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The Effect of Heat Treatment on the Structure and Hardness of Welded Joints in Steel 7CrMoVTiB10-10

Abstract: The article presents results of tests concerning the effect of heat treatment on the structure and hardness of submerged arc welded joints made in steel 7CrMoVTiB10-10 (T24). The tests revealed that the welds made of steel 7CrMoVTiB10-10 required post-weld heat treatment at a temperature 750°C. The heat treatment was performed in order to protect welded structures from cracking during transport and operation as well as to prevent the development of secondary hardness.

Keywords: heat treatment, submerged arc welding, Steel 7CrMoVTiB10-10

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Introduction

Steel 7CrMoVTiB10-10 was launched on the market (and used primarily in the production of waterwalls) as a result of power engineering development, to address issues related to the retrofit of power generation equipment necessitated by an increase in generated power as well as to improve mechanical properties and eliminate the necessity of heat treatment. The steel was obtained through the modification of the chemical composition of steel 10CrMo9-10 (T22), involving the addition of microagents including vanadium, titanium, boron and nitrogen [1,3,4,6,7]. Assumedly, a decreased carbon content in the steel should translate into significantly better weldability and lower hardness, whereas the presence of microagents such as boron, titanium and vanadium should improve creep strength. However, the "reality check" proved the idea to be unfortunate . Welds made in the steel contained numerous hot, cold and relaxation cracks. Such a situation could be ascribed to the presence of numerous welding imperfections (of acceptable size), subsequently leading to the propagation of cracks as well as to the negative effect of secondary hardness resulting from the steel composition, the wide range of brittleness temperature, significant deformations of welds as well as the negative effect of hydrogen, present both during the process of welding and during the operation of welded structures [1–8].

Objective and course of tests

The research-related tests aimed to examine the structure and determine the hardness of submerged arc welded butt joints made in steel 7CrMoVTiB10-10. The chemical composition of the steel is presented in Table 1. Three joints were made using the submerged arc welding method, the with Union S P 24 filler metal having a diameter of 2 mm and flux UV 305.

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Table 1. Chemical composition of steel 7CrMoVTiB10-10, %

C	Mn	P	S	Si	Cr	Mo	V	Ti	N	B
0.05-0.15	0.30-0.70	Max. 0.02	Max. 0.01	0.15-0.50	2.20-2.60	0.90-1.10	0.20-0.30	0.06-0.10	0.012	0.0015-0.0070

Table 2. Parameters applied during the submerged arc welding of the joints

Current [A]	Arc voltage [V]	Welding rate [cm/min]	Electrode extension [mm]
460	32	32	20

Welding parameters are presented in Table 2. One of the joints was not subjected to heat treatment, whereas the other two joints were subjected to heat treatment performed at a temperature of 600°C and 750°C respectively. The hold time amounted to 30 minutes. In both cases, the joints were cooled at two stages, i.e. first to a temperature of 200°C in a furnace and, next to ambient temperature in the open air. The joints after heat treatment and the joint in the as-welded state were subjected to visual and penetrant tests as well as microstructural analysis and hardness measurements. The visual and penetrant tests of the welded joints did not reveal the presence of any welding imperfections. The weld microstructure revealed the presence of titanium nitrides (Fig. 1, 2 and 3). Nitrogen, characterised by the higher chemical affinity for titanium than that of oxygen, combines with titanium during welding. Titanium nitrides are characterised by very high hardness as well as by low toughness and plasticity, thus potentially contributing to the formation of cracks in welds. The structure of the weld in the as-made condition did not change after being subjected to heat treatment at a temperature of 600°C. In both cases, the structure was martensitic-bainitic. The specimen subjected to

