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Original Article

Welding supports of fine-grained steel mobile platforms

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Abstract: The article presents the process of welding of steel movable platform supports. There is a growing demand for the welding of difficult-to-weld fine grain steels used in civil engineering and transport. An example of this could be the use of high-strength movable platform supports. The recently used material in the production of movable platform supports are fine-grained steels due to their high tensile strength of 1000 MPa. The joints formed using them, however, are characterized by much lower strength than the native material. In this article, the most appropriate parameters were selected for welding the movable platform supports made of difficult-to-weld fine-grained steel S960 MC.

Keywords: civil engineering; transport; mobile platforms; fine-grained steel

Introduction

In civil engineering and transport, construction and transport equipment constantly being modernized is. There is a growing demand for welding new, often difficult to weld, high-strength materials and for the development and modernization of new technologies [1÷4]. Updating the regulations on exhaust emissions in motor vehicles requires the introduction of additional components that increase their total weight. In the case of mobile platforms, this increases the weight of the vehicle by almost 200 kg [5]. In order to increase the functional properties of the platform structures, efforts are constantly being made to increase their immediate tensile strength of all elements of the structure of the mobile platform elements. Recently, it has been proposed to use high-strength AHSS steels for platform arms, and high-strength fine-grained steels for supports of mobile platforms in order to reduce the total weight of the vehicle [6].

The article focuses on welding the thin-walled structure of the mobile platform supports. The aim of the article is to select the technological parameters of the process and to check the properties of a thin-walled joint made of S960 MC fine-grained steel.

Materials and methods

High-strength fine-grained steels are increasingly used in civil engineering and transport due to their high tensile strength, max. up to 1300 MPa, high yield point, approx. 950 MPa and an acceptable relative elongation of 10%. [5,6]. During welding of fine-grained steels, a reduction in mechanical properties in the HAZ can be observed. Therefore, it is recommended to limit the heat input during welding to the level of 5 kJ/cm [7÷10].

Fine-grained steels are used primarily for thin-walled structures, because their high strength allows to reduce the total weight of the structure. Welding of such steels is difficult due to the possibility of delayed cracks [11-13]. Typical applications of fine-grained steels include advanced lifting devices, such as mobile cranes and mobile platforms [5,6]. Table I presents the mechanical properties of S960 MC steel used for the supports of mobile platforms.

Table I. Mechanical properties of S960 MC steel [6]

Yield strength YS, MPa	Ultimate tensile strength UTS, MPa	Relative elongation A5, %
950	1250	7

Fine-grained steels are considered as difficult-to-weld, because the heat-affected zone is susceptible to welding cracks even when preheated to the temperature of max. 150 °C. This is related to the high carbon equivalent (CEV) = 0.57%. Table II shows the chemical composition of S960 MC steel.

Table II. Chemical composition of S960 MC steel [6]

C %	Si %	Mn %	P %	S %	Al %	Nb %	V %	Ti %
0.12	0.25	1.3	0.02	0.01	0.015	0.05	0.05	0.07

The chemical composition of both steels is similar. Noteworthy is a higher carbon content than in carbon-manganese steels and a high carbon equivalent (CEV), which translates into an increase in material strength and deterioration of weldability in relation to structural carbon-manganese steels.

In the article, it was decided to check the weldability of S960MC steel. Sheets with a thickness of 2 mm were used for the construction of supports for the mobile lifts.

It was decided to make joints using the MAG (Metal Active Gas) process using Ar+18% CO_2 as a shielding gas.

Two electrode wires UNION X90 (EN ISO 16834-A G 89 6 M21 Mn4Ni2CrMo) and UNION X96 (EN ISO 16834-A G 89 5 M21 Mn4Ni2,5CrMo) with the following chemical composition were selected (Table III).

Table III. Electrode wires used for the research, 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	0.12	0.8	1.9	0.010	0.45	0.55	2.5	0.05

The chemical composition of both wires is similar, but slightly different from the chemical composition of the welded steel. Noteworthy is the addition of chromium in the wires (which is not an alloying element of the S960 MC steel) and the much higher silicon content, which increases the strength, as well as the increased nickel and molybdenum content, which improves the plastic properties of the joint.

Welding parameters for S960 MC steel using both electrode wires were similar. The wire diameter was 1.0 mm, the arc voltage was 19 V, the welding current was 115 A. In both cases, three different welding velocities were checked: 300 mm/min, 400 mm/min and 500 mm/min. The welding velocity was changed three times in order to determine the most appropriate heat input in accordance with the literature recommendations [6,7]. The direct current source was connected with (+) on the electrode, the thin-walled weld had a single-pass character.

