Agnieszka Kiszka, Tomasz Pfeifer

Variable polarity MAG welding of thin protective-coated steel plates

Introduction

Recent development in the field of modern structural materials and welding technologies has been dictated by the needs of the automotive industry. In spite of numerous attempts aimed at the implementation of such materials as magnesium and aluminium alloys, plastics, or composites, steels still dominate in the production of cars due to lower costs, better operating properties, and ease of joining. Automotive industry manufactures continually seek solutions which would allow them to obtain high-quality welds of thin steel plates provided or not provided with protective coatings. A technology currently applied in joining of 3mm-thick steel plates, based on MAG welding, is unable to satisfy all quality-related requirements. Particularly problematic is the supply of excessive heat to the joint, resulting in deformations and spatters. Spatters significantly reduce the aesthetics of joints and are difficult to remove.

Implementation of modern MAG welding technologies in the automotive industry has been possible thanks to newly developed solutions of advanced welding control systems. The new, so-called, low-energy methods such as CTM or ColdArc, are indented to meet requirements specified by car manufacturers. The application of low-energy welding methods decreases the amount of deformations of welded elements, reduces the number of spatters, and as a result significantly improves the appearance of joints. The most recent solution in relation to innovative MAG welding methods consists in the application of variable polarity pulsed current (Fig. 1).

The study presents the analysis of technological conditions of the welding of protective-coated structural materials. The welding methods tested in the research were those of AC Pulse, developed by a Japanese company OTC Daihen and the Cold Process, applied using Cloos-manufactured equipment. The results presented in the study were obtained at Instytut Spawalnictwa while conducting research work [1].

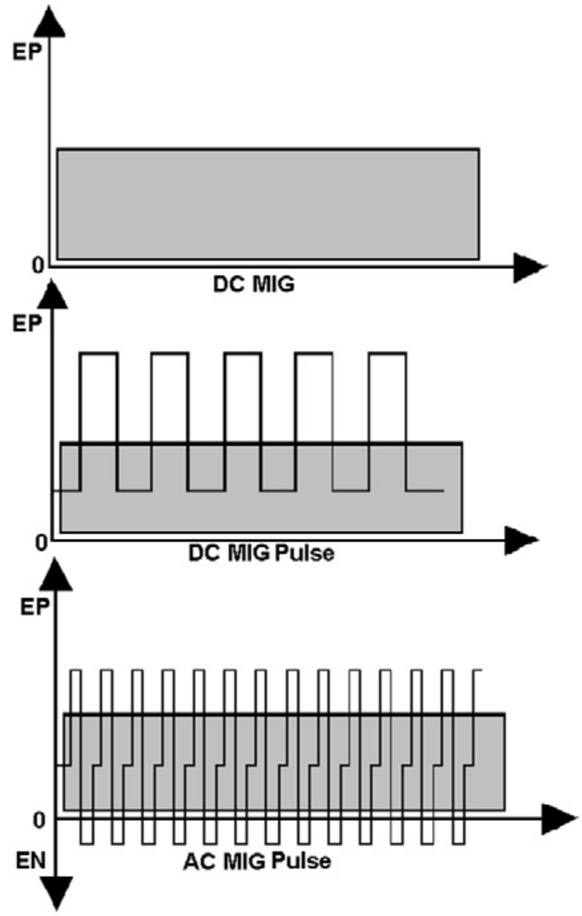


Fig.1 Course of current in various methods of welding with consumable electrode

Mgr inż. Agnieszka Kiszka, dr inż. Tomasz Pfeifer – Instytut Spawalnictwa, Zakład Technologii Spawalniczych (Department of Welding Technologies)

