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The algorithm of constructor and technological

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Abstract. On the basis of the pulse-pressure model of the velocity-induced de-formation of metal pipes proposed by the authors [1] the expanding plas-ma channel of an electric spark, the influence of the collision angle and the contact point speed on the quality of welding of pipes with a tube grid of a heat exchanger were investigated. An algorithm for estimating welding zones is proposed. The applicability of the algorithm is tested on pairs of pipe made of alloy AD1 + tube made of alloy AMg6.

1 Introduction

To create and maintain temperature conditions at technological installations of energy facilities and other industries it is necessary to supply or remove of thermal energy from the working environment. To perform this function heat transfer equipment (heat exchanger) has found wide application.

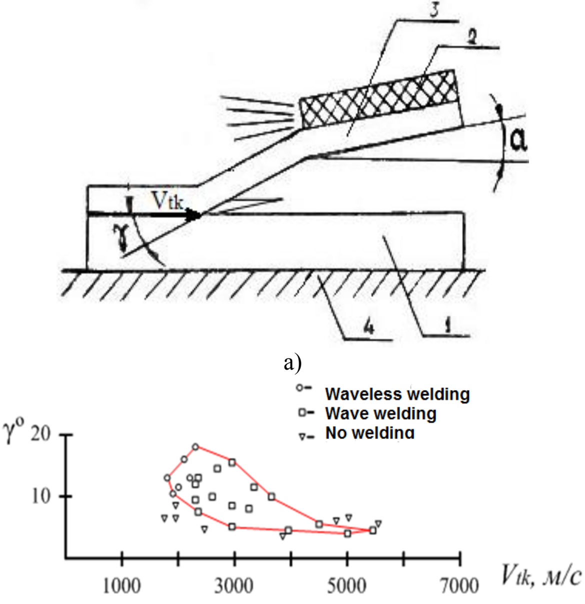
The reliability of the heat exchanging equipment in the modes at elevated pressures and temperatures, cyclic loads, etc., is largely determined by the quality of the one-piece connection pipe-tube system. For all types of heat exchangers the connection of pipes with tube lattice is carried out mainly by placing the pipes in the holes of the tube grid and fixing them with one of the known methods - flaring, soldering, welding, or their combinations. [2, 3]

The main disadvantage of pipe mounting in tube lattice by the method of expansion is a violation of the density of the connection during transportation, installation and operation. Failures for this reason in the initial period are 30%. Replacing rolling by welding increases the reliability of pipe-lattice connections. However, if there is a gap between the pipe and the grille, all the loads perceived by the pipe during operation, caused by the typical expansion of the pipe, its vibration, are transmitted directly to the seam, which can cause its destruction. [2-4]

Fastening pipes in grid of pipes of heat exchangers using a technology based on the use of a pulsed pressure source, for example, an expanding plasma channel initiated by an electrical conductor explosion (ECE) [5, 6], is a good solution to a complex technological operation.

The fastening of the pipe in the grid of pipes connections by this method consists in the high-speed impact of the pipe surface when it is deformed by pulsed pressure with the inner surface of the hole in the grid of pipes. The source of the impulse pressure is the plasma channel of an electric spark initiated by the ECE. ECE itself occurs when current flows through a conductor located in a condensed medium, with a current pulse with an amplitude of up to 100 kA for several tens of microseconds. [7] Thanks to this, in a single operation, it is possible to obtain flaring and joining of a pipe with a tube sheet that is not inferior in quality to welding. [5, 6]

To obtain a welded joint, by means of a velocity impact, the parameters of a collision (angle of impact – γ, throwing speed – $V_м$ and the speed of the contact point – V_{tk}) must be in the range of values that provide welding. [8] The welding scheme and area of welding are shown in Fig. 1. a and b respectively.



a)

b)

Fig. 1 - Scheme of explosion welding: 1 - fixed part (base); 2 - explosive charge; 3 - throwing part; 4 - surface [8]

Despite the fact that the mechanism of formation of a welded joint is the same as technology based on the use of explosives, there are some distinctive features. For

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example, in the case of high-speed deformation of a pipe by impulse pressure, due to the influence of free surfaces of the end parts of an electro-explosive cartridge, where ECE arises, the deformable section has a barrel-shaped shape. Therefore, the parameters of a collision are not constant over the length of the contact (the line or the area of the collision of surfaces), vary widely, and in some cases go beyond the limits where welding takes place.

