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MODERN MATERIALS AND INNOVATIVE WELDING TECHNOLOGY USED IN THE CONSTRUCTION OF ANTENNA MOUNTS

Summary. Telecommunication, transport and civil engineering play an important role in new research areas. New antennas based on innovative materials are being developed. At the same time, the methods of antenna mounting with the use of high-strength materials to ensure high structural rigidity with the lowest possible weight are being planned. These materials include AHSS steels with ultimate tensile strength (UTS) up to 1700 MPa and elevated yield point (YS); however, welded joints made of these steels have much worse mechanical properties, compared to the native materials. In this paper, it was planned to test the MAG welding of DOCOL 1400M steel (AHSS group). Directly after welding, a micro-jet joint cooling was applied. It was determined to create thin-walled joints that could be used in the formation of antenna mounts.
Keywords: antenna mounts, welding, smart city

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1. INTRODUCTION

New construction materials and welding technologies could play an important role in smart city development. Antennas and infrared detectors and methods of fixing them with thin-walled, high-strength welded structures will play a large role in creating smart cities [1]. Recently, metamaterials emerged as a vital part of the construction of antennas and infrared detectors. Advanced antennas are being rapidly developed, operating on more progressive principles and materials. Moreover, a tendency to create ever-lighter structures, both regarding the main part of the antennas, as well as the methods of their mounting, appears. Tripods and antenna mounting elements are made of high-strength materials to reduce the weight of the antenna structure [2]. This article presents the research results leading to the choice of the MAG welding process for structures made of DOCOL 1400 intended for the construction of antennas or infrared detectors [3].

DOCOL 1400 steels have become increasingly popular for various structures in civil engineering and transport means due to their mechanical properties, especially with a good yield point of over 1350 MPa [4-6]. Welding of AHSS steels is currently checked in the industry for mechanical and tribological properties. The authors focused on the unfavourable dominant martensitic structure, which will not affect the good weldability of these steel grades [7-8].

Therefore, it is recommended to apply preheating for DOCOL steel welding structures. The heating is to dry out and remove any additional contaminants, ensuring a lack of high hydrogen concentration in the weld, which is one of the factors contributing to the formation of weld cracks and other defects and non-conformities. Each structure has a different dimension, especially the wall thickness. In thicker joints, chamfering is used, while thinner structures are tried to be welded without chamfering. The most appropriate welding conditions should be carefully selected for each type of structure.

2. RESEARCH MATERIALS

DOCOL 1400M steel should be treated as a difficult material to weld because its weld is susceptible to welding cracks [6]. Table 1 presents some mechanical properties of the tested material.

Tab. 1

DOCOL 1400M steel and its mechanical properties

YS, MPA	UTS, MPa	Relative elongation A_5, %
1155	1370	6.9

DOCOL 1400M steel has a clearly higher amount of Ti and Al than the conventional unalloyed types of steel used in the construction of lightweight structures. Noteworthy is also the low content of sulfur and phosphorus in the material (Table 2) - such chemical composition of the steel enables high strength of the structure.

To assess the suitability of DOCOL 1400M steel for thin-walled antenna structures, a sheet of 1.8 mm thickness was tested. It was planned to create joints MAG (Metal Active Gas) joints using a shielding gas mixture of 90% Ar+10% CO_2. The UNION X96 electrode wire was selected. The chemical composition of the UNION X96 is provided in Table 3.

Tab. 2

DOCOL 1400 steel – chemical composition [7]

Steel grade	C, %	Si, %	Mn, %	P, %	S, %	Al, %	Nb, %	Ti, %
DOCOL 1400M	0.17	0.21	1.40	0.009	0.002	0.041	0.015	0.025

Tab. 3

Welding wire UNION X96 - composition [8]

C, %	Si, %	Mn, %	P, %	Cr, %	Mo, %	Ni, %	Ti, %
0.1	0.82	1.83	0.01	0.46	0.67	2.48	0.006

The composition of the base material and wire was intentionally not exactly the same. Chromium (which was not present in the parent material) was introduced into the electrode wire to increase the strength of the joint, as well as nickel and molybdenum (which also do not exist in the parent material) to correct the plastic properties of a joint. The process parameters were rather typical:

- electrode wire diameter: 1 mm,
- arc voltage:18.5 V,
- welding current was at the level of 114 A,
- welding speed: 385 mm/min.

The weld had a single-pass character, a forming ceramic pad was used. Joints were made both without the use of preheating, as well as with preheating of 75°C. Other welding parameters included:

- use of a direct current source,
- shielding gas flow: 14 l/min,
- the gap between two edges: 0.8 mm,
- lack of bevelling.