Methodology and scope of the research

The scope of the tests included non-destructive testing (NDT):

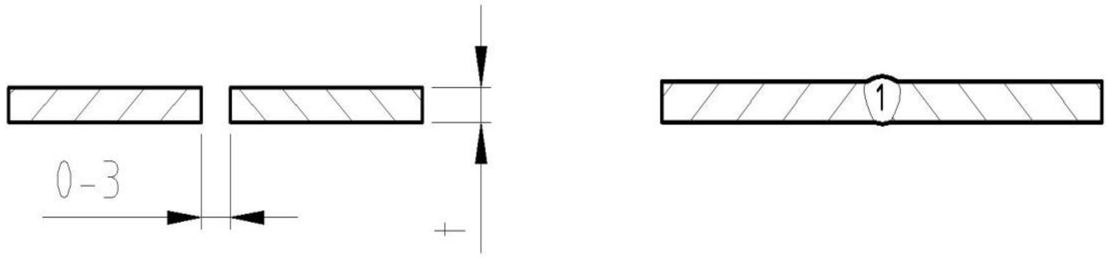
- visual testing (VT) of the welded joints was carried out with an eye armed with a magnifying glass at 3× magnification – the tests were carried out in accordance with the requirements of PN-EN ISO 17638, evaluation criteria according to EN ISO 5817,
- magnetic particle testing (MT) – the tests were carried out in accordance with PN-EN ISO 17638, and assessed in accordance with EN ISO 5817, with a magnetic flaw detector, type REM – 230,
- radiographic tests – the tests were carried out according to PN-EN ISO 15614-1. Type of radiation source – SMART 200.

The destructive tests included:

- static tensile testing according to PN-EN ISO 4136: 2013-5 using the EDZ – 20 testing machine,
- the bending test performed in accordance with PN-EN ISO 5173, using the EDZ – 20 testing machine,
- examination of the microstructure of metallographic specimens etched with Adler's reagent using a light microscope (LM),
- hardness measurement (HPO 250 hardness tester, testing method HV10).

Results and discussion

A butt weld (BW) was made of S960 MC steel, 3 mm and 2 mm thick. The MAG (135) welding method in the flat position (PA) was used in accordance with the requirements of EN 15614-1. The preparation of the material for single-pass welding is shown in figure 1.



(a) (b)

Fig. 1. a) Shape of the groove; b) welding method

To assess the weldability of the mobile platform elements, a mixture of 82% Ar + 18% CO_2 as a shielding gas and both UNION X90 and UNION X96 electrode wires were selected. MAG welding was performed using a forming ceramic backing, although it is not required. Initial welding tests of the mobile platform support without the backing were satisfactory. After welding, non-destructive tests (NDT) were carried out:

- visual testing (VT) of the welded joints was carried out 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,
- magnetic particle testing (MT) – the tests were carried out in accordance with PN-EN ISO 17638, and assessed in accordance with EN ISO 5817, with a magnetic flaw detector, type REM – 230,
- radiographic tests (acceptance criterion: quality level B according to PN EN ISO 5817; image quality was W18 according to EN ISO 19232-1.

The results of the made connections of the mobile platform are shown in Table IV.

Table IV. Assessment of non-destructive testing of the mobile platform joint

Electrode wire	Welding velocity 250 mm/min	Welding velocity 350 mm/min	Welding velocity 450 mm/min
UNION X90	Cracks in the welds and in the HAZ	No cracks	Cracks in the HAZ
UNION X96	Cracks in the welds and in the HAZ	No cracks	Cracks in the HAZ

The table data shows that the heat input has a large impact on the correctness of the joint made of S960MC steel. No cracks were recorded only when the welding velocity was 350 mm/min. Only for these joints the quality level B according to PN EN ISO 5817 was achieved. The image quality was W18 according to EN ISO 19232-1.

Destructive testing results

Only joints made with a welding velocity of 350 mm/min were considered for further tests. The sheets were welded with the use of both tested electrode wires (UNION X90 and UNION X96). A static tensile test of a 2 mm butt joint was performed at the temperature of 20 °C on a testing machine. The test results for a sample with a cross-section of 2×12 mm (length 25 mm) are presented in Table V. Three tensile tests were performed each time.

