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PLANNING AND EXPERIMENTAL STUDIES OF SELECTION THE OPTIMAL WELDING MODE BY THE FRICTION OF FITTING RODS

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The methods of friction welding of various materials have been studied, as well as the design and capabilities of the device for friction welding have been determined. The design of the device for friction welding on the basis of a lathe has been developed taking into account the established requirements and recommendations of machine-building enterprises. To study the influence of technological factors on the quality of welded joint formation, a full factorial experiment (FFE) of type 2^2 was set up according to the plan. The adequacy of the planned experiment was confirmed by calculations (Fcalcul. = 1.1 <Ftabl. = 4.46.) on the basis of which a full-scale experiment was carried out. According to the results of the experimental plan, it was found that the heating time of the work pieces being welded has the most significant effect on the total length of the seam upsetting. The optimal mode with the correct formation of the burr has been chosen. The convergence of the full-scale test results with the planning of the Type 2^2 full factor experiment has been identified, resulting in the determination of the optimal mode.

Keywords: friction welding, lathe, welding of reinforcement bars, optimal welding modes

1 INTRODUCTION

Welding of reinforcing bars is increasingly used in industry and construction. Friction welding will remain the main and most advanced technological process for obtaining an integral connection of parts and structures in modern industrial construction as the most economical and productive process, the volume of application of which continues to grow constantly. The use of friction welding of reinforcing bars of reinforced concrete structures makes it possible to reduce the cost of the process, since expensive equipment, bulky machines, and a highly skilled worker are not required for welding. All this will affect the construction process in Kazakhstan, which is gaining momentum more and more every year. Friction welding is flexible, versatile, economical and affordable in repair production, where universal lathes are available, which allows the widespread use of this type of welding [1].

2 EXPERIMENT SETUP

Considering the relevance of the study, the possibilities of friction welding based on a lathe were studied. In the course of the study [2], the authors proved that friction welding of mild steel AISI 1040 and aluminum alloy AA6351 can be performed on a lathe both in the form of similar and dissimilar combinations with a diameter of up to 20 mm at different spindle speeds, hardness in the heat affected zone was measured; friction welding was also applied to round metal tube made of MS material, diameter 20 mm [3]. The rotational speed during friction welding ranged from 700 to 900 revolutions per minute. The friction pressure was maintained at 7 MPa, and the friction time was kept constant [3]; in operation [4], the manual force was measured with the help of a special device for a hydraulic jack, welding of materials H.S.S M2 and S.S 316, diameter was 10 mm, spindle speed was 1700, 2700 and 3700 per min^{-1}, with pressure from 100-330 (kg/cm^2); in work [5], the authors considered friction welding of stainless steel 070M20 and aluminum 2011-T3, studied the possibilities of performing friction welding on a lathe, and also checked the reliability of the welded joint. In the course of a literary review [6] and a review of open Internet sources, it was established and proved that friction welding can be performed on the basis of a lathe. The review showed that friction welding of 35GS steel reinforcing bars for reinforced concrete structures has not been studied, as well as the problems of this method, such as the development of a technological welding mode depending on the composition of the material and geometric parameters.

Experimental studies were carried out at the laboratory base of the Faculty of Mechanical Engineering of Karaganda Technical Universitynamed after Abylkas Saginov. The study used a physical experiment method to confirm the possibility of using the existing machine park at enterprises for the possibility of performing a friction welding operation without the cost of purchasing of specialized friction welding plants. The following materials were used for the experiment: Struers Unitom 2 cutting machine, 1K62 lathe, friction welding device on a lathe, TL-30 laboratory timer, dynamometer DORM-3-1U 5178, caliper SHC-1-2000.05 .

The purpose of this study is to conduct a full-scale experiment to confirm the choice of optimal welding modes of reinforcing bars.

