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TESTING OF WELDED REINFORCING BARS FOR ELONGATION AND PROCESS SIMULATION

Karibek Sherov[1]*, Aiym Yessirkepova[2], Nazerke Abisheva[2], Rauza Serova[2], Medgat Mussayev[2], Sayagul Tussupova[3], Aizhan Zhakaba[1], Nasiba Ashurova[4]

[1] Kazakh Agrotechnical University named after S. Seifullin, Victory Avenue 62, Nur-Sultan, Kazakhstan
[2] Karaganda Technical University named after A. Saginov, Ave. N. Nazarbayev 56, Karaganda, Kazakhstan
[3] Toraigyrov University, Lomova street 64, Pavlodar, Kazakhstan
[4] Navoi State Mining and Technology University, Galaba street 27, Navoi, Uzbekistan
** shkt1965@mail.ru*

The authors carry out research on the development of technology for the manufacture of concrete products using non-dimensional waste of reinforcing bars, plain bars and wire rods. The studies carried out in the conditions of construction enterprises of the Republic of Kazakhstan, in particular the Karaganda region, have shown that this technology is advisable to use in the manufacture of concrete products such as bar lintels. As a result of the research carried out, a construction of a bar lintel was established, which is made of a concrete mixture with the addition of man-triggered waste and a space frame, reinforcing bars of which are welded from non-dimensional segments of reinforcement. This article presents the results of testing samples of reinforcing bars joint by friction welding and modeling the static tensile testing process with the determination of the tensile strength depending on the loads. At various loads, the stress on the surface of the reinforcing bar is less than 600 MPa, which corresponds to regulatory documents. At the same time, the maximum stresses are formed in the base metal, yet there is the least tension in welded region. The test results showed the possibility of using welded reinforcing bars from non-dimensional segments of reinforcement in the manufacture of concrete products, in particular bar lintels.

Keywords: concrete construction, bar lintel, friction welding, reinforcement bar waste, tension

1 INTRODUCTION

Concrete construction structures are the basis of the modern construction industry. They are used: in industrial, civil and agricultural construction - for buildings of various purposes; in transport construction - for subways, bridges, tunnels; in energy construction - for hydroelectric power plants, nuclear reactors; in irrigation and drainage construction - for barrages and irrigation devices; in mining - for installations above ground and fixing underground workings, etc [1],[2],[3],[4].

The volume of production of precast concrete products (CP) in the Republic of Kazakhstan is increasing every year. At the same time, it is exceedingly important to find reserves for further improving the technical and economic efficiency of the use of precast concrete [5]. The authors carry out research on the development of technology for the manufacture of concrete products using non-dimensional waste of reinforcing bars, plain bars and wire rods [6],[7].

The studies carried out in the conditions of construction enterprises of the Republic of Kazakhstan, in particular the Karaganda region, have shown that this technology is advisable to use in the manufacture of concrete products such as bar lintels. As a result of the studies carried out [6],[7],[8],[9], a construction of a bar lintel [10] was designed, which is made of a concrete mixture [11] with the addition of man-triggered waste and a space frame [12] whose reinforcing bars are welded from non-dimensional segments of reinforcement. Segments of reinforcing bars were joint by friction welding. To select a friction welding method, a study of the technological feasibility and the level of knowledge of this method was carried out.

In [13], the weldability of 316 and AA1100 stainless steel hollow tubes was studied in friction welding. The friction welding process was done through Finite elementanalysis. A 3D model of materials, each of 25.4 mm diameter and 100 mm in length was made usingthe ANSYS workbench. The optimum conditions were friction pressure of 80 MPa, rotational speed of 2000 rpm, friction time of 5 seconds and forging pressure of 160 MPa.

In [14], the authors studied the effect of friction welded joints formed between identical rods of the Ti6Al4V alloy with a diameter of 25.4 mm.The visual observation after the tensile test showed, for higher rotational speeds, the failure pointswere within the zone that was welded. And for lower rotational speeds, the failure points wereoutside the weld zone. It has been found that the ultimate tensile strength is higher at low rotational speeds or higher thrust. In addition, the width of the weld was directly proportional to the rotation speed and inversely proportional to the axial pressure.

