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UNEVENNESS OF CHEMICAL COMPOSITION IN WELD METAL OF AUSTENITIC - FERRITIC WELDED JOINTS

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ABSTRACT
On many welded structures joints between austenitic and microalloyed steels can be found. Filler materials for these joints are selected using the Schaeffler diagram. The results of examinations show uneven microstructure of weld metal for this type of joints.
Keywords: austenitic-feritic welded joints, Schaeffler diagram, chemical composition, microstructure

1. INTRODUCTION
Literature [1, 2] recommends that filler material for welding of microalloyed and austenitic steels should be selected based on Schaeffler diagram and the filler material should be austenitic type. Schaeffler diagram is divided into several zones, figure 1. In all zones, except in the central region of the diagram (white area in the figure 1) weld metal is prone to the formation of different types of imperfections [2, 3] such as: hot cracks, formation of martensitic microstructure, embrittlement due to the increase in grain size and embrittlement due to the precipitation of secondary phases. Therefore, the chemical composition and microstructure of the weld metal should be chosen in such a way to be located in the zone where the tendency to the formation of imperfections is not significant. To achieve this it is necessary to know the chemical composition of the base materials and filler material and the dilution level. Positions of base materials (point A - microalloyed steel, point B - austenitic steel) and position of filler material in the diagram, figure 1, are defined by their chemical compositions, which also define the values of Ni and Cr equivalents. Assuming that both of base materials have the same share in the composition of the weld metal, point C can be determined in the middle of the line connecting points A and B. Point C then connects to the point on the diagram that corresponds to the filler material (for example point D). The newly formed line divides according to the specified ratio, depending on the percentage share of base materials and filler material within the weld metal. Dividing point (for example point E) is to be found in the zone of the diagram in which there is no tendency to the formation of imperfections [2, 3]. If the dividing point is located outside of this area it is necesery to change the chemical composition of the filler material or its share in the weld metal, until the dividing point is found in the zone of the satisfactory weldability. Figure 2 shows how to use the diagram in the case of mulyilayer welding of ferritic-austenitic welded joints [1]. The level of dilution depends on the welding process and welding parameters. Tests have shown that the optimal chemical composition of the weld metal is composition which leads to the formation of austenitic microstructure with 3 % to 10 % of δ - ferrite [1, 2, 3].

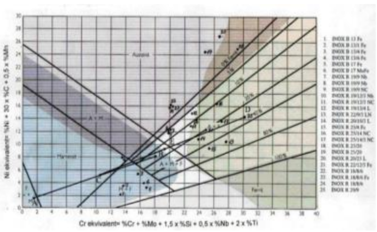

Figure 1. Schaeffler diagram

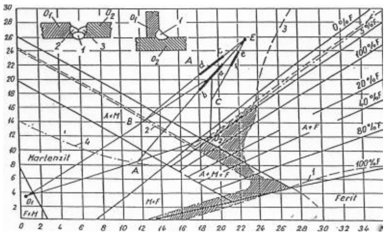

Figure 2. Schaeffler diagram, multilayer welds

When multilayer welding is performed, only the root pass is formed by simultaneously mixing of both base materials and filler material. Therefor, the chemical composition and microtructure only of this part of weld can be determined as shown in figure 1. All other passes are formed by mixing one of the base materials, the previous pass and filler material, whereby any subsequent passes have a different chemical composition and structure. It can be concluded that the left and right sides of ferritic-austenitic joints do not have the same composition, due to differences in the chemical composition of the base materials. Therefore, the chemical composition of each ferritic - austenitic welded joint can be presented by one zone consisting of a number of points that represent the chemical composition of each individual pass. The line that connects the dividing point (A) and point which represents composition of filler material (E), in figure 2, passes through the middle of that zone.

2. EXPERIMENT

The level of dilution can not be precisely defined due to the impact of numerous welding parameters. Therefore, there is always some degree of uncertainty in predicting the chemical composition and microstructure of the weld metal in ferritic - austenitic welded joints. It can be expected that the impact of one of the base materials is limited to a certain part of the volume of weld metal. Therefore weld metal does not have the same chemical composition in every point in the cross section area, which is why there exist differences in the microstructure of certain parts of the same weld metal, and thus differences in tendency to the formation of different types of imperfections. In order to prove these assumptions two butt joints are made on steel plates of 200 x 500 mm. The first welded joint is made by using MMA process (base material M1 - microalloyed steel P460NL1, 14 mm thick, base material V - austenitic steel X6CrNiMo17-12-2, 12 mm thick and filler material - Inox 29/9). The second welded joint is made by using GMAW process (base material V - X6CrNiMo17-12-2, 12 mm thick, base material M2 - S500NL, 14 mm thick and filler material - wire MIG 18/8/6) [2, 3, 5].

