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ANALYSIS OF THE PROCESSES IN THE WELDING ARC DURING ADDITIVE MANUFACTURING

Experimental studies of arc burning have been carried out with a view to use it for wire arc additive manufacturing processes. The values of the welding arc current and voltage were recorded and the records were analyzed. The average duration of the short circuits and its root mean square deviation and normalized root mean square deviation were determined. Investigation of the macro- and microstructure of the 3D printed sample show that it is uniform along its entire height.

Keywords: additive manufacturing; welding arc; current and voltage recording

1. Introduction

The study of the processes in the welding arc and the advanced possibilities for its control led to the creation of a number of processes (surface tension transfer, cold process, cold arc, etc.) oriented mainly to welding the root of the seam, splash reduction and operating in the low power range. These processes compete with the short arc and are in fact its development achieved by controlling the droplet transfer. In most cases, it is the current magnitude that is controlled by using arc voltage feedback. The exception is the Fronius Cold Metal Transfer (CMT), in which the wire feeding device is also controlled. The process control mainly focuses on the short circuit phase. Usually the current is reduced to very low values (5-10 A) when restoring the arc to avoid the hydrodynamic impact on the weld pool. Such lowering of the current magnitude is also used at the beginning of the short circuit phase to provide a good contact between the droplet and the weld pool. In recent years the so-called Wire Arc Additive Manufacturing (WAAM), which is electric arc process for building details layer-by-layer, have been increasingly researched and applied in parallel with the welding processes [1-4]. The electric arc is used as heat source, while the wire provides the required amount of additive material. In the MIG/MAG process, the two functions are combined and interdependent. The speed of the wire feeding determines the magnitude of the current and, respectively, the power of the process. At the same time, this technology provides high melting performance [5]. As the process power decreases, the size of the weld pool decreases too, and therefore less wall thickness can be achieved. In parallel, the increase in heat input leads to greater deformations and distortions of the resulting parts. Therefore, it is necessary to develop and study methods with lower heat input while maintaining or increasing the melting productivity. As can be seen, only the problems related to the formation of the layers that make up the details are indicated here. When using high strength steels, the problem of ensuring the relevant cooling rate also arises. This, in turn, imposes a limit on the minimum value of the heat input. In practice conventional welding equipment is used for implementation of WAAM processes. To define the requirements to the welding current sources, aimed towards the implementation of these processes and their development, it is necessary to study the processes in the low power welding arc. It was found within the frames of earlier studies [6-8] that besides long arc (Fig. 1), transitional arc, jet arc, and short arc (Fig. 2) there is also breaking arc (Fig. 3).

When researching new technological processes such as WAAM the recording of current and voltage values with subsequent analysis of the obtained result is also used [9-11]. The short-circuit durations in the welding arc suitable for WAAM modes are determined in this research. To reduce the heat input, it is advisable to develop and use welding equipment, ensuring the heating and melting of the used material mainly during the short circuit phase.

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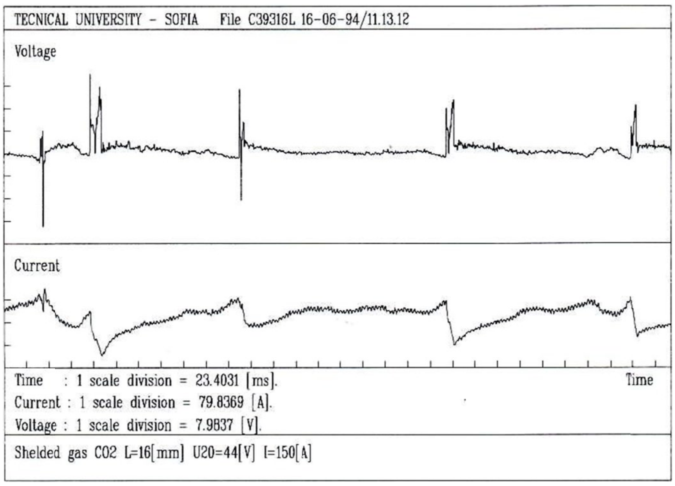