In [15], the authors analyzed the optimal friction parameters in joints between UNS C23000 brass and 2024Al alloy. Finite element analysis was performed to model the friction welding process. A3D model of the specimens each of 100 mm in length and 25.4 mm in diameter was made using the ANSYS workbench software. Friction pressure (40 MPa), rotation speed (1500 rpm), friction time (4 seconds) and upset pressure (37.5 MPa) were obtained under optimal conditions. In these particular welded joints, the forging pressure was lesser or almost equal to frictional pressure, sincethe generated heat during the friction stage was high enough for the materials to weld. The penetration and sliding of materials was good at these optimal levels.

Paper [16] investigated the material flow and temperature propagation during friction stir spot welding (RFSSW) of aluminum alloy Alclad 7075-T6 sheets using finite element numerical simulations. The aim of this paper is to undertake numerical modelling of the RFSSW process to understand the physics of the welding process, which involves large deformations, complex contact conditions and steep temperature gradients. Three-dimensional fully coupled thermomechanical models of RFSSW joints between Alclad 7075-T6 aluminium alloy sheets have been built in the finite-elementbased program Simufact Forming. The simulation results included the temperature distribution and the stress and strain distributions in the overlap joint. The results of numerical computations have been compared with experimental ones. The numerical model was able to predict the mechanics of material flow during the joining of sheets of Alclad aluminium alloys using RFSSW. The predictions of the temperature gradient in the weld zone were in good agreement with the temperature measured experimentally. The numerical models that have been built are capable of simulating RFSSW to reduce the number of experiments required to set optimal welding parameters.

In [17], a comprehensive characterization of the bow of rings obtained by friction stir welding of aluminum alloy 6082 was studied. The main di_erence between the alternate bands in the onion ring was found to be due to the di_erence in their grain size, misorientation, and precipitate content.

Comparison of the shear punch testing results in di_erent regions of the nugget revealed that, in spite of having local di_erences in the hardness of alternate bands in the onion ring, the presence of onion rings has no significant impact on the deterioration of the mechanical properties of the weld nugget.

In [18], a new algorithm was developed to determine the optimal parameters of friction welding with a change, including rotational speed, welding speed, axial reinforcement, tool pin profile and material tool. The objective of welding is to maximize the ultimate tensile strength of the welded aluminum. As a result, the optimal parameters were determined - rotation speed 1417.68 rpm, welding speed 60.21 mm/min, axial force 8.44 kN. And also achieved an increase in tensile strength by 1.48% and is 294.84 MPa.

Friction welding is an advanced technology for joining parts. Various studies have shown a significant dependence of the welding quality on the welding speed and the rotational speed of the tool. Frequently, an inappropriate setting of these parameters can be detected through an examination of the resulting surface defects, such as increased flash formation or surface galling.

In [19], two different learning algorithms were applied to improve the surface topography of friction stir welds. For this purpose, the surface topographies of 262 welds, which were performed as part of ten studies, were evaluated offline. The aim was to use reinforcement learning and Bayesian optimization approaches to determine the most appropriate settings for the welding speed and the rotational speed of the tool. The optimization problem was solved using reinforcement learning, specifically value iteration. However, the value iteration algorithm was not efficient, since all actions and states had to be iterated over, i.e., each possible parameter combination had to be evaluated, to find the best policy. As a result, the authors proposed to solve the optimization problem directly using Bayesian optimization.

In [20], the interfacial temperature, microstructure, and hardness distribution of linear friction-welded Ti-6Al-4V joints obtained at various applied pressures were studied. The sound Ti-6Al-4V alloy joints were successfully fabricated below the β-phase transformation temperature. It has been established that an increase in pressure significantly reduces the welding temperature. It was also found that the hardness in the center of the weld is higher than that of the base material without a softening zone in the thermomechanical impact zone, which indicates an improvement in the mechanical properties of the joints.

In [21], the process of friction welding of SA213 tube and SA387 tube plate was studied. It was revealed that grain refinement occurs in the welding zone, which, in turn, increases the tensile strength. The exceptional weld strength (tensile strength) was obtained when joining of SA213 tube and SA387 tube plate through interference fit using a holding block without a hole in the tube. Experimentally, it was found that the achieved tensile strengths were 836.8 MPa (without a hole) and 789.35 MPa (with hole) using the holding block, respectively.

