# MICROSTRUCTURE OF DISSIMILAR JOINTS BETWEEN DUPLEX STAINLESS STEEL AND LOW ALLOYED STEEL

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**Abstract**

Extending the application area of Duplex stainless steels has led to the necessity of creating components or structures made of dissimilar materials. Due to the differences in the microstructure, the welding of the dissimilar steels is more difficult than that of similar steels.

The research carried out in the current paper focuses on the particularities of completing the heterogeneous welded joints between a Duplex stainless steel and a Cr-Mo low alloy steel using as additional material an electrode wrapped in E 309MoL - 16, which contains approx. 23 % Cr, 12 % Ni and 2%Mo. The implementation of this welding technology focuses on eliminating the technological operations of preheating and post welding heat treatment, which is mandatory for welding low alloy steels sensitive to hardening through martensitic transformation and cold cracking respectively. Based on the Schäffler model a prediction of the metal microstructure deposited by welding is carried out and the quality of the joints made is carried out by metalographical investigations.

**Keywords:** Welding by melting, dissimilar steels, microstructure

## 1. ISSUES OF EXECUTING WELDED JOINTS OF DUPLEX STAINLESS STEEL - LOW ALLOY STEEL

Duplex stainless steels have a microstructure made of approximately equal quantities of austenite and ferrite. During the welding operations, the ferrite content increases and the precipitation of chromium nitrides is intense at very low values of the linear energy. On the other hand, at higher values of the linear energy and/or by long-term exposure to high temperatures, between 600 and 1000°C, it causes the precipitation of the $\sigma$ and $\chi$ fragile intermetallic phases [1,3,5].Generally, the welding specifications must be designed so as phases ratios (ferrite/austenite ratio) close to 1:1 are obtain and the precipitation of the $\sigma$ and $Cr_2N$ phases are avoided by controlling and limiting the linear energy within the range of 5 - 21 kJ/cm [2,3]. Extending the application area of steels has led to the necessity of creating components or structures made of dissimilar materials [4]. Generally, the welding of the dissimilar steels is more difficult than that of similar steels, due to the differences in their microstructure [2].Thus, low alloyed steels need a preheating for welding, a relatively slow cooling of the welded seams and a post welding thermal treatment for high tempering or annealing for stress relieving. The Duplex stainless steels are welded to the extent possible without preheating; the seams must be cooled down under controlled conditions, and, for large mechanical constructions, the post welding heat treatments can only be executed locally. The heterogeneous welded joints need a high toughness of the deposited metal and a tough heat affected zone, without cracks. Therefore, due to the differences in the microstructure and alloy grade, these steels will be welded by taking special precautions. When passing from the high alloyed Duplex steel to low alloyed ferritic steel, the formation of a fragile area, e.g. with a martensitic structure must not be allowed, even if a large martensitic structure field is located between the two fields, on the Schäfflermodel.The heat affected zone (H.A.Z.) in both base materials does not represent an issue characterizing these types of joints, as it also occurs to welded material having the same chemical composition.

## 2. EXPERIMENTAL PROCEDURE

*Original welding conditions*:

- definition of the joint: heterogeneous
- base metals: Duplex stainless steel sheet with low alloyed steel sheet 13CrMo4-5 (EN 10028-2), s = 8 mm;
- joint type: butt seam penetration;
- weld thickness: 8 mm;
- welding position: horizontal PA.;
- welding technique: manual, arc welding;
- filler material: E 309MoL-16 wire (acc. AWS A5.4);
- electrode diameter: $d_s$ = 2.5mm.

The welding was carried out in horizontal position, PA/SRENISO 6943/2000 position. The joint preparation, the positioning of the components and the outside appearance of the executed joint are presented in **Figures 1, 2 and 3**. Butt seam penetration joint was carried out, with the access from the side.

