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Application of variable polarity MIG welding of aluminium alloys

Abstract: The article presents the application of an innovative MIG welding technology using variable polarity for the welding of thin aluminium alloy elements and demonstrates the results of tests related to the impact of the electrode negative (EN) ratio on weld geometry and penetration depth as well as on the quality and structure of welded joints.

Keywords: MIG welding, variable polarity, aluminium alloys

Introduction

The welding equipment market, and in particular, that of MIG/MAG welding equipment has seen fierce competition recently. Leading producers of welding equipment offer highly advanced products as regards their design, control and functionalities. One of the areas where companies try to achieve a competitive edge includes innovative synergic lines making it possible to weld specific base metal grades and, in particular, thin elements. Such lines often constitute additional equipment of welding machinery, yet their significant popularity is responsible for the fact that individual synergic lines are often referred to as welding methods. The recent 10 years have seen the development of devices for Cold Metal Transfer (CMT) and ColdArc welding. Lately it has also been possible to observe a rapid development in Variable Polarity Gas Metal Arc Welding. Devices which enable using variable polarity current for energising an electric arc extend the range of so-called low-energy methods, i.e. especially programmed welding synergic lines offering significant reduction of heat input to the base metal.

This article presents the course and technological test results related to Variable Polarity MIG welding (VP MIG) of EN AW 6082 and EN AW 5754 aluminium alloy sheets as well as the metallographic examination results of welded joints.

Materials and methodology

The objective of the tests was to develop the material-technological conditions of VP MIG welding of aluminium alloy thin-walled elements enabling obtaining the best possible quality of welded joints as well as to determine the properties and structure of joints.

The technological tests of VP MIG welding and of double-pulsed MIG welding were carried out using a mechanised station equipped with a DW 300 welding device manufactured by OTC Daihen. The device is provided with synergic lines referred to as AC Pulse and AC Wave Pulse. The latter, apart from enabling the use of variable polarity current, makes it possible to change voltage and current pulsation frequency. Both the synergic lines mentioned above were applied in the tests. The base metal used in the tests was in the form of 1

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to 4 mm thick EN AW 6082 (AlSi1MgMn) and EN AW 5754 (AlMg3) aluminium alloy sheets according to EN 573-3. The filler metal used in the tests was an AlMg4.5Mn0.7Zr electrode wire (PN-EN ISO 18273 – Al5083) with a diameter of 1.2 mm. The shielding gas used in the tests was argon applied at a constant flow rate of 14 l/min.

The developed testing methodology included in the first instance the determination of the influence of the EN ratio and that of current pulsation frequency on the weld geometry, penetration depth and HAZ width. To this end it was necessary to carry out overlay welding tests using constant technological parameters (welding current I=100 A, welding rate V=50 cm/min.) and changing the EN ratio within the range of 45 to 80% only. The base metal used was in the form of 4 mm thick EN AW 6082 alloy sheets (40 mm × 100 mm). In order to eliminate the effect of heat coming from successive runs, only one overlay weld was made on each test piece. Afterwards, the test pieces with overlay welds were cut crosswise at the half of their length and subjected to macro and microscopic metallographic tests.

The next stage involved carrying out technological welding tests and the determination of the EN ratio influence on the weld geometry. For this purpose it was necessary to make butt joints of 2 mm thick EN AW 6082 aluminium alloy sheets with different EN ratio in current and voltage waveforms (EN from 45% to 80%). Afterwards, using the AC Wave Pulse synergic line and the constant EN ratio of 60% overlay welding tests and butt welding tests with various pulsation frequency (from 2 Hz to 10 Hz) were carried out. The objective of these tests was to determine the influence of frequency on the weld face appearance and the weld shape. During the tests the constant values of welding parameters were used (welding current I=70 A, welding rate V=50 cm/min).

At the next stage, the AC Wave Pulse synergic line, ensuring obtaining the best quality and the most aesthetic joints, was used to develop the most convenient conditions and parameters of the mechanised welding of butt joints, T-joints and overlap joints made of 1, 2, and 3 mm thick sheets. All the joints made underwent macroscopic metallographic examination, and the butt joints made of 1 and 2 mm EN AW 6082 alloy sheets were used to prepare samples for tensile strength tests and microscopic metallographic examination. The microscopic metallographic examination included observations at 50÷500x magnification of the weld area, Heat Affected Zone and the base metal. The results of these tests are presented below.

