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WELDING OF 1.4462 DUPLEX STEEL USED IN MEANS OF ROAD TRANSPORT

Summary. Materials with good mechanical and chemical properties (materials should be resistant to various types of corrosion) are proposed for the various structures of means of transport. For this reason, high-alloy steels, including duplex steels, are increasingly used in the automotive industry. The 1.4462 duplex steel used in means of road transport steel could be treated as an interesting high-strength stainless material used in the automotive industry. Generally, duplex steels have a high resistance to localized and uniform corrosion. The duplex and superduplex steels are assumed to be rather proper weldable materials; however, cracks could be observed both in the heat-affected zone (HAZ) and in the weld. The article analyses the influence of tubular cored metal arc (136) with active gas shield welding (process 136) parameters on the arrangement of correct joints used in tanker truck elements, as an example of welding in the automotive sector. Various mechanical tests checking the properties of joints were realized. The goal of the paper is to choose the correct welding parameters for elements of 1.4462 steel. The construction elements of a tanker truck are made by the 136 method of welding.

Keywords: civil engineering; transport; tanker truck; tubular cored metal arc welding; 1.4462 duplex steel

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1. INTRODUCTION

Duplex and superduplex steels are used in the structure of various means of road transport. Stainless steels are used in transport because of their good corrosion resistance and also because of the durability of important structural elements [1]. In the automotive industry, highly aesthetic aspects of the connections made, which ensure a constant duplex, are important. Corrosion is a continuing problem in the construction of vehicles and other modes of transport. New trucks and trailers are subject to corrosion because the construction materials used, do not have good corrosion resistance. Sometimes the degradation time is very short. Corrosion products on vehicle structures can be observed after only six months of exploitation time. Examples of corrosion damage in the construction of heavy goods vehicles are shown in Figure 1.



Fig. 1. An example of corrosion damage in elements of a heavy vehicle structure

Gradual destruction processes, such as corrosion, may cause various types of damage to means of transport. Non-invasive methods can be used to diagnose them, especially in places inaccessible for optical evaluation, for example vibroacoustic methods [2-4].

For the construction of structural elements of various types of trucks, austenitic stainless steel and duplex steel should be used to a greater extent. Duplex steel is characterized by higher strength than austenitic steel and is used for more responsible structural elements. The good impact toughness of duplex and superduplex steels is an additional advantage [5].

Examples of duplex steel components in the automotive industry include various applications [6]:

- chassis;
- housings of catalysts and turbochargers;
- components of turbochargers (rotor);
- arms;
- safety cages;
- tanks;
- car body and frames;
- mobile platform elements;
- various decorative elements.

Duplex steel is also used in the construction of motor vehicles and motorcycles (Fig. 2).



Fig. 2. Welded duplex steel elements in the motor vehicle

Stainless steels play an important role in various construction projects in the automotive sector. [7]. Duplex 1.4462 steel is mainly suggested for the stainless structure of truck tankers. [8, 9]. The presence of various nonmetallic inclusions in the austenitic-ferritic weld could provoke cracks as a result of corrosion [10]. The biphasic structure (highly redounded: 50% austenite and 50% of ferrite delta) of the weld is more favorable than the austenitic structure [11, 12], however the duplex steel could also have a tendency to crack when welding parameters are incorrectly chosen [13-15]. Preheating before welding of 1.4462 steels is not necessary for thin structures below 20 mm [16-20]. A 12 mm-thick sheet metal was used in the construction of the tanker truck, so the role of preheating was not analyzed in this paper.

2. RESEARCH MATERIALS

Duplex 1.4462 steel sheet was chosen for elements of a truck tanker. The choice of process parameters included the geometry of the weld and current-voltage parameters. Duplex 1.4462 steel was welded by the tubular-cored metal arc process (136 method). The information on duplex 1.4462 steel and its mechanical properties is presented in the Table1. The filler material has a similar composition to the base material. The chemical composition and properties of those materials are included in the standards: EN-ISO-14343, EN-ISO-17633. For tubular-cored metal arc welding (KOBELCO DW-329AP) and other additional materials are recommended by (ISO 17633-A).

Tab. 1

Base material properties

Material	(YS), MPa	(UTS), MPa	Elongation, %	Hardness
1.4462	440	680 MPa	25	260 HB

The chemical composition of the duplex steel and the weld metal deposit is presented in Table 2.

Tab. 2

Base material and filler material composition

Comp.	C, %	Mn, %	Cr, %	Mo, %	Ni, %	Si, %	P, %	S, %
1.4462 duplex steel	0.03	1.91	21.53	2.81	6.41	0.91	0.029	0.019
KOBELCO DW-329AP filler material	0.03	0.78	22.93	3.46	9.51	0.59	0.019	0.008

The table data shows that chemical compositions of both materials are similar. This means that the selection of filler material is correct.