The welding was carried out with 3 passes, 1 deep pass and 2 filling passes with the following technological welding parameters: - average welding current, 85 A; - arc voltage, 26 - 28 V; - welding speed, $v_s$ = 17-19 cm/min; - linear energy, 7.5 - 7.8 kJ/cm;

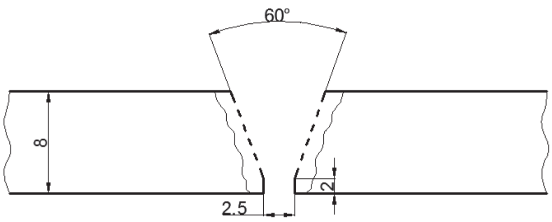



**Figure 1** Shape and size of the welded joint

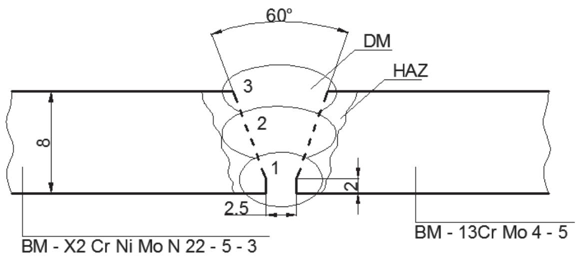



**Figure 2** Location of the passes in the joint

In accordance with **Figure 2**, the joint was filled by 2 passes, and the temperature between two consecutive passes was limited to 200°C. The quality of the welded joints was assessed by means of macro- and micrographic analyses, as well as by means of sclerometer tests.

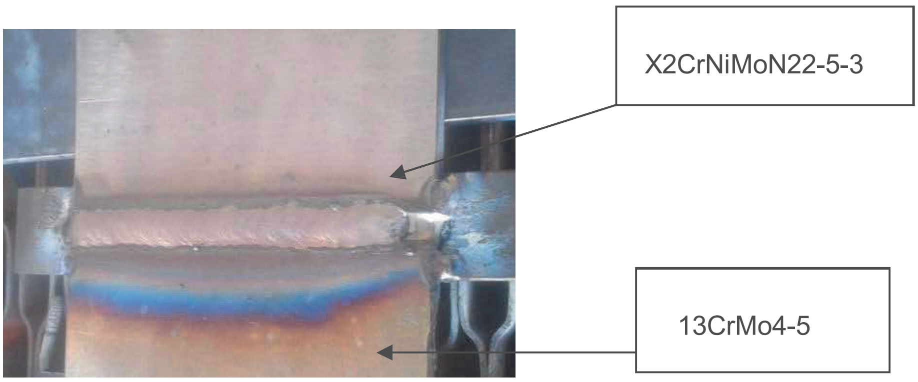



**Figure 3** Temporary attachment and the outside appearance of the heterogeneous welded joint

## 3. CHEMICAL COMPOSITION AND PREDICTION OF DEPOSITED METAL MICROSTRUCTURE

A good compatibility between the basic metals and the filler material must assure the formation of an adequate microstructure, without metal continuity defects and without any hard and fragile phases. This is the reason why the selected filler material, the electrode wrapped in E 309 - 16 has a chemical composition close to the one of the basic metal with the highest alloy grade. The dilution of the high alloyed filler material with both base metals and, mainly, with the low alloyed 13CrMo4-5 steel is extremely important, i.e. it must partly compensate the differences in the chemical composition. The main issue for the selection of the filler material aimed to obtain highly toughness welded joints and without cracks.The most important mean assisting in understanding of the processes taking place during the welding of these materials, respectively in predicting the microstructure of the rough welded deposited metal is the Schäfflermodel (**Figure 4**).

