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DISSIMILAR WELDING OF 316L AUSTENITIC STEEL WITH DOCOL 1200 M STEEL FOR THE STRUCTURES IN AUTOMOTIVE INDUSTRY

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Purpose: The main novelty and the goal of the paper is to develop the possibility of dissimilar welding for automotive application. The welding structure connects two various grades of steel with different structure and properties.
Design/methodology/approach: Two various metals have been checked in welding in order to obtain a high-quality joint of various means of transport. The properties of the joint were checked by non-destructives tests (NDT) and also the bending and the tensile strength were realized.
Findings: Relations between welding parameters and a quality of obtained dissimilar welds.
Research limitations/implications: In the future, it can be suggested to investigate the effect of nitrogen addition in gas shielding mixtures of the MAG process.
Practical implications: The proposed innovation will not cause problems in the production process provided that the technological regime will be respected.
Social implications: Modifying the welding method will not affect the environment and production management methods. Producing dissimilar welds translates into serious savings.
Originality/value: It is to propose a new solution with its scientific justification. The article is addressed to manufacturers of dissimilar material for automotive industry and other means of transport.

Keywords: dissimilar welds, 316L, DOCOL 1200 M, 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. The obtained dissimilar welds of 316L austenitic steel with DOCOL 1200 M steel (from group AHSS - advanced. high-strength steel) were tested. These dissimilar grades of steels were taken into account as materials in the structure of transport means. An austenitic steel and AHSS (advanced high-strength steel) could be used especially in automotive industry. Many applications in other industrial sectors could be also possible. The use of dissimilar welds is mainly recommended in automotive industry because of economic savings (Jaewson et al., 2011; Darabi et al., 2016; Hadryś, 2015). The weldability of these dissimilar steels is not easy because of completely various structures: martensite and austenite (Golański et al., 2018, pp. 53-63; Skowrońska et al., 2017, pp. 104-111).

A major difficulty of 316 L and DOCOL 1200 M welding is diferents between the connection materials. The dominance phase in 316 L steel is austenitic and in DOCOL 1200 M is martensitic, what transfers very often into welding cracks. Therefore it is very important to determine welding parameters very precisely (Silva et al., 2019; Krupicz et al., 2020). The most important welding parameters are:

- beveling method,
- arc voltage,
- welding current,
- welding speed,
- composition of gas mixtures in MAG welding,
- type of electrode wires,
- pre-heating temperature.

Dissimilar welding of austenitic steel with martensitic steel is complicated because of the high amount of nobium and titanium, which play different role in both materials (Fydrych, Łabanowski et al., 2013; Shwachko et al., 2000). Preheating is recommended for proper dissimilar steel welds (Szymczak, 2020). In the article, it was mainly decided to examine the influence of nitrogen added to the shielding gas mixture, because in the case of 316L steel, nitrogen is an austenitic former, and in the case of DOCOL 1200 M steel, nitrogen in small amounts is even desirable because it forms nitrides that strengthen the base material and the weld. However, the nitrogen content in the mixture cannot be too high, as it will translate into too high nitrogen content in the weld metal, which usually leads to cracks (Szymczak, 2020).

2. Materials

For dissimilar MAG welding of austenitic S316L steel with martensitic DOCOL 1200 M steel two various electrode wires were chosen:

- Lincoln LNT 316L (austenitic structure),
- UNION X90 (martensitic structure).

There were used various gas mixtures of argon with nitrogen. Before the welding process, it was suggested to check the preheating to a temperature of 130°C. A thickness of both grades of steel was 2 mm. Table 1 shows the main properties of materials.

Table 1.
Tensile strength of tested dissimilar grades of steel

Steel	YS MPa	UTS, MPa
316L	240	610
DOCOL 1200 M	1050	1200

The data from tab. 1 indicates that both materials have completely different mechanical properties. Martensitic DOCOL 1200 M steel has much higher strength (UTS) and yield strength (YS) than austenitic 316L steel. These different mechanical properties result from the respectively very various chemical composition of both tested materials (Table 2).

Table 2.
Chemical composition of tested grades of steel

Steel	C	Si	Mn	P	S	Al	Cr	Mo	Nb	Ni	Ti
316L	0.07	0.9	1.9	0.035	0.01	0.01	18.5	2.5	0.06	13	0.05
DOCOL 1200 M	0.11	0.13	0.25	0.01	0.002	0.02	0.01	0.01	0.14	0.01	0.22

It was decided to weld both joints with two different wires, one of which had a martensitic structure and the other one had an austenitic structure (Tab. 3).

