Analysis of features of stainless steels in dissimilar welded joints in chloride inducted corrosion

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Abstract. Stainless steels of ferritic-austenitic microstructure that means the duplex Cr-Ni-Mo steels, in comparison with austenitic steel includes less expensive nickel and has much better mechanical properties with good formability and corrosion resistance, even in environments containing chloride ions. Similar share of high chromium ferrite and austenite, which is characterized by high ductility, determines that the duplex steels have good crack resistance at temperatures up to approximately -40°C. The steels containing approximately 22% Cr, 5% Ni, 3% Mo and 0.2% N crystallizes as a solid solution δ, partially transforming from the temperature of about 1200°C to 850°C into the phase α. The stable structure of considered steels, at temperatures above 850°C, is ferrite, and at lower temperatures the mixture of phase γ+α +σ. The two-phase structure α+γ the duplex steel obtains after hyperquenching at the temperature of stability of the mixture of α+γ phases, and the share of the phases depends on the hyper quenching attributes. Hyperquenching in water, with a temperature close to 1200°C, ensures the instance in the microstructure of the steel a large share of ferrite and a small share of the high chromium austenite. This causes the increase of strength properties and reducing the plasticity of the steel and its resistance ability to cracking and corrosion. Slower cooling from the mentioned temperature, for example in the air, enables the partial transformation of the α phase into the γ one (α → γ) and increasing the share of austenite in the steel structure. It leads to improvement of plasticity properties. In the paper are presented the results of investigations of heteronomous welded joints of duplex steel and austenitic one. The results include the relation between the chemical composition of steels and their weldability.

1. Introduction
Duplex stainless steels (DSS) represent a combination of both the ferritic stainless steels with higher amount of Nickel and austenitic ones with higher amount of Chromium as well as Nickel. This specific microstructure of DSS causes that these steels characterize with some synergetic advantages resulted from this specific combination [1-4]. The most important advantage is related with corrosion resistance of DSS. The same corrosion resistance characteristics is obtained, by DSS, at significantly lower content of Nickel what influence on the lower price of DSS. This is why expensive austenitic stainless steels are currently exchange with DSS, particularly in constructions that are extensively exposed to corrosion environment factors. On the other hand it frequently happens that, during the
reparation processes, elements made of austenitic steels are replaced with elements made of DSS. It cases that are performed weld linking elements of these different steel grades. Such dissimilar, heterogeneous welded joints characterize with variant characteristics in comparison to the base materials. Additionally it could be observed other negative phenomena occurring during performing these dissimilar joints. One of them is the heat transfer in the area close to the weld. It causes the undesirable changes in the microstructure of this area. Generally speaking one can say that during welding the microstructure of that area is generally represented by ferrite. However during cooling the process of austenite reformation is initiated. This area susceptible under the heat treatment during welding and cooling is called the heat affected zone (HAZ). It should be stated that the microstructure of HAZ is strongly related with the cooling speed. At higher speed rates of cooling the microstructure of ferrite is conserved because of the lower possibility of austenite reformation. According to investigations conducted in this issue it was stated that required ferrite content in the welded dissimilar joint should be between 25 and 70% [5].

The other problem of these dissimilar welds is considered with the intensity of the heat input. At higher rates of this intensity the probability of precipitating the harmful intermetallic phases becomes significantly higher [3, 4, 5]. It results in significantly lower corrosion resistance of such welds [6, 7]. The other phenomenon observed in such conditions is more intensive dilution of base steels materials. Taking into consideration the corrosion resistance of the analyzed dissimilar joints one should mention the hydrogen degradation. This is one of the main mechanisms lowering the corrosion resistance, particularly in the case of maritime constructions. The most important part of this corrosion mechanism is creating the hydrogen embrittlement (HE) of steels. To HE more susceptible are ferritic steels then the austenitic ones [7]. The susceptibility to HE of DSS is average in comparison to the mentioned previously steel grades.

2. Specimens preparation
To investigate the corrosion resistance of dissimilar welded joints the specimen of the 316L and 2205 stainless steels were prepared. It is presented in figure 1 while in figure 2 are presented the obtained weld. The specimens were prepared on the basis of steel sheets of with a thickness of 15 mm.

![Figure 1. Prepared specimen.](image1)

![Figure 2. Obtained weld.](image2)

The joint was performed using the SAW method. For the welding process the wire of f 3.2 mm made of DSS was used. It was a DSS wire of the chemical composition according to 22Cr-9Ni-3Mo. The flux used in the welding process was of the next features: non-alloyed, agglomerated. It was of the
type ESAB Flux 10.93. Parameters related the heat inputs during the welding process were between 2.4 and 3.4 kJ/mm. The welded joint, as it is visible in figure 2 consists of two beds.

