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WELDING OF PINS TO MOBILE PLATFORMS ARMS

Summary. There is an increasing demand for mixed joints made of hard-weldable steels used in the construction of transport means. An illustration of this is the welding of movable platform elements such as a pin to arm joints. The pin is made of high-strength structural steel S690 QL (1.8928) while the arm of the movable platform is made of DOCOL 1200M steel from the AHSS group (Advanced High-Strength Steel). Such a joint is not easy to make due to the different chemical composition of both steels. The difference in thickness of welded elements creates an additional difficulty. The thickness of the cylindrical pin is 40 mm, whereas the thickness of the sheet metal used for the platform arm is much smaller and amounts to 2 mm. Joints of varying thickness and chemical composition tend to produce cracks in the heat-affected zone as well as in the weld. The purpose of this article is to determine the most appropriate welding parameters

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and the selection of additional materials to obtain correct joint with good mechanical properties, free of welding defects and incompatibilities.
Keywords: civil engineering, transport, mobile platforms, welding

1. INTRODUCTION

In the construction of transport means, there is an increasing demand for welding of new steel grades, including mixed steel joints that support high structural strength [2,4,5,6,10,13]. An example of application of hard-welded mixed joints are elements of movable platforms. This article examines the possibility of making a correct mixed pin to arm joint of such a platform. High-strength steels from the AHSS group (for example, DOCOL 1200M steel) are used for the platforms' arms, whereas lower strength steels (for example, S690 QL steel) are used for the pins [11].

This article focuses on multi-material welding of thin-walled construction of movable platform arms with a pin of much greater thickness. The purpose of this paper is to select the most appropriate welding process parameters to ensure good mechanical properties of the mixed joint made of S690 QL and DOCOL 1200M steels used in the construction of mobile platforms.

2. MATERIALS AND METHODS

Steel S690 QL, from the group of high-strength steels, is increasingly used in civil engineering and transport due to its high strength and high yield strength. Those steels are primarily used for the loaded parts of welded structures, for example, crane elements, mobile platforms, tanks or for pins used in the construction of transport means. The use of S690 QL steel reduces the total weight of a transport vehicle structure. The tensile strength of this steel is high, at the level of 900 MPa, the yield strength is at 700 MPa and the relative elongation is at the level of 15% [11,12]. During the welding of this steel, a reduction of the mechanical properties of the joint compared to the parent material can be observed. Therefore, it is recommended to limit the linear energy during the welding process to the level of 4,5 kJ/cm [1,7,9,14].

DOCOL 1200 M steel from the AHSS group is characterised by very high strength, at the level of 1200 MPa and a yield strength of 950 MPa. DOCOL 1200 M steel has a twice lower relative elongation at a value of 7%. Typical applications of DOCOL 1200 M steel include advanced lifting equipment, mobile platforms as well as truck frames [11,12]. Table 1 presents the mechanical properties of S690 QL and DOCOL 1200M steels used for elements of moving platforms.

Tab. 1

Mechanical properties of S690 QL and DOCOL 1200M steels [11]

Steel	The yield point YS, MPa	Tensile strength UTS, MPa	Relative elongation A5,%
DOCOL 1200M	950	1250	7
S690 QL	690	900	15

DOCOL 1200M and S690QL steels are considered as difficult to weld due to appearing cracks in the weld (less often than in the heat-affected zone) [3]. Welding of both of these steel grades (separately and in mixed joints) produce difficulties due to the presence of a dominant martensitic structure in them [3,8,11]. Mixed joints create additional complications due to the differences in chemical composition and varied plastic properties. Table 2 presents the chemical composition of DOCOL 1200M and S690QL steel.

Tab. 2

Chemical properties of S690 QL and DOCOL 1200M steels [11]

Steel grade	C%	Si%	Mn%	P+S%	Ni%	Al%	Mo%	Ti%
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	0.050

The chemical composition of both steels is not similar. Furthermore, it is worth to note much higher carbon content present in S690 QL steel than in DOCOL 1200 M steel, which significantly increases its strength, however, worsening the plastic properties at the same time. To improve the plastic properties of S690 QL steel, an additional higher content of Ni and Mo shall be introduced.