Test results

Figure 1 presents an exemplary macroscopic photograph of overlay welds made using constant current parameters and various EN ratio in the arc current and voltage waveforms. Figures 2-4 present the results of the microscopic examination along with the HAZ width measurement for EN=45%, 60% and 80%. Figure 5 presents the macrostructure of the welded joints made with various EN ratio. Figure 6 presents the macrostructures of the joints made with various values of current pulsation frequency and the EN ratio of 60%. Figure 7 presents the effect of pulsation frequency on the overlay weld face appearance. Figures 8-11 present selected macroscopic metallographic photographs of joints welded using the AC Wave Pulse synergic line. Figures 12-14 present exemplary photographs of the microstructures of the welded joints obtained. The photographs present the area in the zone of transition from the weld to the base metal.

Analysis of test results

The technological welding and overlay welding tests with various EN ratios in the welding current and the arc voltage waveforms revealed that when the values of welding parameters remained constant the reduction of the EN ratio in relation to the setting EN=60% (the setting designated as "0" on the control panel) increased the

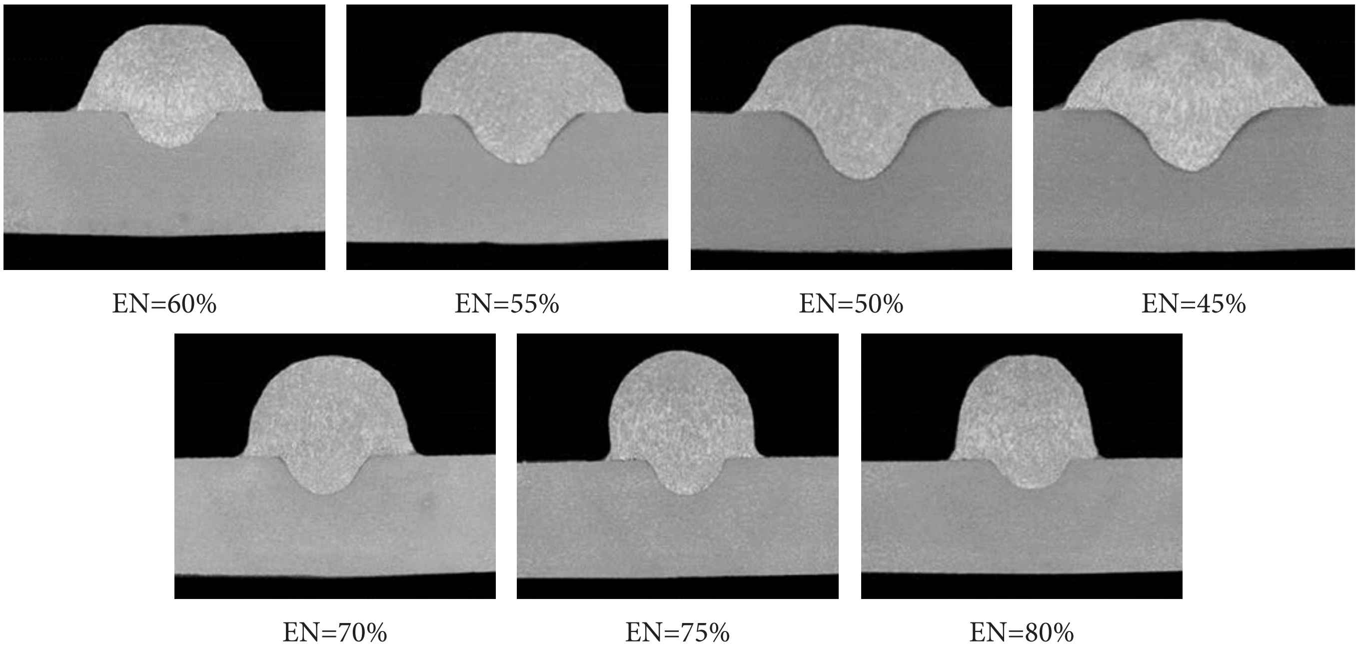

Fig. 1. Macrostructure of the overlay welds made using the AC Pulse synergic line with the welding current of 100 A and the arc voltage within the range between 15.5 V and 23.0 V

