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WELDING OF 690 QL STEEL FOR THE CONSTRUCTION OF VEHICLES AND ANTENNA ELEMENTS

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Purpose: The novelty and the aim of the article is to check the possibility of welding high-strength steels with a mixture containing 7000 ppm of nitrogen.
Design/methodology/approach: A new welding material and method have been developed in order to obtain a high-quality joint for automotive industry and for antenna holders and towers. The properties of the joint were checked by NDT (Non Destructive test) tests and the strength and fatigue 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 in gaseous shielding mixtures of the MIG/MAG welding process.
Practical implications: The proposed innovation will not cause problems in the production process. Only the innovate shielding gas with micro additives will be modified without affecting the technological process, management and economic aspects.
Social implications: Modifying the welding method will not affect the environment and production management methods.
Originality/value: It is to propose a new solution with its scientific justification. The article is addressed to manufacturers of high-strength steel for automotive industry and to manufacturers of antenna components and instrumentation.

Keywords: welding, S690 QL, automotive, antenna, shielding gas mixtures.

Category of the paper: Research paper.

1. Introduction

The paper presents the results of tests leading to the selection of the correct MIG/MAG welding parameters of a thin-walled structure made of S690 QL high-strength steel (HSS). These steels are treated as a new material in the construction of means of transport. The HSS and AHSS (advanced high-strength steel) steels can be used for car bodies, truck frames, and for elements of mobile platforms (Fig. 1). Other applications in the automotive and other industrial sectors are also possible.

Figure1. Tanker truck with elements of HHS steel (own study).

HSS steels are especially very suitable for antenna holders and 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 recognized (Golański et al., 2018, pp. 53-63; Skowrońska et al., 2017, pp. 104-111).

A major difficulty when welding 690 QL steel is the presence of a martensitic structure, which clearly makes it difficult to make the correct joint.

In order to get good weld, it is necessary to carefully determine all welding parameters.

The most important of them are (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.

Welding of S690 QL steel is even more complicated compared to low-alloy steel due to the higher carbon and titanium content to strengthen the base material (Fydrych, Łabanowski et al., 2013); Shwachko et al., 2000). Preheating is recommended for good welding of HSS and AHSS steels (Szymczak, 2020). Recently, a method of producing gas mixtures with a very low content of the second component, even up to 2000 ppm, has been developed. The novelty and the aim of the article is to check the possibility of welding high-strength steels with a mixture containing 7000 ppm of nitrogen. It can be assumed that such a mixture will provide greater strength of the welded joint due to the increase in nitrogen content in the weld metal, which will translate into increased nitride and carbon-nitride precipitates.

2. Materials

For MAG welding of S690 QL steel with a thickness of 1.8 mm, the UNION X90 wire (EN ISO 16834-AG 89 6 M21 Mn4Ni2CrMo) was used and a mixture argon and oxygen. In the welding process, it was decided to check the need for drying preheating to a temperature of 90°C.

Table 1.
Tensile strength of steel S690 QL

YS MPa	UTS, MPa	A5, %
690	970	14

Table 1 shows the mechanical properties of the S690 QL steel used in the construction of various means of transport.

These good mechanical properties result from an interestingly selected chemical composition, where the very high content of titanium and boron deserves attention, which clearly strengthens the material (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	0,009	1,55	0,5	0,7	0,06	2,1	0,05	0,12	0,005

Chemical composition of steel is rather similar with electrode wire composition (Table 3).

Table 3.
Wire UNION X90 – chemical composition [10]

UNION	C%	Si%	Mn%	P%	Cr%	Mo%	Ni%	Ti%
X90	0,10	0,8	1,8	0,010	0,35	0.6	2.3	0,005

Before starting to make joints from sheets with a thickness of t = 1.8 mm, no chamfering was performed. The distance between the sheets and the threshold was 0.5 mm.

The welding parameters were as follows:

- diameter of the electrode wire: 1 mm,
- arc voltage: 19.5 V,
- welding current: 114 A,
- welding speed: was 335 mm/min,

- shielding gas flow: 14 l/min
- the nature of the weld: single-pass.

The workshop is presented in Fig. 2.

