



ISSN: 3060-4966



JIZPI XABARNOMASI

ILMIY-TEXNIK JURNAL

- 05.00.00 - Texnika fanlari
- 05.02.00 - Mashinasozlik va mashinashunoslik.
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Metallurgiya. Aviasiya texnikasi
- 05.03.00 - Asbobsozlik, metrologiya va axborot-o'lchov
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- 05.04.00 - Radiotexnika va aloqa
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- 05.06.00 - To'qimachilik va yengil sanoat materiallari
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- 05.07.00 - Qishloq xo'jaligi ishlab chiqarishini
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O‘zR Oliy attestatsiya komissiyasi Rayosatining 2024-yil 25- dekabrda 365/4-son qarori bilan jurnal 05.00.00 – Texnika fanlari bo‘yicha OAK milliy nashrlari ro‘yxatiga kiritilgan

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Vestnik DjizPI

НАУЧНО-ТЕХНИЧЕСКИЙ ЖУРНАЛ

Bulletin of JizPi

SCIENTIFIC AND TECHNICAL JOURNAL

Bir yilda to‘rt marta chop etiladi.

Jizzax viloyati Matbuot va axborot boshqarmasi tomonidan 2019 yil 14 martda 06-042 raqam bilan ro‘yxatga olingan.

Nashr uchun mas‘ul:

K.Karimova

Bosishga ruxsat etildi: 04.10.2026.

Qog‘oz bichimi: 60x84 1/8.

Bosma tabog‘i: 13,5.

Ofset bosma. Ofset qog‘ozi.

Adadi: 100 dona.

Bahosi kelishilgan narxda.

Buyurtma №14

“JIZPI TIPOGRAFIYASI” MChJ tomonidan tayyorlangan.

“JIZPI TIPOGRAFIYASI” MChJ bosmaxonasida chop etildi.

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Faks: (0372) 226-45-47. Rasmiy sayt jurnal.jizpi.uz

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Optimizing Overlock Seam Parameters for Joining Footwear Uppers to Nonwoven Strobel Insoles

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Abstract This study examines the tensile strength of a single-thread overlock seam joining a footwear upper to a nonwoven Strobel insole intended for special footwear. A three-factor, three-level experimental design varied insole surface density from 500 to 600 grams per square meter, stitch density from three to seven stitches per centimeter, and thread designation from three to five. Twenty-seven settings were tested in triplicate, giving 81 force measurements. A full quadratic response model was fitted to the individual results. The coefficient of determination was 0.937, and the adjusted coefficient was 0.928. The model predicted a maximum force of approximately 205.4 newtons at 560.9 grams per square meter, 4.67 stitches per centimeter, and thread designation 4.49. However, a lack-of-fit test against the within-setting replication error was significant, so this interpolated maximum is provisional. The strongest observed setting used a 550 grams per square meter insole, five stitches per centimeter, and designation four thread, producing a mean force of 204.3 newtons. At designation four, increasing stitch density from five to seven stitches per centimeter reduced mean strength at every material density. The observed setting is a practical starting point for the particular materials and machine studied. Further production runs, other insole materials, durability tests, and product-level compliance assessments are required before wider application.

Keywords *footwear; nonwoven insole; overlock seam; stitch density; seam strength; response surface*

INTRODUCTION

In Strobel-type footwear assembly, the upper is stitched to an insole before sole attachment. The strength of this stitched junction matters because the connection must retain its integrity during lasting and subsequent use. When a nonwoven material is introduced as the insole, its surface density and the selected stitching conditions must be evaluated together. Footwear-specific test standards address seam strength of upper and lining materials and the ability of insole materials to retain stitches [1], [2]. These methods provide relevant context, although the tensile configuration examined here is a separate laboratory procedure.

The present work investigates a single-thread overlock seam joining an upper to a nonwoven Strobel insole. The aim is to quantify the effects of insole surface density, stitch density, and thread designation on the maximum tensile force, then identify a practical combination within the tested conditions. The investigation concerns seam specimens, rather than finished safety footwear; requirements applicable to

complete safety footwear should therefore be evaluated separately [3].

MATERIAL AND METHODS

Samples were sewn using polyester DOUBLE A T5-5S thread, DPX5 needles, and a TKW-600S automatic disc sewing machine. The joint was made with a single-thread overlock seam. Seam specimens measured 45 by 40 millimeters and were cut from the forepart, waist, and heel regions as described in the dissertation section. The initial grip separation was 25 millimeters and the moving grip speed was 100 ± 10 millimeters per minute. The maximum force at failure, in newtons, was recorded as the response. Information on replicate allocation by footwear region, conditioning, and observed failure modes was not available in the source section; these characteristics are not treated as separate factors.