Table V. Mechanical properties of the joints

Electrode wire	UTS	YS	A_5	Place of the breakthrough, Nature of the breakthrough
UNION X90	988	687	7.1	Native material / Plastic cross-section
UNION X90	984	681	6.9	HAZ / Native material / Plastic-brittle cross-section
UNION X90	985	683	7.1	Native material / Plastic cross-section
UNION X96	1008	712	7.1	Native material / Plastic cross-section
UNION X96	1006	707	7.2	Native material / Plastic cross-section
UNION X96	1000	701	7.2	Native material / Plastic cross-section

When analyzing the data from Table V, it can be seen that the joints were made correctly. The breakthrough occurred mainly in the native material near the heat-affected zone. The cross-section of the broken samples was usually plastic-brittle. The tensile strength (UTS) and yield point (YS) are at the required high level (above the required value of 900 MPa). For YS, the requirement is min. 650 MPa and UTS should be in the range of 950÷1250 MPa according to EN ISO 15614-1. In the obtained measurements, YS was in the range of 681÷712 MPa, while the UTS was in the range of 984÷1008 MPa. The strength of the joints made with Union X96 wire was found to be higher (above 1000 MPa).

Then a bending test was performed. For samples with a thickness of 2 mm, the parameters were as follows: sample width b = 20 mm, mandrel d = 14 mm, spacing of the supports d 3a = 31 mm and the required bending angle of 180°. Five measurements were made in the bending test for each tested joint thickness from the root side and from the face side. The test results are summarized in Table VI.

Table VI. Results of the bending test of the tested joints

Electrode wire used	Deformation side	a_o x b_o [mm]	Bending angle [°]	Remarks
UNION X90	Root	2 x 20	180	no cracks, no imperfections
UNION X90	Face	2 x 20	180	no cracks, no imperfections
UNION X96	Root	2 x 20	180	no cracks, no imperfections
UNION X96	Face	2 x 20	180	no cracks, no imperfections

The analysis of the data from Table VI shows that the bending test was carried out correctly, the evaluation of the tests is positive because no cracks or other imperfections were detected in the tested samples, both from the side of the root and the face.

Metallographic examination

Metallographic specimens were made and the structure of the welds was checked (made with two electrode wires: UNION X90 and UNION X96). The structure in both cases was very similar, dominated by martensite. Observations of the specimens etched in Adler's reagent were carried out on a Reichert light microscope. The use of Union X96 electrode wire is shown in figure 2.

The results of structural tests indicate that martensitic and bainitic structures dominate in the examined joints. The results of all tests presented in the article were positive, which confirms that the selected electrode wires are correct.

Then the hardness was measured in the elements of the joint made with two electrode wires (UNION X90 and UNION X96). The results were carried out in accordance with PN-EN ISO 15614-1. The hardness measurement results are presented in Table VII.

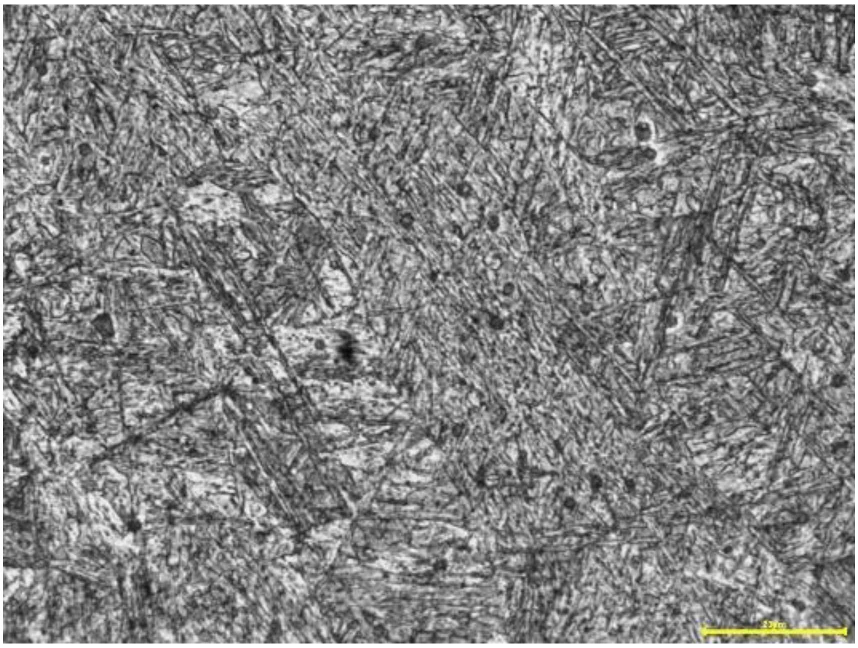


Fig. 2. Weld structure made using the Union X96 electrode wire

When analyzing the table data, it can be noticed that the hardness of the weld, HAZ and the native material are at a comparable level, which is very favourable, but usually very difficult to achieve. The weld made with the UNION X96 electrode wire has a slightly higher hardness. In this case, the hardness of the weld is close to the hardness of the heat-affected zone, which may be influenced by the higher content of the alloying elements of the electrode wire, such as C and Cr (Table III).

