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INCREASING THE STRENGTH OF THE WELDED JOINT IN BAND SAWS

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Abstract:

One of the features of a band saw is the need to weld it to create a closed ring. Since in butt welding of band saws it is necessary to obtain the required strength and reliability of the welded joint, at least of the same values of indicators as those of the base metal, laser welding is used instead of traditional arc welding of band saws. The paper deals specifically with determining the optimal angle at which the weld seam should be located in relation to the line of action of maximum bending stresses, which is needed to increase the welding efficiency.

To identify the effect of laser welding parameters on the strength of the saw section with a weld seam made, the method of mathematical planning of the experiment was used. Two variable factors were chosen: the angle of the weld and the second factor - the speed of movement of the table with a sample of the band saw blade. The output parameter is the tensile strength of the samples.

In addition, a plan for designing the study and the number of repetitions for each selected test was substantiated. After conducting a preliminary series of tests, a set of statistical coefficients was determined, such as the average value of the tensile strength, variance, standard deviation, index of variation, and experimental accuracy. Presented are the results of the study tests performed in accordance with the planned design of the mathematical experiment. An application computer program has been developed to process the above-mentioned results of the study. In addition, coefficients were established for the regression equations of the incomplete quadratic equation both in normalized and explicit form. The normality of the ultimate (tensile) strength distribution was checked by the criteria of asymmetry and excess. The Fisher coefficient test proved the adequacy of the obtained regression equations. The influence of the main factors on the ultimate (tensile) strength is analyzed.

Key words: *band saw; laser welding; seam angle; influential factors; regression equation; tensile strength.*

INTRODUCTION

Currently, the use of band saws is of great interest in the forest industry, construction and mechanical engineering. However, the use of this type of saw has both advantages and disadvantages. Carbon steel blades are the most common in the sawmill industry, but, unfortunately, the operating life of band saws is small, from 50 to 70m^3 of sawn wood for different blades (Arutyunov et al. 2017). Breaking a band saw is extremely dangerous for service personnel. As a result, the time of continuous sawing is significantly reduced.

In this regard, the question arises about the complete depletion of their capacity. In this case, to extend the service life, it is necessary to preserve the full range of mechanical characteristics of band saws without loss of strength compared to the original material. It is also necessary to pay attention to ensuring high reliability of the butt weld of the band saw.

Since it is necessary to obtain the required strength and reliability of the welded joint, comparable to the same indicators of the base metal, then laser welding is used instead of traditional arc welding of band saws. Reducing the likelihood of cold and fatigue cracks is based on reducing welding stresses by setting the optimal parameters of laser welding.

An analysis of band saw blades operating until failure showed that the greatest stress concentrator is the area of the kerf, where a fatigue crack is more likely to originate. The significant size of the kerf does not exclude the effect of this stress concentrator on the modified metal after welding, which leads to a sharp decrease in resistance to fatigue and brittle fracture (Rykalin et al. 1985).

PRESENTATION OF BASIC MATERIAL

This paper considers butt welding of a carbon steel band saw using laser radiation, in which the seam is located at an angle relative to the line of maximum bending stresses (see Fig. 1).