Thus, the purpose of this work is to develop an algorithm for estimating the parameters of the high-speed collision of metal pipes by the pulse pressure of an expanding electric spark plasma channel and determining the dimensions of the connections line which has a welding zone.

The scope of welding in this paper will understand a combination of the parameters of the collision – γ and contact point speeds – V_{tk} (Fig. 1, b). The connection line is the border on which the external surface of the deformable pipe and the internal surface of the tube are collided. The welding zone is the border of collision, in which solid-phase welding is formed due to the joint elastoplastic deformation of the contact volumes of the welded materials [9].

2 Experimental researches

To assess the possibility of applying the method based The scheme of the experiment is shown in Fig. 2.The sequence of the experiment is as follows. A battery of high-voltage capacitors, charged from a constant voltage source, is discharged to a conductor placed in a transmission medium in an electric-explosion cartridge (Fig. 3). When the switch is triggered, a pulsed current in conductor flows in the form of a damped sinusoid with an oscillation period of the order of 40-50 ms with an amplitude of up to 100 kA. As a result, the conductor in the cartridge explode, a pulse pressure wave is formed, which causes the metal pipe to deform at high speed.

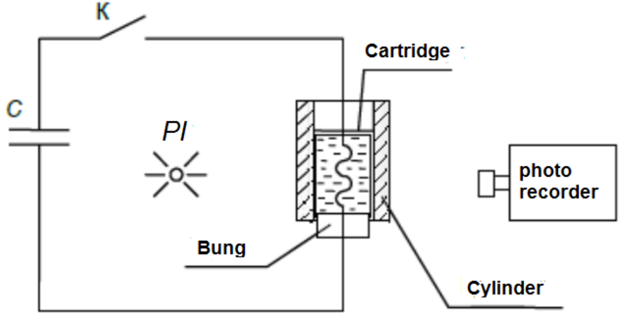


Fig. 2 - Installation diagram for photo-graphic registration of the velocity defor-mation of hollow metal cylinders: K - switch; C - battery capacity; photographic recorder; PI - pulse illumination

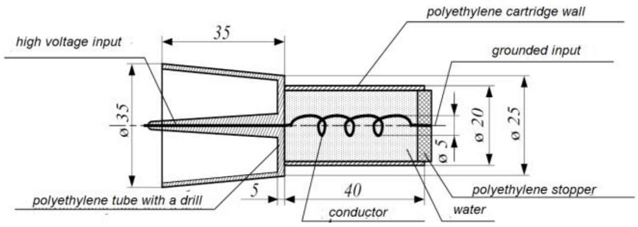
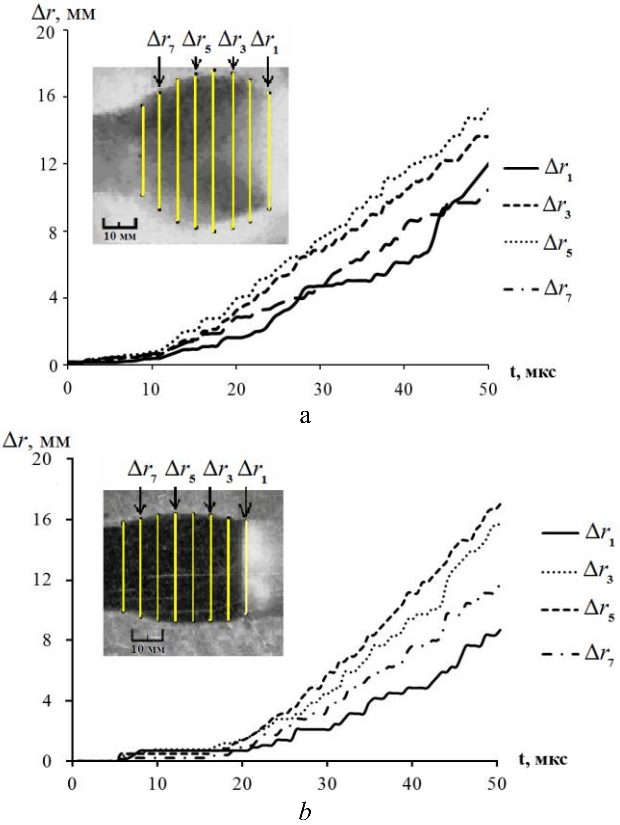


