TESTING

AND DIDACTING EQUIPMENT

MAG welding of thin-walled structures of means of transport made of S690 steel

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ABSTRACT:

An important material in the construction of means of transport are AHSS (Advanced High-Strength Steel) steels with high yield stress of approx. 1300 MPa. Joints made of these steels are difficult compare as to their mechanical properties. The aim of the article is to properly select the parameters for the welding of the thin walled structures of the mobile platform made of S690 QL steel. It was decided to check the impact of welding parameters on the correctness of the joint made.

Spawanie MAG cienkościennych konstrukcji środków transportu ze stali S690 QL

Słowa kluczowe: inżynieria lądowa, transport, środki transportu, stal S690 QL

STRESZCZENIE:

Ważnym materiałem stosowanym w budowie środków transportu są stale o podwyższonej wytrzymałości z uwagi na ich wysoką granicę plastyczności na poziomie 900 MPa i wytrzymałość na poziomie 1300 MPa. Złącza z tych stali nie mają porównywalnych własności mechanicznych. Celem artykułu jest prawidłowy dobór parametrów do spawania cienkościennych konstrukcji podestu ruchomego ze stali S690 QL. Postanowiono sprawdzić wpływ parametrów spawania na poprawność wykonanego złącza.

1. INTRODUCTION

This article aims at presenting the results of the tests leading to the selection of the parameters for welding the thin-walled structure made of S690 QL steel (AHSS). The symbols of this steel shall mean respectively [7]:

- **S:** *structural steel* (structural steel),
- **690:** minimum value of yield strength (690 MPa),
- **Q:** *Quenching & Tempering*,
- **L:** *low notch toughness testing temperature*.

AHSS steels' applications in civil engineering and in the construction of means of transport are being extended due to their high yield stress of 900 Mpa [1-2]. The advantage of S690 QL steel is a favourable value of relative elongation of 14%, which is twice the value of the recorded relative elongation for high strength steels from THE AHSS group [3-4]. When welding steels with increased yield stress, it is recommended to limit the linear energy during welding to 3.5 kJ/cm [5] and use drying preheating.

2. TEST MATERIALS

S690 QL steel is considered difficult to weld because both the weld and the heat affected zone are prone to cracks. The main welding problem of this group of steels is both much lower strength and worse plastic properties of the resulting joint than the parent material [6]. Table 1 shows the mechanical properties of the S690 QL steel as delivered.

Table 1 S690 QL Steel and its Mechanical Properties

Yield stress R_e MPa	Tensile strength R_m MPa	Elongation A5 %	Impact strength KV, J at 0°C
690	905	14.1	50.

S690 QL steel has a much higher titanium content than non-alloy structural steels used in transportation and civil engineering. It is assumed that the Ti content in welded steels shall not exceed 0.003% [6]. In S690 QL steel the titanium level is 0.05%. Also, the total high content of phosphorus and sulphur in steel amounting to 0.04% (Tab. 2) is deserved. This chemical composition allows for increased strength while maintaining acceptable plastic properties.

Table 2 Steel S690 QL – chemical composition, % [7]

C)	SI	MN	P	S	N	B)
0.21	0.8	1.7	0.025	0.015	0.015	0.005

Cr	Cu	MO	NB	NA	TI	V	ZR
1.55	0.5	0.7	0.06	2.1	0.05	0.12	0.15

A 3 mm thick metal plate was used to assess the weldability of S690 QL steel.
It was decided to make the joints using the MAG (Metal Active Gas) method with 2 different mixes of argon and carbon dioxide as the shielding gas. UNION X96 welding electrode was selected (EN ISO 16834-A G 89 6 M21 Mn4Ni2CrMo). The tests focused mainly on the impact of the shielding gas and preheating on the correctness of the MAG joint made (process 135).
The chemical composition of the welding electrode is given in Table 3.

Table 3 UNION X96 welding electrode – chemical composition [8]

C%	Si%	Mn%	P%	Cr%	Mo%	Ni%	Ti%
0.1	0.8	1.8	0.010	0.45	0.65	2.45	0.007

The chemical composition of the electrode is not completely similar to the steel composition. The electrode was provided with chromium for improved strength, as well as with nickel and molybdenum for improved plastic properties as in welded steel.
Welding parameters were as follows: welding electrode diameter – 1.0 mm, arc voltage – 19 V, welding current intensity – 117 A. The weld was of a single-pass type. Welding velocity was 350 mm/min. Shielding mixtures were Ar + 18% CO2 and then Ar + 10% CO2. Joints were made without preheating and with preheating up to 70°C.

