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Welding of Thin-Walled Mobile Platform Structures Made of Steel DOCOL 1400M

Abstract: Because of their high immediate tensile strength and significant fatigue strength, Docol steels (belonging to advanced high-strength steels (AHSS)) are increasingly commonly used in the fabrication of mobile platforms. The welding of the above-named steels is difficult due to the fact that the dominant structure is martensitic. As a result, the welding of such steels requires both experience and high qualifications. The tests discussed in the article aimed to identify appropriate welding parameters as well as to determine the effect of such process parameters as welding rate, the method of bevelling and the application of preheating on the quality of the joints obtained in the process.

Keywords: civil engineering, transport, means of transport, steel Docol 1400M

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Introduction

The past 10 years have seen the application of high-strength steels (HSS), such as s 700 mc or 960 ql, in the fabrication of vehicle elements (e.g. mobile platforms). However, the strength of the above-named steels (900 MPa) is insufficient in terms of advanced mobile platforms [1–3]. The aforesaid situation necessitates the development and implementation of increasingly resistant materials such as Docol steels. Because of their high immediate tensile strength (up to 1500 MPa) and, at the same time, high fatigue strength (400 MPa in relation to 2 million cycles of changing loads), the Docol group steels are enjoying increasingly high applicability [4]. Steel Docol 1400M, characterised by high tensile strength, is used mainly in thin-walled structures, making it possible to reduce the total weight of various means of transport. Steel Docol 1400M can be joined using universal welding methods including gas-shielded metal arc welding (gmaw), manual metal arc welding (mmaw), tungsten inert gas welding (tig) or laser beam welding (lbw) [5–7]. However, according to its manufacturer, steel Docol 1400M is characterised by limited weldability. The reason for the above-named situation results from higher contents of Al and Ti (in comparison with those in unalloyed structural steels) and the dominant presence of the martensitic structure, which, combined with the high hardness of all the joint areas, makes the steel susceptible to various types of cracking [8–9]. In addition, the welding of steel Docol 1400M adversely affects its mechanical properties. The tensile strength and unit elongation of the steel are nearly by twice lower than those of the base material. Reference publications contain little information concerned with the welding of

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steel Docol 1400M. The primary recommendation is that welding linear energy should not exceed 5 kJ/cm [2]. Due to the necessity of reducing the content of hydrogen in the weld, particularly when welding thicker high-strength steels, it is necessary to apply dryout heating [9]. The major welding-related issues accompanying the joining of steel Docol 1400M include the obtainment of joints characterised by strength comparable with that of the base material and appropriate plastic properties [6, 10–11].

Test material

The material used in the tests was steel Docol 1400M. The mechanical and chemical properties of the steel in the as-received state are presented in Table 1 and 2 respectively.

Table 1. Mechanical properties of steel DOCOL 1400M

Yield point R_e, MPA	Tensile strength R_m, MPa	Elongation A5, %
1155	1380	7.3

Information contained in Table 2 reveals that steel Docol 1400M contains fifteen times more titanium and significantly more aluminium than unalloyed structural steels. As regards steels of the Docol group, the total content of Ti and Nb should not exceed 0.45%. Steel Docol 1400M is also characterised by a very low sulphur content (0.002%) (Table 2). Such a chemical content enables the obtainment of high strength without compromising favourable plastic properties (cf. Table 1).

Tests concerning the weldability of steel Docol 1400M involved the use of a 3 mm thick sheet, the MAG welding method and the classical Ar + 18% CO_2 gas shielding mixture. It is recommended that the Docol group steels should be welded using primarily two filler metal wires, i.e. Union X96 and Union X90. The chemical compositions of the recommended filler metal wires are presented in Table 3. Information contained in Table 3 indicates that the differences in the chemical compositions of both filler metal wires were small and concerned with:

- contents of carbon, titanium and chromium – affecting the strength of the joint,
- contents of nickel and molybdenum – affecting the plastic properties of the joint.

It should be noted that the content of silicon (effecting strength) in both wires was four times higher than that in steel Docol 1400M.

The filler metal wire used in the tests was the Union X90 wire, characterised by the lower content of carbon. The tests focused primarily on the effect of welding linear energy and preheating on the quality of test joints.

The parameters of the MAG welding process were the following:

- diameter of the Union X90 filler metal wire: 1.0 mm,
- arc voltage: 20 V,
- welding current: 118 A,
- DC source (+) on the electrode.

