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CONTROL OF THE STRENGTH PROPERTIES OF WELDED CONNECTIONS IN THE MANUFACTURE OF BUILDING STEEL STRUCTURES

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As is well known in construction, mechanized welding with self-shielded cored wire has found wide application. In this case, welding methods that are used do not always allow to realize the potential that is laid in this group of welding materials. In addition, modern welding methods are characterized by a large heat input in parts and welded joints. In this regard, in the article ways to improve the technological capabilities of mechanized welding with flux-cored wire by introducing modulated current into the production of building steel structures are discussed.

Key words: welding, self-shielded flux-cored wire, arc, stress, current strength, wire feed, welded joint, heat-affected zone, metal structure, strength.

Introduction. Steel structures are widely used in construction. There are many ways to connect their elements, but at the same time welding is most in demand. Therefore, the strength properties of steel structures also depend on the quality of welding.

In this regard, in recent years a lot of research has been devoted to improving the strength characteristics of steel structures through the introduction of new technological solutions, primarily in the welding industry.

In the production of building steel structures, mechanized electric-arc welding has found the greatest use since it has high productivity, processability and provides high quality joints.

The main material of the article. It is known that the reducing the power of the arc (1) (and its thermal power q, respectively) is achieved by the reducing of the strength of the welding current, which is performed by mechanized welding by reducing the feed rate of the welding wire [5, 7]:

$$q = \eta \cdot UI , \tag{1}$$

where q is the arc thermal power, *W*; η - effective of the arc, for electric arc welding η = 0.8 - 0.95; U - arc stress, *V*; I - welding current, *A*.

At the same time, for each welding method there is a minimum allowable value of the strength of the welding current, below which the stability of the arc is violated and its break follows. Based on the condition of arc stability, for the currently used mechanized welding of parts, the possibility of reducing the arc power by reducing the strength of the welding current (the wire feed speed) has been exhausted. Consequently, other conditions to control the thermal mode of welding are required.

The first works on the control of arc welding can be attributed to 30 - 50 years of the last century [1, 2-4]. They were aimed mainly at creating automatic systems for regulating the external characteristics of welding current sources for manual arc welding with stick electrodes in order to stabilize the arc process. With the development of mechanized welding methods, the attention of researchers was shifted to increasing the stability of the arc based on the study of processes in the arc space [5-7].

These works were aimed at obtaining a stable arc burning at a rigidly stationary welding mode or on an approximate one, since, according to the researchers, it was in this mode that high welding quality could be ensured. However, over time, it turned out that in this case the possibilities for regulating the welding regime are narrowed. In this case, a contradiction arose: with a decrease in the arc power below a certain limit, the arc burning became unstable. Therefore, there were works aimed at finding welding methods that allow either to reduce the thermal effect of the arc in the welding zone at the previous arc power values [2–4], or to weld with a stable arc at significantly lower power values. In the latter case, positive results were achieved in the study of a new direction of welding — welding on a non-stationary but controlled mode [2–4, 8]. At the same time, some welding parameters were subjected to a forced purposeful and periodic change during the welding process, during which the characteristics of the arc process changed, which ultimately led to a decrease in heat input to the parts to be welded and a change in the thermal cycle of the metal.

Much of the proposals to increase the consumption of thermal energy of the arc to melt the filler material and reduce the proportion of heat going to heat the welded parts have not found practical application due to their low processability. However, the idea of the redistribution of heat has been realized recently in connection with the use of self-shielded flux-cored wires. It turned out that the melting of its metal shell and the mixture containing metal alloying elements requires more thermal energy of the arc than when melting solid welding wire.

The distribution of heat energy during welding to a large surface of the parts being welded plays the role of their concomitant heating, which reduces the cooling rate of the metal, especially the zone of thermal influence. At the same time, the probability of formation of a non-equilibrium quenching structure in the welded metal, and hence the appearance of welding stresses, is significantly reduced.

It should be noted other positive results of the application of arc control by means of an external electromagnetic field and oscillation of the electrode. First of all, these techniques contribute to the separation from the end of the melting electrode droplets of liquid metal smaller than without the use of these techniques.

