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**WELDING OF MOBILE PLATFORM ELEMENTS MADE FROM
MIXED GRADES OF HIGH-STRENGTH STEELS**

Summary. In the mobile platform structure, there is an increasing necessity to weld steels from the various groups. For instance, it has become necessary to connect AHSS (Advanced High-Strength Steel) with fine-grained steels. This article verifies the possibility of obtaining accurate mixed welded joints from different grades of DOCOL 1400 steel (from the AHSS group) with S700 MC steel (from the fine-grained steel group). The structure, quality and mechanical properties of the obtained welded joints were thoroughly analysed. The joints were made at various welding speed with preheating to 80°C and without preheating.

Keywords: civil engineering, transport, mobile platforms, welding

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1. INTRODUCTION

In the automotive industry, mixed joints made of AHSS steel and fine-grained steel play an important role [1, 2]. High-strength AHSS steels find increasing use in civil engineering and automotive industry due to their high tensile strength at the level of around 1300 MPa [3-5]. This article presents the results of tests designed for proper selection of welding parameters of mobile platforms thin-walled structure elements made of tested steel grades (DOCOL 1400M and S700 MC). It was decided to create mixed AHSS/fine-grained steel joints using the MAG process with various welding parameters [6]. Welding of AHSS steel with fine-grained steel is not widely presented in technical literature. The possibility to weld correct and repeatable AHSS/fine-grained steel mixed joints could affect new design constructions and usage of mobile platforms with increasing lifting capacity and working range. The joints were made at a various welding speed from 300 to 400 mm/min. Mixed welds with preheating to 80°C and without preheating, were made.

2. RESEARCH MATERIALS AND WELDING PARAMETERS

From the available AHSS materials, two grades were selected (Tab. 1) and combined with a non-alloy steel S355J2. The welded steel grades differ significantly due to their chemical composition (Tab. 1). Steels from the AHSS group are typically considered as difficult to weld because of cracks that appear in the weld and in the heat-affected zone after the welding [7-10]. Generally, high strength steels are not considered as a well-weldable.

Tab. 1

Chemical composition of selected steel grades [10]

Steel grade	C%	Si%	Mn%	P%	S%	Al%	Ni%	Ti%
Docol 1400M	0.11	0.20	1.70	0.01	0.002	0.04	-	0.025
S700MC	0.12	0.1	2.1	0.025	0.01	0.015	0,09	0.15

For metallurgical reasons, it should be noted that both steel grades differ in the content of Al, Ti, Nb, which affects the strength of the structure. The introduction of these elements into the weld deteriorates their plastic properties, which can be measured by relative elongation. In welding AHSS and fine-grained steel, it is recommended to limit the linear energy during welding to 5 kJ/cm level [4, 5, 7]. The weldability of mixed joints has not been sufficiently investigated yet and there is scarce literature information on it, especially regarding its use in the structure of the transport and civil engineering means. It can be assumed that these steels should be welded with low oxygen and low nitrogen methods [8, 9]. New technologies such as micro-jet cooling have not been tested so far for high-strength steels (neither AHSS nor fine-grained) [9]. During the welding of low-alloy steels, micro-jet cooling is employed with an increasing frequency to control the structure and enhance the plastic properties of the joint. It can be assumed that micro-jet cooling would be used in welding high-strength steels [10].

3. PREPARATION OF SAMPLES FOR TESTING

MAG mixed welded joints were made using the following steel grades: DOCOL 1400M with S700 MC. Significant differences in the chemical composition of the selected steel grades affect the structure, weldability and mechanical properties of the joint. Main mechanical properties of the tested steels are presented in Tab. 2.

Tab. 2

AHSS steels used to build mobile platforms - mechanical properties [10]

Steel grade	The yield point YS [MPa]	Tensile strength UTS [MPa]	Elongation A5 [%]
Docol 1400M	1150	1380	6
S700MC	700	1050	8

It is worth highlighting the vast difference in strength and yield strength for both material groups. It was decided to make mixed joints using electrode wires: Union X96. The chemical composition of the wire is presented in Tab. 3.

