SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2023
ORGANIZATION AND MANAGEMENT SERIES NO. 189

WELDING OF SUPER DUPLEX S32750 WITH DOCOL 1100 FOR THE TRANSPORT PURPOSES

Tomasz WĘGRZYN[1], Bożena SZCZUCKA-LASOTA[2*], Feng CHEN[3], Katarzyna TUROŃ[4], Adam JUREK[5]

[1] Politechnika Śląska; tomasz.wegrzyn@polsl.pl, ORCID: 0000-0003-2296-1032
[2] Politechnika Śląska; bozena.szczucka-lasota@polsl.pl, ORCID 0000-0003-3312-1864
[3] Sino-US Global Logistics Institute, Antai College of Economy & Management, Shanghai Jiao Tong University, China; fchen@sjtu.edu.cn, ORCID: 0000-0001-8656-7910
[4] Politechnika Śląska; katarzyna.turon@polsl.pl, ORCID: 0000-0001-6744-8887
[5] Novar Sp. z o.o., Gliwice; adweld.adamjurek@gmail.com, ORCID: 0000-0002-9552-0062
* Correspondence author

Purpose: The main novelty and the goal of the paper is to present the dissimilar SDSS with AHSS welding for automotive application. The welding automotive structure is connected with two different grades of steel with various structure (martensite with mixture of austenite and delta ferrite).
Design/methodology/approach: Two dissimilar grades of steel were welded in order to get a proper joint for automotive industry. The properties of the joint was carefully tested (NDT and DT).
Findings: Relations between various welding parameters and the properties of weld.
Research limitations/implications: In the future, it can be suggested to investigate the effect of modified shielding gas mixtures for the MAG welding.
Practical implications: The proposed process innovation will result in savings.
Social implications: Modifying the shielding gas mixtures will not affect the environment and production management methods. Producing dissimilar welds translates into savings.
Originality/value: It is to propose a new solution in automotive industry. The article is especially addressed to manufacturers of dissimilar material for means of transport.

Keywords: automotive, dissimilar, welding, SDSS, AHSS, transport, shielding gas mixture, production savings.

Category of the paper: Research paper.

1. Introduction

The paper presents the results of various MAG (metal active gas) welding tests for complicated dissimilar welds. Two various metals were welded with absolutely dissimilar structure. Delta ferrite-austenite steel (EN 1.4410, X2CrNiMoN25-7-4) with martensitic steel DOCOL 1100 M were joined by MAG process with various parameters. These dissimilar welding was dedicated mainly into automotive industry. The dissimilar welds are recommended for transport industry because it corresponds with serious savings (Jaewson et al., 2011; Darabi et al., 2016; Hadryś, 2015). Welding in this case is rather difficult because of completely different structures of base metal: delta ferrite plus austenite (Super Duplex Stainless Steel) with martensite steel (Golański et al., 2018, pp. 53-63; Skowrońska et al., 2017, pp. 104-111). The popular S32750 steel was selected as an example of super duplex steel, while the advanced high-strength DOCOL 1100 M steel was selected as a martensitic steel. In dissimilar welds, there are observed welding incompatibilities and defects, mainly cracks in the WMD (weld metal deposit) and HAZ (heat affected zone). The quality of welds depends mainly on correctly established parameters (Silva et al., 2019; Krupicz et al., 2020). The deciding MAG welding parameters are:

- type of electrode wires,
- composition of gas mixtures in MAG welding,
- pre-heating temperature.

Dissimilar welding of super duplex steel with martensitic steel is complicated because of different physical properties (Fydrych, Łabanowski et al., 2013; Shwachko et al., 2000). Preheating is mainly recommended for delta ferrite steels and duplex steels, and also for some dissimilar welds (Szymczak, 2020). In the article, it was mainly decided to check the influence of various amount of nitrogen added to the shielding gas mixture, because super duplex steels have a high nitrogen content, and in martensitic steels the increased nitrogen content could be treated as beneficial. An important second welding parameter is determining the appropriate preheating temperature, because for both dissimilar steel grades preheating is recommended, but there is no agreement on a common preheating temperature (Szymczak, 2020). Austenitic 309 LSi wire with an elevated chromium content was selected for welding process.

2. Materials

For dissimilar MAG welding of super duplex steel S32750 steel with martensitic DOCOL 1100 M steel the austenitic electrode wire 309LSi was selected. Attempts were also made with low-alloy steel electrode wires (Union X90 and Union X 96) but these tests did not give good results, because there were observed various types of welding defects. The main direction of research was the modification of gas mixtures in the MAG process containing Ar and CO_2, to which it was decided to introduce elevated nitrogen content.