3. RESULTS AND DISCUSSION

Microstructure of the first welded joint are shown on the figure 2. Microstructure is austenitic with dendrit morphology and a certain share of a δ - ferrite. Observed from the root pass, figure 2 a) to the weld face, microstructure becomes coarser and the percentage share of a δ - ferrite reaches the value of 35 %, figure 2 b) [2]. Weld metal of the second joint has austenitic microstructure with a certain share of δ - ferrite, but the exact percentage share of δ - ferrite could not be determined [5]. Hardness of the weld metal of the first welded joint is in the range from 220 HV_{10} to 274 HV_{10} and hardness of the weld metal of the second joint is in the range from 172 HV_{10} to 218 HV_{10}. Near the fusion zone, in both cases, the hardness is approximately equal (joint 1: on the side of M1 - 233 HV_{10}, on the side of V - 232 HV_{10}; and joint 2: on the side of M2 - 209 HV_{10}, on the side of V - 218 HV_{10}).

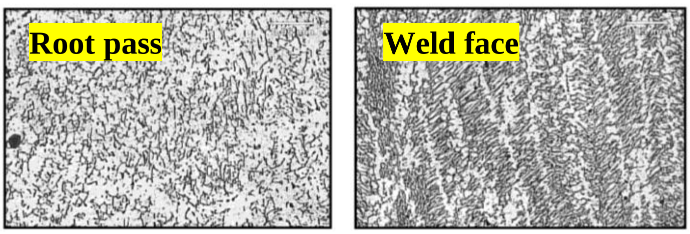

Figure 3. Microstructure of weld metal in ferritic - austenitic joint (filler material Inox 29/9)

The chemical compositions of both weld metals were investigated using the device Niton XL3 for spectral analysis. The device is shown on figre 4. This device can not analyze the carbon content. Analyses were performed on specimens for testing of tensile properties of welded joints. Arrangement of the measuring spots is shown in figure 5 and the results are shown in table 1. Carbon content significantly affects the value of Ni equivalent. Ni equivalents were calculated by using values of carbon content adopted from the catalogue of filler materials as follow: 0,15 % C for Inox 29/9 and 0,08 % C for MIG 18/8/6. In the same manner, the contents of Si necessary to calculate the Cr equivalents, were adopted: 0,9 % Si for electrode Inox 29/9 and 0,8 % Si for wire MIG 18/8/6.

Figure 4. Device for spectral analysis

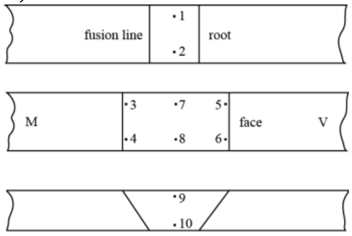

Figure 5. Measurement points

Table 1. Results of chemical analysis

		1	2	3	4	5	6	7	8	9	10
Joint 1 Inox 29/9	Cr	23,96	-	20,48	20,08	26,99	26,53	26,45	26,51	24,50	25,24
	Ni	7,78	-	6,17	5,91	7,85	8,43	8,15	8,09	7,22	7,94
	Mn	1,68	-	1,53	1,41	1,51	1,61	1,63	1,53	1,73	1,52
	$Cr_{ekv.}$	25,3	-	21,8	21,4	28,3	27,9	27,8	27,9	25,9	26,6
	$Ni_{ekv.}$	13,1	-	11,4	11,1	13,1	13,7	13,5	13,4	12,6	13,2
Joint 2 MIG 18/8/6	Cr	16,73	17,06	15,70	15,21	17,45	17,50	16,10	16,60	17,12	16,42
	Ni	7,68	7,83	6,70	6,49	7,18	7,50	6,96	7,08	8,62	7,16
	Mn	5,76	5,83	5,90	5,90	6,34	6,53	5,91	6,11	5,37	5,64
	$Cr_{ekv.}$	17,9	18,3	16,9	16,4	18,7	18,7	17,3	17,8	18,3	17,6
	$Ni_{ekv.}$	13,0	13,2	12,1	11,8	12,8	13,2	12,3	12,5	13,7	12,4

