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Original article

Mag welding of duplex steel for the construction of antenna mounts

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ABSTRACT

The stainless steel must be treated as good material used to construction of antenna mounts. The duplex steel 1.4462 steel has a very good resistance to corrosion in an ambient and also in an elevated temperatures. The duplex steel is rather good weldable, although it is prone to various types of welding incompatibilities. Many factors influence quality of the weld. The goal of the paper is to study of the influence of main MAG welding parameters on creation of proper welds. A novelty in an article is the use of shielding gas mixtures with a very limited amount of oxygen (below 1% O2) in MAG welding. Welding duplex steels with a shielding gas mixture with a very low oxygen concentration was difficult until recently. It could be expected that new technological solution will allow to obtain a duplex joint with good corrosion resistance and good mechanical properties, which is important in antenna structures. The mechanical properties of several tested joints were investigated and the relationship between the oxygen content in the gas mixture and the oxygen content in the weld was determined.

Key words: *Welding, MAG, 1.4462 steel, Experiment, Thermal conditions*

1. INTRODUCTION

The paper presents the results of investigation leading to the selection of the correct MAG welding parameters of a thin-walled structure made of 1.4462 duplex steel (stainless material). Duplex steel could be treated as an important material in the construction of antenna mounts. Duplex steel is especially very proper material for antenna holders and towers due to their very high strength and anti-corrosive properties [1-2]. Other applications in the main industrial sectors are also popular. The weldability of duplex steel is still not well recognized [3-4]. Initially, these steels were welded using low-oxygen welding process and low nitrogen process welding processes (basic coated electrodes and TIG welding processes) [6]. Currently, thanks to the use of modern gas mixtures of argon, it is possible to weld these steels with MAG processes with gas mixtures of argon with oxygen or nitrogen below 1% of each gas. In order to get good quality of weld, it is necessary to carefully determine all welding

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parameters. The most important welding parameters in MAG process are [6-7]:

- type of filler materials,
- composition of shielding gas,
- beveling method,
- welding current,
- arc voltage,
- welding speed,
- additional thermal conditions.

Welding of 1.4462 duplex steel is rather more complicated task compared to austenite steel welding [8-9]. Welding of duplex stainless steel is slightly different from welding of austenitic stainless steel due to the bi-phase nature of duplex steel. This results in different principles leading to a properly made joint due to different metallurgical processes in the weld and different welding technology [10-11, 14].
Thicker duplex steel structures (above 4 mm) could have tendency to welding cracks. Incorrect selection of linear energy during duplex steel welding (especially above 1.3 kJ/mm) can contribute to forming different not beneficial inclusions, especially carbides and nitrides. To limit those negative structure in 1.4462 duplex steel (containing 0.034% C) in the MAG process, electrode wire are applied with a carbon content reduced to approx. 0.022% [6, 12, 13]. At the same time, it is recommended that the amount of carbide forming elements, especially such as Cr, must not increase in the electrode wire [13]. It is advantageous if there are more Ni and Mo in the electrode than the base material, as both elements are responsible for good plastic properties of the joint [6].

2. TESTED MATERIAL

Duplex sheet 1.4462 was chosen to create elements of an antenna mounts. The selection of process parameters included influencing of type of shielding gas mixture, welding current and speed. The main properties of the duplex steel and weld metal deposit (WMD) of the electrode wire MIGWELD 2209 (EN ISO 14343-A G 22 9 3 NL) are presented in the Table 1.

Table 1. Mechanical properties of duplex steel

Material	Yield strength (YS), MPa	Tensile strength (UTS), MPa	Elongation %
Duplex 1.4462	430	670	24
Wire	560	720	25

The composition of the duplex steel and the weld metal of tested electrode wire are presented in the Table 2.

Table 2. *Chemical composition of duplex steel 1.4462 and weld metal deposit of wire*

Chemical composition	C, %	Mn, %	Cr, %	Mo, %	Ni, %	Si, %	P, %	S, %
1.4462 duplex steel	0.035	1.9	21.8	2.8	6.4	0.9	0.029	0.019
Wire MIGWELD 2209	0.022	1.6	21.6	3	9	0.5	0.021	0.018

The table 2 shows that, apart from the carbon content, the chemical composition of the duplex steel and the wire is really similar. Shielding gas according to EN ISO 14175 standard should contain pure Ar or argon-oxygen mixtures up to max. 3% oxygen. In the article, it was decided to analyze the effect of very low oxygen content in shielding mixtures (below 1% O2), which so far were unattainable, because for a long time gas producers were not able to create mixtures with such small and precise additions of the second component of the gas mixture.

