SCIENTIFIC
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Preheating and interpass layer temperature for DOCOL 1200 M steel welding

BOŻENA SZCZUCKA-LASOTA[1], TOMASZ WĘGRZYN[2], JAN PIWNIK[3], ADAM JUREK[4], JERZY KALWAS[5], KRZYSZTOF I.WILCZYŃSKI[6]

[1,2]SILESIAN UNIVERSITY OF TECHNOLOGY, [3]ROAD AND BRIDGE RESEARCH INSTITUTE, WARSAW, [4]NOVAR SP. Z O. O. GLIWICE, [5,6]COBRABID Sp. z o.o.

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ABSTRACT:

DOCOL steels are characterised by high tensile strength and high yield stress. Joints made of these steels are difficult to weld due to the dominant martensitic structure and complex procedure related to the necessity to reduce the hydrogen content in the weld metal. The aim of the article is to select the correct thermodynamic parameters of welding of structures used in means of transport made of DOCOL 1200M steel. It was decided to check the impact of preheating and interpass layer temperature on the correctness of the MAG joint of the structure with a thickness of 8 mm. The strength of the joint was also checked and the content of diffused hydrogen in the weld metal was evaluated.

Podgrzewanie wstępne i temperatura warstw międzyściegowych podczas spawania stali DOCOL 1200 M

Słowa kluczowe: inżynieria lądowa, transport, środki transportu, stale DOCOL

STRESZCZENIE:

Stale z grupy DOCOL charakteryzują się dużą wytrzymałością na rozciąganie i wysoką granicą plastyczności. Złącza z tych stali są trudnospawalne ze względu na dominującą strukturę martenzytyczną i skom- plikowaną procedurę związaną z koniecznością ograniczenia zawartości wodoru w stopiwie. Celem artykułu jest dobór prawidłowych parametrów termodynamicznych spawania konstrukcji stosowanych w środkach transportu ze stali DOCOL 1200M. Postanowiono sprawdzić wpływ podgrzewania wstępnego i temperatury warstw międzyściegowych na poprawność wykonanego złącza MAG konstrukcji o grubości 8 mm. Sprawdzono też wytrzymałość złącza i oszacowano zawartość wodoru dyfundującego w stopiwie.

1. INTRODUCTION

This article aims at presenting the results of the tests leading to the selection of the parameters for welding the structure made of DOCOL 1200M steel (AHSS – Advanced High-Strength Steel). DOCOL 1200 steels' range application in civil engineering and in the construction of means of transport is being extended due to their high strength of 1200 MPa [1–4]. The disadvantage of this steel, however, is low relative elongation (6%) [5–9]. This design facilitates the occurrence of welding cracks caused by, but not limited to:

- welding stresses;
- dominant martensitic structure conducive to cracks;
- the presence of coarse ferrite;
- hydrogen impact.

In order to reduce the welding stresses and the fragmentation of ferrite, it is recommended to reduce the linear energy during welding to the level of 4 kJ/cm [10–16]. In order to reduce the hydrogen content in the weld, however, it is recommended to use preheating and control the temperature of the interpass layers. During welding, individual hydrogen (H) atoms are released in the weld metal which can freely penetrate between iron atoms, where they are combined into H_2 molecules (recombination). The accumulation of hydrogen inside the metal causes internal pressure resulting in internal stresses of the material which, as a result, lead to hydrogen induced cracking (HIC) [17–21]. In DOCOL steels no sulfide stress corrosion cracking (SSCC) occurs since these steels contain traces of sulfur content [22–25]. HIC in DOCOL steels is mainly initiated at the boundaries of martensite-ferrite grains and in contact with non-metallic inclusions [26–31].
Hydrogen cracking spreads mainly parallel to the sheet surface. Since there is very little information on the hydrogen-induced destruction of welded joints made of DOCOL steel, these issues have been therefore the subject of the tests.

