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THEORETICAL AND EXPERIMENTAL RESEARCH OF STRENGTH OF SOLDERED JOINTS (METAL OF SHARE – METAL CERAMICS)

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Abstract. This article presents theoretical estimate of soldered strain and the obtained equivalent stresses distributions along the share length. It is suggested to estimate the soldered joints strength taking into consideration complicated character of stress condition taking place in the elements under loading. The main factors influencing soldered joints strength are defined in the article. Clearance gap between soldered samples, the overlapping area and groove depth are referred to these factors. The soldered samples tests on force of tear and shear showed that strength σ_B of soldered joint for metal of share Л65 and metal ceramic plate of alloy ВК-8, corresponds to σ_B = 119,6…120,6 MPa at clearance gap 0,5...0,75 mm, that is proved with the theory.

Key words: *plow share, metal ceramic plate, hydrogen-oxygen flame, tangential and normal stresses, soldering, hardness, restoration.*

INTRODUCTION

In recent years to increase the wear resistance of operation bodies of tillage machines, particularly, plow shares metal ceramics plates are used. The problem arises at fixing the plates to share surface. Inadequate adhesive strength of today used glued connection decreases the share potential resource [1]. Researches are directed to the practicability and efficiency of operating surface formation by metal ceramics hard-face

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plates applying braze welding aiming at the plow share restoration and increasing its resource by 4-5 times.

Purpose is to estimate the hardness of soldered connection and the peculiarities of strain-stress state at soldering the metal ceramics plates to plow share blade using the hydrogen-oxygen flame.

MATERIALS AND METHODS

To test the soldering applying electrolyser "Energya-1,5 УХЛ4" we carried out the calculations of tangential τ and normal stresses σ_1, σ_2 and the distribution of stresses along the length of the soldered connection, also we carried out laboratory tests of soldered pieces for cutting (τ_{cp}), tear ($\sigma_в$) using device ИР-500.

RESULTS AND DISCUSSION

To solve the problem of application of the electrolysers in the repair industry particularly for metal ceramics plates soldering to plow share is necessary to solve the following problems: to investigate the soldering mechanism with hydrogen-oxygen flame usage, to develop and optimize the technological solutions of realization of soldering with hydrogen-oxygen flame; to investigate the hardness of soldered connections for cutting and compression; to calculate economic efficiency of electrolysers application at plow share restoration.

At estimation of the soldered connections the complicated type of strain-stress state appearing in their elements at on-load was taken into consideration. The hardness of soldered connection is defined first of all by peculiarities of strain-stress state in soldered joint. That is why the main attention we pay to the analysis of stresses in soldered joints of overlapped soldered connections. If we suppose that stresses in a joint do not exceed the solder alloy elastic limit then for soldered connection it is possible to use the data obtained for glued and soldered connections in the limits of elasticity.

Strain-stress state in soldered joint in overlapped soldered connections is considered to be plain. Tangential τ and normal stresses σ_1, σ_2, are created in soldered joint under the influence of external forces. Tangential stresses according to [2-5] correspond to 0,5…0,6 from acceptable values of normal stresses:

$$\tau = (0,5...0,6)\sigma \tag{1}$$

where:

τ [MPa] - tangential stress,
σ [MPa] - normal stress.

More than that, as the connecting elements are inset it is necessary to calculate the connections for tear by normal stresses.

Tangential stresses concentrators will be higher, the higher the ratio of elasticity modules of connected elements E_1 and E_2 to solder alloy elasticity module E.

Stresses, according to Sazhin (1964) [3], in overlapped soldered connections are distributed in the following way. In the connecting elements normal stresses σ_1 and σ_2 and the corresponding to them deformations appear ε_1 and ε_1 in the soldered joint only tangential stresses τ and the corresponding to them angular deformations $\dot{j}$ (Fig. 2) appear.