Fig. 1. Recording of long arc

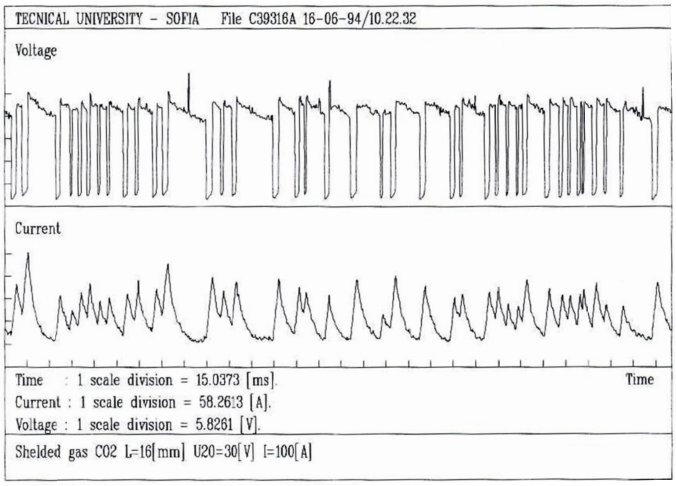

Fig. 2. Recording of short arc with electrode stick-out 16 mm

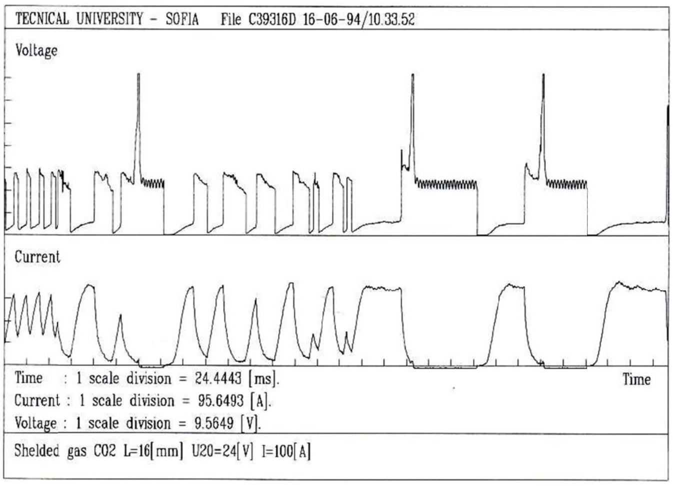

Fig. 3a. Intermittent arc recording – first section of the record

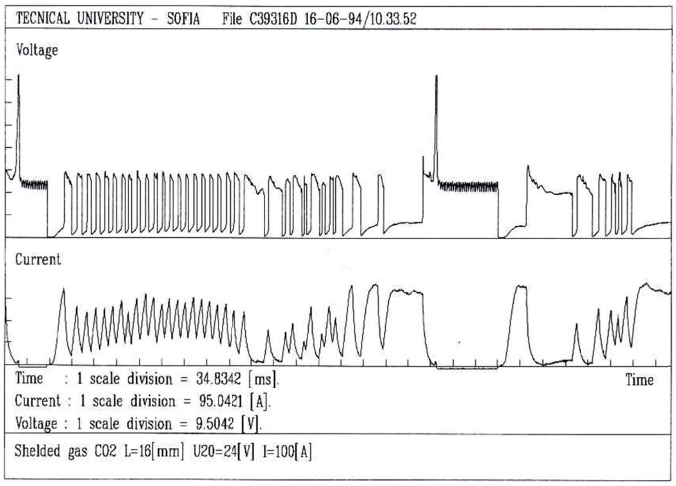

Fig. 3b. Intermittent arc recording – second section of the record

2. Materials and methods

As part of this study, short arc experiments were carried out. The tests were performed with conventional welding equipment and welding wire with a diameter of 0.8 mm was used. The additive material brand is SG2 and its chemical composition is shown in TABLE 1. GMAW process is realized using shielding gas Ar+18%CO_2. The WAAM starts on plate with dimensions 4×150×350 mm. The electrode stick out is changed to two levels and the feed rate, which determines the magnitude of the welding current, is changed to three levels. Two different values for arc voltage were applied for each combination. Arc current and arc voltage values were recorded during the process. Using three different frequencies, it was found that a sufficiently high resolution was achieved at frequency of recorded values 12 kHz (Fig. 4a-c). Through the analysis of the voltage values, the duration of the short circuits and its root mean square deviation were determined.