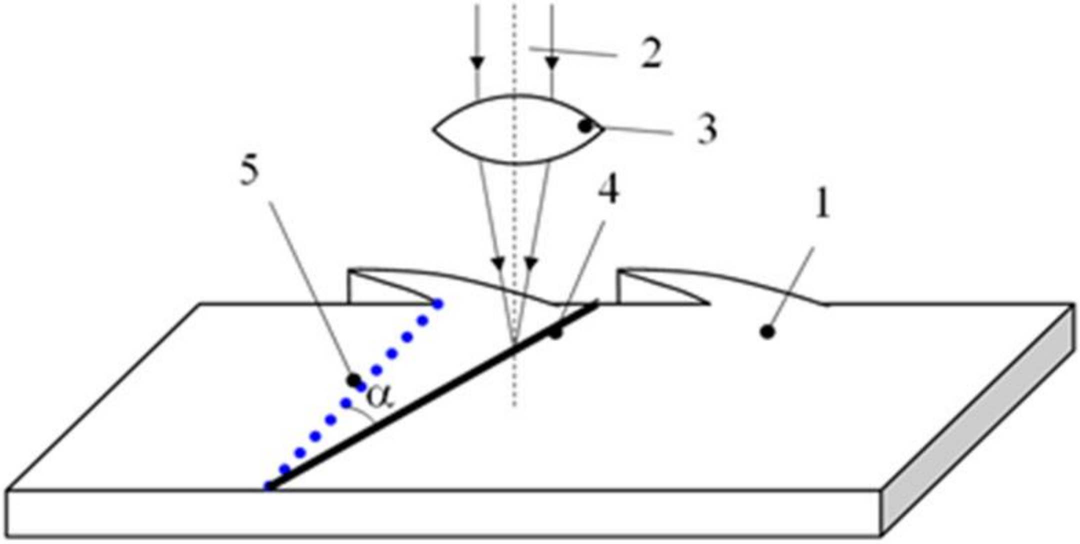

Fig. 1.
Scheme of laser welding of a band saw:
1 – a blade of a band saw; 2 – laser radiation; 3 – optical focusing system; 4 – weld; 5 – line of action of maximum bending stresses.

Laser beam 2 was focused by the optical system 3 on the surface of the butt-welded ends of the band saw blade 1.

Such a welded joint has increased resistance to cyclic tensile and bending loads, which are accompanied by significant deformations during bending on saw pulleys (Rebezniuk et al. 2019). It can be seen that with this method of welding the probability of fatigue cracking is decreased in the weld while (ther) there is an increase in the impact strength of the welded joint along the line of maximum bending stresses due to reducing the number of stress concentrators. The latter is achieved by performing the seam 4 at an angle α to the line of action of the maximum bending stresses 5.

The proposed method was used in butt welding band saw blades into the ring; the band saw blades were made of steel 60HN8 Premium German Steel, 1mm thick. The welding was performed on *a Quantum-15* laser technological installation, with a radiation pulse energy of 15 J and a pulse frequency of 2 Hz, which also contains an automated numerical program control system for the drives of a two-coordinate table which moves the saw blade relative to laser radiation.

To determine the influence of laser welding parameters on the strength of the saw section with the welded seam, the method of mathematical planning of the experiment was used. Two variable factors were chosen: X_1 – the angle of the weld, the second factor X_2 – the speed of movement of the table with a sample of the band saw blade, the range of change is from 200 to 350mm/min. The output-parameter y is the tensile strength of the samples, $F_{breakage}$ in N/mm^2.

All the factors are quantitative, controllable and manageable. Each factor is expected to be modified at two levels. The level values are presented in Table 1.

Table 1

Levels of coding of the factors influencing the strength of the section of the saw with a weld seam

Factors	Marking	Level of variation			Interval
		top code «+1»	middle code «0»	bottom code «-1»	
1. Location of the weld, degrees	α	0	22.5	45	22.5
2. The table speed with a sample of a band saw blade mm/min	*Vs*	200	275	350	75

The regression equation was established for two variable factors in the form of an incomplete quadratic equation:

$$y = b_o + b_1X_1 + b_2X_2 + b_{12}X_1X_2.$$

The coefficients b_o, b_1, b_2, b_{12} are coefficients of the regression equation.

The studies of the tensile strength of samples with welded joints were carried out on a modernized mechanical tensile testing machine 2054 R-5 which is equipped with a Zemic dynamometer (USA) with a maximum force of 5 tons. The studies were carried out taking into account the requirements of DSTU EN ISO 4136:2014 – Destructive tests on welds in metallic materials. The width of the test samples was 20mm and the test speed was set up at 5m/min.

The samples obtained after the welding process are presented in Fig. 2.

Fig. 2.
The samples obtained after welding.

For planning, were set up a complete factorial design (CFD), in which was implemented all possible combinations of two levels of factors - upper and lower. In this case, the number of experiments is N=4.

To set up a design matrix were used the dimensionless normalized notations for variable factors. The design matrix in the code values of the factors is presented in Table. 2.