3. RESEARCH METHODS

The joints were made from duplex steel with a thickness of 3 mm in a flat position with standard V beveling (Fig. 1).

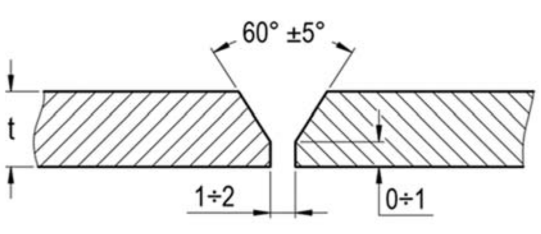

Fig.1 *Method of preparing metal sheets for welding*

After welding with various parameters, the samples for various tests were carried out. The joints were then assessed by certain NDT (non-destructivetest) and destructive testing. Visual tests and ultrasonic tests were carried out in accordance respectively with the EN:970/1999 and EN:1714/2002 standards. After that, the welded joints were checked also with the use of some destructive tests. A bend test was realized in accordance with EN:ISO-5173-201 standard, and the tensile test was done with PN-EN:ISO-6892-1/2020 standard. A hardness test was checked according to the EN:ISO 9015-1/2011 standard. The following duplex steel welding parameters have been selected:

- Uw = 18.5 V,
- Iw = 132 A,
- Vw = 317 mm/min

The bending test was performed based on the EN-ISO-5173-2010 standard. For the bending tests prepared 10 samples with a thickness of 3 mm, width of 6 and length of mm 10 mm. The mandrel diameter was 33 mm and a roll distance was 56 mm. The bending angle was 180°. Five measurements of joint bending from the face side of the weld and also 5 measurements of the weld from the root size.

The next point of the research included joint tensile tests. The measurements were carried out on the ZWICK 100N5A machine. The microstructure of welded joints was tested by Olympus microscopy (Light microscopy – LM). The analysis of the oxygen (as well as nitrogen) content in the weld was performed on the ON 736 Leco device.

4. RESULTS AND ANALISYS

The NDT results are presented in the Table 3. This table is summarizing sample observations as a first part of the tests.

Table 3. NDT observations

Specimen mark	Gas mixture	NDT results	Observations
D1	Ar	No cracks	the shape of the weld is too flat
D2	Ar + 0.25 % O_2	No cracks	the convexity of the weld curve increases as a function of the oxygen content
D3	Ar +0.5% O_2	No cracks	the convexity of the weld curve increases as a function of the oxygen content. Good weld shape.
D4	Ar +0.75% O_2	No cracks	optimal weld shape
D5	Ar +1% O_2	Small cracks	the weld is too narrow

The oxygen content in the Ar-O2 shielding mixture was gradually increased. The oxygen content at the level of 1% O2 was too high as there were small cracks in the weld. The joint shape was most appropriate when 0.5 O2 or 0.75% O2 was added to the argon gas mixture. The next stage of the research were bending tests, which were performed according to EN-ISO-5173-2010 standard. Bending tests results are presented in Table 4.

Table 4. Bending test observations

Specimen mark	*Gas mixture*	*Results*
D1	*Ar*	*small cracks*
D2	*Ar + 0.25 % O_2*	*No cracks*
D3	*Ar +0.5% O_2*	*No cracks*
D4	*Ar +0.75% O_2*	*No cracks*
D5	*Ar +1% O_2*	*small cracks*

The bending test results clearly show that the welded joints (tested samples D2, D3, D4) were made correctly, and that the welding parameters generally were correctly chosen. Minor cracks were observed in sample D1, which proves that the addition of oxygen to the argon shielding mixture is necessary. Cracks were again observed in sample D5. Only those samples with the best results after the bending test observations were selected for the next stage of research. Thus, In the next point of the investigation the samples (D2, D3, D4) were tested on the ZWICK 100N5A machine. The tensile strength results for the joints are presented in the Table 5.