The assessment concerning the weldability of a thin-walled welded joint (3 mm × 200 mm ×

Table 2. Chemical composition of steel DOCOL 1400 [7]

Steel grade	C%	Si%	Mn%	P%	S%	Al%	Nb%	Ti%
DOCOL 1400M	0.17	0.2	1.4	0.009	0.002	0.04	0.015	0.025

Table 3. Chemical composition of the filler metal wires [8]

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	0.11	0.8	1.8	0.010	0.45	0.65	2.45	0.007

400 mm) required the determination of an appropriate welding rate (investigated rates being 270 mm/min and 370 mm/min) and the manner in which test sheets were bevelled before welding (V-groove or square butt weld preparation). The V-groove joint preparation performed at an angle of 60° involved the making of two beads. The welding of the test sheets not subjected to bevelling required the making of a single-run joint. In both cases, the welding process was performed using a ceramic backing strip. The welding rate was changed in order to identify the effect of welding linear energy (one of the most important process parameters) on the properties of the test joints. The welding process was performed automatically using an EWM Phoenix welding machine and a filler metal feed rate of 4 m/min (without specific welding current and arc voltage wavelengths).

The tests also involved the verification whether the preheating of the thin-walled structure was justified.

Tests

The joints were subjected to the following tests:

1. non-destructive tests (NDT):
   - visual tests (VT) performed in accordance with the requirements of the PN-EN ISO 17638 standard (assessment criteria in accordance with EN ISO 5817), magnetic particle tests (MT) performed in accordance with the requirements of the PN-EN ISO 17638 standard (assessment of the tests was performed in accordance with EN ISO 5817); the tests involved the use of an REM 230 magnetic defectoscope;
2. destructive tests:
   - tensile tests performed using an INSTRON 3369 testing machine,
   - bend tests involved the 3 mm thick specimens and the following parameters: specimen width b = 20 mm, specimen thickness = 3 mm, mandrel diameter d = 14 mm, spacing between supports d+3a = 31 mm and a bend angle of 180°. The bend tests involved 5 measurements (corresponding with the number of the specimens) of each specimen (both on the weld root and weld face side); the tests were performed using the aforementioned INSTRON 3369 testing machine.

Each test was followed by the selection of specimens. Only the specimens free from defects and welding imperfections were qualified for subsequent tests.

Test results and analysis

The non-destructive test results are presented in Table 4. The test results presented in Table 4 revealed that the welding process parameters affected the quality of the test joints. Improperly adjusted welding parameters resulted in the

Table 4. Results of the non-destructive tests in relation to the joints made using the Union X 90 filler metal wire

Welding rate, mm/min	Bevelling method	Preheating, 90°C	Remarks
270	V-groove joint preparation, 60°	-	Cracks
370	V-groove joint preparation, 60°	-	Lack of imperfections
270	V-groove joint preparation, 60°	90°C	Lack of imperfections
370	V-groove joint preparation, 60°	90°C	Lack of imperfections
270	Square butt weld preparation	-	Lack of imperfections
370	Square butt weld preparation	-	Cracks
270	Square butt weld preparation	90°C	Lack of imperfections
370	Square butt weld preparation	90°C	Lack of imperfections

formation of small (2-3 mm) cracks (3) in the test joints. The reason for the formation of the cracks was the dominant martensitic structure of steel Docol 1400m. Reference data recommend that the obtainment of proper welded joints (free from defects and welding imperfections) in steel Docol 1400m should be preceded by dryout preheating. It was observed that the application of a lower welding rate when making the joint not subjected to bevelling enabled the elimination of welding imperfections. The tests also revealed that higher welding rates were more favourable in relation to the joints subjected to V-groove preparation.

The assessment concerning the quality of the test joints involved the performance of tensile tests in relation to the effect of the welding rate, preheating and the method of bevelling. The tensile strength of the joints was determined using the Instron 3369 testing machine. The subsequent tests only involved the specimens free from defects and welding imperfections (Table 4). The strength test results (average based on 3 tests) are presented in Table 5.

The above-presented test results revealed the obtainment of comparable results in all of the cases. The most favourable results were obtained in relation to the joint subjected to V-groove preparation and preheating (specimen P3). A fatigue strength of more than 900 MPa was obtained only in one case. However, it should be noted that in all of the cases it was possible to obtain high strength as well as favourable and comparable plastic properties. The preheating temperature, the manner of bevelling and the welding rate did not significantly affect the mechanical properties of the joint subjected to analysis. Therefore, in terms of cost effectiveness, it could be assumed that the welding of 3 mm thick sheets made of steel Docol 1400m does not require preheating or bevelling. The strength of the joint was slightly lower than that of the filler material. The foregoing resulted from the dilution of the base material and the weld deposit of the filler metal wire having a slightly different chemical composition (particularly as regards the content of Cr, effectively hardening the weld deposit).

