine and properly guide the thread: the butt, shank, shoulder, blade, groove, scarf, eye, and point along with the tip [13], as shown in ***Figure 2***.

The needle size is a number that represents the diameter of the needle body, indicating the size of the needle. This parameter is a standardized parameter used for all types of needles; the needle size is printed on the needle shaft and does not depend on any needle [14]. Choosing the right needle size for the sewing thread and fabric characteristics ensures that the sewing process is smooth, the seam is durable, and does not damage the fabric or sewing thread. Using a needle with a size that is too large for the fabric can tear the fabric or create a needle hole that is too large, affecting the aesthetics and durability of the seam.

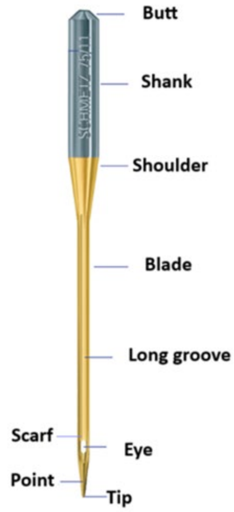

Figure 2. The structure of a sewing needle.

On the contrary, if the needle size is too small, the needle may not be strong enough to penetrate the thick layer of fabric, leading to bending, breaking the needle, or skipping stitches. The shape of the needle tip plays a crucial role in how the needle penetrates the fabric, which in turn influences the extent of damage to the fabric fibers and the overall stability of the seam. Selecting the appropriate needle tip can help minimize defects like fabric tearing, skipped stitches, and broken threads during the sewing process [15].

2.3.2 Sewing thread characteristics and their effects on seam performance

Sewing thread is a flexible and fine strand of yarn, often treated with a surface coating or lubricant, specifically designed for stitching two or more pieces of fabric in garments [16]. Sewing threads are often classified based on the raw material, structure, manufacturing method, or finishing process. Numerous previous studies have explored the influence of sewing thread parameters, including curl, elasticity, fineness, and abrasion resistance, on the sewing process. According to [17], a high twist of sewing thread can increase tensile strength but can easily cause thread twisting during sewing, leading to skipped stitches or uneven seams. A low twist makes the thread softer and easier to sew, but can reduce the strength of the seam. From the study by [18], selecting the incorrect needle size can lead to a reduction in the tensile strength of the seam due to the uneven distribution of tension on the thread. Additionally, research conducted by [6] indicated that increasing the needle size from 12 to 16 could result in a decrease in seam strength of approximately 5%, as this raises the risk of breaking the fabric thread.

2.3.3. Fabric characteristics and their effects on seam performance

In the clothing industry, fabric is one of the most significant raw materials that influences the final quality of garments. According to the study of [19] and [20] have demonstrated that fabric weight has a significant effect on seam performance, especially in seam puckering, as an increase in fabric weight reduces seam puckering. Similarly, lightweight fabrics have poor stability and are more prone to seam puckering than heavy fabrics. However, other studies have shown that seam puckering is more common in heavy fabrics because the sewing thread penetrating the fabric creates a very high contraction force, causing wrinkles to appear on the material. [11] concluded that thicker and stiffer fabrics are less prone to seam puckering, and that seam puckering decreases as fabric thickness and stiffness increase. In addition to fabric weight parameters, the structure of the fabric is a crucial technical standard that significantly impacts seam quality. [21] studied the correlation between fabric thickness and weave styles on seam quality to prove that twill fabric has higher seam puckering than plain weave fabric. In addition, [7] also pointed out that differences in the stretch between fabric and sewing thread can lead to seam slippage.

From the factors affecting the seam performance as presented in the above section, the quality of the seam depends on many factors, of which the three most important components are the characteristics of the needle, thread, and fabric. The correlation between three factors directly influences the ability to form stitches and the durability and stability of the seam.

3. Experiment Design

3.1 Design of Experiments Methods

Design of Experiments (DOE) is a tool to investigate and analyze the impact of input variables on output variables simultaneously. A series of test runs in DOE is conducted with varying input factor levels and measuring the output results. Data is collected for each test run to analyze the effect of input factors on the process output, thereby selecting and establishing the optimal value levels for input factors to optimize the output results.

