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MIG WELDING OF AUSTENITIC 316L STEEL USED IN MEANS OF TRANSPORT

Summary. The austenitic 316L steel (1.4401) is an important stainless material used to build various means of transport. Austenitic steel has high resistance to atmospheric corrosion. The austenitic steel is treated as a good weldable material, although cracks are possible. This paper analyses the influence of various MIG welding parameters on the creation of correct joints used in the stainless steel structures of mobile platforms elements, as an example of welding structures, in various means of transport. Various tests verifying the mechanical properties of MIG welds, including non-destructive tests, tensile strength and hardness tests, were carried out. This article aims to show how important and complex the task is to select the correct welding parameters for elements of means of transport made of austenitic steel on the example of elements of mobile platforms.

Keywords: civil engineering, transport, mobile platforms, MIG welding, 316L steel

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1. INTRODUCTION

Austenitic steels are used in the construction of various means of transport. It is often used in the automotive industry, especially where high corrosion resistance and durability of various structural elements are strongly required [1]. Besides its high corrosion resistance, the possibility of producing visually attractive surface finishes influences its important application in the automotive industry. High impact toughness of austenitic steels makes it possible to use them in the crush zones elements of cars. Further, austenitic steel is also used in the construction of road tankers [2]. Examples of austenitic steel components in the automotive industry include serious applications [3]:

- housings of catalysts and turbochargers;
- chassis, trucks and buses, construction elements;
- components of catalysts;
- components of turbochargers (rotor);
- suspension elements, arms;
- rims and wheel rims;
- safety cages;
- vehicle tanks;
- car body components (controlled crumple zones);
- mobile platform bracket;
- external and internal decorative elements.

An example of austenitic welded elements of a mobile platform exposed to stress and corrosion (an example of a specific means of transport) is shown in Figure 1.

Fig. 1. Welded elements of a mobile platform bracket

Various grades of steel play important roles in the construction of different means of transport [4]. Austenitic 316 L steel is often applied for the stainless structure of mobile platforms. To obtain the desired properties of austenitic steels, their chemical composition is changed by adding various alloying elements such as Ni, Cr, Mo, Ti, and Nb. Nickel increases impact toughness, chromium increases strength, manganese increases tensile strength without reducing plastic properties, and molybdenum increases creep resistance. Sulfur and phosphorus reduce the plastic properties but improve the machinability of the steel. However, the steel tends to crack when welding parameters are poorly selected. Incorrect selection of the process might lead to the formation of various types of non-metallic inclusions such as carbides (for instance

$M_{23}C_6$, where there is a large proportion of chromium) [5-6]. The presence of non-metallic inclusions in an austenitic weld provokes cracks because of intercrystalline corrosion [7]. Cracks in austenitic mobile platform structures might occur when too much heat is introduced during welding. Single-phase austenitic steels have a stronger tendency to hot crack than austenitic steels with even a small amount of delta ferrite (4-7%). The biphase structure of weld is more favourable [8-9]. The presence of delta ferrite in the joint limits the amount of unfavourable oxide inclusions affecting the joint ductility (higher solubility) [10-12]. Preheating of austenitic steels is not necessary, but due to the risk of hot cracking, the interpass temperature must be limited below 110°C for fully austenitic steels and up to 140°C for stainless steel containing even small amounts of delta ferrite [13-16].

2. RESEARCH MATERIALS

Austenitic 316L sheet was used to create elements of a mobile platform bracket. The selection of welding technology parameters included determining of weld geometry and current-voltage parameters. 316L steel was used to assess the weldability by the MIG process. Information on additional 316L steel marks is presented in Table 1.

Tab. 1

316L steel – the equivalents according to various standards

PN	According to standard	EN	AISI
00H17N14M2	1.4404	X2CrNiMo17-12-2	316L

The mechanical properties of the austenitic 316L steel is presented in Table 2.

Tab. 2

Mechanical properties

Material	Yield strength (YS), MPa	Tensile strength (UTS), MPa	Hardness
316L	250 MPa	600 MPa	190 HB

Weld metals for welding of austenitic steels have a structure and chemical composition similar to the base material and are included in the standards: EN 1600, EN ISO 14343, and EN ISO 17633. For TIG welding, an additional filler material was used: Lincoln LNT 316L in a cylindrical shape with a diameter of 2.4 mm and length of 500 mm. The chemical composition of 316L steel and the weld metal of the two tested electrode wires are presented in Table 3. Welding wire MIGWELD 316 L wire (EN ISO 14343-A) has a lower carbon content and welding wire MIGWELD 319Si EN ISO 14343-A (N ISO 14343-AG 19 12 3 NbSi) is characterized by a carbon content that is twice higher. Chemical composition of the steel and weld metal deposit of the two tested electrode wires are presented in Table 3.

