DOI: http://dx.doi.org/10.26628/wtr.v92i4.1111

PRZEGLĄD SPAWALNICTWA Welding TECHNOLOGY REVIEW

Article

Welding supports of pins in mobile platforms

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Received: 03.01.2020; Accepted: 01.04.2020

Abstract: The demand for dissimilar joints of hard-welded steels used in civil engineering and transport is increasing. An example of this can be welding of pins of high-strength steel S690 QL (1.8928) with the arms of a movable platform made of DOCOL 1200M steel from the AHSS group. This joint is difficult to make properly, due to significant differences in the thickness of welded elements and different chemical composition of both steels. The diameter of pin is 40 mm. The thickness of the metal sheet used for the mobile platform arm is 2 mm. Joints of varying thickness and chemical composition may have cracks in the heat affected zone and in the weld. The purpose of the article is to determine the welding parameters and the selection of filler materials that will allow to obtain the correct joint without welding defects.

Keywords: civil engineering; transport; mobile platforms

Introduction

In civil engineering and transport, the demand for welding of new, often difficult-to-weld materials, including dissimilar joints, allowing for high quality [1÷5], is increasing. In order to increase the usability of the construction of mobile platforms, we are constantly striving to increase their immediate tensile strength. Welding difficulties arise, among others when making a mixed joint, the pin – the platform arm. In order to reduce the total weight of the vehicle on the arms of the platforms, high-strength steel grades from the AHSS group (Advanced High-Strength Steel, e.g. DOCOL 1200M steel) are used, and for pins – high-strength structural steel (e.g. S690 QL steel) [6].

The article focuses on the welding of dissimilar joints of thin-walled construction of the mobile platform arms with a pin of a much larger thickness (which is an additional welding difficulty). MAG welding tests were carried out for elements made of S690 QL and DOCOL 1200M steel used in the construction of mobile platforms. The joints were subjected to non-destructive and destructive tests. On the basis of the results obtained, a set of technological parameters of the process was determined enabling to obtain a good quality joint.

Materials and methods

Due to good mechanical properties, S690 QL steel is becoming more and more widely used, above all on loaded parts of welded structures, e.g. cranes, moving platform pins, bridges, buildings, tanks, working at room temperature and reduced temperature. Their high strength makes it possible to reduce the total weight of the structure [6]. When welding this steel, a reduction in the mechanical properties in the heat affected zone (HAZ) can be observed. It is recommended to maintain the heat input up to 4.5 kJ/cm [7÷10].

Typical applications of DOCOL 1200 steel include advanced lifting devices, such as mobile cranes and mobile platforms, truck frames, passenger car bodies [5,6]. Table I summarizes the mechanical properties of S690 QL and DOCOL 1200M steel. Welding of both steel grades creates difficulties due to the possibility of delayed cracks, which is influenced by the martensitic structure dominating in both materials [11÷13]. Dissimilar joints create additional difficulties due to the difference in chemical and phase composition as well as different mechanical properties (Tables I and II).

Table I. Mechanical properties of S690QL and DOCOL 1200M steel [6]

Material	Yield strength YS [MPa]	Tensile strength UTS [MPa]	Relative elongation A_5 [%]
Steel DOCOL 1200M	950	1250	7
Steel S690 QL	690	900	15

Table II. Chemical composition of S690QL and DOCOL 1200M steel [6]

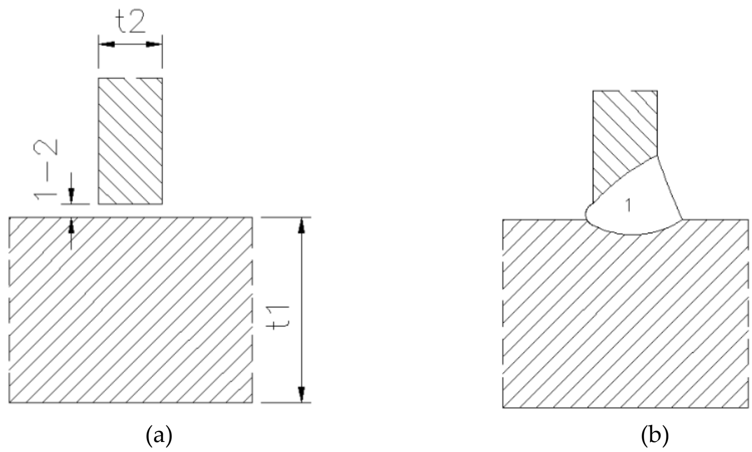
Material	Element [%]								
	C	Si	Mn	P+S	Ni	Al	Mo	Ti	Cr
DOCOL 1200M	0.11	0.2	1.7	0.012	0.1	0.041	0.05	0.025	–
S690 QL	0.19	0.8	1.7	0.019	2.1	0.015	0.72	0.05	<1.5