Fig. 3 - Sketch cartridge

Mechanisms for the explosion of a conductor are described in [7]. The cartridge (Fig. 3) is made according to [5] and is a hollow thin-walled polyethylene cylinder with the acoustic stiffness of a material comparable in size to water. From the end with a grounded end of the exploding conductor was performed sealing polyethylene tube. On the high-voltage side, the polyethylene tube was made in the form of a truncated cone. Aluminum wire with a diameter of 0.6-0.8 mm in the form of a spiral was used as a conductor. According to [5, 10–13], such a cartridge design provides for the rate of deformation of pipes made of aluminum and brass alloys more than 100 m / s.

For the evaluation of parameters high-speed imaging was used. Alloy tubes were used as samples AD1 и L70. The high-speed deformation of pipes made of aluminum alloy AD1 with a diameter of 28 mm and a wall thickness of 4 mm (28x4 mm) and brass L70 25x2.5 mm was filmed with an SFR-2M camera in frame-by-frame mode at a speed of 1.75 106 frames per second. According to the results of high-speed frame processing, the pipe deformation kinetics for a number of sections was constructed. The dependences of the increments of pipe radii over sections (Δr) and the photo image of the deformation are shown in Fig. 4 a, b.



a

b

Fig. 4 - Kinetics of pipe deformation: at the top of the frames of high-speed shooting with sections along the length of the pipe Δr_1, Δr_3, Δr_5, Δr_7; bottom tube deformation from time to time; a - alloy AD1; b - alloy L70

The analysis of dependencies (Fig. 4) showed that the deformation occurs discretely with decreasing speed towards the ends of the electroexplosive cartridge. This is particularly evident at the end of the pipe near the polyethylene tube of the cartridge in sections $\Delta r_1 - \Delta r_3$.

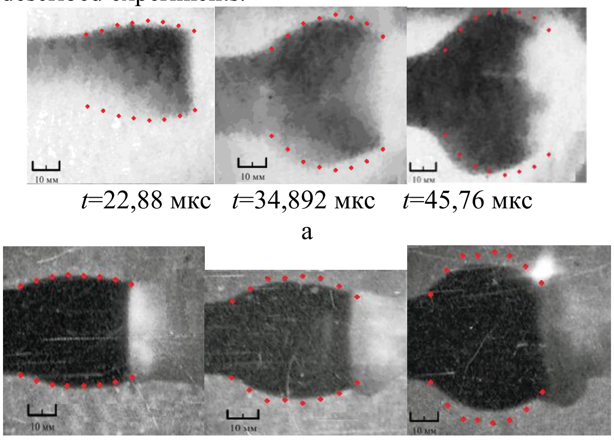
Discreteness of deformation is a consequence of the impact of a pulsed pressure wave that undergoes repeated reflections in the gap between the plasma channel and the pipe wall. [13] The barrel-shaped profile of deformation and a smaller amount of deformation of the pipe wall at the ends of the electro-explosive cartridge are explained by the decrease in pressure on pipe wall by pressure waves reflected from the free end parts of the cartridge. The obtained frames of filming the deformation of the pipe walls made it possible to estimate the amplitude of the pressure wave from the movement curves of the polyethylene plug in the end part of the cartridge, constructed from photographs of high-speed photographing. Amplitude of the pressure wave amounted to more than 750 MPa.

3 Modeling

To study the rate of tube deformation, a physic-mathematical model has been proposed that allows reproducing the pipe deformation kinetics, which is basically based on the wave nature of acoustic wave propagation in condensed media. [1] To simulate the wave process of propagation and reflection of acoustic waves in the transmitting medium, in the gap the spark channel - the pipe wall used an analogy in the description of the wave process of acoustic and electromagnetic waves. Model representations are implemented in a computer program. The algorithm and programs are detailed in [1].

According to the simulation results, the calculated values (shown by dots in Fig. 5) of the velocity deformation of pipes were found, then they were compared with the experimental high-speed deformation images for pipes of the brand AD1 (28x4 mm) and L70 (25x2.5 mm).