To achieve this goal, the design of friction welding equipment and the possibility of its use on a lathe were determined [7]. The design of a friction welding device based on a lathe has been developed taking into account the established requirements and recommendations of machine-building enterprises (Fig.1). Detailed drawings of assemblies and devices were developed, on the basis of which parts and assemblies were manufactured. The accuracy of the kinematic movement of the working bodies is ensured, the device has passed laboratory tests [8].

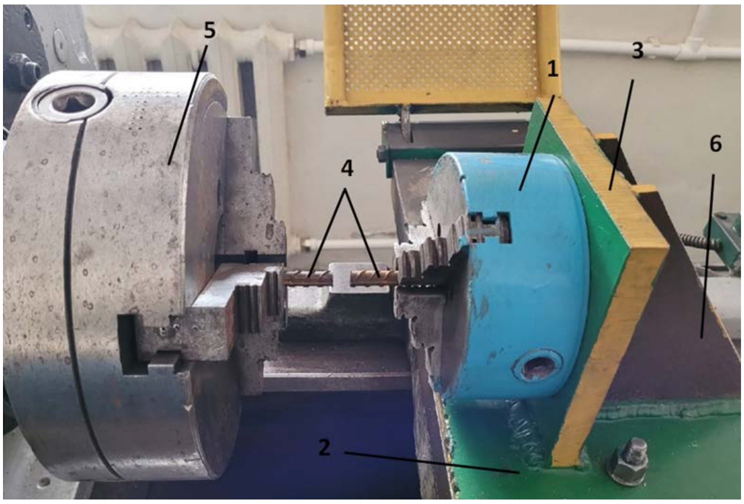

Fig. 14. The design of the device for friction welding on the basis of a lathe:

1-three-jaw chuck (GOST 2675-80); 2-base; 3-bracket; 4- welded blanks; 5- clamping equipment of the machine;

6- angular.

Welding of workpieces of different diameters and setting up equipment is simple and does not require much time. At the beginning of work, the reinforcing bars of the workpiece under study are clamped in the chuck of the machine 5 and a special device 1. Bring the device all the way to the end of the bars and hold it with the handwheel of the manual movement of the caliper in order to increase the clamping force during the welding process.

The machine turns on, the rotation of the workpiece clamped in the chuck of the machine 5 begins. The workpiece fixed in device 1 is stationary. At the points of contact of the workpieces, the color of the metal is observed, which is a sign of the heating of the metal as a result of friction. After a certain time (t=25-30s), the metal in the contact zone will glow brightly and begin to be squeezed out in the form of an annular formation beyond the dimensions of the rods. At the moment of the brightest glow of the contact point, the machine must be turned off so that the metal of the two workpieces sets. At the same time, the pressure gradually increases, which is controlled according to the readings of the dynamometer DORM-3-1U 5178 at the junction of the bars, using the flywheel of the caliper. After the glow stops, it is necessary to loosen the cartridge of the device 5 and take away a special installation 1. To check for the absence of radial runout, the quality of friction welding, the machine is switched on again. If a radial runout of more than 0.5 mm of welded workpieces is detected, it is eliminated by grinding the extruded grate in the contact zone [8].

To plan the experiment, reinforcing bars made of 35GS steel (analog A3 (A400)) with diameters of 10mm and 14mm, length of 100mm were used as a blank (Fig.2, 3). The grades, chemical composition and properties of the studied steels recommended by GOST 5781-82, GOST 2590-2006, mechanical properties are given in Table 1.

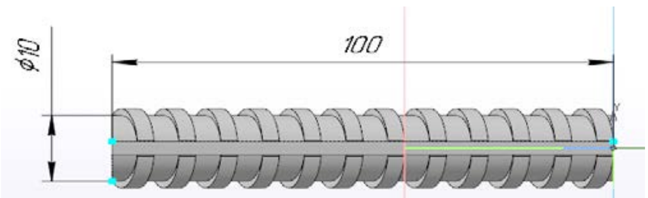

Fig. 2. Dimensional reinforcing bar diameter 10 mm.