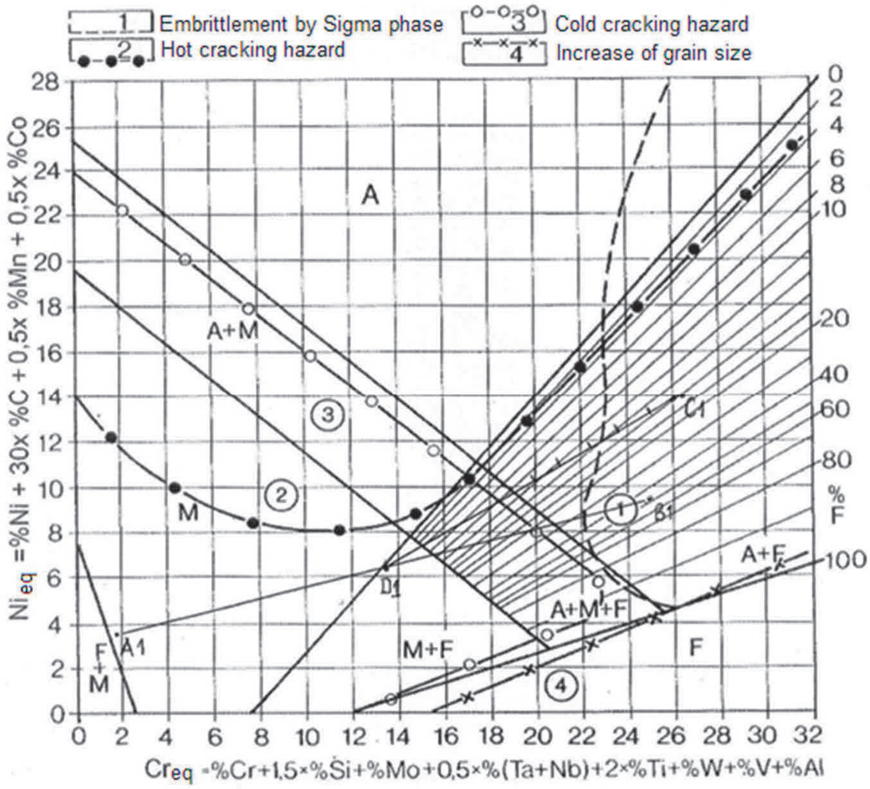



**Figure 4** Prediction of deposited metal microstructure by manual arc welding of 13CrMo4-5 low alloyed steel with Duplex X2CrNiMoN22-5-3 stainless steel using the E 309MoL-16 electrode as filler material

The chemical composition of the materials that were used for the welded joint execution is shown in **Table 1**.

**Table1** Chemical composition of materials used

| Type of material | Chemical composition, % mass | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | P | S | Cr | Ni | Mo | Cu | N |
| Base metal, X2CrNiMo22-5-3 | 0.026 | 1.86 | 0.74 | 0.019 | 0.014 | 22.2 | 5.10 | 2.94 | - | 0.16 |
| Base metal, 13CrMo4-5 | 0.11 | 0.59 | 0.32 | 0.021 | 0.022 | 0.94 | - | 0.51 | 0.18 | - |
| Filler material, E309MoL-16 | 0.024 | 1.06 | 0.75 | 0.019 | 0.015 | 22.96 | 12.8 | 2.35 | - | - |

The values of the chromium equivalent and nickel equivalent defining the nominal characteristic point (A1 for 13CrMo4-5 steel, B1 for X2CrNiMoN22-5-3 Duplex stainless steel and C1 for E 309MoL-16 filler material) were calculated on the basis of these data. During manual arc welding, the fact that the dilution is 20-30% must be taken into consideration. Accepting that equal parts of the 13CrMo4-5 steel, as well as of the X2CrNiMo22-5-3 stainless steel will be melted, is arises that the deposited metal will combine with the D1 alloy made of half of the low alloyed steel and half of the high alloyed steel. Connecting the points D1 and C1 by a straight line and taking into consideration the dilution ratio, we will find that a deposited austenitic metal with a share of approx. 15 % ferrite δ is obtained, presenting an increased safety against hot cracking. If the dilution ration is higher, for example 30% (the area of the welded root), the deposited metal will comprise approx. 14% ferrite δ, and, at a dilution ratio of 50%, the limit of 12% ferrite δ will be reached and, therefore, the hot cracking hazard is eliminated.

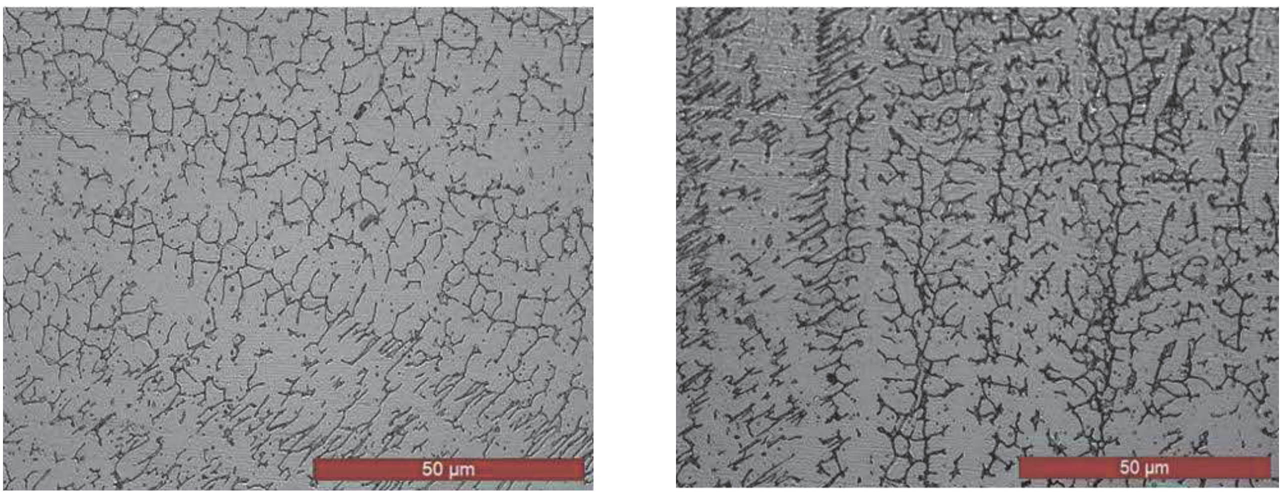
## 4. MACRO- AND MICROGRAPHIC ANALYSIS OF WELDED JOINTS