Before the welding process, it was proposed the pre-heating at three different temperatures of 120°C, 150°C and 200°C. A thickness of weld was 2 mm. Table 1 presents the mechanical properties of welded dissimilar materials.

Table 1.
Tensile strength of tested materials

Steel grade	YS, MPa	UTS, MPa
S32750	520	830
DOCOL 1100 M	910	1070

The data from tab. 1 indicates that both grade of steel do not have completely different properties. Martensitic DOCOL 1100 M steel has much higher strength (UTS) and elevated yield strength (YS) than super duplex S32750 steel. Although the mechanical properties of both materials are rather similar. Super duplex steel has much lower coefficient of thermal expansion than martensitic steel, but simultaneously super duplex steel has a higher thermal conductivity than martensitic steel, which makes welding both materials together difficult. These physical properties of both materials result from their various chemical composition (Table 2).

Table 2.
Chemical composition of tested grades of steel

Steel	C	Si	Mn	P	S	Al	Cr	Mo	N	Ni	Ti
S32750	0.01	0.9	1.1	0.01	0.01	0.01	25	3.8	0.27	6.8	-
DOCOL 1100 M	0.1	0.12	0.22	0.01	0.002	0.03	0.02	0.04	0.01	0.02	0.21

The table shows that the chemical composition of both materials is different. Both steels do not have good plastic properties, so it was decided to weld them with austenitic wire (Tab. 3).

Table 3.
Electrode wire–composition

wire	C%	Si%	Mn%	P%	Cr%	Mo%	Ni%	Ti%	P	S
309LSi	0.02	0.85	1.8		24	0.2	14	0.001	0.02	0.02

It was decided to realize welding process of 2 mm thickness without chamfering. The electrode wire diameter in both cases was 1 mm. The weld was formed as single-pass. At the beginning of welding process, the current and the voltage parameters were suggested:

- welding current: 116 A,
- arc voltage: 22 V.

Other important welding parameters were determined as follow:

- welding speed: 310 mm/min,
- • shielding gas flow: 14.2 dm^3/min.

The joints were made with a several combinations. The most important element of investigation included checking the preheating temperature and selecting of proper shielding gas mixture for MAG welding process containing:

- Ar-18%-CO_2-2% N_2,
- Ar-18%-CO_2-3% N_2,
- Ar-18%-CO_2-4% N_2.

Also a very important element of the research was to determine the most appropriate preheating temperature:

- pre-heating to the temperature of 120°C,
- pre-heating to the temperature of 150°C,
- pre-heating to the temperature of 200°C.

3. Methods

After the welding process with various parameters, some non-destructive tests (NDT) and also some destructive tests (DT) were carried out to assess the best quality of the joints.

Initially some NDT were carried out:

- VT - visual test corresponded with → PN-EN ISO-17638) standard,
- MT - magnetic particle test corresponded with → PN-EN ISO-17638 standard.

Then, some DT testing were carried out:

- nitrogen amount in weld metal deposit (measured on the LECO ONH836 analyzer),
- tensile strength → PN-EN ISO 527-1 standard,
- bending test → PN-EN ISO 7438 standard.

4. Results and discussion

The dissimilar joints were made using one austenitic electrode wires, three different of shielding gas mixtures and with three different pre-heating temperature. In total, 12 different welds were made, marked with samples from E1 to E-9 (tab. 4).

Table 4.
Samples designations

Sample	Shielding gas mixture	Pre-heating temperature, °C
E1	Ar-18%-CO_2-2% N_2.	120
E2	Ar-18%-CO_2-3% N_2.	120
E3	Ar-18%-CO_2-4% N_2.	120
E4	Ar-18%-CO_2-2% N_2.	150
E5	Ar-18%-CO_2-3% N_2.	150
E6	Ar-18%-CO_2-4% N_2.	150
E7	Ar-18%-CO_2-2% N_2.	200
E8	Ar-18%-CO_2-3% N_2.	200
E9	Ar-18%-CO_2-4% N_2.	200

NDT tests were performed for all samples (E1-E9) after welding process. Most of the samples (E2, E4, E5, E6, E8) were defect-free (column rows marked in green colour), but there were also samples (E1, E3, E7, E9) made incorrectly (column rows marked in orange colour). The NDT results with comments on the observations during inspection are presented in Table 5.

