Examining the Impact of Stitch Density, Thread Size, and Direction on the Seam Strength of Cow Upper Leather

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Abstract:
Leather is a flexible, long-lasting material composed of interwoven collagen fibers that are used to make footwear, apparel, and other leather goods. This study examines the impacts of the direction of leather, stitch density, and thread size on the seam strength of cow-upper leather. The Taguchi design of experiment and ANOVA methods have been employed to evaluate and examine the seam strength of cow upper leather. The study employed control variables ranging from 6 to 12 SPI for stitch density, 60/2, 40/2, and 40/3 thread sizes, and parallel, perpendicular, and diagonal leather direction. The strongest seams are produced with stitch densities of 12 SPI, thread sizes of 40/3, and parallel orientations. According to the results of the study, the seam strength of cow upper leather was significantly impacted by the stitch density or the number of stitches per inch. Based on the Taguchi design of the experiment and the ANOVA result of cow upper leather the stitch density increases and the seam strength also increases. From the graph of the S/N ratio, the slope is higher in higher significant stitch density. As the stitch density increases the seam performance also increases (when the stitch density is 6 SPI, S/N ratio 54.67 N, and when the stitch density is 12 SPI, S/N ratio 59.15 N). Based on these findings, several recommendations are presented. These include determining the optimal stitch density range, selecting appropriate thread sizes, considering stitching direction, implementing quality control measures, fostering collaboration, and encouraging further research

Keywords:
Leather; Seam Strength, Thread; Stitch

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1. Introduction:
Leather is composed of interwoven networks of collagen fibers[1] and it has long been regarded as a premium material, valued for its durability, aesthetic appeal, and versatility. In various industries, including fashion, automotive, and upholstery, the strength and quality of leather seams play a crucial role in determining the overall performance and longevity of the final product[2]. Among the factors influencing seam strength, stitch density, thread size, and stitching direction have emerged as key variables in recent research[3]. This study aims to investigate the impact of stitch density, thread size, and stitching direction on the seam strength of cow upper leather. By examining these specific factors, we can gain valuable insights into the optimal stitching parameters for enhancing the durability and reliability of leather seams.

Stitch density refers to the number of stitches per unit length along a seam[4]. It plays a significant role in determining the strength and durability of leather seams. Higher stitch densities distribute the load more evenly along the seam, potentially increasing the seam's resistance to failure. Conversely, lower stitch densities may lead to weaker seams and reduced seam strength[5]. The study can investigate various levels of stitch density to identify the optimal range for achieving maximum seam strength without compromising the leather's structural integrity. It has been suggested that varying stitch densities can influence the load-carrying capacity and resistance to seam failure. Thread size, on the other hand, relates to the thickness and strength of the thread used in stitching. The choice of thread size can significantly impact seam strength. Thicker threads generally possess higher tensile strength and can withstand greater stress. However, excessively thick threads may cause damage to the leather, while thinner threads may compromise seam strength[6]. The research can evaluate different thread sizes to determine the thread size that optimizes seam strength while maintaining the desired aesthetic and functional characteristics of the leather product. Different thread sizes may affect the tensile strength and overall integrity of the seam. Additionally, stitching direction, whether parallel or perpendicular to the leather grain, can influence the seam's resistance to stress and deformation[7]. The stitching direction, whether parallel or perpendicular to the grain of the leather, can influence seam strength. Stitching along the grain may provide enhanced strength and resistance to tearing, as the stitching follows the natural alignment of the leather fibers. Conversely, stitching across the grain may result in weaker seams due to potential fiber disruption[8]. Understanding the interplay between these factors and their impact on seam strength is crucial for leather manufacturers, designers, and product engineers. By optimizing stitch density, thread size, and stitching direction, manufacturers can enhance the performance and durability of leather products, leading to increased customer satisfaction and reduced product failures[9].

Through a comprehensive experimental approach, this study aims to provide empirical data and quantitative analysis to evaluate the relationship between stitch density, thread size, stitching direction, and seam strength in cow upper leather. The findings will contribute to the existing body of knowledge and serve as a practical guide for industry professionals seeking to improve the quality and longevity of leather-based products. Overall, this research endeavors to shed light on the intricate factors influencing seam strength in cow-upper leather and provide valuable insights for optimizing stitching techniques in leather manufacturing processes.

