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UPE-500 COMPLEX FOR DETERMINING WELDING AND TECHNOLOGICAL CHARACTERISTICS OF COATED ELECTRODES

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The article presents the methodology of quantitative evaluation of welding-technological characteristics of coated electrodes using the UPE-500 complex, which provides a high stability of the control welding process in all spatial positions in the automatic mode. The complex is equipped with the measuring system PicoScope 4444 with the software PicoScope 6 which fix and statistically process high reliability parameters of welding process stability that provides online-control of quality of manufacturing industrial batches of electrodes. 8 Ref., 1 Table, 3 Figures.

Keywords: electrode, melting stability, evaluation methodology, automatic mode

The modern technology of manufacturing coated electrodes from the moment of their invention by Oscar Kelberg in 1904 have passed a complex way of improvement and provides a high-quality welding of a wide range of structural materials. The vast majority of properties of electrodes, such as mechanical characteristics of deposited metal, its chemical and structural composition, content of harmful impurities and gases, corrosion resistance, etc. are regulated and easily controlled by manufacturers according to quantitative indices. However, welding and technological characteristics of coated electrodes, that have a crucial importance in providing stability of welding process is traditionally controlled, relying on a subjective qualitative evaluation of a highly-skilled welder. This is not fully objective and needs to be improved.

Despite the fact that the scientific society actively uses quantitative indices of arc burning stability during the development of new compositions of coatings and improvement of the technology of manufacturing electrodes, manufacturers do not have serial equipment, that could evaluate welding and technological characteristics in the manufacture of industrial batches of coated electrodes according to quantitative criteria. The use of such equipment in electrode production will automatically provide a high-accuracy evaluation of the quality of electrode manufacturing, which is extremely relevant. In this regard, the Scientific-Industrial Company of the LLC «AMITI» (Mykolaiv) by order of the PJSC «PlasmaTec» (Vinnytsia) designed and produced a laboratory complex UPE-500 (TU U 27.9-20864642-003:2021), with the help of which manufacturer can control the quality of products online. The work was carried out according to the methodological assistance of the experts of the Ukrainian Certification Committee of Welders and with the assistance of the Society of Welders of Ukraine.

Analysis and research methodology. The welding process stability is a complex and multifactorial concept and does not have a standardized definition. According to many authors, the most successful formulation of this physical phenomenon is the definition of Yu.M. Lankin, which he provided in the article [1]: «The process of welding, the deviation of whose parameters from average values does not exceed a set level, is called stable. The measure of stability is the deviation from a parameter of the average value. As a deviation of a parameter from the average value, its dispersion is taken, mean square deviation or variation coefficient.» Thus, the welding process stability can be controlled by quite quantitative indices.

In this regard, basic parameters of welding mode, which are traditionally used to evaluate the stability of mass transfer, is a short circuit duration of arc gap ($\tau_{sh.-c}$, ms), cycle duration — period of formation and transfer of a drop ($T_{sh.-c}$, ms), current value (maximum I_{max} and minimum I_{min}, A); rate of current increment ($V_{increment}\ I_w$ and $V_{drop}\ I_w$, A/s) [1, 2]. In this case, for

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example, in [3], as a criterion of stability, the authors propose to use mean square deviation of short-circuit duration (σ $\tau_{sh.-c)}$ and their frequency (σ $T_{sh.-c}$) and the authors of work [2, 4] use mean square deviation of the amplitude value of current (σ I_w), short-circuit current (σ $I_{w\,max}$) and variation coefficient of rate of increment of short-circuit current (K_v, $I_{w\,max}$).

The choice of specific parameters of the process stability depends on the type of mass transfer, as far as the mass transfer stability does imply the stability of the process. Academician B. Paton clearly described the boundary types of mass transfer as a coarse-droplet (with short circuits or without them) and foggy [5]. Each type of electrode coating is characterised by the own type of mass transfer. For example, electrodes with the main type of coating are characterized by a coarse-droplet transfer (usually with short circuits). Therefore, the criteria for stability of the process are criteria of short circuits stability (droplet transfer): dispersion and coefficient of frequency variation of short circuits or their period. Electrodes with rutile-cellulose coating are characterized by a fine-droplet and even fog-shaped transfer, during which a short circuit is an exception and can not serve as a criterion for stability of the process and vice versa — small deviations of welding current is an index of a stable fine-droplet transfer. Therefore, to evaluate the stability of the process of melting electrodes with rutile-cellulose coating, dispersion and coefficient of variation of welding current are used [4]. Therefore, the only standardized methodology for determining the stability of welding process does not exist and the choice of research methodology is based on the parameters of studying object.