TABLE 1

Chemical composition of the used welding wire

C	Mn	Si	P	S	Ni	Cr	V	Cu
mass. %								
0.07	1.45	0.82	0.005	0.010	0.02	0.03	0.004	0.03

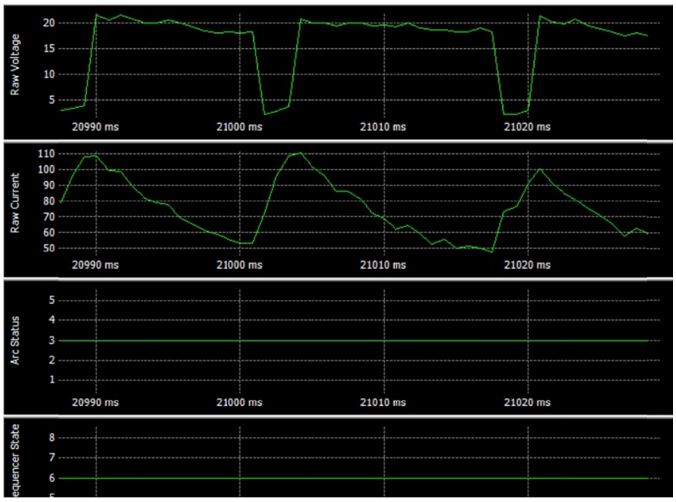

Fig. 4a. Arc parameter recording with frequency 1200 Hz

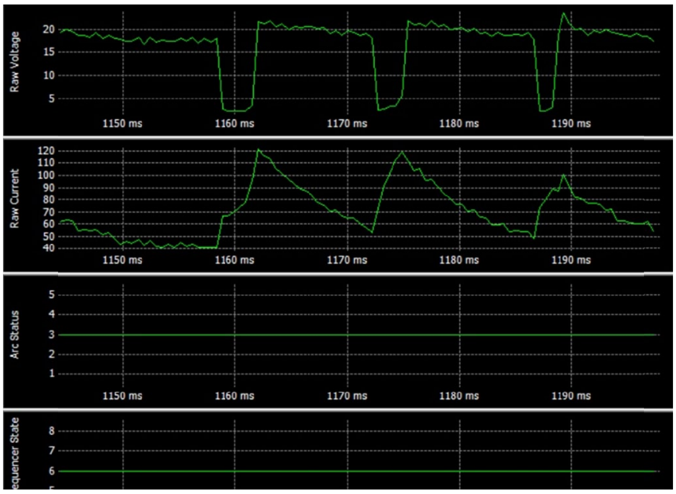

Fig. 4b. Arc parameter recording with frequency 1850 Hz

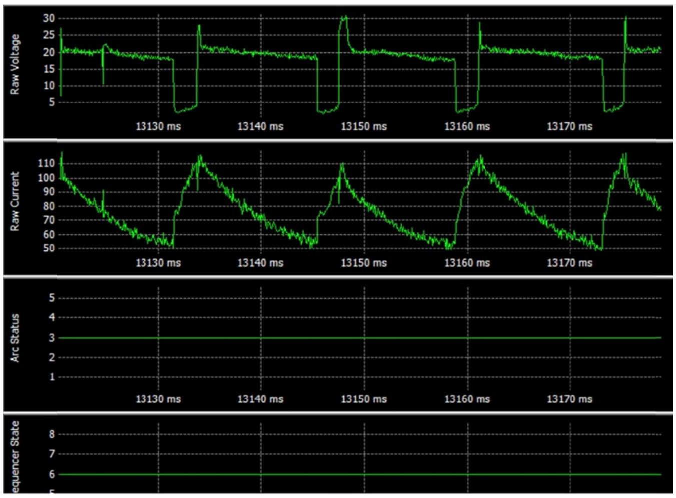

Fig. 4c. Arc parameter recording with frequency 12 kHz

In connection with the realization and research of layers obtained by wire arc additive manufacturing (WAAM) an experimental setup based on conventional welding current source was used (Fig. 5). The equipment used for conducting the experiments includes (Fig. 6): the welding power source Kempact; the welding current and arc voltage recording devise Arc Tracker™ from Lincoln Electric; welding torch; 3D printer Wanhao D12/500 (modified to be used with GMAW process).