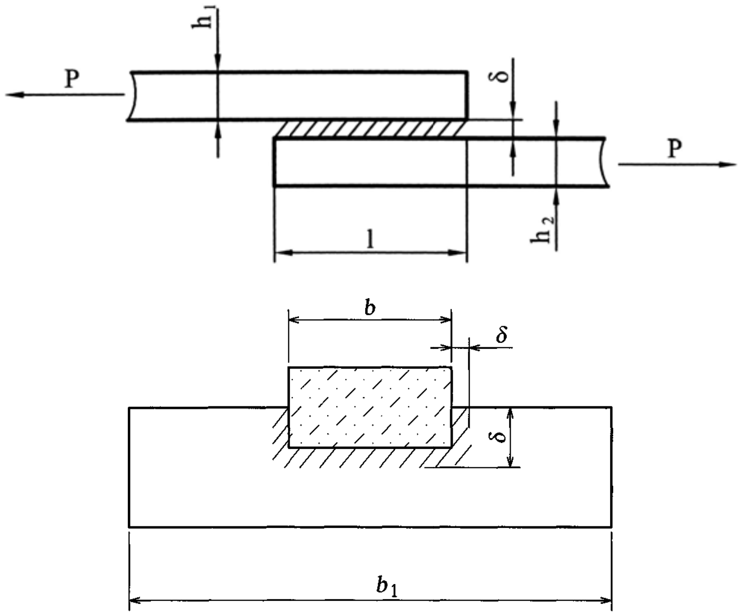


Figure 1. overlapped soldered connection:
l - lap length, mm; δ - soldered joint thickness, mm; h_1, h_2 - elements thickness, mm;
P - force, H; b – lap width, mm; b_1 – piece length, mm

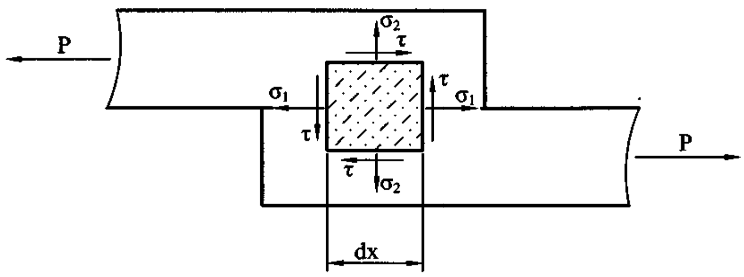


Figure 2. Type of the strain-stress state in overlapped soldered joint:
σ_1 - axial stress, MPa; σ_2 - tear stress, MPa; τ - tangential stress, MPa

$$\frac{\delta \cdot dj}{dx} = \varepsilon_2 - \varepsilon_1 \qquad (2)$$

where:

δ [mm] - soldered joint thickness,
ε_1 [-] - axial deformation,
ε_2 [-] - tear deformation.

From equilibrium condition of soldered connection we obtain:

$$\frac{h_1 \cdot d\sigma_1}{dx} = -\tau \qquad \frac{h_2 \cdot d\sigma_2}{dx} = \tau$$

$$\sigma_1 \cdot h_1 + \sigma_2 \cdot h_2 = P / b \tag{3}$$

where
σ_1 [MPa] - axial stress,
σ_2 [MPa] - tear stress,
h_1, h_2 [mm] - elements thickness,
P [N] - force,
b [mm] - lap width.

According to Guck's law:

$$\sigma_1 = E_1 \cdot \varepsilon_1$$

$$\sigma_2 = E_2 \cdot \varepsilon_2 \tag{4}$$

$$\tau = j \cdot G$$

where:
E_1, E_2 [10^{-9}Pa] - elasticity modules of joint elements related to elasticity module of alloy E,
j [-] - angular deformation,
G [MPa] - shear module of soldered seam

Solution to equations (4) – (6) gives:

$$\sigma_2'' - \alpha_{\Pi} \cdot \sigma_2' + \beta_{\Pi} \cdot \sigma_2 = 0 \tag{5}$$

where:
σ_2'' [MPa] - the second derived function of stresses,
σ_2' [MPa] - the first derived function of stresses,
$\alpha_{\Pi} = \sqrt{\beta_{\Pi} / \psi_{\Pi}}$ [$1 \cdot mm^{-1}$]- ratio showing the changes of stiffness properties of metal of share Л-65 at its connection with soldered element (metal ceramics alloy ВК-8),
$\beta_{\Pi} = G / (\delta \cdot E_1 \cdot h_1)$ [$1 \cdot mm^{-2}$] - aspect ratio of shear stiffness and tension to joint width and soldered element (metal

ceramics alloy BK-8),

$\psi_{\Pi} = E_2 \cdot h_2 / (E_1 \cdot h_1 + E_2 \cdot h_2)$ [-] - Aspect ratio of resistance (stiffness) of elements in soldered connection.