In this research, the full factorial design is applied to analyze the interaction between the characteristics of needle, thread, and fabric simultaneously. A factorial design is a type of experiment that examines the effects of multiple factors on a particular outcome. In this type of experiment, changing the levels of all factors simultaneously- rather than adjusting them one at a time - allows researchers to study the interactions between these factors more effectively.

3.2 Statistical Design of Experiment

Full factorial design experiments involve conducting tests for every possible combination of selected levels. Typically, a factorial design can be represented by the formula $N = b^k$, where N indicates the total number of combinations or experiments, b denotes the number of levels, and k represents the number of factors. Among the factors affecting the seam quality, it is necessary to focus on those that directly impact the geometrical deformation and stability of the seam and are specified in the technical standard table of the order, including: *fabric weight, needle size, and thread size*. These parameters can be adjusted and controlled in production conditions while having a precise meaning when assessing seam quality.

3.2.1 Input variables of the experiment

Fabric weight (g/m^2) is an important physical factor affecting the sewing process and seam quality. According to the study of [22], fabric weight affects the needle penetration ability and the slippage between fabric layers, thereby significantly affecting the stability of the stitch. In addition, fabric weight is an important specification that is determined in clothing orders. Therefore, fabric weight was chosen as the input variable to investigate the influence of material properties on seam quality.

Needle size (Nm) or needle index represents the diameter and size of the sewing needle, which directly affects the ability to penetrate the fabric, the accuracy of the needle puncture point, and the level of damage to the material. According to [6], using a needle size that is unsuitable for the fabric and thread is the leading cause of technical errors such as broken threads, repeated stitches, or incorrect stitch length. Therefore, needle size is chosen as an input variable to evaluate the impact on the ability to form stable stitches under different sewing conditions.

Thread size (tex) reflects the fineness or thickness of the thread, an important factor in forming stitches and maintaining the bond between layers of fabric. According to [23], thread size variation significantly impacts stitch tension and stability, especially under high-speed sewing conditions. Therefore, thread size is used as an input variable to determine the level of influence on seam quality through the index of stitch length variation.

The levels for three factors, including needle, thread, and fabric, were selected based on common clothing order requirements in the apparel industry, to ensure that the experiments reflect the practical conditions that manufacturers often encounter. An expert panel with five members was established to determine the levels of the factors. The members all had experience in production and quality management in the apparel industry. The fabric weight (g/m^2) was determined to represent a standard range of fabrics, from light-medium to heavy-weight, and the most common needle and thread sizes in the garment industry. Although these levels are not the only industry standards, they were chosen for their representativeness and feasibility in this study. To generalize the results, the results obtained from the experimental design can be used for analysis and extension to other levels. The value level of the three input variables is represented in ***Table 1***.

Table 1. The level of three input variables.

Variables	***Index***	***Level values***		
Fabric weight (g/m^2)	A	171	196	253
Needle size (Nm)	B	65	70	80
Thread size (tex)	C	21	24	30

3.2.2. Response variable

In the clothing industry, seam length is an important output quality factor and a technical parameter that customers consider. The interaction between needle, thread, and fabric during the sewing process can lead to variations in seam length and cause defects such as seam puckering. It is necessary to minimize seam length variation to ensure product quality. The seam length variation is calculated following equation (1):

$$\Delta L = |L_1 - L_2| \qquad (1)$$

Where ΔL : the seam length variation

L_1 : the seam length as required

L_2 : the seam length after sewing

To ensure the reliability of the experimental results and facilitate practical statistical analysis using the full factorial design method, a total of $N = 3^3 = 27$ experiments will be conducted. Each experiment will be repeated twice, resulting in a total of 54 experiments being collected.

