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MAG DISSIMILAR WELDING OF S355JR WITH DOCOL 1200 M STEEL FOR THE STRUCTURES OF CAR BODY

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Purpose: Main novelty and the aim of the paper is to analyses possibility of dissimilar MAG welding of two various grades of steel with significantly different structure.
Design/methodology/approach: Two various metals have been checked in welding in order to obtain a high-quality joint of car body elements. The properties of the joint were checked by NDT (Non Destructive Test) and DT (Destructive Tests).
Findings: Relations between MAG welding process parameters and the quality of joint.
Research limitations/implications: In the future, it can be tested the effect of micro addition of nitrogen or oxygen in gas shielding mixtures of the MAG process.
Practical implications: Suggested materials and innovation will not cause problems in the production process provided that the technological regime will be respected.
Social implications: Modifying the welding materials and method will not affect the environment and production management methods. Producing of dissimilar welds must translate into production savings.
Originality/value: The paper is addressed to manufacturers of low-alloy and advanced high-strenth steel for automotive industry.
Keywords: dissimilar welding, S355JR, DOCOL 1200 M, transport, shielding gas mixture, production savings.
Category of the paper: Research paper.

1. Introduction

The paper shows the results of dissimilar MAG welding parameters of low-alloy S355JR steel with advanced high-strength steel (AHSS) DOCOL 1200 M. These various grades of steel could be used in automotive industry. Other applications in the transport means and other industrial branches are also recommended. The use of various dissimilar joints is actually chected in various laboratories because of economic reasons (Jaewson et al., 2011; Darabi et al., 2016; Hadryś, 2015). The weldability of low alloy steel is rother easy, because of the dominant soft alpha ferrite structure, but weldability of AHSS is much more difficult because of the hard martensite structure (Golański et al., 2018; Skowrońska et al., 2017). Dissimilar welding is much more complicated due to the different structure of both materials and their properties. Theoretically, it is difficult to imagine how a joint made of soft ferrite and hard martensite will behave. It turns out that there is a great demand for such connectors, although they cause great problems and welding challenges. A main problem in 355JR and DOCOL 1200 M welding steel is the tendency to various welding cracks. Therefore it is very important to determine welding parameters separately for each structure made of a dissimilar joint. To avoid cracks, welding parameters must be selected very carefully, taking into account the thermodynamic features of the process (Silva et al., 2019; Krupicz et al., 2020):

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

Dissimilar welding of low-alloy with AHSS steel is difficult because of different chemical composition and serious differences in metallographic structure (Fydrych, Łabanowski et al., 2013; Shwachko et al., 2000). Preheating could be recommended for proper steel welding, but there is a distinct lack of information about dissimilar welding (Szymczak, 2020).

2. Materials and methods

For dissimilar MAG welding of S355JR with DOCOL 1200 M the UNION X90 and UNION X96 wires (EN ISO 16834-AG 89 6 M21 Mn4Ni2CrMo) were chosen. There were used and a gas mixture of CO_2 and small amount of nitrogen. It was decided to check welding process with preheating at temperature of 110° C and without pre-heating. A thickness of both elements was 3 mm. Table 1 presents the mechanical properties of the S355JR and DOCOL 1200 M.

Table 1.
Tensile strength of tested materials

Steel	YS, MPa	UTS, MPa	A5, %
S690 QL	590	605	12
DOCOL 1200 M	950	1200	6

The table data shows that both materials have totally different mechanical properties. DOCOL 1200 M has twice the strength, but at the same time two times lower relative elongation. These large differences in mechanical properties depend on the metallographic structure, which in turn depends on the chemical composition, as shown in the table 2.

Table 2.
Chemical composition of S690 QL [6]

Steel	C	Si	Mn	P	S	Al	Cr	Nb	Ni	Ti
S355JR	0.19	0.4	1.5	0.028	0.025	0.02	1.55	0.06	2.1	0.05
DOCOL 1200 M	0.12	0.21	0.21	0.01	0.002	0.03	0.03	0.13	0.3	0.23

Both types of steel differ significantly in their chemical composition. The two tested electrode wires are much more similar chemically. Composition of UNION X90 and UNION X96 electrode wires is given in Table 3.