2. Materials and Methods :

2.1 Materials

Cow upper leather of thickness 1.6mm and Polyester thread (40/2, 40/3, and 60/2) were purchased from Bahir Dar tannery and the local market respectively in Amhara region, Bahir Dar, Ethiopia.

2.2 Methods:

Specimens for seam strength tests were cut manually (using a cutter) based on the standard seam strength testing machine of ISO 13935/1. The dimensional details of each type of specimen for both parallel and perpendicular samples are presented in Figure 1.

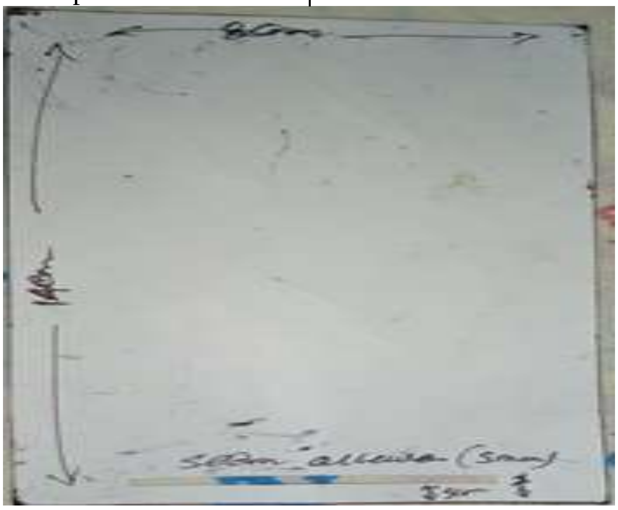

Figure 1 Cutting Pattern of Test Specimen

Thirty-six test specimens were cut (140x80 mm); six pairs were cut from perpendicular to the backbone, six pairs were cut from parallel to the backbone and six were cut from diagonal to the backbone of the same thickness cow upper leather. The superimposed seam was selected for this study because of the machine availability and a single-needle flatbed sewing machine (Juki) was used. To investigate the effect of different sewing threads on seam strength, two different polyester threads were used for the seam constructions. These polyester threads are commonly used in the footwear industry. These threads have the same fiber compositions and different thread twists. These threads are 40/2, 40/3, and 60/2.

The stitch density was determined by counting the stitches per inch[10]. The two or one pair of perpendicular samples was stitched with a seam allowance of 5 mm by a single needle flatbed sewing machine. The test specimens were stitched to the two perpendicular, diagonal, and parallel samples at a stitch density of six, eight, and twelve SPI and different thread size levels of size 40/2, 40/3, and 60/2. About 18 samples were obtained six perpendiculars to the backbone, six diagonal to the backbone, and six parallel to the backbone cutting for cow upper leather and take the average. Cow upper leathers were cut to dimensions of 120 mm by 80 mm. The stitched samples were tested for seam strength for parallel, diagonal, and perpendicular samples.

Figure 2 Stitched Samples and Seam Strength Test of Cow Upper Leather

3. Designing the experiment:

Taguchi design was used to design the experiment and analyze the results of the experiments. Taguchi's design can increase estimates of effectiveness, minimize the number of experiments needed, and be used for both quantitative and qualitative variables[11]. After identifying the factors that affect the seam strength, the upper and lower levels of each factor were determined. The individual and interactive effects of stitch density, thread size, and direction of leather on seam strength are studied at three levels using (3^3) L9 orthogonal design.

Table 1. Specification code of the factors

Factor	Code	Level		
		-1(1)	**0(2)**	**1 (3)**
Stitch density	A	6 SPI(stitch per inch)	8 SPI(stitch per inch)	12 SPI (stitch per inch)
Thread size	B	60/2 (polyester thread)	40/2 (polyester thread)	40/3 (polyester thread)
Direction	C	Perpendicular	Parallel	Diagonal

Table 2 Experimental design layout

Trails No	Stitch density	Thread size	direction	Seam strength (N)
1	6	20	-1	
2	6	40	0	
3	6	60	1	
4	8	20	0	
5	8	40	1	
6	8	60	-1	
7	12	20	1	
8	12	40	-1	
9	12	60	0	

3.1 Analysis of Variance for SN Ratios:

A statistical analysis of variance (ANOVA) [12]is conducted along with the Taguchi technique to find the contribution of each of the process parameters for the wear loss. The percentage contribution of various process parameters to the selected performance characteristic can be estimated by ANOVA. Depending on the target of the experiments, different S/N ratios can be selected. Under these different selections, S/N ratios quantify how the variation in the response happened relative to the target value [7].

