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Analysis of the Effect of Arc Welding Characteristics in Modern MAG Welding Variants on Welding Properties and Weld Geometry

Abstract: The article presents experimental tests aimed to compare welding conditions and technological properties of butt joint welding using low-energy gas-shielded metal arc welding variants such as MAG Standard, MAG Puls, TwinPuls, SpeedPuls, SpeedUp, SpeedArc, SpeedRoot and SpeedCold. The article also presents a comparison of welding efficiency of these processes and the effect of power source dynamic characteristics on the geometry and macrostructure of welds.

Keywords: arc welding, MAG welding variants, welding efficiency

Introduction

One of more important properties of welding power sources is their technological usability defined by electric arc ignition ability and arc burning stability, amount and size of metal spatter during welding (for welding methods utilising consumable electrodes) and arc flexibility [1,2,3]. The technological usability is primarily determined by the static and dynamic characteristics of the welding arc power supply.

Each arc welding method is specific due to the range of parameters used, power density, arc properties (chemical composition of arc space, electrode material etc.) and manners of metal transfer in the arc. Such parameters set various requirements for welding power sources, primarily in terms of their dynamic properties [4,5,6,7,8,9].

The notion of welding process stability includes source resistance to various kinds of internal and/or external disturbances to which the source can be exposed during welding. For this reason, welding stability testing is usually limited to the obtainment of a good quality weld of practically unchanging geometry along its whole length (width, face height, penetration depth). In accordance with reference publications, welding process stability assessed in this manner is referred to as technological stability [10,11,12]. The development of new MIG/MAG method variants (SpeedUP, STT, CMT, AC Puls, etc.) has led to the better control of heat input to the weld, the improvement of weld quality and penetration depth as well as the increase in welding process efficiency. The tests discussed in this article refer only to selected MAG method variants characterised during welding and overlay welding of high-alloy steel.

Experimental Tests

The primary objective of the tests was to compare welding and overlay welding properties

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in the flat position (PA) using the MAG Standard, MAG Puls, TwinPuls, SpeedPuls, SpeedUp, SpeedARC, SpeedRoot and SpeedCold methods, taking into consideration the basic weld properties and welding efficiency. Another objective was to determine which of the MAG method variants caused the lowest heat input to the material welded. The tests were partly conducted in the laboratory of the Welding Engineering Department at Częstochowa University of Technology and at the Nederman Manufacturing Poland Ltd. The analysis involved power source dynamic properties, mainly welding current and arc voltage waveforms referred to the geometry of welds and overlay welds obtained. The tests involved making joints of the 1.4301 grade alloy steel (according to PN-EN 10088). The filler metal wire used in the test was the MOST-manufactured 1.4404 grade wire (according to PN-EN 10088) [14] having a diameter of 1.0 mm. The shielding gas used was the Cronigon S2 Group M13 mixture (according to PN-EN ISO 14175:2008). The overlay welding efficiency for the individual MAG method variants was assessed by comparison with the reference (model) specimen made using the MAG Standard method. Overlay welding during the comparative tests of all the variants was performed using the comparable overlay welding current of approximately 100 A. Overlay welding was carried out in a mechanical manner using a progressive manipulator. The test involved the use of a LORCH-manufactured Saprom-S inverter device.

The results obtained were used to develop and implement a technology for overlay welding of an innovative fan made of 1.4301 steel and intended for food industry applications. The requirements of the investor included reinforcing and increasing the thickness of the fan elements, i.e. the "nose" and the outlet reducer. During fan operation these elements are exposed to the greatest abrasion caused by airborne dust and other particulates. The expectation of the investor was connected with the development of an overlay welding technology characterised by possibly low linear energy in order to maximally reduce deformations of the structural elements subjected to overlay welding.

The objective of the tests included the comparison of the basic overlay weld properties and welding efficiency as well as the industrial implementation of a method selected following the tests.

The assumption was to implement (at Nederman Manufacturing Poland Sp. z o.o. (Ltd.)) a proper overlay welding method in order to meet the expectations of the investor who had commissioned the design and construction of a fan made of 1.4301 steel for operation in dust conditions. Warsaw University of Technology in conjunction with RYWAL-RHC adopted the preliminary concept of overlay welding the alloy steel with the 1.4404 grade wire followed by gentle grinding and polishing of the face. Initially, the use of the short-circuit arc MAG Standard was planned, yet after the preliminary analysis and having in view the necessity of minimising the effect of welding stresses and strains, the testing of various MAG method variants was undertaken.

