V. I. Savuliak, Dc. Sc. (Eng), Prof.; S. A. Zabolotny, Cand. Sc. (Eng); D. V. Bakalets

MINIMIZATION OF DEFORMATIONS AND THERMAL IMPACTS IN FRAME CONSTRUCTIONS WHILE WELDING OF REINFORCEMENT STRAPS

The problem of restoration of frame zones with originated cracks by means of welding is the hazard of basic metal damage as a result of physical structural transformations. The paper studies, using the design of multi-factorial experiment, the possibilities of reduction of temperature differences and deformations, which create the danger of microcracks emergence.

Key words: *cracks, repair welding, reinforcement, deformations, regression analysis.*

Introduction

Frame constructions of transport and technological vehicles in the process of operation receive static and dynamic loads, as a result of these loads cracks and other damages appear in certain areas of the frame [1].

The problem of reinforcement of dangerous areas by means of installation of additional elements as well as repair of such areas with originating cracks, is the danger of frame basic metal damaging as a result of negative processes, which may occur while welding. Powerful heat flows from welding arc, stresses and deformations, occuring as a result of welding, can be referred to negative processes [2 – 3]. Quality and strength of the weld (joint) depend on many factors and its form and dimensions in many cases become determining for evaluation of these indices [4 – 5]. But the research, carried out, do not contain definite recommendations, regarding the technology of welded joints execution in order to minimize deformations and stresses.

The aim of the paper is the search of the possibility to control heat flows and deformations in the materials of the pieces being welded, by means of process parameters change. In [2 – 4] it is shown, that formation of stress fields and deformations is influenced by nonumiformity and power of heat fluxes, generated by welding.

One of factors, influencing redistribution of heat flows between the material of the construction and the environment is spatial position of the electrode relatively the surfaces being welded.

In [6] it is shown that the angle of slope of the electrode influences the distribution of thermal energy along the volume of the piece and relation between absorbed and dissipated heat. These factors influence the form, the depth and the width of the joint being welded and especially influence the change of deformation value of the construction. Elaboration of recommendations regarding the choice of rational position of the electrode by the criterion of deformation minimization in the process of welding is the main task of the given paper.

Model of lap welding and main factors, influencing this process

The set of process parameters influence the temperature of construction while welding and the deformations, emerging as a result of this process [7 – 9]. However, the same temperatures t at the given point at certain distance l from the weld, can emerge at different sets of welding parameters values, and deformations Δ (Fig. 1), which are their consequence, change, depending on the duration of arc impact and variation of system thermal balance. Total geometry of the weld will change, in particular, penetration depth, side and coefficient of penetration form.

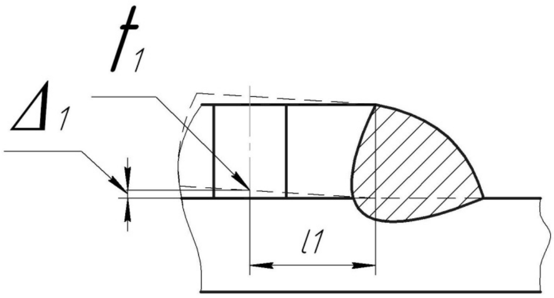


Fig. 1. Basic design variables

Let us consider the parameters performing the greatest impact on temperature fields and deformations in the process of lap welding of reinforcement elements. With the increase of metal thickness of these elements we have to decrease proportionally welding speed. Increase of the diameter of welding wire directly proportional increases welding speed, as it was established by the previous research. We take as variational such parameters: welding speed V_w, current I, and spatial position of the electrode relatively the piece, that is determined by the angle to the axis of weld β and by the angle in the plane, perpendicular to the axis of the weld α (Fig. 2).

It should be noted, that the angle to the axis of the weld β in the process of welding practically does not change. Variation of α angle while lap welding (Fig. 2) influences greatly the form of cross-section of the weld (Fig. 3) and, correspondingly, the volume of the metal to be introduced, this defines the welding speed.

