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Investigation of the Criteria for Evaluating Electrode Metal Transfer in Short Circuit Gas-Shielded Arc Welding

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Abstract. Based on the developed information-measuring complex, the investigation of processes of melting and electrode metal transfer during short circuit arc welding was carried out. The close relationship between the energy of the arc at the stage of its formation and the diameter of an electrode metal droplet was found. It is proposed to evaluate the transfer stability by the harmonic composition of welding current.

1. Introduction

The strength properties of welded joints are closely related to the processes of heating, melting and transfer of electrode metal droplets. The type of transfer is determined by the parameters of welding conditions [1]. In consumable electrode gas-shielded arc welding, the short circuit transfer of droplets to the weld puddle has become widely used and it has a number of technological advantages such as deep penetration, high productivity and high-quality weld formation in any spatial position [2].

The study of electrode metal transfer in arc welding is relevant to the recording of fast processes, since the frequency of droplet separation can reach 300 Hz. Complexes for studying droplet transfer during welding are unique equipment and they make it possible to synchronously playback frames of the recorded welding process and oscillograms of the welding current and voltage [3,4]

2. Equipment and research methods

An information-measuring complex for investigating the processes of melting and electrode metal transfer in arc welding was developed at the Belarusian-Russian University [5]. The overall view of the complex is shown in Figure 1.

The movement of the welding torch at a programmable speed is carried out using the FANUC Robot ARC Mate 100iC industrial robot. The Fronius TransPuls Synergic 3200 is used as a welding power source, which allows performing consumable electrode gas-shielded arc welding using a 0.8 ... 1.6 mm diameter welding wire over a welding current range of 3 to 320 A (wire feed speed of 0.5 – 22 m/min) at the arc voltage of 14 – 30 V. The welding table is installed on an optical bench. To illuminate the welding zone and eliminate powerful light emission of the welding arc, a 3W 850nm LED was used supplied with 700 – 800 mA current from the APS-1721L source. The selection of the required radiation spectrum was carried out using the IKS6 infrared filter (850-3,000 nm) and the NS13 neutral light filter (to weaken the brilliance of radiation emitted by red-hot objects). The Evercam 1000-4-C with a CMOS sensor was used as a high-speed camera with frame rates between 1,000 and 4,000 fps and the minimum exposure time of 1 μs. The recording of welding process

parameters, such as instantaneous values of welding current and arc voltage, and shielding gas consumption, was carried out by the RSP-BRU-2001 recorder developed at the Belarusian-Russian University. The NI USB-6009 with a sampling rate of 20 kHz, the LT 1000-SI current sensor (1...1,000 A), the LV 25-P voltage sensor (10...500 V), and the AWM5104 shielding gas flow meter (0...20 l/min) were used as a data acquisition unit of the recorder. The complex makes it possible to perform welding in the modes set by the operator, to record and measure the parameters of welding processes with a synchronous superposition of frames recorded with the high speed camera on the obtained oscillograms.
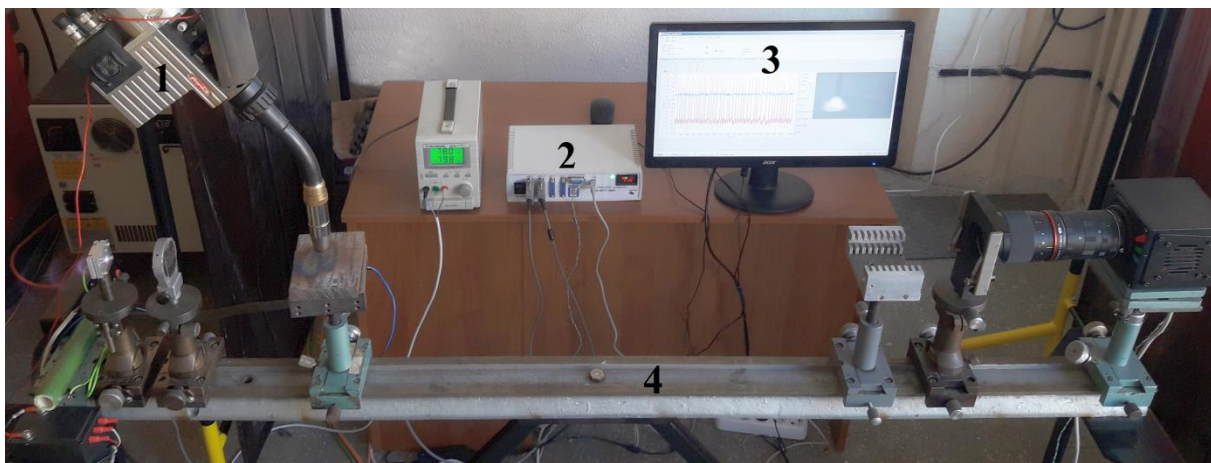