The experiment was connected with designing and making a test rig (Fig. 1 and 2). Manual welding was used while testing the selected MAG method variants (as is the case in the real fan prefabrication conditions).

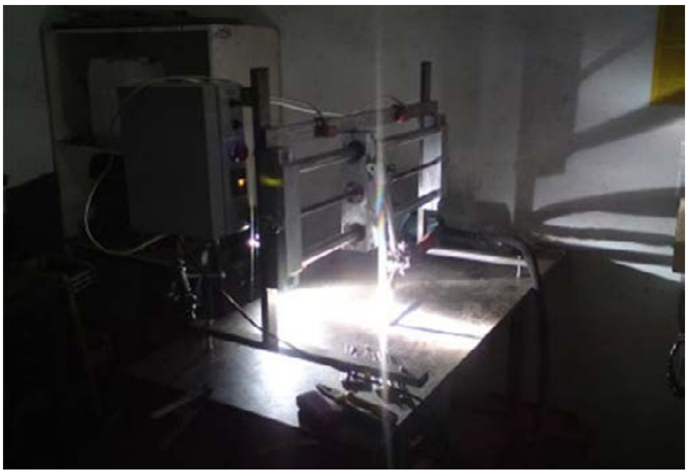


Fig. 1. Test rig used in the comparative investigation of the MAG method variants

Fig. 2. Welding test rig featuring the progressive manipulator during recording current waveforms in time

The assessment of power source dynamic properties was conducted on the basis of the analysis of recorded welding current and voltage waveforms in time.

The tests involved making overlay welds being approximately 1500 mm in length. The welding parameters are presented in Table 1. The overlay welding specimens had the length of 1500 ± 5 mm, width of 500 ± 2 mm, thickness of 2 mm and were made of the 1.4301 grade steel sheet. The specimen surface was metallically pure and free from impurities.

The welding efficiency reference for the overlay welds assessed was a model overlay weld made previously using the MAG Standard method. For all the MAG methods the constant overlay welding rate of 300 mm/min and the constant electrode extension length of 15mm were used. The basic overlay welding parameter comparable for all the cases was the welding current of approximately 100 A (Table 1). The remaining parameters were selected automatically by the synergic device control system. Table 2 presents dynamic current-voltage-time waveforms recorded and overlay weld macrostructure images.

Fig. 3. Fan for overlay welding

Fig. 4. Workpieces for overlay welding

Table 1. Overlay welding parameters for various MAG method variants

No.	Welding method	Welding current [A]	Arc voltage [V]	Filler metal feeding rate [m/min]	Welding rate [cm/min]	Linear energy E[kJ/cm]	Mixture M13 [l/min]	Exposed electrode wire [mm]
1.	MAG Standard	110	18.9	5.0	30	4.16	10	15
2.	SpeedARC	111	17.8	6.2	30	3.95	10	15
3.	PULS	90	22.4	5.2	30	4.03	10	15
4.	TwinPuls	96	23.4	5.2	30	4.49	10	15
5.	SpeedPulse	99	22.1	5.7	30	4.38	10	15
6.	SpeedUP	110	20.1	5.6	30	4.46	10	15
7.	SpeedRoot	106	18.3	6.2	30	3.88	10	15
8.	SpeedCold	112	16.6	7.1	30	3.72	10	15

Table 2. Current and voltage waveforms in time and macro-metallographic specimens of the welds and overlay welds made using various MAG method variants