Table 2

Detailed CFD design-matrix 2^2

Experiment No.	Code values factors		Natural values of factors	
	X_1	X_2	*α, degrees*	*Vs, мм/хв*
1	-1	-1	0	200
2	+1	-1	45	200
3	-1	+1	0	350
4	+1	+1	45	350

The number of repeated experiments was determined according to the method (Pylypchuk et al. 2007) on the basis of preliminary experiments taking into account the required reliability coefficient *p* = 0.95, the confidence interval of accuracy estimate ε = 0.05N/mm^2 and the variance of preliminary measurement results in previous experiments S^2=0.00986. The obtained results showed that n = 2.49, which means that at each point of the plan at least three experiments must be carried out.

The obtained results for the tensile strength of the tested samples are presented in Table. 3.

The coefficients of the regression equation were found by processing the design matrix of the experiment which had the following values:

b_0 = 917.2; b_1 = 186.4; b_2 = 80.9; b_{12} = 30.7.

The regression equation in normalized form is presented below:

$$y = 917.2 + 186.4X_1 + 80.9X_2 + 30.7X_1 X_2.$$

Table 3

The obtained results for the tensile strength of the tested samples, $F_{breakage}$

Test No.	The results of repeated measurements of the tensile strength of the samples, N / mm²			The average tensile strength of the samples, N / mm²	Dis-per-sion, S^2	Mean quadratic deviation, σ, Н / мм²	Deviation coefficient, υ, %	Average errors, *m*	Accura-cy of testing, *p*, %
	$F_{1breakage}$	$F_{2breakage}$	$F_{3breakage}$						
1	680	682	681	681	1.0	1.0	0.15	0.5	0.07
2	992	994	990	992	4.0	2.0	0.40	1.0	0.10
3	780	782	781	781	1.0	1.0	0.12	0.5	0.06
4	1,216	1,215	1,214	1,215	1.0	1.0	0.08	0.5	0.04

The significance of the coefficients of the regression equation was tested using the Cochran test. First, the homogeneity of the variances was determined by identifying the actual value of the criterion – G_f = 0.235, the tabular value of the Cochran test with the number of samples N = 3 and the number of degrees of freedom f = n–1 = 5–1 = 4 for the significance level q = 0.05 G_t = 0.39.

Therefore, $G_f < G_t$ the hypothesis of homogeneity of variances is accepted.

To determine the significance of the regression coefficients, the average variance of the experiment was compared with the variances of the estimates of the regression coefficients. The results revealed that all the coefficients turn out to be significant.

The adequacy of the regression equation was assessed using Fisher's test. The estimated value of Fisher's criterion F = 0.0000035. Tabular value of Fisher's criterion at f_1 = 3, f_2 = 8 F_t = 4.07. F_t =4.07 > F =0.0000035.

This confirms the adequacy of the model.

The regression equation is explicit:

$$F_{breakage} = 547.7 + 3{,}3\alpha + 0.7V_s + 0.02\ \alpha V_s.$$

RESULTS AND DISCUSSIONS

Normalized and explicit regression equations make it possible to construct graphical dependences of the most significant factors, such as the angle of the weld and the feed rate during welding, which, in turn, allows visual analysis of this relationship.

The most significant impact on the tensile strength of the material of the welded band saw has the angle of the weld (see Fig. 3).

The test results showed that the tensile strength increases with increasing the angle of inclination of the weld seam up to 1.55 times from 787 to 1316N/mm^2. This value is most important for the sample with a weld seam angle of 50º.

Comparing welding at different angles, we can see that the tensile strength of the weld seam welded at 15-25 degrees approaches the tensile strength of the original material (989N/mm^2) and these angles are the optimal welding angles. When welding at 50 degrees, the tensile strength, although greater, complicates the processing of the seam because of its high value.