Three different S/N characteristic formulations (conditions) are present in the following equations[13].

$$\text{Smaller is the best: } S/N = -10\text{Log}\left[\frac{1}{n}\sum_{i=1}^{n}\left(y_i^2\right)\right]$$

$$\text{Larger is the best : } S/N = -10\text{Log}\left[\frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{y_i^2}\right)\right]$$

Nominal is the best: $S/N = -10Log\left[\frac{y_o}{s^2 y}\right]$

Where: - yi is the observed data, yo is its average, s2y is its variance, and n is the number of observations. Smaller is the best which requires the smallest possible performance value.

For this study, larger is the best were selected for the seam strength of cow upper leather.

3.2 Regression Analysis:

According to [14], Regression is a statistical modeling process that establishes relations among dependent (response) and independent variables (input parameters or predictor). Regression can be modeled as linear and in polynomial relationships. The most common regression is linear regression, for which an investigator finds the linear function that is most closely close to the data.

$$y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \ldots \beta_{xn}$$

βo is the constant value of the response (y) for the predictor (x) value 0. Additionally, it determines where the regression line intercepts the y-axis with the predictor variable(s) is zero. Depending on the relationship x can be a polynomial term. βo, β1, · · · βxn are the coefficients that determine the change in response to the one-unit change in the input parameter value.

4. Result and Discussion

4.1 Analysis of the Means and S/N Ratios of the Results

The seam strength of cow upper leathers was conducted by Taguchi design of experiments for the different factors of stitch density, thread size, and direction of leather. To minimize the error, each experiment is repeated four times[15]. Optimization of the control factors is performed by the calculated S/N ratios for the seam strength of cow upper leather and the highest seam strength values are desirable for better system performance[16].

Table 3 Orthogonal array with the seam strength of cow upper leather

Exp't No	Stitch density	Thread size	Direction	Seam strength (N)
1	6	20	-1	516
2	6	40	0	557
3	6	60	1	553
4	8	20	0	673
5	8	40	1	774
6	8	60	-1	677
7	12	20	1	847
8	12	40	-1	920
9	12	60	0	958

Where -1 indicates perpendicular direction, 0 indicates parallel direction and 1 is diagonal direction.

Table 4 shows the average response of the S/N ratios, which analyze the effect of the control factors (stitch density, thread size, and direction) on the seam strength. It reveals all the levels based on the S/N ratios for the control factors that provide the highest seam strength; stitch density at level 3 (S/N = 59.15), thread size at level 2 (S/N = 57.32), and direction at level 3 (S/N = 57.06). As reported by[17], Delta and the rank determine which of these three factors has the greatest impact on the response. Delta measures the magnitude of the impact by subtracting the lowest average response value of a factor from its highest value[18]. Rank assigns the order number to the factors with the highest to lowest impact depending on the delta values[19]. Stitch density has the highest impact (delta: S/N = 4.48, and rank = 1) and direction has the lowest impact (delta: S/N = 0.35, and rank = 3).

Table 4 Response for Signal to Noise Ratios of Larger is better

Level	Stitch density(SPI)	Thread size	Direction
1	54.67	56.46	56.71
2	56.98	57.32	57.03
3	59.15	57.03	57.06
Delta	4.48	0.87	0.35
Rank	1	2	3

Table 5 Response for Means

Level	Stitch density	Thread size	Direction
1	542.0	678.7	704.3
2	708.0	750.3	729.3
3	908.3	729.3	724.7
Delta	366.3	71.7	25.0
Rank	1	2	3

The graphical representation (main effects plot) of the levels of the factors in Table 4 is shown in Figure 3. These main effect plots show the optimum values of the control factors to achieve the highest seam strength. The main effect is called the difference in the means due to various levels within a factor. If the graph line is horizontal then there is no main effect present for the levels of a factor but the line with a higher slope or difference between vertical points will have a higher main effect. Thread size shows the graphical lines with higher slopes, and therefore it has the highest main effect. The main goal of the experimentation is to find the control factor levels that minimize the noise factors in the responses. The best level for each control factor was found according to the highest S/N ratio in the levels of those input parameters (control factors). The control factors range in the experiments is 6, 8, and 12 SPI for stitch density, for thread size 60/2, 40/2, and 40/3, and direction of leather parallel, perpendicular, and diagonal. Seam strength is highest at Stitch density 12 SPI, thread size at 40/3, and direction in parallel direction. From the graph of the S/N ratio, the slope is higher in higher significant stitch density.