Course of tests and obtained results

The technological tests of welding with variable polarity pulsed current were conducted on a mechanised station provided with a welding tractor equipped with holder-fixing fixtures, a guide bar, and an element for setting and fixing the position of elements to be welded. Technological tests involved the use of an OTC Daihen-manufactured device DW 300 and a Cloos-made welding power source Qineo Champ 450 as well as an electrode wire PN-EN ISO 14341-A-G3Si1 of 1.0-mm and 1.2-mm diameter [2]. The shielding gas used for welding with the DW 300 was a mix containing 82 % Ar and 18 % CO2 (PN-EN ISO 14175-M21-ArC-18). In turn, the shielding gas used for welding with the Qineo Champ 450 was a mix composed of 92% Ar and 8% CO2 (PN-EN ISO 14175-M20-ArC-8) as it was for this gas that a specified synergic line was developed and used in research-related tests. The application of another shielding gas would have impeded a welding process [3]. A gas flow rate applied in the tests was constant and amounted to 12l/min. Steels used in the tests were HX 420 LAD Z 100 MBO, HX 260 LAD Z140 MBO, DX53D ZF 100 RBO, HCT600X ZF100 RBO, H380 LAD Z140 MBO, DX56D ZF100 RBO [4, 5].

Recording of course of current and voltage in time

The first stage of tests consisted in recording the courses of current intensity and arc voltage in a function of time. A system for monitoring the welding process electric parameters was developed at Instytut Spawalnictwa [6]. During recording, several padding welds were built up in 3mm-thick sheets. Courses were recorded for constant settings of technological parameters. The only parameter altered during recording was the percentage EN ratio (Electrode Negative ratio) in the course of welding current. The aforesaid parameter is a non-dimensional value and can be set within a range from -30 to +30 (DW 300) and from – 50 to + 50 (Qineo Champ). Courses for extreme settings of EN ratio are presented in Figures 2-7.

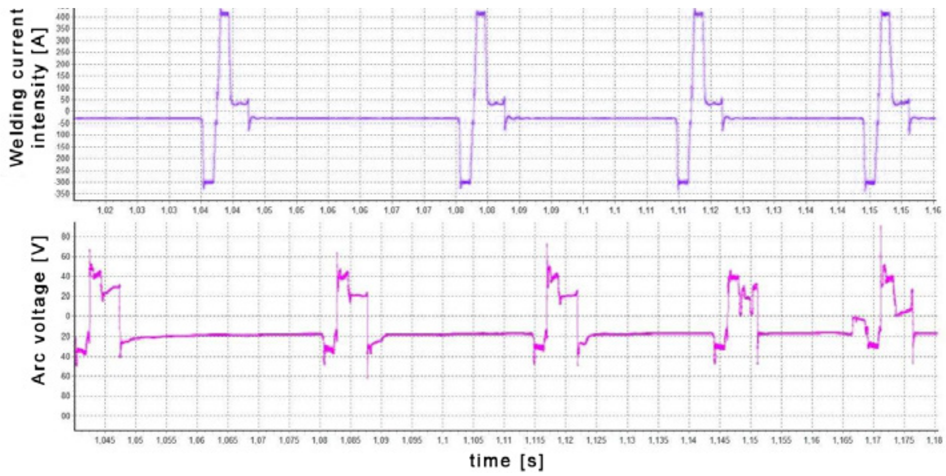


Fig. 2. Course of changes in current and voltage during surfacing of zinc-coated plate using DW 300. Neutral setting of EN ratio

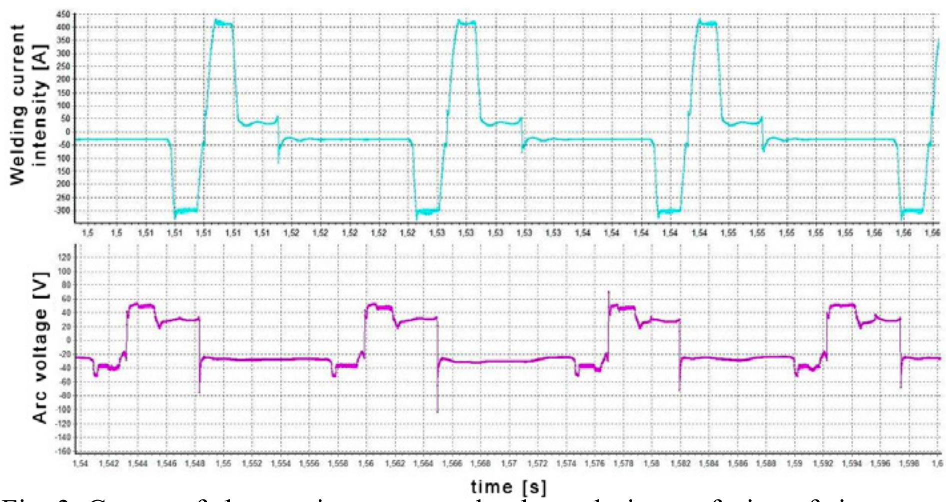


Fig. 3. Course of changes in current and voltage during surfacing of zinc-coated plate using DW 300. Minimum EN ratio

