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MAG Welding of Structures Used in Means of Transport and Made of Steel DOCOL 1200M

Abstract: Steels of the DOCOL group, characterised by high tensile strength and yield point, play an important role in the manufacturing of means of transport. However, the above-named steels are difficult to weld and joints made in them do not guarantee comparable mechanical properties. The research work discussed in the article aimed to determine process parameters suitable for the welding of a moving platform made of steel DOCOL 1200M as well as to assess the effect of welding parameters on the quality of obtained joints. The tests also involved analysing the effect of shielding gases, preheating and interpass temperature on the quality of an 8 mm thick MAG welded moving platform structure.

Keywords: civil engineering, transport, means of transport, DOCOL steels

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Introduction

The article presents results of tests aimed to adjust MAG process parameters enabling the welding of plates made in steel DOCOL 1200M (belonging to the group of advanced high-strength steels (AHSS)), used in the production of moving platform elements.

Because of its high strength (1200 MPa), steel DOCOL 1200M is enjoying growing popularity in civil engineering as well as in the production of means of transport. However, one of the primary disadvantages of the steel is its low relative elongation (6%) resulting from the dominant martensitic structure, favouring the formation of welding cracks [2–4]. To reduce welding stresses, it is recommended to limit linear energy during welding to 4 kJ/cm [5–6]. Thin-walled structures made of steel DOCOL 1200M do not require bevelling and are welded using UNION X90 or UNION X96 filler metal wires. Shielding gases used in the welding process include CO_2 as well as mixtures of argon with carbon dioxide or with oxygen [7–9]. Preheating is recommended in relation to thick-walled structures. However, no explicit welding process-related guidelines have been developed for 6 mm, 8 mm and 10 mm thick plates made of steel DOCOL 1200M. Important aspects may include the manner of the bevelling of plates, welding sequence-related current-voltage parameters, types of electrode wires and shielding gases as well as welding rates [10–12]. The

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research work discussed in the article involved the making of a proper joint in steel 8 mm thick DOCOL 1200M used in the production of moving platform structures. The welding process was performed using various shielding gases under various temperature-related welding conditions (preheating, interpass temperature).

Test materials

Steel DOCOL 1200M, dominated by the martensitic structure, belongs to steels which are considered as difficult to weld because both the weld and the heat affected zone are susceptible to the formation of welding cracks. The primary welding issue of steel DOCOL 1200M is the significantly lower tensile strength of the joint than that of the base material and even less favourable plastic properties [13]. Table 1 presents the mechanical properties of steel DOCOL 1200M in the as-received state.

Table 1. Steel DOCOL 1200M and its mechanical properties [13]

Yield point R_e, MPa	Tensile strength R_m, MPa	Elongation A_5, %
730	1190	6.1

The analysis of the above-presented data (Table 1) indicates that, because of its high tensile strength (significantly higher than that of other low-alloy steels) steel DOCOL 1200M can be very useful in the making of moving platforms. The use of steel DOCOL 1200M could enable the extension of the operational range of the platform and make it possible to increase its carrying capacity without increasing the weight of the vehicle. The high strength properties of steel DOCOL 1200M (in comparison with those of other low-alloy steels) result from its chemical composition, i.e. significantly higher contents of titanium and aluminium than in unalloyed steels used in civil engineering and in the manufacturing of means of transport. The chemical composition of steel DOCOL 1200M (Table 2) makes it possible to increase tensile strength without compromising acceptable plastic properties.

Another important aspect of steel DOCOL 1200M is its very low sulphur content, translating into increased toughness [13] (Table 2). The weldability of steel DOCOL 1200M was assessed on the basis of an 8 mm thick plate used in the making of elements of a moving platform.

The tests involved the making of MAG (Metal Active Gas) welded joints using CO2 or 98% Ar+2% O2 and 82% Ar+18% CO2 as shielding gases and a UNION X96 (EN ISO 16834-A G 89 6 M21 Mn4Ni2CrMo) filler metal wire. During the tests, attention was paid primarily to the effect of the shielding gas (mixture), preheating and interpass temperature on the quality of the MAG welded joint. The chemical composition of the filler metal wire is presented in Table 3.