The joints were made with the MAG process using the application of micro-jet (mj) cooling. The most important mj cooling parameters included:

- cooling gas selection: shielding gas: 90% Ar+10% CO_2 (selected also to MAG process),
- diameter of micro-nozzle injector: (60 µm; 70 µm),
- gas flow rate (0.55 MPa; 0.65 MPa).

All samples selected for the creation of welded joints had dimensions of 400 mm × 150 mm × 1.8 mm. After the welding, samples for mechanical tests were made out of them according to the relevant standards.

3. RESULTS AND DISCUSSION

After the welding process of thin-walled sheets used for antenna holders with application of MAG and the shield, NDT tests (non-destructive) were carried out, which included:

- VT test (visual) test of the weld performed (3× magnification) following the PN-EN ISO 17638 standard,
- MT test (magnetic particle) - following the PN-EN ISO 17638 standard.

The results of the NDT tests are shown in Table 4.

Tab. 4

Analysis of NDT tests

Type of process	Micro-nozzle diameter, μm	Gas flow rate, MPa	Assessment of the joint quality
MAG without cooling	-	-	Cracks in the weld and HAZ
MAG without micro-jet cooling, with preheating (75°C)	-	-	Lack of cracks
MAG with micro-jet-cooling, without preheating	60	0.55	Cracks in the weld and HAZ
MAG with micro-jet-cooling, without preheating	60	0.65	Lack of cracks
MAG with micro-jet-cooling, without preheating	70	0.55	Lack of cracks
MAG with micro-jet-cooling, without preheating	70	0.65	Cracks in the weld and HAZ
MAG with micro-jet cooling, with preheating (75°C)	60	0.55	Lack of cracks
MAG with micro-jet cooling, with preheating (75°C)	60	0.65	Lack of cracks
MAG with micro-jet cooling, with preheating (75°C)	70	0.55	Lack of cracks
MAG with micro-jet cooling with preheating (75°C)	70	0.65	Cracks in the weld and HAZ

The presented data shows that welding of DOCOL 1400M requires preheating in the classic MAG process. No cracks were identified mostly in these joints and the HAZ (heat affected zone) where micro-jet cooling was taken. Furthermore, it was observed that too weak and too intense micro-jet cooling does not provide good quality joints. The preheating temperature of 75°C was found to be correctly selected. Only the connections made using the parameters supporting the creation of joints without welding defects and non-conformities were considered for further (destructive) tests (Table 4). Joints with obtained welding defects have not been further investigated.

The next stage of the research included mechanical tests. The immediate tensile strength of the connections was tested using the INSTRON 3369 machine. The results of the tensile strength (the average of 3 measurements) are shown in Table 5.

Tab. 5

Tensile strength results of DOCOL 1400M after welding with preheating

Type of MAG process	Micro-nozzle diameter, μm	Gas flow rate, MPa	UTS, MPa	YS, MPa
Classic, without mj cooling, with preheating (75°C)	-	-	796	489
with mj cooling, without preheating	60	0.65	805	501
with mj cooling, without preheating	70	0.55	811	512
with mj cooling, with preheating (75°C)	60	0.55	836	527
with mj cooling, with preheating (75°C)	60	0.65	846	531
with mj cooling, with preheating (75°C)	70	0.55	831	521

High strength and yield points were obtained in all the tested cases. It is important to note that weld tensile strength is much lower than the mechanical properties of the base material. The best properties have the joints obtained through welding with the use of preheating and micro-jet cooling. The UTS of such joints is at the level of around 830 MPa, and the YS about 520 MPa (the three last columns in Table 4). The results of the tensile strength tests should be perceived as positive based on their results it can be concluded that the DOCOL 1400M steel might be used for thin-walled elements of antenna mounts.

A bending test was executed, as the next point of the investigation, for all the joints that had been previously tested in the strength test (presented in Table 4). The test was realized with the EN ISO 5173 standard. Five measurements were taken for each test. The root side and separately face side were verified. No cracks were found in the weld and the HAZ, neither on the root nor the face sides. No incompatibilities were detected in all the tested joints, which confirms that DOCOL 1400M could be used for thin-walled elements of antenna mounts.

Next, the microstructure analysis of the same joints tested for tensile strength and bend tests was performed. The dominant martensitic structure was found in all the cases. It was also noticed that MAG welding with micro-jet cooling produces a slightly finer martensitic structure than the process without mj cooling. The research was executed on transverse sections (PN-EN ISO 9015) using a Neophot microscope. The structure of the weld, which allowed obtaining the highest immediate tensile strength (UTS = 846 MPa), is shown in Figure 1.