It was decided to verify the possibility of proper circumferential welding of the thick-walled pin (40 mm high and 40 mm in diameter) made of S690 QL steel to the thin-walled arm of the mobile platform (with a thickness of 2 mm) made of DOCOL 1200M steel. Further, we resolved to produce welds with the use of MAG (Metal Active Gas) process testing the following gas mixture acting as a shielding gas: Ar + 18% CO_2 and Ar +10% CO_2 (according to the PN-EN 14175 norm).

The following electrode wires were selected: UNION X90 (EN ISO 16834-A G 89 6 M21 Mn4Ni2CrMo) and UNION X96 (EN ISO 16834-A G 89 5 M21 Mn4Ni2, 5CrMo), their chemical composition is presented in Table 3.

Tab. 3

Electrode wires used in the research - chemical composition [1]

UNION	C%	Si%	Mn%	P%	Cr%	Mo%	Ni%	Ti%
X90	0.10	0.8	1.8	0.010	0.35	0.60	2.3	0.005
X96	0.12	0.8	1.9	0.010	0.45	0.55	2.5	0.050

The chemical composition of both wires is similar; however, it differs slightly from the chemical composition of the welded steels. The parameters of peripheral welding of the pin to the platform arm with the use of both electrode wires were comparable. The diameter of the electrode wire was 1.0 mm, arc voltage 18 V and welding current 110 A. In both cases, three different peripheral welding speeds were verified: 25 mm/min, 35 mm/min and 45 mm/min. According to literature recommendations, the welding speed was changed three times to assess the linear energy that is most appropriate [11,14]. The source of a direct current was connected to (+) on the electrode, the thin-walled weld was single-stitched. Each time before the welding, pre-heating drying to the temperature of 70°C was applied.

In addition, a mixed testing joint of the tested sheets (DOCOL 1200 M and S690 QL) was made with a thickness of 3 mm, to analyse the strength and bending resistance. Similarly, as before, the diameter of the electrode wire was 1.0 mm, arc voltage 18 V and welding current 110 A. The weld was single-stitched. Furthermore, in this part of the study two different electrode wires: UNION X90 and UNION X96, as well as two various argon shielding mixtures: Ar + 18% CO_2 and Ar +10% CO_2 (according to PN-EN 14175 norm) were used. Each time before the welding, pre-heating drying to the temperature of 70°C was applied.

3. METHODS, SCOPE OF RESEARCH

The research included non-destructive testing (NDT):

- visual testing (VT) of prepared welded joints was done with the use of an eye armed with a magnifying glass at the magnification of 3× – test was done according to the PN-EN ISO 17638 norm, assessment criteria according to the EN ISO 5817 standard,
- magnetic particle testing (MT) - tests were carried out according to the PN-EN ISO 17638 norm, with assessment performed according to the EN ISO 5817 standard, using a magnetic flaw detector of REM-230 type,
- radiographic tests - tests were carried out according to the PN EN ISO 15614-1 norm. The type of radiation source was SMART 200.

Amongst the destructive tests, the following assessments of the researched pin to platform arm weld were performed:

- examination of the microstructure of specimens digested with the use of Adler's reagent and a light microscope (LM),
- hardness measurement (HPO 250 hardness tester, HV10 test method).

Additionally, for a mixed testing MAG joint made of the two 3 mm thick sheets, the following tests were carried out:

- tensile strength test using a machine (ZWICK 100N5A strength testing machine),
- bending test (ZWICK 100N5A strength testing machine).

4. RESULTS AND DISCUSSION

A mixed butt-type welded joint (BW) from S690 QL steel with the thickness of t1 = 40 mm and from DOCOL 1200 M steel with the thickness of t2 = 2 mm was made. MAG (135) welding method was applied in the down position (PA) according to the EN 15614-1 norm. The material preparation for single-stitched welding is presented in Figure 1.