Table 3.
Electrode wire UNION-X90 – composition

Wire	C%	Si%	Mn%	P%	Cr%	Mo%	Ni%	Ti%	P	S
UNION X90	0.11	0.8	1.8	0.010	0.35	0.6	2.3	0.005	0.015	0.01
LNT 316L	0.02	0.85	1.4		18.9	2.6	12.5		0.02	0.02

It was found that to make a 2 mm thick joint there was no need to chamfer the samples. The electrode wire diameter was selected to be 1 mm. The weld was single-pass. At the beginning, the most important voltage and current parameters were determined.

- arc voltage: 20 V.
- welding current: 117 A.

The remaining parameters were determined based on preliminary observations:

- welding speed: 300 mm/min,
- shielding gas flow: 14 dm^3 / min.

The typical joint is presented in Fig. 1.

Figure 1. View on the tested dissimilar joint.

Source: own study.

The joints were made with two variants:

- pre-heating to the temperature of 130°C,
- without pre-heating.

The shielding gas mixture was changed twice in the MAG dissimilar welding process and contained respectively:

- pure Ar,
- Ar-1.3 % N2,
- Ar-2.6 % N2.

3. Methods

After dissimilar MAG welding with the mention parameters variants non-destructive tests (NDT) and also (DT) destructive tests were realized.

NDT generally corresponded with:

- VT - visual test in accordance with PN-EN ISO:17638 standard with criteria of evaluation based on EN ISO 5817,
- MT- magnetic particle test in accordance with the PN-EN ISO:17638 standard.

The most important destructive tests include:

- a light microscope (LM) observation. The observation was carried out in accordance with the PN-EN ISO 9016 2021 standard;
- nitrogen content analysis in the weld metal. Measurements was realized on the LECO ONH836 analyzer;
- A bending test was performed in accordance with PN-EN ISO 7438 standard;
- Tensile strength according to PN-EN ISO 527-1 standard.

4. Results and discussion

The dissimilar austenitic-martensitic joints were made using two different electrode wires, three different variants of shielding gases and with two different thermodynamics variants with pre-heating, and without pre-heating. In total, 12 different joints were made, marked with samples from Q1 to Q-12 (tab. 4.).

Table 4.
Samples designations

Sample	Electrode wire	Type of shielding gas (mixture)	Temperature, °C
Q1	UNIONX90	Ar	20
Q2	UNIONX90	Ar + 1.3 N_2	20
Q3	UNIONX90	Ar + 2.6 N_2	20
Q4	UNIONX90	Ar	130
Q5	UNIONX90	Ar + 1.3 N_2	130
Q6	UNIONX90	Ar + 2.6 N_2	130
Q7	LNT 316L	Ar	20
Q8	LNT 316L	Ar + 1.3 N_2	20
Q9	LNT 316L	Ar + 2.6 N_2	20
Q10	LNT 316L	Ar	130
Q11	LNT 316L	Ar + 1.3 N_2	130
Q12	LNT 316L	Ar + 2.6 N_2	130

The effect of NDT tests is presented in Table 5.

Table 5.
NDT results for tested dissimilar welds

Sample	Observation
Q1	Small cracking in HAZ from the 316L steel side
Q2	Correct joint
Q3	Small cracking in HAZ from the 316L steel side
Q4	Small cracking in HAZ from the 316L steel side
Q5	Correct joint
Q6	Small cracking in HAZ from both sides
Q7	Small cracking in HAZ from the DOCOL 1200M steel side
Q8	Correct joint
Q9	Small cracking in HAZ from both sides
Q10	Correct joint
Q11	Correct joint
Q12	Correct joint

It was noticed that the most important factor influencing the good quality of the weld is the selection of the appropriate gas mixture. It was decided to test all joints that had no defects in subsequent destructive tests (marked with green colour in the Table 5). The next part of the research was to count the nitrogen content in the weld in terms of the kind of gas mixture. All measurements were carried out on the LECO ONH836 analyzer. The test results are shown in Table 6.