Tab. 3

Electrode wire UNION X96 - chemical composition [10]

C%	Si%	Mn%	P%	Cr%	Mo%	Ni%	Ti%
0.12	0.87	1.89	0.010	0.29	0.46	3.3	0.005

The chemical composition of the wire is not quite similar to welded steels. Noteworthy, it has at least four times higher silicon content in wire than in steel, which increases strength. In addition, chromium was introduced with a relatively high content of 0.45%, which greatly increases strength, but also reduces the impact toughness of the joint. To improve the plastic properties of the joints, nickel (2.45% Ni) and molybdenum (0.65% Mo) were introduced into the weld. Nickel delivered to the weld metal with 2% content and molybdenum introduced to the weld metal with 0.5% content, significantly increases the impact toughness of the joint at negative temperatures. For joints made of the C-Mn low alloy steel, these two elements introduced into the weld metal guarantee an impact strength of 50 J at -40°C, which meets the 4th impact class. Similarly, in AHSS and fine-grained steel mixed joints of two elements significantly should improve the plastic properties.

The steel welding parameters were as follows: the diameter of the electrode wire was 1 mm, the arc voltage was 20 V and the welding current was 118 A. The welded sheets had dimensions of 400×50×3 mm and the weld was of single stitch type. In the MAG process, a gas mixture of 82% Ar-18% CO₂ was selected to act as shielding gases. The shielding gas flow rate was at a level of 14 l/min. A 3 mm thick (single stitch) welded butt joint (BW) was made (KT sample). The welding process was applied in the down position (PA) and according to the requirements of the EN 15614-1 norm.

The joints were made at various speeds of 300, 350 and 400 mm/min, respectively. Joints with preheating to 80°C and without preheating were made for each tested welding speed.

4. METHODS (SCOPE OF RESEARCH)

The scope of this research included non-destructive testing (NDT):

- visual tests (VT) of welded joints were made with the eye fitted with a magnifying glass at 3x magnification - the test was performed according to the PN-EN ISO 17638 standard and the assessment criteria according to the EN ISO 5817 norm,
- magnetic-powder tests (MT) - the tests were carried out in accordance with the PN-EN ISO 17638 standard and the assessment criteria according to the EN ISO 5817 norm using a magnetic flaw detector device type REM - 230.

The destructive tests included:

- the tensile tests were carried out in accordance with the PN-EN ISO 4136:2013-5 standard, using a ZD-40 strength testing machine,
- the bending tests were carried out in accordance with the PN-EN ISO 5173 standard, using a ZD-40 strength testing machine,
- examinations of the microstructure of the samples were investigated on a light microscope (LM).

5. RESULTS AND DISCUSSION

The results of the non-destructive testing are presented below.

Visual inspection of sheets with a thickness of 3 mm was carried out using standard auxiliary equipment: 3x magnifiers and a lux meter with a white light of 520 Lx. It was found that the welds were made correctly, met the quality requirements and were characterised by the acceptability limit "B" according to the PN EN ISO 5817 norm. The magnetic-powder test for sheets with a thickness of 3 mm was made using the wet method at the following conditions: field strength 3 kA/m, white light 515 Lx, temperature 20°C, detection means MR -76, contrast MR -72. The results of the magnetic-powder tests are presented in Tab. 4.

Tab. 4

Results of the magnetic-powder tests

Speed [mm/min]	Preheating [°C]	Detected implications	Test results
300	without	small cracks were observed	negative
300	80	small cracks were observed	negative
350	without	small cracks were observed	negative
350	80	improper surface indications were not detected	positive
400	without	small cracks were observed	negative
400	80	improper surface indications were not detected	positive

Table data shows that pre-heating is strongly required for the proper welding of DOCOL 1400M with S700 MC steel. After assessing the joints with non-destructive tests, it was decided to the tensile strength of the welded platform elements. Welding speed of 300, 350 and 400 mm/min was also tested (process with preheating and without preheating). A speed of 300 mm/min cannot be considered as appropriate for welding the tested joint due to welding defects. The welding speed should be in the range of 350-400 mm/min. A preheat temperature of 80°C was accepted as sufficient.

For further (destructive) tests, only positive joints (made with preheating and welding speed in the range of 350-400 mm/min) were considered. In addition, the destructive strength test was carried out on the ZWICK 100N5A strength testing machine. The results of the tensile test of the welds are presented in Tab. 5.