In fig. 6 a, b there are calculated and experimental strain kinetics of aluminum alloy pipes, respectively AD1 and brass L70 in the central section for the previously described experiments.



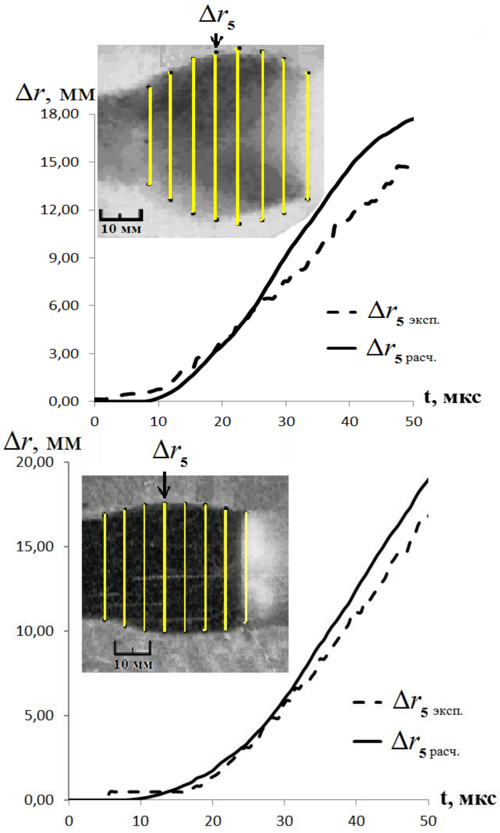
t=22,88 мкс *t*=34,892 мкс *t*=45,76 мкс

a

t=22,88 мкс *t*=34,892 мкс *t*=45,76 мкс

b

Fig. 5 - Estimated (points) and experimental strain velocity images for pipes a) of the mark AD1 (28x4 мм) and b) marks L70 (25x2,5 мм) for some points in time



a *b*

Fig.6 - Kinetics of the calculated (dotted) and experimental deformation of aluminum AD1 (*a*) and brass L70 (*b*) pipe section Δr_5

Comparison of the calculated and experimental deformation profiles of the pipe shows their good agreement.

4 Algorithm for estimating impact parameters and welding zones

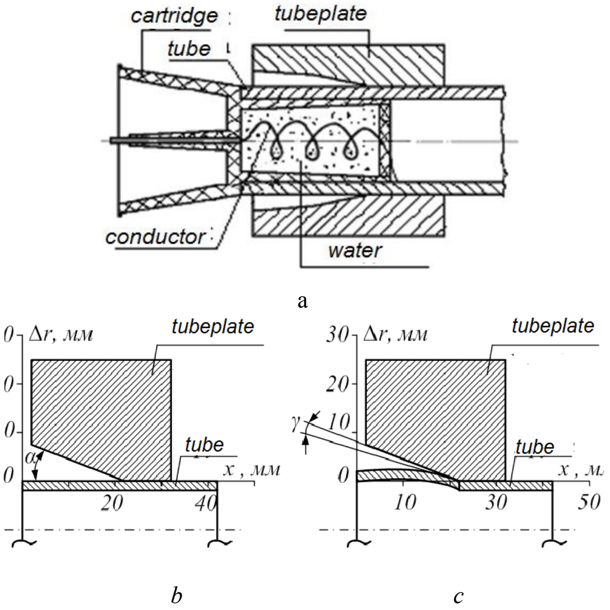
The results of experimental studies and modeling of pipe deformation allow us to determine the amount of pipe deformation in the corresponding section in any point in time. From the values of the distance between the joined parts, it is possible to estimate the parameters of the collision. The following algorithm has been developed for estimating collision parameters based on computer simulation results.

1. A diagram of the connection of tubular parts (Fig. 7).
2. For a deformable pipe, computer modeling is performed, as it was described previously.
3. Based on the simulation results, an array of deformations is built $\Delta r_n(x_n, t_n)$, where x_n – the distance from the pipe end on the outer surface of the pipe to the section *n*, t_n – time of deformation before collision in cross section *n*, the number of sections n is chosen arbitrarily at the modeling stage.
4. Based on the results, an array of values is compiled (Table 1).

