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TIG WELDING OF 1.4462 DUPLEX STEEL IN ANTENNA AND CAR STRUCTURES

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Purpose: The aim of the article was to obtain high-quality connectors for the automotive industry and antenna structures.
Design/methodology/approach: For the welding joint the duplex steel and parameters of TIG welding process were chosen. The mechanical properties of the joint were carefully checked.
Findings: Relations between process parameters and the quality of welds.
Research limitations/implications: In the future, it can be suggested to investigate the effect of micro addition of nitrogen in gaseous shielding mixtures of the welding process.
Practical implications: The development allows to obtain high-quality welded joints made of duplex steel. The solution can be implemented in the automotive industry or for the production of antenna structures.
Social implications: Modifying the welding method will not affect the environment and production management methods.
Originality/value: The article is addressed to manufacturers of stainless steel for automotive industry and to manufacturers of antenna instrumentation.

Keywords: welding, 1.4462, duplex, automotive, antenna.

Category of the paper: Research or technical papers.

1. Introduction

The paper presents the results of tests leading to the selection of the TIG welding parameters of a structure made of 1.4462 duplex steel (stainless material). Duplex steel is an important material in the construction of transport and antenna means. The stainless steels can be used for car bodies, truck frames, and antenna elements (Fig. 1).

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Figure 1. Applications for superduplex stainless steel in seawater: Fasteners for rubber dock fenders (part b) (Francis, Burne, 2021).

Duplex steels could be used for antenna holders and towers due to their very high strength and anti-corrosive properties (Francis, Burne, 2021). The weldability of duplex steel depends on the selected process (Jaewson et al., 2011; Darabi, Ekula, 2016).

Mainly, these steels are connecting by low-oxygen welding processes (basic coated electrodes and TIG welding). Also it is possible to weld these steels with MAG, laser and with the tubular cored metal arc (136)-process (Hadryś, 2015). In order to get good results, it is necessary to carefully choose main welding parameters (Golański et al., 2018; Skowrońska et al., 2017; Szczucka-Lasota, Piwnik, 2017).

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

Duplex stainless steels usually contain more than 20% chromium and 9% of nickel (which can easily be found in a Schaeffler diagram, Fig. 2).

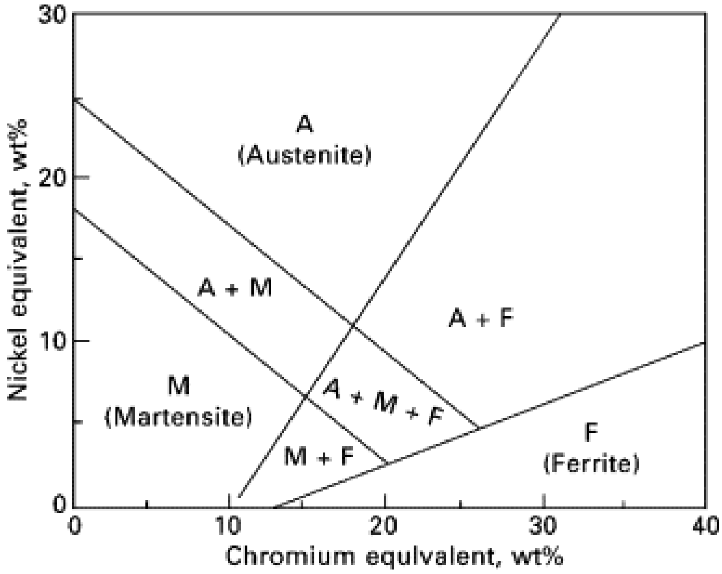

Figure 2. Schaeffler diagram (https://www.sciencedirect.com/topics/engineering/Schaeffler-diagram).