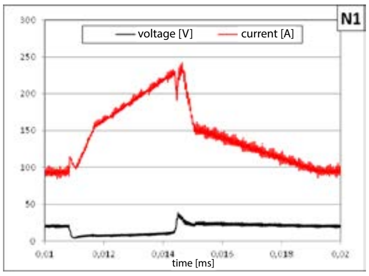
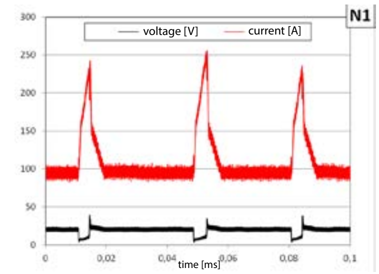
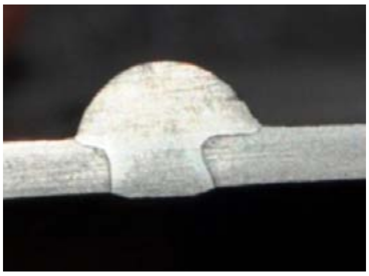
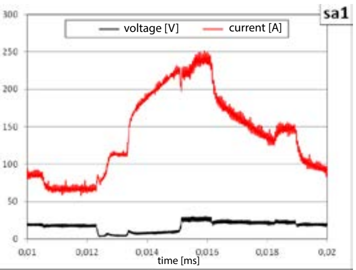
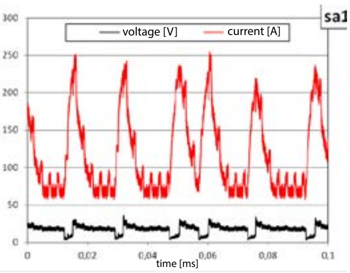
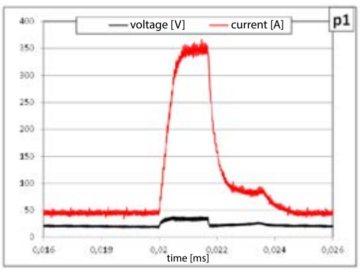
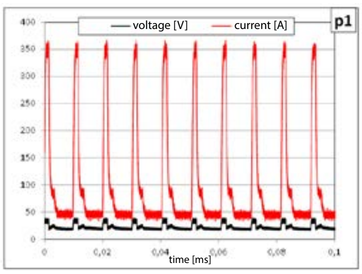
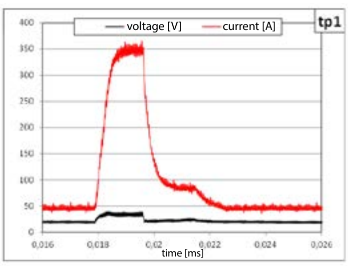
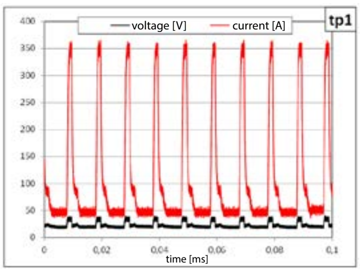
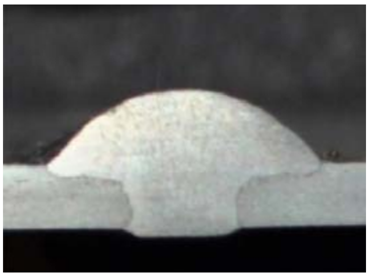
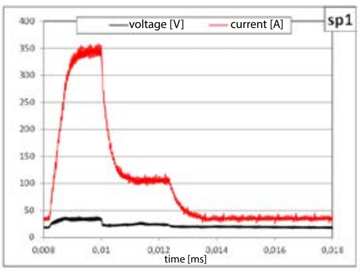
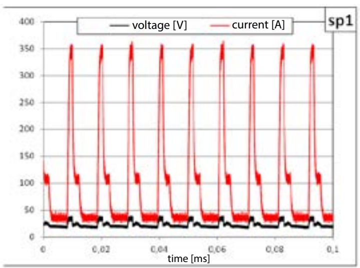
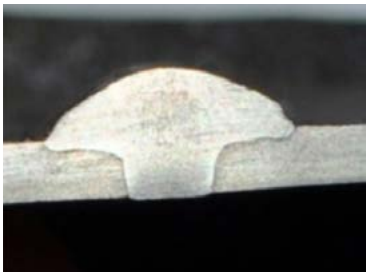
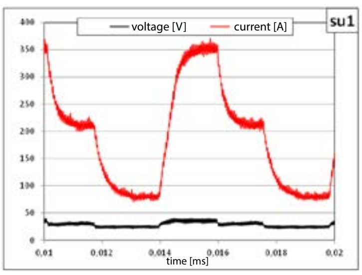
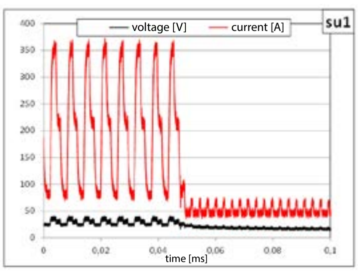
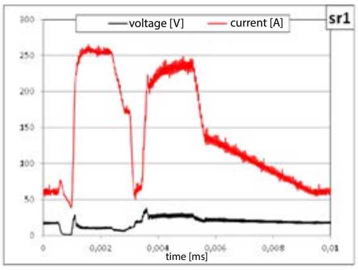
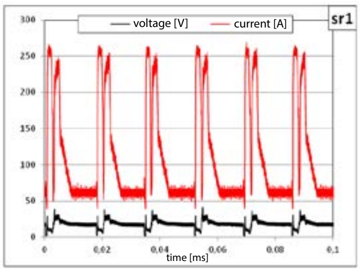
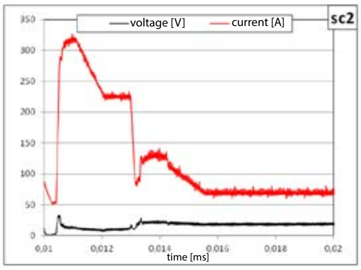
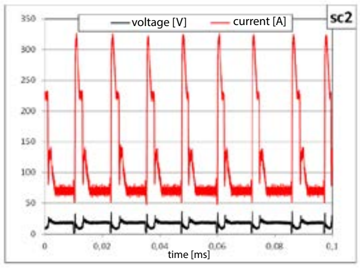
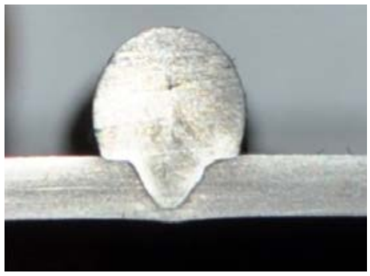
No.	Welding method	Current waveforms in time	Current waveforms in time	Macrostructure of overlay weld cross-section
1	MAG Stanard			
2	Speed-ARC			
3	Puls			
4	Twin-Puls			
5	Speed-Pulse			
6	Speed-UP			