To ensure that the interaction between the needle, thread, and fabric was the primary cause of the variance in seam quality, the experiments in this study were carried out under very stringent control. Throughout the experiment, every specification—including the type of sewing machine, the skill level of the workers, the stitch density, and the machine speed—was standardized and set up at a fixed value. The ambient humidity was also monitored and maintained at a stable level, corresponding to the regulation in the actual production environment, to eliminate its influence on seam quality. The fabric component will be 65% cotton and 35% polyester; one of the most common fabrics is used to create clothes in the apparel industry. The material type is homogenized, ensuring that variations in seam length reflect only the interaction between needle, thread, and fabric, and are not influenced by differences in material properties.

4. Results analysis and Discussion

Each experiment created a 25 cm long seam on a 6 x 30 cm fabric sample, totaling 54 fabric samples. After the seam was completed, the sewn fabric sample was placed on a flat surface in its natural position, and the variation in the seam was recorded using a specialized measuring ruler.

Based on the Pareto chart in ***Figure 3***, all three main factors are statistically significant. Specifically, fabric weight (A) is the factor that has the most significant impact on seam length variation. Fabric weight is a factor that reflects the combination of mechanical properties such as thickness, stiffness, surface stability, and load-bearing capacity. Fabrics with low weight are often thin, soft, and easily displaced under the impact of the feed table and presser foot during sewing. When the material is not stable enough, even a slight vibration from the sewing machine or the transmission process can cause the fabric to deviate from the straight axis, leading to horizontal seam fluctuations, which can easily cause seam variation and surface defects.

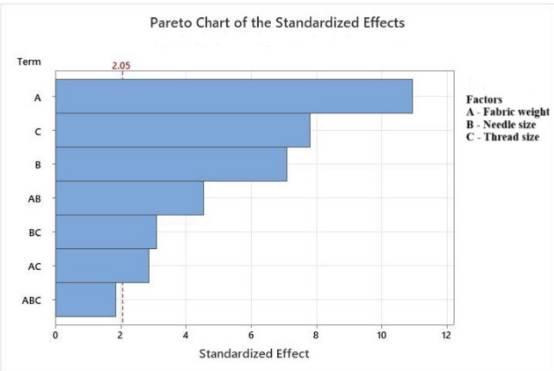

Figure 3. The Pareto chart of the standardized effects on seam length variation.

On the contrary, heavier fabrics have high stiffness; stiff fabrics can resist the fabric's guiding force, making the movement forced and jerky, especially at the beginning and end points or when accelerating the sewing machine. This resistance to uniform linear motion is also a cause of seam deviation. Thus, too light or heavy fabrics can reduce stability during sewing, leading to variation in seam length.

In addition, the thread size (C) also significantly impacts seam length variation. When using a large thread, the thread is stiffer and less flexible, so during the sewing process, the thread may not be evenly distributed on the fabric surface through the stitch structure, but is slightly pushed or compressed in some sections. These small changes are repeated many times, causing the actual seam to be shorter than the specified length and causing seam surface defects. On the contrary, if the thread is too small, it is easily overstretched, causing it to stretch longer than usual along the seam, leading to seam stretch and thread breakage.

Among the three factors, needle size (B) is determined to have the least influence on the variation of seam length. When the needle size is large, the force through the fabric surface increases and the contact area expands, changing how the fabric responds to the sewing movement. In some cases, especially when combined with high-stiffness fabrics or large threads, the strong piercing force of the needle can cause the fabric to be slightly bunched during the movement, causing the stitch not to be evenly spread along the straight axis. As a result, the actual stitch length may be shorter than the specified length, increasing the variation. Conversely, if the needle is too small compared to the weight of the fabric, the needle may vibrate slightly when piercing the fabric, or not create an accurate piercing point, causing the actual stitch to deviate from the standard axis.

The analysis of variance (ANOVA) in ***Table 2*** shows the level of influence of each factor and interaction combinations on the output variable in the model. The P-value is an important index used to determine whether or not a factor has a statistically significant influence. If the P-value is less than 0.05, the factor clearly impacts the output and is considered statistically significant. On the contrary, the influence is insignificant if the P-value is greater than 0.05. In addition, the Adj SS value (adjusted sum of squares) shows the variation that each factor contributes to the model. The larger this value, the greater the influence of that factor. The F-value is used to compare the level of variation between groups with the standard error; the larger the F-value, the more apparent the difference between the levels of the factor. Based on these three indices, assessing which factor is the most important and which factors need to be prioritized for control is possible.