Tab. 3

Chemical composition of the steel 316L and weld metals of two tested wires

Chemical composition	C, %	Mn, %	Cr, %	Mo, %	Ni, %	Si, %	P, %	S, %
Steel 316 L	0.07	2	18.5	2.5	13	1	0.045	0.015
MIGWELD 316Si	0.025	1.75	19	2.75	11.5	0.7	0.015	0.015
MIGWELD 318NbSi	0.05	1.8	19	2.8	12	0.8	0.015	0.015

The table data shows that, apart from the carbon content, the remaining chemical composition of the steel and the filler material is similar. This means that the selection of wires is correct. Only the difference in carbon content in all three cases presented is noteworthy because the connection of carbon determines the phase character of the weld.

3. RESEARCH METHODS

The welded joints were made from 316L steel with a thickness of 6 mm in a flat position with V bevelling. The groove shape and method of arranging subsequent layers are shown in Figure 2.

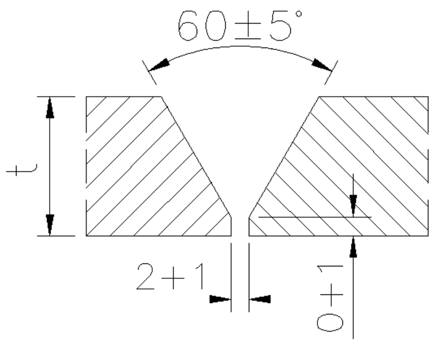

Fig. 2. The groove shape and bevelling method from the 316 L steel
with a thickness t = 6 mm

After making the MIG welded joints from 316L steel with a thickness of 8 mm with various parameters (different linear energy of the process), visual tests were used following the PN-EN 970: 1999 standard. The tests aimed to verify the correctness of the joints, identify any defects and incompliances in the form of cracks and elimination of incorrectly prepared joints. The tests were extended with the results of non-destructive tests: penetrant (PN-EN 571: 1999) and ultrasonic (PN-EN 1714: 2002). Thereafter, all welds were carefully checked with the use of some destructive tests. The bending test was carried out following the EN ISO 5173: 201 standard. The tensile test was performed following the PN-EN ISO 6892-1: 2020 standard and hardness was carried out test following the PN-EN ISO 9015-1: 2011 and PN-EN ISO 6507-1: 2018-05 standards. Argon was chosen as a shielding gas. The diameter of the electrode wire was 1 mm. The most important changing welding parameters included:

I_1 - current intensity while laying the first layer,

U_1- arc voltage while laying the first layer,

v_1- welding speed when laying the first layer,

I_n - current intensity while arranging subsequent layers,
U_n - arc voltage while arranging subsequent layers,
v_n - welding speed while arranging subsequent layers,
type of current/polarity (+, ~).

When laying the first layer, the current intensity I_f was modified in the range of 140 A - 175 A, U_1 - arc voltage in the range of 19 V - 21 V and welding speed v_1 in the range of 360 to 440 mm/min. The welds were made using alternating current and direct current with negative polarity on the electrode. The shielding gas was always argon. The gas flow rate was at the constant level of 13 l/min. Due to the geometrical features of the first stitch (the shape of the root layer) and the absence of welding defects, it has been established that the best results are obtained when:

- I_1 = 150 A,
- U_1= 20 V,
- v_1 = 390 mm/min.

When arranging subsequent stitches, the current I_s was modified to the value of either 150 A or 185 A. The value of the arc voltage U_n was kept constant at the value of 20 V, based on the observations made while selecting the arc voltage for the laying of the first stitch (U_1 = 20 V). The welding speed v_n was also modified in the range from 360 to 440 mm/min. The influence of the type of current (alternating or direct with positive polarity at the electrode) was also investigated. Due to the differences of the carbon content in the steel and in the welding wires, which could cause a formation of delta ferrite in the weld (Table 3), it was decided to control the temperature of the interpass layers not exceeding the value of 140°C. The results of the NDT tests (non-destructive test) are presented in Table 4.