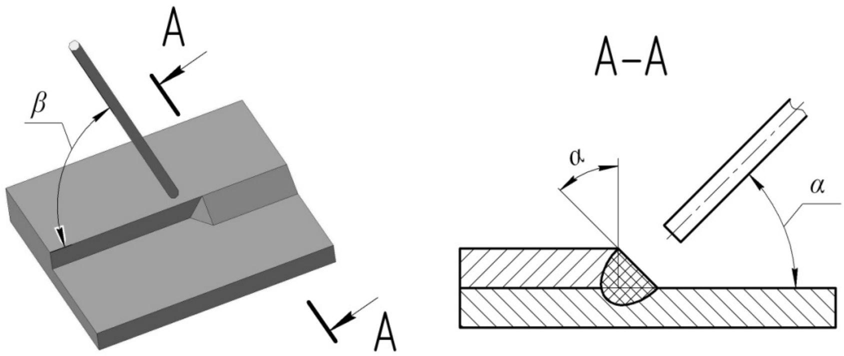


Fig. 2. Angles, determining the position of the electrode in the space

Values of the angle α, according to [10] may vary within the limits of 30 – 60°. Thicknesses of maintenance plates h in many cases do hot exceed 10 mm. Table 1 contains recommended values of welding speed for plates of different thicknesses and α angle.

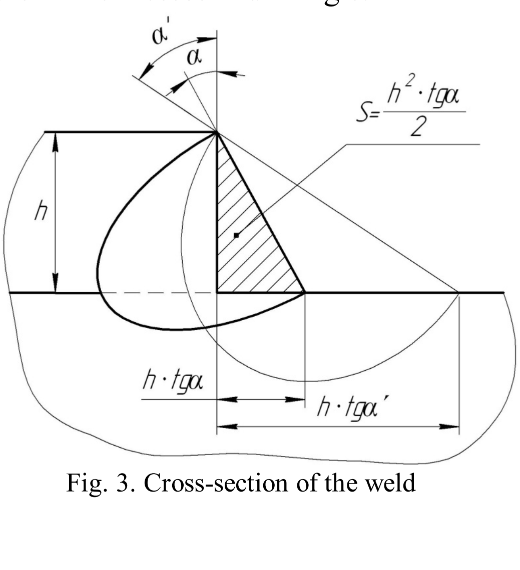


Fig. 3. Cross-section of the weld

Table 1

Recommended welding speed, m / h

Angle α °	Thickness of the plate h, m					
	0.003	0.004	0.005	0.006	0.008	0.010
30°	39.48	22.21	14.20	9.87	5.55	3.55
35°	32.55	18.31	11.72	8.14	4.58	2.93
40°	27.16	15.28	9.78	6.79	3.82	2.44
45°	22.79	12.82	8.21	5.70	3.21	2.05
50°	19.12	10.76	6.88	4.78	2.69	1.72
55°	15.96	8.98	5.75	3.99	2.24	1.44
60°	13.16	7.40	4.80	3.29	1.85	1.18

Calculation of welding parameters of reinforcement elements applying regression analysis

For the solution of the given problem, mathematical model, describing the influence of the determined parameters (V_w, I, α) on the temperature and deformations (T, Δ) has been developed. It is expedient to apply the method of planning and designing of complete factorial experiment with carrying out of regression analysis.

The technique of performing regression analysis is described in details in [11], that is why further we will describe only the results of its application.

The experiments have been carried out using the inverter welding power source, stand for measuring temperatures and deformations. Welding of test pieces, made of steel 09Г2С was performed with the electrode of Ø 3 mm.

Linear model obtained before, showed its inadequacy. That is why, it is expedient to use approximation of y_T and y_Δ by the polynomial of the second order:

$$y = b_0 + \sum_{1\le i\le k} b_i x_i + \sum_{1\le i\le l\le k} b_{il} x_i x_l + \sum_{1\le i\le k} b_{il} x_i^2 \qquad (1)$$

Variation intervals and levels of factors are given in Table 2.

For each separate experiment the set of blanks was manufactured. In the process of welding data, regarding temperature and deformation were taken from these blanks. Measurements were carried out by means of thermocouples, data from which were transmitted to the recorder and indicator with scale factor of 0.01 mm, the data from the indicator were recordered by video-camera.

Table 2

Variation intervals and levels of factors influencing the state of the piece in the process of welding

Factors	Variation intervals	Levels of factors		
		basic 0	upper +1	laver -1
x_1 – current, A	20	120	140	100
x_2 – welding speed, m / h	4.7	9.5	14.2	4.8
x_3 – electrode angle of slope, α °	15	45	60	30

Applying the technique, described in [11], the coefficients of regression equation for functions $y_T = f\ (I,\ V_w,\ \alpha)$ and their $y_\Delta = F\ (I,\ V_w,\ \alpha)$ and their dispersion are found. By the results of calculations and taking into account the significance of the coefficients regression equations have the form:

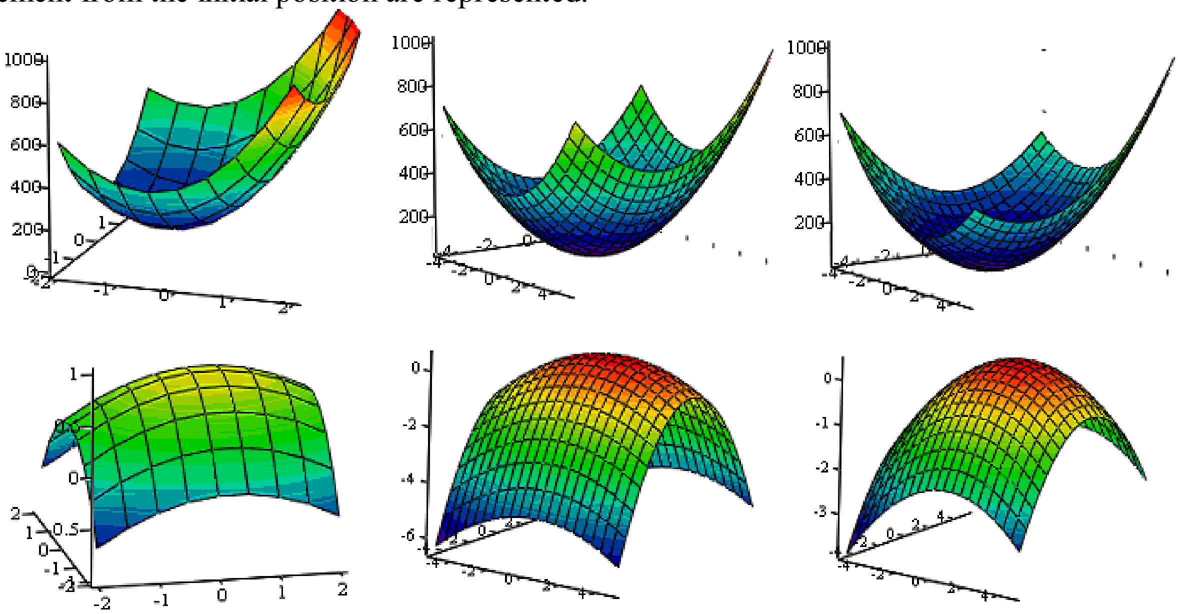
$$y_T = -12{,}104 + 98{,}596 \cdot x_2 + 23{,}523 \cdot x_3 + 13{,}884 \cdot x_1 \cdot x_3 + 28{,}643 \cdot x_2 \cdot x_3 + 90{,}02 \cdot x_3^2 . \quad (2)$$

$$y_\Delta = -0{,}537 + 0{,}095 \cdot x_1 + 0{,}017 \cdot x_3 + 0{,}075 \cdot x_1 \cdot x_3 - 0{,}199 \cdot x_3^2 . \quad (3)$$

The adequacy of the obtained models was checked by Fisher criterion. At 5% level of significance the table value of the criteria is F_T = 4.7. Calculation values of the criteria are F_{Tc} = 3.85 and $F_{\Delta c}$ = 4.4. Since calculation values are less than tabular value, the models are considered to be adequate.

Using the obtained regression equations (2, 3) a number of problems, emerging in the course of technological processes design, using arc welding can be solved. Problems of voltage minimization and welding deformations, as well as problem of heat absorption in order to avoid non-desirable structural deformations in the area of temperature influence are among these problems.

In Fig. 4 a – b, for the point, located at the distance of 5 mm from welding area, response surfaces which show the impact of current, welding speed, slope of the electrode on its temperature and displacement from the initial position are represented.



a) b) c)

Fig. 4. Response surfaces of the functions: a) $y(_T)$ and $y(_\Delta)$ at $I\ max$; b) $y(_T)$ and $y(_\Delta)$ at V_{max}; c) $y(_T)$ and $y(_\Delta)$ at α_{max}

All response surfaces (Fig. 4) showed the extremes, the smallest and greatest values of functions in the area of parameters variation. That is why, it is expedient for real technological processes to solve problems, using graphic-analytical method or by means of methods of linear programming by the algorithm, given below.

According to the obtained models (regression equations), at fixed value of one of the parameters of reinforcement elements welding process, isometric lines, showing the influence of other values of the parameters on temperature fields and deformations, caused by welding arc burning are built. For instance, setting minimal and maximum value of α angle (Fig. 4 a, b) we obtain isometric lines, that characterize the influence of welding speed and the strength of current on the temperatures and deformations in corresponding points.