Table 3.
Electrode wires–composition [10]

UNION	C%	Si%	Mn%	P%	Cr%	Mo%	Ni%	Ti%
X90	0.11	0.81	1.82	0.01	0.35	0.61	2.3	0.005
X96	0.12	0.87	1.88	0.01	0.29	0.46	3.3	0.005

The MAG welding process parameters were as follows:

- diameter of both electrode wires: 1 mm,
- voltage: 19.5 V,
- welding current: 114.5 A,
- welding speed: was 340 mm/min,
- shielding gas flow: 16.5 dm^3/min
- the nature of the weld: single-pass.

The MAG (135) process was used in the down position (PA) according to the requirements of EN 15614-1 norm. The preparation of the single stitch made from AHSS/low-alloy steel with thickness of 3 mm are presented on the Fig. 1.

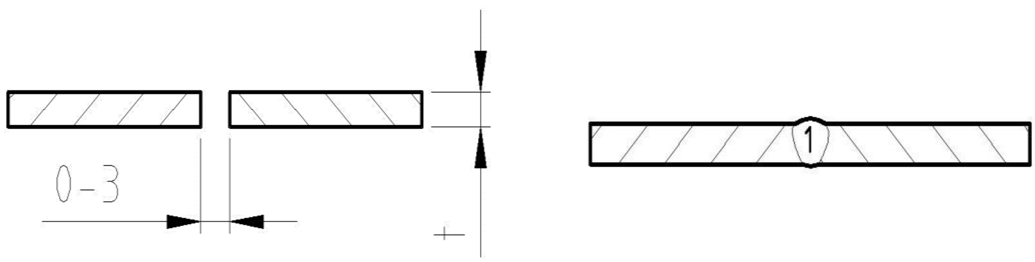

Figure 1. Weld shape.

Two different sheets of metal welded on a macro scale are shown in Figure 2.

Figure 2. View on the MAG welding (own study).

The joints were made with a drying pre-heating to the temperature of 110° C and without pre-heating. The shielding gas was changed 3 times:

- CO_2,
- CO_2-1%N_2,
- CO_2-2% N_2.

After welding, some non-destructive tests (NDT) and further destructive tests were realized. NDT examination generally based on VT(visual) and MT (magnetic particle) tests:

- VT: the observation was carried out with the accordance with PN-EN ISO:17638 standard with criteria of evaluation based on EN ISO 5817,
- MT: the observation was carried out with the PN-EN ISO:17638 standard, the observation was assessed in accordance with EN ISO 5817 using detector REM - 230.

The dissimilar welds were also structurally examined (destructive tests) using a light microscope (LM). The observation was carried out in accordance with the PN-EN ISO 9016 2021 standard. Amount of nitrogen content in the weld metal was performed on the LECO ONH836 analyzer. A bending test was taken in accordance with EN ISO 7438 standard. A tensile strength was performed with EN-10088 standard.

3. Results and discussion

The dissimilar joints were made with six different variants (shielding gas/pre-heating) using only electrode wire UNION X90:

- CO_2 without preheating – sample B1,
- CO_2 - 1% N_2 without preheating– sample B2,
- CO_2 - 2% N_2 without preheating– sample B3,

- CO_2 with preheating (110°C) – sample B4,
- CO_2 - 1% N_2 with preheating (110° C) – sample B5,
- CO_2 - 2% N_2 with preheating (110° C) – sample B6.

The result of non-destructive test is presented in Table 4.

Table 4.
NDT results for tested dissimilar welds

Sample	Welding with pre-heating up to 105°C
B1	No cracks
B2	No cracks
B3	Cracks in weld
B4	No cracks
B5	No cracks
B6	Cracks in heat effected zone

On this stage of research it has not been found yet that preheating before dissimilar steel welding S355JRwith DOCOL 1200 M is recommended. It was noticed that too high a nitrogen content in the CO_2 mixture should be treated as unfavorable, because after welding with such a mixture, cracks were found in the weld (fusion zone) or in the heat affected zone, depending on the welding conditions (preheating effect).

The second part of the investigation was to count the nitrogen content in the fusion zone. Measurements were carried out on the LECO ONH836 tester. The test results are shown in Table 5.