The results of the tensile strengths were positive. Tested joints were characterized with a high value of ultimate tensile strength, much above the recommended value of 500 MPa (for antenna structures). In one case (D4), the result was even above 600 MPa, which proves perfectly selected welding parameters. The last stage of the work was to check the content of both occurring phases in the welded joint and compare this content with the base material (Fig 2).

Fig.2 shows that the base material (lighter shade) and weld have very similar contents of both phases (austenite and delta ferrite). The austenite grains in the base material and in the weld are also of a similar level. No welding defects and non-conformities were found, which proves a good welding process. Finally, it was decided to check the oxygen content in the weld metal depending on the type of gas mixture used. The oxygen content in the alloy was checked on a ON 736 Leco device. The test results are presented in Table 6.

Table 5. Tensile strenght of the joints

Specimen	UTS, MPa	Elongation, %
D2	585	23
D3	593	24
D4	602	24.5

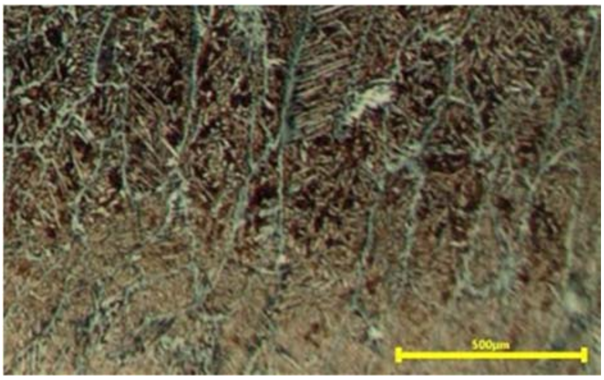

Fig.2 *Structure of the duplex connector (sample D4)*

By analyzing the table data, it can be easily noticed that with increasing oxygen content in the shielding gas mixture, there is a non-linear increase in the oxygen content in the weld metal deposit.

These results inspired the authors to check whether the relationship will be similar when nitrogen is added to the shielding argon gas mixture in similar contents. For this purpose, similar joints were made as in the part of the research on the influence of various small oxygen-containing mixtures.

Table 6. Oxygen content in WMD

Specimen mark	Gas mixture	O in WMD
D1	Ar	455 ppm
D2	Ar + 0.25 % O_2	460 ppm
D3	Ar +0.5% O_2	470 ppm
D4	Ar +0.75% O_2	485 ppm
D5	Ar +1% O_2	510 ppm

In this part of the research, it was decided to focus only on the relationship between the nitrogen content in the argon mixture and the nitrogen content in the weld metal. The test results are presented in Table 7.

Table 7. Nitrogen content in WMD

Specimen mark	Gas mixture	N in WMD
N1	Ar	55 ppm
N2	Ar + 0.25 % N_2	56 ppm
N3	Ar +0.5% N_2	59 ppm
N4	Ar +0.75% N_2	64 ppm
N5	Ar +1% N_2	65 ppm

By analysing the table data, it can be easily noticed that with increasing nitrogen content in the argon shielding gas mixture, there is a non-linear increase in the oxygen content in the weld metal deposit.
Adding nitrogen to argon is highly recommended as nitrogen is an austenitic factor and allows to control the relationship between the austenite and delta ferrite content in the base material and in the weld. This article only focuses on the presence of oxygen and gas mixtures. Tests on nitrogen content are only comparisons in the last point of the research.

5. CONCLUSION

Duplex steel structures are more and more often used for various antenna elements due to their high strength and good anti-corrosion properties. The paper analyses the weldability of duplex steel with the modern MAG process. The article focuses on the selection of shielding gas mixtures with very small amount of second component. Due to the possibility of obtaining mixtures with a very low content of the second component, the influence of oxygen (in the range of 0 to 1% O_2, stroke 2.5% O_2) on the weldability of duplex steels was checked. NDT studies have shown that oxygen should be introduced into the argon shielding mixture. Further destructive tests (bending, tensile strength, microscopic tests) showed that the most advantageous was the use of argon mixture containing 0.75% O_2.
According to the presented results, the following conclusions can be drawn:

- Pitting corrosion occurred due to welding.
- Welding consumable was selected correctly, enabling sufficient strength values.
- Preparation of the inside of the pipe in form of wire brushing caused creases to occur. These creases keep a certain amount of acidic cleaning agent, with relatively low concentration. After the evaporation of solvent, the concentration rises, becoming corrosive for the pipe material.
- During welding, the inside of the pipe was protected by shielding gas, however, an insufficient purging time caused the occurrence of heat tinting. This layer has a compromised corrosion resistance.
- After welding, passivation of heat tinting could have been performed, however, visual inspection proved that such treatment has not been done.