Application of such techniques enables to determine necessary welding modes. Thus, we can determine modes, providing minimal value of deformations in the zone of temperature influence. Necessary relations of electrode angles of slope to welding speed should be taken into account. Their recommended values are given in Table 1.

The problem is solved by means of graphical method. For definition of deformations at fixed value of α angle (60˚ is chosen) on the graph of response surface $y_{(\Delta)}$ (Fig. 5a) the straight line of welding speed is built, it corresponds to the coordinate (-1), cross-section points with isometric lines of deformations are obtained. Minimal deformations will occur, at the strength of current I, that corresponds to the coordinate –0.95 along the axis I, maximum – deformations will be in region 1, they will be 0.228 mm. The graph (Fig. 5b) shows the response surfaces for the angle α = 30˚, welding speed will be maximum and will pass across the coordinate 1 and the axis V. Minimal and maximal deformations will be 0.147 and 0.362 mm, correspondingly.

By overlapping isothermic lines of the graph $y_{(T)}$ (Fig. 5c) on isothermic lines of deformations $y_{(\Delta)}$ (рис. 5 a) we obtain cross-section points, that enable to define the temperature and deformations for any point from the range of values (Fig. 5 d). For instance to obtain temperature 300 ˚C and deformations 0.27 at the point with the coordinates (-0.2; 0.8) it is necessary to set such modes: I = 116 A, V_w = 11.36 m / h, α = 60˚.