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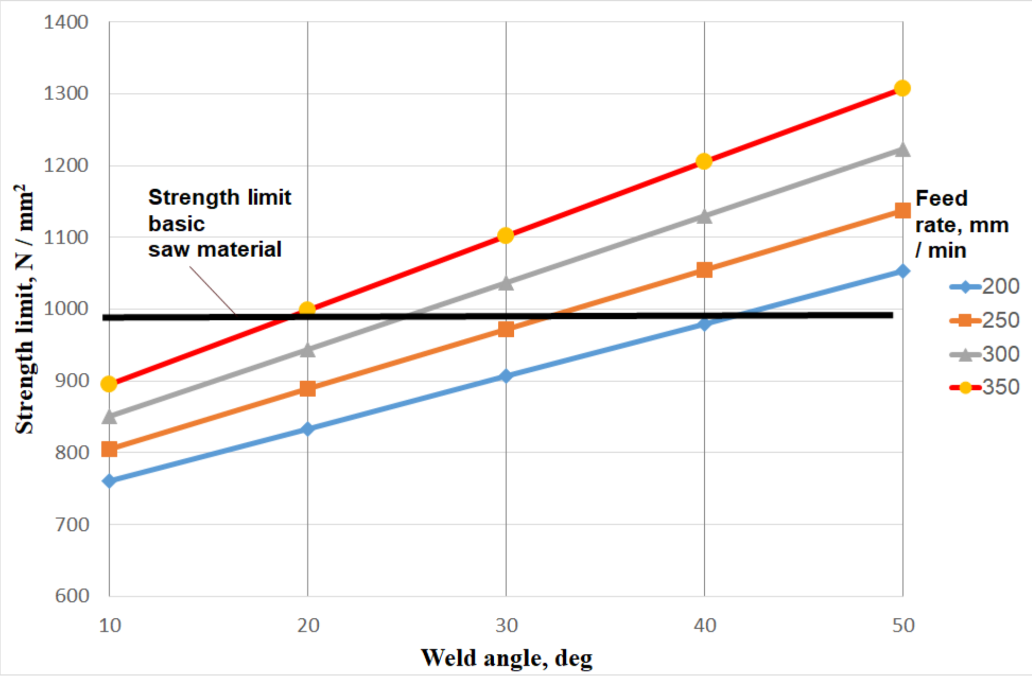

Fig. 3.
The relationship between the tensile strength, the angle of the weld and the feed rate during welding.

The influence of the feed rate on the tensile strength at certain angles of the seam is shown in Fig. 4.

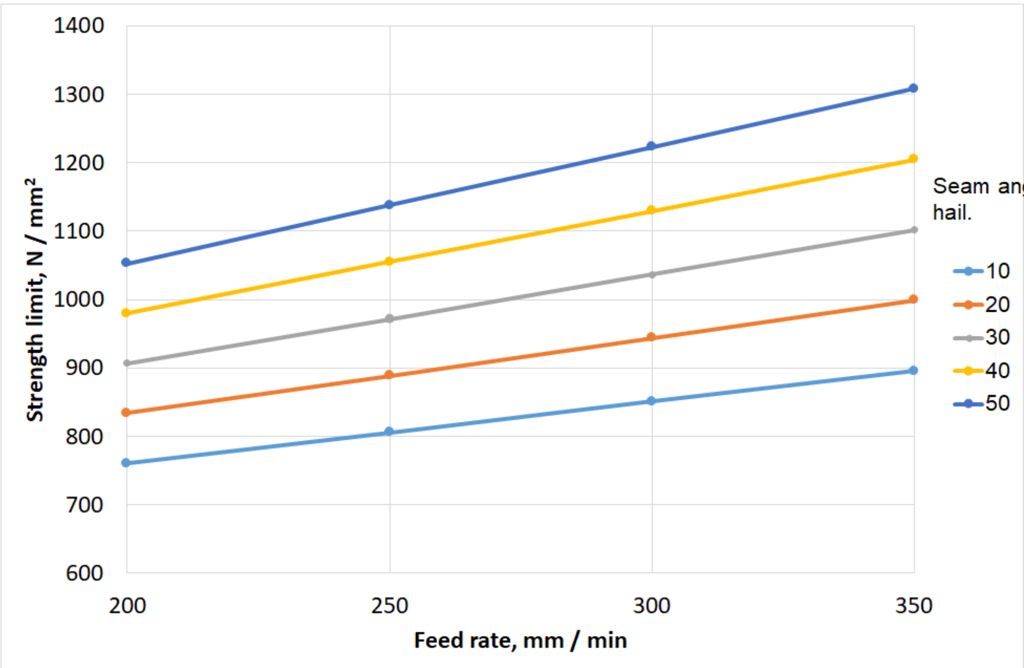

Fig. 4.
Influence of feed rate on the tensile strength at certain weld angles.