To assess the weldability of the mobile platform components (pin and platform arm) two argon mixtures: 82% Ar-18% CO_2 and 90% Ar-10% CO_2 were selected to act as shielding gases, and the two electrode wires: UNION X90 and UNION X96 were applied. Each time before the welding, pre-heating drying to the temperature of 70°C was applied.

After welding, the following non-destructive tests (NDT) were carried out: visual (VT), magnetic-particle (MT) and radiographic.

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

Table 4 data shows that the type of shielding mixture, as well as the type of electrode wire and especially the type of linear energy, affect the quality of the produced joint. For all four cases tested, no cracks in the weld appeared only the welding speed was at the level of 35 mm/min. Those welds received the quality level B according to the PN EN ISO 5817 norm. The image quality was W18 according to the EN ISO 19232-1 norm. Non-destructive testing showed that the less oxidising argon mixture (90% Ar-10% CO_2) is more appropriate as its use allows to avoid cracks in welds made with a different speed than 35 mm/min.

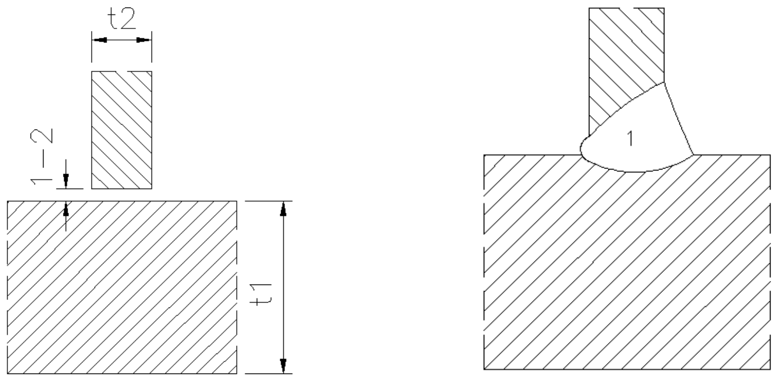

Fig. 1. (a) Groove shape; (b) Welding method

Tab. 4

Assessment of non-destructive testing of the movable platform joint

Shielding gas	Electrode wire	Welding speed 25 mm/min	Welding speed 35 mm/min	Welding speed 45 mm/min
90% Ar-10% CO_2	X90	No cracks	No cracks	Cracks in the weld
90% Ar-10% CO_2	X96	Cracks in the weld	No cracks	No cracks
82% Ar-18% CO_2	X96	Cracks in the weld	No cracks	Cracks in the weld
82% Ar-18% CO_2	X96	Cracks in the weld	No cracks	Cracks in the weld

4.1. Results of destructive testing

For further testing, only joints made with the welding speed of 35 mm/min were considered. Joint hardness distribution was carried out as well. The results are presented in Table 5.

Tab. 5

Hardness distribution in a mixed joint

Wire	Gas mixture	DOCOL 1200M	HAZ-1	Weld	HAZ-2	S690 QL
UNION X90	90% Ar-10% CO_2	395	317	376	386	256
UNION X96	90% Ar-10% CO_2	396	315	407	384	259
UNION X90	82% Ar-18% CO_2	398	312	381	380	257
UNION X96	82% Ar-18% CO_2	398	310	413	381	258

Analysing the data from Table 5, it can be noted that the electrode wire UNION X90 is more appropriate due to the similar hardness value in the whole joint (below 400 HV). Similar hardness in the entire welded joint promotes cracks resistance. The use of UNION X96 electrode wire is less advantageous. The increased content of C and Cr in the wire increases the hardness of the weld exceeding the value of 400 HV. The weld hardness at the level of 413 obtained with the use of UNION X96 electrode wire is too high and may cause joint cracks that occur when the welding energy is not selected properly (Table 4). At the same time, it was observed that the mixture of 90% Ar-10% CO_2 is the most suitable to act as a shielding gas. The weld made in the shield of 82% Ar-18% CO_2 characterises with a higher hardness, which might be a result of numerous and larger non-metallic oxide inclusions in the weld metal due to the more oxidative nature of the shielding mixture [11].