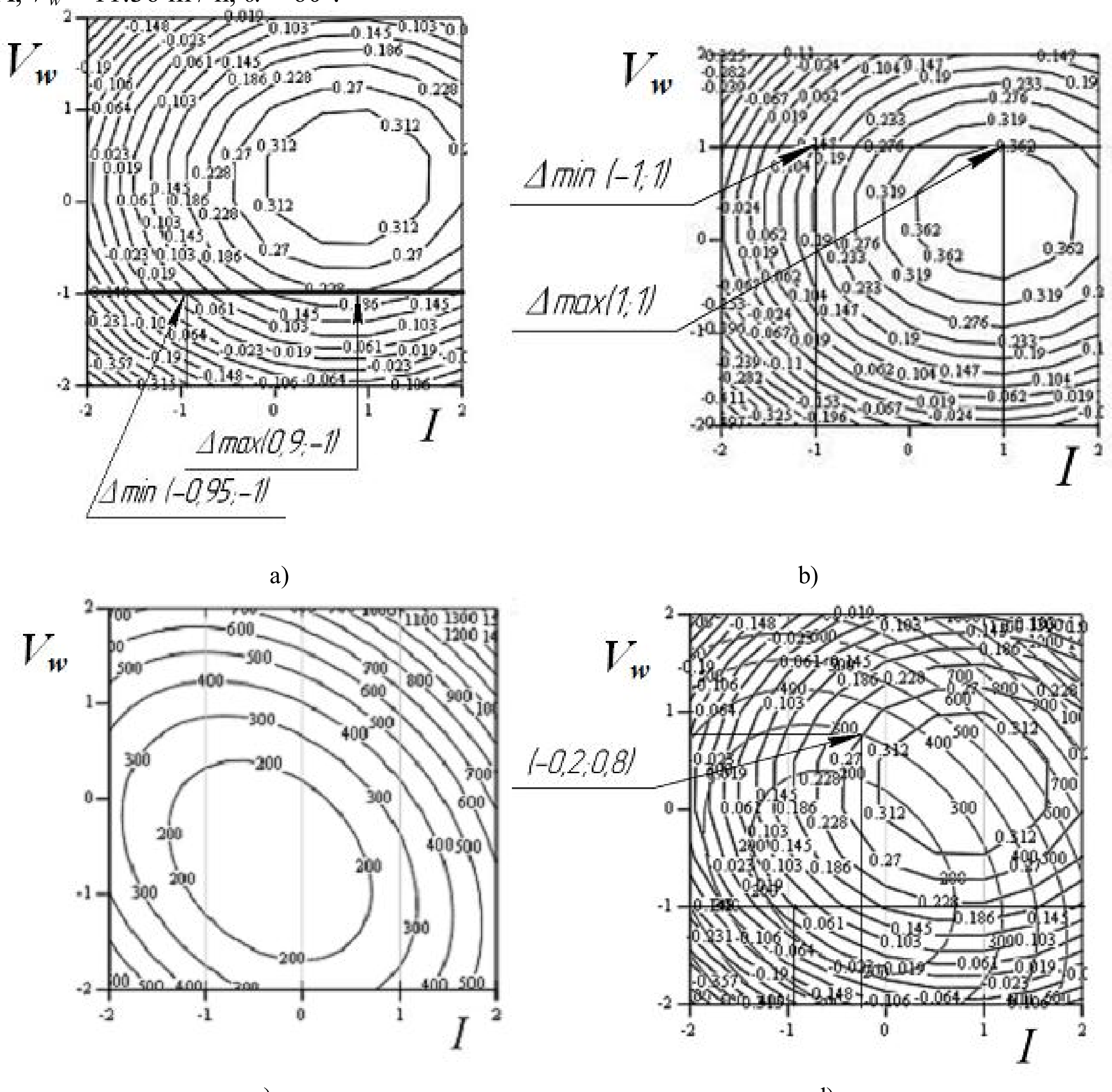


Fig. 5. Graphic solution of the problem of welding modes optimization problem

Conclusions

Determination of rational parameters, that provide minimal temperature influences and deformations in the process of reinforcement elements welding is expedient to perform using the suggested regression equations. Research, carried out, using the plan of multifactorial experiment, proved the possibility of deformations reduction, which provoke the danger of microcracks emerging, by means of changing electrode angle of slope in the process of welding.

Application of the technique of deformations minimization at the stages of the development of technological process of repair welding with welding of plates for reinforcement provided the reduction of deformations within the limits of 10 – 12% and allowed to calculate correctly temperature fields for prediction of phase transformations in the area of temperature influence of welding arc.

REFERENCES

1. Циклические деформации и усталость металлов. Т. 2. Долговечность металлов с учетом эксплуатационных и технологических факторов / [В. Т. Трощенко, Л. А. Хамаза, В. В. Покровский и др.]. – К. : Наук. думка, 1985. – 222 с.

2. Василик А. В. Теплові розрахунки при зварюванні / А. В. Василик, Я. А. Дрогомирецький, Я. А. Криль. – Івано-Франківськ : Факел, 2004. – 209 с.

3. Кархин В. А. Тепловые основы сварки / В. А. Кархин. – Л. : Изд-во Ленинград. гос. ин-та, 1990. – 100 с.

4. Осадчук В. А. Визначення тривісного розподілу залишкових напружень в зварних з’єднаннях елементів конструкцій прямолінійними швами і оцінка їх впливу на міцність з’єднань за наявності дефектів типу тріщин / В. А. Осадчук, Л. І. Цимбалюк, А. Р. Дзюбик // Математичні методи та фізико-механічні поля. – 2011. – 54, № 1. – С. 121 – 129.

5. Махненко В. И. Ресурс безопасной эксплуатации сварных соединений и узлов современных конструкций / В. И. Махненко. – Киев: Наук. думка, 2006. – 620 с.

6. Металлургия дуговой сварки: Процессы в дуге и плавление электродов / [И. К. Походня, В. Н. Горпенюк, С. С. Миличенко и др.] ; под ред. И. К. Походни. – АН УССР. Ин-т электросварки им. Е. О. Патона. – К.: Наукова думка, 1990. – 224 с.

7. Рыкалин Н. Н. Расчеты тепловых процесов при сварке / Н. Н. Рыкалин. — М. : Машиностроение, 1951. — 296 с.

8. Пригоровский Н. И. Методы и средства определения полей деформаций и напряжений: Справочник / Н. И. Пригоровский. – М. : Машиностроение, 1983. – 248 с.

9. Палаш Р. В. Визначення раціональних факторів впливу на залишкові напруження в зварних з'єднаннях конструкцій із високоміцних сталей / Р. В. Палаш // Науковий вісник УкрДЛТУ : зб. наук.-техн. праць. – Львів : УкрДЛТУ. – 2006. – № 16.6. – С. 87 – 89.

10. Сварка в машиностроении: Справочник в 4-х т. / Редкол.: Г. А. Николаев (пред.) и др. – М.: Машиностроение, 1978. – Т. 1 / Под ред. Н. А. Ольшанского. 1978. – 504 с.

11. Спиридонов А. А. Планирование эксперимента при исследовании технологических процессов / А. А. Спиридонов. – М.: Машиностроение, 1981. – 184 с.

Savuliak Valeriy – Dc. Sc.(Eng.), Professor, Head of the Chair of Wear Resistance Increase.

Zabolotny Sergiy – Cand. Sc.(Eng.), assis. Prof.; Chair of Wear Resistance Increase.

Bakalets Dmytro – Post Graduate, Chair of Wear Resistance Increase
Vinnytsia National Technical University.