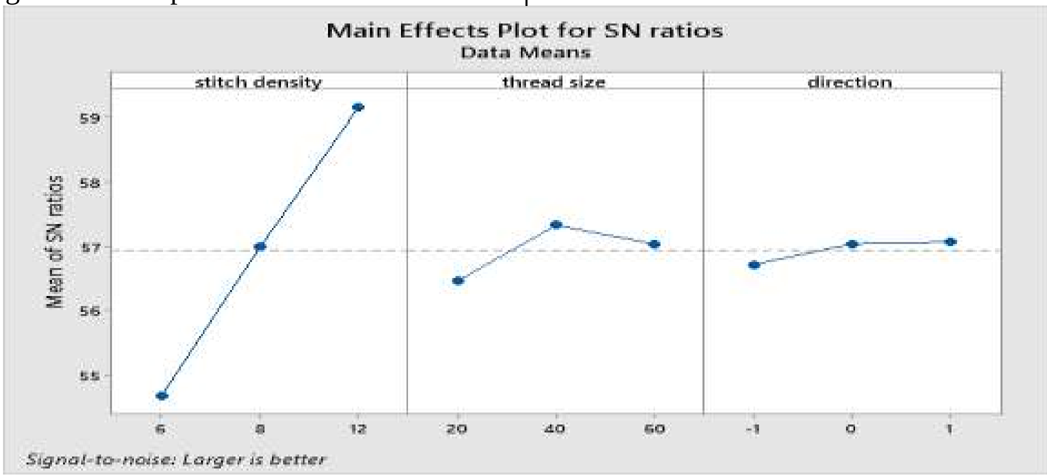

Figure 3. Main Effect Plot for S/N Ratio Data Mean

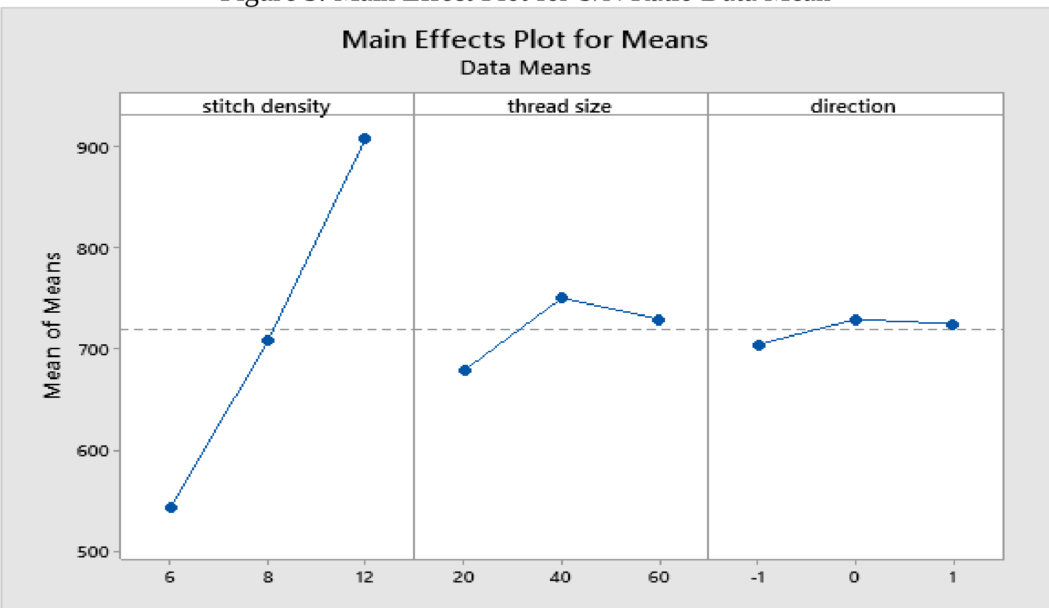

Figure 4 Main Effects Plot for Mean

4.2 ANOVA:

The Taguchi method helped to find out the optimal number of experiments and provided a way to optimize the system through the S/N ratio. According to [20], The significance of control factors in ANOVA is determined by comparing the F values of each control factor. These tables were calculated with a 5% significance level and a 95% confidence level. If the p-value for the factor is greater than 0.05 then it will be considered as a non-significant factor. Therefore, based on the p-values of thread size and direction of leather, the p-value is not a significant parameter for the seam strength of cow upper leather. Similarly, stitch density (p-value = 0.000) is the significant factor for the seam strength of cow upper leather.

Table 6 ANOVA table for seam strength of cow upper leather
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	202646	67549	25.64	0.002
Stitch Density	1	198175	198175	75.22	0.000
Thread Size	1	3851	3851	1.46	0.281
Direction	1	620	620	0.24	0.648
Error	5	13173	2635		
Total	8	215818			

4.3 Regression Analysis of Seam Strength

In this study, a relationship between response variables and the three input variables is modeled and analyzed by using regression analysis. Some important parameters to judge the regression models are R2 (it describes, how much variation is present in the response), R2 (adj) (it is a modified R2 that has been adjusted for the number of expressions), and R2 (pred) (how good the model predicts the response for new observations). For a good regression model, these values must be high in this study the predicted R2 value is 75.96 %. The difference between the adjusted R2 and predicted R2 less than 20% is adequate research, in this study, the difference is 14.27% so the research study was adequate.

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
51.3278	93.90%	90.23%	75.96%

Regression Equation

The linear regression for seam strength is as follows:

Seam Strength=153.2 + 59.49 Stitch Density + 1.27 Thread Size + 10.2 Direction

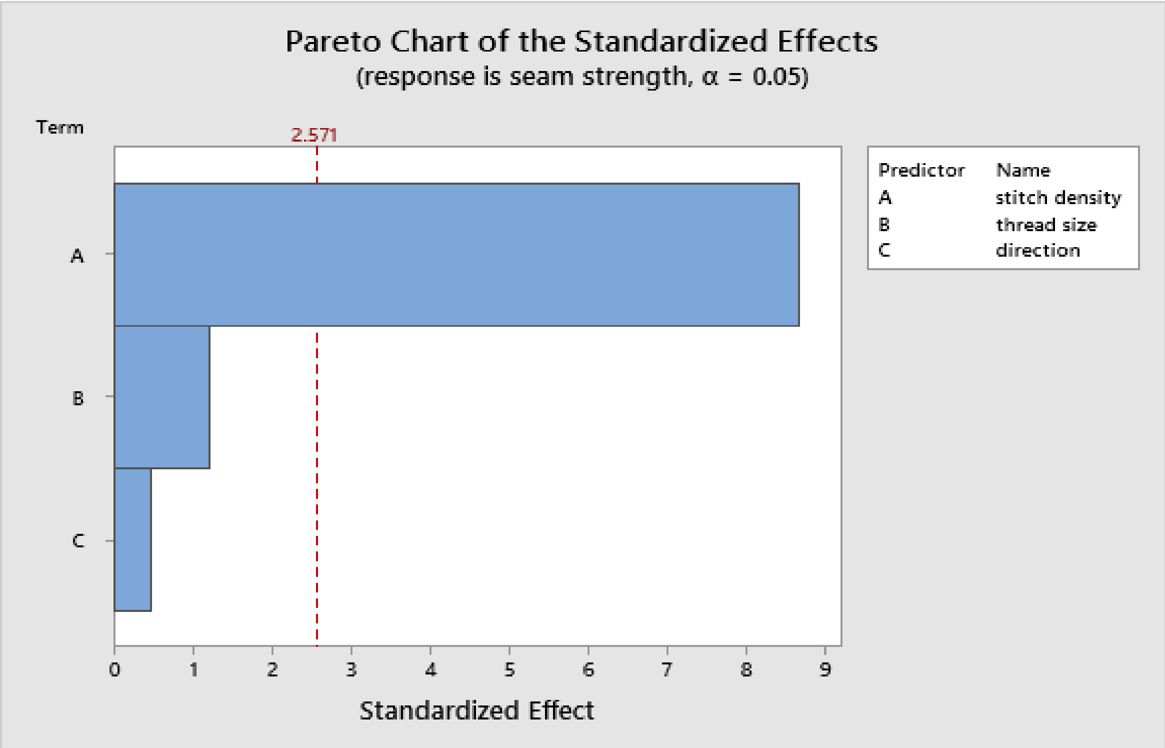

Figure 5 Petro Chart of the Standard Effect at 95% CI

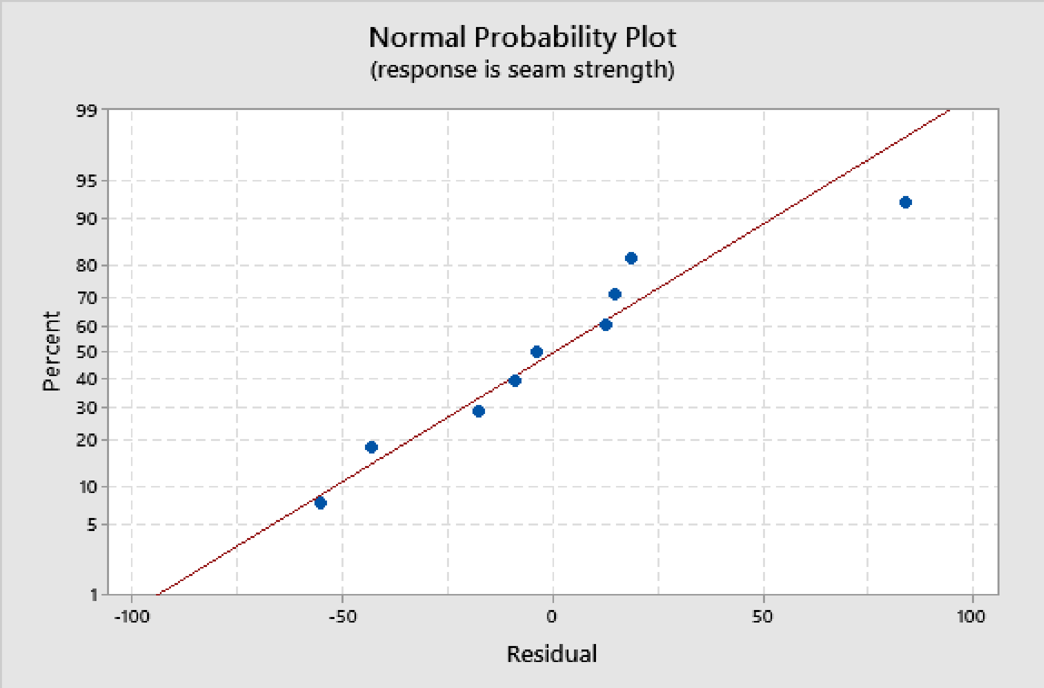

Figure 6. Normal Probability of the Factors and Response

The graph shows the difference between the adjusted and predicted value R2 which means the scatter points are far apart from the straight line the model shows some variations but, in this study, the residual value shows slight variation the predicted and adjusted values are model adequate.