The macrographic image in **Figure 5** shows the shape and width of the characteristic areas of the welded joints, as well as the absence of crack-type metal continuity, slag deposits, pores etc.


**Figure 5** Macrogeometry of the welded joint

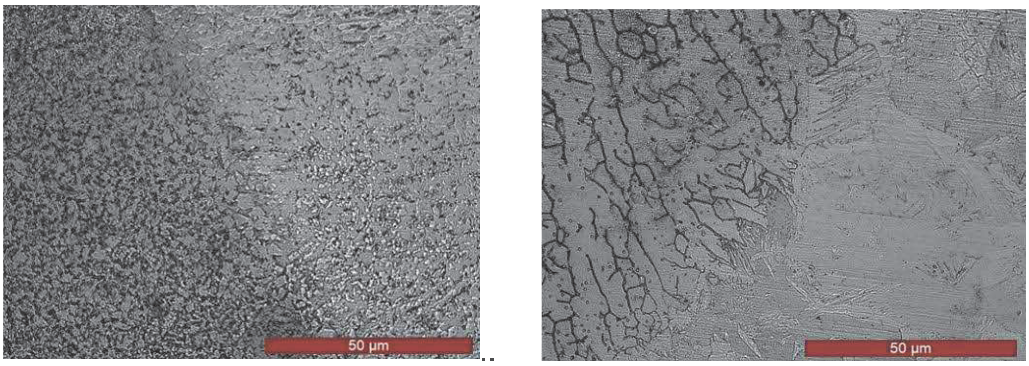
The results of metallographic tests (**Figures 6** to **8**) performed on samples collected perpendicularly on the longitudinal axis of the weld confirm the predictions given by the Schäffler model. Thus, the welded seam shows a dendritic structure comprising austenite and a ratio of 12 - 16% of ferrite δ (**Figure 6**) preventing hot cracking. The base Duplex stainless steel shall show a microstructure made of approx. 40 - 42 % austenite and 58 - 60 % ferrite (**Figure 7a**) in the overheating subzone of the heat affected zone (H.A.Z.). The solidification process sets in on the walls of the crystals of both base metals that remained in a solid state, and the increase size of the grains is epitaxial. In the area adjacent to the Duplex stainless steel fusion line, the heat from welding led to solution treatment of secondary phases particles and a slight increase in the size of crystal grains (**Figure 7a**).

By contrast, the overheating subzone of the heat affected zone (H.A.Z.) of the steel with the point of transforming in solid state is characterized by a heterogeneous ferritic-bainitic-martensitic microstructure (**Figure 7a**) mainly determined by the heterogeneous characteristics of the dilution.