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REFERENCES

[1] Jaewson, L., Kamran, A., Jwo, P. (2011). Modeling of failure mode of laser welds in lap-shear speciments of HSLA steel sheets. Engineering Fracture Mechanics, Vol 1, p.p. 347-396.

[2] Darabi, J., Ekula, K. (2016). Development of a chip-integrated micro cooling device. Microelectronics Journal, Vol 34, Issue 11, pp. 1067-1074, https://doi.org/10.1016/j.mejo.2003.09.010.

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

[4] Golański, D., Chmielewski, T., Skowrońska, B., Rochalski, D., (2018). Advanced Applications of Microplasma Welding. Biuletyn Instytutu Spawalnictwa w Gliwicach, Vol. 62, Issue 5, p.p. 53-63. http://dx.doi.org/10.17729/ebis.2018.5/5.

[5] Skowrońska, B., Szulc, J., Chmielewski, T., Golański, D. (2017). Wybrane właściwości złączy spawanych stali S700 MC wykonanych metodą hybrydową plazma + MAG. Welding Technology Review, Vol. 89 (10), p.p. 104-111. http://dx.doi.org/10.26628/ps.v89i10.825.

[6] Silva, A., Szczucka-Lasota, B., Węgrzyn, T., Jurek, A., (2019). MAG welding of S700MC steel used in transport means with the operation of low arc welding method. Welding Technology Review, Vol. 91 Nr 3, PL ISSN 0033-2364, 23-30.

[7] Krupicz, B., Tarasiuk, W., Barsukov, V.G., Sviridenok, A.I. (2020). Experimental Evaluation of the Influence of Mechanical Properties of Contacting Materials on Gas Abrasive Wear of Steels in Sandblasting Systems. Journal of Friction and Wear, Vol. 41, Issue: 1, p.p. 1-5.

[8] Shwachko, V. l. (2000). Cold cracking of structural steel weldments as reversible hydrogen embrittlement effect. International Journal of Hydrogen Energy, no. 25.

[9] Fydrych, D., Łabanowski, J., Rogalski, G., (2013). Weldability of high strength steels in wet welding conditions. Polish Maritime Research, Vol 20(2(78), p.p. 67-73. https://doi.org/10.2478/pomr-2013-0018.

[10] Kosarac, A., Mladenovic, C., Zeljkovic, M., Tabaković, S., Knezev, M. (2022). Neural-Network-Based Approaches for Optimization of Machining Parameters Using Small Dataset. Materials 15 (3):700. DOI: 10.3390/ma15030700.

[11] Ramon, J., Basu, R., Voort, G. V., Bola, G. A. (2021). Comprehensive study on solidification (hot) cracking in austenitic stainless steel welds from a microstructural approach, International Journal of Pressure Vessels and Piping, 2021. Vol. 194. Part B. pp.104-560. https://doi.org/10.1016/j.ijpvp.2021.104560.

[12] Rogalski, G., Świerczyńska, A., Landowski, M., Fydrych, D., (2020). Mechanical and microstructural characterization of TIG welded dissimilar joints between 304L austenitic stainless steel and Incoloy 800HT nickel alloy. Metals. Vol. 10. No. 5. P. 559-570.

[13] Niedzielska, M., Chmielewski, T. (2017). HVOF spraying process conditions of coating Cr3C2-NiCr deposited onto 316L steel. Welding Technology Review. Vol. 89, No. 3. Mar. 2017.

[14] Szymczak, T., Makowska K., Kowalewski, Z.L., (2020). Influence of the welding process on the mechanical characteristics and fracture of the S700MC high strength steel under various types of loading. Materials, 13; 5249:1-17.10.3390/ma13225249.