Table 5.
Nitrogen in the weld

Sample	Nitrogen in WMD, ppm
B1	50
B2	57
B3	65
B4	50
B5	57
B6	65

It is possible to notice that after welding only in CO_2 shield (without N_2), the weld metal deposit had the lowest nitrogen amount: 50 ppm. The usage of shielding gas containing 1% N_2 translated into a increase in the nitrogen content in the weld to the 57 ppm. The amount of a shielding gas containing CO_2 and 2% N_2 translated into increase in nitrogen content in weld metal deposit on the level of 65 ppm%. This high amount of nitrogen (65 ppm) concentration in the weld metal and this may correspond to the cracks observed in table 4 (NDT results).

For destructive tests such as microstructure and tensile strength, only 4 joints were analyzed (samples B1, B2, B4, B5). Initially, observations were made under a light and scanning microscope. The structure was typical, high amount of martensite, bainite, ferrite and nonmetallic inclusions. Observations using a scanning microscope allowed for a more precisely results regarding inclusions. Mainly were observed:

- carbides; mainly TiC, NbC, NbC,
- carbonitrides; mainly Ti(N, C),
- nitrides; mainly TiN,
- oxides; mainly TiO,
- sulfides; mainly MnS.

The last part of the research was to check the tensile strength. Table 6 shows the mechanical properties of dissimilar welds (tensile strength UTS).

Table 6.
Tensile strength of joints

Sample	UTS, MPa	Elongation, %
B1	432	6.4
B2	457	6.2
B4	443	6.9
B5	465	6.4

The table shows that the tensile strength is rather at a similar level everywhere, but sample B4 has the best relative elongation, and therefore plastic properties. The highest tensile strength is for joints made in CO_2-1%N_2 shielding gas mixture. Therefore, based on this part of the research, it can be concluded that both protective gas mixtures containing nitrogen and preheating should be used to get the best mechanical properties of the dissimilar weld. It was decided to make welds using UNION X-96 electrode wire with a higher carbon content (sample C5: pre-heating and gas mixture with 1% N_2) compared to the tested joint previously made only with UNION X90 wire. Strength for conditions corresponding to sample B5. Changing the electrode wire did not cause any major difference in the mechanical values, Table 7.

Table 7.
Tensile strength of joints

Sample	UTS, MPa	Elongation, %
B5	465	6,4
C5	462	6,3

The last part of the research was the realize of bending tests, which were made from the face and root (ridge) side of the dissimilar weld. Next, the bending test of the created joints was performed. For the test a sample with thickness of a = 3 mm, width of b = 25 mm, mandrel of d = 25 mm and support spacing of 30 mm was taken, the required bending angle was at the level of 150° and 180°. Five bending tests measurements were carried out both on the face side and on the root side of the weld. The test result of bending test is presented in Table 7.

Table 7.
Bending test of dissimilar weld

Sample	Face side	Root side
B1	No cracks	No cracks
B2	No cracks	No cracks
B4	No cracks	No cracks
B5	No cracks	No cracks
C5	No cracks	No cracks

The bending test result was positive in all tested cases. No welding incompatibilities were found. It was decided to check the behavior of the joints after bending by 150 degrees and 180 degrees. In both cases, no cracks were found, which proves that the joint was made correctly. for additional purposes, it was decided to straighten the joints again and bend them to 150 degrees, but again no cracks appeared.

4. Summary

In the article, it was decided to check the possibility of welding unalloyed S355JR steel with DOCOL 1200 M steel. These are materials with different structures and different mechanical properties. there was a fear that making such joints would be very difficult. Research was carried out, mainly focusing on the gas mixture and the preheating temperature. Preheating should ensure better plastic properties, while adding nitrogen to carbon dioxide should translate into higher joint strength. It was initially determined what the nitrogen content should be, which improves strength but does not impair plastic properties. Preheating has been observed to give good results. In the examined dissimilar welding, the selection of the shielding gas mixture is more important than the type of electrode wire. The following conclusions were made:

1. Preheat (110°C) is strongly recommended in dissimilar S355JR QL/DOCOL 1200 M welding.
2. It is possible to obtain the tensile strength of the dissimilar joint S355JR QL/DOCOL 1200 M 1400 M at the level over 465 MPa.
3. In the weld, it was observed martensite, bainite, ferrite and various nonmetallic inclusions
4. On the basis of the research it can be concluded that the CO_2 + 1% N_2 gas mixture is more appropriate for the dissimilar welding of S355JR QL/DOCOL 1200 M.

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