Figure 1. The information- measuring complex: 1 – device for automatic welding torch movement, 2 – welding process recorder, 3 – personal computer, 4 – optical bench with a high-speed video camera.

The software to control the information-measuring complex was developed in the NI LabVIEW graphical programming environment [5].

To study the criteria for assessing the electrode metal transfer in short circuit arc welding, a series of welding deposition experiments was performed on 100x100x10 mm plates made of low-carbon steel using a 1.2 mm diameter Sv08G2S wire in an 82% Ar + 18% CO_2 gas mixture. The welding speed was 18 m/h with the electrode protrusion of 14 mm and shielding gas consumption of 14 l/min. The experiments were carried out at the welding current values ranging from 130 A to 200 A, with a stepwise arc voltage change from 16 to 24 V. The main criteria for evaluating the welding process were programmatically determined for each microcycle of the electrode metal transfer (Figure 2). The determined criteria are as follows: the frequency of droplet short circuits f_{cycle}, the duration of arc burning t_{arc}, the duration of short circuit t_{shot}, the maximum short circuit current I_{peak}, the rate of its rise dI_{peak}/dt, as well as the arc energy Q spent to form a drop of molten metal. These criteria were compared with the diameter of the drop d_{drobe} at the moment of the short circuit with the weld puddle.

3. Research findings and their discussion
The frequency of droplet short circuits f_{cycle} is considered to be the main criterion for evaluating the welding process [6-8]. The typical values of the cycle frequency in short circuit welding are 5 – 200 Hz [2].

Figure 2 shows the oscillograms of welding current i, arc voltage u, welding power p and the frames of high-speed recording during one microcycle of one drop transfer corresponding to points 1, 2, 3 on the graphs. At the time point corresponding to point 1, the arc is ignited, while the current attains a maximum value of $I_{peak} = 370$ A. As the electrode wire is fed and melted, the drop diameter increases (point 2), while the welding current and arc voltage fluctuate within insignificant limits. At the moment when a molten electrode metal droplet develops the short circuit with the weld puddle