In [22] the effect of different friction pressure on the microstructural and mechanical properties of a friction welded joint was studied. These friction pressures are 110, 130, 150 and 170 MPa, with all other conditions remaining constant. The tensile tests carried out on the standardized test piece with diameter 6 mm and 8 mm, thus, compression tests were extracted from the positions of 0°, 45° and 90° with test specimen of 4 mm diameter and 6.5 mm length at weld center. Whereas, the impact test pieces were picked up in two positions, the first one is symmetrical, which it obtained to the respect of the rotation axis and the interface, on the other hand, the second one is non-symmetrical with the axis of rotation and symmetrical to the interface, for making the notch head coincide with the center of the welded joint, The obtained results showed that with reducing of friction pressure will present lack of bonding increasing from peripheral toward the welding center, which will responsible on reducing of the mechanical properties such as tensile, compression and impact strength.

The results of the study showed that the friction welding method is widely studied by scientists from different countries and is used to join homogeneous as well as dissimilar materials.

The purpose of this article is to determine the strength of welded joints obtained by friction welding. For this, tensile tests were carried out in a special test center and using the Solidworks program.

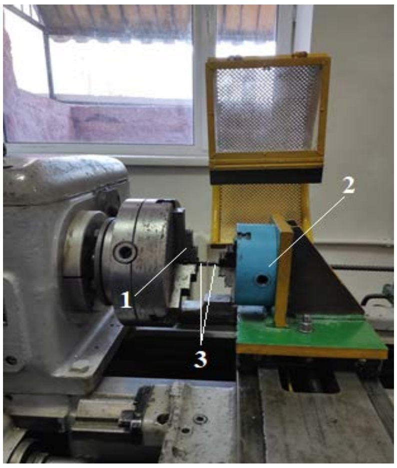
2 MATERIALS AND METHODS

2.1 Research methodology

The research methodology is based on the position of such sciences as concrete products manufacturing technology, welding technologies and equipment, theory of welding processes. To joining the non-dimensional segments of the reinforcement, a friction welding method was selected. Experimental studies were carried out on a special friction welding device mounted on the basis of a lathe in the conditions of the laboratory base of the Department of Technological Equipment, Mechanical Engineering and Standardization of the Karaganda Technical University. The samples of reinforcing bars joint by friction welding passed a tensile test at the testing center of "National Center of Expertise and Certification" JSC (Karaganda, Kazakhstan). 'Solidworks' computer program was used to test samples of welded reinforcing bars for static tension with the determination of the tensile strength depending on the loads.

2.2 Connection of non-dimensional segments of reinforcement by friction welding

The non-dimensional segments of the reinforcement were joining by friction welding. To implement the friction welding method, a special device based on a lathe was developed [23] and manufactured. Figure 1 shows a friction welding device based on a lathe.



1 – three-jawed lathe chuck; 2 – three-jawed special device chuck; 3 – fixed workpieces

Figure 1. Friction welding device based on a lathe

Figure 2 shows the process of friction welding of non-dimensional segments of reinforcement.

a) b) c)

a – slab process; b,c – friction welding process

Figure 2. The process of friction welding of non-dimensional segments of reinforcement

For joining by friction welding, non-dimensional segments of reinforcing bars with diameters of 8 mm, 12 mm and 14 mm were used as blanks.

Table 1 shows the chemical composition of reinforcing steel 25G2S.

Table 1. Chemical composition of reinforcing steel 25G2S, %

C (carbon)	Mn (manganese)	Si (silicon)
0,20 - 0,32	1,20 - 1,60	0,60 - 0,90

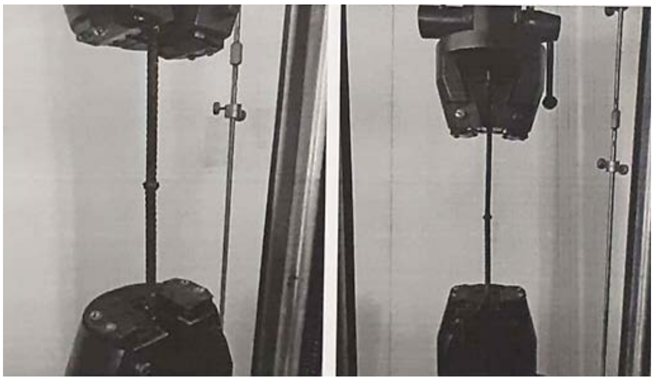
Slabs were fixed in three-cam cartridges of a lathe and a special device. During welding, the workpiece fixed in the three-jawed chuck of the machine has a rotational movement, while the second workpiece fixed in the three-cam chuck of the device is not movable. The friction welding force is carried out by the feeding movement of the device fixed on the lathe caliper. During the experiments, the spindle speed of the machine was varied in the range of $n_{шп}$ = 685-2000 rpm. Figure 3 shows some reinforcing bars joint by friction welding.