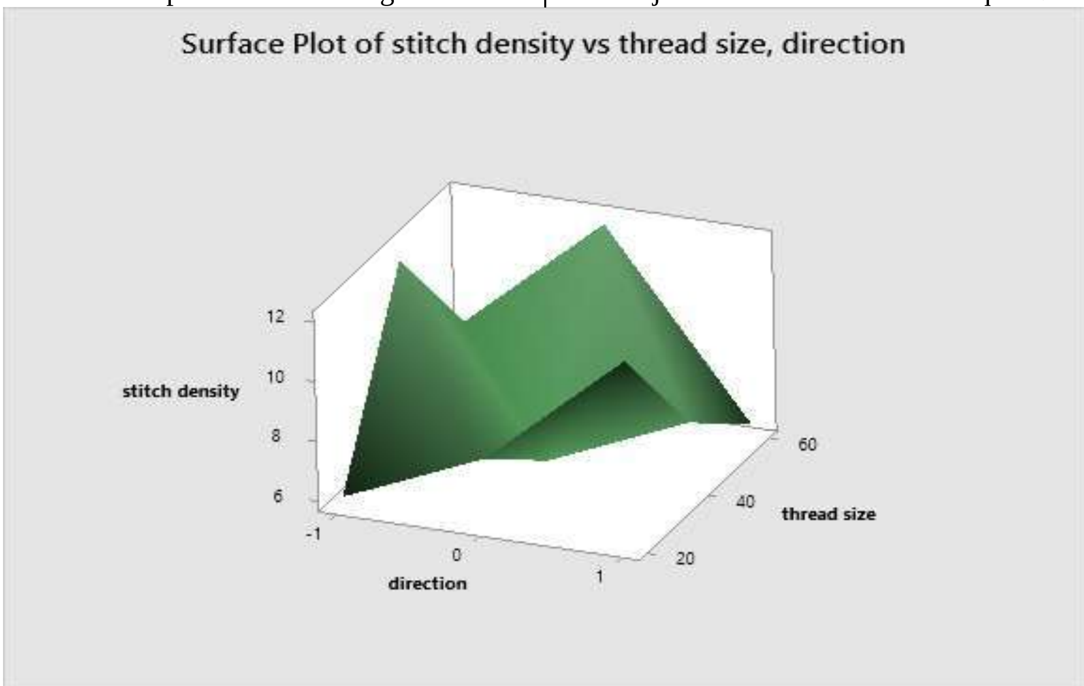

Figure 7 Surface Plot of Stitch Density Vs Thread Size Vs Direction

Conclusion:

In conclusion, the study examining the impact of stitch density, thread size, and direction on the seam strength of cow-upper leather has shed light on the intricate relationship between these variables and the overall durability of leather seams. The findings have significant implications for leather manufacturers, designers, and product engineers seeking to enhance the quality and longevity of leather-based products. Through systematic experimentation and analysis, it was determined that stitch density, thread size, and stitching direction are critical factors influencing seam strength in cow upper leather. Higher stitch densities generally contribute to increased seam strength, distributing the load more evenly along the seam. However, excessively high stitch densities may lead to potential damage to the leather. Thread size was found to be crucial, with thicker threads generally exhibiting higher tensile strength and improved seam strength. Careful consideration should be given to selecting an appropriate thread size that balances strength and compatibility with the leather material. Stitching along the grain of the leather was found to offer greater seam strength due to the alignment of the leather fibers, while stitching across the grain may result in weaker seams. This study shows the effect of stitch density, direction of leather, and thread size on the seam strength of cow upper leather by using the Taguchi design of experiments. The S/N ratios analysis from the Taguchi method shows the best levels of the control factors for the highest seam strength. Based on the result stitch density has the highest effect on the seam strength of cow upper leather. As the stitch density increases the seam performance also increases based on the S/N ratio (when the stitch density is 6 SPI, S/N ratio 54.67 N, and when the stitch density is 12 SPI, S/N ratio 59.15 N).

Recommendation:

Based on the findings of the study examining the impact of stitch density, thread size, and direction on the seam strength of cow upper leather, the following recommendations are suggested: Determine the optimal stitch density range that enhances seam strength without compromising the integrity of cow upper leather. Conduct further research and experimentation to identify the specific stitch density values that result in the highest seam strength for different types and thicknesses of cow upper leather. Consider the appropriate thread size that maximizes seam strength while maintaining the desired aesthetic and functional characteristics of the leather product. Manufacturers should carefully evaluate the thread options available in the market and select threads with sufficient tensile strength to withstand anticipated stress levels during product usage. Whenever possible, stitch along the grain of the cow upper leather to capitalize on the inherent strength provided by the alignment of the leather fibers. This stitching direction is likely to enhance seam strength and resistance to tearing. However, in cases where stitching across the grain is necessary for design or construction reasons, additional reinforcement techniques such as backstitching or using reinforcing tapes should be considered to compensate for potential weaknesses. Finally, implement stringent quality control measures during the manufacturing process to ensure consistent stitch density, thread size, and stitching direction. Regularly monitor and assess the seam strength of cow upper leather products using standardized testing methods to identify any deviations or potential issues. This will help maintain a high level of quality and durability in the finished leather goods.

Data Availability

All the data used to support the findings of this study are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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