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SAW - Narrow Gap Welding CrMoV Heat-Resistant Steels Focusing to the Mechanical Properties Testing

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Abstract

The paper deals with verification of multi-layer SAW welding the raw material W Nr. “1.6946” by different welding consumables (TOPCORE 838 B, Thermanit MTS 616) in the "ultra" narrow gap. An evaluation of the mechanical properties was done for both types welding consumables. The measured values of yield strength and the tensile strength exhibit comparable properties. The welded work piece by the welding consumable “Thermanit MTS 616” was found falling below the specified values of impact energy, ductility.

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Keywords: Submerge arc welding; "Ultra" narrow gap; Interpass; Heat Treatment; Welding consumable

1. Introduction

To make strong connections for the various turbine components (rotors), it is possible to use only certain welding methods that allow a welded joint with the smallest area, mainly in order to keep the heat affecting the base material [3]. Nowadays, there are many variants of welding technology that can be used for welding of cylindrical energy units. One of the verified "the low cost" welding technology [9] is a method of "Submerged Arc Welding".

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This welding method is used mainly for high efficient process and high deposition rate. Using the applications referred above, it is necessary to proceed it by the minimum the input affecting the base material & welded area [8]. To ensure an appropriate combination (quality of welded joints vs. productivity) is recommended [4] the use of SAW welding method in the narrow gap (assuming multi-pass welding of larger thicknesses). Purpose of combination method submerged arc welding application together with innovative modifications of welded surfaces [1, 9], is to reduce the economic demands of production by the welding times & the amount of the welded metal ensuring the repeatable welding parameters.

As a raw material for the manufacture of turbine rotors (operating between temperatures of 350 – 500 ˚C) [6] is usually used creep resistant steel. It is a widely-used the raw materials based on CrMo and CrMoV. These raw materials represent the largest share of thermally stressed components of energy units.

High heat resistance is determined by the optimum alloying, especially the elements Mo and V. They are easily weldable and can be combined to produce the desired metallurgical intermediate products [10]. Good weldability is, however, subject to compliance with the requirements of temperature cycle in order to avoid exceeding the critical cooling rate in the surroundings of the done weld. For these raw materials it is necessary strict compliance with the welding methods (temperature cycle, the heat input and the subsequent heat treatment). An important factor is the selection of suitable welding consumable. The rule applies; the welding consumable must fulfill at least the same chemical composition and mechanical properties as the raw material [15].

2. Experiment

The work piece, was made to verify the use of a suitable welding consumable for multi-pass SAW welding into the „ultra" narrow gap (size of the gap follows 15/15 mm). Basically, the tested steel is the low-alloy creep resistant steel according to the chemical composition 30CrMoNiV 5-11.

The „ultra" narrow gap welding is a multilayer welding where the gap is designed with the specific shape [1] to create one layer by the maximum of two welds (the „ultra" narrow gap width is chosen between 10 – 15 mm). The thickness of the work piece was 50 mm prepared by using raw material marked like W Nr. 1.6946, the flux "F25" (according to EN 760: SF AB 1 64 AC, drying prescription 350 °C – 2 hours, max. content of diffusible hydrogen 5 ml / 100 g) was used in multi-pass welding. Two types of welding consumables were examined: Thermanit MTS 616 (ø 3.2 mm, solid wire, received from the co. Bohler Uddeholm [5] and TOPCORE 838 B (ø 3 mm, cored wire, received from the co. DRATHZUNG STEIN) [2].

The Chemical composition and mechanical properties of the base material (W Nr. 1.6946) are shown in Table 1, 2. The typical mechanical and other technical characteristics of the flux are shown in Table 3 and the chemical composition and mechanical properties of the additive materials are shown in Table 4, 5.

Table 1. Chemical composition of the steel W Nr. 1.6946 [% of weight].

Element [%]	**C**	**Si**	**Mn**	**Cr**	**Mo**	**Ni**	**V**	**S**	**P**
	0,34	0,15	0,8	1,4	1,2	0,75	0,35	0,007	0,01
	-	-	-	-	-	-	-	-	-

Table 2. Mechanical properties of the steel W Nr. 1.6946.