First of all, it should be noted that the overwhelming majority of certified electrodes, providing metal surfacing with a low content of harmful impurities and gases, guarantee the serviceability of welded structures operating under the conditions of a dynamic limit load, especially at negative temperatures, belong to the coatings of the basic type. In this regard, the work was focused on studying stability of the welding process with the electrodes of the basic type of coating. Based on the analysis of existing publications on this occasion and preliminary studies, the following criteria for evaluation of the mass transfer process stability were selected: average frequency of short circuits (mass transfer) — f_{av}; mean square deviation of frequency of short circuits (mass transfer) — σ; coefficient of variation of frequency of short circuits (mass transfer) — $K_{vf} = \sigma/f_{av}$; calculated mass of a drop, which is determined as a physically obvious ratio of the mass melting rate to the frequency of mass transfer $m_{av} = dM/f_{av}$.

The calculated mass of a drop is required for its comparison with a critical mass of a drop m_{dr}, which is one of the boundary criteria for evaluation of the process stability. As a critical mass of a drop, the authors took a mass of a drop with a diameter, equal to diameter of the electrode (for example, for the electrode of 4 mm diameter m_{dr} = 0.26 g). It is physically obvious, that further exceeding in the size, and, consequently, in the mass of a drop leads to its insufficient protection by slag and causes increased spattering and a complete destabilization of welding process. The data on the effect of a drop size on the stability of welding process, obtained by other authors, confirm the validity of applying this criterion [6]. The real mass of a drop will be slightly less than the calculated one, taking into account the processes of burnout, evaporation and a partial dispersion of liquid metal, which provides a safe margin to researchers. Therefore, the first condition of the process stability is the inequality $m_{av} < m_{dr}$.

The statistical indices of mass transfer (short circuits) characterize the stability of the process, but not fully determine the convenience and quality of welding. All previous researchers note the importance of increasing the frequency and reduction in the mass of a drop to increase the convenience and quality of welding, including the completeness of running exchange reactions [6]. Therefore, the welder in case of the same stability of the process, intuitively prefers the electrodes providing a higher frequency of mass transfer and a smaller drop size. In this regard, taking into account the fact that the average short-circuit frequency can not be absolutely objective for comparison, as far as it varies within the limits described by the coefficient of variation, in the work a new indice was for the first time introduced — critical frequency of mass transfer, which is equal to the difference of medium frequency and mean square deviation of frequency $f_{dr} = f_{av} - \sigma$. Mathematically, critical frequency of mass transfer corresponds to the properties of a normal distribution described by specific values of an average short circuit frequency and a mean square deviation of the short-circuit frequency and physically it determines the lower boundary of the mass transfer frequency. Moreover, 82 % of drop transition occurs with a higher frequency. Accordingly, in such circumstances, it is possible to form drops with an average maximum size $m_{max} = dM/f_{dr}$, which can additionally be taken into account for comparison with a critical mass of a drop m_{dr}.

The reliability of the obtained results depends in the first turn on the methods of obtaining and processing of results. In this regard, the measurement and fixation of electrical parameters, as well as their statistical characteristics were performed with the use of the measuring system PicoScope 4444 and the software PicoScope 6. During measurements, a digital frequency filter with a frequency of 40 Hz is used, built in the PicoScope 4444 [4], which eliminates the impact of 50 Hz mains. As compared to most of the measuring systems, PicoScope 4444 is in a set with PicoScope 6 has a number of advantages. Let us consider them in detail because this determines the quality and reliability of the obtained data.