Table 5.
NDT results for tested dissimilar welds

Sample	Observation
E1	Small cracking in HAZ from the S32750 steel side
E2	Correct weld, defect free, correct dimension of HAZ
E3	Small cracking in HAZ from the DOCOL 1100 M steel side
E4	Correct weld, defect free, correct form and dimension of HAZ
E5	Correct weld, defect free, correct form and dimension of HAZ
E6	Correct weld, defect free, correct form and dimension of HAZ
E7	Small cracking in HAZ from the DOCOL 1100M steel side
E8	Correct weld, defect free, but too expanded HAZ on the side of DOCOL 1100 M steel
E9	Small cracking in HAZ from both sides, too expanded HAZ on the side of DOCOL 1100 M steel

It was found that the preheating temperature has the greatest impact on the possibility of defects occurring. Preheating is recommended differently for the two dissimilar materials tested. AHSS steels, represented by DOCOL 1100 M steel, tend to expand the heat affected zone (HAZ) when the preheating temperature is too high. This is unfavorable because it affects various types of phase transformations, including the growth of nitrides and carbonitrides. In turn, duplex and super duplex steels require preheating due to the brittleness of delta ferrite. Therefore, you need to find a "compromise" temperature, which is not an easy challenge.

The selection of shielding gas mixture was less important. The next part of the research focused on the nitrogen content in the shielding gas mixture, which directly translates into the nitrogen content in the weld. It was decided to carefully check the relationship between the nitrogen content in the gas mixture and the nitrogen content in the weld metal. For this purpose, tests were performed on the Leco-ONH-836 device. In that part of the investigation it was decided to check only joints that did not have defects (marked row with green colour in the Tab. 5). The nitrogen amount in the dissimilar weld S32750/DOCOL 1100 M is presented in Table 6.

Table 6.
Nitrogen amount in the weld metal

Sample	Nitrogen in weld metal, ppm
E2	65
E4	55
E5	65
E6	70
E8	65

The assumptions were confirmed that the increase in nitrogen in the shielding mixture Ar-CO_2 would significantly translate into the nitrogen content in the weld. Only in one of the examined cases a high nitrogen content of 70 ppm was obtained. This corresponded to the supply of 4% N_2 to the shielding mixture (sample E6, table row marked in blue colour). An increased nitrogen content in the weld was also observed to the level of 65 ppm N, which corresponded to the addition of 3% N_2 to the shielding gas (E2, E5, E8 samples). Then it was decided to check the mechanical properties of the samples, assuming that the nitrogen content in the weld should significantly increase the strength. The tests were performed at room temp. (20°C). Table 7 shows the tensile strength (UTS) of the joints.

Table 7.
Tensile strength of joints

Sample	UTS [MPa]
E2	501
E4	488
E5	515
E6	533
E8	512

The data from the tab. 7 indicate that it is possible to achieve high tensile strength (of the dissimilar super duplex stainless steel with martensite steel) joint over the 530 MPa (table row marked in green colour). It has been proven that nitrogen should be added to the protective Ar-CO_2 mixture in an elevated amount (of 3% N_2 or 4% N_2), because the low nitrogen content in the mixture (of 2% N_2) does not allow for achieving a joint strength of even 500 MPa (table row marked in orange colour).

The best results were achieved when simultaneously:

- pre-heating temperature is 150°C,
- amount of 4% N_2 is added to the Ar-18% CO_2 shielding gas mixture.

As the last part of the article a bending tests was carried out. Measurements were done from the face and from the root sides of the joint. A bending test was performed at ambient temperature. The observation and results of bending test are presented in Table 8.

Table 8.
Bending test of dissimilar weld

Sample	Face side	Root side
E2	No cracks	small cracks
E4	No cracks	No cracks
E5	No cracks	No cracks
E6	No cracks	No cracks
E8	No cracks	No cracks

The bending tests were very positive, as no cracks were observed in almost all samples. This proves very good properties of the thin-walled dissimilar joint. In dissimilar joints, it is easier to obtain good strength properties than plastic ones, which is why the result of the bending test is very valuable and satisfactory for the authors of this publication.