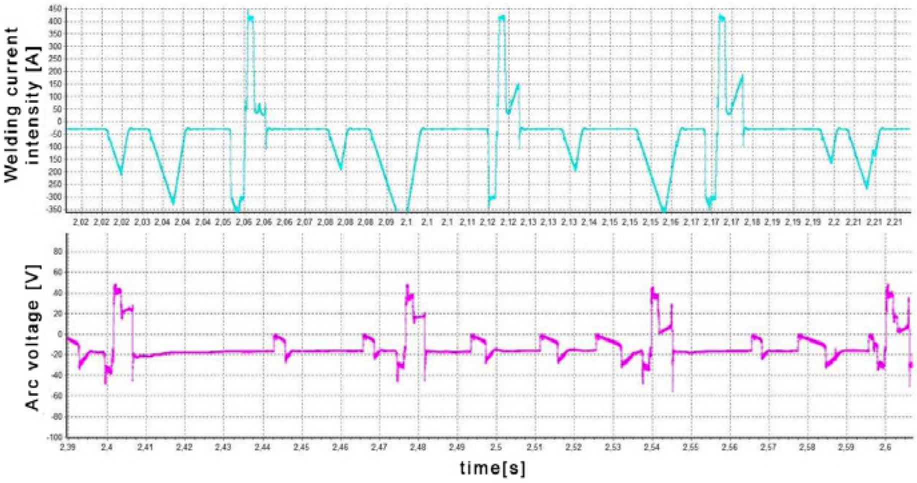


Fig. 4. Course of changes in current and voltage during surfacing of zinc-coated plate using DW 300. Maximum EN ratio

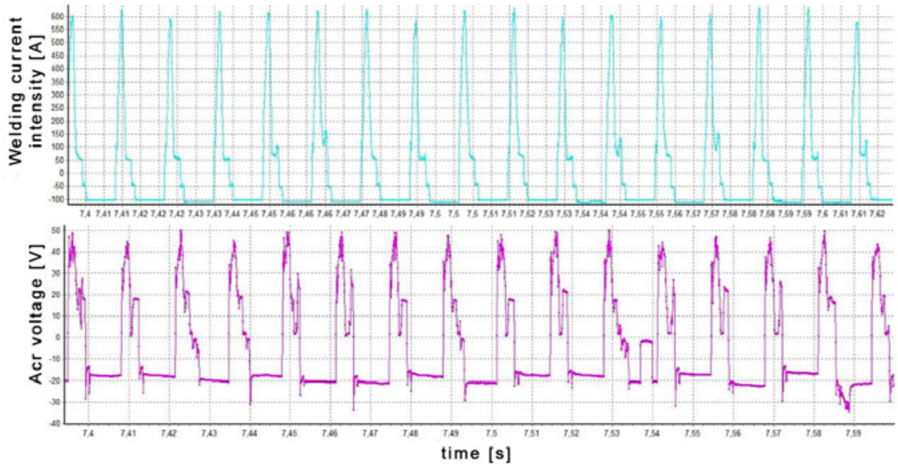


Fig. 5. Course of changes in current and voltage in function of time, recorded during surfacing of zinc-coated plate using Qineo Champ 450. Neutral setting of EN ratio