The behavior of the system "current source-arc" in a short-circuit process was investigated. For this purpose, the instantaneous current and voltage values were recorded using

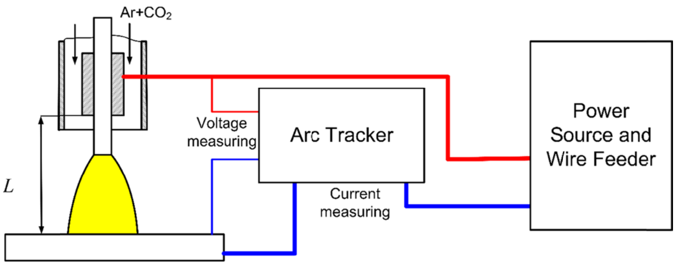

Fig. 5. Scheme of the experimental setup

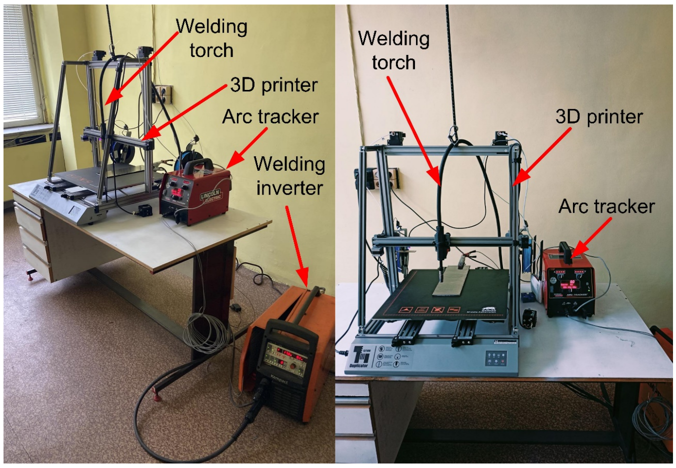

Fig. 6. Apparatus used during the experiments

Arc Tracker welding process monitoring device. The data is transmitted and recorded in real time on a laptop computer with Power Wave Manager software installed. The results of these recordings were processed in accordance with the methodology described in [12-15]. In order to verify the absence of defects in the deposited metal, the macro- and microstructure of the printed layers (Fig. 7) was examined. For this purpose, a cross-section of the layers structure was made (Fig. 8). The surface of the section was machined according to standard metallographic profile preparation procedure by grinding and polishing and was etched with 5% HNO_3.

Fig. 7. Specimen obtained by WAAM

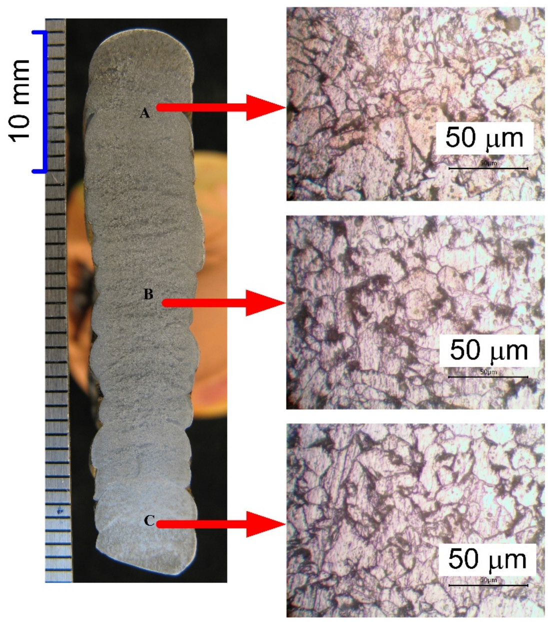

Fig. 8. Macro- and microstructure in cross-section of the specimen obtained by WAAM

The recorded current and voltage were processed by determining their average values and their root mean square deviations and normalized root mean square deviations (Fig. 9).