Table 2. Current and voltage waveforms in time and macro-metallographic specimens of the welds and overlay welds made using various MAG method variants (continuation)

No.	Welding method	Current waveforms in time	Current waveforms in time	Macrostructure of overlay weld cross-section
7	Speed-Root			
8	Speed-Cold			

The experimental tests revealed that the time-related current-voltage waveforms differed significantly. The most similar were the dynamic waveforms observed for the Puls and TwinPulse variants. The drop transfer in these two methods, recorded with the high-speed camera, did not show significant differences as regards the manner of the drop transfer to the weld pool. The longest current pulse peaks were present during welding with the Speed-Pulse method. Their shape was similar to that observed in the Puls or TwinPulse variants only at the first peak increase stage, near the peak value, where the current increase rate significantly decreased. During the current decrease in the SpeedPuls method, the current began to decrease slower to approximately 2/3 of the current peak value (the easily visible drop in the diagram) to decrease similarly as in the Puls method. Such a shape of the current impulse increased its duration. While assessing the character of the drop transfer to the weld pool, recorded using the high-speed camera, it was possible to observe fine-drop (stream-like) metal transfer.

The decision of the investor was significantly influenced by the innovativeness of the low-energy MAG SpeedRoot and SpeedCold processes (by LORCH). These new MAG method variants are based on the drop transfer process utilising the forces of the metallic bath fluid surface tension, known in 1980s. The older generation devices were based on the hardware, which significantly increased their price in relation to the MAG Standard method devices and, as a result, limited their availability. While developing the SpeedRoot and SpeedCold methods, the LORCH company constructors adopted a different, i.e. software-based, approach. In addition to the control programme, synergic control-based procedures were developed, due to which, after entering such data as the electrode wire type and diameter and the gas shielding type, welding parameters are selected in the function of welding current. The remaining parameters such as arc voltage, filler metal feeding rate and other descriptive quantities are selected on a synergic basis by the device control system.

In the SpeedRoot process, after touching the material being welded with the electrode wire, welding current increases rapidly until the moment when the minimum liquid metal contraction (connecting the electrode tip with the weld pool) is formed. The bridge break and drop transfer are performed using the force coming from the surface tension already at a low current value, which results in a spatter-free metal transfer. At the successive cycle stage, the current impulse heats the electrode wire tip forming a relatively big drop, so that, during the next cycle, as much of the low-oxidised and low-nitrided filler metal as possible can be transferred to the weld.

A new MAG method variant is referred to as SpeedCold. This method is very similar to that of SpeedRoot with the difference consisting in faster current decrease during the contact so that the drop transfer can utilise surface tension force and, at the second stage, the value of current peak, responsible for heating the electrode wire tip, can decrease. These changes resulted in a decrease of overlay welding linear energy. It was observed that of all the methods compared the SpeedCold variant was characterised by the lowest linear energy -20% lower than that during TwinPulse welding.