Tab. 4

Mechanical properties of the tested joints

Sample mark, Electrode wire	Parameters of the lower stitch pattern/Type of current, polarity	Parameters of the upper stitches pattern/Type of current, polarity	NDT results, observation
P1, MIGWELD 316Si	U_1=20 V I_1=150 v_1= 390 mm/min „~”	U_n=20 V I_n=150 A and 185 A v_n= 440 mm/min „~”	cracks in the weld
P2, MIGWELD 316Si	U_1=20 V I_1=150 v_1= 390 mm/min „~”	U_n=20 V I_n=160 A V_n= 400 mm/min „~”	cracks in the weld
P3, MIGWELD 316Si	U_1=20 V I_1=150 v_1= 390 mm/min „~”	U_n=20 V I_n=160 A V_n= 360 mm/min „~”	cracks in the weld
S4, MIGWELD 316Si	U_1=20 V I_1=150 v_1= 390 mm/min, „+„	U_n=20 V I_n=160 A v_1= 360 mm/min „+„	no cracks

S5, MIGWELD 316Si	U_1=10 V I_1=150 v_1= 390 mm/min, „+”	U_n=20 V I_n=180 A v_1= 400 mm/min „+„	no cracks
S6, MIGWELD 316Si	U_1=10 V I_1=150 v_1= 390 mm/min, „+”	U_n=20 V I_n=180 A v_1= 440 mm/min „+„	cracks in the weld
P7, MIGWELD 318Si	U_1=20 V I_1=150 v_1= 390 mm/min „~”	U_n=20 V I_n=150 A and 185 A v_n= 440 mm/min „~”	cracks in the weld
P8, MIGWELD 318Si	U_1=20 V I_1=150 v_1= 390 mm/min „~”	U_n=20 V I_n=160 A V_n= 400 mm/min „~”	cracks in the weld
P9, MIGWELD 318Si	U_1=20 V I_1=150 v_1= 390 mm/min „~”	U_n=20 V I_n=160 A V_n= 360 mm/min „~”	cracks in the weld
S10, MIGWELD 318Si	U_1=20 V I_1=150 v_1= 390 mm/min, „+„	U_n=20 V I_n=160 A v_1= 360 mm/min „+„	no cracks
S11, MIGWELD 318Si	U_1=10 V I_1=150 v_1= 390 mm/min, „+”	U_n=20 V I_n=180 A v_1= 400 mm/min „+„	no cracks
S12, MIGWELD 318Si	U_1=10 V I_1=150 v_1= 390 mm/min, „+”	U_n=20 V I_n=180 A v_1= 440 mm/min „+„	cracks in the weld

Based on the non-destructive tests (Table 4), the following conclusions were drawn:

- occurrence of small cracks in the case of poorly selected parameters,
- lack of defects and non-conformities for the B level (according to PN-EN ISO 5817: 2005) for joints made with correctly chosen parameters (samples S4, S5, S10),
- when creating joints, it is recommended to use a direct current with positive polarity on the electrode,
- welding speed must not exceed 400 mm/min,
- better welding results are achieved by welding wire with lower carbon content.

Only those joints, which presented a lack of defects and non-conformities for level B (samples S4, S5, S10) were selected for further tests (bending test). For the analysed joints, the bending test was carried out following the EN ISO 5173: 2010 standard. For the tests, a sample with a thickness of a = 8 mm, width b = 12 mm, mandrel d = 36 mm and roll distance 54 mm was used, with the bending angle at 180°. Five bending measurements were taken from the face and the root side of the weld. In all tested cases, no cracks were found in the weld at the bending angle of 180°. The results of the bending test show that the welded joints were made correctly and that the welding parameters were properly selected.

The next stage of the research included immediate tensile strength test. The strength tests were carried out on the ZWICK 100N5A testing machine. The results of the performed mechanical tests of the joints (average of 3 measurements) are presented in Table 5.

Tab. 5

Mechanical properties of the tested joints

Sample	UTS, MPa	Elongation, %
S4	531	26
S5	534	26
S10	567	24

The results of the mechanical tests are positive. All joints are characterized by a high temporary tensile strength above the recommended value of 500 MPa for the construction of stainless steel mobile platform supports. For joints made with electrode wire with a higher carbon content, slightly increased UTS was observed. This results in a slight decrease in the relative elongation. The next part of the investigation was connected to the microscope observations. The microstructure of the S10 weld, which is characterized by the most favourable UTS (compared to the S4 and S5 joints), is presented (Figure 3).