3. RESEARCH METHODS

The tested joints were prepared from 1.4462 steel with a thickness of 12 mm. A flat position with V beveling was chosen. The groove shape and other details are shown in the Figure 3 and Figure 4.

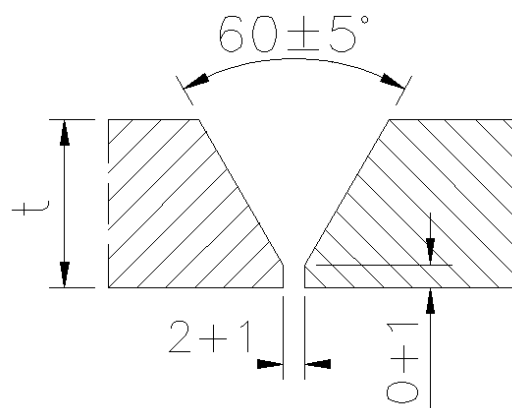


Fig. 3. The groove shape and beveling method, thickness $t = 12$ mm

The tabular core welding (136) process is similar to the MAG welding process. The sequence of laying subsequent layers of the joint is shown in Figure 2. In the case of welding steel in the MAG process, current-voltage parameters are often set that are different for each stitch. Process 136 seeks to ensure that all seam beads laid are made to the same parameters (Fig. 4).

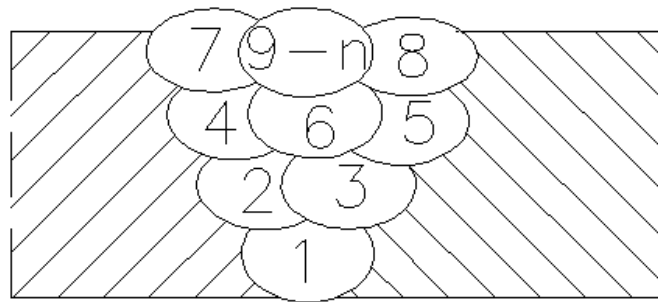


Fig. 4. The order of laying the weld beads from the 1.4462 duplex steel

Welding was not a complicated process, and the welding process proceeded correctly. Joints were prepared with various shielding gases. Another important parameter was welding speeds. After welding, some non-destructive tests (NDT) and some destructive tests were carried out.

Visual tests were done according to EN 970: 1999 standard. The magnetic-powder tests were done according to the EN 571: 1999 norm. The ultrasonic test was done by EN 1714: 2002 norm.

The tests aimed to identify defects and noncompliance in the weld. The obtained result allows for the elimination of incorrectly prepared welds.

After that, all welds were checked with destructive tests. The bending test was realized using the EN ISO 5173: 201 standard. The tensile strength test was prepared according to the EN ISO 6892-1: 2020 standard. Finally, the hardness test was studied according to the EN ISO 9015-1: 2011 standards. Three different argon gas mixtures were taken as shielding gases. The diameter of the filler material was 1.2 mm. Three shielding gases were used in the experiments (recommended by the EN ISO 14175 standard):

- Corgon 10 (gas mixture: 90% Ar + 10% CO₂);
- Corgon 18 (gas mixture: 82% Ar + 18% CO₂);
- Corgon 25 (gas mixture: 75% Ar + 25% CO₂).

The welding process has the following main parameters:

- current intensity was 140 A; 150 A and 170 A,
- arc voltage was always 21 V
- The flow rate was at 13 l/min.
- welding speed was mainly 250 mm/min,
- but at the end of all tests, the effect of welding speed was also checked at a slightly higher and lower level (respectively 200 mm / min and 300 mm / min).

In the MAG welding process and in tubular core welding (136), it is important to select the welding current source. To evaluate the joint made of duplex XXX steel, a direct current welding method with “+” polarity on the electrode was chosen. At the end of the research, it was decided to additionally compare the direct current (DC) with the alternating current (AC) (assuming that DC welding is the main choice).

The welds were made using DC with “+” polarity on the electrode. The results of the non-destructive tests after welding are presented in Table 3.

Tab. 3

NDT results

Sample symbol	Shielding gas	Welding current, A	Observation
A10	Corgon 10	140	cracks in the weld
A18	Corgon 18	140	no cracks
A25	Corgon 25	140	cracks in the weld
B10	Corgon 10	150	no cracks
B18	Corgon 18	150	no cracks
B25	Corgon 25	150	no cracks
C10	Corgon 10	170	cracks in the weld
C18	Corgon 18	170	no cracks
C25	Corgon 25	170	cracks in the weld

Analysing data in Table 3, it can be concluded that:

- in the joint, the 0,2 - 0,5 mm length of cracks is observed when the welding parameters were poorly selected.
- joints A18, B10, B18, B25, C18 were characterized by a lack of defects.
- the results indicated, that a welding current of 150 A is the most appropriate.