Tab. 5

Mechanical properties of the mobile platform joint (mixed joint S700 MC/Docol 1400M)

Welding speed [mm/min]	YS [MPa]	UTS [MPa]	A ₅ [%]
350 mm/min	684	992	5.9
400 mm/min	679	984	5.7

The analysis of the array data shows that the connectors were made correctly. The strength of all joints is at a similar level. The highest relative elongation value of the mixed joint was obtained when welding with the use of MAG method, preheating 80°C, welding speed 350 mm/min. Thereafter, the bending test of the created joints was performed. For the test, a sample with 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 test measurements were carried out both on the face side and on the root side of the weld. The same joints were subjected to the bending test. The tests results are summarised in Tab. 6.

Tab. 6

Mixed joints bending test results

Welding speed [mm/min]	Side deformation	Size [mm]	Bending angle [°]	Comments
350	root of the weld	3 × 20	180	no cracks, no incompatibilities
350	face of the weld	3 × 20	180	no cracks, no incompatibilities
400	root of the weld	3 × 20	180	no cracks, no incompatibilities
400	face of the weld	3 × 20	180	no cracks, no incompatibilities

The analysis of Tab. 7 shows that the joints were made correctly. No cracks or other incompatibilities were found in the tested samples. Afterwards, microstructure analysis was performed. Similarly, the structure of those mixed joints that ensured the best relative elongation was analysed. The microstructure of the cross-section of the S700 MC/Docol 1400M weld is presented in Fig. 1.

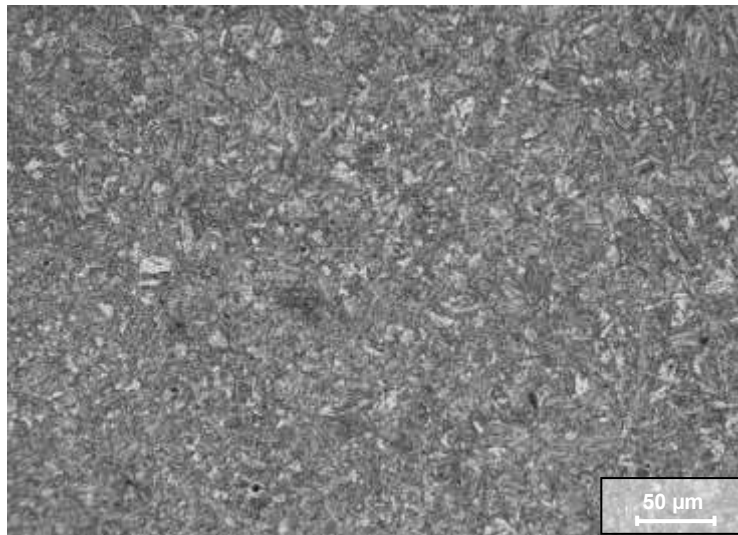


Fig. 1. Structure of the S700 MC/Docol 1400M weld (after preheating, welding speed 350 mm/min)

The dominant area with martensitic structure, bainite and ferrite is shown (Fig. 1). All analysed welds were made correctly, the metallography observation result was positive and confirm good properties of obtained joints by the selected parameters.

5. CONCLUSION

Hard to weld AHSS steel and fine-grained steel are materials with increasing use in the construction of transport means as a result of its high strength. It was decided to verify the MAG welding process of the thin-wall structure of mobile platform elements with a thickness of 3 mm made of AHSS steel (Docol 1400M, with S700 fine-grained steel). Joint strength test, bending test and metallography structure observations were executed. The most favourable welding parameters were selected (preheating and welding speed). Based on the performed research, the following conclusions were deduced:

1. It is possible to create correct and repeatable joints made of two different grades of AHSS steel and fine-grained steel.
2. The strength of mobile platforms elements' joints made of AHSS and fine-grained steel grades is at the required level of 900 MPa.
3. The electrode wire UNION X96, shielding gas mixture of 80% Ar-18%, preheating before welding up to 80°C, welding speed in the range of 350-400 mm/min provides the most preferred plastic properties of a joint during the MAG welding.

4. Bending test, structure testing, as well as non-destructive tests, confirmed the possibility of correct mixed welding elements of the mobile platform elements.

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