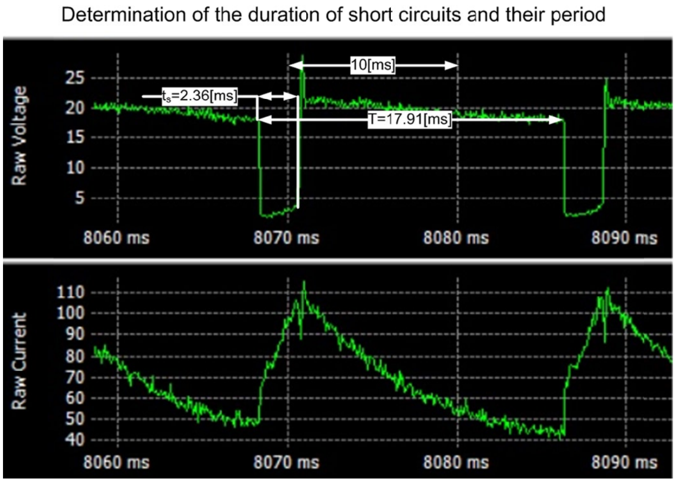

Fig. 9. Short circuit parameters

3. Results and discussions

The conditions of carrying out the experiments and the obtained results are systematized in TABLE 2. Here, L is the electrode stick out, V_w is the wire feed rate, I_w is the current magnitude, t_s is the mean short circuit duration, RMSD is the root mean square deviation of the short circuit duration, and NRMSD is the normalized root mean square deviation. Typical sections of the arc voltage records are shown in Fig. 10 and Fig. 11. It can be seen from these figures that the frequency of the short circuit is greatest at the smallest arc current.

TABLE 2

Parameters and results of the conducted experiments

Parameters			Measured		Calculated	
L, [mm]	V_w, [m/min]	U_a, [V]	I_w, [A]	t_s, [ms]	RMSD, [ms]	NRMSD
8	2.9	16	50	2.3	0.23	0.11
		17		2.4	0.19	0.08
	4.6	17	76	2.99	0.37	0.12
		18		2.6	0.32	0.12
	7.0	18	104	2.99	0.56	0.19
		20		2.85	0.7	0.24
14	2.9	16	49	2.6	0.26	0.1
		17		1.99	0.12	0.06
	4.6	17	76	2.69	0.33	0.12
		18		1.96	0.16	0.08
	7.0	18	104	3.63	0.44	0.12
		20		2.13	0.17	0.08

The effect of current magnitude, arc voltage and electrode stick out on the average short circuit duration is illustrated in Fig. 12. Here, U1 indicates the lower voltages, and U2 indicates

