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DISSIMILAR METAL WELDING OF S690 QL WITH DOCOL 1400 M STEEL FOR THE STRUCTURES OF VARIOUS MEANS OF TRANSPORT

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Purpose: The novelty and the aim of the article is to check the possibility of dissimilar welding of two grades of steel with significantly different properties.
Design/methodology/approach: Two various materials 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 NDT (Non Destructive Test) and also bending and tensile strength were tested.
Findings: Relations between process parameters and the quality of welds.
Research limitations/implications: In the future, it can be suggested to investigate the effect of micro addition of nitrogen and oxygen in gas shielding mixtures of the MIG/MAG welding 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 (although it is very difficult) translates into large savings.
Originality/value: It is to propose a new solution with its scientific justification. The article is addressed to manufacturers of high-strength steel and advanced high-strenth steel for automotive industry and other means of transport.

Keywords: dissimilar welding, S690 QL, DOCOL 1400 M, transport, shielding gas mixture, production savings.

Category of the paper: Research paper.

1. Introduction

The article presents the results of tests leading to the choice of the correct MAG dissimilar welding parameters of of S690 QL high-strength steel (HSS) with DOCOL 1400 M advanced. high-strength steel (HSS). These steels are taken into account as a new materials in the construction of various means of transport. The HSS and AHSS (advanced high-strength steel) steels can be used in automotive and shipbuilding industry and for elements of mobile platforms and tower cranes (Fig. 1). Other applications in the transport and other industrial sectors are also possible. The use of dissimilar welds is strongly recommended because of economic reasons.

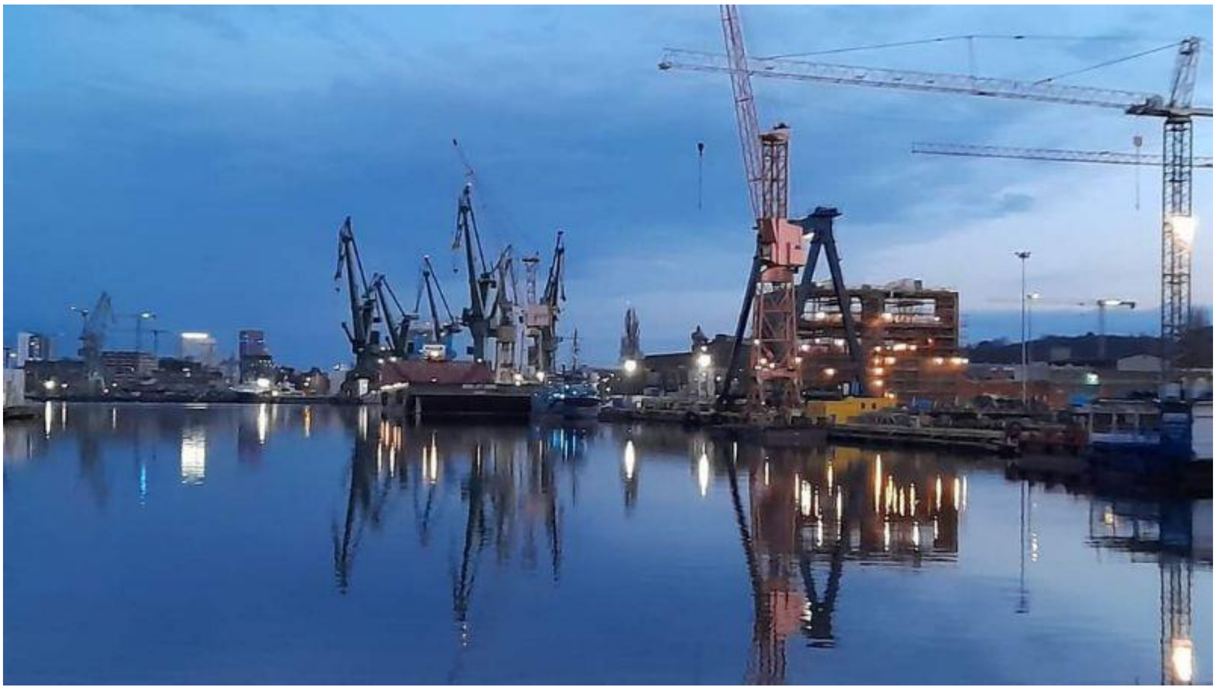

Figure1. Tower cranes with elements made from HHS and AHSS steels.

Source: own study.

HSS and AHSS steels are very often used for antenna towers due to their very high strength (Jaewson et al., 2011; Darabi et al., 2016; Hadryś, 2015). The weldability of this steel is still not well easy because of the martensite structure (Golański et al., 2018, pp. 53-63; Skowrońska et al., 2017, pp. 104-111).

A major difficulty of 690 QL and DOCOL 1400 M welding steel is the tendency to welding cracks. Dissimilar joints made of this two steel grades could crack even more often. Therefore it is very important to determine welding parameters separately for each structure made of a dissimilar joint (Silva et al., 2019; Krupicz et al., 2020):

- welding current,
- arc voltage,
- welding speed,

- beveling method,
- type of electrode wires,
- composition of gas mixtures,
- pre-heating temperature.