R_{p02} [Mpa]	**R_m** [Mpa]	**KV** [J]	**T** [°C]
≥ 550	≤ 850	≥ 24	≤ 560

Table 3. Typical characteristics and the intended mechanical properties of the weld metal using the flux „F25“.

Grain size [mm]	**Basicity index** -	**R_e** [Mpa]	**R_m** [Mpa]	**KV/T** [J/cm2]/[°C]		**A_5** [%]
0,3	1,4	440	500	150/20	90/0	27
max 1,6	-	-	-	-	-	-

Table 4. Typical chemical composition of the welding consumables [% of weight].

	C	**Si**	**Mn**	**Cr**	**Mo**	**Ni**	**W**	**V**	**Nb**	**N**	**S**	**P**
Thermatit MTS 616	0,1	0,38	0,45	8,8	0,4	0,4	0,2	0,4	0,06	0,04	N/A	N/A
	-	-	-	-	-	-	-	-	-	-	-	-
TOPCOR E 838 B	0,1	0,3	0,9	1,1	1,2	0,35	N/A	0,25	N/A	N/A	0,009	0,015
	-	-	-	-	-	-	-	-	-	-	-	-

Table 5. Predicted mechanical properties of the weld metal using the welding consumables. .

	R_{p02} [Mpa]	**R_m** [Mpa]	**KV** [J]	**T** [°C]
Thermatit MTS 616	560	720	41	-
	-	-	-	max 625
TOPCORE 838 B	500	650	47	150
	-	max 780	-	max 550

2.1. Weldability of the base material (W NR. 1.6946)

CrMoV type heat resisting steel (W Nr. 1.6946) can be classified as susceptible to hot, cold cracking, for which it is necessary to follow the prescribed temperature cycles during all phases of the production process (preheating temperature, interpass temperature, controlled cooling process and heat treatment).

The Computational analysis of the base material confirmed the need of the special temperature cycle (preheating temperature, interpass temperature) and heat treatment of the work piece during the welding process because there is the danger of the internal stresses formation accompanied by the hard martensitic structures forming. To determine the temperature of preheating and the interpass temperatures were used two independent methods (Seferian´s method, normative method in accordance with EN 1011-2: 2000).

The calculation formulas given in [11, 12] were used. Comparing the results of the preheating temperature was recommended to 350˚C. The preheating temperature, interpass temperature selected 300 °C based on the results and through the consultations with low-alloy creep resistant steels processors (Siemens Industrial Turbomachinery). This determination is based on the consideration that when the temperature reaches less than 300 °C during the multi-pass welding process (multi-pass layer), the permitted limit of the cooling rate can crossed and the formation of the brittle layers by precipitation of solid disperse phase by alloying elements can be expected. Considering the calculated Mf temperature ($M_f \div$ 100˚C), the final temperature of the controlled cooling before heat treatment - was set at 150 °C – holding time 1 hour - cooling rate 50 °C / h.

The applied heat treatment: heating to a temperature of 650˚C - 80°C / h, holding time 5 hours, controlled cooling 50 °C / h.

2.2. The welding process

After optimization of the welding parameters, the parameters have been set: the welding current 450 A, the voltage 29 V, the welding speed 58 cm/min. Before performing the multi-pass welding the work piece was preheated in an electric furnace at 300 °C, the heating time for sufficient warming was 4 hours. The flux was dried according to the manufacturer's instructions. The „ultra“ narrow gap was done by 18 weld beads (9 layers) followed by the interpass temperature of 300 °C.

The experiment was conducted in the Laboratory of cross-faculty teaching welding technology of Czech Technical University in Prague, Faculty of Mechanical Engineering, and Institute of Welding & Technology Engineering (laboratory). The welding equipment and the integrated welding tractor co. ESAB type: LAF 681 with the control system PEK + A2 Multitrac was used during the experiment. Temperature check of the preheating process and the interpass temperature were carried out by the fixed thermocouple using the "ALMEMO" measuring device. The low temperature than the predicrebed one was not measured during the whole experiment.