The subsequent stage involved the performance of bend tests of joints free from defects and welding imperfection (Table 4). The testing methodology was as presented in the previous section of the article. The bend tests included 5 measurements performed on the weld root and on the weld face side of each specimen. The bend tests did not reveal the presence of any cracks in the weld or in the haz; both the weld face and the weld root were free from cracks. The general evaluation of the tests was positive as no cracks or other imperfections were

Table 5. Strength test results in the relation to the welded joints made of steel DOCOL 1400M (individual study)

Specimen no.	Welding rate, mm/min	Bevelling method	Preheating, 90° C	R_m	A5
P1	370	V-groove joint preparation, 60°	-	882	6.5
P2	270	V-groove joint preparation, 60°	90° C	891	6.6
P3	370	V-groove joint preparation, 60°	90° C	902	6.6
P4	270	Square butt weld preparation	-	875	6.4
P5	270	Square butt weld preparation	90° C	878	6.5
P6	370	Square butt weld preparation	90° C	874	6.3

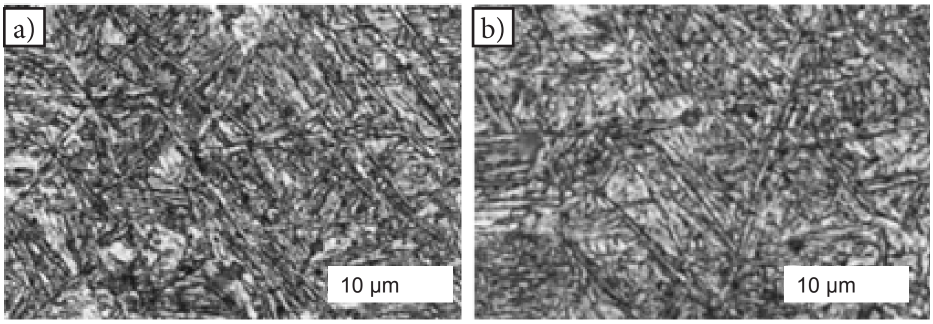

Fig. 1. Microstructure of the weld of steel DOCOL 1400M: a) specimen P3 and b) specimen P5 (from Table 5)

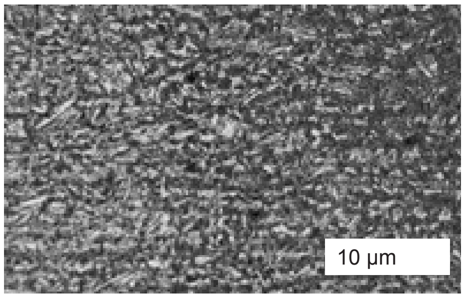

Fig. 2. Microstructure of the HAZ of steel DOCOL 1400M: a) specimen P3 (from Table 5)

detected in any of the test joints made of steel Docol 1400M.

Afterwards, it was necessary to analyse the structure of the weld (Fig. 1) and that of the heat affected zone (Fig. 2) using light microscopy (LM). The observations confirmed the dominant presence of the martensitic structure (typical of steel Docol 1400M) both in the weld and in the HAZ. The morphology of the martensitic structure was similar in all of the test joints (Fig.1 a, b). The final stage included tests of fatigue strength involving specimen P3.

The fatigue tests were performed using an 8874 Instron testing machine having an axial force of ±25 kN and a torque of ±225 Nm.

In relation to a stress of 450 MPa, the fatigue test revealed the formation of a crack after 1 822 436 load cycles, i.e. close to the expected fatigue strength of the steel, amounting to 2 million cycles. Based on the foregoing it could be concluded that the material will have infinite fatigue strength in relation to stresses of slightly below 450 MPa. The Wöhler curve related to the test joint made it possible to estimate the fatigue strength of the test joint at 425 MPa. The positive results of the fatigue strength tests justified the conclusion that the structure would satisfy operational safety conditions.

Summary

Materials increasingly often used in the production of means of transport are advanced high-strength steels of the Docol group. The high strength of the aforesaid group of steels is usually significantly higher than that of welded joints made using such steels. The unit elongation of the joint obtained applying previously used welding processes amounted to more than 6%. Therefore, it is necessary to search for solutions making it possible to improve the weldability of structures made of hard-to-weld advanced high-strength martensitic steels, increase immediate tensile strength and improve the unit elongation of joints.

The above-presented test results revealed that the obtainment of proper joints made of 3 mm thick steel Docol 1400M did not require the preheating and bevelling of the test sheets. The tests also revealed that the more favourable welding rate in relation to the unbevelled joint amounted to 270 mm/min. In turn, the more favourable welding rate as regards the joint subjected to V-groove preparation was higher and amounted to 370 mm/min. All of the joints obtained in the tests were proper and free from defects and welding imperfections. The joints were characterised by comparable mechanical properties (identified in related tensile, bend and fatigue tests). It was ascertained that, in terms of cost effectiveness, the obtainment of proper joints made of steel Docol 1400M (test sheet having dimensions 3 mm × 200 mm × 400 mm) required the use of the MAG method, the Union X90 filler metal wire having a diameter of 1.0 mm, an arc voltage of 20 V and a welding current of 118 A. The preheating and the bevelling of the test sheets proved unnecessary.

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