Due to the chemical composition, duplex steel can have 30% to 60% austenite in the delta ferrite. Super duplex stainless steels should contain approximately 50/50 austenite and ferrite in their structure. The small addition of nitrogen gives higher strength, better corrosion resistance, and improved weldability (Francis, Burne, 2021). Welding of 1.4462 duplex steel is treated as more complicated compared to austenite steel (Silva et al., 2019). Welding of duplex stainless steel is different from welding of austenitic stainless steel due to the different structure (the phase nature) (Shwachko et al., 2000; Fydrych, 2013; Szymczak et al., 2020)

The aim of the article is the use of an argon shielding mixture with a micro addition of nitrogen (much below 1%) for welding in the TIG process. Such mixtures have been produced for a short time and checking duplex steel welding with such a mixture can be treated as a material and technological novelty.

2. Materials

TIG welding process was chosen to the investigation regarding duplex steel welding. Table 1 shows the mechanical properties of the 1.4462 duplex steel.

Table 1.
Tensile strength of 1.4462 duplex steel

YS MPa	UTS, MPa	A5, %
430	670	23

Source: Golański, Chmielewski, 2018.

Corrosion resistance and good mechanical properties result from the chemical composition. High content of nickel and chromium (and equivalents) gives especially anti-corrosion and good plastic properties and also high strength by producing a beneficial structure consisting of austenite and delta ferrite (Table 2).

Table 2
Chemical composition of 1.4462 duplex steel

Material	C, %	Si, %	Mn, %	P, %	S, %	Ni, %	Cr, %	Mo, %
1.4462	0.029	0.91	1.94	0.027	0.18	9.7	22.9	2.9

Source: Golański D., Chmielewski T., 2018.

Chemical composition of 1.4462 duplex steel is rather similar with filler material composition AWS A5.9: ER 2209 (Tab. 3).

Table 3.
Wire 2209 – chemical composition

Material	C, %	Mn, %	Cr, %	Mo, %	Ni, %	Si, %	P, %	S, %
2209	0.026	1.8	23.1	3.2	9.1	0.8	0.027	0.018

Source: Shwachko V., 2000.

The comparison of table 2 and table 3 shows that the chemical composition of both materials is similar, which should translate into the formation of a ferritic-austenitic structure.

3. Research methods

The welded joints were made from duplex steel 1.4462 with a thickness of 4 mm in a flat position with V beveling. The groove shape and the method of arranging subsequent layers are shown on the Figures 3.

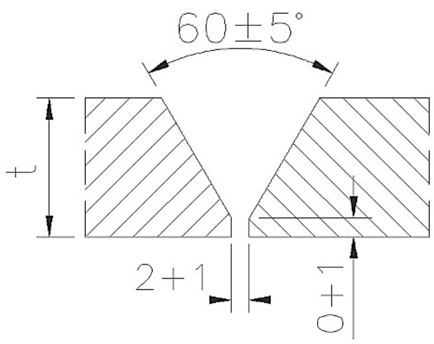

Figure 3. The groove shape and beveling method from the duplex steel 1.4462 o with a thickness t = 4 mm.

After making the TIG welded joints from duplex steel 1.4462 with a thickness of 4 mm with various parameters (different composition of shielding gas mixture), visual tests were realized in accordance with the PN-EN 970: 1999 standard. The tests aimed to verify the correctness and quality of the welds. The tests were extended with the results of non-destructive tests:

penetrant (PN-EN 571: 1999) and ultrasonic tests (PN-EN 1714: 2002). After that, all joints were seriously checked also with the use of main destructive tests. The bending test was performed in accordance with EN ISO 5173: 201 standard. The tensile test was carried out according to the PN-EN ISO 6892-1: 2020 standard and hardness test according to the PN-EN ISO 9015-1: 2011 and PN-EN ISO 6507-1: 2018-05 standards. The main welding parameters included:

- I_1 - current intensity of the first layer,
- U_1- arc voltage of the first layer,
- v1- welding speed of the first layer,
- I_n - current intensity of the next layers,
- U_n - arc voltage of the next layers,
- v_n - welding speed of the next layers,
- type of a shielding gas: Ar and gas mixture of Ar with small addition of N_2.