2. TEST MATERIALS

It was decided to use a UNION X96 welding electrode (EN ISO 16834-A G 89 6 M21 Mn4Ni2CrMo) for MAG welding of DOCOL steel with a thickness of 8 mm. A mixture of 90% Ar – 10% every CO_2 was selected as the shielding gas. For thick-walled structures it was recommended to use preheating due to dehydrogenation of the weld. As part of the research works, it was decided to make a correct joint of 1200M DOCOL steel made of 8 mm thick sheets to be used as the structures of the means of transport. Different temperature welding conditions were used in the welding process (preheating, variable interpass layer temperature values).
The fundamental welding-related problem pertaining to this group of steels is, however, significantly lower tensile strength of the manufactured joint than the strength of the parent material and even worse plastic properties [13]. Table 1 presents the mechanical properties of DOCOL 1200M steel, while Table 2 presents the chemical composition of DOCOL 1200M steel.

Table 1: DOCOL 1200M steel and its mechanical properties [13]

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

Table 2 DOCOL 1200M steel – chemical composition [14]

Steel grade	C%	Si%	Mn%	P%	S%	Al%	Nb%	Ti%
Docol 1200M	0.15	0.20	1.30	0.008	0.001	0.045	0.009	0.021

When analysing the above data (Tables 1 & 2), it can be noted that high strength properties of the steel in question compared to low-alloy steels result from the chemical composition. DOCOL 1200M steel has a much higher titanium and aluminium content than the structural non-alloy steels. The tests focused mainly on determining the impact of preheating and proper temperature of interpass layers on the correctness of the manufactured MAG joint. The chemical composition of the welding electrode is given in Table 3.

Table 3 UNION X96 welding electrode – chemical composition [8]

Electrode type	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

The chemical composition of the electrode is slightly different from the parent metal. The UNION X96 welding electrode has chromium and higher silicon content to improve the strength, and nickel and molybdenum to improve the plastic properties of the joint.
Prior to the execution of the joints made of sheets with a thickness t = 8 mm, V-type chamfering was performed. The chamfering angle was 60°, and the distance between the sheets and the threshold was 1.5 mm.
The welding parameters were as follows: the diameter of the UNION X96 welding electrode was 1.0 mm, the arc voltage of the first root fusion was 18 V, the welding current was 114 A. The welding velocity of the first layer was 300 mm/min. The weld was of a six-pass type. The subsequent layers were welded with increased current and voltage parameters (for deeper fusion) which are presented in Table 4.

Table 4 Welding parameters of subsequent layers of DOCOL 1200M steel joint (own study)

Layer number (from the root side)	Arc voltage, V	Current intensity, A	Welding velocity, mm/min
first	18	114	320
layers 2-6	21	230	340

Joints were made without preheating and with preheating up to 120°C. Additionally, the interpass temperature of the joint was determined during laying out of layers 2–6 (130°C, 150°C, 170°C, 190°C).

3. TEST METHODS

After MAG welding, the following non-destructive tests (NDT) were carried out:
• Visual inspection (VI) of the welded joints made was carried out with corrected vision at the magnification of 3x – the tests were performed according to the requirements of PN-EN ISO 17638, whereas the assessment criteria were in accordance with EN ISO 5817.
• Magnetic particle inspection (MPI) – the tests were performed according to PN-EN ISO 17638; the assessment was performed according to EN ISO 5817; the test equipment used was REM 230 magnetic flaw detector.

The analysis of the obtained results of the non-destructive tests allowed joints for ultimate tensile strength testing to be selected. The strength of the joints was determined using INSTRON 3369 strength testing machine. The samples were also examined structurally in design terms using a light microscope (LM). The tests were performed in accordance with PN-EN ISO 9016 2021. Immediately after welding it was also decided to check the content of diffused hydrogen in the weld. The tests were performed according to the indicative glycerine method described in the following standard: "Determination of the total amount of hydrogen in the weld metal of steel electrodes with acid, rutile or basic coating. BN-64/4130" since no instruments for more precise determination of hydrogen were available according to the mercury method described in the following standard from 2018: PN-EN ISO 3690:2005 "Determination of hydrogen content in ferritic steel arc weld metal".

