Mechanical properties of dissimilar welded joints of duplex 2205 and austenitic 316L steels

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Abstract. The presented work is the result of the author's investigations connected with the examination of the usefulness of welding methods of dissimilar welded joints for their use in industrial practice (grade 2205 - X2CrNiMoCuN22-5-3 steel with the number 1.4462 and typical, low-carbon austenitic steel of grade 316L - X2CrNiMo17-12-2 steel with the number 1.4404). In order to assess the characteristics of these joints the mechanical properties tests have been conducted. Mechanical properties tests included static tensile testing, static bending testing, impact tests and hardness measurements. Static testing did not produce results indicating the differentiation of mechanical properties. Impact tests have confirmed the negative correlation between the amount of heat introduced into the weld (including linear welding energy) and the impact strength of the welded joint. Hardness tests also confirmed the relationship between the heat input and the grain size of the main phases. The results of the mechanical properties shown that the lower the linear energy, the finer morphology of the manufactured welds.

1. Introduction
The grade of duplex stainless steels (DSS) is a merger of two separate phases: the ferritic one and the austenitic one [1]. The ferritic phase characterises by higher amount of Nickel however the austenitic one by higher amount of Chromium and Nickel. This microstructure causes that DSS characterize with unique features. Among them the corrosion resistance is the most important one. DSS characterise with the high level of corrosion resistance at significantly lower content of Chromium and Nickel then for example austenitic steels. This factor causes that austenitic stainless steels are currently being exchanged with DSS. This is particularly visible in maritime and shipyard industries. Constructions of these industries are particularly extensive exposed to corrosion caused by the environment of salt sea water [2]. Moreover, nowadays it is the norm that some components of such constructions are manufactured from austenitic steels why the others from DSS. It raises the problem of parameter estimation of such dissimilar joints, particularly when they are manufactured during the reparation processes. This is why it is important to determine the characteristics of such joints especially when they are welded. Such dissimilar, heterogeneous welded joints characteristics are determined by many inner and outer factors hence it is difficult to model the properties of them [3,4].

It should be pointed that one could observe some negative phenomena occurring during the welding process of such dissimilar joints. These phenomena are related with the heat transfer in the region of the weld. The heat input induces detrimental changes of the phase structure of the weld
region. The changes of the phase structure generally depend on vanishing of the austenitic phase (as the results of thermal processes) and increasing the amount of the ferritic phase. This process is however sometimes slowed down by austenite precipitation. The described processes take specially place in the region of the heat affected zone (HAZ). Its microstructure relates from the parameters of the welding and cooling processes. In the case of the cooling process the most important is the cooling speed rate. Higher speed rates cause the conservation of ferrite structure. At lower rates the possibility of austenite precipitation is more possible leading to two-phase structure [5,6].

Similarly, in the case of dissimilar welded joints it is also important the heat input intensity rate. At its higher value the probability of precipitating of not required phases is significantly larger [7]. They are mainly the harmful intermetallic phases. This situation causes that the corrosion of welds including such phases decrease largely [8].

2. Types of welded dissimilar joints
To determine the main mechanical properties of analysed type of dissimilar joints one prepared specimens representing four different types of welded joints. Two of them were two-pass joints and next two multiple-pass ones (5 and 7). They are presented in figure 1.

![Figure 1. Investigated types of dissimilar welded joints (2205 – 316L).](image)

The dissimilar joints were welded on the basis of DSS of the 2205 grade and the austenitic steel of the 316L grade. It was used the austenitic welding wire Avesta P5. The joints represented three types of welds: I, Y and 2Y.

3. Mechanical properties analyses
During investigations it has been conducted a variety of tests. But the most important and valuable are hardness tests and toughness ones. The hardness tests were performed according to the standard PN-
EN ISO 9015-1:2011. However, the toughness tests were performing according to the standard PN-EN ISO 9016:2013-05. In figures 2 - 9 are presented obtained results for particular joints.