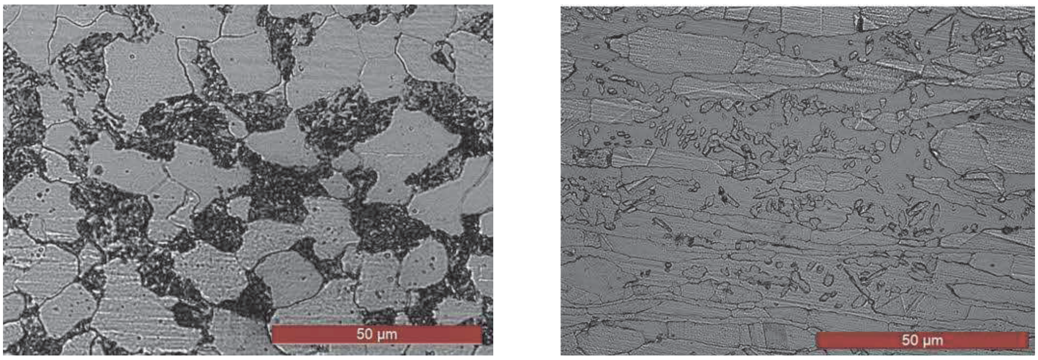

- a - - b -

**Figure 6** Welded seam: a - root layer; b - filling layer




-a- -b-

**Figure 7** DM - BM Interface; a - weld + low alloyed steel; b - weld + Duplex stainless steel




-a- -b-

**Figure 8** Base metals: a - low alloyed steel; b - Duplex stainless steel

The two base metals that are not affected by the welding process have a microstructure made of alloyed ferrite + bainite + pearlite (**Figure 8a** -13CrMo4-5 steel), respectively austenite + ferrite (**Figure 8b** -X2CrNiMoN22-5-3 steel). It must also be noted that no porosities or bubbles were found in the laid metal, not on the interface between this and the basic metals, or micro-cracks or other defects of metal continuity.

## 5. SCLEROMETRIC TESTS ON THE WELDED JOINTS

As the hardness values are the most sensitive values to the microstructural changes due to the thermal welding cycle, these tests were performed on samples collected perpendicularly on the welded seam.

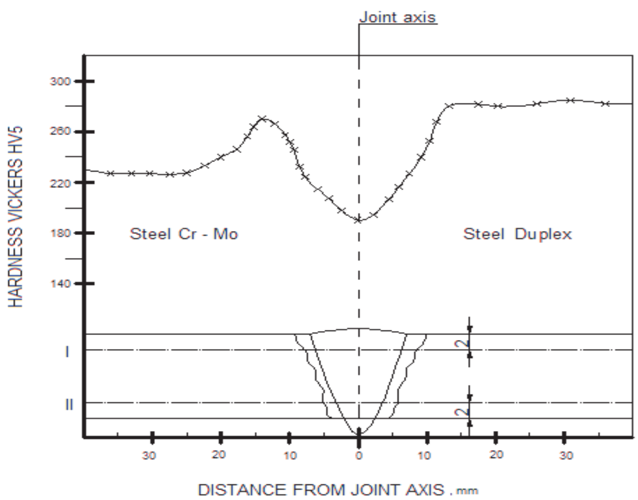



**Figure 9** Hardness distribution on the cross-section of the welded joint

**Figure 9** presents the hardness gradient on the section of the welded joint on two measurement directions, comprising all its characteristic zones.

The Duplex base metal has hardness values of HV = 270...280 daN/mm$^2$, corresponding to an austenitic-ferritic microstructure.The thermal influenced zone of the 13CrMo4-5 basic metal, adjacent to the fusion line, shows a slight increase in hardness, up to values of HV = 260...270 daN/mm$^2$, due to the relatively high hardenability of this type of steel. Finally, the 13CrMo4-5 base metal has hardness values of HV = 235...245 daN/mm$^2$, corresponding to the normalizing thermal treatment, followed by a high tempering treatment before welding.

## CONCLUSIONS

The execution of heterogeneous welded joints between 13CrMo4-5 and X2CrNiMoN22-5-3 steel by manual arc welding using the electrode wrapped in E 309MoL-16 as filler material is opportune and gives important technical and economic benefits, mainly due to a good quality of the welding and a high flexibility in performing the process. For basic materials with a thickness of 8 mm and an electrode with a diameter of 2.5 mm, the optimum parameters values of the welding process are:

$I_s$ = 85 A; $U_s$= 26...28 V; $v_s$ = 17...19 cm/min.

The prediction of the metal microstructure laid by welding by means of the Schäffler model, together with the results of the micrographic analysis esperformed on the samples collected from welded joints demonstrates the existence of a dendritic structure comprising austenite with a ratio of 12...16% ferrite δ that shall prevent the hot cracking phenomenon.

As the 13CrMo4-5 steel has a relatively high hardenability, due to alphagene alloying elements (Cr, Mo) generating carbons, a heterogeneous austenite will be obtained in the thermal influenced zone, which, which, by quick cooling, will lead to the local formation of martensitic colonies with high carbon content and hardness values of HV = 260...270 daN/mm$^2$ .

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