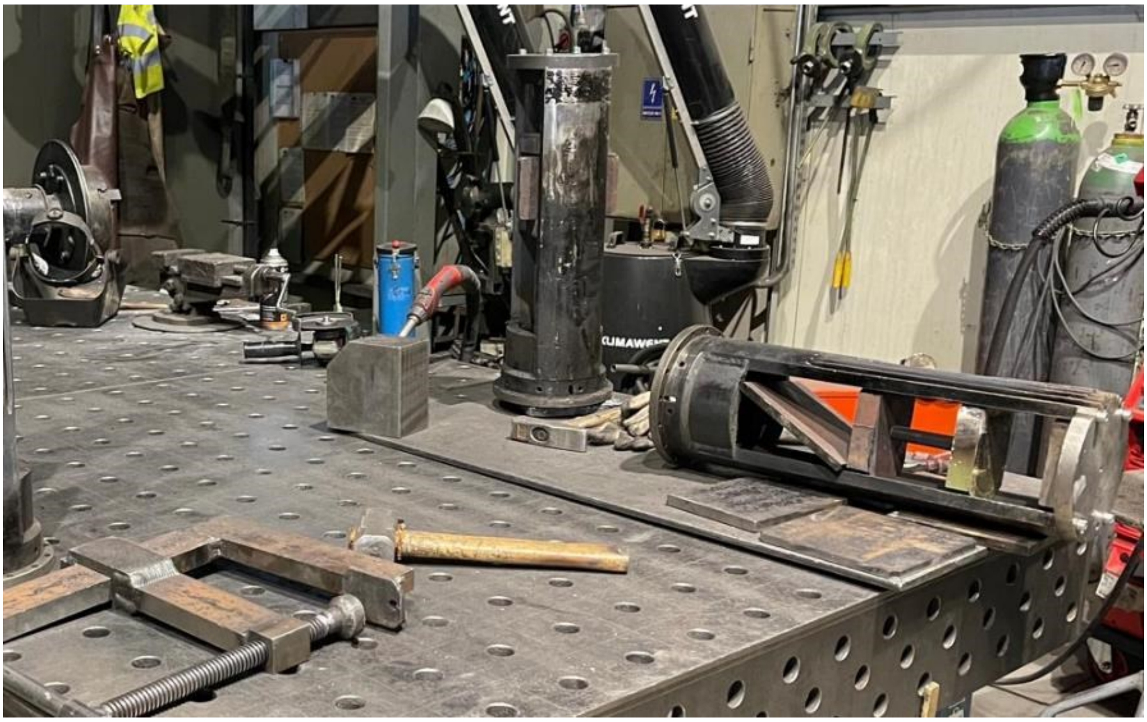

Figure 2. View on the MAG welding workshop (own study).

The joints were made with a drying pre-heating to the temperature of 90° C and without pre-heating. The shielding gas was changed twice in the MIG / MAG welding process.

3. Methods

After MAG welding, standard non-destructive testing (NDT) and destructive tests of the joints was carried out.

NDT tests were based on:

- VT – visual examination with an eye armed with a magnifying glass at 3 × magnification – the tests were carried out in accordance with the requirements of PN-EN ISO 17638, evaluation criteria according to EN ISO 5817.
- MT – magnetic particle testing – the tests were carried out in accordance with the PN-EN ISO 17638 standard, the tests were assessed in accordance with EN ISO 5817, with a magnetic flaw detector test device type REM-230.

The analysis of the obtained results of non-destructive tests allowed to select joints for destructive tests, which consisted of the temporary tensile strength tests. The samples were also structurally examined using a light microscope (LM). The tests were 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 joints were made using two different shielding gases with slightly different chemical compositions. The first shielding gas was argon and the second was an argon mixture containing only 7,000 ppm nitrogen. The joints were made in two ways: without preheating and with preheating to the temperature of 90° C. The results of macroscopic visual tests carried out with the naked eye and the magnetic-powder tests of the joints made with the use of various sheath mixtures are presented in Table 4. It was found that for proper welding of 1.8 mm thick sheets of S690 QL steel, preheating before welding is recommended.