4.2. Strength tests

To obtain additional information regarding the correctness of the joint, it was decided to perform tensile strength tests. For this purpose, an additional mixed joint made of other sheets (DOCOL 1200M and S690 QL) with a thickness of 3 mm was carried out.

The MAG (135) welding method was applied again in the down position (PA) and according to the requirements of the EN 15614-1 norm. Once the joints welded with various parameters were completed, tests of immediate tensile strength were performed. Joint strength tests were carried out on the ZWICK 100N5A strength testing machine. The results of the mechanical tests of the welds: S690 QL/DOCOL 1200M (an average of three measurements) are presented in the Tables 6-7.

Tab. 6

Mechanical properties of the mobile platform joint (mixed jointS690 QL /DOCOL1200M)

Welding types	Electrode wire	Shielding gases	R_m, MPa	R_e, MPa	A_5, %
S690 QL / DOCOL 1200M	Union X90	90% Ar-10% CO_2	719	562	7.3
S690 QL / DOCOL 1200M	Union X96	90% Ar-10% CO_2	741	589	6.9
S690 QL / DOCOL 1200M	Union X90	82% Ar-18% CO_2	723	567	7.2
S690 QL / DOCOL 1200M	Union X96	82% Ar-18% CO_2	745	591	6.8

The analysis of the array data shows that the connectors were correctly made. The best plastic properties were obtained for the joint created with the use of Union X90 electrode wire and the shielding gas mixture containing 90% Ar-10% CO_2. Union X96 wire supports greater joint strength, but at the cost of plastic properties deterioration. The highest relative elongation value of the mixed joint was obtained when welding with the use of MAG method, Union X90 electrode wire and the gas mixture 90% Ar-10% CO_2.

Afterwards, the bending test of the created joints was performed. For the test, a sample with a thickness of a = 3 mm, width of b = 20 mm, mandrel of d = 22 mm and support spacing of d + 3a = 31 mm was used, the required bending angle was at the level of 180°. Five bending measurements were carried out both on the face side and on the root side of the weld.

Those joints that obtained the best plastic properties (with the use of UNION X90, UNION X96 electrode wires and 90% Ar-10% CO_2 and 82% Ar-18% CO_2 gas mixtures) were subjected to the bending test. The tests results are summarised in Table 7.

The analysis of Table 7 shows that the joints were correctly made. No cracks or other incompatibilities were found in the tested samples. However, cracks were observed in the joints from the root of the weld side where the Union X96 electrode wire was used.

Tab. 7

Mixed joints bending test results

Welding types	Side deformation	Side deformation	Size [mm]	Comments
Union X90	90% Ar-10% CO_2	Root of the weld	3 x 20	No cracks, no incompatibilities
Union X90	90% Ar-10% CO_2	Face of the weld	3 x 20	No cracks, no incompatibilities
Union X90	82% Ar-18% CO_2	Root of the weld	3 x 20	No cracks, no incompatibilities
Union X90	82% Ar-18% CO_2	Face of the weld	3 x 20	No cracks, no incompatibilities
Union X96	90% Ar-10% CO_2	Root of the weld	3 x 20	Cracks in weld
Union X96	90% Ar-10% CO_2	Face of the weld	3 x 20	No cracks, no incompatibilities
Union X96	82% Ar-18% CO_2	Root of the weld	3 x 20	Cracks in weld
Union X96	82% Ar-18% CO_2	Face of the weld	3 x 20	No cracks, no incompatibilities

4.3. Metallographic examination

The microstructure analysis was performed next. Similarly, the structure of those mixed joints that presented the best relative elongation was analysed. The microstructure of the cross-section of the S690 QL/DOCOL 1200M joint is presented in Figure 2.

Observations of specimens digested in the Adler's reagent were performed on the Reichert light microscope. A typical structure of the pin to arm joint made with the use of UNION X90 electrode wire and in the shielding mixture of 90% Ar-10% CO_2 is shown in Figure 2.