It is known that with the drop-by-drop transfer of a liquid metal, the stability of arc burning increases and the possibilities for mastering alloying elements are improved. In addition, the mixing of the metal in the liquid metal bath in the forming weld is increased, which contributes to increasing the uniformity of the metal and the formation of fine-grained structures, which, in turn, improves the mechanical characteristics of the weld.

As already noted, due to the traditional method of mechanized welding, the reduction of arc power is achieved by reducing the welding current by reducing the feed rate of the welding wire by controlling the electric motor of the feed mechanism. This increases the length of the arc and its electrical resistance, which leads to a decrease in the welding current. However, an increase in the length of the arc is possible to a certain limit, after which an arc break occurs.

To prevent this effect, it was proposed to increase the electrode reach at a constant welding wire feed rate by moving the welding current inlet point to it. But it was not possible to significantly increase the electrode reach, since a disorderly wandering of the end of the softened welding wire occurs, which causes instability of the arc and splashing of the electrode metal.

The methods, mentioned above, for reducing the welding current have another major drawback - a small range of variation of the welding current, which does not allow to achieve a tangible effect of reducing the thermal power of the arc.

Thus, all of the above methods for changing the thermal regime of mechanized welding at a constant value of the welding current (and hence the arc power), i.e. on stationary mode, although they gave positive results, they did not find wide distribution due to their inherent flaws. Therefore, another direction of controlling the heat flow of the arc is attracted by applying a non-stationary welding mode, in which a forced periodic change of the mode parameters is performed, which leads to a similar change in the arc power. In accordance with accepted terminology, such welding can be attributed to pulsed arc welding [2–4].

One of the first proposals in the field of pulsed arc welding in the early 80s of the last century was a method of welding with modulated current [3, 4], the analogue of which is the modulation technique in radio engineering.

The implementation of this method was carried out by exposing the power circuits of the welding current source, in particular, by periodically applying a pulse to the low value of the welding current from an additional low-power power source. In this case, a pulsation of the parameters of the welding arc, i. e, welding current and stress, occurred.

Studies [1–4] showed that the pulsation of the arc leads to a significant reduction in the influence of the thermal field of the arc on the weld, a favorable change in the thermal cycle of formation of the properties of the weld metal and the zone of thermal influence, the refinement of the metal structure, and the likelihood of welding stresses.

In the development of the considered modulation method, it was proposed to act not directly on the welding chains, but on the feed rate of the welding wire. Namely, with a certain periodicity, briefly reduce the feed rate of the welding wire by controlling the feed mechanism from the nominal value to a value that is lower than the minimum required for stable arc burning (until the feed stops), followed by restoring it to the nominal value. But at the same time, the delivery time with a reduced speed was selected in such a way that the arc did not have time to break due to the inertia of the change in the welding current as compared with the change in the feed speed. In this mode, the filing of the welding wire, the average value of the welding current, and hence the thermal power of the arc, is less than with a stationary feed.

The practical implementation of the considered welding wire feed has confirmed its effectiveness. However, the results turned out to be more modest than expected due to the large inertia of the control of the feeder, consisting of an electric motor as a drive and a mechanical gearbox [8].

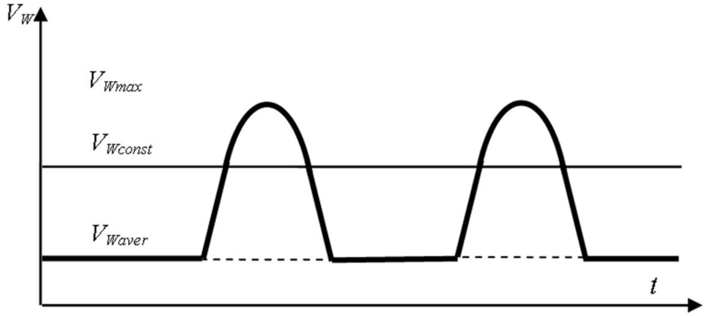

Fig. 1. The sequence diagram of the additive method of welding wire

However, in the process of research and practical application, the disadvantages of these techniques and devices for their implementation were identified. In particular, there was a deformation of the welding wire, especially when using flux-cored wire, the electrode wire went out of engagement with the feed rollers, which disrupted the process of its feeding, and, consequently, the arc stability deteriorated. In addition, it is difficult to regulate the feed mode (pulse time, pauses, their frequency).

