Welding of the mixed joint in construction of the mobile platforms made of steel S690 QL and S960 MC

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ABSTRACT:

The article analyses the possibility of making a proper joint of two different high strength steel grades (S960 MC) with high yield strength steel (S690 QL). For the construction of mobile platforms, various steel grades are increasingly used and homogeneous and mixed joints are made of them. The aim of the article is to properly select the parameters for welding the joint joint of the components of the mobile platform made of steel S690 QL and S960 MC with a thickness of 6 mm. It was decided to check the impact of welding parameters on the correctness of the joint made. Different electrode wires and different shielding gases were used. Non-destructive and destructive tests were performed to check the quality of the mixed joint.

Spawanie złącza mieszanego w budowie podestów ruchomych ze stali S690 QL i S960 MC

Słowa kluczowe: inżynieria lądowa, transport, środki transportu, złącze mieszane

STRESZCZENIE:

W artykule analizowano możliwość wykonania prawidłowego złącza mieszanego z dwóch różnych gatunków stali o wysokiej wytrzymałości (S960 MC) ze stalą o podwyższonej granicy plastyczności (S690 QL). Do budowy podestów ruchomych stosuje się coraz częściej różne gatunki stali i wykonuje się z nich złącza jednorodne i mieszane. Celem artykułu jest prawidłowy dobór parametrów do spawania mieszanego złącza elementów podestu ruchomego wykonanego ze stali S690 QL i S960 MC o grubości 6 mm. Postanowiono sprawdzić wpływ parametrów spawania na poprawność wykonanego złącza. Zastosowano różne druty elektrodowe i różne gazy osłaniające. Wykonano badania nieniszczące i niszczące dla sprawdzenia jakości złącza mieszanego.

1. INTRODUCTION

The results of tests leading to the selection of MAG welding parameters (process 135) of the mixed joint occurring in the structure of the mobile platform made of S690 QL steel with S960 MC steel are presented.

Steel mixed joints are used in various structures used in civil engineering and transport [1-2]. A good example of using mixed joints made of tested steel grades is the structure of a mobile platform for which it is intended to extend the operational arm of the platform and at the same time to increase the lifting capacity [3-4]. For simultaneous welding of both steel grades (S960 MC and S690 QL), it is recommended to limit the linear energy during welding to the level of 4 kJ/cm [5] and to use preheating for sheet thicknesses above 4 mm. Depending on the increase of the thickness of the welded plates, the preheat temperature [6] should increase accordingly. Manufacturers do not advise about the rules for the selection of preheat temperature for the mixed joint of the tested steels [7]. The article provides for the selection of the most appropriate parameters for welding of S960 MC steel with S690 QL steel in order to ensure the best possible quality of the joint.

2. TEST MATERIALS

Both steel grades S960 MC with S690 QL are considered as difficult to weld since the joint is subject to cracks in the heat affected zone (HAZ). The main welding problem of the uniform joints made of S960 MC steel with S690 QL steel is lower impact strength and strength of the resulting joint from the base material [6]. Table 1 shows the mechanical properties of S960 MC steel with 6 mm thick S690 QL steel as delivered.

Table 1 Mechanical properties of S960 MC steel and S690 QL steel

Steel	Yield stress YS, MPa	Tensile strength UTS, MPa	Relative elongation A_5,%
S690 QL	692	910	14.2
S960 MC	950	1250	8.1

Both steel grades have different mechanical properties, making it more difficult to construct the mixed joint correctly. Yield strength, strength and relative elongation are different levels. These steels also differ in chemical composition (Tab. 2). Both steels have a controlled level of Al and B which does not deteriorate the weldability of the steel. In both, increased sulphur content may also be observed, which may facilitate the formation of sulfur non-metallic inclusions of MnS. The chemical composition of both tested steels guarantees high strength, but does not promote good weldability [7].

It was decided to make a 6 mm thick S960 MC/S690 QL steel mix connection using MAG process. Two different argon-oxygen curtain mixes with 2% and 3% 2 respectively were tested. Additionally, two electrode wires were tested: UNION X96 (EN ISO 16834-AG 89 6 M21 Mn4Ni-2CrMo) and UNION X90 wire (EN ISO 16834-AG 89 6 M21 Mn4Ni- 2CrMo) with the following chemical composition (Tab. 3).

The tests focused primarily on the effect of the type of shielding gas and the type of electrode wire with different Cr, Ni and Mo content on the

Table 2 Mechanical properties of S960 MC steel and S690 QL steel, % [7]

Steel	C)	SI	MN	P	S	Al	Cr	Cu	MO	NB	NA	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
S960 MC	0.12	0.25	1.3	0.02	0.01	0.015	0.8	0.3	0.7	0.05	2.0	0.07	0.05	0.005

Table 3 Electrode wires used in tests – 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
X96	0.11	0.8	1.8	0.010	0.45	0.65	2.45	0.007

mechanical properties and the correctness of the made MAG joint. In both electrode wires, a lower content of C and Ti may be observed in relation to the content of these elements in the S690 QL and S960 MC steels, 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 – 21 V, welding current intensity – 121 A. The weld was of a multi-pass type. Welding velocity was 400 mm/min. MAG shielding mixtures represented Ar + 2% by $_2$ and then Ar + 3% by $_2$. Joints were made with preheating to a temperature of 120°C.