(point 3), the voltage tends towards zero due to the overlap of the interelectrode gap, and the welding current begins to increase to a maximum value. A gradual transfer of the droplet into the weld puddle occurs during t_{shot} = 4 msec, and after the rupture of a liquid bridge, the re-excitation of the arc takes place. The complete cycle of one drop transfer is T_{cycle} = 68 msec (frequency f_{cycle} = 1/ T_{cycle} = 14.7 Hz) with the drop diameter d_{drob} = 2.7 mm, and arc burning time t_{arc} = 64 msec.
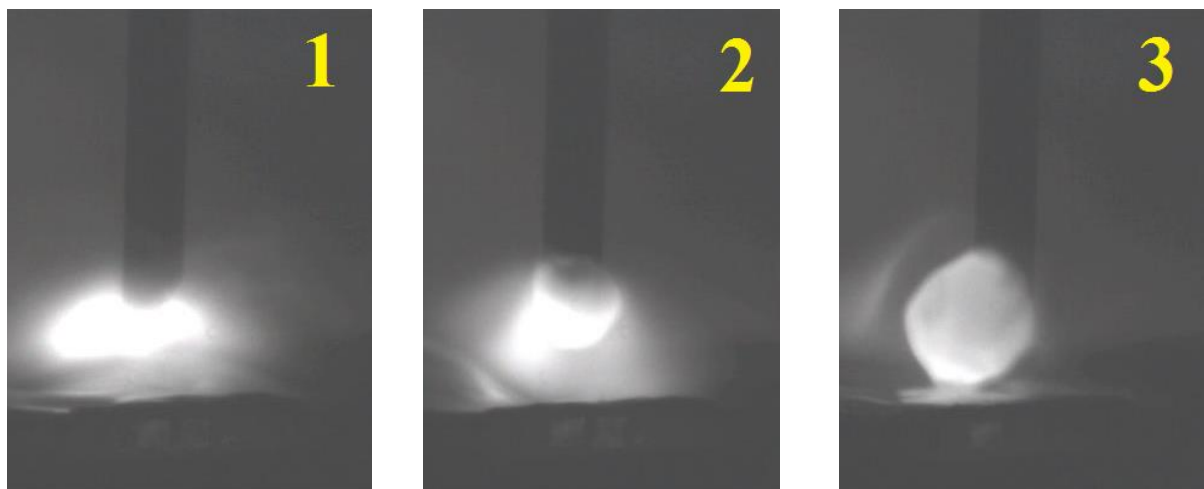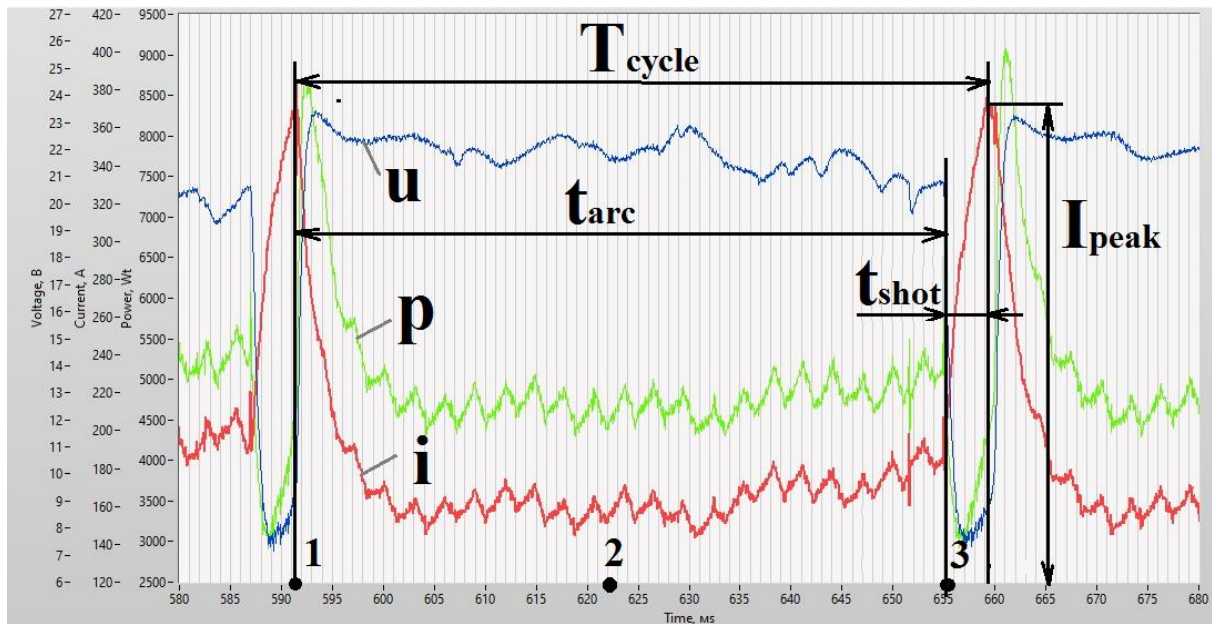

Figure 2. Oscillograms and frames of video shooting of short circuit electrode metal transfer.

Over the course of research, it was found that an increase in the welding current (wire feed speed) leads to an increase in the frequency of short circuits (table 1, figure 3). With an increase in the arc voltage, the frequency of the cycle of short circuits decreases, which is due to an increase in the interelectrode gap and an increase in the droplet size. At low arc voltage, the frequency of short circuits decreases faster.

Table 1. Results of the research into the criteria for evaluating the arc GMAW process.