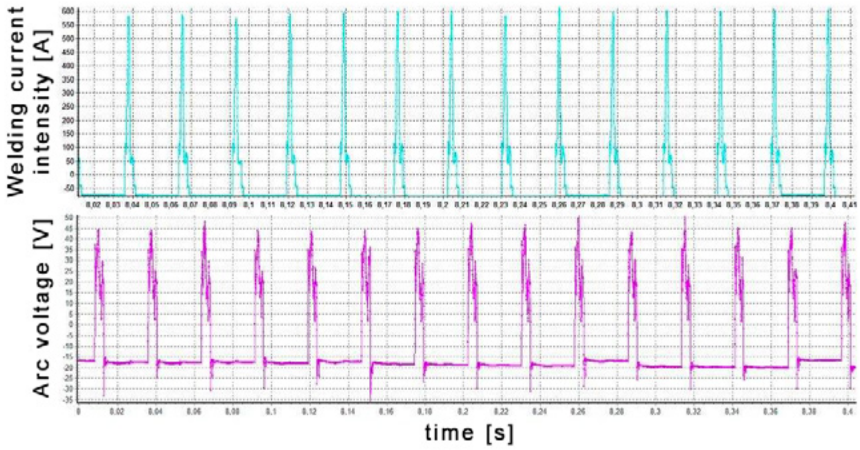


Fig. 6. Course of changes in current and voltage in function of time, recorded during surfacing of zinc-coated plate using Qineo Champ 450. Maximum EN ratio

Results obtained through the recording of electrical parameters during surfacing confirmed that current intensity and arc voltage indeed alter their polarity. A time-related course of welding current revealed two components of the EN ratio i.e. basic current and pulse current. Basic current maintains an arc during the change of voltage polarity; a negative pulse controls a drop of liquid filler metal. Reference publications indicate that this process takes place only for ratio values exceeding 30%; otherwise, the change of polarity may destabilise an arc [7]. As the EN ratio setting is non-dimensional in the case of both devices, it is not possible to directly determine the percentage of EN ratio in the course of welding current intensity and arc voltage (works on this topic are underway). During the test it was possible to observe that there was no EN (electrode negative) for a setting ensuring the minimum EN ratio for the Qineo Champ device (Fig. 7). In the above case, the course of current is characteristic of a classical pulsed arc welding.

During the recording of parameters it was possible to observe that a change of EN ratio significantly affects the course of a welding process and the appearance of padding welds. For this reason, the next stage involved technological tests of welding and surfacing with various settings of the parameter (i.e. course

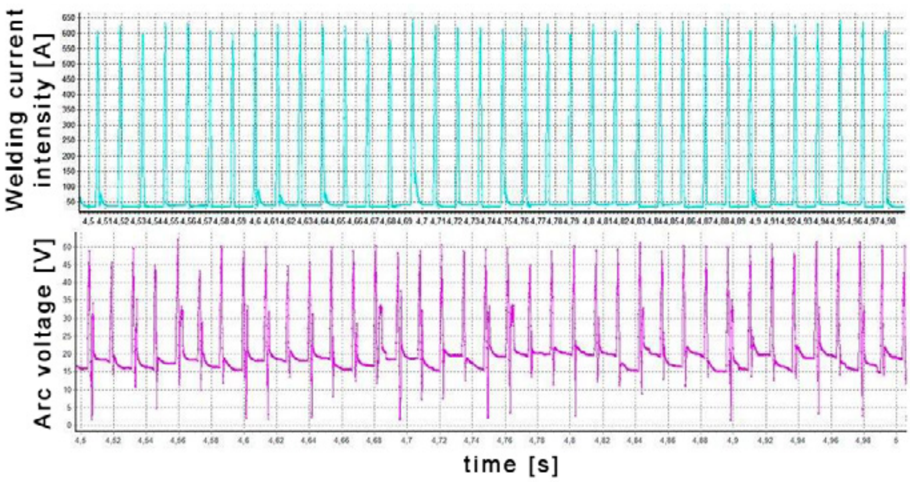


Fig. 7. Course of changes in current and voltage in function of time, recorded during surfacing of zinc-coated plate using Qineo Champ 450. Minimum EN ratio

