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DISSIMILAR WELDING OF FERRITIC STEEL H17 WITH DOCOL 1100 FOR THE AUTOMOTIVE APPLICATION

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Purpose: The main novelty and the goal of the paper is to develop the possibility of dissimilar welding for automotive resort. The welding automotive structure is connected with two various grades of steel with different structure.
Design/methodology/approach: Two dissimilar metals were checked in welding process in order to get a high-quality joint for automotive industry. The properties of the joint were checked by non-destructives and destructive tests.
Findings: Relations between welding parameters and the quality of welds.
Research limitations/implications: In the future, it can be suggested to investigate the effect of modern shielding gas mixtures for the MAG welding.
Practical implications: The proposed process innovation will not cause problems in the production.
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 resort with modern welding process and scientific justification. The article is especially addressed to manufacturers of dissimilar material for automotive industry and other means of transport.

Keywords: automotive, dissimilar, welding, H17, DOCOL 1100 M, transport, shielding gas mixture, production savings.

Category of the paper: Research paper.

1. Introduction

The article shows the results of various MAG (metal active gas) welding tests for dissimilar welds. Two various materials were joined with totally dissimilar structure. Ferritic steel H17 (1.4016, X6Cr17) with martensitic steel DOCOL 1100 M were welded by MAG process with various gas mixtures. These dissimilar grades of steels were dedicated into automotive industry, however many applications in other sectors might be possible. The dissimilar welds are recommended for automotive industry because it corresponds with economic savings (Jaewson et al., 2011; Darabi et al., 2016; Hadryś, 2015). Dissimilar welding in this case is difficult because of completely different structures: delta ferrite and martensite (Golański et al., 2018, pp. 53-63; Skowrońska et al., 2017, pp. 104-111).The popular H17 steel was selected as an example of ferritic steel for the application in the automotive industry, while the high-strength DOCOL 1100 M steel was selected as a martensitic steel. In this type of welds, there are often observed welding defects and incompatibilities, mainly cracks in the HAZ (heat affected zone). The quality of connections depends on correctly selected parameters (Silva et al., 2019; Krupicz et al., 2020). The main MAG welding parameters are:

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

Dissimilar welding of ferritic (delta) steel with martensitic steel is complicated because of different mechanical properties (Fydrych, Łabanowski et al., 2013; Shwachko et al., 2000). Preheating is sometimes recommended for some dissimilar welds (Szymczak, 2020). In the paper, it was mainly decided to check the influence of various amount of nitrogen added to the shielding gas mixture and the pre-heating temperature. In the case usage of H17 steel, nitrogen is treated as an austenite former, and in the case of DOCOL 1100 M steel, nitrogen taken from shielding gas forms nitride inclusions that strengthen the base material and the weld. However, there is a rule, that nitrogen content in the weld metal deposit cannot be too high, because it leads to cracks (Szymczak, 2020).

2. Materials

For dissimilar MAG welding of austenitic H17 steel with martensitic DOCOL 1100 M steel two austenitic electrode wires were chosen: Lincoln IMT 307Si and 309LSi (both with austenitic structure). Attempts were also made to weld this dissimilar joint with non-alloy steel wires, but these tests did not give good results. There were various types of welding defects, mainly in the form of cracks. 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 different nitrogen contents.

Before the welding process, it was realized the drying preheating at three different temperatures of 115°C, 125°C and 135°C. A thickness of both grades of steel was 4 mm. Table 1 shows the mechanical properties of both materials.

Table 1.
Tensile strength of tested dissimilar grades of steel

Steel grade	YS, MPa	UTS, MPa
H17	280	590
DOCOL 1100 M	920	1080

The data from tab. 1 indicates that both grade of steel have completely different properties. Martensitic DOCOL 1100 M steel has much higher strength (UTS) and elevated yield strength (YS) than delta ferritic steel H17. These dissimilar mechanical properties result from various composition of 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
H17	0.08	0.9	1.1	0.035	0.02	0.01	17.5	-	-	-	-
DOCOL 1100 M	0.1	0.12	0.22	0.01	0.002	0.03	0.02	0.04	0.11	0.02	0.21

The table shows that both steel grades differ mainly in their chromium content. Both steels do not have good plastic properties, so it was decided to weld them with authentic wire. It was decided to weld both materials with two different wires (Tab. 3). The wires were selected to differ significantly in their chromium content.

Table 3.
Electrode wire UNION-X90 –composition

Wire	C%	Si%	Mn%	P%	Cr%	Mo%	Ni%	Ti%	P	S
307Si	0.19	0.8	3	0.010	14	0.1	10	0.005	0.015	0.01
309LSi	0.02	0.85	1.8		24	0.2	14	0.001	0.02	0.02

It was tried to make make a 2 mm thick joint without chamfering. The electrode wire diameter in both cases (307Si and 307LSi) had 1 mm. The weld was only made as single-pass. At the beginning of weldin process, the voltage and current parameters were determined:

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

After that, other welding parameters were determined as follow:

- welding speed: 320 mm/min,
- shielding gas flow: 14.5 dm^3/min.

The joints were made with few variants. The most important analyzes included checking the preheating temperature and selecting wire with different chromium content (14% and 24% Cr). MAG welding process was realized with a shield of two gas mixtures containing:

- Ar-18%-CO_2,
- Ar-18%-CO_2-1% N_2.

A very important point of the research was to determine the most appropriate preheating temperature:

- pre-heating to the temperature of 115°C,
- pre-heating to the temperature of 125°C,
- pre-heating to the temperature of 135°C.

3. Methods

After welding process with various parameters non-destructive tests (NDT) and also (DT) destructive tests were realized to assess the quality of the joint.

As NDT testing was proposed:

- VT – visual test → PN-EN ISO:17638.
- MT- magnetic particle test → PN-EN ISO:17638 standard.