The measuring system PicoScope 4444 and the software PicoScope 6 allow determining the mean square value and the mean square deviation not only of welding current and voltage, but also frequency of mass transfer. In this case, the automatic use of amplitude-frequency analysis based on Fourier transformation does take into account the used digital frequency filter, provides a reliable automatic determination of frequency and other characteristics of the mass transfer, even at a partial or a complete lack of short circuits in the mass transfer, which is especially important for obtaining characteristics at a large arc length. In addition, automatic determination and registration of the mean arithmetic value and the mean square deviation of frequency of mass transfer allow increasing the time of process to be analyzed, which significantly increases reliability of the results. In our case, we restricted the time of automatic analysis to 50 s, that even at a frequency of 3 Hz provides 150 cycles of mass transfer. The reliability of the obtained data also increases the use of automatic processing of oscillograms. The obtained reliability of the results allows applying one of the principles of mathematical statistics in full: «If the value of the variation coefficient does not exceed 33 %, then the population is considered homogeneous, and if more than 33 %, then it is inhomogeneous». In our case: if the value of the variation coefficient of the frequency of mass transfer does not exceed 33 %, then the process is stable, and if it more than 33 %, then it is unstable. Therefore, the second condition of the process stability is the inequality $K_{vf} < 33$ %.

In order to realize all the advantages of the mentioned methodology, the integrated evaluation of welding and technological characteristics of coated electrodes was constructed and the laboratory UPE-500 complex was manufactured, which corresponds to the needs of modern production of welding consumables.

Laboratory UPE-500 complex. The UPE-500 complex is designed to determine and optimize welding and technological characteristics of electrodes and welding wire in combination with shielding gases during welding in all spatial positions. In the work of the complex, Bi-auto principle is realized, which involves automated fixation, processing and registration of obtained data with simultaneous stabilization of welding modes, which is also performed in automatic mode. This principle of work allows obtaining authentic characteristics of stability of melting electrodes without a subjective intervention of operator.

The complex allows welding with the use of different power sources both of direct as well as alternating current. It is strictly forbidden to use welding power sources with oscillators, stabilizers or other pulsed high-voltage devices for arc stabilization. The complex consists of three parts: control panel with the port for connecting personal computer, measurement and switching unit with the possibility of connecting oscilloscope and directly manipulator. Appearance of the manipulator is shown in Figure 1.

Figure 1. Appearance of manipulator

The manipulator provides movements of welding tool across and along the weld and the electrode feed in the automatic mode typical for welder during welding with a coated electrode. In this case, the function of dynamic regulation of its feed rates with a feedback stabilizes the arc voltage, which fixes its length with a high accuracy. The complex also provides a digital fixation of parameters and video records of welding process. In addition, the complex is connected to the central server of the enterprise, which provides the online control of the quality of electrode manufacturing. All the received information is archived, which makes it possible to have a data bank for further statistical analysis in order to determine the optimal ways of improving the electrode production.

Basic performance characteristics of the UPE-500 complex:

Dimensions of the workplace:
- length, mm 450
- width, mm 400
- height, mm 400

Feed of coated electrode in welding zone with a smooth adjustment of welding voltage in the range, V 12–50

Movement of a product or a welding tool with a smooth rate adjustment in the range, cm/min 0–87

Smooth adjustment of movement of a welding tool across the weld: linear and circumferential movement for all spatial positions
- amplitude of oscillations, mm . . . . 0–55 (0–100 %)
- separately adjustable (left/right) delays along the edges, s . . . . 0–5 (0–100 %)
- oscillation speed, cm/min . . . . 17.8–178 (0–100 %)