Dissimilar welding of HSS with AHSS steel is complicated because of the high titanium content (Fydrych, Łabanowski et al., 2013; Shwachko et al., 2000). Preheating is very often recommended for proper welding of HSS and AHSS steels, but there is no mention in literature of preheating during dissimilar welding of HSS with AHSS (Szymczak, 2020).

2. Materials

For dissimilar MAG welding of S690 QL with DOCOL 1400 M the UNION X90 wire (EN ISO 16834-AG 89 6 M21 Mn4Ni2CrMo) was proposed. There were used and a gas mixture of argon and nitrogen. In the welding process, it was decided to check the need for drying preheating to a temperature of 100°C. A thickness of both elements was 1.8 mm. Table 1 shows the mechanical properties of the S690 QL and DOCOL 1400 M.

Table 1.
Tensile strength of tested materials

Steel	YS MPa	UTS, MPa	A5, %
S690 QL	690	970	14
DOCOL 1400 M	1150	140	5

The table data shows that both materials have different mechanical properties. DOCOL 1400 M steel has high strength, and S 690 QL has good plastic properties. These differences result from the chemical composition of both materials (Table 2).

Table 2.
Chemical composition of S690 QL [6]

Steel	C	Si	Mn	P	S	Al	Cr	Cu	Mo	Nb	Ni	Ti	V	B
S690 QL	0.21	0.8	1.7	0.025	0.015	0.01	1.55	0.5	0.7	0.06	2.1	0.05	0.12	0.005
DOCOL 1400 M	0.17	0.2	0.24	0.01	0.02	0.04	0.02	-	-	0.15	-	0.25	-	-

Chemical composition of electrode wire is given in Table 3.

Table 3.
Electrode wire UNION-X90 –composition [10]

UNION	C%	Si%	Mn%	P%	Cr%	Mo%	Ni%	Ti%
X90	0.11	0.8	1.8	0.010	0.35	0.6	2.3	0.005

Before starting to make dissimilar joints no chamfering was performed. The welding parameters were as follows:

- diameter of the electrode wire: 1 mm,
- arc voltage: 20.5 V,
- welding current: 115.5 A,
- welding speed: was 320 mm/min,
- shielding gas flow: 14.5 l/min
- the nature of the weld: single-pass.

The workshop is presented in Fig. 2.

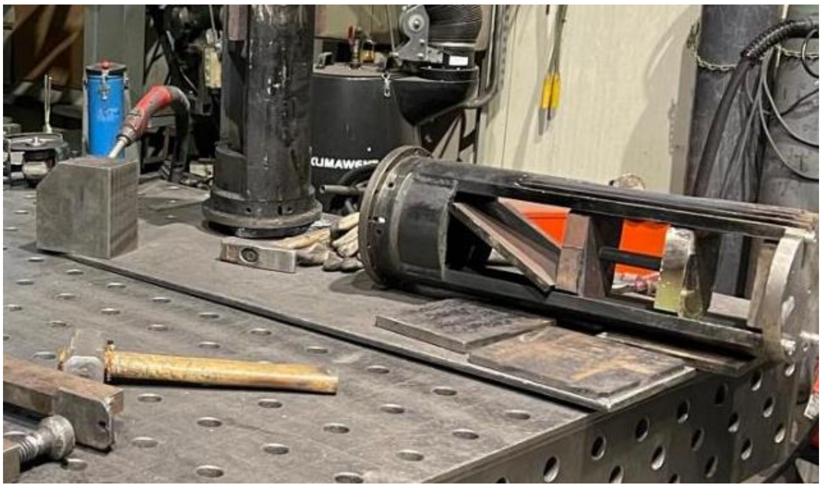

Figure 2. View on the MAG welding workshop.

Source: own study.

The joints were made with a drying pre-heating to the temperature of 105°C and without pre-heating. The shielding gas was changed twice in the MAG dissimilar welding process.

3. Methods

After dissimilar MAG welding, some non-destructive tests (NDT) and further destructive tests were carried out.

NDT examination generally based on:

- VT - visual test with a magnifying glass at 3 × magnification; the observation was carried out 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 observation was assessed in accordance with EN ISO 5817 using a magnetic flaw detector REM - 230.

The dissimilar welds were also structurally examined 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 performed in accordance with PN-EN ISO 7438 standard.

4. Results and discussion

The dissimilar joints were made using three different variants of shielding gases with various chemical composition:

- Argon,
- gas mixture containing argon and 0.8% N_2,
- gas mixture containing argon and 1.6% N_2.

The joints were additionally made in two ways:

- without preheating (samples A2, A4, A6),
- with preheating to the temperature of 105°C (samples A1, A2, A3).

The effect of visual tests is presented in Table 4.