Only those joints without defects (samples A18, B10, B18, B25, C18), were chosen for the bending test (EN ISO 5173: 2010 standard). The bending angle was 180°. Five bending measurements were taken both from the root and face sides. The results of the bending were positive and show that the welded joints were made correctly. The welding parameters in the mentioned cases were properly chosen.

The next step of the investigation included another destructive test: tensile strength. The measurements were done on the ZWICK 100-N5-A machine. The results of the tests (average of three measurements) are presented in the Tab. 4.

Tab. 4

Tensile test results

Sample	UTS, MPa	Elongation, %
A18	592	23
B10	624	23
B18	657	24
B25	626	24
C18	598	23

The results for tensile strength are positive. The recommended value of the temporary tensile strength for the construction of a tanker is 550 MPa. All joints are above the recommended value. It can be noticed that the B18 joints made in an argon shield gas mixture containing 18% CO₂ have the highest strength (marked in green colour).

The purpose of the analyses was to determine the oxygen content in the weld using the LECO ON-H-836 analyzer. The oxygen amounts in weld are presented in Table 5.

Tab. 5.
Oxygen in welded metal deposit (WMD)

Sample	Mixture	Oxygen in weld, ppm
B10	Ar + 10% CO ₂	410
B18	Ar + 18% CO ₂	460
B25	Ar + 25% CO ₂	520

The table data shows that various oxygen contents in the welded metal were possible in terms of the kind of gas mixture. The oxygen content influences the phase changes during the weld formation. The oxygen in the weld is rather present in various oxides, the shape and size of which depend on the total oxygen amount in the weld. On contact with oxides, austenite nucleates during the transformation of delta ferrite. In the case of welding duplex steels, the oxygen amount in the weld at the level of 460 ppm is the most advantageous, which corresponds to the best strength properties (tab. 4). Having information about the oxygen content in the welded metal, it was decided to evaluate the metallographic structure. The dominant structures were austenite (brighter color), delta ferrite (matrix) and some non-metallic inclusions (Fig. 5).

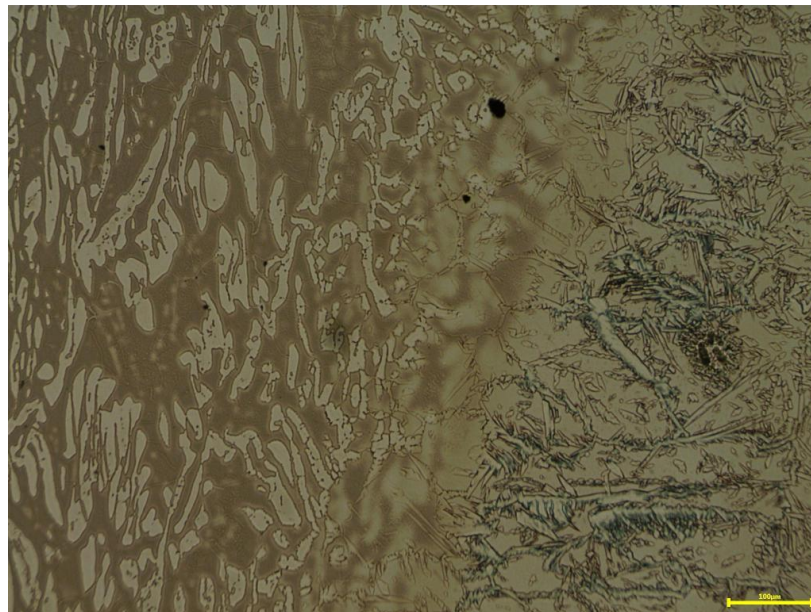


Fig. 5. A microstructure of the joint (B18) made of 1.4462 duplex steel, the weld is situated on the left and the joint is welded on the right

The figure indicates that the austenite grains in the weld are finer than in the base material. It is worth noting that, thanks to well-chosen welding parameters, the difference in the austenite grain size between the base material (BM) and the weld (W) is very small.

As a result, the properties of the joint of the base material and the weld should be comparable, which will be confirmed by hardness tests. Figure 6 shows a fragment of the last joint layer (face) under a larger magnification.

In the ferritic matrix, the austenite grains have different sizes. For the best strength, it is most advantageous; the average austenite size is 40 μm . Such a dominant grain size was obtained for sample B18. The microstructure result corresponds with the tensile strength of the tested sample (Table 4). A much smaller amount of austenite grain was obtained for the B10 and B25 samples. These samples were made by welding with an argon gas mixture containing 10% CO_2 or 25% CO_2 . The average size of austenite grains was about 40 μm (Fig. 3). There were also observed precipitations, mainly MnO and MnS and carbides, or carbonitrides.