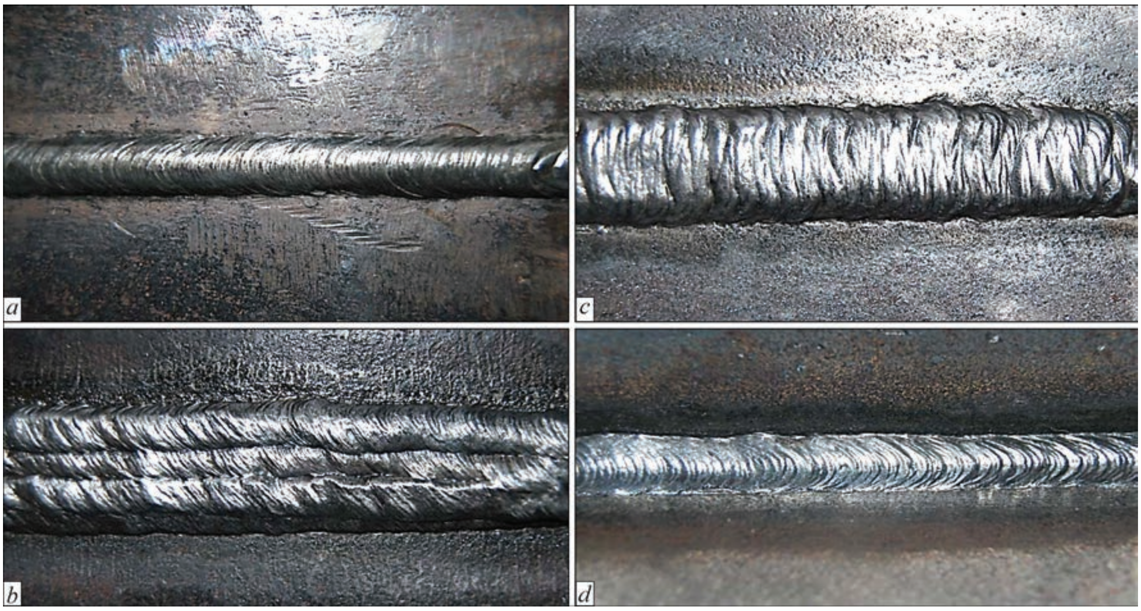

Figure 2. Appearance of butt (*a–c*) and fillet (*d*) welds in spatial positions: *a* — flat; *b* — horizontal; *c* — overhead; *d* — horizontal overhead

Positioning of welding tool in all spatial positions:
- range of linear positioning across the weld, mm 0–400
- range of linear positioning along the vertical, mm . . . 0–400
- range of circumferential positioning in a transverse weld plane, grad 0–360
- range of inclination in a longitudinal weld plane, deg 0–45
- maximum admissible length of electrode, mm 500

To provide a high-quality test welding with the use of the UPE-500 complex, welding process specifications (WPS) were developed for butt and fillet welded joints, as well as for surfacing in all spatial positions. Welding process specifications are executed in accordance with the requirements of the standard DSTU EN ISO 15609-1:2019. Welding and surfacing technologies are certified in accordance with the requirements of standards DSTU EN ISO 15614-1: 2019 and DSTU EN ISO 15614-7:2019. The typical appearance of welds produced using the UPE-500 complex is shown in Figure 2.

The possibilities of the complex provide a quantitative evaluation of stability of melting electrodes that are serially produced and their automatic comparison with the reference values, which allows providing the desired quality of electrode manufacturing. In addition, the laboratory complex can be used to evaluate the effective range of parameters of welding specific grades of electrodes, arc elasticity (a recommended range of arc length in welding), effect of coating components and their condition on the stability of electrode melting, testing of new grades of electrodes to introduce them into serial production, solving the promotional issues related to the controversial evaluation of quality of electrode products by a consumer and much more accompanied by modern electrode production.

Example of application. The PJSC «PlasmaTec» successfully produces electrodes UONI-13/55 «PLASMA», which are in a great demand for a consumer due to a balanced relation of price to quality. One of the advantages of these electrodes relating to type E 7018 according to the AWS A5.1 standard is the presence of iron powder in coating mixture [7, 8], which increases the efficiency of their use by 20 %. In this case, the losses of metal on burnout and spattering are compensated, the cost of electrodes is reduced by 10–15 %, the deposition rate is increased by 8–10 %, weld formation and slag crust separation are improved. Traditionally, for manufacture of these electrodes at the company enterprises, a mixture of iron powders PZhRV 2.200.28 (TU 14-1-5365–98) and DIP 400 30W (EN 10204 3.1) is used. After purchasing a complex of equipment at the Company Atomising System Ltd (England), it became possible to produce the own iron powder.

To determine the influence of the method of producing and composition of iron powder on the characteristics of stability of melting electrodes UONI-13/55 «PLASMA», two batches of electrodes of 4 mm diameter were manufactured according to conventional and improved technology based on the use of powder of the own production in the equipment of the Company Atomising System Ltd. The work was preceded by large-scale studies on optimization of granulometric characteristics and chemical composition of iron powder of the own production.