Table 4.
NDT results

Type of shielding gas (mixture)	**Welding without pre-heating**	**Welding without pre-heating up to 90°C**
Ar	Cracks in weld	No cracks
Ar + 7,000 ppm N_2	Cracs in weld	No cracks

The preheating temperature at the level of 90°C was treated to be correct, as no welding defects and incompatibilities were observed in joints. It was additionally noted that the shielding gas mixture Ar +7,000 ppm N_2 allows for obtaining a correct joint, comparable to a joint made in a pure argon shield.

The next stage of the research was to compare the nitrogen content in the weld metal, which was performed on the LECO ONH836 analyzer. The test results are presented in Table 5.

The table data shows that after welding the joint made of S690 QL steel in a pure argon shield, the weld metal was obtained with a lower nitrogen content, at the level of 55 ppm. On the other hand, the use of a shielding gas containing 7,000 ppm of nitrogen allowed for a slight increase in the nitrogen content in the weld metal to the level of 60 ppm. This translated into the metallographic structure of the weld, which was analyzed in the next stage.

For further destructive tests (structure and mechanical properties), only joints made with preheating of 90°C were taken into account. The dominant structure was martensite, small amount of ferrite and non-metallic inclusions.

Table 5.
Nitrogen in weld metal deposit (WMD)

Type of shielding gas (mixture)	Nitrogen in WMD, ppm
Ar	55
Ar + 7,000 ppm N_2	60

Main observed precipitations included mainly oxides (especially MnO and TiO), carbides (mainly TiC, NbC) carbonitrides and nitrides (mainly TiN). In a joint containing 60 ppm nitrogen (table 5), more amount of TiN nitrides were observed than in a joint containing 55 ppm nitrogen. It is very important, because nitrides strengthens the joint. The next stage of the research was to check the mechanical properties. Table 6 shows the immediate tensile strength of joints (UTS) made in various sheathing compounds.

Table 6.
Tensile strength of joints

Type of shielding gas (mixture)	UTS [MPa]
Ar	567
Ar + 7,000 ppm N_2	612

The table data shows that it is possible to obtain high tensile strength of the joint (at the level of 600 MPa). This result was obtained in only one case when 7000 ppm N_2 was added to argon. The strength of the joint made in the argon shield is significantly lower. A blend containing 7,000 ppm nitrogen was found to be more preferable. This fact can be explained by the fact that nitrogen has a high affinity for titanium and forms TiN nitrides, as well as other non-metallic inclusions such as Ti (N, C) carbonitrides, the size and distribution of which is strongly related to the nitrogen content in the weld metal and determines the strengthening weld metal.

The last stage of the research was the performance of bending tests of the examined joints, which were made from the side of the ridge and from the side of the face. The test results are presented in Table 7.

Table 7.
Bending test results

Type of shielding gas (mixture)	Face side	Ridge side
Ar	No cracks	No cracks
Ar + 7,000 ppm N_2	No cracks	No cracks

It was not possible to ensure continuity in the joint, both from the side and the face, so now they are getting the benefits of having good plastic properties.

5. Summary

In the paper, it was decided to test in an innovative way the influence of the micro nitrogen content added to the argon shielding mixture in the MIG / MAG process when welding high-strength S690 QL steel. For this purpose, joints were made in an argon shield and in a gas mixture containing argon and 7,000 ppm N_2. At the same time, the influence of the application of preheating at the level of 90°C was checked. In further tests, joints made only with the use of preheating were tested. Tensile strength and bending tests were performer.

The metallographic structure and nitrogen content in the tested welds were assessed. It has been shown that the gas mixture containing the micro nitrogen content allows to increase the mechanical properties of the joint. Making gas mixtures with micro-additives may contribute to revolutionizing the current knowledge of welding, which can be used in the construction of many means of transport and various antenna holders and towers.

The following conclusions were made:

1. Preheat (90°C) is recommended prior to MIG/MAG welding of S690 QL.
2. It is possible to obtain the tensile strength of a joint made of S690 QL steel at the level of 600 MPa.
3. In the tested welds, it was observed that the dominant phase is martensite, which is not conducive to good weldability.
4. On the basis of all the tests performed, it can be concluded that the Ar + 7,000 ppm N_2 gas mixture is more appropriate for the welding of S690 QL steel in the MIG/MAG process.

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