These drawbacks are absent with the additive method of welding wire. Its essence lies in the fact that the change in the feed rate of the welding wire is achieved by periodically applying a constant amplitude of the pulse acceleration of a certain amplitude and frequency (Fig. 1), that is, we can say that the mechanical modulation of the welding wire feed is performed. This technique allows you to significantly reduce the constant component of the feed rate of the welding wire and, ultimately, the thermal power of the arc. The value of the constant component of the feed rate of the welding wire may be less than the critical value necessary to maintain stable arc burning in the traditional method of mechanized welding.

It should also be noted that with a decrease in welding current, the diameter of the arc column also decreases, as a result of which the thermal effect of the arc on the base metal of the parts being welded decreases, i.e. zone of thermal influence width decreases:

$$d_{CT} = 1,6\left(\sqrt{I^3} \Big/ \sqrt{U_F{}^3}\right), \tag{2}$$

where I – the arc current, U_F – the arc stress.

For the implementation of the proposed method of filing the welding wire was proposed an appropriate feed mechanism (10).

At the same time, it should be noted that, despite the presence of certain a priori information in the field of modulated-current welding and the use of self-shielded flux-cored wire, it is not possible to decide on its basis the feasibility of using this technology to produce welded joints of parts. First of all, a priori information about the study of welding with modulated current mainly concerns welding in carbon dioxide and in most cases with respect to pipeline welding, therefore, not all conclusions from these studies can be directly applied to welding with self-shielded cored wire.

Many aspects of current-modulated welding with self-shielded cored wire are not disclosed. In particular, the mechanism of formation of service properties of a welded joint has not been studied, there are no data on the impact of this technology on the strength properties of a welded joint, the nature of the influence of regime parameters on the technological parameters of the welding process and the formation of weld metal and zone of thermal influence. As a result, there are no reasonable recommendations on the welding process. There is no technical and economic assessment of the feasibility of the practical application of this technology.

Therefore, despite the indication of a priori information about the prospects of using mechanized welding with modulated current of self-shielded cored wire, experimental studies are needed to confirm the possibility and determine the feasibility of using it to obtain welded joints of parts.

In this regard, experimental studies were conducted during which a comparative evaluation of mechanized welding with self-shielded flux-cored wire with mechanized welding and current-modulated flux-shielded self-shielded wire was performed.

Experimental studies were carried out by applying single rollers on a steel plate (roller test method). In this case, the aim of the work was first of all to work out the modes of the proposed welding method and their influence on the properties of the weld metal. In the course of research, it was found that by controlling the welding modes of the modulated current without changing the idling stress of the source and the average wire feed speed, it is possible to achieve various properties of the weld. In this case, a controlled process of formation of a welded joint occurs (Fig. 2) by influencing the frequency and amplitude of the modulation. Also, in the course of statistical processing of experimental data, mathematical models were obtained of the influence of welding modes by modulated current on the properties of a welded joint. For example, the hardness (3) of the weld metal (Fig. 3):

$$H=35{,}73+3{,}932\cdot x_1+0{,}6096\cdot x_2+1{,}578\cdot x_3-0{,}5124\cdot x_4+0{,}8737\cdot x_5-0{,}7565\cdot x_1\cdot x_2+$$
$$+1{,}379\cdot x_1\cdot x_3-0{,}626\cdot x_1\cdot x_4+1{,}653\cdot x_1\cdot x_5-0{,}7148\cdot x_2\cdot x_3+0{,}0068\cdot x_2\cdot x_4+1{,}863\cdot x_2\cdot x_5+$$
$$+0{,}6023\cdot x_3\cdot x_4-0{,}9306\cdot x_3\cdot x_5-1{,}038\cdot x_4\cdot x_5-0{,}158\cdot x_{12}-0{,}263\cdot x_{22}+2{,}467\cdot x_{32}-$$
$$-0{,}6114\cdot x_{42}-1{,}13\,x_{52}, \qquad (3)$$

where H – the seam hardness, HRC; x_1 – no-load stress of the welding source U, B; x_2 – welding speed V_{CB}, m/s; x_3 – base wire speed $V_{ПР}$, m/s; x_4 – modulation amplitude δ, mm; x_5 - modulation frequency f, sec^{-1}.

