Investigation of the deformation and strength characteristics of the thread connection in the manufacture of products from fur waste

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Abstract. By the method of mathematical planning of the experiment, regression equations were obtained for the breaking load and the breaking relative elongation of the thread connection of a special furrier's seam in the manufacture of products from fur waste. As input factors were taken: the number of stitches in 1 cm., Thread thickness, needle diameter. The features of the behavior of the strength model of this thread connection are revealed.

1. Introduction
At present, thread connections continue to be one of the main methods used in the manufacture of clothing from natural fur. In the threading method, the flap and waste are sewn together on a furrier machine. Therefore, the quality of these compounds is given increased attention, especially in the manufacture of products that are exposed during operation to force and the action of the environment (high humidity, low or high temperature) [1, 2].
The resistance of thread compounds to various influences is the most important quality indicator that determines the functional reliability and durability of garments made from fur waste. The strength of the thread connections is estimated by the breaking load of the line, i.e. thread connection, and the breaking load of a section of leather tissue on the line of punctures with a needle. It must be borne in mind that thread connections are considered broken even if several stitches are broken [3]. The factors that affect the value of breaking loads in the first and second cases differ significantly. So, for example,
the breaking load of a line depends on the structure of the stitches, the length of the stitches, the type of thread, and the breaking load of the leather fabric near the line depends on the degree of damage (cut through) of the skin by the needle of the sewing machine [4].

In most cases, data on the strength of thread connections are obtained experimentally, since theoretical methods for determining the breaking load of lines have not yet found practical application due to significant discrepancies between the calculated and actual values of breaking load. A large number of works have been devoted to the experimental determination of the breaking loads of thread joints of fur skins [5, 6]. The existing standards [7-9] for assessing the deformation and strength properties of seams are developed for knitted fabrics and products, fabrics, artificial knitted fur and nonwoven fabrics [10]. The study of the theoretical provisions and the results of experimental studies presented in the publications showed the insufficiency and unreasonableness of the modes of performing thread connections when using them on fur plates from waste. There are practically no data on the breaking load of thread connections of various types for clothing, which is known to be distinguished by a large variety of seams in the manufacture of clothing of various assortments and purposes [11]. This is an incentive for experimental research, the results of which, despite some limited distribution, provide valuable information about the strength of materials in substantiating theoretical solutions [12].

To establish the complex influence of various factors on the breaking load of the shuttle linear stitch for the thread connection of fur waste, their analysis was carried out using mathematical methods of experiment planning [13].

2. Materials and Methods
In the experimental study, a full factorial experiment was used with the implementation of all possible combinations of N levels of factors:

\[ N = m^k \]  \hspace{1cm} (1)

where, \( m \) - is the number of levels of each factor and \( k \) - is the number of factors.

Obtaining a linear model at the first stage of planning an extreme experiment involves varying factors at two levels, and then the possible number of combinations of factor levels is \( 2^k \).

As input parameters were taken: \( x_1 \) - number of stitches in 1cm; \( x_2 \) - thread thickness or trade number of threads; \( x_3 \) - diameter (number) of the needle. It is known from a priori data that these factors most strongly affect the deformation and strength properties of the materials to be ground.
The levels and intervals of variation of the factors are presented in Table 1. Prepared specimens of broadtail fur with a size of 180 × 25 mm (working area 50 × 10 mm) were sewn with a special furrier seam and tested on an AUTOGRAPH tensile testing machine, which allows registering the breaking load $F_p$ and the corresponding relative deformation $\varepsilon_p$. These discontinuous characteristics were taken as output parameters.

| Factors                                      | Code | Designation Variation intervals | Factor levels |
|----------------------------------------------|------|---------------------------------|---------------|
| Number of stitches in 1 cm                  | $x_1$| 1-2                             | Upper +1 7-8 5-6 3-4 | Lower -1 |
| Thread trade number (thread thickness, mm)  | $x_2$| 10                              | Main 40 50 60 |
| Needle diameter, mm (needle number)         | $x_3$| 10                              | Lower 75 65 55 |

For three factors $(x_1, x_2, x_3)$ polynomial of the first degree (regression equation) has the form $[11]$:

$$
Y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 + b_{123} x_1 x_2 x_3,
$$

(2)

where the coefficients of the equation are found from the following dependencies:

1) free member $b_0$

$$
b_0 = \frac{1}{N} \sum_{j=1}^{N} y_j;
$$

(3)

2) regression coefficients characterizing linear effects $b_i$:

$$
b_i = \frac{1}{N} \sum_{j=1}^{N} x_{ij} y_j
$$

(4)

3) regression coefficients characterizing the effects of paired interactions:

$$
b_{il} = \frac{1}{N} \sum_{j=1}^{N} x_{ij} x_{lj} y_j
$$

(5)

where $i, l$ - factor numbers; $j$ - line or experience number in the planning matrix; $y_j$ - the value of the optimization parameter in the $j$-th experiment; and $x_{ij}, x_{lj}$ - encoded values ($\pm 1$) factors $i$ and $l$ in $j$-th experience.