The chemical composition of the wire was intentionally not the same as that of the base material (dominated by the martensitic structure). The UNION X96 electrode wire contained chromium and a higher silicon content to increase the strength of joints. The wire also contained nickel and molybdenum to improve plastic properties of joints. It follows that some chemical elements are responsible for the fine-grained structure in materials subjected to plastic working (e.g. steel subjected to rolling), whereas others are responsible for the

Table 2. Steel DOCOL 1200M – chemical composition [14]

Steel grade	C%	Si%	Mn%	P%	S%	Al%	Nb%	Ti%
DOCOL 1400M	0.15	0.20	1.30	0.008	0.001	0.045	0.009	0.021

Table 3. Filler metal wire UNION X96 – chemical composition [8]

Wire grade	C%	Si%	Mn%	S%	Cr%	Mo%	Ni%	Ti%
UNION X96	0.1	0.8	1.8	0.001	0.45	0.65	2.45	0.007

fine-grained structure in castings; the weld is a cast material, not subjected to plastic working. The very low content of sulphur (approximately 0.001%) in the steel and in the wire aims to provide the most favourable plastic properties.

Before welding, the 8 mm thick plates were subjected to bevelling (Fig. 1). Dimension a (distance between the plates) and b (threshold) were determined experimentally. An 8 mm thick test joint was made using the 98%Ar+2%O2-shielded welding process. The initial experimental test results revealed that the most favourable results of the welding process were obtained in relation to a = 1.5 mm and b = 2 mm.

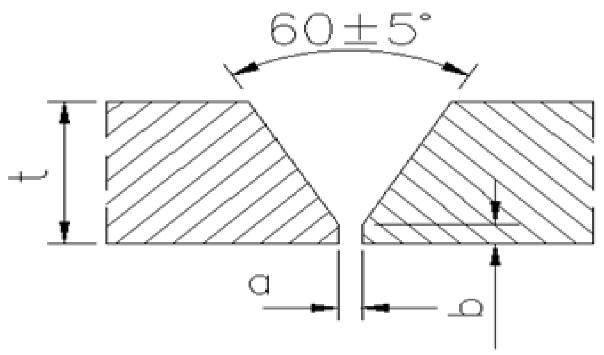

Fig. 1. Bevelling of the plates made of steel DOCOL 1200M [individual study]

The welding process parameters included an arc voltage of 18 V (in relation to the first root run) and a welding current of 115 A. The diameter of the UNION X96 filler metal wire amounted to 1.0 mm. The welding rate applied when making the first layer amounted to 300 mm/min. The weld was made in six runs. The subsequent layers were made using higher current-voltage parameters (for deeper penetration). The parameters are presented in Table 4.

Table 4. Parameters used in the making of the subsequent layers of the joint in steel DOCOL 1200M [individual study]

Layer number (from the root side)	Arc voltage, V	Current, A	Welding rate, mm/min
first layer	18	115	300
second layer	20	220	330
layers nos. 3–6	22	240	360

The tests involved the making of joints without preheating and with preheating to a temperature of 120°C. Interpass temperature values tested during the deposition of the subsequent layers amounted to 150°C, 170°C and 190°C.

Testing methods

The quality of the joint was tested in relation to the type of shielding gas (mixture) and welding-related temperature conditions (preheating temperature and interpass temperature). The joints obtained using the CO2–shielded (and next 82%Ar+18%CO2 and 98%Ar+2% O2-shielded) MAG welding method were subsequently subjected to the following non-destructive tests (NDT):

- aided eye visual tests (VT) of the welded joints performed using a magnifying glass (a magnification of 3×) and following requirements of the PN-EN ISO 17638 standard; assessment criteria were in accordance with EN ISO 5817,
- magnetic particle tests (MT) performed using an REM-230 magnetic defectoscope; the tests were performed and their results were assessed in accordance with the above-named standards.

The analysis of the non-destructive test results enabled the selection of joints for the subsequently performed immediate tensile strength tests. The strength of the joints was determined using an INSTRON 3369 testing machine.

The structure of the specimens was tested using a light microscope (LM) (LECO). The specimens not containing welding imperfections were qualified for impact strength tests, performed in accordance with the PN-EN ISO 9016 2021 standard.

The test results enabled the adjustment of process parameters used during the welding of joints in 8 mm thick plates made of steel DOCOL 1200M.

Test results and analysis

The results of the macroscopic (unaided eye) visual tests and of the magnetic particle tests of the moving platform joints are presented in Table 5.