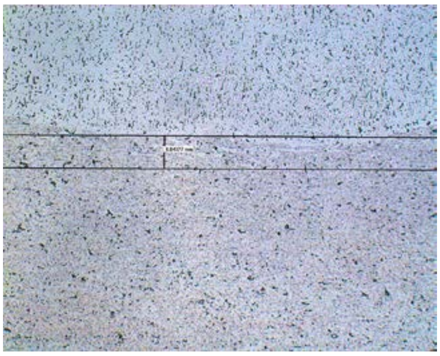

Fig. 2. Microstructure of the overlay weld made with 60% EN ratio; HAZ width: 0.044 mm, mag. 200x, etching with Keller's reagent

Fig. 3. Microstructure of the overlay weld made with 45% EN ratio; HAZ width: 0.151 mm, mag. 200x, etching with Keller's reagent

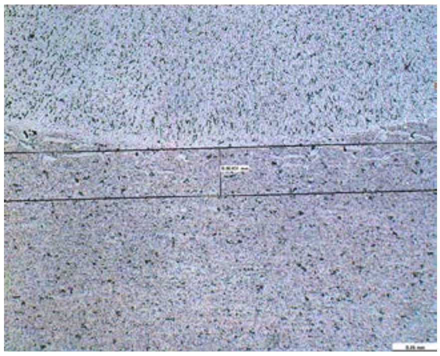

Fig. 4. Microstructure of the overlay weld made with 80 % EN ratio; HAZ width: 0.0643 mm, mag. 200x, etching with Keller's reagent

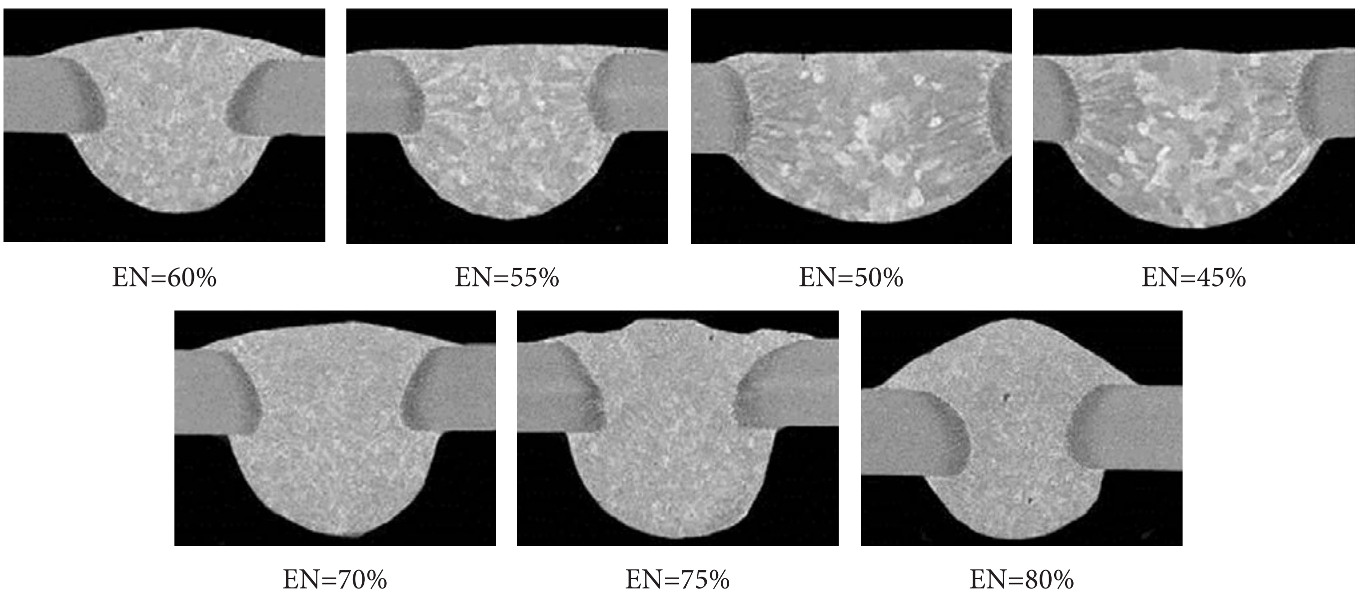

Fig. 5. Macrostructure of the joints welded using the AC Pulse variant and various EN ratio, mag. 3x