5. Summary

The paper is intended for the automotive industry, where there is an increasing demand for various types of dissimilar welds. In the last 3 publications for this magazine, the authors focused on presenting the possibilities of welding AHSS steel (advanced high strength steel) with other types of steel. The possibility of welding AHSS steels with HSS steels with worse plastic properties was demonstrated. Then, research was carried out on the possibility of welding AHSS steel with austenitic steels and AHSS steel with ferritic steels (delta ferrite). All these publications emphasized the precision of selecting the appropriate process parameters in order to obtain a product of excellent quality. Similarly, for the purposes of this article, a lot of research (9 variants) was carried out to demonstrate what the preheating temperature should be and what the size of the shielding gas mixture should be. For this purpose, the composition of the shielding gas mixtures was simultaneously changed (based on the Ar-CO_2 mixture, adding 2% N_2, 3% N_2, 4% N_2, respectively) and the preheating temperature was changed (120°C, 150°C, 200°C). Nine combinations of results were created, from which subsequent tests eliminated the joints with the worst properties. After NDT tests, it was noticed that the most appropriate preheating temperature is 150°C. Only destructive tests (tensile strength, bending) allowed the determination of the most appropriate process parameters.

Based on the research study, the following conclusions were given:

1. Dissimilar joints allows for process savings, but are not easy to produce.
2. Dissimilar steel joints dominated by austenite and delta ferrite in first material and martensite in the second material are possible to produce.
3. All welding parameters should be selected very precisely.
4. The most important parameters of the dissimilar welding are the pre-heating temperature and the chemical composition of the shielding gas mixture.

5. The best welding results were obtained when simultaneously:
   - the preheating temperature was 150°C,
   - the shielding gas mixture should contain Ar-18% CO_2-4%N_2,
   - an electrode wire should have austenite structure.

Acknowledgments

The article is related to the implementation of the COST project, CA 18223.

References

1. Darabi, J., Ekula, K. (2016). Development of a chip-integrated micro cooling device. *Microelectronics Journal, Vol. 34, Iss. 11,* pp. 1067-1074, https://doi.org/10.1016/j.mejo.2003.09.010.
2. Fydrych, D., Łabanowski, J., Rogalski, G. (2013). Weldability of high strength steels in wet welding conditions. *Polish Maritime Research, Vol 20, no. 2/78,* 67-73. https://doi.org/10.2478/pomr-2013-0018
3. Golański, D., Chmielewski, T. (2018). Skowrońska B., Rochalski D., Advanced Applications of Microplasma Welding. *Biuletyn Instytutu Spawalnictwa w Gliwicach, Vol. 62, Iss. 5,* 53-63. http://dx.doi.org/10.17729/ebis.2018.5/5.
4. Hadryś, D. (2015). Impact load of welds after micro-jet cooling. *Archives of Metallurgy and Materials, Vol. 60, Iss. 4,* pp. 2525-2528, https://doi.org/10.1515/amm-2015-0409.
5. Jaewson, L., Kamran, A., Jwo, P. (2011). Modeling of failure mode of laser welds in lap-shear speciments of HSLA steel sheets. *Engineering Fracture Mechanics, Vol. 1,* pp 347-396.
6. Krupicz, B., Tarasiuk, W., Barsukov, V.G., Sviridenok, A.I. (2020). Experimental Evaluation of the Influence of Mechanical Properties of Contacting Materials on Gas Abrasive Wear of Steels in Sandblasting Systems. *Journal of Friction and Wear, Vol. 41, Iss. 1,* pp. 1-5.
7. Shwachko, V.L. (2000). Cold cracking of structural steel weldments as reversible hydrogen embrittlement effect. *International Journal of Hydrogen Energy, no. 25.*
8. Silva, A., Szczucka-Lasota, B., Węgrzyn, T., Jurek, A. (2019). MAG welding of S700MC steel used in transport means with the operation of low arc welding method. *Welding Technology Review, Vol. 91, No. 3,* PL ISSN 0033-2364, 23-30.

9. Skowrońska, B., Szulc, J., Chmielewski, T., Golański, D. (2017). Wybrane właściwości złączy spawanych stali S700 MC wykonanych metodą hybrydową plazma + MAG. *Welding Technology Review, Vol. 89(10),* 104-111. http://dx.doi.org/10.26628/ps.v89i10.825.
10. Szymczak, T., Makowska, K., Kowalewski, Z.L. (2020). Influence of the Welding Process on the Mechanical Characteristics and Fracture of the S700MC High Strength Steel under Various Types of Loading. *Materials (Basel), Vol. 13, 22,* pp. 5249-5259. doi: 10.3390/ma13225249. PMID: 33233651; PMCID: PMC7699769