Table 5. Results of the non-destructive tests of the moving platform joints [individual study]

Shielding gas	Welding without preheating	Welding with preheating to 120°C, interpass temperature:		
		150°C	170°C	190°C
Ar+18% CO_2	cracks in the welds and HAZ	lack of cracks	lack of cracks	cracks in the welds
CO_2	cracks in the welds and HAZ	cracks in the welds and HAZ	cracks in the welds and HAZ	cracks in the welds and HAZ
98% Ar-2% O_2	cracks in the welds and HAZ	lack of cracks	lack of cracks	cracks in the welds

The data contained in the above-presented Tables revealed that the CO2–shielded process failed to produce positive results as both the weld and the HAZ contained cracks. The tests also involved the use of two argon-based shielding gas mixtures (with carbon dioxide and with oxygen). Both mixtures enabled the obtainment of positive tests results. It was ascertained that the proper welding of the 8 mm thick plates made in steel DOCOL 1200M required preheating at a temperature of 120°C. A preheating temperature of 120°C was recognised as sufficient as the joints did not contain any cracks. At the same time it was noticed that interpass temperature should not exceed 170°C. The joints made using a preheating temperature of 120° C and an interpass temperature of 190°C contained cracks. Further destructive tests (immediate tensile strength, toughness) only included the joints subjected to preheating at a temperature of 120°C and made using an interpass temperature of 170°C. The strength of the joints, measured using an INSTRON 3369 testing machine, is presented in Table 6. The averaged immediate tensile strength results were based on three tests.

Table 6. Strength of the joint made of steel DOCOL 1200M (preheating to 120°C, interpass temperature of 170°C) [individual study]

Shielding gas	R_e [MPa]	R_m [MPa]	A_5 [%]
98%Ar+2%O_2	531	717	6.0
Ar+18%CO_2	522	706	6.1

The data presented in Table 5 reveal the obtainment of high strength Rm and acceptable relative elongation A5, corresponding to that of the base material. Slightly higher strength was characteristic of the Ar+2%O2-shielded MAG-welded joints. In turn, higher relative elongation was observed in the Ar+18%-CO2-shielded joint. The analysis of information presented in reference publication [8] and the comparison of the aforesaid information with the test results indicated that the differences in

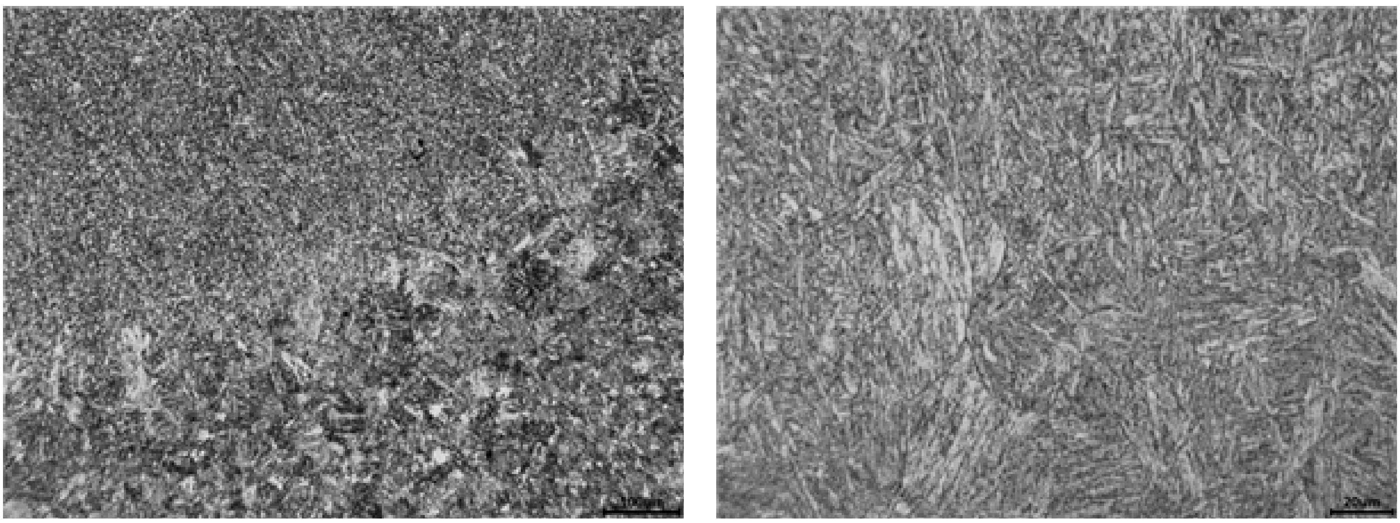

Fig. 2. Dominant martensite and fine-grained ferrite in the MAG weld near the fusion line; shielding gas mixture: Ar+18% CO_2; etchant: Nital) [individual study]