3. RESULTS AND DISCUSSION

After welding the MAG in two tested mixtures (Ar + 2% O_2 and Ar + 3% O_2) and using two tested electrode wires (UNION X90 and UNION X96), 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 provided joints are presented in Table 4.

Table 4 Evaluation of NDT of the joint

Shielding gas	Electrode wire	Observation
Ar + 2% O_2	UNION X90	No cracks
Ar + 2% O_2	ZWIĄZKI X96	No cracks
Ar + 3% O_2	UNION X90	Cracks in the HAZ
Ar + 3% O_2	ZWIĄZKI X96	Cracks in welds and HAZ

The tables indicate that only the gas mixture Ar + 2% O_2 is suitable for application. The mixture Ar + 3% by $_2$ has a more oxidative nature of weld metal than the mixture Ar + 2% by $_2$, which makes it easier to crack the joint made with a curtain mixture Ar + 3% by $_2$.
In the more oxidized weld metal, there are larger amounts of non-metallic oxide inclusions (and larger amounts) which have a direct impact on the formation of cracks in the weld.
For further (destructive) tests, the mixed joints made with two tested electrode wires in the mixture cover Ar + 2% by $_2$ after preheating 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 Results of strength tests of the joint made of two steel grades: S690 QL and S960 MC

Shielding gas	Electrode wire	R_e [MPa]	R_m [MPa]	A_5 [%]
Ar + 2% O_2	UNION X90	427	701	7.1
Ar + 2% O_2	ZWIĄZKI X96	435	717	6.8

The table data shows that high strength (700 MPa) and acceptable relative elongation (7%) were obtained. The strength of the mixed joint is much lower than that of both welded steel grades S690 QL. Then a bending test was performed for the mixed joints made only in the curtain gas mixture Ar + 2% O_2 with the use of two tested electrode wires, after preheating to the temperature of 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 mixed joints.
In the further part of the tests a macro - and microstructure analysis was carried out. After welding of the S690 QL steel with S960 MC steel in the MAG process, two tested electrode wires (UNION X90 and UNION X96) and in the cover of two casing mixtures used for testing (Ar + 2% by $_2$ and Ar + 3% by $_2$), a dominant martensitic structure was observed, which proves that the joint may be additionally subject to cracking. The macrostructure analysis showed no cracks.

4. SUMMARY

It can be concluded from non-destructive and destructive tests that the use of a curtain gas mixture Ar-2% O_2 allows achieving a relatively good yield strength and strength of the joint. The use of the Ar-2% O_2 shielding gas mixture also al-

lows for better plastic properties, as measured by the relative elongation at the level of 7%. Good plastic properties of the joint have been confirmed by the sample bending test. Both electrode wires (UNION X90 and UNION X96) can be used to make a mixed joint made of S690 QL and S960 MC steel. With UNION X96 electrode wire, a slightly higher R_m and R_E can be obtained. With UNION X90 electrode wire, a slightly higher relative elongation can be obtained.

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BIBLIOGRAPHY

[1] Jaewon L., Kamran A., Jwo P., Modeling of failure mode of laser welds in lap-shear specimens of HSLA steel sheets, Engineering Fracture Mechanics 2011, 1, pp. 347-396.
[2] Darabi J., Ekula K., Development of a chip-integrated micro cooling device, Microelectronics Journal 2003, 34(11), pp. 1067-1074, https://doi.org/10.1016/j.mejo.2003.09.010.
[3] Hadryś D., Impact load of welds after micro-jet cooling, Archives of Metallurgy and Materials 2015, 60(4), pp. 2525-2528, https://doi.org/10.1515/amm-2015-0409.
[4] Muszynski T., Mikielewicz D., Structural optimization of microjet array cooling system, Applied Thermal Engineering 2017, 123, pp. 103-110, https://doi.org/10.1016/j.applthermaleng.2017.05.082.
[5] Celin R., Burja J., Effect of cooling rates on the weld heat affected zone coarse grain microstructure, Metallurgical and Materials Engineering 2018, 24(1), pp. 37-44.
[6] Walsh S. M., Smith J. P., Browne E. A., Hennighausen T. W., Malouin B. A., Practical Concerns for Adoption of Microjet Cooling, ASME Proceedings 2018 Power Electronics, Energy Conversion, and Storage, https://doi.org/10.1115/IPACK2018-8468.
[7] Strona internetowa producenta stali Htsteelmill: http://www.htsteelmill.com/s690ql-steel-plate.html?gclid=EAIaIQobChMIoqT4o9Gw6QIVGoGyCh2PtQupEAAYAiAAEgKgsfD_BwE.