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Impact on welded supports of mobile platform made of S690 QL steel

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ABSTRACT:

Different steel grades with different tensile strength are used for the construction of mobile platforms. Most of them are high strength structural steels (AHSS), non-alloy steels and steels with increased yield strength. An example of steel with elevated yield strength is S690 QL due to a high yield strength of 900 MPa. Joints made of these steels have good strength but low impact strength at negative temperatures. The purpose of the work described in this article is to correctly select the parameters for welding the supports of the mobile platform made of 12 mm thick S690 QL steel. It was decided to check the impact of welding parameters on the correctness of the joint made.

Udarność spawanych podpór podestu ruchomego ze stali S690 QL

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

STRESZCZENIE:

Do budowy podestów ruchomych stosuje się różne gatunki stali o różnej wytrzymałości na rozciąganie. Przeważnie są stale konstrukcyjne wysoko wytrzymałe (AHSS), stale niestopowe i stale o podwyższonej granicy plastyczności. Przykładem stali o podwyższonej granicy plastyczności jest S690 QL z uwagi na wysoką granicę plastyczności na poziomie 900 MPa. Złącza z tych stali mają dobrą wytrzymałość, ale niską udarność w ujemnych temperaturach. Celem prac opisanych w artykule jest prawidłowy dobór parametrów do spawania podpór podestu ruchomego wykonanego ze stali S690 QL o grubości 12 mm. 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 MAG welding the structure of the support for the mobile platform made of S690 QL steel. 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 [1-2]. The advantage of this group of steel is a favorable value of relative elongation of 14%, which is twice the value of the 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. Depending on the increase of the thickness of the welded plates, the preheat temperature should increase accordingly. Manufacturers do not advise about the rules for the selection of preheat temperature for this type of steel [7]. The authors of the article decided to select the most appropriate parameters for welding S690 QL steel (typical AHSS steel) in order to ensure the best possible impact resistance of the joint in low temperatures.

2. TEST MATERIALS

S690 QL steel is considered difficult to weld since the joint is vulnerable to cracks. The main welding problem of this group of steels is lower impact resistance and strength of the resulting joint from the parent material [6]. Table 1 shows the mechanical properties of 12 mm thick 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
692	910	14.2	55

S690 QL steel has a much higher titanium and nitrogen content than non-alloy structural steels used in transportation and civil engineering. It is assumed that the Ti content in welded structural steels shall not exceed 30 ppm (0.003%) and the N content shall not exceed 50 ppm (0.005%) [6]. High affinity of titanium to nitrogen causes that nitric non-metallic inclusions of TiN may appear in the weld, which may cause fracture. Due to the large affinity of titanium to oxygen, only low-oxygen processes should be used for welding of S690 QL steel in order to prevent the occurrence of non-metallic oxide inclusions of TiO in the weld, which may have an impact on cracking. Attention should be paid to the total higher content of phosphorus and sulfur in steel at the level of 0.04%. Whereas, high content of Mn and S in steel may facilitate the formation of sulfur non--metallic inclusions of MnS. For the same reason, S690 QL steel should be welded with low-oxygen processes to reduce the formation of MnO oxide inclusions. The chemical composition of S690 QL steel guarantees its high strength, but does not promote good weldability (Tab. 2).

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

C	SI	MN	P	S	N	MO	NB	NA	TI
0.21	0.8	1.7	0.025	0.015	0.015	0.7	0.06	2.1	0.05

A 12 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, as recommended with 2 using two different low-oxygen mixtures of argon and carbon dioxide as the shielding gas [7]. 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.

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 electrode was provided with chromium for improved strength, as well as with nickel and molybdenum for improved plastic properties. In the electrode wire, a lower content of C and Ti may be observed in relation to the content of these elements in S690 QL steel, which promotes the weldability of the mixed joint made of these steels.
Welding parameters were as follows: welding electrode diameter – 1.0 mm, arc voltage – 19 V, welding current intensity – 119 A. The weld was of a multi-pass type. Welding velocity was 434 mm/min. Low-oxygen shielding mixtures in the MAG process were Ar + 10% CO_2 and then Ar + 2% CO_2. Joints were made with preheating to three different temperatures of: 90°C, 120°C, 150°C.