3. RESULTS AND DISCUSSION

After welding the MAG in the mixture cover Ar + 18% EVERY $_2$ (and then Ar + 10% EVERY $_2$), non-destructive testing (NDT) and destructive testing were carried out.
As part of the non-destructive tests, the following were performed:

- visual inspection (VI) of the welded joints was carried out with corrected vision at the magnification of 3x – the tests were performed according to the requirements of PN-EN ISO 17638, whereas the assessment criteria were in accordance with EN ISO 5817.

- magnetic particle inspection (MPI) – the tests were performed according to PN-EN ISO 17638; the assessment was performed according to EN ISO 5817; the used test equipment was REM 230 magnetic flaw detector.

The results of the joints of the mobile platform are presented in Table 4.

Table 4 Evaluation of NDT of the mobile platform joint

Shielding gas	Without preheating	With preheating at 70°C
Mixture Ar + 18% CO_2	Cracks in welds and HAZ	No cracks
Mixture Ar + 10% CO_2	Cracks in welds and HAZ	No cracks

The table shows that preheating for drying is required for proper welding of S690 steel. Two different mixture of shielding gases were used. In both cases, comparable results were obtained indicating that the used shielding gases were appropriate. Based on the non-destructive tests, it was found that the pre-heating temperature of 70°C is sufficient.

For further (destructive) tests, only the joints made with preheating were taken into account. The strength of the joints was tested using INSTRON 3369 strength testing machine. The results of the strength tests (average of 3 tests) are presented in Table 5.

The table shows that high strength and acceptable, comparable plastic properties were obtained in all the cases tested. Slightly higher strength and yield strength are achieved by MAG welded joints in the mixture cover Ar + 10% EVERY $_2$. The use of Ar + 10% MIXTURE every $_2$ turned out to be more favourable, guaranteeing the relative elongation of the joint above 12%.

Table 5 The results of strength tests of S690 QL steel after welding with the use of preheating to the temperature of 70°C

Shielding gas	R_e [MPa]	R_m [MPa]	A_5 [%]
Ar + 18% CO_2	419	671	11.8
Ar + 10% CO_2	434	675	12.1

Then a bending test was performed for all the joints made after preheating to 70°C. As part of the bending test, 5 measurements were performed for each tested joint thickness from the root side and from the face side. No cracks were observed in the weld and HAZ both from the root and face sides. The bending test was carried out correctly, no cracks or other non-conformities were detected in all tested S690 QL joints.

In the further part of the tests, the microstructure analysis was performed. After MAG welding, a dominant martensitic structure was observed in the shield of both mixtures, which proves that the joint may be susceptible to cracks. The structure analysis showed no cracks. Additionally, it was decided to check the impact of the joint. For this purpose, 6 mm thick MAG sheets were welded, using the parameters from the previous process: the diameter of the electrode wire was 1.0 mm, the arc voltage was 19 V, the welding current was 117 A. Welding velocity was 350 mm/min. Shielding mixtures were again Ar + 18% CO2 and Ar + 10% CO2. The weld was of a multi-pass type. Joints were made only with preheating to a temperature of 70°C. The results of the impact tests are presented in Table 6.

Table 6 Connector failure

Shielding gas	KV, J temp. 0 ° C	KV, J temp. -20°C
Mixture Ar + 18% CO_2	42.	31.
Mixture Ar + 10% CO_2	48.	35.

The analysis of Table 6 indicates that the welding minimum 47 J criterion is met only in one case, at 0°C. The criterion of the second impact class is not met, which assumes that the sample energy at -20°C would be greater than the required 47 J. Impact tests are complementary to the above tests. These are not exactly the same welding conditions due to different sheet thickness, since no impact tests are performed for a sample cut out of 3 mm sheet thickness. As in previous cases, argon shielding mixture with 10% carbon dioxide is more favourable.

4. SUMMARY

Difficult to weld material used in civil engineering and transport are steels with increased yield point. The non-destructive tests show that in order to obtain the correct joint made of S690 QL steel, preheating to 70°C is needed. It can be concluded from the destructive tests that the use of a 90% Ar-10% SHIELDED gas mixture every $_2$ allows for obtaining good mechanical properties of the joint, which is measured by R_m at the level of 675 MPa, R_e at the level of 434 MPa, relative elongation at the level of 12%. The worse effects were achieved after welding of the joint with more oxidizing curtain gas mixture 82% Ar-18 %CO_2. Good mechanical properties of the joint have been confirmed by the bending test. Additional impact tests for a different thickness of the tested steel sheet, THE steel of S690 QL demonstrated that good impact (above 47 J) is only possible at 0°C with a less oxidative 90% Ar -10% CO curtain gas mixture in the MAG process.

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