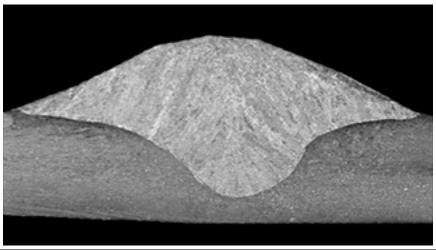
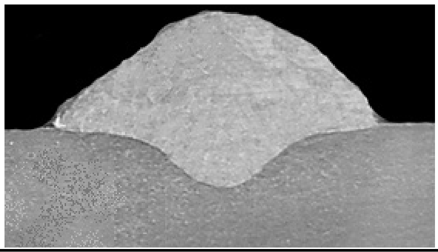
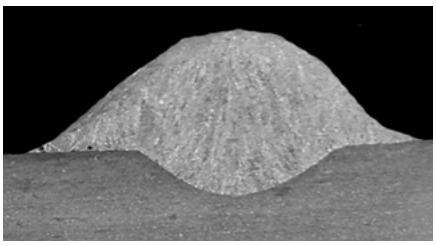
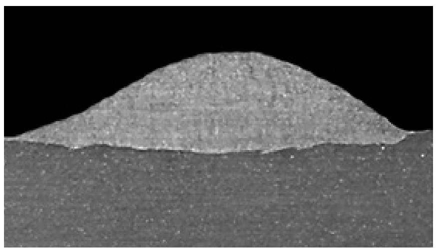
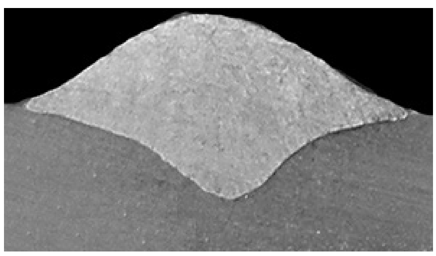
of current) in order to determine its impact on the shape of weld/padding welds and the aesthetics of a welded joint.

Impact of various settings of EN ratio on the course of welding process

In order to determine the impact of EN ratio on the quality and geometry of a joint as well as on the depth of penetration, it was necessary to build up a number of padding welds at various settings of the parameter and with constant values of other technological parameters (filler wire feeding rate and welding rate). Padding welds were built up on 3mm-thick plates of steel HX420 LAD Z 100 MBO. Table 1 presents examples of the macrostructure of padding welds produced with various settings of EN ratio.

Technological and macroscopic metallographic tests revealed that EN ratio affects the geometry and aesthetics of padding welds. The maximum EN ratio resulted in the smallest penetration depth, whereas the minimum EN ratio led to the greatest depth of penetration. The obtained padding welds were characterised by good quality and appearance. The surfacing process was stable and produced very few spatters, resulting in a smooth and uniform face of padding welds. Sectional views of padding welds did not reveal any welding imperfections. Only when settings were

Table 1.Macrostructures of padding welds built up on 3mm-thick plates of steel HX420 LAD Z 100 MBO at various settings of EN ratio

EN ratio	Macrostructure	
	AC Pule	Cold Process
Neutral setting of EN ratio		
Maximum EN ratio		
Minimum EN ratio		
Note: Adler etchant		

extreme, the process was less stable, repeatability was lower, and spatters became bigger, which significantly deteriorated the aesthetics.

Another purpose of the research was to investigate the impact of EN ratio on the course of a welding process as well as on the quality and aesthetics of welded joints. The plates used for the tests were 1.5 mm thick, made of steel grade DX 53 D ZF 100 RBO and provided with a zinc-iron protective coating. The tests involved the production of overlap joints for various parameter settings and in constant welding conditions (filler wire feeding rate and welding rate). During the process, assessment was connected with the process stability. After the completion of the process, each joint underwent a visual inspection. The criterion used in the evaluation of the selection of parameters and welding conditions was the quality level B according to standard PN-EN ISO 5817 [8]. Another process-related criterion was the smallest possible damage to the zinc-iron layer. A visual inspection of joints produced at various settings of EN ratio revealed that practically in the whole range of EN ratio settings (except for extreme ones) it is possible to obtain joints of a very good quality. The smaller the EN ratio in the course the greater the damage to a zinc-iron layer near a weld. A decrease in EN ratio resulted in an increase in heat supplied to the material being welded which was manifested by an increased width of the joint overheating-affected area, greater deformations, and local burn-throughs of elements being joined.

Technological tests of welding of various steels with protective coatings

The next stage involved technological tests related to the welding of various joints (butt, T-shaped and overlap joints) made of plates of various thicknesses. Tests revealed that MAG welding with variable polarity current makes it possible to obtain butt, T-shaped, and overlap joints characterised by very good quality. Apart from technological parameters, the basic variable affecting the possibility of joining elements and the course of a welding process is the EN ratio. Welding of thin elements is most advantageous if accompanied by a high EN ratio as it translates to small deformations and minimum damage to the zinc-iron layer. In turn, T-shaped and butt joints of greater thicknesses should be welded with a lower EN ratio as the process of welding is more "energetic" (i.e. heat input is higher). According to the test results, the appropriate selection of technological parameters makes it possible to produce overlap and butt joints of plates having as little as 0.75 mm and 0.8 mm thicknesses. Figures 8-10 present selected joints and their macrostructure.