In the SpeedUp method during the contact phase current waveforms are "knocked up" by additional impulses. SpeedUp utilises one of the latest MAG method variants, namely SpeedArc, already described in specialist reference publications ([12]). The transport of metal in the MAG Standard method is performed in a classical manner, i.e. when the liquid metal drop comes into contact with the material being welded. The process is accompanied by a rapid voltage decrease with the simultaneous increase in current until the formation of the liquid metal contraction (mainly due to electrodynamic force) connecting the electrode with the weld pool. The compressive force is responsible for tearing the drop off and "moving" it to the liquid metal pool. In the SpeedUp method during the contact, current is cyclically "knocked up" with current impulses increasing the contracting force whose value is directly proportional to the square of welding current, or more precisely, to the square of the current flowing in the arc. Therefore, each momentary current value change has a significant effect on the drop formation and transfer processes.

The timelapse high-speed camera photographs show that during the drop transfer in the SpeedUp method, similarly as in SpeedArc, the welding arc is "narrowed". After the phase of contact it is possible to observe a smooth transfer to the short-circuit arc as in the SpeedPuls method. The impulse shape is similar to that in the Puls and TwinPulse methods but already at the first stage of current increase at the impulse phase. At the amplitude phase, the current increase rate decreases significantly. While decreasing the current value in the SpeedPuls variant, the current starts decreasing slower to approximately 2/3 of its peak value (making an easily visible drop in a diagram) and next continues to fall similarly as in the Puls method. Such a current peak shape extends the peak duration.

While assessing the character of the drop transfer to the weld pool, recorded using a Photron-made 1024 PCI high-speed camera, it was possible to observe fine-drop (stream-like) metal transfer. This creates the possibility of a significant filler metal wire feeding rate increase [11,12] in comparison with the MAG Standard method. It should be noted that the short-circuit phase is followed by current impulses of significantly higher value, which is gently lowered to the average current value set on the device. The frequency of short-circuit phase changes and that of the SpeedPuls phase amount to 3 Hz.

Due to the appropriately programed drop-cutting procedure, the tip of the electrode wire has a conical shape after the welding process. The electrode wire tip is void of the drop impeding the arc re-ignition. This is a significant advantage of the SpeedUp welding method as the resumption of the welding process does not have to be preceded by cutting off the electrode wire tip.

The tested devices for welding by means of the MAG SpeedRoot and SpeedCold variants feature many modern solutions. One of the most important characteristics of such devices is high processor timing frequency enabling quick and proper control and adjustment system response. Such systems systematically check welding process conditions and react accordingly, e.g. to a prolonging short circuit time or a welding arc length change, in order to maintain the stable material transfer to the weld. The device can quickly react to various disturbances and limit the risk of welding imperfection formation [13]. An additional advantage characterising the SpeedRoot and SpeedCold methods in comparison to the solutions of the 1990's is the fact that on the same structure it is possible to use several power sources without mutual interference, as is the case with other low-energy MAG variants based on additional voltage measurement. The feature mentioned above was one of the most important factors taken into consideration at Nederman Manufacturing Poland Ltd., i.e. to provide the opportunity of using several non-interfering stands on one section.

The LORCH-manufactured Saprom S device used in the tests is a universal MAG welding power source enabling the use of all the programme variants described in this article. The device is universal. As an example, it is possible to first use the SpeedRoot variant for making root runs and penetrations in the vertical downwards progression (PG) and pipe position for welding downwards (PJ), and next to apply the SpeedUp software for making fillings in the vertical upwards progression (PF) as well as other MAG method variants such as Standard, SpeedPulse and SpeedArc. The last two variants enable spatter-free solid wire welding at a significantly greater welding rate than in the classical MAG method.

Summary

The objective of the tests performed was to analyse and compare the basic properties of selected electric power welding sources with the internal frequency conversion. The tests involved one of the latest devices for arc welding with external voltage static characteristics. The test results were used to implement a new welding method, i.e. SpeedCold, in the production process of preventive high-alloy steel overlay welding. The use of this method increased overlay welding efficiency and enabled the obtainment of spatter-free joints with proper penetration and limited deformation.

Attention should be paid to the increasing versatility of modern welding power sources. For instance, while making pipelines, root runs are welded using the SpeedRoot variant. Next, the same device, after switching over to another function, is made to make the filling, e.g. using solid or flux-cored wires.

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