I, A	U, V	Δf, Hz	f_{cycle}, Hz	I_A, A
130	16	45-59	52,5	8,6
130	17	32-46	39	9
130	18	23-32	28	20,3
130	19	21-22	21,2	21,6
130	20	8-18	12,5	13,2
130	21	5-20	10	8,3
200	18	35-51	43,5	7,5
200	19	24-34	29	8,3
200	20	16-23	19	9,5
200	21	13-17	15	10,1
200	22	11,5-13	12,7	10,5
200	23	9-12	10,5	6,5
200	24	5-14	9,5	5,7
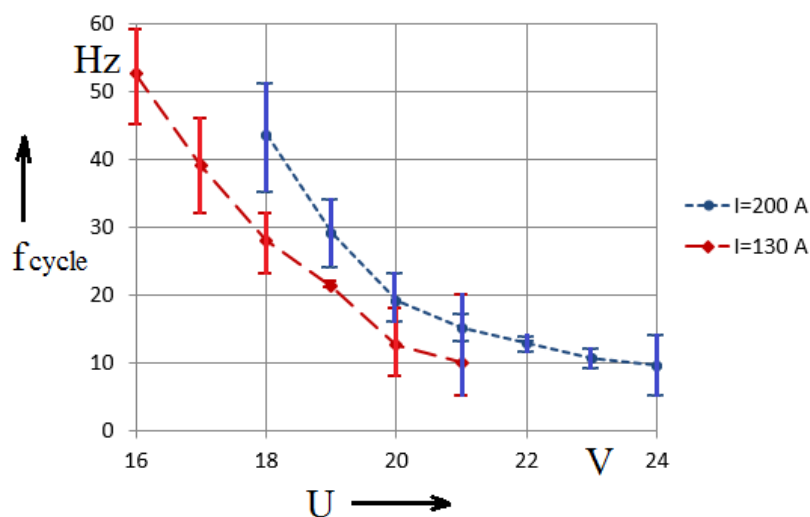
Figure 3. The relationship between the frequency of the cycle of short circuits and the parameters of the welding mode.

It was found that short circuiting of the arc gap does not always cause drop transfer, and when determining the transfer frequency, short circuits with the duration of $t_{shot} <1.6$ msec should not be taken into account. The relationships between the investigated criteria for evaluating transfer and the diameter of electrode metal droplets were obtained. It was found that the energy of the arc at the stage of its formation has the closest relationship with the droplet diameter (Figure 4). The regression equation will be

$$d_k=1,63+0,0566 \cdot Q$$

The correlation coefficient is 0.98. The resulting relationship indicates that when the arc energy changes from 2.7 to 22.6 J, the diameter of an electrode metal droplet formed, changes from 1.8 to 2.9 mm. This linear relationship is valid when a Sv08G2S welding wire of 1.2 mm diameter is used in a 82% Ar + 18% CO_2 mixture in the welding modes that provide short-circuit transfer of the arc gap, and it can be used in the systems for automatic control of welding processes to dose energy needed to form drops of the desired size.
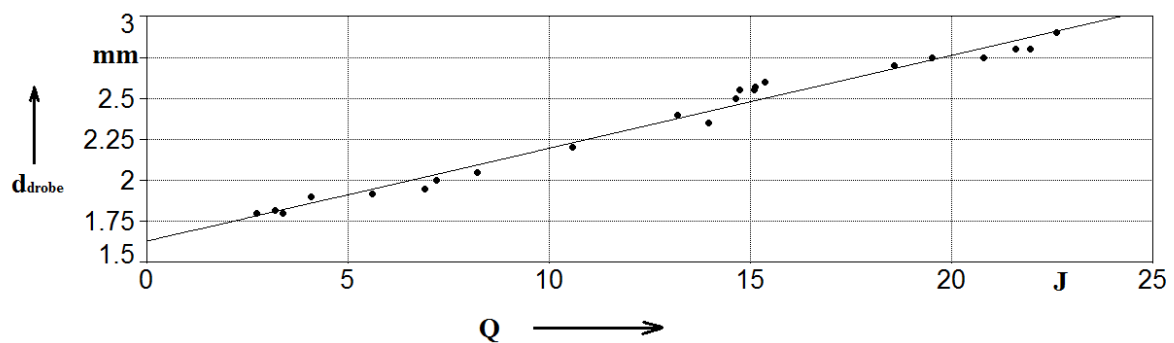
Figure 4. Relationship between the diameter of an electrode metal droplet and the arc energy.