Table 2. Analysis of Variance.

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	26	168.454	6.4790	155.50	0.000
Linear	6	165.833	27.6389	663.33	0.000
A	2	160.565	80.2824	1926.78	0.000
B	2	2.481	1.2407	29.78	0.000
C	2	2.787	1.3935	33.44	0.000
2-Way Interactions	12	2.111	0.1759	4.22	0.001
A*B	4	0.741	0.1852	4.44	0.007
A*C	4	0.602	0.1505	3.61	0.018
B*C	4	0.769	0.1921	4.61	0.006
3-Way Interactions	8	0.509	0.0637	1.53	0.194
A*B*C	8	0.509	0.0637	1.53	0.194
Error	27	1.125	0.0417		
Total	53	169.579			

Figure 4 shows the relationship between three inputs – fabric weight (A), needle size (B), and thread size (C) – with the dependent variable being seam variation (mm).

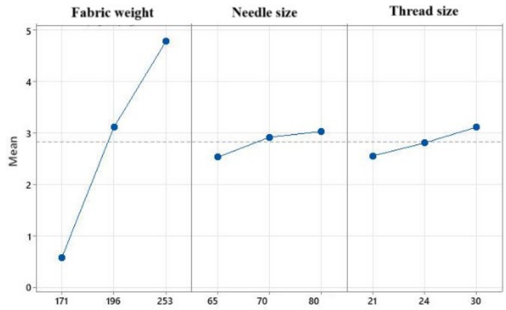

Figure 4. The main effects plot on seam length variation.

The fabric weight is the most influential factor among the three factors examined. When the fabric weight increases from 171 g/m^2 to 253 g/m^2, the value of the seam variation increases significantly. The explanation for this is that, theoretically, as the fabric weight increases, the fabric thickness and stiffness also increase, making it more difficult for the needle to pass through the fabric, thereby easily creating a high shrinkage force, causing a significant variation in the seam length. In addition, needle size also tends to increase seam length variation when changing from a small needle size (65) to a larger one (80). The larger the needle size, the larger the needle hole in the fabric. If not properly combined with the thread and fabric thickness, it will cause loose stitches, and the thread will not adhere firmly to the fabric. The incompatibility between needle size and fabric is a common cause of sewing performance errors, including uneven seam length. Like needle size, thread size also has a stable effect on seam length variation. The average value increases gradually from thread size 21 to 30, demonstrating that stitch variation tends to increase when using larger threads. This can be explained by the fact that when using larger thread sizes, the thread takes up more space in the seam, which can easily cause bumps or pinches on the fabric surface, especially when combined with small needles or thin fabrics. Larger threads also have higher stiffness, which can easily cause fabric deformation when sewing.

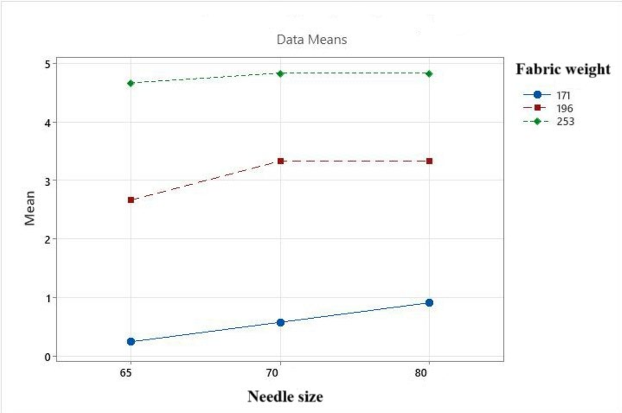

Figure 5. The interaction plot between Fabric weight and Needle size on seam length variation.