3. Chloride corrosion tests

According to the investigations assumptions the influence of the chloride environment on the stress corrosion cracking was determined using the test of the slow strain rate (SSR). The strain rate which was applied to the tested specimen was equal to 2.2 x 10^-6 s^-1. To cause the corrosion environment which is chloride inducted it was used the 35% water solution of MgCl₂ at 125°C. In that solution the specimens were immersed. They were also mounted to the clasps of the tensile testing machine. The end of the test was designated by the deformation of the specimen. For comparison purpose the comparative test were conducted with specimen immersed in an inert environment (Glycerin at 125°C). The tested parameters were: ultimate tensile strength (UTS), uniform elongation (UE) as well as reduction of area at fracture (RA) and consumed energy (En). The results of the conducted tests are shown in table 1 and in figures 3 and figure 4.

| Specimen | Environment | UTS [MPa] | UEL [%] | RA [%] | En [MJ/m^3] | Cracking area |
|----------|-------------|-----------|---------|--------|-------------|---------------|
| **Base materials** |             |           |         |        |             |               |
| 316L-G   | Glycerin    | 484       | 43.2    | 81.1   | 174         |               |
| 316L     | MgCl₂      | 463       | 28.1    | 26.9   | 99          |               |
| 2205-G   | Glycerin    | 628       | 45.2    | 76.0   | 236         |               |
| 2205     | MgCl₂      | 520       | 23.0    | 39.2   | 88          |               |
| **Welded joints** |         |           |         |        |             |               |
| 2Y-G     | Glycerin    | 517       | 28.2    | 77.9   | 124.2       | 316L          |
| 2Y-Mg1   | MgCl₂      | 466       | 14.8    | 27.8   | 41.1        | 2205 HAZ      |
| 2Y-Mg2   | MgCl₂      | 433       | 17.4    | 30.3   | 59.6        | 2205 HAZ      |

Figure 3. Curves presenting the relation between strain and stress in SSR tests (base materials).
Figure 4. Curves presenting the relation between strain and stress in SSR tests (dissimilar joint).

Analysis of the results of the tests, in the case of base materials, show that steels: DSS 2205 and austenitic 316L steels are both liable to stress corrosion in 35% water solution of MgCl₂ what means that they are less corrosion resistant in chloride environment. The other mechanical properties were also reduced particularly in the case of RA. On the other hand similar results were obtained for the dissimilar welded joint. It characterizes with even larger susceptibility to corrosion inducted by stress in the chloride environment. Interesting is the comparison of breaking places of particular specimens. The specimens subjected to SSR in Glycerin were broken in the area of the 316L steel. The specimens subjected to SSR tests in 35% water solution of MgCl₂ were broken on the side of 2205 steel. In figure 5 are presented the specimens after tests.

Figure 5. Specimens after SSR tests.
All investigated specimens of the dissimilar welded joint which were subjected to tests in Glycerin characterize with good plasticity. The surfaces of the fracture are fully ductile. All investigated specimens of the dissimilar welded joint which were subjected to tests in 35% water solution of MgCl₂ were broken in a brittle manner. The surfaces of fracture of welded joints show features of a brittle or at most ductile-brittle character. The change of plasticity characteristics should be treated as strongly related with the stress corrosion. This especially applies to the area of HAZ on the side of the 2205 steel that means of the DSS side. The value of the UTS parameter, for the fractures in that area, were even lower than that which were measured in the case of the 316L steel. In figure 6 is presented the cracks propagation in the HAZ area at the 2205 side.

![Crack propagation paths at welded specimen after SSR test in boiling MgCl₂ solution at 125°C.](image)

**Figure 6.** Crack propagation paths at welded specimen after SSR test in boiling MgCl₂ solution at 125°C.

It should be stated that the boundary between ferrite and austenite is the place were cracks were initiated. The course of their propagation runs either along the phase boundaries or across the ferrite grains. So it could be stated that austenite grains are more resistant to that phenomenon. It was observed that cracks sometimes ended up perpendicular located, to the propagation direction, austenite elongated grains.

4. Conclusions
Concluding it could be stated the chloride inducted corrosion environment resulted in a significant decrease in some mechanical properties of DSS. On the other hand, in such corrosion conditions the 316L, of austenitic microstructure, characterizes with higher resistance. This conclusion shows that in the case of dissipar welded joints, obtained on the basis of DSS and austenitic steel, could be susceptible to chloride inducted stress corrosion. This conclusion is particularly important for such frequent composition of a dissimilar welded joint like system of 2205 and 316L steels. The SST tests of base material show similar susceptibility to chloride inducted corrosion of both steels. However the dissimilar welded joints show decreasing of mechanical properties in HAZ at DSS side.

It should be mentioned that the weld is characterized by a dendritic structure [8, 9]. This structure was resulted by creation of a matrix of ferrite and ferrite σ [10, 11]. They are accompanied by acicular precipitates of primary and secondary austenite.
5. References

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