Figure 3. Some reinforcing bars joint by friction welding

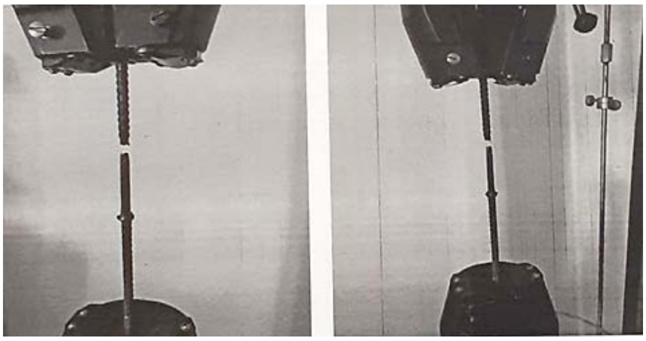
During an external inspection of samples of non-dimensional segments of reinforcement joint by friction welding, external defects of the welding zone, such as splashes, cracks and sinks were not detected.

2.3 Tensile testing of samples

The received samples of reinforcing bars have passed a tensile test at the testing center of "National Center of Expertise and Certification" JSC. Figure 4 shows the process of testing a sample of a welded reinforcing bar.



a)



b)

a – the process of elongation to break; b – after break

Figure 4. The process of testing a sample of a welded reinforcing bar

As a result of the test, it was found that the fittings comply with the requirements established by GOST (State Union Standard) 34028-2016 [24]. The mechanical properties of the welded joint are higher than the properties of the base metal of the reinforcing bar (see Table 2).

Table 2. Mechanical properties of metal

The name of the indicator	Regulatory document for the test method	The norm of the indicator according to GOST 34028-2016	The actual value of the indicator
Yield strength, not less than, N/mm^2	GOST 12004 - 81	390	490
Breaking strength, not less than, Н/мм^2		590	670

2.4 Simulation of the elongation testing process

To determine the strength of the reinforcement, static tensile tests are carried out with the determination of the strength limit depending on the loads. In bar lintels, Class A-III reinforcement is used as a frame. Class A-III steel is considered the most common in the production of untensioned working reinforcement. The diameter of Class A-

III steel is from 6 to 40 mm, the tensile strength is 600 MPa [25]. Due to these characteristics, Class A-III reinforcing steel is perfectly suitable for the manufacture of prestressed reinforced concrete structures used in construction. In the 'Solidworks' program, a model of a reinforcement with a welded region was built (Figure 5).

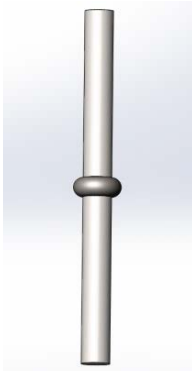
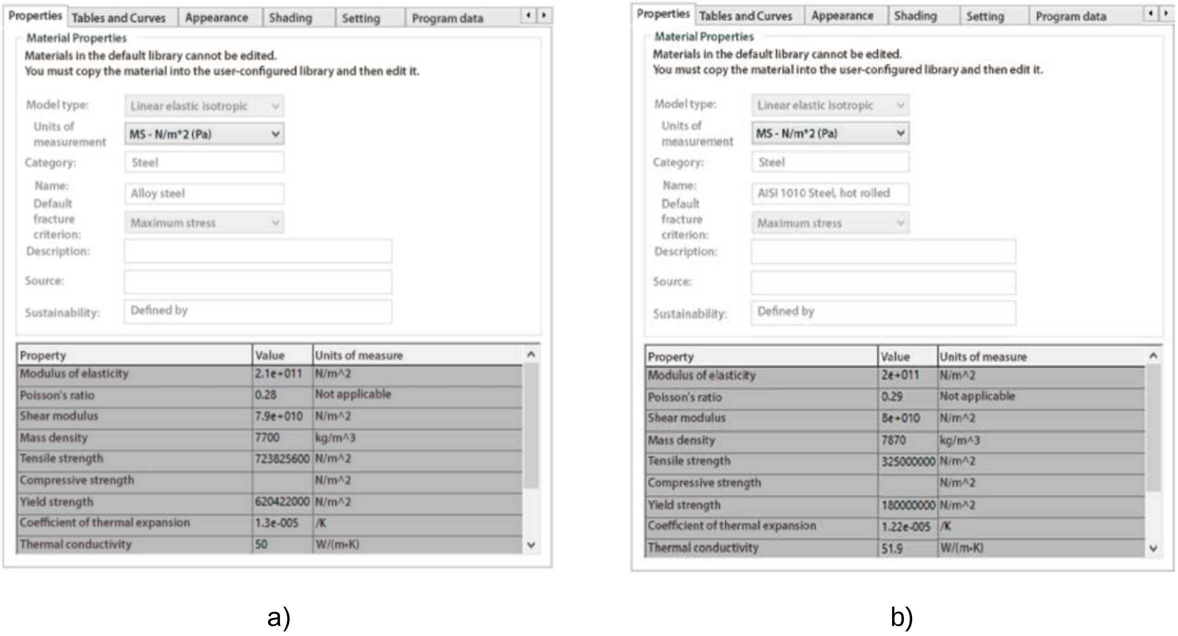