The analysis of a priori data and the conducted research shows that the use of mechanized welding with controlled feeding of welding wire according to the additivity principle stated above using self-shielded flux cored wire will allow achieving the following technological effects compared to the traditional method of mechanized welding:

- reduce the heat input of the electric arc into the welded joint and thereby change the thermal cycle of formation of properties of the weld metal and heat affected zone, which contributes to the formation of a more favorable metal structure, reduces the likelihood of welding stresses and various defects in it, and also reduces the width of the zone of thermal influence;
- to improve the conditions of alloying of the molten metal due to more atomized transfer of the electrode metal;
- to increase the arc stability at low values of the welding current;
- to increase the degree of grinding of the structure of the weld metal and ЗТВ and the degree of its homogeneity due to the influence of the pulsating thermal field; increase the hardness of the weld metal.

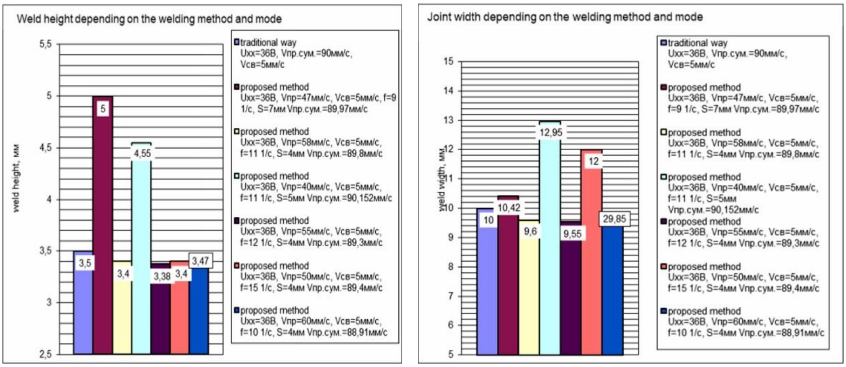

Fig. 2. The influence of the welding method on the height and width of the seam

All of the above suggests that the use of modulated current mechanized welding technology will significantly improve the quality of the welded joint.

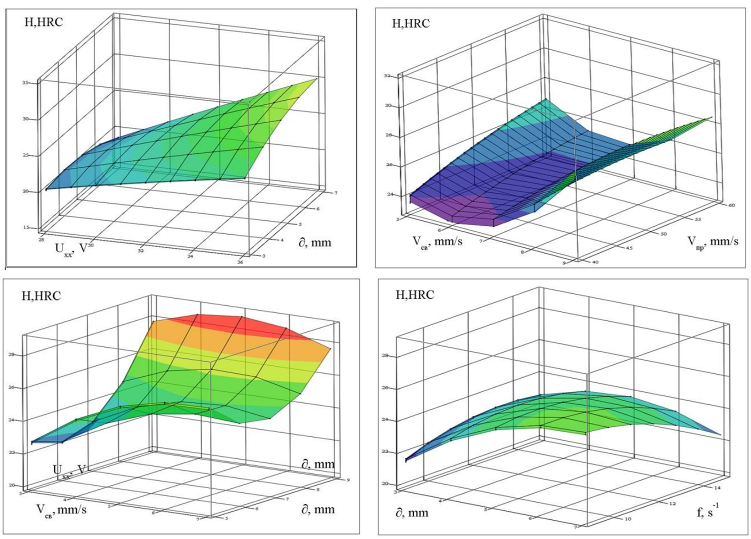

Fig. 3. Influence of modulated current welding modes on weld metal hardness

Conclusion. The analysis of the physicomechanical properties of the welded joint showed that it is not homogeneous in its quality and has a complex zonal structure. The formation of the properties of welded joint zones is interrelated and due to the complex interactions of endogenous and exogenous factors that influence their formation.

To substantiate technological solutions aimed at increasing the strength of welded joints, a research methodology has been developed based on the theoretical determination of cause-effect relationships between the main properties of welded joint zones and the factors that form them. As a result of the study, it has been established that the resistance of a welded joint is determined by the properties of the metal of the formed zones, which are formed under the influence of a complex of physicochemical, mechanical, electromagnetic processes occurring when an electric arc is applied to the base metal, filler material and protective medium, and its environmental impact (atmosphere, quality of the welded surface). The intensity of the arc depends on the welding method and its mode.