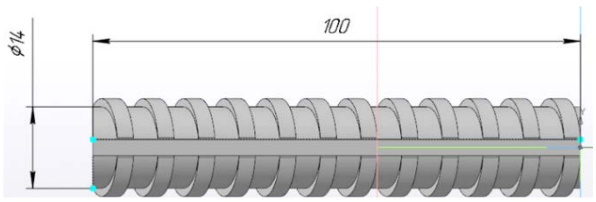

Fig. 3. Dimensional reinforcing bar diameter 14 mm.

Table 1. Mechanical properties of 35GS steel

Diametr [mm]	Yield strength, sT [MPa]	Ultimate rupture resistance, sv [MPa]	Elongation at break, δ [%]
6-40	> 390	> 590	> 14

The fittings of the periodic profile of the 35GS brand are used as welded products in construction for reinforcing reinforced concrete structures. Weld ability without restrictions.

The initial data for the experiment are given in Table 2.

Table 2. Baseline data for experimental planning

Mode	Sample no.	Sample diameter [mm]	Welding mode		
			heating time, th [s]	spindle speed n [rpm]	the total draught length Δl [mm]
1	1	∅10	25	1600	3.5
	2	∅10			5
	3	∅10			3.5
2	4	∅14	30	2000	5.5
	5	∅14			5
	6	∅14			4.5
3	7	∅10	30	1600	6
	8	∅10			6
	9	∅10			5.5
4	10	∅14	25	2000	3.5
	11	∅14			3.5
	12	∅14			0

To conduct the experiment on selection of optimal mode [9] three samples are considered in 4-modes of welding (Fig. 4). During the experiment, the following factors were taken into account: heating time, spindle speed, the level of which is determined by the following values affecting the total settlement length (Δl, mm), they are: heating time (th) in the accepted interval of 25-30 s and spindle speed (n) in the range of 1600-2000 rpm. The forging time in all cases was t_{fr} = 2 s, heating pressure P_h = 4MPa, forging pressure R_{fr} = 7MPa.

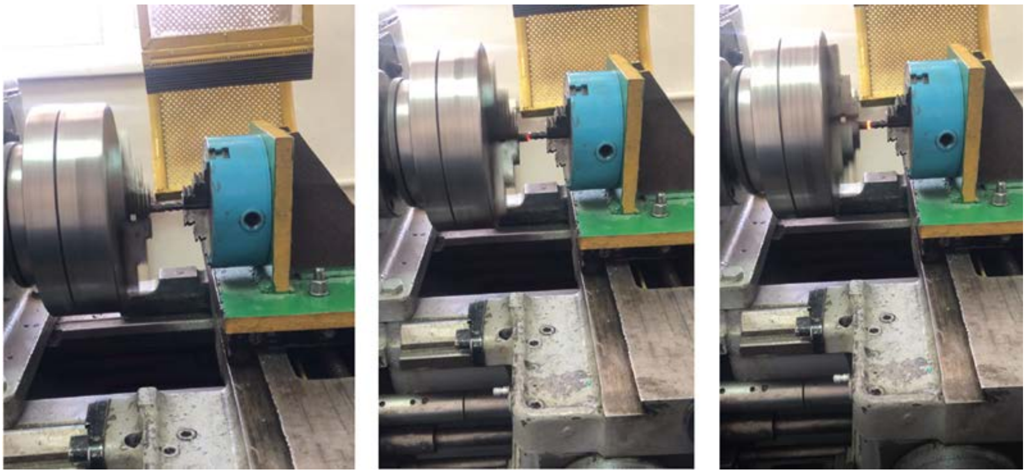

Fig. 4. Welding of reinforcing bars on the basis of a lathe.