Table 4.
NDT results for tested dissimilar welds

Sample	Type of shielding gas (mixture)	Welding without pre-heating	Welding with pre-heating up to 105° C
A2, A1	Ar	Cracks in weld	No cracks
A4, A3	Ar + 0.8 N_2	Cracs in weld	No cracks
A6, A5	Ar + 1.6 N_2	Cracs in weld	Cracs in weld

It was discovered that preheating before dissimilar steel welding S690 QL with DOCOL 1400 M is strongly recommended. The preheating temperature at the level of 105°C was accepted to be correct, because neither welding defects nor incompatibilities were observed in joints. It was easily noted that only in two teste cases it was possible to obtain correct dissimilar joints:

- argon,
- gas mixture containing argon and 0.8% N_2.

The next part of the research was to determine and compare the nitrogen content in the weld metal deposit, which was done on the LECO ONH836 analyzer. The test results are shown in Table 5.

Table 5.
Nitrogen in weld metal deposit (WMD)

Sample	Shielding gas mixture	Nitrogen in WMD, ppm
A1	Ar	50
A3	Ar + 0.8 N_2	55
A5	Ar + 1.6 N_2	65

It is easy to observe that after dissimilar welding only in argon shield, the weld metal was obtained with the lowest nitrogen amount: 50 ppm. The use of a shielding gas containing 0.8% N_2 ppm allows only for a slight increase in the nitrogen content in the metal deposit to the amount of 55 ppm. The use of a shielding gas containing 1.6% N_2 translates into a significant increase in nitrogen content in weld metal deposit on the level of 65 ppm%. This is clearly too high a nitrogen concentration in the weld metal and this may correspond to the cracks observed during NDT tests.

For main destructive tests i.e. microstructure and tensile strength, only dissimilar joints made with preheating of 105° C were analyzed (samples A1, A3). The dominant structure was martensite, bainite, small amount of ferrite and non-metallic inclusions (Figure 3).

Figure 3. Structure of dissimilar weld (above S690 QL, below DOCOL 1400 M). The area around the main diagonal of the rectangle corresponds to a dissimilar weld; sample A3, Nital etch.

Additional observations using a scanning microscope allowed for a more complete identification of the structure due to the nature of the inclusions in the dissimilar weld.

Mainly identified such as inclusions as:

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

In a dissimilar weld A3 containing 55 ppm nitrogen (table 5), more amount of TiN nitrides were observed than in the dissimilar weld A1containing 50 ppm nitrogen. It is very important observation, because nitrogen in weld metal deposit strongly strengthens steel welds. 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	Type of shielding gas (mixture)	UTS [MPa]
A1	Ar	575
A3	Ar + 0.8 N_2	615

The table data indicate that it is possible to get higher tensile strength of the dissimilar joint (over the 600 MPa level). This result was achieved when 0.8 N_2 was added to Ar. The tensile strength of the dissimilar weld made only in the argon shield is much lower. The gas mixture containing 0.8 N_2 nitrogen was found to be a preferable choise. This fact might be explained by the relationship that nitrogen has a high affinity for titanium and and niobium. The presents of inclusions such as TiN, NbN, TiC, Ti (N, C), their size and distribution determine the dissimilar weld strengthening.

The last stage of the research was the performance of bending tests of the dissimilar welds, which were made from the face and ridge 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	Ridge side
A1	No cracks	No cracks
A3	No cracks	No cracks

The bending test result was positive. No welding defects or nonconformities were found. Bending tests were carried out only for joints A1 and A3, because they had the best properties in previous tests. In assessing good weldability, it is important to check both good joint strength and plastic properties. All completed weldability tests of the dissimilar joint S690 QL with DOCOL 1400 M can be treated as very positive.

5. Summary

In the paper, it was decided to find a way to weld together two types of steel with different mechanical properties, of which S 690 QL steel has good plastic properties and average strength value, and DOCOL 1400 M steel has high strength but poor plastic properties. Dissimilar joints are difficult to weld, but they are often made to save money, because one of the welded materials is always cheaper. in this case, the focus was on two different high-strength steels that are used in the construction of various types of means of transport. To assess the good weldability of dissimilar joints, it was decided to check the influence of the various nitrogen content added to the argon shielding gas mixture. Simultaneously, the influence of the application of the preheating before welding at the level of 105°C was checked. Several non-destructive and destructive tests were performed. The nitrogen content in the weld was tested, tensile strength and bending tests were performed. Destructive tests were selected due to the diverse nature of two dissimilar materials that were joined together. One steel was more durable, but had worse plastic properties. The second steel, on the contrary, had lower strength, but much better plastic properties. It has been shown that the gas mixture containing the small nitrogen content (0.85 N_2) allows to noticeable increase the tensile strength of the joint with good plastic properties. Making recommended gas mixtures might improve knowledge of dissimilar welding, which can be used in the construction of many means of transport.

The following conclusions were made:

1. Preheat (105°C) is strongly recommended in dissimilar S690 QL/DOCOL 1400 M welding.
2. It is possible to obtain the tensile strength of the dissimilar joint of S690 QL/DOCOL 1400 M at the level over 600 MPa.
3. In the tested welds, it was observed that the dominant phase is martensite, bainite, ferrite and various nonmetallic inclusions.
4. On the basis of the research it can be concluded that the Ar + 0.8% N_2 gas mixture is more appropriate for the dissimilar welding of S690 QL/DOCOL 1400 M.

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