When laying the first layer, the current intensity I1 was modified in the range of 60-80 A, U1 - arc voltage in the range of 10-12 V and welding speed v1 in the range of 65 mm/min to 115 mm/min. The welds were made using direct current with negative polarity on the electrode. The shielding gas was argon with small addition of nitrogen. The gas flow rate was at the constant level of 13 l/min in all tested cases. Due to the proper shape of the root layer, it has been established that the best results are obtained when:

I_1 = 75 A,

U_1 = 11 V,

v_1 = 75 mm/min.

When laying next stitches, the current In was modified to the value of either 90 A or 120 A. The value of the arc voltage Un was always 11 V, based on the observations made while selecting the arc voltage for the first stitch. The welding speed v_n was also modified in the range from 65 mm/min to 115 mm/min. The influence of the current intensity, welding speed, and chemical composition of shielding gas is presented in Table 4.

Table 4.
The results of the NDT tests (non-destructive test)

Sample mark	Current intensity, A	Welding speed, mm/min	N_2 in shielding gas mixture, % ppm	Observation
S1	70	70	0	cracks
S2	70	70	0.3	cracks
S3	70	80	0	cracks
S4	70	80	0.3	positive
S5	80	70	0	positive
S6	80	70	0.3	positive
S7	80	80	0	positive
S8	80	0.3	0.3	positive
S9	90	70	0	cracks
S10	90	70	0.3	cracks
S11	90	80	0	cracks
S12	90	80	0.3	cracks

Source: own research.

Based on non-destructive observations (Table 4), the following conclusions were put down:

- occurrence of the small cracks in the case of poorly selected parameters,
- lack of any defects and incompatibilities for the B level (according to the PN-EN-ISO 5817: 2005) for joints made with low linear energy (samples S4, S5, S6, S7, S8),
- when creating joints, it is recommended to use a direct current with negative polarity on the electrode.

Only those welds which presented lack of incompatibilities energy (samples S4, S5, S6, S7, S8) were chosen for the bending test. For the analyzed welds, the bending test was carried out in accordance with the EN ISO-5173: 2010 standard. For the tests a sample with a thickness of a = 4 mm, width b = 10 mm, mandrel d = 34 mm and roll distance 60 mm was used, with the bending angle at 180°. 5 bending measurements were done both from the face and from the root side of the weld. In all tested cases, no cracks were found. results of the bending test show that the welded joints were made correctly, and that the welding. Thus, it can be assumed that bending tests confirmed that the joints were made correctly

The next part of the investigation included tensile strength test. The strength tests were realized on the ZWICK 100N5A testing machine. The results of the tensile strength of the joints (average of 3 measurements) are presented in the Table 5.

Table 5.
Tensile strengths of the tested joints

Sample	UTS, MPa	Elongation, %
S4	589	23
S5	587	23
S6	604	23
S7	569	22
S8	575	22

Source: own research.

The results of the mechanical tests must be treated as very positive. All welds are characterized with a high tensile strength above the recommended value of 500 MPa for the construction of stainless steel for automotive or antenna supports.

Next, the microstructure of the same tested welds (S4, S5, S6, S7, S8) was tested. Results are presented in Table 6.

Table 6.
Percentage of austenite in joints

Sample	Percentage of austenite, %
S4	40
S5	39
S6	40
S7	39
S8	40

Source: own research.

The dominant structure of the steel and the weld is delta ferrite. The structure results (table 6) indicate that nitrogen as an austenitic element slightly increases the austenite content in the weld. Due to the fact that an increase in the austenite content in the weld was observed, it was decided to check the nitrogen content in the weld, which was performed on the LECO ONH836 analyzer. The test results are presented in Table 7.

Table 7.
Nitrogen in weld metal deposit (WMD)

Sample	Nitrogen in WMD, ppm
S4	55
S5	50
S6	55
S7	50
S8	55

Source: own research.

