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BADAWCZA I DYDAKTYCZNA

Welding parameters for thin-walled structures of means of transport made of DOCOL 1400M steel

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ABSTRACT:

Recently, more and more often used material in the construction of means of transport are AHSS (Advanced High-Strength Steel) steels with high tensile strength of approx. 1500 MPa. Joints made of these steels are difficult to weld as a result of the dominant martensitic structure. The purpose of the studies described in this article is to select the parameters for welding thick-walled AHSS structures on the example of DOCOL 1400M steel. It was decided to check the impact of linear energy of welding and preheating on the correctness of the joint made.

Parametry spawania cienkościennych konstrukcji środków transportu ze stali DOCOL 1400M

Słowa kluczowe: inżynieria lądowa, transport, środki transportu, stal AHSS

STRESZCZENIE:

Ostatnio coraz częściej stosowanym materiałem w budowie środków transportu są stale z grupy AHSS (AHSS – *Advanced High-Strength Steel*) z uwagi na ich dużą wytrzymałość na rozciąganie na poziomie 1500 MPa. Złącza z tych stali są trudnospawalne ze względu na dominującą strukturę martenzytyczną. Celem prac opisanych w artykule jest dobór parametrów do spawania cienkościennych konstrukcji ze stali AHSS na przykładzie stali DOCOL 1400M. Postanowiono sprawdzić wpływ energii liniowej spawania i podgrzewania wstępnego na poprawność wykonanego złącza.

1. INTRODUCTION

In civil engineering and transport, feet with constantly increasing strength are used. This article aims at presenting the results of the tests leading to the selection of the parameters for welding the thin-walled structure made of DOCOL 1400M steel (AHSS).
DOCOL 1400 steels' applications in civil engineering and in the construction of means of transport are being extended due to both their high tensile strength of 1500 MPa and high yield stress of 1200 MPa. The disadvantage of this steel is that apart from high strength, it does not have good plastic properties, which is reflected in the relative elongation of 7-8% [2-4]. At welding DOCOL 1400M steels, their mechanical properties in the HAZ deteriorate. The strength of the joint and the relative elongation are thus significantly smaller than the strength of the parent material. It is therefore recommended to reduce the linear energy during welding to 5 kJ/cm [5]. DOCOL steel 1400M is mainly used for thin-walled structures since its high strength allows the total weight of the structure of the means of transport to be reduced.

2. TEST MATERIALS

AHSS steels are considered to be difficult to weld because the heat affected zone tends to crack. This is due to martensitic structure of these steels and high material hardness. However, the fundamental welding-related problem pertaining to this group of steels is significantly lower strength of the manufactured joint than the strength of the parent material and worse plastic properties [6]. Table 1 presents the mechanical properties of DOCOL 1400M steel in as-delivered condition.

Table 1 DOCOL 1400 steel and its mechanical properties

Yield stress R_e	Tensile strength R_m	Elongation A_5
MPa	**MPa**	**%**
1160	1375	7.2

AHSS steels have ten times the titanium content and twice the aluminium content than the carbon and manganese steels used in the construction of the means of transport and in civil engineering. This is possible due to very low sulphur content (Tab. 2). This chemical composition allows for increased strength while maintaining acceptable plastic properties.

Table 2 DOCOL 1400 steel – chemical composition [7]

Steel grade	C%	Si%	Mn%	P%	S%	Al%	Nb%	Ti%
DOCOL 1400M	0.17	0.20	1.40	0.009	0.002	0.040	0.015	0.025

A 1.8 mm thick metal plate was used to assess the weldability of DOCOL 1400M steel.
It was decided to make the joints using the MAG (Metal Active Gas) method with the mixture of 82% of Ar and 18% of CO_2 as the shielding gas. UNION X96 welding electrode was selected (EN ISO 16834-A G 89 6 M21 Mn4Ni2CrMo). The tests focused mainly on the impact of linear energy of welding and preheating on the correctness of the joint made.
The chemical composition of the welding electrode is given in Table 3.