Based on the analysis above and the results shown in Figure 3, fabric weight and needle size are the two factors that significantly influence seam length variation. ***Figure 5*** illustrates the interaction between fabric weight and needle size on seam length variation. Increasing needle size significantly increased seam length variation at low fabric weight (171 g/m^2). However, as fabric weight increased (196 and 253 g/m^2), the effect of needle size on seam length variation became less pronounced. This effect was especially notable at 253 g/m^2, where changing the needle size had a minimal impact on stitch length variation. This suggests that the effect of needle size depends on fabric thickness, and only causes significant variation in seam length when the fabric is thin.

Figure 6 shows that thread size and needle size influence seam length variation. As the thread size increases from 21 to 30, the average seam length variation tends to increase at all three needle sizes, but the increase differs depending on the needle size used. Specifically, the variation increases significantly with the largest needle (80) when moving from small to large threads. In contrast, with the smaller needles (65 and 70), the trend line is relatively flat or increases slightly.

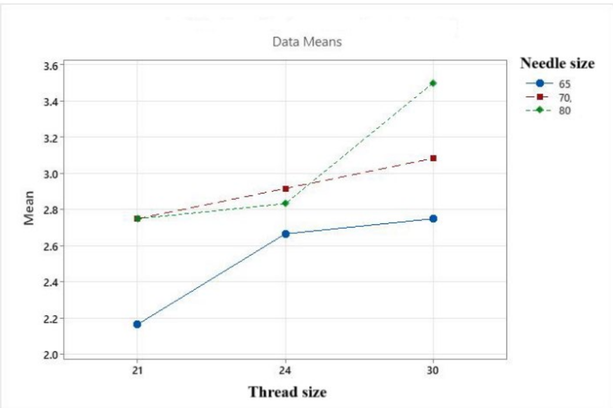

Figure 6. The interaction plot between Needle size and Thread size on seam length variation.

Based on the analysis results, in practical applications, production management could base the value of fabric weight on choosing the needle size and thread size for minimum seam length variation. In this experiment, the optimized results for the interaction between three factors, including fabric weight, needle size, and thread size for minimum seam length variation, are described with fabric weight = 171 g/m^2, needle size = 65 Nm, and thread size = 21 tex.

5. Conclusion

In measuring and evaluating seam quality, fabric weight, needle size, and thread size are important specification factors that significantly affect seam stability, especially in production stages that require high precision, such as assembly, decorative sewing, or heavy-duty seams. These factors have an individual effect and correlate with each other. Changes in each parameter can lead to significant seam length changes between needle passes, increasing seam deviation and affecting the appearance quality as well as the final durability of the product.

Through the design of the experiment according to the full factorial design, the research has determined the influence of each factor, in which the fabric weight is the factor with the most significant impact on the variation of the seam length, followed by the needle size and thread size. The results of ANOVA analysis and main effect plots show that when using light fabric, thin thread, and a small needle, the seam length has a significantly lower variation than the remaining combinations. In addition, the interaction diagrams clearly show that the influence of one factor will change significantly when the remaining factors change, demonstrating the complexity and necessity of determining a reasonable parameter combination instead of just adjusting each factor. Determining the relationship between material parameters (fabric, thread) and equipment parameters (needle) not only helps to minimize errors but also creates the premise for building standardization processes for technical parameters according to each specific product group. In the industrial production environment, where sample testing time and machine adjustment need to be optimized, analyzing the relationship between needle - thread - fabric to determine the optimal parameter set as in this study will support the operator to adjust the machine faster, more accurately and less dependent on manual experience, thereby improving productivity and efficiency of the whole system.

One limitation is that fabric weight, needle size, and thread size were the only three primary elements examined in this study; other specifications that can impact seam quality, including seam type, stitch density, and thread tension, were not taken into account. Future research should consider additional technical aspects, including seam type, stitch density, and thread tension, that are often important to consumers in technical requirements of orders, to develop a more thorough model of seam quality. Additionally, more studies on different environmental elements and materials would improve the outcomes.

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