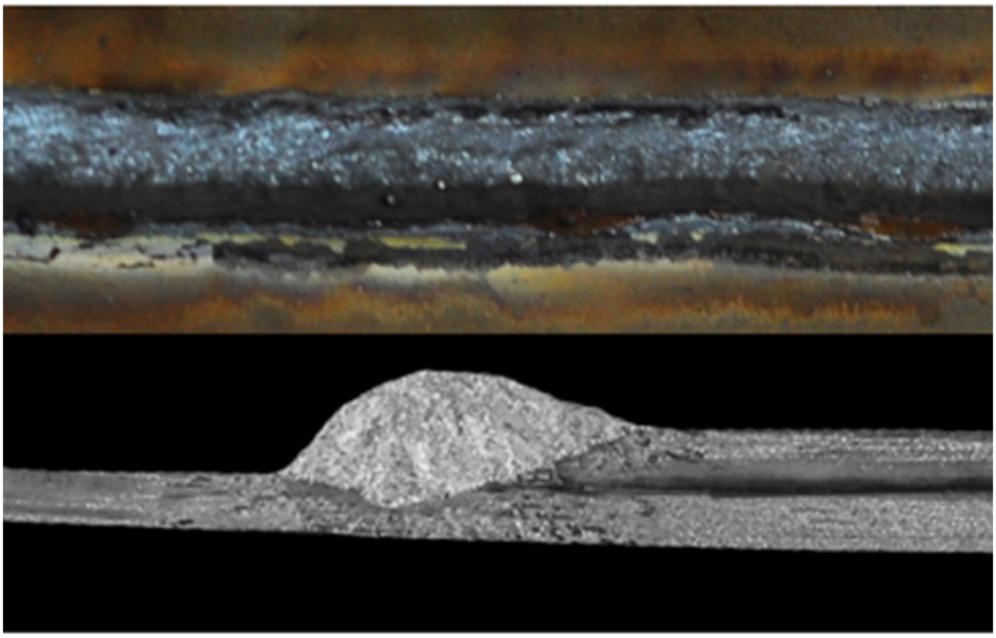


Fig. 8 General view and macrostructure of overlap joint of 0.75mm-thick steel DX56D ZF100 RBO; etchant: Adler, magnification x8

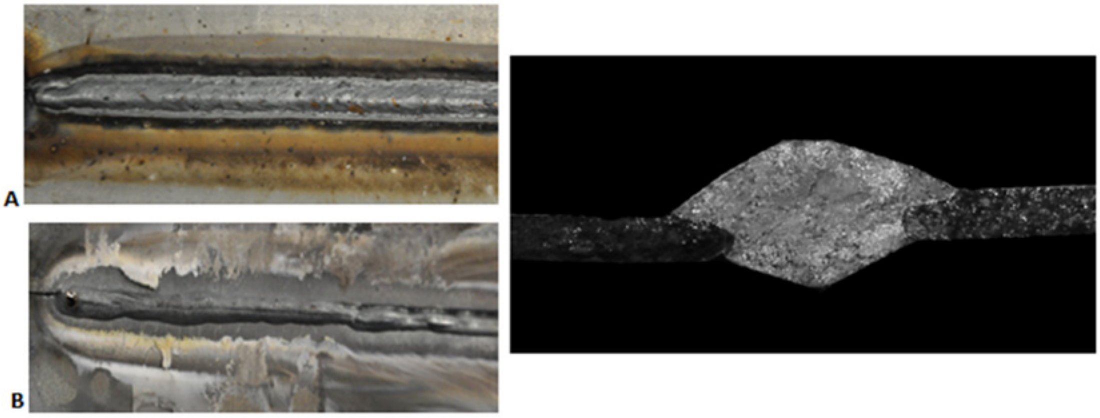


Fig. 9. Main view and macrostructure of butt joint with square preparation, made of 0.8mm -thick steel DC04+ZE 25/25 AO, test piece no. 24 from Table 9. A - view from face of weld, B- view from root of weld; etchant: Adler, magnification x8.5