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

C%	Si%	Mn%	P%	Cr%	Mo%	Ni%	Ti%
0.1	0.8	1.8	0.010	0.45	0.65	2.45	0.007

The chemical composition of the electrode is not completely similar to the steel composition. Attention is paid to four times the content of silicon in the wire than in steel, which has an impact on the increase of strength. Additionally, a relatively high content of chromium (0.45%) was introduced, which considerably increases the strength, but at the same time reduces the impact resistance of the joint. To improve the plastic properties of the joint, nickel (2.45% of Ni) and molybdenum (0.65% of Mo) were introduced to the weld. Nickel (2%) and molybdenum (0.5%) introduced into the weld metal highly increase the impact resistance of the joint at negative temperatures. For carbon and manganese steel joints, both of these elements introduced into the weld metal ensure the joint's impact resistance of 50 J at -40°C, which meets the requirement for impact resistance class 4. Similarly, in the AHSS joints both elements significantly improve plastic properties.
Welding parameters were as follows: welding electrode diameter – 1.0 mm, arc voltage – 20 V, welding current intensity – 118 A, DC source (+) on the electrode, the weld was of single-pass type. For the assessment of weldability of the

thin-walled joint (with a thickness of 1.8 mm), it was decided to determine the appropriate welding velocity (the welding velocity was changed twice: to 300 mm/min and 400 mm/min) and the preheating temperature (the joints were made without preheating and during preheating up to 80°C and 120°C), and to determine whether preheating is necessary for welding of this structure.

3. RESULTS AND DISCUSSION

The manner of preparation of the DOCOL 1400M steel joint is shown in Figure 1.

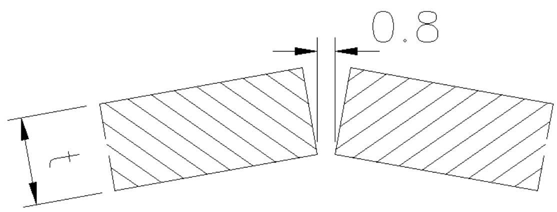

Figure 1 Method of preparation of the joint for MAG welding

Welding was performed with a ceramic washer. After 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 3× – 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 results of the joints of the mobile platform are presented in Table 4.

Table 4 Evaluation of NDT of the mobile platform joint

Welding velocity, mm/min	Without preheating	With preheating at 80°C	With preheating at 120°C
300	Cracks in welds and HAZ	No cracks	No cracks
400	Cracks in welds and HAZ	No cracks	No cracks

The table shows that preheating is required for proper welding of 1400M DOCOL steel. After evaluation of the joints with non-destructive tests, it was decided to perform the tensile strength test of the welded platform elements. The welding velocity was also examined at 300 mm/min and 400 mm/min. In both cases, comparable results were obtained indicating that the welding velocity should range from 300 to 400 mm/min. It was stated that the preheating temperature of 80°C is sufficient. For further (destructive) tests, only the joints made with preheating were taken into account. The strength of the joints was tested using INSTRON 3369 strength testing machine. The results of the strength tests (average of 3 tests) are presented in Table 5.

Table 5 Results of the strength tests of DOCOL 1400M steel after welding with preheating

Preheating temp. [°C]; Velocity [mm/min]	R_e [MPa]	R_m [MPa]	A_5 [%]
80°C; 300 mm/min	557	892	6.7
120°C; 300 mm/min	544	884	6.8
80°C; 400 mm/min	559	891	6.7
120°C; 400 mm/min	541	883	6.8

The table shows that the preheating temperature and welding velocity do not have a significant impact on the mechanical properties of the joint. High strength and good comparable plastic properties were obtained in all the cases tested.

Then a bending test was performed for all the joints made after preheating to 80°C and 120°C and at two different welding velocities (300 and 400 mm/min). For samples with a thickness of 1.8 mm, the parameters were as follows: sample width b = 20 mm, mandrel d = 14 mm, spacing of supports d + 3a = 31 mm, and the required bending angle – 180°. As part of the bending test, 5 measurements were performed for each tested joint thickness from the root side and from the face side. No cracks were observed in the weld and HAZ both from the root and face sides. The bending test was performed correctly and test evaluation is positive since no cracks and other discrepancies were detected in all tested DOCOL 1400M steel (with different preheating temperature and welding velocity).