The planning matrix and the results of the experiments are shown in Table 2.
Table 2. Full factorial experiment matrix of type $2^3$ and experimental results

| Exp. number | $x_0$ | $x_1$ | $x_2$ | $x_1x_2$ | $x_1x_3$ | $x_2x_3$ | $x_1x_2x_3$ | $F_p$ | $H$ | $\varepsilon_p$, % |
|-------------|-------|-------|-------|----------|----------|----------|-------------|-------|----|------------------|
| 1           | +     | -     | +     | +        | -        | +        |             | 6.8   | 15.8 |
| 2           | +     | +     | -     | +        | -        | +        |             | 3.8   | 18.9 |
| 3           | +     | -     | +     | +        | -        | +        |             | 4.4   | 21.2 |
| 4           | +     | +     | +     | +        | +        | +        |             | 5.2   | 17.9 |
| 5           | +     | -     | -     | +        | +        | +        |             | 5.4   | 17.0 |
| 6           | +     | +     | -     | +        | -        | +        |             | 12.4  | 30.6 |
| 7           | +     | -     | +     | +        | -        | +        |             | 16.2  | 38.7 |
| 8           | +     | +     | +     | -        | -        | -        |             | 15.2  | 41.3 |

3. Results and Discussion

The experimental results were processed for the variant in the absence of duplication. In this case, to calculate the variance $s_y^2$ of the reproducibility of the experiment, three parallel experiments were performed at the zero point (in the center of the plan) (Table 3). When setting up experiments at the zero point, all factors are at zero levels. Based on the results of the experiments in the center of the plan, the variance $s_y^2$ of the reproducibility of the experiment is calculated:

$$s_y^2 = \frac{1}{n_0-1} \left[ \sum_{u=1}^{n_0} (y_u - \bar{y})^2 \right]$$  \hspace{1cm} (6)

where, $n_0$ - number of parallel experiments at zero point; $y_u$- optimization parameter value; and, $\bar{y}$- the arithmetic mean of the optimization parameter in $n_0$ parallel experiments.

The coefficients of the model, calculated by formulas (3), (4) and (5) for the optimization parameter $y_1$- breaking load ($H$), were the values:

$$a_0 = 8.675; \ a_1 = -0.375; \ a_2 = 1.575;$$
$$a_3 = -3.625; \ a_{12} = -0.525; \ a_{13} = -1.025;$$
$$a_{23} = -1.825; \ a_{123} = 1.475.$$  

Taking these values of the coefficients into account, the regression equation with coded variables for the breaking load $F_p$ takes the form:

$$y_1 = 8.675 - 0.375x_1 + 1.575x_2 - 3.625x_3 - 0.525x_1x_2 - 1.025x_1x_3 + 1.475x_2x_3$$ \hspace{1cm} (7)

We will check the statistical significance of the coefficients of the regression equation (7) by comparing the absolute value of the coefficient with the confidence interval $\Delta b_1$, determined by the equation:
\[ \triangle b_i = \pm t_{\tau} s\{b_i\} \]  

(8)

Table 3. Auxiliary table for calculation \( s^2_y \)

| Experience number in the center of the plan | \( y_u \) | \( \bar{y} \) | \( y_u - \bar{y} \) | \( (y_u - \bar{y})^2 \) | \( s^2_y \) |
|------------------------------------------|---------|---------|----------------|----------------|---------|
| 1                                        | 14.5    | -0.53   | 0.2809         | \( \sum\frac{(y_u - \bar{y})^2}{n_0 - 1} \) = 0.9671 |
| 2                                        | 15.8    | 0.77    | 0.5929         | \( \sum\frac{(y_u - \bar{y})^2}{n_0 - 1} \) = 0.4634 |
| 3                                        | 14.8    | -0.23   | 0.0529         | \( \sum\frac{(y_u - \bar{y})^2}{n_0 - 1} \) = 0.9671 |

Note: \( n_0 \) is the number of experiments in the center of the plan; \( y_u \) - value of the optimization parameter in and \( u \)-th experiment in the center of the plan.