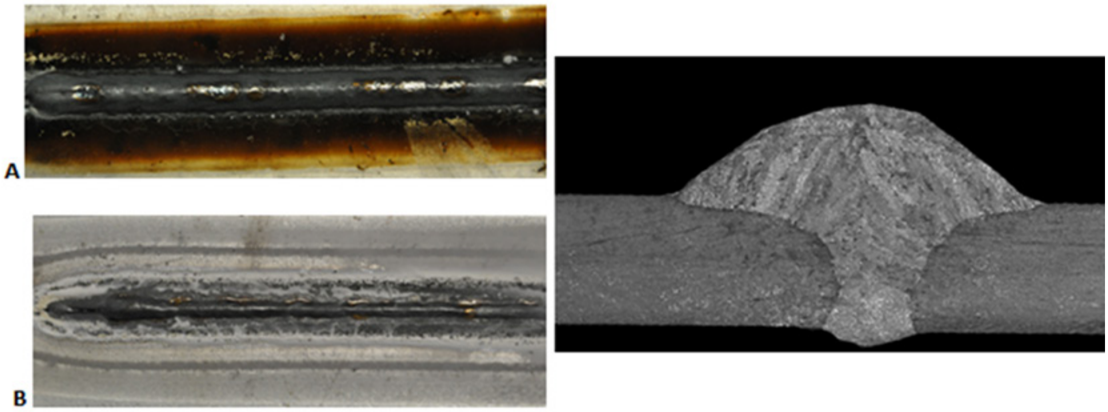


Fig. 10. Main view and macrostructure of butt joint with square preparation, made of 3.0mm-thick steel HX 420 LAD Z 100 MBO, test piece no. 10.1 from Table 9. A - view from face of weld, B- view from root of weld; etchant: Adler, magnification x5.5

A considerable advantage of MAG welding with variable polarity current is the possibility of producing inaccurately matched joints, even with a gap of 2 mm. Such a possibility is of particular importance in the automotive industry, where one often faces the necessity of welding such joints. The above mismatching is a frequent cause of such welding imperfections as burn-through or inadequate joint penetration. Elements having such imperfections are forwarded to corrective welding which increases the cost of production and the number of unacceptable products resulting in deteriorating production statistics. For this reason, technological tests included the welding of inaccurately matched overlap joints, butt joints with square preparation, and T-shaped joints. Overlap joints were made of 1.2mm-thick steel HCT 600X ZF 100 RBO, butt joints with square preparation were made of 3.0mm-thick steel HX 420 LAD Z100 MBO, and T-shaped joints were made of 2.0mm-thick steel H380 LAD Z140 MBO. All the joints were made with 0.5mm and 1.0mm gaps. Figures 11-13 present selected macroscopic photographs of inaccurately matched joints.

Tests revealed that MAG welding with variable polarity current can be used for welding of inaccurately matched butt, T-shaped and overlap joints. Good quality, aesthetics, and an effective bridging effect were obtained for all kinds of coatings. Properly selected welding conditions can minimise or even entirely eliminate spatters.

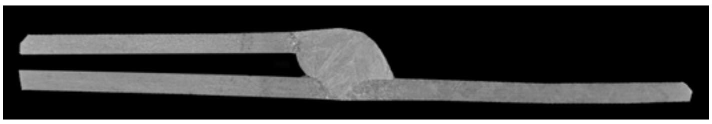


Fig. 11. Macrostructure of overlap joint of 1.2mm-thick steel HCT600X ZF 100 RBO; joint welded with 1.0 mm gap; etchant: Adler, magnification x4

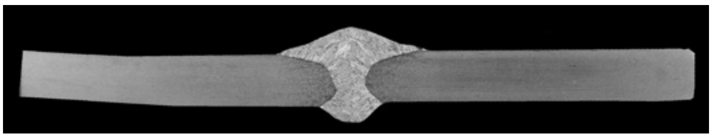


Fig. 12. Macrostructure of butt joint with square preparation, made of 3.0mm-thick steel HX 420 LAD Z100 MBO; joint welded with 1.0 mm gap; etchant: Adler, magnification x3