As destructive testing was proposed:

- nitrogen measurements in metal deposit (was realized 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 ferritic-martensitic joints were made using two different electrode wires, two different variants of shielding gases and with three different pre-heating temperature. In total, 12 different joints were made, marked with samples from D1 to D-12 (tab. 4).

Table 4.
Samples designations

Sample	Wire	Shielding gas mixture	Pre-heating temperature, °C
D1	307Si	Ar-18%-CO_2	115
D2	307Si	Ar-18%-CO_2	125
D3	307Si	Ar-18%-CO_2	135
D4	307Si	Ar-18%-CO_2-1% N_2	115
D5	307Si	Ar-18%-CO_2-1% N_2	125
D6	307Si	Ar-18%-CO_2-1% N_2	135
D7	309LSi	Ar-18%-CO_2	115
D8	309LSi	Ar-18%-CO_2	125
D9	309LSi	Ar-18%-CO_2	135
D10	309LSi	Ar-18%-CO_2-1% N_2	115
D11	309LSi	Ar-18%-CO_2-1% N_2	125
D12	309LSi	Ar-18%-CO_2-1% N_2	135

After welding, NDT tests were performed. It was found that a significant part of the joints made were free from welding defects and inconsistencies (marked in green colour), but there were also joints made incorrectly (marked in pink colour). The NDT results with comments during inspection are presented in Table 5.

Table 5.
NDT results for tested dissimilar welds

Sample	Observation
D1	Small cracking in HAZ from the H17 steel side
D2	Correct joint
D3	Small cracking in HAZ from the H17 steel side
D4	Small cracking in HAZ from the DOCOL 1100 M steel side
D5	Correct joint
D6	Small cracking in HAZ from both sides
D7	Small cracking in HAZ from the DOCOL 1100M steel side
D8	Correct joint
D9	Small cracking in HAZ from both sides
D10	Correct joint
D11	Correct joint
D12	Small cracking in HAZ from both sides

It was observed that the main factor for the good quality of the weld is proper preheating temperature. The selection of the correct gas mixture and electrode wires was less important. In next part of the investigation it was decided to test all joints that did not have defects (marked with green colour in the Table 5). The first part of the destructive tesst corresponded with counting the nitrogen amount the weld in terms of main welding parameters. All analysis were realized on the analyzer LECO-ONH-836. The nitrogen amount in the weld is presented in Table 6.

Table 6.
Nitrogen amount in dissimilar weld metal (WMD)

Sample	Nitrogen in WMD, ppm
D2	55
D5	60
D6	60
D8	50
D10	60
D11	60

It was noted that in all tested joints made with shielding gas A, the nitrogen in the weld was at a lower level of 55 ppm. It was observed that in all tested joints made with shielding gas B, the nitrogen in the weld was at a higher level of 55 ppm.

The next step of the investigation was to realize tensile strength of the selected samples free from welding defects (horizontal rows marked in green colour in tables 4 and 5). The tests were performed at a temperature of 20° C. The mechanical properties of the tested joints are presented in Table 7.

Table 7 shows the tensile strength (UTS) of the tested welds.

Table 7.
Tensile strength of joints

Sample	UTS [MPa]
D2	486
D5	499
D6	498
D8	511
D10	527
D11	513

The data from the tab. 7 indicate that it is possible to achieve high tensile strength of the dissimilar delta ferrite-martensite joint over the 500 MPa (horizontal rows marked in blue colour). Such good results were achieved only when simultaneously:

- pre-heating temperature is 125°C,
- austenitic wire with higher amount of Cr is chosen (24% Cr),
- amount of 1% N_2 is added to Ar-18%CO_2 gas mixture,

As the next part of the project a bending tests was realized. Measurements were done from the face and ridge sides of the weld The obserwation of bending test are put in Table 8.

Table 8.
Bending test of dissimilar weld

Sample	Face side	Ridge side
D2	No cracks	No cracks
D5	small cracks	No cracks
D6	No cracks	small cracks
D8	No cracks	No cracks
D10	small cracks	No cracks
D11	No cracks	No cracks

In a half of the samples tested, the results were positive. Bending tests indicate that the pre-heat temperature must be 125°C.

5. Summary

The paper was devoted to the development of appropriate welding parameters for a dissimilar steel joint with two completely different structures: delta ferrite and martensite. Such joints are very difficult to make and require extensive material knowledge and welding experience. Initially, attempts were made to weld the joints with various electrode wires, but it was noticed that the best results were achieved with a wire with an austenitic structure. A large number of tests (initially 12) were performed with various combinations of process parameters, which included 2 different electrode wires, two different shielding gas mixtures, and three different preheating temperatures. The results of NDT tests, and then gradually implemented results of destructive tests, successively allowed for narrowing down the joints with the unsatisfactory mechanical properties and quality. The nitrogen content in the joints was checked and they did not show any cracks. It was found that the addition of 1% N_2 to the standard Ar-18% CO_2 shielding mixture slightly increases the nitrogen content in the weld from 55 ppm to 60 ppm. Therefore, the strength of the joints increased to a very satisfactory level of over 500 MPa.

Based on the research conducted, the following conclusions were proposed:

1. The ability to make dissimilar joints allows for significant process savings.
2. Dissimilar steel joints dominated by delta ferrite in first material and martensite in the second material are difficult to produce.
3. The process parameters should be selected very carefully.
4. The most important parameters of the process are the preheating temperature, the chemical composition of the shielding gas mixture and the type of electrode wire.
5. The best welding results were obtained when:
   - the preheating temperature was 125°C,
   - the shielding gas mixture contained Ar-18% CO_2-1%N_2,
   - an electrode wire with 24% Cr was used.

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