The graph in Fig. 5 shows that in order to strengthen the blade of the laser-welded band saw, it is necessary to choose both larger values of the angle of the weld and the feed rate during welding. The experimental data can be used in industrial conditions during laser welding of band saws.

According to the regression equation, a chart of dependence between the tensile strength of the sample material, the angle of the seam and the feed rate of the table, is presented in Fig. 5.

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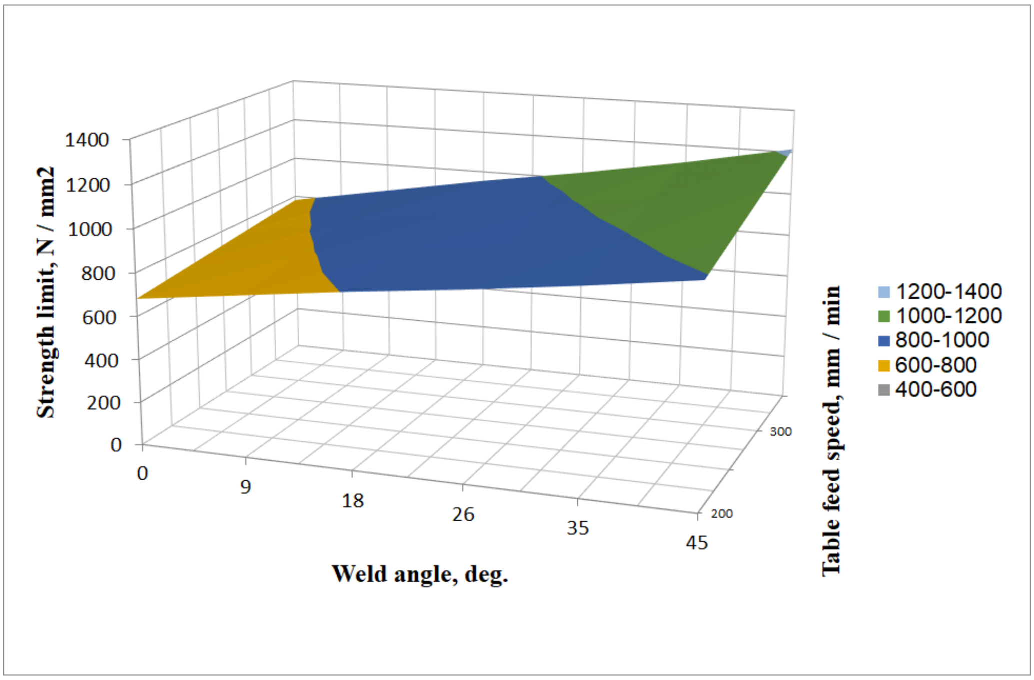

Fig. 5.
Graph of the dependence of the tensile strength of the sample material on the angle of the seam and the feed rate of the table.

CONCLUSIONS

The conclusions based on the analysis of the conducted tests, performed after the laser welding of band saws, were as follows:

– the experimental tests, conducted to establish the ultimate tensile strength of band saw samples, established a relationship between the changes in welding angle and feed rate and the tensile strength of band saw samples;

– the coefficients of the regression equation for two variable factors are established in the form of an incomplete quadratic equation both in normalized and explicit forms;

– the results of the research allow us to approach the issue of optimizing the processes of laser welding of band saws and, in the future, to determine the rational modes of welding;

– the use of laser butt welding at an angle to the line of action of maximum bending stresses for the blades of band saws makes it possible to increase the tensile strength of the blades and increase their service life.

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