Paying attention to the obtained aspect ratios solution to Eq. (5) allows the definition of stresses in arbitrary point of soldered connection depending on coordinate x.

$$\begin{cases} \sigma_1 = \sigma_{10}\left[1 - \psi_{\Pi} \cdot \left(1 - ch(\alpha_{\Pi} \cdot x)\right)\right] - \dfrac{1 - \psi_{\Pi} \cdot \left(1 - ch(\alpha_{\Pi} \cdot l)\right)}{sh(\alpha_{\Pi} \cdot l) \cdot sh(\alpha_{\Pi} \cdot x)} \\ \sigma_2 = \sigma_{2l}\left[\psi_{\Pi}\left(1 - ch(\alpha_{\Pi} \cdot x)\right)\right] + \dfrac{1 - \psi_{\Pi} \cdot \left(1 - ch(\alpha_{\Pi} \cdot l)\right)}{sh(\alpha_{\Pi} \cdot l) \cdot sh(\alpha_{\Pi} \cdot x)} \\ \tau = \tau_m \cdot \alpha_{\Pi} \cdot l \cdot \dfrac{1 - \psi_{\Pi} \cdot \left(1 - sh(\alpha_{\Pi} \cdot l)\right)}{sh(\alpha_{\Pi} \cdot l) \cdot ch(\alpha_{\Pi} \cdot x) - \psi_{\Pi} \cdot sh(\alpha_{\Pi} \cdot x)} \end{cases} \quad (6)$$

where:

l [mm] - lap length,
τ_m [MPa] - tangential stress of flow limit,
ch [-] - hyperbolic cosine of cut angle,
sh [-] - hyperbolic sine of cut angle.

We'll obtain: $\tau_{x=0} = \tau_{x=l} = 8 \cdot \tau_m$.

Stresses are connected with deformations by the following relations:

$$\varepsilon_1 = \frac{N_1 \cdot F_1}{E_1}$$

$$\varepsilon_2 = \frac{N_2 \cdot F_2}{E_2} \quad (7)$$

$$\varepsilon_y = \frac{\sigma_y}{E}$$

$$j = \frac{\tau}{G}$$

where:

N [N] - normal force undergoing deformations of extension or compression,
F [mm^2] - cross-section area of soldered connection.

From equilibrium condition:

$$N_1' = -\tau$$
$$N_2' = \tau \tag{8}$$

where:

N_1', N_2' [-] - the first area derivative.

From equation system (6) – (8):

$$\tau''' - \mu_1^2 \cdot \tau = 0 \text{ – transcendent equation,} \tag{9}$$

where:

τ''' [MPa] - the third derivative from tangential stress,

$\mu_1 = \sqrt{8 \cdot G/(E_1 \cdot h_1 \cdot \delta)} = \sqrt{8 \cdot \beta_\Pi}$ [1·mm^{-1}] - ratio taking into consideration the force distribution to soldered connection width.

Solution to equation (11) gives particular and total solution for center.

$$\tau = \eta_1 + \upsilon_1 \cdot \frac{ch\left(\frac{\mu_1}{x}\right)}{sh\left(\frac{\mu_1}{l}\right)} \tag{10}$$

where:

$\eta_1 = 3 \cdot N_0/(8 \cdot \ell)$ [N/mm] - ratio taking into consideration the force distribution to unit length of soldered connection.

$$\upsilon_1 = \mu_1 \cdot \frac{N_0}{8}$$

where:

N_0 [kN·mm^{-1}] - effort from extension of solid beam, having a form of soldered connection to width of element being soldered:

$N_0 = P/b = 52{,}945$ kN·mm^{-1}

The ratio analysis (6) shows that the most hard will be connections with straps that have $h_1 = 0{,}5 \cdot h_2$. Bearing capacity of this connections is by 1,31 times higher in comparison with the connection with one strap. Deviation of straps width in any side from optimal ratio can decrease bearing capacity of connection.