Table 1

$\Delta r_n(x_n, t_n)$	x_1	x_2	…	x_{n-1}	x_n
t_1	$\Delta r_1(x_1, t_1)$	$\Delta r_1(x_2, t_1)$	…	$\Delta r_{n-1}(x_{n-1}, t_1)$	$\Delta r_n(x_n, t_1)$
t_2	$\Delta r_2(x_1, t_2)$	$\Delta r_2(x_2, t_2)$	…	$\Delta r_{n-1}(x_{n-1}, t_2)$	$\Delta r_n(x_n, t_2)$
…	…	…	…	…	…
t_{n-1}	$\Delta r_{n-1}(x_1, t_{n-1})$	$\Delta r_{n-1}(x_2, t_{n-1})$	…	$\Delta r_{n-1}(x_{n-1}, t_{n-1})$	$\Delta r_{n-1}(x_n, t_{n-1})$
t_n	$\Delta r_n(x_1, t_n)$	$\Delta r_n(x_2, t_n)$	…	$\Delta r_{n-1}(x_{n-1}, t_n)$	$\Delta r_n(x_n, t_n)$
t_{n+1}	$\Delta r_n(x_1, t_{n+1})$	$\Delta r_n(x_2, t_{n+1})$	…	$\Delta r_{n-1}(x_{n-1}, t_{n+1})$	$\Delta r_n(x_n, t_{n+1})$

Based on table 1, a deformation profile is constructed depending on the x coordinate, where each pipe deformation curve corresponds to its own moment of time t. To demonstrate the model, the calculation is made for a pipe made of brass L62 and shown in Fig. 8.



b c

Fig. 7 - Connection diagram of tubular parts: a) layout of the cartridge, pipe and tube sheet; b) before deformation; c) after deformation

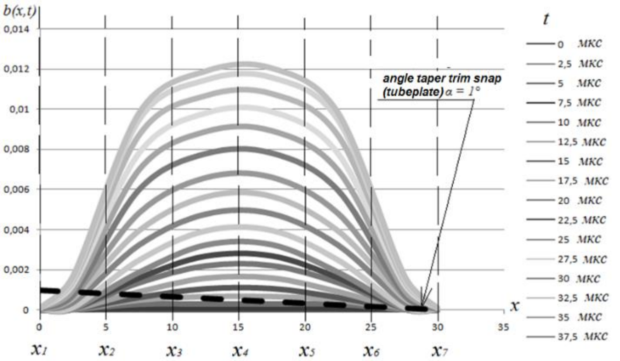
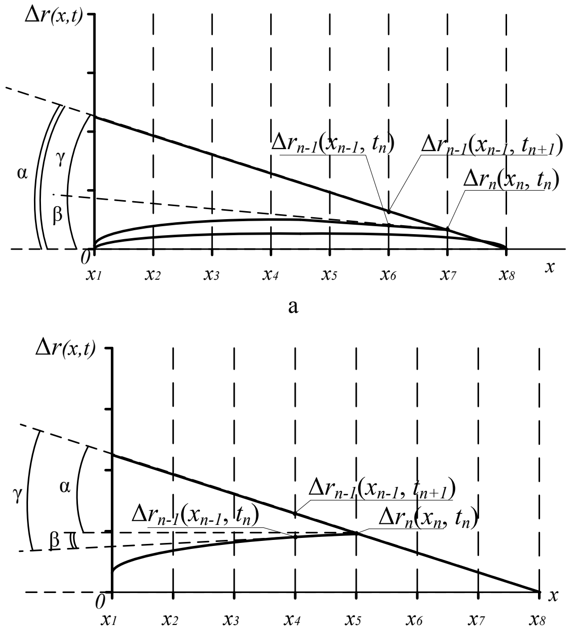


Fig.8 - Simulated deformation profile, for example, for brass pipe L63 (20x2 мм) at a taper angle $\alpha = 1^{\circ}$

5. According to the profile of the deformation and the angle of the conical cutting, for each section $n(x_n)$ determined by $\Delta r_n(x_n, t_n)$ at the point of impact (at the point of intersection of the deformation curve and the line forming the angle of the conical groove (Fig. 7)), $\Delta r_{n-1}(x_{n-1}, t_n)$ and $\Delta r_{n-1}(x_{n-1}, t_{n+1})$ in the adjacent section (Fig.9).