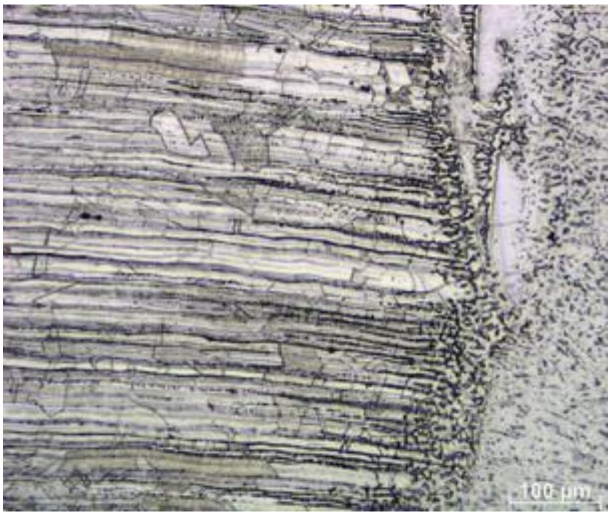

Fig. 3. The structure of the joint (S10) made of 316 L steel, electrolytically etched with 10% oxalic acid

The dominant structure of the 316L steel is austenite; however, a two-phase structure (austenite-delta ferrite) is visible at the fusion line. The delta ferrite phase is clearly visible between the austenitic arms of the dendrites. As a result of properly selected process parameters, delta ferrite has a beneficial fine-grain character. The last stage of this research was the HV hardness test in the central part of the weld. The tests were carried out for S4, S5, and S10 joints (samples), which were characterized by the lack of welding defects. The hardness in the base material (BM), heat affected zone (HAZ), and the weld (W) were verified. Test results, the average of 5 measurements, are presented in Table 6.

Tab. 6

Hardness distribution in the welded joints

Sample	BM	HAZ	W
S4	171	189	183
S5	172	191	185
S10	171	197	192

The hardness test distribution is very positive. In all cases, a comparable hardness was found along all areas of the joint (base material, heat affected zone, weld). The hardness value did not exceed 200 HV.

For joints made with electrode wire with a higher carbon content, a slightly increased hardness was observed.

4. CONCLUSION

Welded joints in automotive structures must have very good mechanical properties. Because austenitic steel is prone to cracking, the entire technological process should be prepared very carefully so that there are no welding defects and imperfections. The test results confirmed that the selection of welding parameters for the 316L steel is complicated. Increasingly, austenitic steels are being used in the construction of various means of transport. In this paper, the possibility to produce welding mobile platform supports made of austenitic 316L was analysed. For this purpose, 12 test joints were created with the use of different MIG welding parameters. First, NDT (non-destructive test) tests were carried out. It was observed that only three austenitic joints (S4, S6, S10) made with carefully selected welding parameters were done with good quality. Thereafter, after further destructive tests, it was observed that only joints without welding defects and incompatibilities (S4, S6, and S10) were verified. During the bend test, all tested joints presented a lack of cracks. Next, the analysis of immediate tensile strength proved the good mechanical properties of the joints: UTS and relative elongation. The structure analysis showed that delta ferrite may be formed near the fusion line. The biphase structure of the weld (approx. 95% austenite - 5% delta ferrite) is more favourable than the single-phase austenitic structure, which is more susceptible to hot cracking.

Subsequently, it was concluded that the MIG welding parameters were chosen correctly, allowing to obtain joints with acceptable mechanical properties. Based on the performed research, the following conclusions were submitted:

- 316L steel could be treated as a suitable material for welded structures of elements of means of transport,
- the selection of welding parameters is difficult in the case of welding austenitic steels,
- the best results are achieved when MIG welding with a direct current with positive polarity on the electrode,
- the use of a material filler with a lower carbon content than 316L steel may lead to the formation of 3-5% delta ferrite at the melting line, which improves the weldability,
- the correct selection of the main MIG welding parameters (current, arc voltage and speed) allows obtaining safe structures for use in the automotive industry,
- the MIG welding applied to create mobile platform supports allows obtaining welds with good quality.

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