Figure 5. Three-dimensional model of the fitting under test

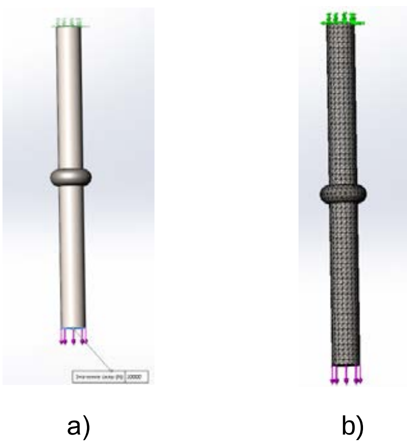
We enter the properties of the model material (reinforcement and weld) into the program library, the data are shown in Figure 6.



a – for fitting; b – for welded region

Figure 6. Purpose of the model material for reinforcement and welded region

We conducted a simulation of the tensile reinforcement with welded region. The load on the bar is given static, this is a strength calculation, in which it is assumed that the load will be unchanged over time, and the behavior of the material will be linear, that is, the stresses change in proportion to the increase in load. Figures 7 show the mounting and loading locations, as well as the creation of a finite element grid.



a – attachment points and loads; b – finite element grid

Figure 7. Attachment points and loads, finite element grid

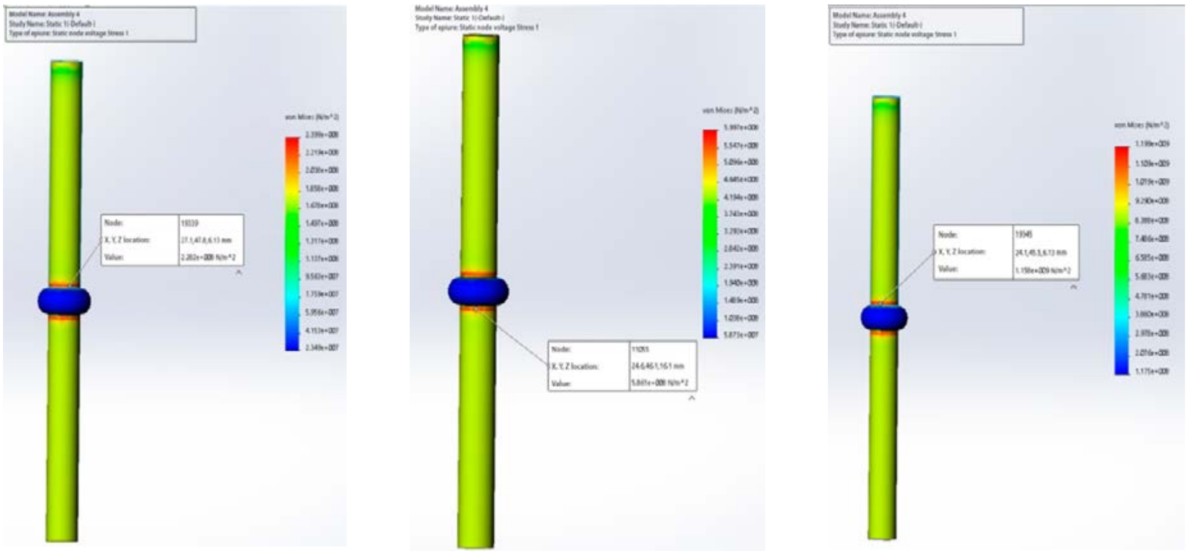
To assess the suitability of the reinforcement steel with a welded region for a specific operation, it is necessary to take into account the effect of stresses acting on the wall at each segment of the reinforcement. This is necessary in order to make sure that the cumulative value of all stresses does not exceed a certain percentage (usually 80%) of the yield strength of the material from which the reinforcement is made. The generally accepted approach in this situation is to use von Mises formula, which allows us to calculate the total equivalent voltage at each section of the reinforcement caused by the combination of forces acting on the column. The stresses are determined from von Mises yielding condition by the formula:

$$(\sigma_1-\sigma_2)^2+(\sigma_1-\sigma_2)^2+(\sigma_1-\sigma_2)^2=2\sigma_{\text{т}}^2.$$

or

$$\sigma_{\text{мизес}}=\sqrt{\frac{(\sigma_1-\sigma_2)^2+(\sigma_1-\sigma_2)^2+(\sigma_1-\sigma_2)^2}{2}}$$

where σ_1, σ_2,σ_3 – main simple tensions; von Mises criterion determines the moment of exhaustion of the bearing capacity by comparing the equivalent stress with the ultimate strength in the simulation. When simulating the tensile test of the reinforcement with a welded region, loads equal to 20kN, 50kN, 100kN were selected (Figure 8).



a) b) c)

a – at a load of 20kN; b – at a load of 50kN; c - at a load of 100kN

Figure 8. Simulation of the elongation testing process of welded reinforcement under various loads

The breaking strength of the reinforcement material is 600 MPa [25]. Let's compare the obtained values of the tensile strength with the corresponding load of the reinforcement.

3 RESULTS AND DISCUSSION

When analyzing Figure 8, it can be seen that the rod has certain stresses on the surface, the greatest stress value is formed around the weld joint, i.e. in the base metal of the reinforcement, and welded region is not significantly loaded. Figure 8, a shows that at a load of 20 kN, the stress on the surface of the rod is about 149 MPa along the axis, the greatest stress value is formed around the joint of the weld, i.e. in the base metal and is 228-240 MPa, which is below the tensile strength of 600 MPa, while the region itself has the lowest tension up to 50 MPa.

With further loading of the reinforcement with a force of up to 50 kN (Figure 8, b), the stress values around the cross section of the weld (i.e. in the base metal) increase to 586 MPa, which approaches the permissible strength limit of 600 MPa. The stresses on the surface of the rod and on the weld increase to values up to 450 MPa and up to 100 MPa, respectively.

With further loading up to 100 kN (Fig. 8, b), the maximum stress is 1158-1199 MPa, which exceeds the tensile strength of 600 MPa and leads to the destruction of the reinforcement, which is natural. The results of the elongation testing carried out at the testing center and the simulation of the tensile testing process show the possibility of using welded reinforcing rods from non-dimensional segments of reinforcement in the manufacture of reinforced concrete products, in particular bar bridges. Prototypes of welded reinforcing bars have been tested in accordance with the regulatory data for reinforced concrete products, in particular bar lintels.

If we compare the results of the tensile test carried out in the test center and the simulation of the tensile test process, we can make sure that the welded region is stronger than the base metal of the reinforcement. During tensile tests in the testing center of JSC "National Center for Expertise and Certification", the rupture of welded reinforcement occurs in the metal (see Fig. 4, b). When modeling, the highest stress value is also formed in the metal near the welded region. Both results confirm the applicability of welded reinforcement in the manufacture of frames for reinforced concrete products.

4 CONCLUSIONS

As a result of the tests carried out, the possibility of using welded reinforcing rods from non-dimensional segments of reinforcement in the manufacture of reinforced concrete products, in particular bar lintels, was established.

At various loads, the stress on the surface of the reinforcing bar is less than 600 MPa, which corresponds to regulatory documents. At the same time, the maximum stresses are formed in the base metal, and there is the least tension in the weld. This coincides with the test results at the testing center of "National Center of Expertise and Certification" JSC (see Fig.4)

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