2.3. The joints integrity and mechanical properties verification

The non – destructive & destructive testing was done on the prepared thin sections after the welding process. The quality requirement of multi-pass beads was determined according to EN ISO 5817 in the quality level "B". The Visual inspection (all made of welded layers) and magnetic powder test found no unacceptable surface (and subsurface) defects. The X-ray examinations have demonstrated satisfactory internal multi-pass joint integrity. The uniformity heat-affected zone that has been demonstrated metallographic examination on the macro -sections for evaluation macrostructure and micro hardness measurements (which are not the topic of this publication). The examination was successful for both test pieces as is shown on the fig. 1. (Thermanit MTS 616) in addition on the fig. 2. (TOPCORE 838 B). Metallographic samples were created as indicated in [7, 13, 14].

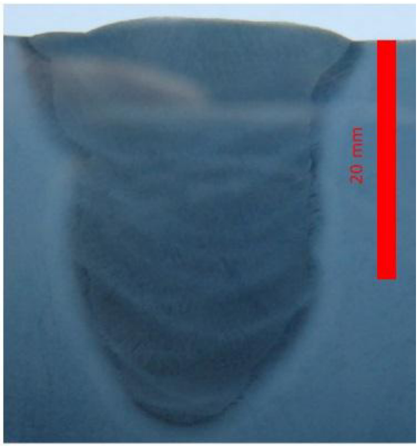

Fig. 1. Metalografic sample (W Nr. 1.6496 + Thermanit MTS 616).

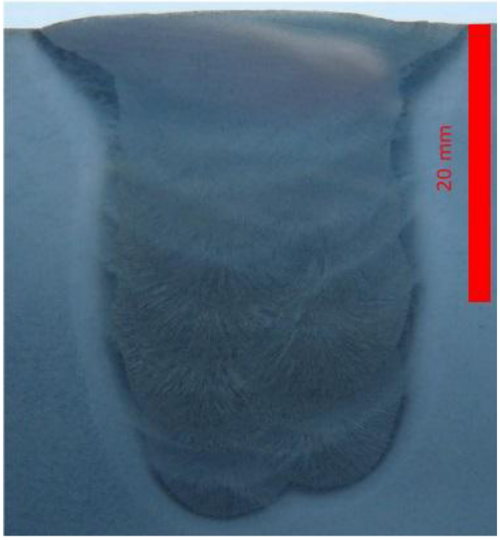

Fig. 2. Metalografic sampe (W Nr. 1.6496 + TOPCORE 838 B).

Due to the working environment in which the base material is determined (work at temperatures up to 550 °C), the Charpy impact test was conducted for the three groups of temperatures (0 °C, +20 °C, +50 °C) and a tensile test at temperatures (0, 290 °C). The verification of the prediscredbed values has been carried out in the direction of rotor rotation for both welding consumables.

The test sample with "V - notch" for the impact test was made in accordance with EN 148-1. Testing rods were made for examination of the welded zone (the weld metal properties) as well as of the heat-affected zone (HAZ) in accordance with standard EN ISO 9016. The surface of the testing rod with the "V - notch" was perpendicular to the surface of the welded work piece (referred to as the position T). The distance "b" side faces of the test rods was approximately 5 mm measured from the welded work piece surface. The tensile test, done under the higher temperatures, was conducted in accordance with the group of standards EN ISO 6892-1, 2, 5. The loading speed 2 mm / min, weight range of the testing device was 50 kN.

Table 6, 7, 8 shows the results of Impact Charpy test.

The tendency of the average values of the resulting notch impact strength of the weld metal and heat affected zone is plotted in Fig. 3.

Table 6. Impact Charpy test 0 ˚C.