In analogy (6) to normal stresses σ_1 and σ_2 ratio deduced by Sazhin (1964) [3] the formula to calculate the elements with symmetric lap along tangential stresses is obtained.

$$\tau = \tau_m \left\{ 1 - \left[\frac{A_1}{\cos(2\pi x)} + A_2 \cdot \cos(4\pi x) \right] \right\} \qquad (11)$$

where:

$$A_1 = \frac{a^2 + 53{,}2 \cdot a + 1000}{0{,}5 \cdot a^2 + 35{,}6 \cdot a + 542}$$

$$A_2 = \frac{9 \cdot a + 42}{0{,}5 \cdot a^2 + 35{,}6 \cdot a + 542}$$

[-] - ratios being obtained at approximation the obtained solutions by program complex Table Curve 2.0,

$$a = \frac{G \cdot l^2}{E_1 \cdot h_1 \cdot \delta}$$

[-] - ratio of joint resistance to metal cutting of share Л-65.

Polynominal functions in Fig. 3 are obtained.

All the described dependences show good reproducibility.

Calculations on the ratios for stresses obtained by different ways coordinate with each other with error to 5% that is a result of the correctness of the presented model.

Maximum stresses values obtained at the calculations on cutting and tear are 5 times less than stresses in the maximum loaded connection element that gives evidence of its high durability.

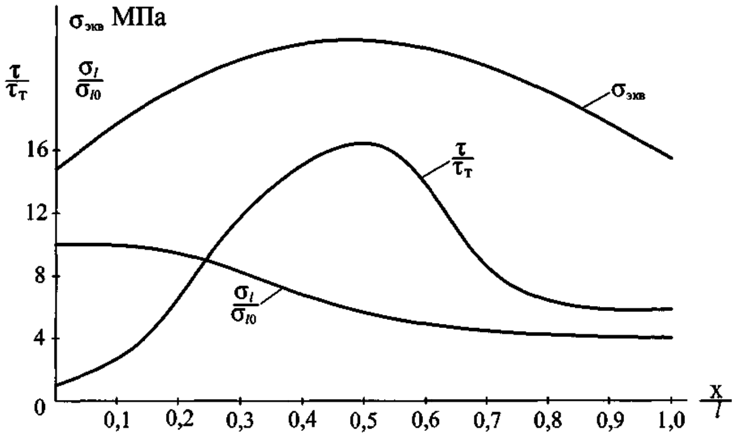


Figure 3. Distribution of the stresses influencing a share to the stresses corresponding to the material elastic ratio

For alloy ВК-8 stresses values correspond to 115…120 MPa.

The calculation results and their checking according to III and IV failure theory show that the equivalent stresses in the given soldered connection reach 25…28 MPa, that is as mentioned above considerably lower than the ultimate values obtained at the experiment.

III – failure theory $\sigma_{экв} = \sqrt{\sigma^2 + 4 \cdot \tau^2} \leq [\sigma] = 120$ MPa.

IV – failure theory $\sigma_{экв} = \sqrt{\sigma^2 + 3 \cdot \tau^2} \leq [\sigma] = 115$ MPa.

The suggested type of connection can bear the calculated load excess by 4…5 times. That gives the evidence reliability of connection at dynamic effects with the dynamic response factor ($k_д$) $k_д = 5$ and is a good result.

To proof the theoretical calculations the investigations of experimental determination of the soldered connections indicators according to the requirements of the state standard at using hydrogen-oxygen flame are carried out.