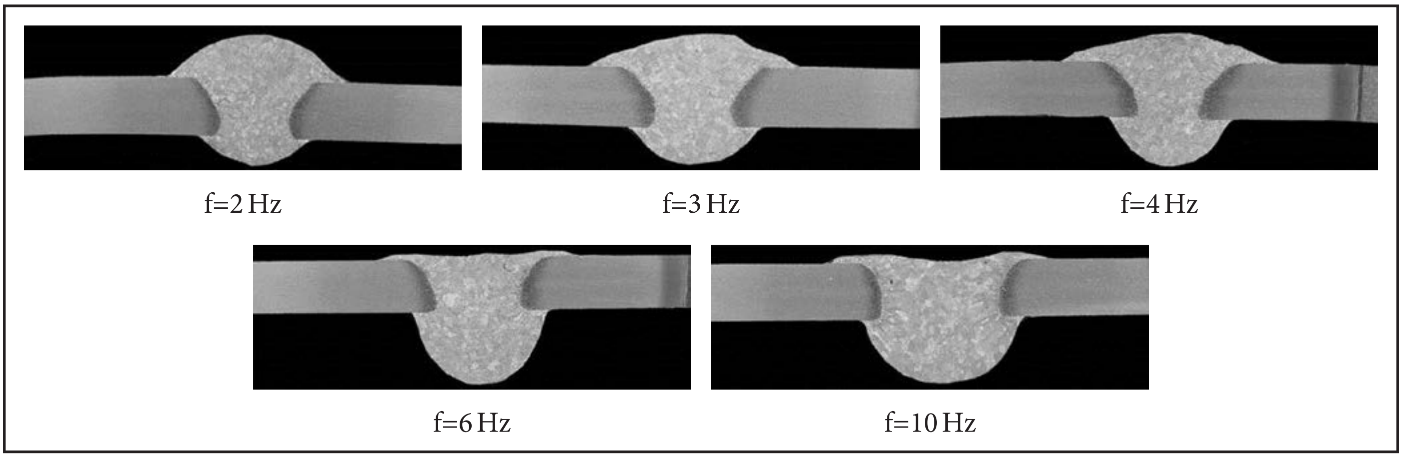

Fig. 6. Macrostructure of the joints welded using the AC Wave Pulse variant and various pulsation frequency settings, mag. 3x

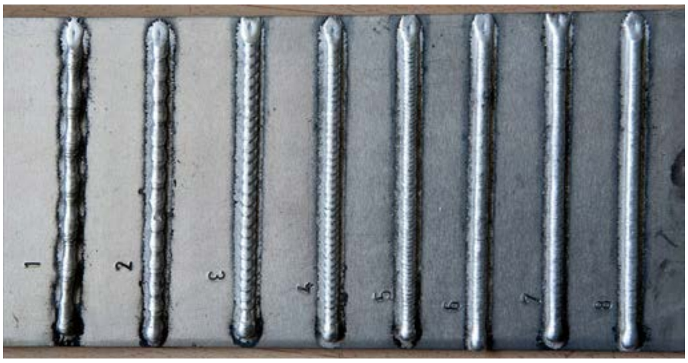

Fig. 7. Overlay weld faces obtained using various pulsation frequency settings and the AC Wave Pulse synergic line

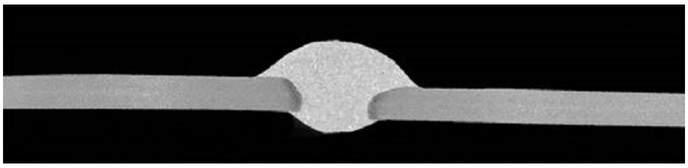

Fig. 8. Macrostructure of the butt joint made of 1 mm thick EN AW 6082 alloy sheets, mag. 5x; welding parameters: I=20 A; U=17.8 V; Vsp=55 cm/min., EN=60%, frequency 3 Hz