The conducted research allowed to develop a set of technological measures aimed at increasing the soil quality of welded structures. It was established that: in the applied method of mechanized welding, the power of the arc, necessary for its stable combustion, is excessive for parts. The thermal cycle of heating and cooling a welded joint occurring in this process contributes to the formation of a heterogeneous structure of its metal with insufficient physical and mechanical properties and increases the likelihood of welding stresses and, as a consequence, various kinds of structural defects.

The results of the studies made it possible to substantiate the possibility of controlling the heat flux of the arc by using non-stationary welding modes, under which a forced periodic change of the parameters of the welding mode is performed, and to choose a welding method.

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УПРАВЛІННЯ ВЛАСТИВОСТЯМИ МІЦНОСТІ ЗВАРНИХ З'ЄДНАНЬ ПРИ ВИГОТОВЛЕННІ БУДІВЕЛЬНИХ СТАЛЕВИХ КОНСТРУКЦІЙ

Як загально відомо в період бурхливого розвитку людства та індустріалізації виникла нагальна потреба в будівництві багатоповерхових та надміцних будівель. У зв’язку з цим понад століття сталеві конструкції є невід’ємною частиною споруд. В період бурхливого розвитку будівництва для з’єднання металевих деталей використовувались різні технології, спочатку це було клепання та болтові з’єднання, а нарубежі 20-30 років XX століття поступово стало використовуватися зварювання.

На даний час понад 70% сталевих конструкцій виготовлено за допомогою електродугового зварювання. Тому до якості їх виготовлення та показників міцності висуваються підвищені вимоги. Це пов’язано з тим що за своїми властивостями, хімічним складом та мікроструктурою вони відрізняються від основного металу конструкції.

В процесі будівництва широко застосовуються різні способи електродугового зварювання, як ручне так і напівавтоматичне (механізоване). В якості зварювальних матеріалів використовують: штучні електроди, сталеву проволоку та самозахисну порошкову проволоку. В даній статті значну увагу приділяється механізованому електродуговому зварюванню порошковою самозахисною проволокою.

На даний час технології зварювання, які використовуються не завжди дозволяють реалізувати потенціал, який закладений в дану групі зварювальних матеріалів. Крім цього сучасні способи зварювання характеризуються великим тепловкладення в деталі і зварні з'єднання. У зв'язку з цим в статті розглянуті шляхи підвищення технологічних можливостей механізованого зварювання порошковим дротом шляхом впровадження у виробництво будівельних сталевих конструкцій механізованого зварювання модульованим струмом.

Ключові слова: зварювання, самозахисна порошкова проволока, дуга, напруження, сила струму, подача дроту, зварене з'єднання, зона термічного впливу, структура металу, міцність

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As is well known in construction, mechanized welding with self-shielded cored wire has found wide application. In this case, welding methods that are used do not always allow to realize the potential that is laid in this group of welding materials. In addition, modern welding methods are characterized by a large heat input in parts and welded joints. In this regard, in the article ways to improve the technological capabilities of mechanized welding with flux-cored wire by introducing modulated current into the production of building steel structures are discussed.
Fig. 3. Ref. 10

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Даценко І.П., Коцюруба В.І., Мірненко В.І., Ткач І.М., Тригубенко С.С., Шишанов М.О. **Управління властивостями міцності зварних з'єднань при виготовленні будівельних сталевих конструкцій** // Опір матеріалів і теорія споруд: наук.-тех. збірн. – К.: КНУБА, 2019. – Вип. 102. – С. 150-158.

Як відомо в будівництві широке застосування знайшло механізоване зварювання порошковою самозахисною проволокою. При цьому способи зварювання, які використовуються не завжди дозволяють реалізувати потенціал, який закладений в дану групі зварювальних матеріалів. Крім цього сучасні способи зварювання характеризуються

великим тепловкладення в деталі і зварні з'єднання. У зв'язку з цим в статті розглянуті шляхи підвищення технологічних можливостей механізованого зварювання порошковим дротом шляхом впровадження у виробництво будівельних сталевих конструкцій механізованого зварювання модульованим струмом.
Іл. 3. Бібліог. 10 назв.

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