Table 6.
Nitrogen in weld metal deposit (WMD)

Sample	Nitrogen in WMD, ppm
Q2	55
Q5	55
Q8	55
Q10	50
Q11	55
Q12	65

It is easy to deduce that only argon, used as a shielded gas allows to obtain with the lowest nitrogen content on the level of 50 ppm, regardless of other factors (type of wire, pre-heating).

The use of a shielding argon gas mixture containing 1.3% N_2 ppm allows for a low increase in the nitrogen content in the weld up to the 55 ppm. The usage of a gas mixture containing 2.3% N_2 is not beneficial, because it translates into a higher increase in nitrogen amount in the on the level of 65 ppm.

The next part of the research was to realize tensile strength of the selected samples free from welding defects. Table 7 shows the tensile strength (UTS) of the tested welds.

Table 7.
Tensile strength of joints

Sample	UTS [MPa]
Q2	472
Q5	488
Q8	491
Q10	505
Q11	525
Q12	497

The data from table 7 indicate that it is possible to get good tensile strength of the dissimilar joint (over the 520 MPa level). This result was achieved when simultaneously:

- amount of1.3 N_2 was added to Ar gas mixture,
- pre-heating was performed,
- austenitic wire was chosen.

All other tested variants do not allow for obtaining such good joint properties. The last part of the research was bending tests realization, made both from the face and ridge side of the joint. The test result of bending test is shown in Table 8.

Table 8.
Bending test of dissimilar weld

Sample	Face side	Ridge side
Q2	No cracks	Small cracks
Q5	No cracks	No cracks
Q8	No cracks	Small cracks
Q10	No cracks	No cracks
Q11	No cracks	No cracks
Q12	No cracks	No cracks

The bending tests result were mainly positive. No welding defects or nonconformities were found, when austenitic wire was used.

Finally, a microstructure was analyzed for sample Q11, which was characterized by the best tensile strength (Figure 2).

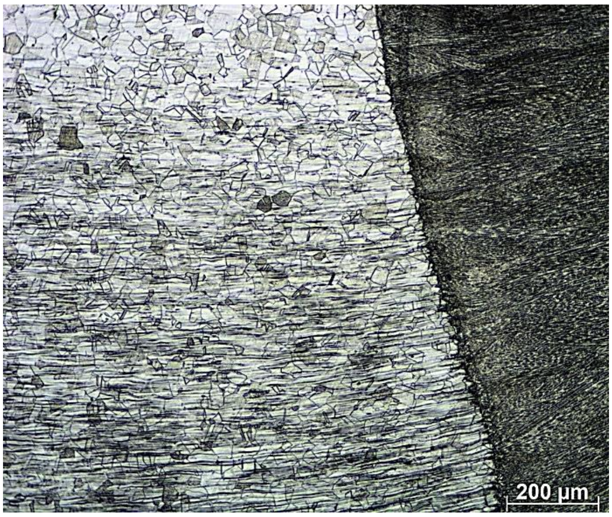

Figure 3. Structure of correct dissimilar weld (above 316L on the left, DOCOL 1200 M on the right). Sample Q11, electrolytic etched with 10% oxalic acid.

5. Summary

The article was about finding the best MAG welding parameters of two dissimilar grades steel. The welding materials characterized completely different mechanical properties, and structures. 316L steel has austenitic structure, and DOCOL 1200 M steel has a martensitic structure. Dissimilar joints are not easy to create, but they are often lead serious savings, because one of the welded materials is always cheaper. To assess the best method of dissimilar joints, it was mainly decided to check the influence of the various nitrogen content added to shielding gas mixture. Apart from that, simultaneously two different electrode wire with respectively austenitic structure and martensitic structure were tested. The influence of the preheating before welding at the level of 130°C was additionally checked. Some non-destructive tests and also destructive tests were performed. The nitrogen amount in the weld was carefully tested. Also bending tests and tensile strength were carried out. The following conclusions were made:

1. Preheat (130°C) is recommended in dissimilar 316L/DOCOL 1200 M welding.
2. It is possible to obtain the tensile strength of the dissimilar austenite steel-martensite steel joint at the level over 520 MPa.
3. On the basis of the research it can be concluded that the Ar + 1.3% N2 gas mixture is more appropriate for the dissimilar welding of 316L/DOCOL 1200 M.

The obtained corrected welds can be applied in automotive industry.

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