A microstructural analysis was then performed. Both after preheating to 80°C and 120°C and at two different welding velocities (300 and 400 mm/min), a dominant martensitic structure was observed which was presented in Figure 2, where martensite, coarse ferrite and traces of bainite are visible.

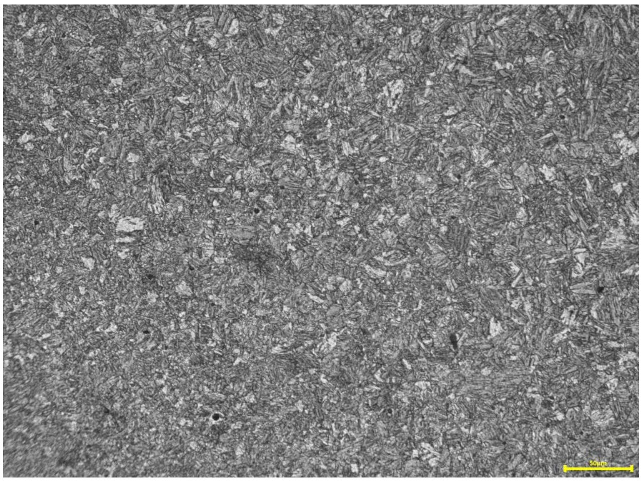

Figure 2 Microstructure of a MAG welded DOCOL 1400M steel weld made using shielding gas (82% Ar + 18% CO_2) at preheating temperature of 80°C and welding velocity of 300 mm/min

4. SUMMARY

In civil engineering and transportation, difficult to weld AHSS steels are materials gaining greater and greater recognition. Their high strength is almost twice the strength of the welded joint. The relative elongation of the processes used so far is rather low (approx. 6%). Therefore, new solutions are sought to guarantee the improvement of the weldability of thin-walled AHSS structures while allowing for the increase of temporary tensile strength and relative elongation. The tests indicate that preheating is required for making a proper 1400M DOCOL steel joint. A preheating temperature of 80°C is sufficient for thin-walled design. The welding velocity was also examined at 300 mm/min and 400 mm/min. In both cases, comparable results were obtained indicating that the welding velocity should range from 300 to 400 mm/min.

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BIBLIOGRAPHY

[1] Jaewon L., Kamran A., Jwo P., Modeling of failure mode of laser welds in lap-shear specimens of HSLA steel sheets, Engineering Fracture Mechanics 2011, 1, pp. 347-396.

[2] Darabi J., Ekula K., Development of a chip-integrated micro cooling device, Microelectronics Journal 2003, 34 (11), pp. 1067-1074, https://doi.org/10.1016/j.mejo.2003.09.010.

[3] Hadryś D., Impact load of welds after micro-jet cooling, Archives of Metallurgy and Materials 2015, 60(4), pp. 2525-2528, https://doi.org/10.1515/amm-2015-0409.

[4] Muszynski T., Mikielewicz D., Structural optimization of microjet array cooling system, Applied Thermal Engineering 2017, 123, pp. 103-110, https://doi.org/10.1016/j.applthermaleng.2017.05.082.

[5] Celin R., Burja J., Effect of cooling rates on the weld heat affected zone coarse grain microstructure, Metallurgical and Materials Engineering 2018, 24(1), pp. 37-44.

[6] Walsh S. M., Smith J. P., Browne E. A., Hennighausen T. W., Malouin B. A., Practical Concerns for Adoption of Microjet Cooling, ASME Proceedings 2018 Power Electronics, Energy Conversion, and Storage, https://doi.org/10.1115/IPACK2018-8468.

[7] https://www.yumpu.com/xx/document/view/11500058/docol-m-zimnowalcowana-stal-martenzytyczna-ssab.

[8] https://www.thyssenkrupp-steel.com/media/content_1/publikationen/grobblech_migration/perform/verarbeitung_1/schweissen_1/klassifikation_der_schweisszusaetze.pdf.