**Figure 2.** Results of the hardness test (joint No 1)
- **BM 2205** – base material (steel 2205),
- **HAZ 2205**, - heat affected zone on the side of the 2205 steel,
- **HAZ 316L**, - heat affected zone on the side of the 316L steel,
- **BM 316L** – base material (steel 316L).

**Figure 3.** Results of the toughness test (joint No 1)
- **FZ 2205, FZ 316L** – fusion zone,
- **HAZ 2 2205, HAZ 2 316L**, - HAZ 2 mm from FZ,
- **HAZ 5 2205, HAZ 5 316L** – HAZ 5 mm from FZ.
Above are presented results for the first welded joint. It is two-pass joint of the I type. It can be seen that the hardness of the weld decreases from the side of steel 2205 towards steel 316L what results directly from the increase of the austenite phase. Fracture energy values are average.

**Figure 4.** Results of the hardness test (joints No 2)
BM 2205 – base material (steel 2205),
HAZ 2205, - heat affected zone on the side of the 2205 steel,
HAZ 316L, - heat affected zone on the side of the 316L steel,
BM 316L – base material (steel 316L).

**Figure 5.** Results of the toughness test (joint No 1)
FZ 2205, FZ 316L – fusion zone,
HAZ 2 2205, HAZ 2 316L, - HAZ 2 mm from FZ,
HAZ 5 2205, HAZ 5 316L – HAZ 5 mm from FZ.
The second analysed joint is multiple-pass one of the Y type welded at limited heat input. It is visible an increase in hardness in the direction from the axis of the weld to the HAZ region. In this joint the lowest value of the fracture energy is 106 J, and the highest is 243.

![Figure 6. Results of the hardness test (joint No 3)](image)

**Region of specimen measuring**

- BM 2205 – base material (steel 2205),
- HAZ 2205, - heat affected zone on the side of the 2205 steel,
- HAZ 316L, - heat affected zone on the side of the 316L steel,
- BM 316L – base material (steel 316L).

![Figure 7. Results of the toughness test (joint No 3)](image)

**Region of specimen preparing**

- FZ 2205, FZ 316L – fusion zone,
- HAZ 2 2205, HAZ 2 316L, - HAZ 2 mm from FZ,
- HAZ 5 2205, HAZ 5 316L – HAZ 5 mm from FZ.
The third analysed joint is also a multiple-pass one of the Y type welded without limiting the heat input. It is visible a decrease of hardness what confirms that hardness at higher heat input is lower. In this joint the lowest value of the fracture energy is 74 J, and the highest is 245.

![Hardness Test Results](image1)

**Figure 8.** Results of the hardness test (joint No 4)
- BM 2205 – base material (steel 2205),
- HAZ 2205, - heat affected zone on the side of the 2205 steel,
- HAZ 316L, - heat affected zone on the side of the 316L steel,
- BM 316L – base material (steel 316L).

![Toughness Test Results](image2)

**Figure 9.** Results of the toughness test (joint No 4)
- FZ 2205, FZ 316L – fusion zone,
- HAZ 2 2205, HAZ 2 316L, - HAZ 2 mm from FZ,
- HAZ 5 2205, HAZ 5 316L – HAZ 5 mm from FZ.
The last analysed joint is a two-pass one of the 2Y type. The lowest mixing of materials causes the decrease of hardness in comparison with other joints. In this joint the lowest value of the fracture energy is 152 J, and the highest is 242.

4. Conclusions
It could be observed that the hardness of welds is intermediate between the hardness of base materials (2205 and 316L), with hardness in the HAZ area being higher on the side of the 2205 steel. Additionally, one can state that according the presented results, the two lowest values of toughness occur in specimens for the weld axis or specimens for the fusion line on the side of the duplex steel (FL 2205). Thus, the highest material hardness should be noted in this area. However, the highest values of fracture energy were recorded for specimens on the side of the 316L steel in the HAZ area. Additionally, it should be noted that the toughness of two-pass joints is higher than the toughness of multiple-pass joints.

5. References
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