b

Fig. 9 - Diagrams for determining the angle of impact

6. Determining the angle of collision of parts γ, as the sum of the angles α - the angle of the conical cutting and β – the angle formed by the tangent at the point of impact to the surface of the deformable pipe section:

when $\Delta r_{n-1}(x_{n-1}, t_{n+1}) \geq \Delta r_{n-1}(x_{n-1}, t_n) \geq \Delta r_n(x_n, t_n)$ (Fig. 9 a), when

$$\gamma = \alpha - \beta \tag{1}$$

where β determined by the ratio

$$\beta = \arccos\left[\frac{\Delta x}{\sqrt{(\Delta r_{n-1}(x_{n-1}, t_n) - \Delta r_n(x_n, t_n))^2 + \Delta x^2}}\right] \tag{2}$$

where $\Delta x = x_n - x_{n-1}$.

when $\Delta r_n(x_{n-1}, t_{n+1}) \geq \Delta r_n(x_n, t_n) \geq \Delta r_{n-1}(x_{n-1}, t_n)$ (Fig. 9 *b*)

$$\gamma = \alpha + \beta \tag{3}$$

where β is determined

$$\beta = \arccos\left[\frac{\Delta x}{\sqrt{(\Delta r_n(x_n, t_n) - \Delta r_{n-1}(x_{n-1}, t_n))^2 + \Delta x^2}}\right] \tag{4}$$

If $\Delta r_{n-1}(x_{n-1}, t_n) \geq \Delta r_n(x_n, t_n) \geq \Delta r_n(x_n, t_n)$, then the point of contact has the opposite direction and moves from $\Delta r_{n-1}(x_{n-1})$ to $\Delta r_n(x_n)$, then the condition is $\Delta r_{n-1}(x_{n-1}, t_n) \geq \Delta r_n(x_n, t_{n+1}) \geq \Delta r_n(x_n, t_n)$

$$\gamma = \beta - \alpha \tag{5}$$

where β is determined from the relation

$$\beta = arctg\left[\frac{\Delta r_{n-1} - \Delta r_n}{\Delta x}\right] \tag{6}$$

Thus, the angle of collision is determined in each section.

7. At this stage, we determine the speed of the point of contact($V_{m\kappa}$). Δl- moving from point $\Delta r_n(x_n)$ to the point $\Delta r_{n-1}(x_{n-1})$ on the surface of the tube plate (Fig. 10)

$$\Delta l = \frac{\Delta x}{\cos\alpha} \tag{7}$$

The magnitude of the velocity of the point of contact is estimated by the formula

$$V_{m\kappa} = \frac{\Delta l}{\Delta t} = \frac{\Delta x}{\Delta t \cdot \cos\alpha} = \frac{\Delta r}{\Delta t \cdot \sin\alpha} \tag{8}$$

Where $\Delta r = \Delta r_{n-1}(x_{n-1}) - \Delta r_n(x_n)$; $\Delta t = t_{n-1} - t_n$.

8. Compiled dependence in the coordinate systems ($V_{m\kappa}$, γ, x), where ($V_{m\kappa}$, γ) area of welding is marked by coordinates.

The calculated welding location determines the boundaries of its probable existence in coordinates ($V_{m\kappa}$, γ). Borders can be determined by empirical or calculated methods. Consider an empirical method for determining the areas of welding to test the algorithm for determining the parameters of a collision and the applicability of the deformation model. Based on the proposed mathematical model of deformation according to the algorithm for calculating the collision parameters ($V_{m\kappa}$, γ) welding zones for a pair are defined: alloy pipe AD1 Ø 28x4 mm and alloy tube plate AMg5. After that dependencies in the coordinate systems ($V_{m\kappa}$, γ, x) (fig.10) for the angle of the conical groove tube α = 6, 9, 12, 15^0 according to the scheme (Fig. 7, b) are built. Experimental welding zones for α = 6, 9, 12, 15^0 are built on the results of numerous experiments (≈ 100 experiments) electric explosion welding, the specified pair of pipe – tube plate. Welding zones were determined by polished micro-sections. Typical polished micro-sections is shown in Fig. 11.