Steel grades DOCOL 1200M and S690QL are considered as difficult to weld due to the tendency to crack formation in the weld and in the HAZ, even with the use of preheating [11]. The higher carbon content in S690 QL steel significantly increases its strength, but also reduces plastic properties. Alloying additives, i.e. approx. 2% Ni and 0.7% Mo, are introduced to improve them. DOCOL steel has a high content of elements, i.e.: Al> 0.03% and Ti> 0.003%, which leads to a significant deterioration in the plastic properties of the weld. As a consequence, this promotes the appearance of cracks in the weld (less frequently observed in HAZ) [6]. In the case of S690 QL steel, the Ti content ten times higher than that considered as the threshold level in structural steels, can promote cracking, especially in combination with a high carbon content in this steel [6].

The tests included circumferential welding of thick-walled pin (ø40 mm, L = 40 mm) with a thin-walled arm of a mobile platform (g = 2 mm). Butt dissimilar welded joints (t_1 = 40 mm in S690 QL steel and t_2 = 2 mm in DOCOL 1200M steel) were made using the MAG welding method (135) in the downhand position (PA) according to the requirements of EN 15614-1. The shielding gas was a mixture: 82% Ar + 18% CO_2 and Ar (according to EN 14175), two different 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) were used. The chemical composition of filler materials is presented in table III. The preparation of materials for single-pass welding is shown in figure 1. Prior to welding, preheating was used to dry the components to the temperature of 50 °C.

Table III. Chemical composition of filler materials [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



(a) (b)

Fig. 1. a) shape of welding groove; b) weld geometry

Filler materials were selected due to the similar chemical composition to welded steels. Noteworthy is the addition of chromium in electrode wires, which is not introduced into DOCOL 1200M steel, but in S690 QL steel it is up to 1.5%. The electrode wires used differ mainly in the Ti content, which is characterized by high affinity for oxygen, nitrogen and carbon [6]. Similar welding values were used for both electrode wires.

In order to determine the proper value of the welding heat input with literature recommendations [6,7], tests of circumferential welding of the pin to the platform arm were carried out for three values of the welding speed: 20 mm/min, 30 mm/min and 40 mm/min. Other welding parameters in each test were adopted at the same level: the wire diameter was 1.0 mm, arc voltage 19 V, welding current 115 A. The DC source was connected with (+) on the electrode.

Welded joints were subjected to non-destructive (NDT) and destructive tests, such as:

- visual tests (VT) of welded joints were performed with an eye armed with a magnifying glass at 3× magnification – tests were performed according to the requirements of EN ISO 17638, evaluation criteria according to EN ISO 5817;
- magnetic particle tests (MT) – tests were carried out according to EN ISO 17638, tests were assessed according to EN ISO 5817, REM – 230 magnetic flaw test device was used;
- radiographic tests – tests were carried out according to EN ISO 15614-1. Type of radiation source – SMART 200;
- examination of the microstructure of specimens digested with Adler's reagent using a light microscope (LM);
- hardness measurement (HPO 250 hardness tester, HV10 method).

Research results

The results of non-destructive tests are presented in table IV. Heat input has a big impact on the correctness of the made mixed joint. No cracks in the weld were noted for the welding speed of 30 mm/min. Only for these connectors the quality level B according to PN EN ISO 5817 was obtained. The image quality was W18 according to EN ISO 19232-1.

Table IV. NDT assessment of mobile platform welded joints

Electrode wire	Welding speed 20 mm/min	Welding speed 30 mm/min	Welding speed 40 mm/min
UNION X90	Cracks in the weld	No cracks	Cracks in the weld
UNION X96	Cracks in the weld	No cracks	Cracks in the weld

Due to the result of non-destructive tests, only joints made with a welding speed of 30 mm/min were subjected to destructive tests.

Metallographic tests

Metallographic specimens were made for mixed joints made with both electrode wires (UNION X90 and UNION X96). The specimens were etched with Adler's reagent, observations were carried out on a Reichert light microscope. In both cases, the weld’s structure was very similar – martensite dominated. A typical structure of the MAG connector made with the use of UNION X90 electrode wire is shown in figure 2.