ZVS1_0	**KV** [J]	**Ø KV** [J]	**ZVS2_0**	**KV** [J]	**Ø KV** [J]
RK1S	10		**RD1S**	9	
RK2S	13,5	10,8	**RD2S**	10,5	9
RK3S	9		**RD3S**	7,5	
RKS4P	13,5		**RDS4P**	9	
RK5P	14,5	14,6	**RD5P**	7	8
RK6P	16		**RD6P**	8	

Table 7. Impact Charpy test +20 ˚C.

ZVS1_20	KV [J]	Ø KV [J]	ZVS2_20	KV [J]	Ø KV [J]
RK1S	26		**RD1S**	14	
RK2S	24,5	25,1	**RD2S**	16,5	15,3
RK3S	25		**RD3S**	15,5	
RK4P	25,5		**RDS4P**	14,5	
RK5P	34	30,5	**RD5P**	17,5	14,5
RK6P	32		**RD6P**	11,5	

Table 8. Impact Charpy test +50 ˚C.

ZVS1_50	KV [J]	Ø KV [J]	ZVS2_50	KV [J]	Ø KV [J]
RK1S	33		**RD1S**	23,5	
RK2S	36,5	34,3	**RD2S**	12	20,3
RK3S	33,5		**RD3S**	25,5	
RKS4P	45		**RDS4P**	20,5	
RK5P	37	43,8	**RD5P**	20	18,8
RK6P	49,5		**RD6P**	16	

Remarks

ZVS1_x – testing rod x˚C, welding consumable TOPCORE

ZVS2_x - testing rod x ˚C, welding consumable Thermanit

RxxS - specimen - weld metal section

RxxP - specimen - HAZ

Table 9, 10, 11, 12 shows the results of tensile tests.

Table 9. Tensile test - Strength properties (20 ˚C).

ZVS1_20	R_{p02} [MPa]	R_m [MPa]	A_5 [%]	Z [%]
min. limit	550	700	12	40
1	609	749	14,4	69,5
2	604	749	14	68,7
3	600	751	15,1	69,4
ø	604,3	749,6	14,5	69,2

Table 10. Tensile test - Strength properties (290 ˚C).

ZVS1_290	R_{p02} [MPa]	R_m [MPa]	A_5 [%]	Z [%]
min. limit	465	-	-	-
1	521	621	13,2	69,5
2	528	615	12,9	69,3
3	516	632	13,4	68
ø	521,6	622,6	13,2	68,9

Table 11. Tensile test - Strength properties (20 ˚C).

ZVS2_20	R_{p02} [MPa]	R_m [MPa]	A_5 [%]	Z [%]
min. limit	550	700	-	-
1	743	819	1,9	59,8
2	735	810	2,5	60,1
3	729	813	2,2	58,6
ø	735,6	814	2,2	59,5

Table 12. Tensile test - Strength properties (290 ˚C).

ZVS2_290	R_{p02} [MPa]	R_m [MPa]	A_5 [%]	Z [%]
min. limit	465	700	-	-
1	658	711	3,3	59,7
2	640	710	2,9	59,5
3	651	715	3,4	59
ø	649,6	712	3,2	59,4

Remarks

ZVS1_x – testing rod x˚ C, welding consumable TOPCORE

ZVS2_x - testing rod x ˚C, welding consumable Thermanit

3. Discusion

For satisfactory assessment of the resulting impact values are based on the prescription document control base material (W Nr. 1.6946), where the threshold KV is at least 24 J at 20 °C.

The first sample (created the welding consumable Thermanit MTS 616) showed lower values of notch impact strength (KV = 16.5 J) in the weld metal section in addition (KV = 17.5 J) in the heat-affected zone at the temperature of 20˚C. The measured values of notch impact strength did not meet the assumption of minimal impact work. The test sample (done by the welding consumable Thermanit) showed very poor elongation (A_5 ÷ 2.2% at 20 °C, A_5 ÷ 3.2% at 290 °C) after the done tensile test. The yield stress R_{p02} ÷ 735.6 MPa, tensile strength R_m ÷ 814 MPa, contraction Z ÷ 59.5% at 20 ° C, as well as the value of R_{p02} ÷ 640 MPa, Rm ÷ 710 MPa, Z ÷ 59.4% at 290 ˚C was measured on a sample with satisfactory results.