the mechanical properties of both joints could probably be ascribed to the content of oxygen in the weld deposit. In accordance with information contained in reference publication [8], the more oxidising mixture should enable the obtainment of weld deposit containing more oxygen (up to approximately 500 ppm) [8], which, in turn, should determine the morphological variety of ferrite. Appropriate ferrite varieties, characterised by finer grains, provide more favourable plastic properties. In the case under discussion, the tests were limited to observations of the joint microstructure. The tests involved cross-sectional metallographic specimens previously subjected to etching in Nital.

The results of the microscopic observations of the joints made using two different shielding gas mixtures, a preheating temperature of 120°C and an interpass temperature of 170°C are presented in Figure 2.

The specimens subjected to the Ar+18% CO2 and Ar +2% O2-shielded MAG welding process contained the dual-phase structure with dominant martensite and fine-grained ferrite (affecting the plastic properties of the joint). The dominant martensitic structure makes the joint potentially susceptible to crack formation. The macrostructural analysis and the microscopic tests did not reveal the presence of any defects or welding imperfections.

The final stage of the non-destructive tests was concerned with the toughness of the joint at a temperature of –40° C. The specimens selected (on the basis of NDT results presented in Table 5) for the determination of impact energy were free from cracks and made using:
– Ar+18%CO2 mixture, preheating to a temperature of 120°C and maintaining an interpass temperature of 170°C,
– Ar+2%O2 mixture, preheating to a temperature of 120°C and maintaining an interpass temperature of 170°C.

The dimensions of the specimen used in the impact strength tests were 7.5 mm × 10 mm × 55 mm (in accordance with PN-EN ISO 9016 2021). The averaged impact strength test results (based on five measurements) are presented in Table 7.

Table 7. Impact energy [individual study]

Shielding gas	***KV, J (at -40°C)***	**Fracture**
Ar+18%CO_2 mixture	77	mixed: plastic-brittle
Ar+2%O_2 mixture	68	mixed: plastic-brittle

The analysis of the data contained in Table 6 revealed that the satisfaction of the criterion of the fourth toughness class (assuming that impact energy at a temperature of -40°C should amount to a minimum of 47 J) was satisfied with a significant margin. The impact strength tests revealed that the use of the Ar+18% CO2 shielding gas mixture enabled the obtainment of more favourable results than those obtainable using the Ar+2% O2 mixture.

Summary

In spite of being difficult to weld, steels from the DOCOL group are becoming increasingly popular in civil engineering and in the production of means of transport. The tensile strength of the above-named steels is significantly higher than that of the welded joint. A significant welding-related problem is the obtainment of plastic properties of joints made steel DOCOL 1200M comparable with those of the base material. The article discusses the adjustment of parameters enabling the welding of thick-walled structures made of steel DOCOL 1200M and the obtainment of proper and repeatable joints characterised by elongation comparable with that of the base material (6%). The macroscopic tests of the joints did not reveal the presence of welding imperfections. In addition, the joints were characterised by high toughness. The tests also revealed that the obtainment of proper joints in 8 mm thick plates made of steel DOCOL 1200M required preheating up to a temperature of 120°C and maintaining interpass temperature not exceeding 170°C. The tests were also focused on the effect of various shielding gases (mixtures). The tests revealed that carbon dioxide is useless in the MAG welding of an 8 mm thick moving platform structure, yet it can be successfully applied when welding thin-walled (particularly 2 mm and 3 mm thick) structural elements made of the same steels. The use of the Ar+2% O_2 shielding gas mixture makes it possible to obtain slightly higher joint strength. In turn, the use of the Ar+18% CO_2 mixture leads to the obtainment of more favourable plastic properties, demonstrated by a relative elongation of 6.4%. The structural analysis revealed that the dual-phase structure was dominated by martensite. The presence of the second (ferritic) phase was responsible for plastic properties. The impact strength tests revealed that the use of Ar+18%CO_2 mixture enabled the obtainment of higher toughness, leading to the conclusion that the welding of thick-walled structures made of steel DOCOL 1200M should be shielded by the gas mixture of argon with carbon dioxide.

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