From the analysis of the data in Table 6 and Table 7, it can be seen that the addition of 0.3% nitrogen to the argon shielding gas raises the nitrogen content to 55 ppm. The last part of the research was to measure the HV hardness in the central part of the weld. The tests were carried out for S4, S5, S6, S7, S8 joints, which were characterized with the lack of welding defects (Table1). The hardness in the base material (BM), heat effected zone (HAZ), and the weld (W) was observed. Test results, the average of 3 measurements, are presented in the Tab. 8.

Table 8.
Hardness distribution in the duplex joint

Sample	BM	HAZ	W
S4	274	298	281
S5	274	293	287
S6	274	295	289
S7	274	293	288
S8	274	292	289

Source: own research.

The hardness test results are positive. In all tested samples, a comparable hardness was found along the all tested areas of the joint. The hardness value did not exceed value of 300 HV.

4. Conclusion

In the paper, it was decided to analyze weldability of duplex 14462 steel with TIG process.

It was decided to carefully re-analyze the welding parameters, paying attention to the fusion layer and the remaining welds. It was noticed that the selection of the welding current intensity, welding speed and the composition of the shielding gas have a large impact on the quality of the welds. In the TIG process, active gases are rarely added to the argon. The article decided to study a small addition of nitrogen at the level of only 0.3%. This resulted in a more favorable metallographic structure and better mechanical properties of the joint. For this purpose, 12 joints were created with the use of different welding parameters. After NDT (non-destructive test) observations it was noted that only 5 joints (S4, S5, S6, S7, S8) were made correctly. During further destructive tests, only those joints were verified. After the bend test, it was noted, that all tested joints presented lack of cracks. Similarly, the analysis of the tensile strength proved the good mechanical properties of the duplex joint. The structure analysis showed that delta ferrite is the dominant phase and that austenite is on the level of 40%. Based on the performed investigation, the main conclusions were drawn:

- the TIG welding applied to create antenna supports or automotive elements allow to obtain joints with a good quality and good mechanical properties.
- better results were achieved using a shielding mixture containing 0.3 nitrogen in relation to the shielding gas, which was pure nitrogen.

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References

1. Darabi, J., Ekula, K. (2016). Development of a chip-integrated micro cooling device. *Microelectronics Journal, Vol. 34, Iss. 11,* pp. 1067-1074, https://doi.org/10.1016/j.mejo.2003.09.010.
2. Francis, R., Burne, G. (2021). Duplex stainless steels _ Alloys for the 21 Century. *MDPI, Metals, 11(5),* 836, https://doi.org/10.3390/met11050836.
3. Fydrych, D., Łabanowski, J., Rogalski, G. (2013). Weldability of high strength steels in wet welding conditions. *Polish Maritime Research, Vol. 20(2(78)),* 67-73. https://doi.org/10.2478/pomr-2013-0018.
4. Golański, D., Chmielewski, T., Skowrońska, B., Rochalski, D. (2018). Advanced Applications of Microplasma Welding. *Biuletyn Instytutu Spawalnictwa w Gliwicach, Vol. 62, Iss. 5,* 53-63. http://dx.doi.org/10.17729/ebis.2018.5/5.
5. Hadryś, D. (2015). Impact load of welds after micro-jet cooling. *Archives of Metallurgy and Materials, Vol. 60, Iss. 4,* pp. 2525-2528, https://doi.org/10.1515/amm-2015-0409.

6. https://www.sciencedirect.com/topics/engineering/schaeffler-diagram.
7. 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,* pp 347-396.
8. 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, Iss, 1,* pp. 1-5.
9. Shwachko, V.L. (2000). Cold cracking of structural steel weldments as reversible hydrogen embrittlement effect. *International Journal of Hydrogen Energy, no. 25*.
10. 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, No. 3,* PL ISSN 0033-2364, 23-30.
11. 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),* 104-111. http://dx.doi.org/10.26628/ps.v89i10.825.
12. Szczucka-Lasota, B., Piwnik, J. (2017). New technological concept for thermal spray protective coatings. *Arch. Metall. Mater., vol. 62.* DOI: 10.1515/amm-2017-0232.
13. 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.