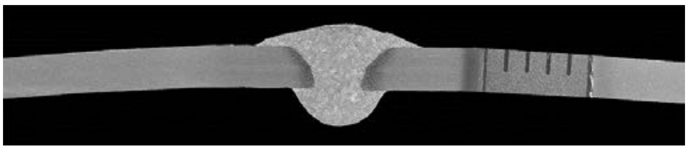

Fig. 9. Macrostructure of the butt joint made of 2 mm thick EN AW 6082 alloy sheets, mag. 4x; welding parameters: I=70 A; U=17.1 V; Vsp=50 cm/min., EN=50%, frequency 5 Hz

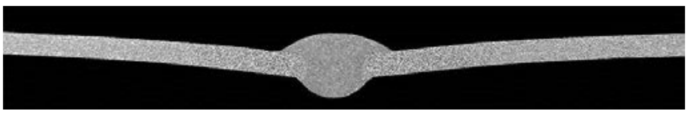

Fig. 10. Macrostructure of the butt joint made of 1 mm thick EN AW 5754 alloy sheets, mag. 4x; welding parameters: I=20 A; U=18.0 V; Vsp=55 cm/min., EN=60%, frequency 3 Hz

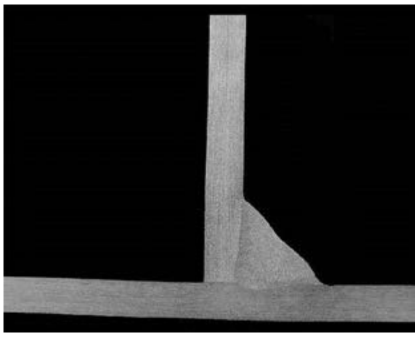

Fig. 11. Macrostructure of the T-joint made of 3 mm thick EN AW 5754 alloy sheets, mag. 3x; welding parameters: I=110 A; U=19.9 V; V_{sp}=35 cm/min., EN=10, frequency 4 Hz

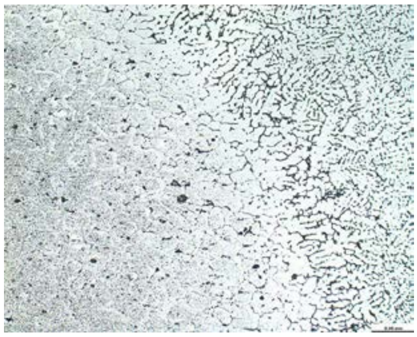

Fig. 12. Microstructure of the joint made of 1 mm thick EN AW 6082 alloy, the view in the fusion area (on the right – the weld, on the left – the base metal), etching with Keller's reagent, mag. 200x

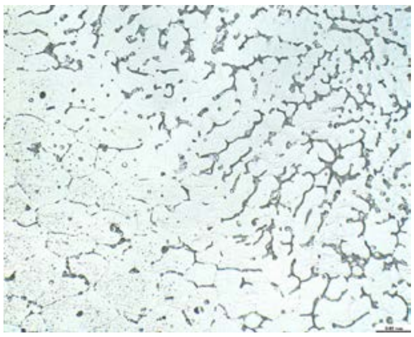

Fig. 13. Microstructure of the joint made of 1 mm thick EN AW 6082 alloy, the view in the fusion area (on the right – the weld, on the left – the base metal), etching with Keller's reagent, mag. 500x

Fig. 14. Microstructure of the joint made of 2.00 mm thick EN AW 6082 alloy, the view in the fusion area (on the right – the weld, on the left – the base metal), etching with Keller's reagent, mag. 200x

width of the weld face, decreased the height of the reinforcement and increased the excess penetration bead from the weld root side. In turn, increasing the EN ratio in welding current significantly improved the joint quality; the weld face became higher and the excess penetration bead from the weld root side was smaller. However, the excessively increased EN ratio resulted in the formation of a weld with an excessively high weld face reinforcement and a disadvantageous shape (Fig.1 and 5). Therefore, it is possible to conclude that increasing the EN ratio in the current and voltage waveforms decreases the heat input to the joint. The best quality can be achieved with a slight advantage of the EN ratio in the waveform (approximately 60-65%).