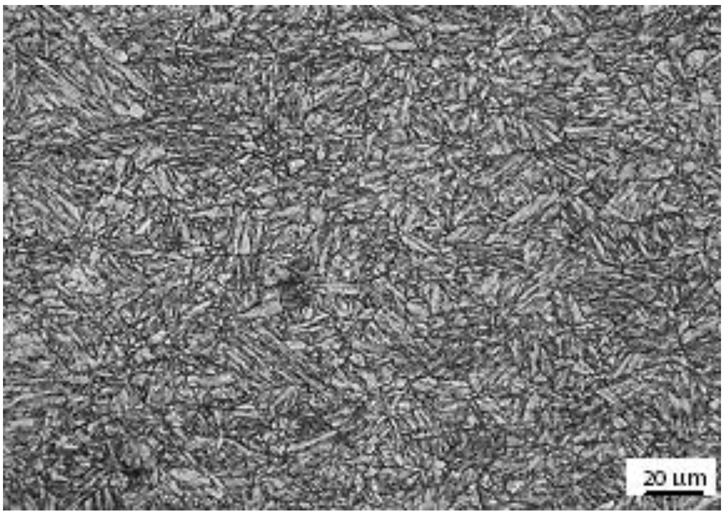


Fig. 2. Microstructure of welded joints with filler material Union X96

Hardness measurement

The hardness measurements in joints were carried out on metallographic specimens. The results are shown in table V.

Table V. Hardness distribution in dissimilar welded joints

Electrode wire	**DOCOL 1200M**			**S690 QL**	
	NM1	HAZ1	Weld	HAZ2	NM2
UNION X90	397	314	376	380	257
UNION X96	399	311	407	381	258

After comparing the results obtained, it can be stated that due to the similar hardness value of DOCOL 1200M steel and the heat affected zone on the S690 QL steel side, UNION X90 electrode wire is better for a given pair of materials. Uniform distribution of hardness throughout the entire welded joint promotes crack resistance. In this case, the hardness of the weld is similar to the hardness of the heat affected zone, which may be due to the lower content of alloying elements of the electrode wire such as C and Cr (Table III). The average weld hardness of 407 HV10 obtained with UNION X96 wire is too high and can cause joint breakage that occurs when using incorrect welding heat input (Table IV).

Summary

In civil engineering and transport, the demand for the use of mixed joints of high-strength steels with steels from the AHSS group is increasing. S690 QL steel and DOCOL 1200M steel are increasingly used materials for structures used in the construction of mobile platforms. The mixed joint of these steels is prone to welding cracks. In order to make the correct connection of the elements of the mobile platform, it is important to carefully select welding parameters. In addition to choosing the gas mixture, type of electrode wire and voltage parameters, it is important to determine the appropriate welding speed. In the first part of the study, mixed joints with a different heat input were made, which allowed to select the most appropriate value for it, at which no welding defects and incompatibilities were observed. The possibility of making the correct mixed joint has been confirmed by non-destructive testing. Then the weld's metallographic structure was assessed and hardness measurements along the joint were made. Non-destructive and destructive tests have shown that the most appropriate way to make a dissimilar joint from S690 QL steel with DOCOL 1200M steel is to use MAG welding as a mixture of protective gases Ar+18% CO_2, electrode wire UNION X90, which allows obtaining a joint without defects and welding incompatibilities and obtaining hardness on a comparable level in the entire joint, i.e. 380 HV10 on average.

Author Contributions: conceptualization A.S., B.S-L.; methodology T.W., A.J.; validation K.J.W.; formal analysis T.W., A.S.; investigation B.S-L, A.J; resources T.W.; data curation A.S., K.I.W.,; writing—original draft preparation T.W.; writing—review and editing B.S-L., T.W.; visualization A.J., K.I.W.; supervision T.W., A.J.; project administration, K.I.W.
Funding acquisition: The paper is part of the COST project, CA 18223
Conflicts of Interest: The authors declare no conflict of interest.

References

[1] Skowrońska B., Chmielewski T., Golański D., T. 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

[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. https://.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. https://.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., Selected properties of Plasma+MAG welded joints of 700 MC steel, *Welding Technology Review*, 2017, Vol. 89(10), 104-111. https://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*, 2019, Vol. 91(3), 23-30. https://doi.org/10.26628/wtr.v91i3.1043
[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). https://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. https://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] Tomków J., Janeczek A., Underwater In Situ Local Heat Treatment by Additional Stitches for Improving the Weldability of Steel, *Appl. Sci.*, 2020, Vol. 10(5), 1823. https://doi.org/10.3390/app10051823
[13] 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, https://doi.org/10.24425/123782