It is proposed to evaluate the stability of electrode metal transfer by the harmonic composition of the welding current in the 5 – 200 Hz range determined by the software spectrum analyzer (Figure 5). Thus, at 130 A welding current and 19 V arc voltage, a stable process of the transfer of electrode metal droplets with a frequency of 21 Hz is observed, which corresponds to the maximum amplitude of the welding current harmonic at the same frequency.
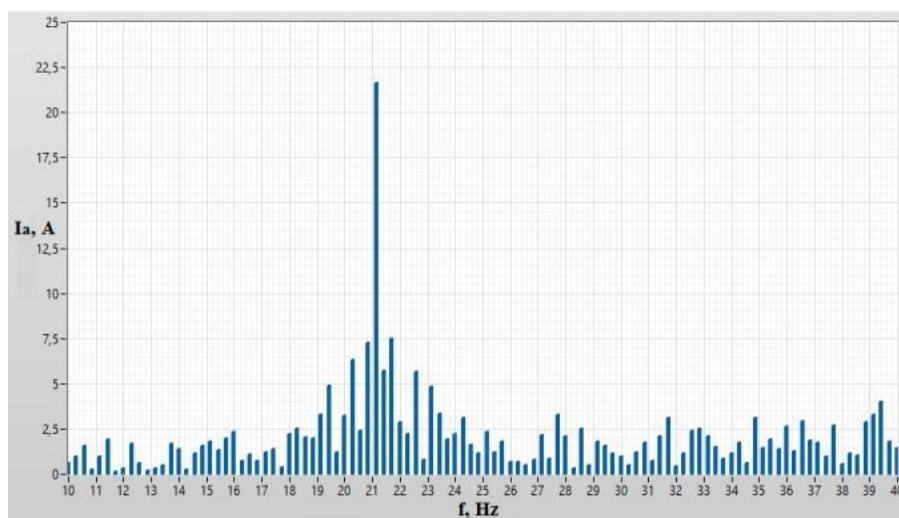

Figure 5. Harmonic composition of the welding current for a stable process.

It was found that for a stable welding process, the current frequency corresponding to the fundamental frequency of electrode metal droplet transfer has the maximum value of amplitude I_a (Table 1). The width of the spectrum with current amplitudes commensurate with the amplitude of the fundamental frequency does not exceed 1 – 3 Hz. With an increase in the value of the welding current from 130 to 200 A, the amplitude of fundamental harmonic of current I_a, corresponding to the fundamental frequency of droplet short circuits, decreases from 21.6 A to 10.5 A (Figure 6).

The obtained relationships can be used to assess the stability of the arc welding process with short circuits of the arc gap.
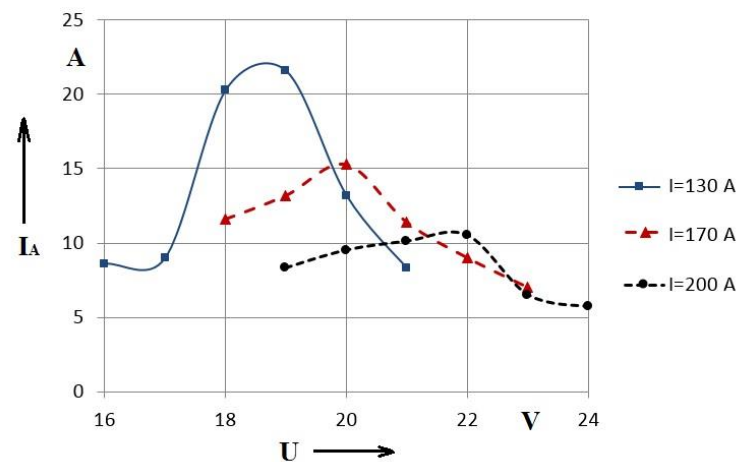
Figure 6. The relationship between the amplitude of the current of fundamental harmonic and the parameters of the welding mode.

4. Conclusions

The information-measuring complex was developed to study the processes of melting and electrode metal transfer in arc welding.

It was discovered that the energy of arc at the stage of its formation has the closest relationship with the diameter of an electrode metal droplet, when short circuit welding is performed using a 1.2 mm diameter Sv08G2S wire in an 82% Ar + 18% CO_2 shielding gas mixture within the 130 – 200 A current and 16 – 24 V arc voltage range.

It is proposed to evaluate the stability of the arc welding process based on the harmonic composition of the welding current in the 5 – 200 Hz range determined by the software spectrum analyzer. It was found that for a stable welding process, the current frequency corresponding to the fundamental frequency of the electrode metal droplet transfer has the maximum value of the spectrum amplitude, which decreases as the current increases.

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