Metallographic investigations 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. Four different types of dissimilar welded joints were used to determine their weldability as a part of the research program. These joints were made on the basis of typical duplex steel (grade 2205 - X2CrNiMoCuN22-5-3 steel with the number 1.4462) and typical, low-carbon austenitic steel (grade 316L - X2CrNiMo17-12-2 steel with the number 1.4404) using the welding wire Avesta P5. The weldability of investigated joints was assessed with regard to its three basic aspects: metallurgical weldability, technological weldability and technical weldability. Metallographic studies allowed, basing on microscopic studies, evaluating qualitative parameters of the morphology of investigated joints and to indicate some quantitative quantities. In welds welded at lower linear energies, dendrites are less densely packed and are typically column ones. The results of the metallographic studies have shown that low welding energy and a small number of passes result in better morphology of the weld material.

1. Introduction
Duplex stainless steels (DSS) characterised with excellent corrosion resistance. Simultaneously it could be stated that their mechanical properties are also increased in comparison to typical constructional steels. It causes that DSS are a very good material for maritime constructions. Moreover, the yield strength of DSS is higher than 450 MPa. It could be used for decreasing the weight of welded constructions [1,2]. In the table 1 is presented the chemical composition of main grades of DSS.

| Steel name | C  | N  | Cr  | Ni  | Mo  | Others |
|------------|----|----|-----|-----|-----|--------|
| 2101       | 0.03| 0.22| 21.5| 1.5 | 0.3 | 5Mn Cu |
| 2304       | 0.02| 0.10| 23.0| 4.8 | 0.3 | Cu     |
| 2205       | 0.02| 0.17| 22.0| 5.7 | 3.1 |        |
| 2507       | 0.02| 0.27| 25.0| 7.0 | 4.0 |        |

This specific chemical composition of DSS allows obtaining balanced system of ferrite and austenite phase. It should be stated that the ferrite content in DSS is directly related with the annealing
temperature what could influence the welding process. One should point that the corrosion resistance feature of DSS also could be affected by the welding process [3]. Hence it is used the extending content of molybdenum and nitrogen [4]. It allows increasing the stability of phase structure of DSS. Therefore, the application of DSS for welded constructions must be of particular interest of technologists [5]. Generally, DSS are relatively easy to weld but in some conditions their features could be significantly decreased. It is particularly important in the case of dissimilar joint on the base of DSS and austenitic steels. To determine the features of the resulting such, welded joints one should analyse a variety of different aspects of obtained joints. It allows preventing wrong behaviour of constructions based on such joints at specific environmental factors.

2. Analysed types of joints
Welds were done for elements with dimensions of 1000x300x15, using industrial welding technology. Welding was made with a submerged arc (SAW) method, in the low position, which was selected due to the smallest way affecting the characteristics of the obtained welded joint. The electrode in the welding machine was set horizontally. The weld was performed using the wire of $\phi$ 3.2 mm made of austenitic steel (Avesta P5). In figure 1 are presented the obtained 4 types of investigated joints.

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

- first row – I type weld, two passes; Y type weld, seven passes;  
- second row – 2Y type weld, two passes, y type weld, five passes.

Since all welds were multiple-pass, it was assumed that the inter-pass temperature will be limited to 100°C, what was measured using the photoelectric pyrometer.

3. Metallographic investigations
Basic macro and microstructures investigations of welded joints were performed on light microscopy. Specimens for metallographic examinations were prepared in a traditional way (grinding and polishing). The Berah reagent was used to reveal the microstructure of the joints. This reagent with the
The general composition of 1g K$_2$S$_2$O$_3$ + 15ml HCl + 85ml H$_2$O, dyes ferrite to a dark brown colour. The microscope images of particular welded joints are presented in figures from 2 to 5.

**Figure 2.** Microscope images of the first joint
- First row – magnification 25x, surface layer of the joint
- Second row – magnification 100x, middle layer of the joint
- Third row – magnification 200x, root layer of the joint.
Figure 3. Microscope images of the second joint
first row – magnification 25x, surface layer of the joint
second row – magnification 100x, middle layer of the joint
third row – magnification 200x, root layer of the joint.
Figure 4. Microscope images of the third joint (Y type, not limited heat input)
first row – magnification 25x, surface layer of the joint
second row – magnification 100x, middle layer of the joint
third row – magnification 200x, root layer of the joint.
Figure 5. Investigated types of dissimilar welded joints (2205 – 316L) first row – magnification 100x, surface layer of the joints first row – magnification 100x, surface layer of the joints first row – magnification 100x, surface layer of the joints.
The presented images of the chosen parts of analysed joints have been done in three different magnifications (x25, x100 and x200). Three lines of images represent the three horizontal cross-sections of analysed joints: the surface one, the middle one and the root one.

4. Results of investigations
Observations of collected microscopic material allowed concluding that there is austenite in the form of dendrites in the cross-section of the weld. Ferrite occurs in the form of precipitates located between austenite dendrites. The proportion of ferrite, based on image analysis, should be assessed as being in the range of 10 - 20%. A higher proportion of ferrite should be noted only in the area of the weld at the border with steel 2205. It is the result of ferrite penetration from the area of the two-phase steel. This mechanism causes that the hardness of the HAZ is significantly higher [6].

The SWC areas were subject to more detailed observations. Generally, it should be stated that their width is rather small, however on the steel side 2205 SWC is clearly wider than on the side of 316L steel. On the steel side 2205, the SWC’s width varies between 300 and 600 μm. However, on the side of steel 316L its width varies between 100 and 300 μm. Thus, it can be concluded that the SWC on the steel side 2205 is 2 to 3 times greater than on the steel side of 316L.

5. Conclusions
The structures and phases observed in microscopic investigations confirm the correctness of the description of phase transformations of the analysed type of welded joint. In the weld area, after crystallization, there is an austenitic structure. At 1300°C, some ferrite grains convert into austenite, hence the formation of a two-phase structure. These phase changes take place according to the scheme: \( \alpha \rightarrow \alpha + \gamma \) [7]. The rate of change depends on the amount of energy supplied (in the form of thermal energy) and on the local chemical composition of the alloying elements. The first of these two factors also affects the size of the observed grains of the main phases. Together with the longer time of temperature influence, the grains grow more frequently, as well as the formation of dendritic structure. In welds welded with higher linear energies of welding, dendritic structures are clearly larger.

6. References
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