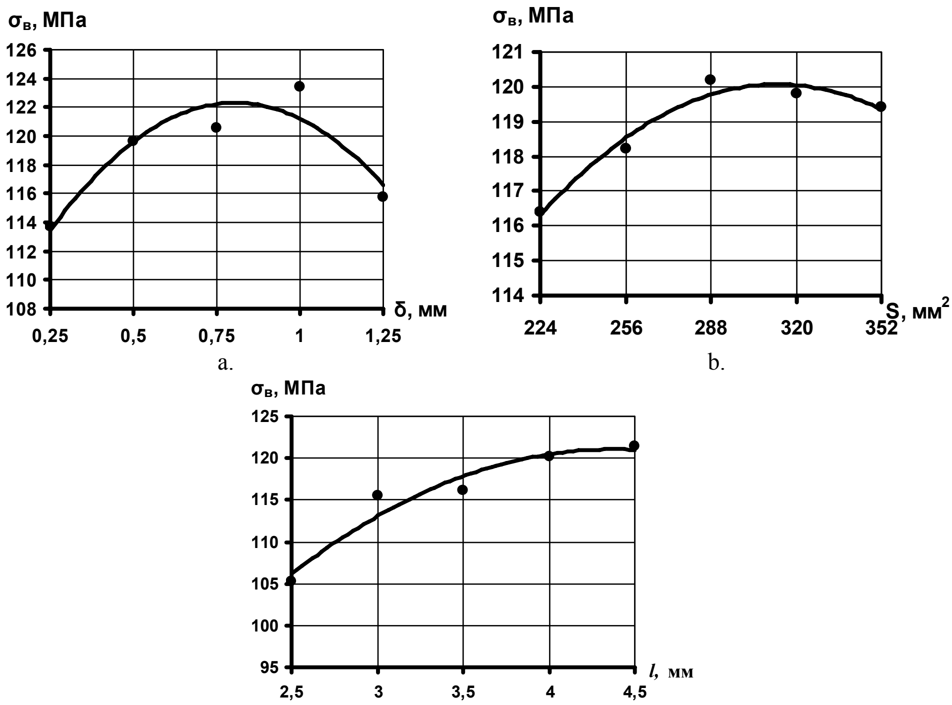
Results of experimental research

It is proved that with the overlapping area increase the joint strength increases too. The rational overlapping area is 288…320 mm^2 (Fig. 4, б). At overlapping area increase more than stated values the ultimate strength decreases. It corresponds to the dependence of solder flowing area from contact angle (Fig. 5). For example, for alloy ВК-8 at contact angle decrease β=16^o solder flowing area increases (S=395 mm^2), but at increase of β=25^o solder flowing area decreases (S=316 mm^2). Such kind of dependence is typical for share steel Л-65. The obtained data corresponds to the necessary technical requirements.

At increase of slot depth strength increases (Fig. 4, c), the rational slot depth is 4…4,5 mm. The mentioned depth is provided with the ultimate share thickness.

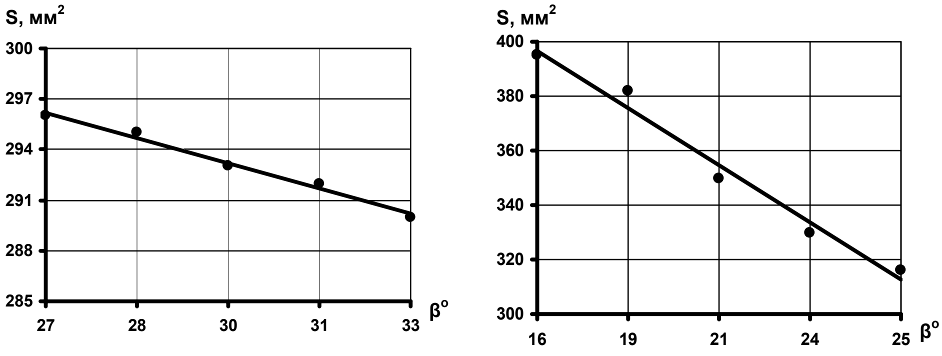
The analysis of slot between soldered samples (Fig. 4, a) showed that the optimal strength of the soldered joint 123 MPa is obtained when slot is 1,0 mm. Rational slot between soldered samples is 0,5…0,75 mm. Thus the soldered joint strength will be 120…121 MPa. It is connected with the fact that when the slots are more than 0,8 mm the layered directed crystallization resulting in fraction formation is observed.

To define the influence of the main factors, influencing on the strength change σ_B, and also their mutual interaction complete factor test is done 2^3. Investigated factors: x_1 – slot between soldered samples, δ, mm; x_2 – the overlapping area of metal ceramics plates, S, mm^2; x_3– slot depth, l, mm. Response function y is strength σ_B of soldered samples from metal ceramics (ВК-8) and share steel (Л65), MPa.



c.

Figure 4. Dependence of strength σ_B of soldered sample joint from metal ceramics (ВК-8) and share metal (Л65) from:
a. slot between soldered samples δ, mm,
b. solder flowing areas S, mm^2,
c. slot depth l, mm.



a) b)

Figure 5. Dependence of solder flowing area from contact angle for materials from metal ceramics plate ВК-8 (a) and share metal Л65 (b)

The investigated process is adequately described with the regression equation:

$$Y=41{,}5649+34{,}4625x_1+0{,}1767x_2+8{,}3407x_3-0{,}0107x_1x_2+3{,}3926x_1x_3+ \\ +0{,}0162x_2x_3-22{,}97x_1^2-0{,}0004x_2^2-1{,}1493x_3^2 \quad (12)$$

The given equation rather precisely describes the factor influence depending on the slot between soldered samples, slot depth and plate overlapping area.