A complete three-level factorial plan covered 27 combinations. Each combination had three measured specimens, yielding 81 results. Insole surface density S was 500, 550, or 600 grams per square meter; stitch density D was three, five, or seven stitches per centimeter; and the experimental thread designation T was three, four, or five. Thread designation is a categorical manufacturing label expressed as numbered levels in the supplied experimental plan. Interpolated values of T from the polynomial model are therefore mathematical estimates, not directly selectable thread sizes.

The coded factors were $x_1 = (S - 550)/50$, $x_2 = (D - 5)/2$, and $x_3 = T - 4$. A full second-order polynomial, containing three linear terms, three squared terms, and three pairwise interaction terms, was fitted by ordinary least squares to the 81 individual measurements. The squared terms were retained to describe the nonmonotonic changes across the tested levels. This fit is descriptive for the studied material and machine, and its predictions outside the tested ranges were not assessed.

EXPERIMENTAL RESULTS

Table I reports every tested combination as the mean of its three measured force values. The largest observed mean across the entire 27-setting design was 204.3 newtons for $S = 550$ grams per square meter, $D = 5$ stitches per centimeter, and $T = 4$, with the three individual forces being 204, 205, and 204 newtons. At thread designation four, raising stitch density from five to seven reduced the mean force at every measured surface density. At five stitches per centimeter, increasing surface density from

500 to 550 grams per square meter raised the mean from 182.7 to 204.3 newtons, whereas a further increase to 600 gave 200.0 newtons.

S is in grams per square meter, D is in stitches per centimeter, and T is the experimental thread designation. SD is the sample standard deviation of the three force readings in each setting.

TABLE V. MEAN FORCE BY INSOLE DENSITY, STITCH DENSITY, AND THREAD DESIGNATION

S	D	T	Mean, N	SD, N
500	3	3	150.3	1.2
500	3	4	152.7	2.3
500	3	5	162.7	1.5
500	5	3	180.3	0.6
500	5	4	182.7	0.6
500	5	5	192.0	1.0
500	7	3	141.7	0.6
500	7	4	148.7	1.5
500	7	5	144.7	2.5
550	3	3	182.3	2.1
550	3	4	186.0	1.0
550	3	5	190.3	0.6
550	5	3	191.7	1.5
550	5	4	204.3	0.6
550	5	5	198.3	2.1
550	7	3	148.3	1.2
550	7	4	158.0	1.0
550	7	5	150.3	1.5
600	3	3	164.7	2.1
600	3	4	168.7	0.6
600	3	5	172.3	0.6
600	5	3	197.7	0.6
600	5	4	200.0	1.0
600	5	5	195.7	0.6
600	7	3	148.7	1.5
600	7	4	156.7	1.5
600	7	5	151.3	1.2

Two means in the source table were arithmetically inconsistent with their replicate readings: the means for S=600, D=3, T=3 and S=600, D=7, T=4 are recalculated here directly from the reported measurements.

The full response is not monotonic across the experimental levels. The mean at 550 grams per square meter exceeds the corresponding mean at 500 grams per square meter at most of the tested stitch and thread settings. However, 600 grams per square meter does not consistently improve the junction: for instance, at five stitches per centimeter and designation four, the mean decreases by 4.3 newtons when density increases from 550 to 600 grams per square meter. The size and direction of a density change therefore depend on the starting level and the other chosen settings.

Figure 1 makes the effect of stitch density visible at thread designation four. For all three insole surface densities, the measured mean peaks at five stitches per centimeter. The loss between five and seven stitches per centimeter is 34.0, 46.3, and 43.3 newtons for surface densities of 500, 550, and 600 grams per square meter, respectively. These are within-design differences, not estimates of performance under different sewing equipment or different insole compositions.

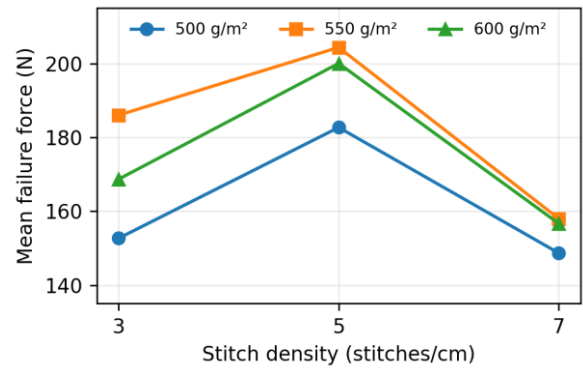


Fig. 3. Mean measured failure force at thread designation four (three specimens per setting).