The results of the structural tests indicate that in the pin to arm platform weld, martensitic and fine-grained ferrite structures dominate. The results of all the tests presented in this article were positive, confirming that the selected UNION X90 electrode wire, the gas mixture 90% Ar-10% CO_2 and the selected welding parameters are correct (U = 18 V, I = 110 A, v = 35 mm/min).

5. CONCLUSION

In the construction of transport means, there is an increasing demand for the use of mixed joints made of high-strength steels with steels from the AHSS group. Steels S690 QL and DOCOL 1200M are increasingly used to construct mobile platforms structures. Mixed joints created from those steels are prone to welding cracks. This article presents the selection of welding parameters to welding the pin (S690 QL steel) to movable platform arms (DOCOL 1200M steel). Apart from an appropriate selection of gas mixture, type of electrode wire and voltage parameters, it is important to determine the appropriate welding speed. During the first part of the study, mixed joints made with different linear energy were performed, promoting the selection of the most appropriate welding speed (v = 35 mm/min) which did not produce welding defects and incompatibilities. The possibility of making correct mixed joints was confirmed by non-destructive and destructive tests. Furthermore, the tests showed that the most appropriate way to make a mixed joint from S690 QL steel (used for the pin) with DOCOL 1200M steel (used for the platform arm) is the application of the protective gas mixture 90% Ar-10% CO_2 with a UNION X90 electrode wire during the MAG welding. Those parameters produce joints without welding defects and incompatibilities and promote comparable hardness of 380 HV on the entire joint. The strength of the mixed joint obtained with such parameters is high, at the level of 720 MPa. The change of argon gas mixture to a mixture with a higher CO_2 content (introduction of additional oxygen to the weld metal) and the change of electrode wire (which increases the content of Fe and Cr in the weld metal) leads to an increase in the strength of the joint and at the same time to a decrease in its plastic properties.

Further, the metallographic structure of the weld (made of Union X90 electrode wire in the shielding gas mixture of 90% Ar-10% CO_2) was assessed, with dominating martensitic structure and a fine-grained ferrite. This leads to the conclusion that the welding parameters should be carefully selected to avoid cracks and other welding defects and incompatibilities.

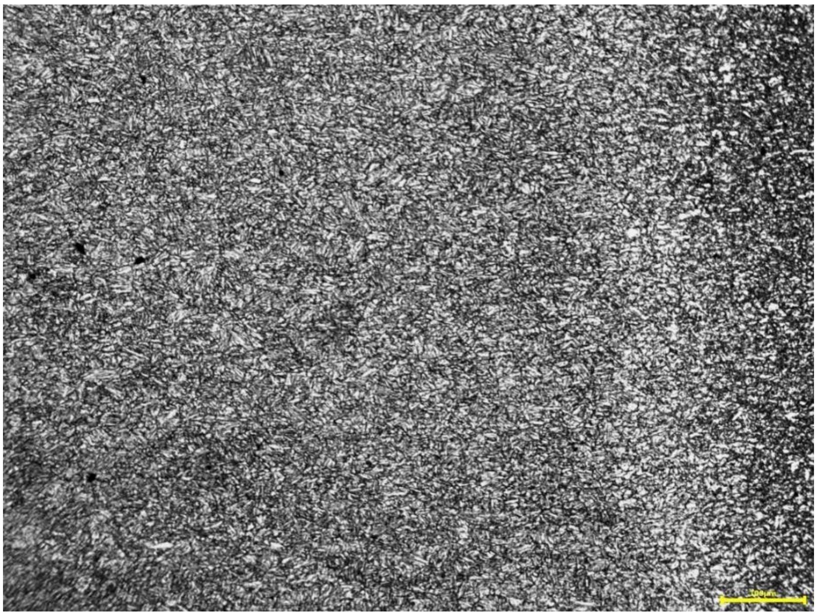

Fig. 2. The structure of the mixed joint made of Union X90 electrode wire in the shielding gas mixture of 90% Ar-10% CO_2. Martensite and fine-grained ferrite are the dominant phases in the weld

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