Regression coefficient calculations and other statistical indicators were carried out with computing aids usage, application soft Microsoft Excel. According to the analysis the change of soldered joint strength is maximally influenced with the slot between soldered samples and minimally with slot depth. The influence of plate overlapping area is inconsiderable.

It follows from the theory that the most dangerous section along the tangent stresses is midsection of soldered seam. Maximum normal stress at the boundary of soldered seam, according to the chart (Fig. 3), but the most dangerous will be the section of soldered seam where tangent and normal stresses are great. The results agree with theory because the practically obtained correlation is x/l=0,45, but in theory is x/l=0,5.

Overlapping of three charts (Fig. 4, a, b, c) with single scale of abscissas allows to chose the rational parameters of overlapping area, slot depth, slot between soldered samples using three maximum peak stresses. Matching them with Fig. 3 shows good reproducibility according to III and IV strength theory.

At the same time we determined: wetting along the contact angle and spreading radius; gap-filling with solder alloy; corrosive resistance; adhesive strength; we carried out the metallographic observations.

In Orel State Agrarian University soldered hydrogen-oxygen device "Energya-1,5 УХЛ4" [6] was used at the investigation of the soldered process with application of hydrogen-oxygen flame.

CONCLUSIONS

1. As the result of the analysis the theoretical dependences of ultimate stress σ_B of soldered joints of samples from share metal (Л65) and metal-ceramics plate (ВК-8) from clearance gap between soldered samples δ, from overlapping area of plate S and groove depth l are obtained. The most rational values of ultimate stress will be provided at S=256…320 mm^2, δ=0,5…1,0 mm, l=3,5…4,0 mm.

2. The suggested type of connection can bear the calculated load excess by 4…5 times. That gives the evidence reliability of connection at dynamic effects with the dynamic response factor (k_∂) $k_\partial = 5$.

3. Adhesive strength of metal-ceramics plates on share metal obtained by means of soldering using hydrogen-oxygen flame depends on overlapping area, groove depth and clearance gap between soldered samples.

4. Soldered sample tests using hydrogen-oxygen flame on force of tear and shear demonstrated strength σ_B of soldered joint for metal of share Л65 and metal-ceramics plate was σ_B = 119,6…120,6 MPa at clearance gap 0,5...1,0 mm, that is proved with the theory.

5. The mentioned full 2-leveled factor experiment of type 2^3, that was done in the local time limit demonstrates that the theoretical values of ultimate stress σ_B practically do not differ from experimental values.

6. The technology of plow share restoration by soldering using hydrogen-oxygen flame with high strength properties of soldered connections is developed. It allows reducing the production cost of restoration using cheap hydrogen-oxygen gas mixture being obtained as a result of water electrolyser and through utilization of metal ceramics plates in tool-producing industry.

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TEORIJSKO I EKSPERIMENTALNO ISTRAŽIVANJE JAČINE LEMLJENIH SPOJEVA (METAL METAL – METAL KERAMIKA)

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Sažetak. Ovaj rad predstavlja teorijsku procenu jačine lema i postignutih ekvivalentnih distribucija duž spoja. Predloženo je da se proceni jačina lemljenih spojeva uzimajući u obzir komplikovani karakter uslova kojima su elementi izloženi pod opterećenjem. U radu su definisani osnovni faktori koji utiču na jačinu lemljenih spojeva. Zazor između lemljenih uzoraka, zona preklapanja i dubina su svrstani u ove faktore. Testovi lemljenih spojeva na sile kidanja i smicanja pokazali su da jačina σ_B lemljenog spoja metala Л65 i metal-keramičke ploče legure ВК-8, odgovara intervalu σ_B = 119,6…120,6 MPa pri zazoru 0,5...0,75 mm, što je teorijski dokazano.

Ključne reči: *plužno smicanje, metal-keramička ploča, vodonično-kiseonični plamen, tangencijalna i normalna opterećenja, lemljenje, tvrdoća, obnova.*

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