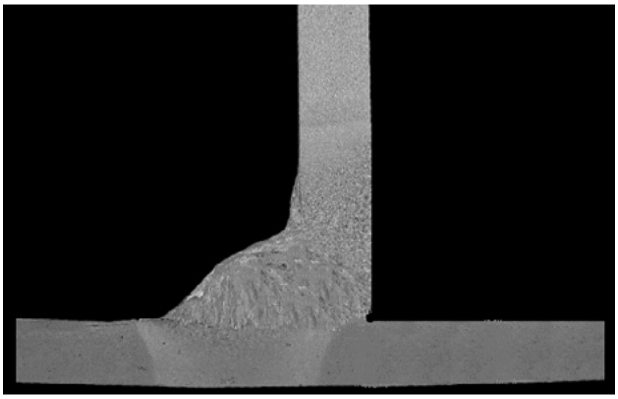


Fig. 13. Macrostructure of T-shaped joint, made of 2.0mm -thick steel H389 LAD Z140; joint welded with 0.5 mm gap; etchant: Adler, magnification x5

Summary

Conducted technological tests of the welding of thin plates made of unalloyed and low-alloy steels of increased strength and protected with various zinc-based coatings revealed that the application of variable polarity current makes it possible to build up joints characterised by good quality and aesthetics. A process of welding with variable polarity current is less stable than traditional MAG welding and emits specific sounds, yet joints welded in such a process are characterised by good quality and tend to be free from spatters.

The basic process variables having the greatest impact on the course of the process as well as on the weldability, quality, and aesthetics of joints are the technological parameters (filler wire feeding rate, welding rate, torch inclination angle and arc length) and EN ratio in the course of welding current. A change of EN ratio significantly affects arc voltage and the amount of heat supplied to a joint. Research results revealed that the best results are achieved with neutral settings of the parameter. An increase in EN ratio reduces the penetration depth and bridging ability of an arc. If one needs to weld thin plates and avoid, as much as possible, damage to the zinc coating, a higher EN ratio should be applied in the course of current. The application of high EN ratio in the course of current also makes it possible to weld inaccurately matched joints. A decreased EN ratio increases heat input of the process and reduces the depth of penetration. T-shaped joints and thicker elements require a higher EN ratio in the course of current. The most convenient solution consists in applying a neutral EN ratio, as such an approach enables obtaining good quality welds and sufficient penetration depth.

References

1. Matusiak J., Pfeifer T., Wyciślik J., Kiszka A.: Analiza wpływu warunków technologicznych innowacyjnych technik spajania różnych materiałów konstrukcyjnych z nowoczesnymi powłokami ochronnymi na stan środowiska pracy. Praca badawcza Instytutu Spawalnictwa nr Ma-34, Gliwice 2011 r.
2. PN-EN ISO 14341:2011 „Materiały dodatkowe do spawania. Druty elektrodowe i stopiwo do spawania łukowego elektrodą metalową w osłonie gazu stali niestopowych i drobnoziarnistych. Klasyfikacja”
3. PN-EN ISO 14175:2009 „Materiały dodatkowe do spawania. Gazy i mieszaniny gazów do spawania i procesów pokrewnych”
4. PN-EN 10346:2011 „Wyroby płaskie stalowe powlekane ogniowo w sposób ciągły. Warunki techniczne dostawy”
5. PN-EN 10152:2011 „Wyroby płaskie stalowe walcowane na zimno ocynkowane elektrolitycznie do obróbki plastycznej na zimno. Warunki techniczne dostawy”
6. Szubert L., Skoczewski P, Welcel M.: System rejestracji parametrów elektrycznych procesu spawania dla wielu stanowisk produkcyjnych. Praca badawcza Instytutu Spawalnictwa nr Fc-89, Gliwice 2010 r.
7. Jaskólski K.: Robotyzacja OTC z wykorzystaniem niskoenergetycznych metod spawania. Materiały firmy SAP, 2010
8. PN-EN ISO 5817:2009 „Spawanie. Złącza spawane ze stali, niklu, tytanu i ich stopów (z wyjątkiem spawanych wiązką). Poziomy jakości według niezgodności spawalniczych”