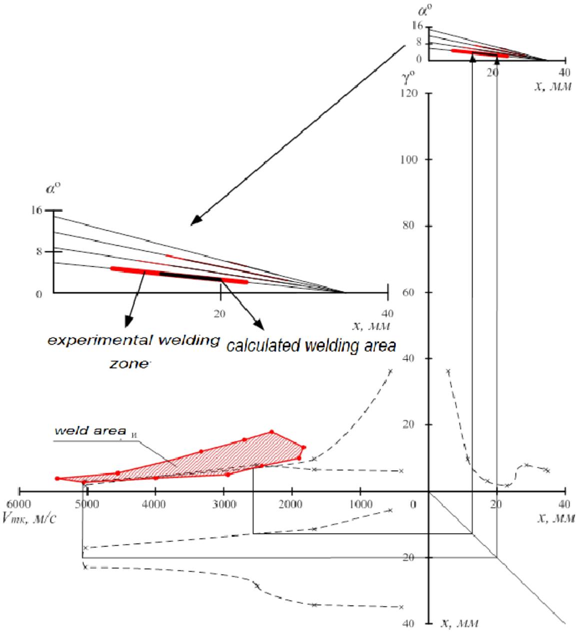


Fig. 10 - Welding zone assessment schemes

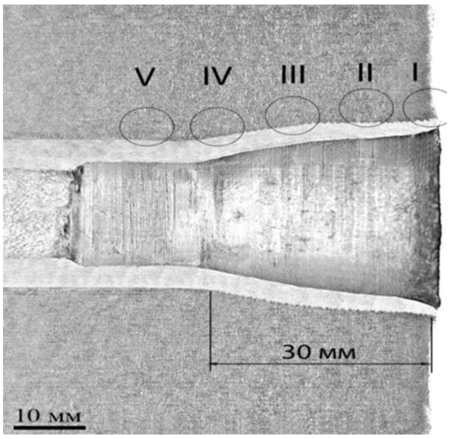


Fig. 11 - Macro sections of one-piece pair connections AD1+AMg5

The calculated areas of welding were determined by comparing the graphs of the calculated dependences of the collision angle on the point of contact with the boundaries of the experimental area of welding (according to literature data). The calculated zones of welding were compared with the experimental ones obtained during electric-explosion welding (Fig. 12). Comparison of the calculated and experimental zones of electric explosion welding (Fig. 12) shows their good agreement, which is more than 60%.

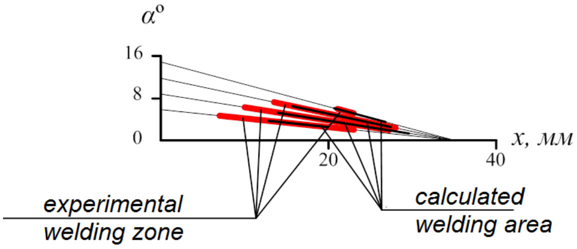


Fig. 12 - Comparison of the calculated and experimental zones of electric explosion welding for a pair AD1 and AMg5 for α = 6, 9, 12, 15^0

5 Conclusions

With the help of high-speed shadow photo-recording of tube deformation by the pulse pressure of an expanding electric-spark plasma channel, the strain kinetics of metal pipes was experimentally investigated.

On the basis of theoretical calculations using a mathematical model of the velocity deformation of tubular details by the pressure pulse of an expanding spark plasma channel, an algorithm is proposed and welding zones for a pair of AD1 + AMg6 alloys are determined. The calculations showed good coincidence with experiments on the connection of pipes with a tube sheet of AD1 + AMg6 alloys. The proposed algorithm for estimating the parameters of a collision makes it possible to determine the welding zone with a probability of more than 60%. Regulation of the mode of the pulse generator, change of the design parameters of an electrically explosive cartridge and parameters of the orifice of the tube plate allows control of the collision of the parts to be joined and to ensure high quality welding. The estimates are made for the material of the pipe, which has information in the literature. However, in the production such materials are often used about which there is no information on the areas of welding, for example, a pair of brass L63 and steel grade Art.3. Therefore, further research in this area is planned to focus on other materials with the goal of developing an information base and debugging models for the velocity deformation of pipes and an algorithm for estimating impact parameters.

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