The fitted polynomial in coded factors was:

$$\Pi = 203.259 + 5.556\xi_1 + 10.093\xi_2 + 2.889\xi_3 + 11.556\xi_1^2 + 33.722\xi_2^2 + 2.889\xi_3^2 + 1.528\xi_1\xi_2 + 1.556\xi_1\xi_3 + 1.694\xi_2\xi_3. \quad (1)$$

Here P is the predicted maximum force in newtons. Based on all 81 specimen results, $R^2=0.9365$, adjusted $R^2=0.9285$, and the overall regression F statistic is 116.43 with 9 and 71 degrees of freedom ($p<0.001$). The model residuals include within-setting variation as well as deviation of setting means from the fitted quadratic surface. The observed triplicate spread is small at some settings, but the fitted response does not exactly reproduce every setting mean; goodness of fit therefore does not constitute independent validation.

A plot of specimen residuals against fitted values is given in Fig. 2. The deviations are not confined to the within-setting standard deviations shown in Table I; they also reflect the finite flexibility of a quadratic surface when it is fitted to all 27 setting means simultaneously. The plot should be used to see the scale of disagreement between the model and observations, rather than to infer predictive accuracy on new materials. No external test set or repeated production batch was provided in the underlying data.

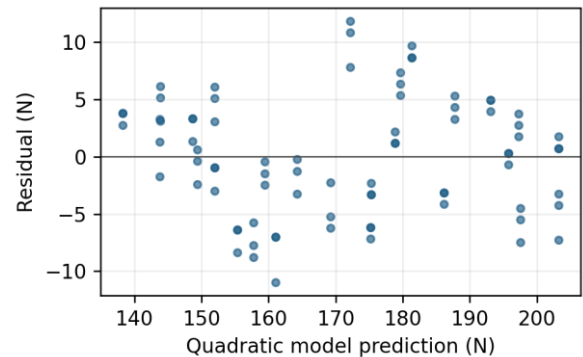


Fig. 4. Residuals for all 81 individual measurements under the fitted quadratic model.

The stationary maximum of (1) lies at approximately $x_1=0.218$, $x_2=-0.167$, and $x_3=0.490$. In natural units, this corresponds to S=560.9 grams per square meter, D=4.67 stitches per centimeter, and T=4.49, with predicted P=205.4 newtons. Because the thread designation is discrete, the nearby tested setting S=550, D=5, and T=4 is more directly usable; its observed mean

is 204.3 newtons. Selecting a setting still requires checking the stitch appearance and relevant performance under the intended footwear production and use conditions.

The predicted optimum differs by just 1.1 newtons from the strongest measured setting, which is smaller than some setting-to-setting differences and should not be interpreted as a demonstrated production gain. In particular, an intermediate insole surface density of 560.9 grams per square meter was not separately manufactured and tested for this experiment, and a designation of 4.49 does not describe an available thread. The proposed manufacturing combination uses only experimentally observed factor levels. A confirmation series at that setting on independently prepared shoes would be the appropriate next step before recommending it for routine production.

MODEL ADEQUACY CHOICE OF SETTING

The 27 triplicate groups permit an additional check that the overall R^2 cannot provide. The residual sum of squares for the quadratic regression is 2094.76 square newtons with 71 residual degrees of freedom. Replicate variation within the 27 settings contributes only 99.33 square newtons, with 54 degrees of freedom. The difference, 1995.43 square newtons on 17 degrees of freedom, measures lack of fit of the quadratic form relative to the distinct setting means. The resulting lack-of-fit F statistic is 63.81 with 17 and 54 degrees of freedom, with p below 0.001. Accordingly, the fitted surface misses the pattern of some setting means by more than can be attributed to the observed variation among the triplicate tests.

This calculation clarifies the different roles of the fitted polynomial and the measured comparisons. A large R^2 describes the portion of variation captured by the polynomial over the entire force range; it does not establish that an interpolated maximum is accurate to one newton or that the polynomial is an adequate physical law. The model usefully summarizes the general hill-shaped response across the design, but its precise stationary coordinates should not be used as a validated process target. The strongest observed setting is supported directly by replicate measurements, although replication at a single preparation or production run cannot measure between-batch uncertainty.

The three specimens in the strongest setting have a sample standard deviation of 0.58 newtons. This small local spread describes those three tests only. It cannot replace information on how seam force changes between different upper batches, insole lots, operators, machines, and footwear regions. Likewise, selecting the largest of 27 observed means can create an upward selection effect. A fresh confirmation experiment should compare the chosen setting with nearby alternatives using independently produced specimens and a prespecified sampling plan. Such confirmation is especially relevant because the setting at 600 grams per square meter and five stitches per centimeter achieved a mean force of 200.0 newtons under designation four, relatively close to the selected 204.3 newtons.