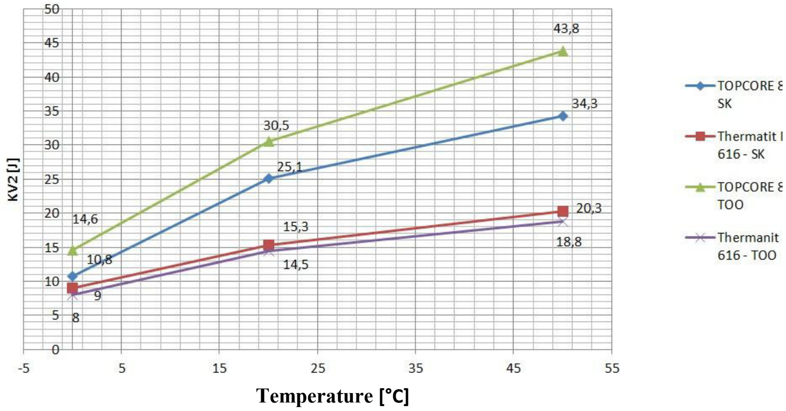

Fig. 3. The tendency of values KV at the temperatures (0, +20, +50 ° C).

Remarks

X - SK – weld metal section

X - TOO – HAZ (heat-affected zone)

The welded work piece filled by TOPCORE 838 B has had the better testing results in the very parts of the mechanical properties testing. The results from the Impact test crossed the minimum prescribed value by the inspection certificate of the base material (W Nr. 1.6496). The second sample (created the welding consumable TOPCORE 838 B) of notch impact strength (KV = 26 J) in the weld metal section in addition (KV = 34 J) in the heat-affected zone at the temperature of 20˚C. The yield stress R_{p02} ÷ 604,3 MPa, tensile strength R_m ÷ 749,6 MPa, elongation A_5 ÷ 14,5%, contraction Z ÷ 69,2% at 20 °C, as well as the value of R_{p02} ÷ 521,6 MPa, R_m ÷ 622,6 MPa, A_5 ÷ 13,2%, Z ÷ 68,9% at 290 ˚C was measured on a sample with satisfactory results.

From tendentious curve of temperature (0, 20, 50 °C) are shown better results for the welding consumables „TOPCORE 838 B“. As part of the average KV and the KV individual measured values at + 20 °C, the lower limit has been reached values prescription of incpection certificate of the raw material for welding consumable „TOPCORE 838 B“. Furthermore, it can be seen that the welding consumable “Thermanit MTS 616” has the low values of the notch impact strength in the heat-affected zone, while the welding consumable “TOPCORE 838 B” has the low value in the weld metal section.

Conclusion

Based on these results we can conclude that the limit values determined according to the SIEMENS internal inspection certificate [1] the base material using the welding consumable „TOPCORE 838 B“ were observed as succesfull for the temperatures of 20 °C and 290 °C, which fully covers the prescribed limits for basic material in these temperature levels. For welding consumable “Thermanit MTS 616” measured values meet the strength requirements, while the values of elongation & notch toughness did not reach the required limits. The measured values of the elongation were below 3% and the notch toughness KV ÷ 17.5 J at temperature of 20 °C.

The critical point in the multi-pass weld joint is identified transition area between the weld metal & heat-affected zone which is presented by the higher risk of precipitation of the solid dispersion particles. To confirm the occurrence of brittle zones in the heat affected zone the further research of the macro and internal structure micro analysis of the welded joints with accompanying micro-hardness measurements must be carried out.

From the presented results it can be stated that the base material W Nr. 1.6496 is susceptible to turbidity and therefore it is very important to pay considerable attention to the two temperature changes during and after the welding process. The achieved results document the need for further study of the optimization operation in order to improve the mechanical properties.

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