Table VII. Results of the bending test of the tested joints

Electrode wire used	Native material			HAZ			Joint		
UNION X90	332	334	338	351	353	354	340	339	341
UNION X96	333	335	339	353	352	352	353	350	351

Summary

There is an increasing need to improve the weldability of new high-strength steel grades for civil engineering and transportation applications. Difficult-to-weld fine-grained steel is more and more often used for constructions. The joint made of this steel is susceptible to welding cracks. In order to make the correct joint of the mobile platform, it is important to select the welding parameters. In addition to the selection of the electrode wire, voltage and current parameters, it is important to determine the appropriate welding velocity. In the first part of the research, joints with different heat input were made, which allowed to select the most appropriate value, at which no welding defects and imperfections were observed. The possibility of making the correct joint has been confirmed by non-destructive tests. Then, the mechanical properties of the joint were assessed. Tensile strength, bending resistance and hardness tests were performed. Non-destructive and destructive tests have shown that the most appropriate way to make a thin-walled joint made of S960MC steel is to use the UNION X96 electrode wire in the MAG process, which allows to obtain a joint without welding defects and imperfections and to obtain high strength above 1000 MPa.

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References

[1] Golański D., T. Chmielewski T., Skowrońska B., Rochalski D., Advanced Applications of Microplasma Welding, *Biuletyn Instytutu Spawalnictwa w Gliwicach*, 2018, Vol. 62(5), 53-63. http://dx.doi.org/10.17729/ebis.2018.5/5

[2] Giles T. L., Oh-Ishi K., Zhilyaev A. P., Swami S., Mahoney M. W., McNelley T. R., The Effect of Friction Stir Processing on the Microstructure and Mechanical Properties of an Aluminum Lithium Alloy, *Metallurgical and Materials Transactions*, 2009, Vol. 40(1), 104-115. http://dx.doi.org/10.1007/s11661-008-9698-8

[3] Hamilton C., Dymek S., Węglowska A., Pietras A., Numerical simulations for bobbin tool friction stir welding of aluminum 6082-T, *Archives of Metallurgy Materials*, 2018, Vol. 63(3), 1115-1123. http://dx.doi.org/10.24425/123784

[4] Benato R., Dughiero F., Forzan M., Paolucci A., Proximity effect and magnetic field calculation in GIL and in isolated phase bus ducts, *IEEE Transactions on Magnetics*

[5] Skowrońska B., Szulc J., Chmielewski T., Golański D., Wybrane właściwości złączy spawanych stali S700 MC wykonanych metodą hybrydową plazma + MAG, *Welding Technology Review*, 2017, Vol. 89(10), 104-111. http://dx.doi.org/10.26628/ps.v89i10.825

[6] Silva A., Szczucka-Lasota B., Węgrzyn T., Jurek A., MAG welding of S700MC steel used in transport means with the operation of low arc welding method, *Welding Technology Review*, Vol. 91 Nr 3/2019, PL ISSN 0033-2364, 23-30.

[7] Szymański G., A. Patecki A., Eddy current and temperature of the sheath in tree-phase pipe sheathing system, *IEEB Transaction of magnetics*, 2004-2006, Vol. 20(5). http://dx.doi.org/10.1109/TMAG.1984.1063218

[8] IEEE Standard for Metal-Enclosed Bus. In *IEEE Std C37.23-2015* (Revision of IEEE Std C37.23-2003), IEEE. http://dx.doi.org/10.1109/IEEESTD.2016.7470712

[9] Jaeschke B., Węglowski M., Chmielewski T., Current State and Development Opportunities of Dynamic Power Source for GMA Welding Processes, *Journal of Manufacturing Technologies*, 2017, Vol. 42(1), 23-30.

[10] Agrawal K. C., Industrial Power Engineering and Applications Handbook, 1st ed.; Publisher: Elsevier Inc, 2001.

[11] Ferenc K., Cegielski P., Chmielewski T., *Technika spawalnicza w praktyce: Poradnik inżyniera konstruktora i technologa*, 1st ed.; Publisher: Verlag Dashofer, Warszawa, Poland, 2015.

[12] Izairi N., Ajredini F., Vevecka-Pfiftaj A., Makreski P., Ristova M. M., Microhardness evolution in relation to the cFigtalline microstructure of aluminum alloy AA3004, *Archives of Metallurgy Materials*, 2018, Vol. 63(3), 1101-1108, http://dx.doi.org/10.24425/123782

[13] Skowrońska B., Chmielewski T., Golański D., Szulc J., Weldability of S700MC steel welded with the hybrid plasma+MAG method, *Manufacturing Review*, 2020, Vol. 7(4). https://doi.org/10.1051/mfreview/2020001