A subsequent experiment could test 550 and 600 grams per square meter at four, five, and six stitches per centimeter, with actual commercial thread designations

specified by linear density and material. Including intermediate stitch levels around five would distinguish a broad working plateau from a narrow maximum. At each setting, reporting failure location, broken threads, insole tearing, and seam opening would help relate the force reading to the physical failure mechanism. The setup should document specimen direction, the position within the upper, conditioning time, and the number of independent insole sheets sampled. These details would make the observed ranking transferable to manufacturing decisions.

DISCUSSION

Within this design, stitch density had the largest curvature term in coded units. The lower forces at seven stitches per centimeter are consistent with a possible weakening of the stitched nonwoven by more frequent needle penetration, but this mechanism was not directly measured and remains a hypothesis. The fitted surface-density response peaks near the middle of the studied range; this result should not be extrapolated to materials with different fiber composition, thickness, or bonding. Thread designation showed a smaller change in the fitted response than stitch density, and its apparent effect may depend on the particular thread product represented by each number.

The comparison of experimental levels also indicates why tuning one factor alone would give an incomplete account of the joint. At 500 grams per square meter and three stitches per centimeter, the three thread designations give mean forces of 150.3, 152.7, and 162.7 newtons. At 550 grams per square meter and five stitches per centimeter, the corresponding values are 191.7, 204.3, and 198.3 newtons. Thus the ordering of thread designations changes with the other settings. The fitted model includes pairwise interaction terms to accommodate such behavior, although the coefficients of these terms are relatively small in coded units. Their presence in a polynomial does not by itself establish the mechanism of interaction.

Surface density is only a convenient summary of the nonwoven insole. Two materials with equal surface density can differ in fiber blend, thickness, web orientation, and bonding, with corresponding differences in needle penetration and stitch retention. The studied data do not report these properties for each of the three experimental densities. Consequently, the numerical optimum belongs to this particular set of insole materials. Future comparisons should hold fiber composition and processing constant where possible and document thickness, local variation, and seam failure mode, alongside the surface density.

Averaging across the nine combinations of the other two factors provides another view of the design. The marginal mean force at three, five, and seven stitches per centimeter is 170.0, 193.6, and 149.8 newtons, respectively. The corresponding marginal means at 500, 550, and 600 grams per square meter are 161.7, 178.9, and 172.9 newtons. Across thread designations three, four, and five, they are 167.3, 173.1, and 173.1 newtons. These averages confirm that the middle stitch level is strongest on average in this design, while the difference between thread designations four and five disappears after averaging. A marginal mean is nevertheless an

average across combinations and must not be used to replace the setting-specific values in Table I when selecting a machine adjustment.

The present measurement is a peak force from one tensile loading event. It does not show how much the seam elongates before failure or how its load-bearing ability changes after wetting, drying, bending, or abrasion. Those conditions matter for the intended special-footwear application, but they were not tested in this experiment. An extended evaluation could report a force–displacement trace, separation mode, and post-conditioning force for the same material combinations. It could then compare both the peak load and the durability of the upper-to-insole junction under a specified use simulation. Any acceptance criterion should be chosen from the requirement actually applicable to the intended product and the particular seam, with the test method and units stated unambiguously.

The reported forces are specimen failure loads obtained under the laboratory configuration stated above. They should not be interpreted as seam strength per unit length, as a pass/fail safety-footwear threshold, or as evidence that the complete shoe meets ISO 20345. Such claims require the correct test setup, any prescribed calculations, and finished-product testing under the applicable standard [4], [5], [6]. The original section did not establish a standardized threshold for this specific upper-to-Strobel-insole junction; a generic range of 150–250 newtons was therefore excluded from the present paper.

CONCLUSIONS

A three-factor study of an upper-to-nonwoven-insole overlock seam found its highest observed mean force at a 550 grams per square meter insole, five stitches per centimeter, and thread designation four. The mean of three measurements was 204.3 newtons. A quadratic model fitted to 81 individual measurements explained

93.65 percent of observed force variation and predicted an interior maximum of 205.4 newtons, but its lack of fit was significant relative to within-setting replication. The measured setting gives a practical starting point for the studied equipment and materials; the exact model optimum remains unverified. Further insole compositions, repeated production runs, cyclic loading, and complete footwear must be evaluated before wider adoption.

ACKNOWLEDGMENT

This research was conducted as part of the Erasmus+ project “Textile Manufacturing for the Future of Uzbekistan and Kazakhstan” (TEX4FUTURE, Project No. 101128738). The authors thank the project partners for their advice and recommendations during the research.

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