4. TEST RESULTS AND ANALYSIS

The result of the assessment of the joints revealed the impact of changes in the process parameters (application of preheating, different interpass temperatures). The results of macroscopic visual inspections carried out with the unaided eye and magnetic particle inspection of the mobile platform joints are presented in Table 5.

Table 5 Results of non-destructive testing

Welding without preheating	Welding at 130°C	Preheating up to 120 °C, interpass temperature:		
		150°C	170°C	190°C
Cracks in: welds, HAZ	Cracks in: welds, HAZ	No cracks	No cracks	Cracks in welds

It was claimed that for proper welding of 8 mm thick sheets made of DOCOL 1200M steel preheating to 120°C is absolutely necessary. It was considered that the preheating temperature of 120°C is sufficient as no cracks were observed in these joints. At the same time, it was noted that the interpass temperature of the joint should be within the range of 150–170°C. In joints made with preheating up to 120°C and with an interpass temperature of 190°C cracks in welds occurred due to another reason. Although the content of diffused hydrogen in the weld was low, there was a disturbing expansion of the heat affected zone along with the increase of the interpass temperature. The content of dispersing hydrogen in the weld was checked immediately after welding. The results of the tests are presented in Table 6.

Table 6 Diffused hydrogen in the weld

Type of sample	Diffused hydrogen content, ml/100 g of weld metal
Without preheating	7.1
Interpass layer temp. 130°C	6.2
Interpass layer temp. 150°C	4.3
Interpass layer temp. 170°C	4.2
Interpass layer temp. 190°C	3.9

Based on the test results presented in Table 6, it was found that the hydrogen content is at the level of 3–5 ml/100 g of weld metal only if at the same time:

- preheating is applied;
- the interpass temperature is set at 150–170°C.

For further destructive tests (assessment of the structure and ultimate tensile strength), only joints made with preheating at 120°C and simultaneous provision of the correct interpass temperature were taken into account. Martensite was the dominant structure and small amounts of bainite and fine ferrite were found.

The strength of the joints recorded with INSTRON 3369 is presented in Table 7. The results of the ultimate tensile strength test are the average of 3 tests.

Table 7 Strength of the DOCOL 1200M joint (preheating 120°C, interpass temperature 150°C and 170°C)

Interpass temp.	R_e [MPa]	R_m [MPa]	A_5 [%]
150°C	542	729	6.0
170°C	531	707	5.9

The data in Table 5 indicates that high strength R_m and acceptable relative elongation A_5 were obtained at the level of the parent metal.

5. SUMMARY

The DOCOL steels are materials with low weldability which are increasingly used in civil engineering and in the construction of means of transport. Their high tensile strength is considerably greater than the strength of the welded joint. A major welding problem is to provide comparable plastic properties of the 1200M DOCOL joint and the parent metal. This article specifies the welding parameters of thick-walled structures made of DOCOL 1200M steel. The following conclusions were drawn up:

1. Preheating (at 120°C) should be applied prior to MAG welding of DOCOL 1200M steel;
2. It is important to control the interpass temperature which should be 150–170°C;
3. Preheating and properly selected temperature of the interpass layers will allow the hydrogen content in the weld to be reduced below 5 ml/100 g of the weld metal, which guarantees good mechanical properties of the joint.

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PhD Eng, prof. Jan Piwnik (COBRABiD Sp. z o.o.)
MSc Eng, Adam Jurek (Novar Sp. z o.o. Gliwice, Gliwice, Poland)
MSc Eng, Jerzy Kalwas (COBRABiD Sp. z o.o.)
MSc Eng, Krzysztof Ireneusz Wilczyński (COBRABiD Sp. z o.o.)