Cr and Ni equivaelents for base materials are calculated based on the results of chemical examination of plates used in this experiment [2, 5]: for M1 - Cr_{eq} = 0,87 and Ni_{eq} = 3,74; for M2 - Cr_{eq} = 20,60 and Ni_{eq} = 13,64; and for V - Cr_{eq} = 1,68 and Ni_{eq} = 3,42. Calculated values for base material M1 and base material M2 are relatively close and in the figure 6 these are presented by only one point (point A). The values for austenitic base material are presented by point B in figure 6. Due to the lower melting temperature and lower thermal conductivity of austenitic base material, with respect to another two base materials, it was adopted that the share of austenitic steel in the weld metal is approximately 60 %. Based on this the position of the dividing point C was determined. Cr and Ni equivalents for filler materials were determined based on the chemical compositions specified in producer catalogue (for electrode Inox 29/9 - Cr_{eq} = 30,35 and Ni_{eq} = 13,95 and for wire MIG - 18/8/6 Cr_{eq} = 19,70 and Ni_{eq} = 14,90). Entering the values from table 1 on the diagram shown in figure 6, the areas with the chemical compositions of both weld metals were obtained. In the case where the filler material Inox 29/9 was used, this area is located on the line which connecting deviding point and point which represents filler material. In the case where the filler material MIG 18/8/6 was used this area is loceted below the line which connecting dividing point and point which represents used filler material. This deviation is probably due to variation of the chemical composition of used filler material batch, compared to catalog values. Based on the position of line which connects dividing point and point which represents filler material Inox 29/9, figure 6, and assumed level of dilution, which for the MMA process is in the range from 15 % to 30 % [1, 2], it is expected that the weld metal has austenitic microstructure with content of δ - ferrite in the range from 15 % to 35 %. All points from table 1, expect the points from colums 3 and 4, are located in specified zone. The results of microstructural examinations confirm that the obtained microstructures are provided in the diagram. Obtained microstructures are loceted in the area of diagram, where embrittlement due to the precipitation of secondary phases can occur. Part of the weld metal which lies along the fusion line with the base material M1 (table 1, columns 3 and 4) has a microstructure loceted in the zone of diagram in which there is no tendency to the formation of imperfections. Based on the location of the line which connects dividing point and point which represents filler material MIG 18/8/6 and assumed level of dilution, which for the MIG process is in the range from 25 % to 40 % [1, 2] it is expected that this weld metal has austenitic microstructure. However, some of the points from table 1 are loceted in the zone of austenitic microstructure in diagrame, some other are positioned in the area of austenitic-martensitic microstructure and some are loceted in the area of the ferritic-austenitic structure. In this case, microstructural examinations have confirmed the presence of δ - ferrite.

Hardness measurements were not determined higher values to indicate the presence of martensite. Due to insufficient amount of δ - ferrite in the weld metal there is a risk of formation of hot cracks.

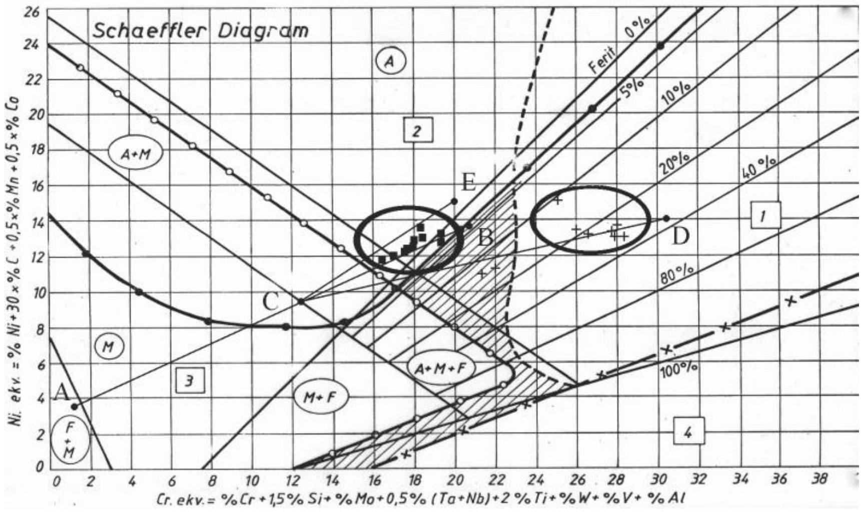

Figure 6. Distribution of the chemical composition of layers: left - MIG 18/8/6, right - Inox 29/9

Comparing the data from the table 1, it can be seen that there is a decrease in the concentration of alloying elements in the zone of the weld metal located near the base material M1 or base material M2 (table 1, columns 3 and 4). This is understandable considering that this is a zone of mixing high-alloyed filler material and low-alloyed base material. In the zone of weld metal located near the base material V, the concentration of alloying elements is the highest, because it is the area of mixing high-alloyed base material and high-alloyed filler material (table 1, columns 5 and 6). In the central region of the weld metal (table 1, columns 7 and 8) the concentration of alloying elements is lower due to the interference with low-alloyed material.

4. CONCLUSIONS

Deviations of obtained microstructures in weld metal compared to those provided by Schaeffler diagram may occur due to inability to determine the precise level of dilution. The level of dilution depends on the welding process and welding parameters, whose impact can not be precisely determined in advance. Obtaining the position of weld metal in an area of Schaeffler diagram where the imperfections are expected does not mean that those imperfections will necessarily occur. The diagram does not take into account all factors that can lead to the appearance of imperfections in the weld metal. Therefore, the diagram should be used only as a guide to reduce the probability of formation of imperfections in the weld metal.

5. REFERENCES

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