Fig. 6. A microstructure of the weld (B18)

Finally, the HV hardness test was done in the central part of the weld (B18). This sample is the most advantageous joint from the studied group. The hardness of all important zones was analyzed, i.e., in the base material (BM), the heat affected zone (HAZ), and the weld (W). The results are presented in Table 6.

Tab. 6

Hardness of the joint B18

Sample	BM	HAZ	W
B18	260	273	246

The results of the hardness test should be considered very positive. It was noticed that the hardness distribution was comparable in the main zones of the joint. The hardness value did not have a higher value than 280 HV, which is very beneficial for producers of duplex steel.

The results of current research on the B18 joint are very satisfactory; therefore, it was proposed to additionally check the influence of the linear energy on the tensile strength and the hardness. For this suggestion, new joints with various speeds were made. The results of that test are shown in Table 7.

Tab. 7

Tensile results for a B18 joint made with various welding speeds

Sample	Welding speed, mm/min	UTS, MPa	Elongation, %
B18	200	639	22
B18	250	657	24
B18	300	642	23

The best results were obtained if the welding speed was 250 mm/min. All other tested joints were welded at this speed (A10, A18, A25, B10, B18, B25, C10, C18, C25). This is evidence of a well-planned experiment. The welding speed is one of the important parameters that has an impact on the tensile strength value. It was also suggested to compare the effect of the welding speed on hardness (Tab. 8).

Tab. 8

Hardness distribution in the welded joints B18

Welding speed, mm/min	BM	HAZ	W
200	260	288	251
250	260	273	246
300	260	283	260

The study of the hardness distribution in the joint showed that the welding speed may affect the test results. As in the previous case, the best hardness test results correspond to a welding speed of 250 mm /min. This is another confirmation of a well-planned experiment for all tested samples (A10, A18, A25, B10, B18, B25, C10, C18, C25). The last step of the research was an additional comparison of the properties of a B18 joint made with direct and alternating current. In the welding processes, the same current-voltage parameters were used. It was assumed, that direct current welding was the main test method. All results are presented in Table 9.

Tab. 9

Hardness distribution

Type of welding current	BM	HAZ	W
Direct current	260	260	273
Alternating current	260	292	241

It turned out that welding with alternating current leads to large disproportions in the hardness of individual parts of the joint, so the authors do not recommend the welding process of duplex steel with alternating current should.

4. CONCLUSION

Welded constructions for transport (automotive) applications should have very good mechanical and chemical properties. The corrosion process must be considered when the construction of transport means is planned. Hence, there is a growing interest among vehicle designers in new materials and technologies. The article presents an important group of steels, which is Duplex steel 1.4462 and a new welding technology (136), which allows obtaining a joint of excellent quality.

Due to the fact, that Duplex steel may be prone to welding cracking, the complete process should be planned carefully to avoid welding defects and incompatibilities.

Welding of 1.4462 duplex steel has been tested for the construction of the truck tanker. The innovative welding process, (with tubular-cored metal arc, welding method 136) was tested. The most important welding parameters were checked, especially the value of welding current and the kind of shielding gas mixtures. The main non-destructive tests and the destructive tests played an important role in research. Each of the tests narrowed down the set of parameters that could guarantee the best properties of the weld. After the NDT investigation, the defects and noncompliance in the weld structure were identified. The correctly made joints were chosen. The bending tests, and tensile strength analysis confirm the proper properties of the joints.

The metallographic structure was analyzed in terms of oxygen content in the weld metal. It has been shown that a shielding argon mixture gas containing 18% CO₂ is the most appropriate for obtaining the high tensile strength and the good hardness of tested joints. The newly developed technology (welding method 136) is perfect for construction in the automotive sector. It was concluded, that the welding parameters were chosen properly. Based on all the test results, the main conclusions were:

- the 1.4462 duplex steel may be treated as a main material for welding constructions in the automotive industry;
- the selection of welding parameters for duplex steels is difficult,
- a material filler KOBELCO DW-329AP proved to be suitable for welding duplex steel;
- the attentive selection of all welding parameters (especially current, and kind of shielding gas) allows obtaining structures with excellent mechanical properties;
- the 136 welding method and the duplex steel may be recommended for the construction of a truck tanker with excellent mechanical properties;
- the results confirm, the best welding parameters correspond to a current of 150 A and the use of a shielding gas containing 18% CO₂ content;
- the joint should be made with direct current.

The obtained results show, that the specially considered construction of a truck tanker can be made of duplex sheet with a thickness of 12 mm and 136 method.

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