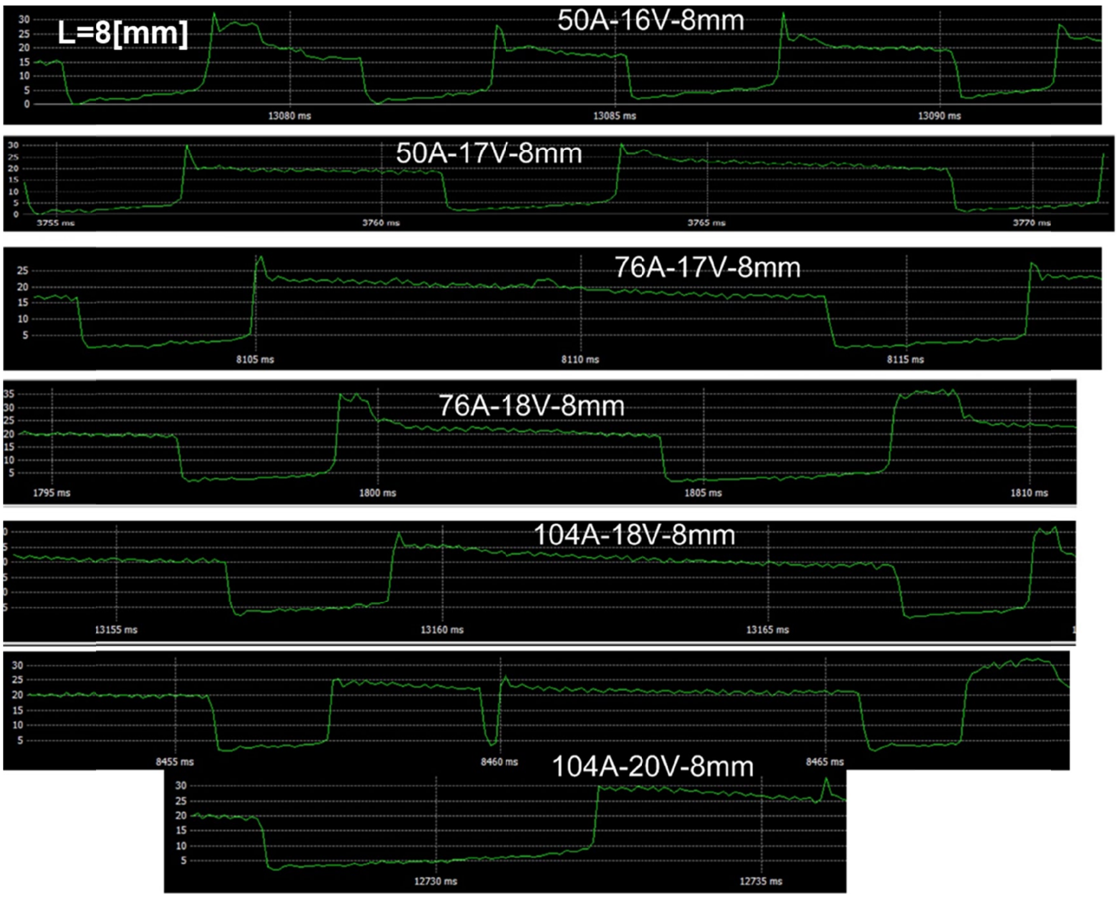

Fig. 10. Typical sections of the arc voltage records at electrode stick out 8 mm

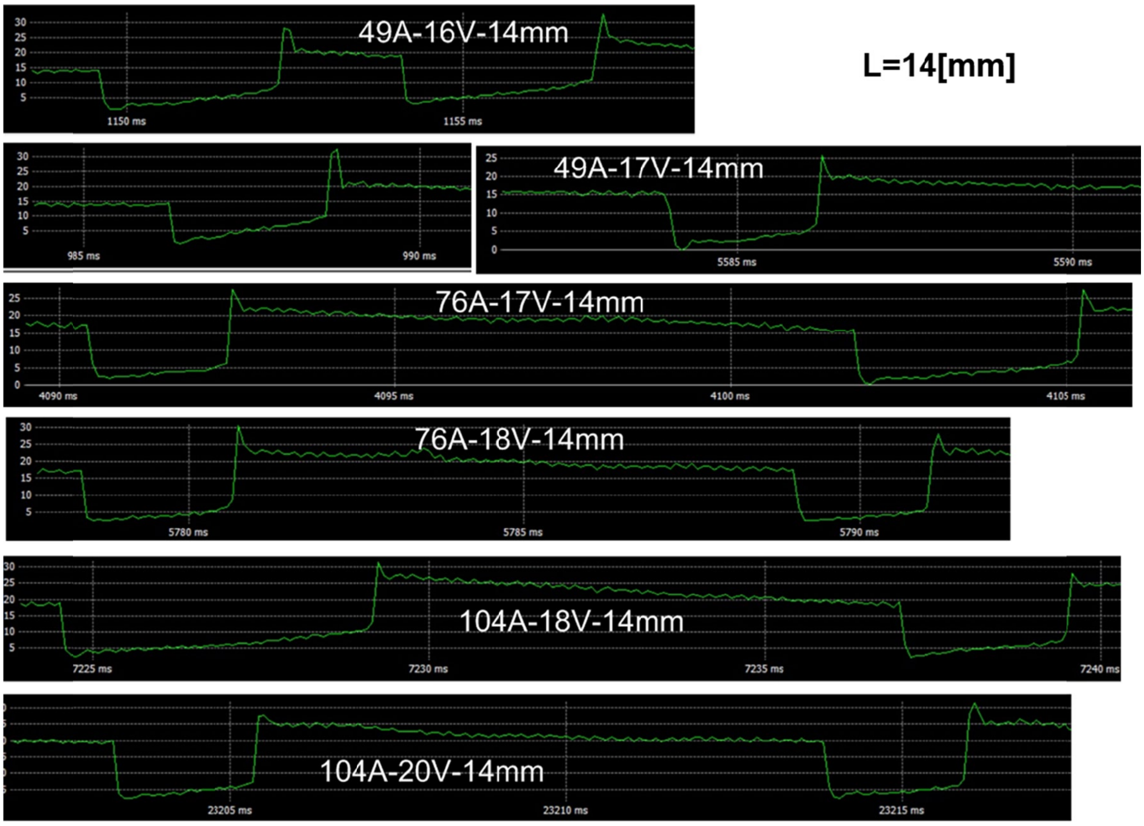

Fig. 11. Typical sections of the arc voltage records at electrode stick-out 14 mm