The measurements of the HAZ width in the overlay welds were carried out using a LEICA MEF4M optical microscope with a digital image analysis system based on appropriate software. The tests revealed that a greater EN ratio did not cause a significant decrease of the HAZ width – the differences were so insignificant that they could be contained within the limits of a measurement error (0.044 and 0.064 for EN = 60% and 80% respectively). In turn, increasing the EP ratio (EP – Electrode Positive) significantly increased the HAZ width (almost three times in the case of the maximum EP ratio). However, it should be noted that the HAZ was very small as its width did not exceed two tenths of a millimetre).

The technological welding tests and the macroscopic metallographic examination revealed that the frequency of pulsation affected the depth of penetration, the shape of the weld and the heat input to the joint. An increase in frequency was accompanied by an increase in the excess penetration bead from the root side and a decrease in the weld face height (Fig. 1). In the case of 2 mm thick sheets the most advantageous geometry of the butt weld and the very aesthetic appearance of the weld face (Fig. 7) were obtained within the 2÷4 Hz range. The metallographic examination did not reveal the presence of gas cavities and pores in the welds, which indicated that the welding process applied enabled the proper degassing of the weld. This was due to the motion and the size of the liquid metal pool. The technological tests also revealed that it was possible to obtain the quality level B (according to PN-EN ISO 10042) of butt welded joints made of 1÷2 mm thick sheets and of T-joints with the fillet weld. Welding with variable polarity current as well as welding with double-pulsed current and voltage makes it possible to obtain very aesthetic welded joints with even weld faces characterised by very regularly shaped flakes (Fig. 15).

Fig. 15. View of the weld face in the T-joint with the fillet weld made of 3 mm thick EN AW 5754 alloy sheets using the AC Wave Pulse variant

The tensile tests revealed that all the welded joints satisfied the minimum tensile strength criteria. The values obtained were from the 200÷220 MPa range. In most cases the weld ruptured. This was due to the fact that the strength of the filler metal used for welding high strength alloys was lower than that of the base metal. Therefore, in the case of a properly conducted process a rupture usually takes place in the weld. If the HAZ or the area very near the fusion line contain many clusters with Al-Mg_2Si eutectics it is possible that, due to liquation cracks occurring in the aforesaid places, the rupture may take place in the HAZ or directly in the fusion line, thus giving significantly lower tensile strength results. The results were close to those obtained for low-energy methods such as CMT and Cold Arc [1-3].

The microscopic metallographic results revealed slight stirring of the material in the weld area as well as a slight grain growth and a small number of phase precipitates in the weld and in the HAZ. None of the joint areas revealed the excessive amount of precipitates or the presence of cracks and microcracks. The analysis of the microscopic metallographic photographs (Fig. 12-14) of the joint made of the EN AW 6082 alloy with the Al5087 filler metal revealed that the weld had the AlMg type structure with a small number of phase β (Al_3Mg_2) precipitates [4]. The HAZ structure was similar to that of joints welded with low-energy methods. However, the width of that zone was over twice as wide (approximately 0.25 mm if compared with 0.1 mm in the CMT method) if comparable welding parameters and conditions were used [1-2].

Conclusions

1. The VP MIG welding process utilising the phenomenon of double current pulsation (AC Wave Pulse) carried out using a DW 300 device manufactured by Daihen makes it possible to obtain the good quality, aesthetics and high mechanical properties of welded joints.

2. The basic parameter affecting the course of the process, the quality of the joint and the depth of penetration, apart from the basic technological parameters, is the EN ratio in the welding current waveform. In welding aluminium alloys the most advantageous setting of this parameter as regards the stability of the process and the aesthetics of joints should involve a slight advantage of the EN ratio. Increasing the EN ratio enables welding thin sheets and mismatched joints, whereas increasing the EP ratio increases the heat input of the process and the depth of penetration, which enables welding T-joints with fillet welds.

3. The use of EN ratio advantage in the current and voltage waveforms enables the reduction of the HAZ width and, in particular, of the partially melted zone.

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