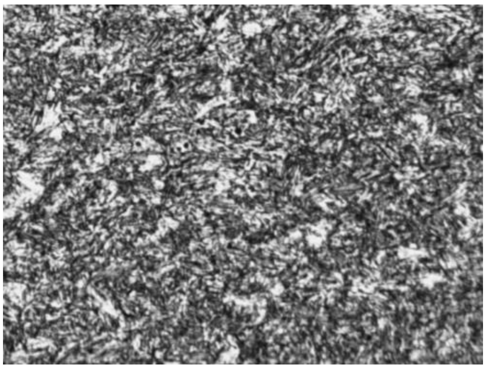

Fig. 1. Weld microstructure of DOCOL 1400M steel
(joint made with preheating up to 75°C and with mj cooling) × 200

The final stage of the tests included verification of the fatigue strength of the joint. For this purpose, hourglass samples (Figure 2) were made for the joint that provided the highest tensile strength of 846 MPa (Table 4, Figure 1). The hourglass type was selected due to the weld location in the smallest cross-section of the measuring base, which is the physical plane of destruction, regardless of the type of mechanical test.

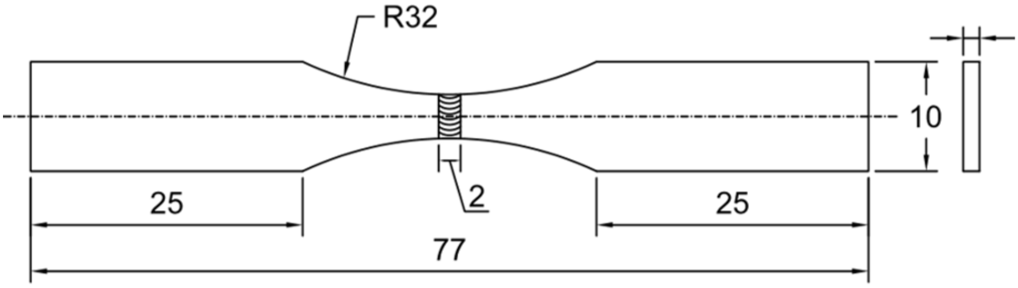

Fig. 2. Hourglass samples used for testing the fatigue strength of the joint

The static and fatigue tests were realized on the 8874 INSTRON machine. The fatigue test was performed using a cyclically alternating stress signal with a sinusoidal waveform. The following standard control signal parameters were used in the fatigue test. Selected parameters of the tested connection made of DOCOL 1400M steel after MAG welding fellfield with mj cooling are presented in Table 6.

Tab. 6

Selected parameters of the fatigue test of the tested joint

Maximum stress value [MPa]	The number of cycles performed at each stage of the fatigue test	Final result
500 MPa	1^{th} stage: 623 710	positive
	2^{nd} stage: 1 220 150	positive
Total number of cycles	1 843 860	crack in the sample in the centre of the measuring zone

The joint fatigue test of the value of the applied stress presented a crack at the number of load cycles of 1 843 860 (Table 6), the second expected value for the steel fatigue limit, which is 2×106. Based on this result, it can be concluded that at a stress value slightly below 500 MPa, the material will have an infinite fatigue life. The fatigue limit of the tested micro-weld joint was estimated at the level of 490 MPa.

The positive results of the joint fatigue strength tests show that the welded thin antenna structure meets the safety requirements.

4. CONCLUSION

The difficult-to-weld material proposed for mounting modern antennas might be DOCOL 1400M (AHSS group). Tensile strength of base material is much greater than weld. In this article, it was planned to create welds using two processes (the classic MAG method and the method including micro-jet cooling) to choose better welding parameters and to prove that DOCOL 1400M steel joints can be proposed for the construction of thin-walled welded antenna structures due to their good mechanical properties. First, thin-walled samples were prepared, and the quality of the joints was made using various processes and parameters were checked through non-destructive testing. The non-destructive assessment shows that the best results are obtained after the welding where preheating and micro-jet cooling were applied in the MAG process. The research shows that to produce a good joint from DOCOL 1400M steel, preheating (75°C) is required and micro-jet cooling is recommended. The influence of the main mj cooling parameters on the mechanical properties of the joint was also investigated. Temporary tensile strength and bending tests were performed, the metallographic structure was analysed, and the fatigue strength of the joint was determined. The use of micro-jet cooling helps to obtain higher yield points and joint strength compared to the classic MAG process. Micro-jet cooling allowed to receive a favourable fineness of the martensitic structure. The fatigue strength tests show that the structure made simultaneously with the use of preheating and mj cooling is safe as the proper fatigue limit of the tested welds (490 MPa). The non-destructive tests proved that DOCOL 1400M steel is correctly selected as the new material for the construction of thin-walled welded antenna structures.

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