To investigate the influence of technological factors [10] on the formation of a welded joint, experiments according to the FFE 2^2 plan were carried out, and each experiment was repeated three times (see Table 3). The following factors were selected as influencing the total draught length y (mm):

Z_1- heating time (s), $Z-$=25, $Z+$=30;

Z_2 - spindle speed (rpm), $Z-$=1600, $Z+$=2000.

Then we need to construct a regression equation, taking into account all interactions of factors, test the resulting model for adequacy and interpret it.

Table 3. FFE 22 original planning matrix

Experiment no.	Investigated factors		Experimental results (the total draught length Δl [mm])		
	z_1	z_2	y_1	y_2	y_3
1	+	+	3.5	5	3.5
2	–	+	5.5	5	4.5
3	+	–	6	6	5.5
4	–	–	3.5	3.5	0

The work is done in the following order [10]:

- encoding the variables;
- completing the planning matrix in coded variables, taking into account paired interactions and supplement with a column of average response values;
- calculating the regression equations;
- check of the calculated coefficients for significance, having previously determined the reproducibility variance, and obtaining the regression equation in coded variables;
- check of the resulting equation for adequacy;
- carrying out the interpretation of the resulting model;
- writing out the regression equation in natural variables.

1. For each factor, we find the center, the variation interval and the dependence of the coded variable xi on the natural z_i. The results are presented in the form of a table. (see Table 4).

Table 4. Coding of factors

Factors	Upper level z_i^+	Lower level z_i^-	Centre z_i^0	Variation interval, λ	Dependence of the encoded variable on the natural
z_1	25	30	27,5	2,5	$x_1 = \frac{z_1 - 27,5}{2,5}$
z_2	1600	2000	1800	200	$x_2 = \frac{z_2 - 1800}{200}$

2. The average sample results for each experiment are calculated.

If to denote by yji the value of the result obtained in the i-th experiment (i = 1, ..., m) for the j-th experiment (j = 1, ..., n), then the sample mean for each experiment is calculated according to the known formula:

$$y_j = \frac{1}{m}\sum_{i=1}^{m} y_{ji},\ j = 1, n;$$

$$\overline{y_1} = \frac{1}{3}(3.5 + 5 + 3.5) = \frac{12}{3} = 4;$$

$$\overline{y_2} = \frac{1}{3}(5.5 + 5 + 4.5) = \frac{15}{3} = 5; \qquad (1)$$

$$\overline{y_3} = \frac{1}{3}(6 + 6 + 5.5) = \frac{17.5}{3} = 5.8;$$

$$\overline{y_4} = \frac{1}{2}(3.5 + 3.5) = \frac{7}{2} = 3.5.$$

The planning matrix for all interactions and average feedback values, is shown in Table 5.

Table 5. Planning matrix for processing results

Experiment no	Factors		Interaction	Experimental results			Average of results
	x_1	x_2	x_1x_2	y_1	y_2	y_3	$\bar{y}_j$
1	+	+	+	3.5	5	3.5	4
2	-	+	-	5.5	5	4.5	5
3	+	-	-	6	6	5.5	5.8
4	-	-	+	3.5	3.5	0	3.5

The regression equation is:

$$y=b_0+b_1x_1+b_2x_2+b_{1,2}x_1x_2 \quad (2)$$

3. The coefficients of the regression equation are calculated by formula (3-5):

$$b_0 = \frac{1}{n}\sum_{j=1}^{n} \bar{y}_j \quad (3)$$

$$b_0 = \frac{1}{n}\sum_{j=1}^{n} x_{ji}, \bar{y}_{j,}\ i = \overline{1,k}, \quad (4)$$

$$b_0 = \frac{1}{n}\sum_{j=1}^{n} x_{ji}, x_{jp}, \bar{y}_{j,}\ r < p, r = \overline{1,k}, p = \overline{1,k},$$

$$b_0 = \frac{1}{4}\sum_{j=1}^{4} \bar{y}_j = \frac{1}{4}(4+5+5.8+3.5) = \frac{18.3}{4} = 4.575;$$