the higher voltages at a given wire feeding speed, respectively magnitude of the arc current. For each of the welding current values, the voltage differences are very small. In fact, this parameter is set based on the expected current magnitude and the corresponding reference point for welding in a shielding gas mixture of Ar+CO_2 according EN 60974. The duration of short circuits is in the range of 2 to 3.5 ms. It can be noted from the figure that when the electrode stick out increases and arc voltages lower, the short circuits durations tend to increase while at higher voltages the trend is reversed.

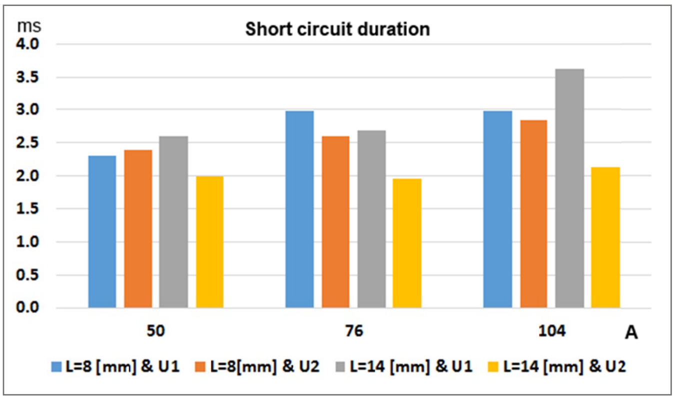

Fig. 12. Effect of experimental conditions on the average short circuits duration

The root mean square deviations obtained indicate that there is a substantial deviation from the mean values mainly at arc current 104 A (Fig. 13). Increasing the length of the electrode stick out and using a lower arc voltage lowers the short circuit duration variance. For used modes, the normalized RMS value of the short circuit duration is within 10% when the arc current is less than 100 A.

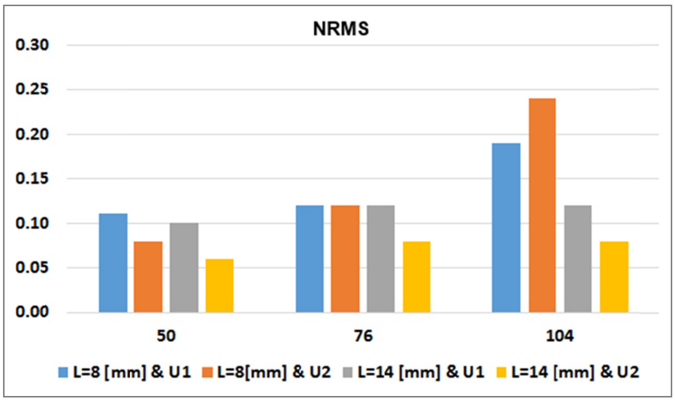

Fig. 13. Effect of experimental conditions on the normalized root mean square deviations of the short circuit duration

Macroscopic observation of the cross-sectional surface of the 3D printed specimen showed no pores or other defects produced during metal deposition. The metallographic examination of the microstructure at points A, B and C located on the axis of the specimen (Fig. 8) shows that the microstructure is ferrite-pearlite and is uniform over the entire 45 mm height of the printed specimen. The photos were taken at a magnification of ×500.

4. Conclusion

In different welding modes realized by using a conventional current source, the duration of short circuits is in the range of 2 to 3.5 ms. For these modes, the normalized RMS value of the short circuit duration is within 10% when the arc current is less than 100 A. When implementing the technologies for weld arc additive manufacturing and reduction of heat input, it is appropriate to develop and use current sources providing greater relative short circuits durations.

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