The table value of the criterion at the accepted level of significance (at 5%) and the number of degrees of freedom \( f \), which is determined by the expression:

\[ f = n_0 - 1 = 3 - 1 = 2; \]

\( s\{b_i\} \)- error in determining the \( i \)-th regression coefficient, calculated by the equation:

\[ s\{b_i\} = \sqrt{\frac{s^2_y}{f}} \]  

(9)

\( t_{\tau} \) value at the number of degrees of freedom \( f = 2 \) equally [11]: \( t_{\tau} = 4.3 \). Thus, taking into account the data in Table 3 and the calculation equations (8) and (9), we have:

\[ \triangle b_i = \pm 4.3 \cdot 0.2407 = \pm 1.035 \]

The regression coefficient is significant if its absolute value is greater than the confidence interval. Therefore, equation (7) is transformed and has the final form:

\[ y_1 = 8.675 + 1.575x_2 - 3.625x_3 - 1.825x_1x_2 + 1.475x_1x_2x_3. \]  

(10)

Variance \( s^2_{\Delta a} \) the adequacy is determined by the equation:

\[ s^2_{\Delta a} = \frac{\sum_{j=1}^{N}(y_j - \bar{y})^2}{f} = \frac{\sum_{j=1}^{N}(y_j - \bar{y})^2}{N - (k + 1)} \]  

(11)

where, \( y_j \) - observed value of the optimization parameter in \( j \)-th experience; \( \bar{y}_j \) - the value of the optimization parameter calculated by the model for the conditions of the \( j \)-th experiment; and, \( f \) - the number of degrees of freedom determined by the expression \( f = N - (k + 1) \), where \( k \) - number of factors.
Taking into account the data in Table 4, the variance $s^2_{	ext{ adeq}}$ adequacy equals:

$$s^2_{	ext{ adeq}} = \frac{12.54}{8 - (3 + 1)} = 3.135$$

The final stage of processing the results of the experiment is to test the hypothesis of the adequacy of the found model according to $F$-Fisher's criterion:

$$F_p = \frac{s^2_{	ext{ adeq}}}{S^2_Y}$$

(12)

If the calculated value $F_p < F_t$ (tabular) for the accepted level of significance and the corresponding numbers of degrees of freedom, then the model is considered adequate. When $F_p > F_t$, adequacy hypothesis rejected.

$$F_p = \frac{s^2_{	ext{ adeq}}}{\frac{S^2_Y}{0.4634}} = \frac{3.135}{6.765}$$

When the 5% significance level and the number of degrees of freedom for the numerator $f_1 = 4$ and for the denominator $f_2 = 2$, the table value of the criterion $F_t = 19.3$. Since $F_p < F_t$, the model represented by equation (10) is adequate.

**Table 4. Auxiliary table for calculation $s^2_{	ext{ adeq}}$**

| Experience number | $y_j$ | $\bar{y}_j$ | $y_j - \bar{y}_j$ | $(y_j - \bar{y}_j)^2$ |
|-------------------|-------|--------------|--------------------|----------------------|
| 1                 | 6.8   | 6.8          | 0                  | 0                    |
| 2                 | 3.8   | 3.83         | -0.03              | 0.0009               |
| 3                 | 4.4   | 3.3          | 1.1                | 1.21                 |
| 4                 | 5.2   | 5.4          | -0.2               | 0.04                 |
| 5                 | 5.4   | 7.4          | -2                 | 4                    |
| 6                 | 12.4  | 10.1         | 2.3                | 5.29                 |
| 7                 | 16.2  | 17.2         | -1                 | 1                    |
| 8                 | 15.2  | 14.2         | 1                  | 1                    |

Let's make the appropriate calculation for the optimization parameter $y_2$ - elongation at break %.