$$b_0 = \frac{1}{4}\sum_{j=1}^{4} \bar{y}_j\, x_{j1} = \frac{1}{4}(4-5+5.8-3.5) = \frac{1.3}{4} = 0.325;$$

$$b_0 = \frac{1}{4}\sum_{j=1}^{4} \bar{y}_j\, x_{j2} = \frac{1}{4}(4+5-5.8-3.5) = \frac{-0.3}{4} = -0.075;$$

$$b_0 = \frac{1}{4}\sum_{j=1}^{4} \bar{y}_j\, x_{j1}x_{j2} = \frac{1}{4}(4-5-5.8+3.5) = \frac{-3.3}{4} = -0.825.$$

The results of the calculations are recorded in Table 6.

Table 6. Coefficients of the regression equation

b_0	b_1	b_2	b_3
4.757	0.325	-0.075	-0.825

4. Find the $S^2_{\{y\}}$ variance of reproducibility.

$$S^2_{\{y\}} = \frac{1}{n(m-1)}\sum_{j-1}^{n}\sum_{j-1}^{m}\left(y_{ji}-\bar{y}_j\right)^2 = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{1}{m-1}\sum_{i=1}^{m}\left(y_{ij}-\bar{y}_j\right)^2\right) = \frac{1}{n}\sum_{j=1}^{n} S_j^2. \quad (6)$$

where S_j^2 are internal sums that are sample variances of experiment results for the j-th experiment (j=1,..., n). The estimates are recorded in Table 7.

Table 7. Calculation of sample variances

j	y_1	y_2	y_3	$\bar{y}_j$	$(y_{j1}-\bar{y}_j)^2$	$(y_{j2}-\bar{y}_j)^2$	$(y_{j3}-\bar{y}_j)^2$	S_j^2
1	3.5	5	3.5	4	0.25	1	0.25	0.75
2	5.5	5	4.5	5	0.25	0	0.25	0.25

j	y_1	y_2	y_3	$\bar{y}_j$	$(y_{j1}-\bar{y}_j)^2$	$(y_{j2}-\bar{y}_j)^2$	$(y_{j3}-\bar{y}_j)^2$	S_j^2
3	6	6	5.5	5.8	0.04	0.04	0.09	0.08
4	3.5	3.5	0	3.5	0	0	0	0

The elements of the last column of Table 6 are summarized:

$$\sum_{j=1}^{4} S_j^2 = 1.08$$

Hence the variance of reproducibility:

$$S_{\{y\}}^2 = \frac{1}{4}\sum_{j=1}^{4} S_j^2 = \frac{1}{4}\cdot 1.08 = 0.27 \quad (7)$$

The square deviation mean of the coefficients is determined by the formula:

$$S_{coeff} = \sqrt{\frac{s_{\{y\}}^2}{n\cdot m}} = \sqrt{\frac{0.27}{4\cdot 3}} \approx \sqrt{0.017} \approx 0.15 \quad (8)$$

From the Student's distribution tables [11] on the number of freedom degrees n (m – 1) = 4 · 2 = 8, at a value level α = 0.05 we find that $t_{critic} = 2.306$.

Therefore, $t_{critic} \cdot S_{coeff.} = 2.306 \cdot 0.15 = 0.3459 \approx 0.35$.

Comparing the obtained value of $t_{critic} \cdot S_{coeff} \approx 0.35$ with the coefficients of the regression equation presented in Table 5, we confirm that the coefficients b0 and b1.2 are greater in absolute value than 0.35, but b1 and b2 are less. Therefore, only the coefficients b0 and b1.2 are significant. Assuming that b1 and b2 are equal to 0, the regression equation in the encoded variables is got:

$$y=4,575-0,825x1x2 \quad (9)$$

5. The resulting equation (9) is checked for adequacy according to Fisher's criterion [11]. Since the variance of reproducibility is known, then to determine the calculated value of the criterion $F_{cal.}$ it is necessary to calculate the residual variance $S^2_{res.}$. For this, the values of the studied parameter are determined according to the obtained regression equation y_j(j = 1,… 4), substituting +1 or –1 instead of x_i in accordance with the number j of the experiment from Table5:

$$\widetilde{y_{1,4}} = 4.575-0.825=3.75;$$

$$\widetilde{y_{2,3}} = 4.575 - 0.825(-1) = 5.4.$$

The residual dispersion S^2_{res} is calculated:

$$S_{res.}^2 = \frac{3}{4-2}\sum_{j=1}^{4}\left(\tilde{y}_j - \bar{y}_j\right)^2 = 0.6675 \quad (10)$$

The calculated value of the Fisher criterion F_{calc} is determined:

$$F_{calc.} = \frac{S_{ост.}^2}{S_{\{y\}}^2} = \frac{0.6675}{0.2} \approx 3.34. \quad (11)$$

The tabular value of the criterion ($F_{tab.}$) is found from the tables of the Fisher distribution [11] critical pointsat the significance level α = 0.05 for the corresponding degrees of freedom: k1 = n - r = 4 - 2 = 2 and k1 = n (m - 1) = 4 (3 - 1) = 8:$F_{tabl.}$=4,46. Since $F_{calc.}$= 1,1 < $Ft_{able.}$= 4,46, the regression equation is adequate [11].

6.Interpretation of the resulting model (9).

According to the equation, it can be seen that only a combination of factors x_1 and x_2 has the strongest effect on the response (total drought length). We conclude that the heating time has a greater effect on the total drought than the spindle speed.

7. The regression equation (9) is written out in natural variables, substituting instead of x_i their expressions through z_i, which are taken from the last column of Table 3:

$$y = 4.575 - 0.825\left(\frac{z_1 - 27.5}{2.5} \cdot \frac{z_2 - 1800}{200}\right)$$

Having transformed this equation, its form in natural variables is finally obtained:

$$y = 2.97z_1 + 0.045375z_2 - 0.00165z_1z_2 - 77.1. \qquad (12)$$

Further, according to the planning results, a full-scale experiment will be set up and blanks will be weld from 35GS steel with diameters of ∅10мм, ∅14мм in the appropriate modes according to Table 1. As a result of processing, the following welds were obtained (fig. 5-8).

Fig. 5. *∅10 mm sample welded in mode 1 (t_h=25s, n=1600 rpm).*

Fig. 6. *∅14mm sample welded in mode 2 (t_h=30s, n=2000 rpm).*

Fig. 7. *∅10mm sample welded in mode 3 (t_h=30s, n=1600 rpm).*

Fig. 8. *∅14mm sample welded in mode 4 (t_h=25s, n=2000 rpm).*

For the tensile test, one sample was selected from each welding mode. Tests were carried out in accordance with GOST 6996 in order to determine the strength of the weakest section of the butt welded joint by friction on a machine for static testing of materials of type MUP-100, which confirmed the required physical and mechanical properties of the resulting joint.

3 RESULTS AND DISCUSSION

The results of the study were applied to the production of steel fittings made of 35G steel with diameters of ∅10mm, ∅14 mm with periodic profile.

The adequacy of the planned experiment was confirmed by calculations (Fcalc. = 1.1 <Ftabl. = 4.46.) on the basis of which a full-scale experiment was conducted.

The results of the full-scale experiment converge with the results obtained during the planning of the experiment, which confirms the adequacy of the accepted conditions and parameters of the experiment.

According to the results of a full-scale experiment, it was found that in order to obtain a high-quality seam, it is recommended to weld blanks made of 35GS steel with a diameter of ∅10mm, under the following modes:th=30 s, n=1600 rpm.

The obtained results prove that the developed installation allows the use of a lathe for welding reinforcing bars as well as it provides high quality weld for 35GS steel in selected welding modes.

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