The electrodes were tested in the UPE-500 complex. Welding was performed in the flat position within the requirements of the welding process specification WPS No. 111-01-20 on the following modes: welding current: 160 A, arc voltage: 24 V, welding rate: 14 cm/min. From each batch of electrodes, five pieces of electrodes were randomly selected that passed tests. Characteristic oscillograms and operating indices of

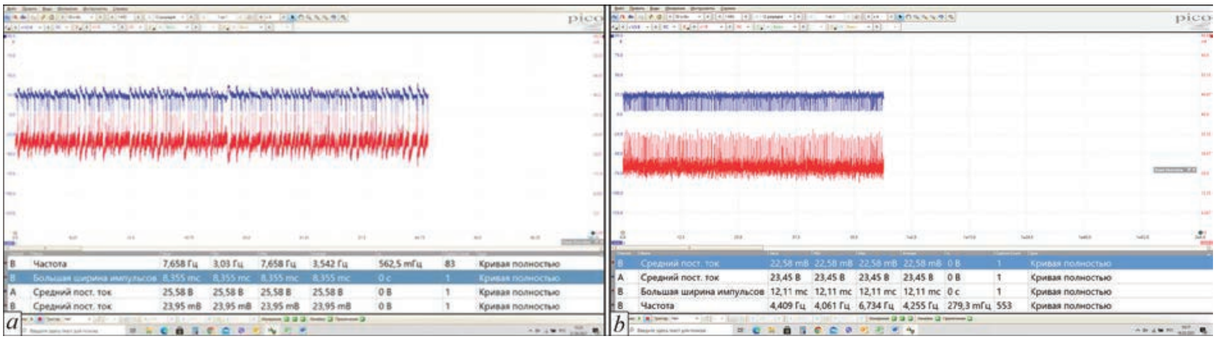

Figure 3. Oscillogram of welding process: *a* — conventional technology; *b* — improved technology

Criteria of welding process stability

Technology of electrode manufacturing	Average frequency f_{av}, Hz	Critical frequency f_{cr}, Hz	Coefficient of variation K_{vf}, %	Average mass of drop m_{av}, g	Maximum mass of drop m_{max}, g
Conventional	3.7	3.53	6.2	0.161	0.168
Improved	4.14	3.92	5.3	0.148	0.156

mass transfer of welding processes using electrodes of conventional and improved manufacturing technology, calculated in the automatic mode, are shown in Figure 3. The average indices of the criteria for the stability of melting electrodes in the mentioned conditions of welding are given in Table.

The analysis of the obtained results showed that in both cases, the conditions of the process stability ($m_{av} < m_{dr}$ and $K_{vf} < 33$ %) are provided, but welding with the electrodes, containing an optimized iron powder of its own production, allows a significantly increase in the stability of the process and an increase in the frequency of mass transfer. In absolute units, the average frequency of mass transfer increased by 10.6 %, the critical frequency of mass transfer increased by 9.9 %, and the variation coefficient decreased from 6.2 to 5.3 %. Characteristically, that the average mass of drop decreased by 8.1 % and the maximum average mass of a drop (0.156 g) decreased to less than the average mass of a drop (0.161 g) for the conventional technology of manufacturing electrodes, which is a significant positive effect and provides a considerable improvement in welding-technological properties of electrodes and the quality of welding.

Therefore, the use of the UPE-500 complex unlike the qualitative standard method of evaluation in the form of a questionnaire of welder, provides a high reliability quantitive evaluation of parameters of the welding process stability.

Conclusions

1. The methodology for evaluation of criteria of welding process stability using coated electrodes with the basic type of coating (average frequency of short circuits, mean square deviation of short circuit frequency, coefficient of variation of short circuit frequency, calculated average mass of a drop and, in addition, critical average short circuit frequency) provides a quantitative evaluation of parameters of the welding process stability with a high reliability.

2. The UPE-500 laboratory complex performs welding in all spatial positions with a simultaneous stabilization of the process in an automatic mode and performs automatic fixation, processing and registration of received data, which provides a quantitative evaluation of welding and technological characteristics of coated electrodes without a subjective intervention of operator.

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