1. Variance of reproducibility $s^2_Y$ optimization parameters:

$$s^2_Y = \frac{1}{n_0 - 1} \left\{ \sum_{i=1}^{n_0} (y_{i\text{tr}} - \bar{y})^2 \right\}$$
\[ S^2_y = \frac{1}{3-1} \left[ (46.2 - 46.1)^2 + (43.6 - 46.1)^2 + (48.4 - 46.1)^2 \right] = 5.775 \]

2. Model coefficients:

\[ b_0 = 22.94; \quad b_1 = 2.038; \quad b_2 = 4.6; \quad b_3 = -6.725; \]
\[ b_{12} = -2.175; \quad b_{13} = -2.05; \quad b_{23} = -3.6; \quad b_{123} = 0.575 \]

3. Checking the statistical significance of the coefficients of the regression equation:

\[ s^2 \{ b_i \} = \frac{1}{N} \frac{S^2_y}{n} = \frac{1}{8} \cdot 5.775 = 0.722 \]
\[ s(\{ b_i \}) = \sqrt{s^2 \{ b_i \}} = +\sqrt{0.722} = 0.85 \]
\[ \Delta b_i = \pm t_{\eta S_0 \{ b_i \}} = \pm 4.3 \cdot 0.85 = \pm 3.655 \]

Taking into account the obtained value of the confidence interval \( \Delta b_i \) and comparison with the coefficients of the model (regression equations), the dependence for elongation at break was obtained in the following form:

\[ y = 22.94 + 4.6x_2 - 6.725x_3 - 3.6x_2x_3 \]  

(13)

Testing the hypothesis of the adequacy of the model

The variance of the adequacy of the model, calculated from the data in Table 5, was:

\[ S^2_{ad} = \frac{\sum_{j=1}^{N} (y_j - \bar{y})^2}{f} = \frac{\sum_{j=1}^{N} (y_j - \bar{y})^2}{N-(k+1)} = \frac{146.055}{4} = 36.5 \]

| Experience number | \( y_j \) | \( \bar{y} \) | \( y_j - \bar{y} \) | \( (y_j - \bar{y})^2 \) |
|-------------------|---------|-----------|----------------|------------------|
| 1                 | 15.8    | 15.115    | 0.685          | 0.469            |
| 2                 | 18.9    | 15.115    | 3.785          | 14.33            |
| 3                 | 21.2    | 17.315    | 3.885          | 15.09            |
| 4                 | 17.9    | 17.315    | 0.585          | 0.342            |
| 5                 | 17.0    | 21.565    | -4.565         | 20.84            |
| 6                 | 30.6    | 21.565    | 9.034          | 81.61            |
| 7                 | 38.7    | 37.765    | 9.035          | 8.74             |
| 8                 | 41.3    | 37.765    | 3.535          | 12.50            |

Calculated value of \( F_p \)-Fisher test:
The tabular value of $F_p$-Fisher's test at a 5% significance level and the number of degrees of freedom for the numerator $f_1 = 4$ and for the celebrity $f_2 = 2$ is equal to 19.3.

The model presented by equation (13) is adequate since $F_p < F_c$.

Confirmation of the adequacy of the models described by Eqs. (10) and (13) allows one to proceed to their analysis in order to determine the degree and nature of the influence of factors both separately and in pair interaction.

As follows from equations (10) and (13), the number of stitches 1 cm ($x_1$) turned out to be an insignificant factor for breaking force $F_p$ and elongation at break $\varepsilon_P$, which confirms the data of experimental studies of the strength of thread joints of garments made of natural fur [14, 15].

The diameter (number) of the needle has the greatest effect on the strength of the thread connection in the furrier's seam. Moreover, an increase in the diameter of the needle naturally reduces the strength of the connection, which is especially typical for leather fabric of small thickness (for example, the thickness of broadtail fur averages 0.8-0.9 mm).

4. Conclusions

For the fabric, this factor is of little importance, since the fabrics have the expandability of the threads upon contact with the needle and its structure is almost completely restored due to the elastic consequence. In contrast to the fabric, the leather tissue of a fur skin exhibits a more pronounced property of cut-through and therefore the larger the diameter of the needle, there is a larger residual hole, which leads to a decrease in the strength of the thread connection. With an increase in the thickness of the thread, both the breaking load and the breaking elongation increase, i.e., it manifests itself as a positive factor. The factors $x_2$ (thread thickness) and $x_3$ (needle diameter), while remaining significant separately, in pair interaction also affect the optimization parameters.

By the method of mathematical planning of the experiment, adequate models and regression equations were obtained for important indicators of mechanical properties when threading parts of clothing made of thin natural leather (broadtail) - breaking load and relative deformation at break. Some features of the behavior of the strength model of the thread connection of genuine leather elements are revealed. The data obtained create the basis for predictive assessment of the strength and deformation properties of the thread connections of the furrier seam in the manufacture of products from fur waste, and also contribute to the reasonable choice of rational grinding modes.
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