3. RESULTS AND DISCUSSION

After welding the MAG in two tested low-oxygen mixtures (Ar + 10% O_2 and Ar + 2% O_2) with pre- -heating in three different temperatures (90°C, 120°C, 150°C) non-destructive and destructive tests were carried out.
As part of non-destructive testing (NDT), the following was performed:
• the visual test (VT) of the welded joints made according to the requirements of PN-EN ISO 17638, evaluation criteria according to EN ISO 5817, with an eye armed with a magnifying glass with 3x magnification,
• magnetic particle inspection (MT) — performed according to PN-EN ISO 17638. The tests were assessed according to EN ISO 5817 with a REM 230 magnetic flaw detector.
The results of the non-destructive tests of the tested joints are presented in Table 4.

Table 4 Evaluation of NDT of the joint

Shielding gas	Preheating temperature, 90°C	Preheating temperature, 120°C	Preheating temperature, 150°C
mixture Ar + 10% CO_2	Cracks in the HAZ	No cracks	No cracks
mixture Ar + 2% O_2	Cracks in welds and HAZ	Cracks in the HAZ	No cracks

The table shows that preheating up to at least 120°C is required for proper welding of S690 steel, provided that the shielding gas of Ar + 10% CO_2 was used. It is assumed that CO_2 added in the argon mixture is 15 times less oxidizing than oxygen [6]. Therefore, it can be assumed that 2% O_2 in argon mixture corresponds to 30% content of CO_2. To sum up, the mixture of Ar + 10% CO_2 is clearly less oxidizing than the mixture of Ar + 2% by $_2$, which makes it easier for a crack in the joint made with a shielding mixture of Ar + 2% O_2 to appear, which mixture hardens the weld metal more, which in turn promotes the release of more oxide non-metallic inclusions directly affecting the initiation of cracks.
For further (destructive) tests, mainly joints made in the low-oxygen shield of the mixture of Ar + 10% CO_2 with preheating up to 120°C 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.

Table 5 The results of strength tests of S690 QL steel after welding with the use of preheating to the temperature of 120°C

Shielding gas	R_e [MPa]	R_m [MPa]	A5 [%]
Ar + 10% CO_2	426	670	11.5

The table data shows that high strength and acceptable relative elongation (average from 3 measurements) were obtained.
Then a bending test was performed for all the joints made with the shield gas mixture of Ar + 10% CO_2 after preheating to 120°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 a macro - and microstructure analysis was carried out. After welding of S690 QL steel, both with the shield of Ar + 10% CO_2 and Ar + 2% CO_2 a dominant martensitic structure was observed, which proves that the joint may be additionally subject to cracking. However, the macrostructure analysis showed no cracks. The main test point was to check the joint impact strength. For this purpose, all tested joints where no cracks were observed were tested (based on NDT):
• Mixture of Ar + 10% CO_2, initial temperature 120°C,

• Mixture of Ar + 10% CO_2, initial temperature 150°C,
• Mixture of Ar + 2% O_2, initial temperature 150°C.
The results of the impact tests are presented in Table 6.

Table 6 Impact strength of joints made at different parameters

Shielding gas	Preheating temp., °C	KV, J Temp. 0°C	KV, J Temp. -20°C	KV, J Temp. -30°C
Mixture Ar + 10% CO_2	120	48	36	27
Mixture Ar + 10% CO_2	150	49	41	29
Mixture Ar + 2% O_2	150	43	31	22

The analysis of Table 6 shows that the welding criterion of the minimum value of 47 J is met only in case of breaking the sample at the temperature of 0°C. The criterion of the second and third impact class is not met, which assumes that the sample breaking energy at -20°C and -30°C would be at least 47 J. Impact tests confirmed that the argon shielding mixture of Ar + 10% CO_2 is more favorable than the mixture of Ar + 2% O_2, which application did not allowed to obtain the impact strength of the required level of 47 J.

4. SUMMARY

Steels with increased yield strength are the low-weldable material used for the construction of the support of the mobile platforms. High strength of steel from this material group, S690 QL, is far greater than the strength of the welded joint. The non-destructive tests show that in order to obtain the correct joint made of S690 QL steel, preheating to 120°C is needed. From the analysis of the results of the destructive tests, it can be concluded that the use of mixture of 90% Ar 10% CO_2 allows achieving high yield limit and strength of the joint. The use of the shielding gas mixture of 90% Ar -10% CO_2 also allows for better plastic properties, as measured by the relative elongation at the level of 11.5%. Good plastic properties of the joints confirmed impact tests which demonstrated that it is possible to obtain them (above the required 47 J) at the temperature of 0°C using in the MAG process the shielding gas mixture of 90% Ar-10% CO_2.

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