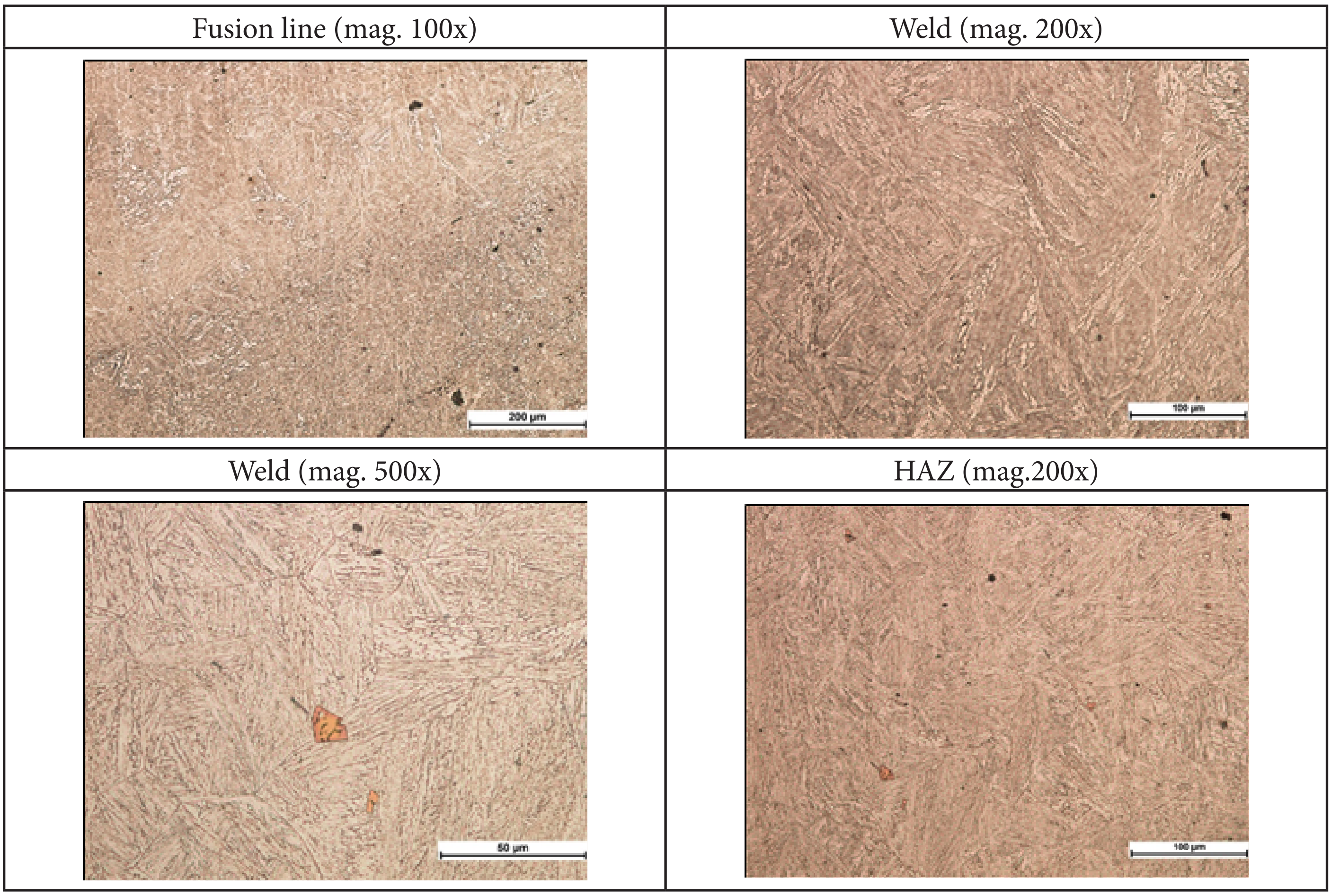


Fig. 1. Microstructure of the as-welded joint made in steel 7CrMoVTiB10-10

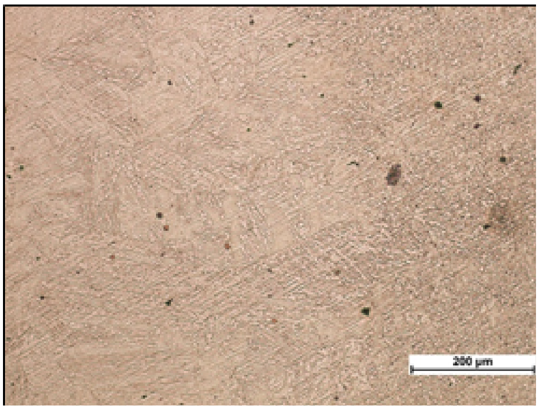
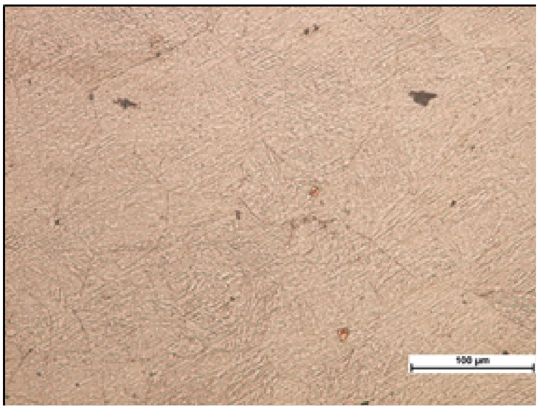
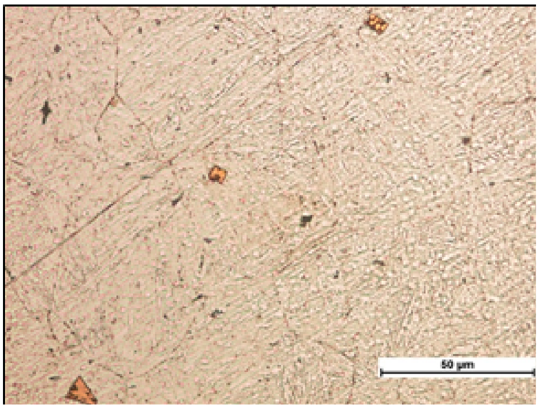
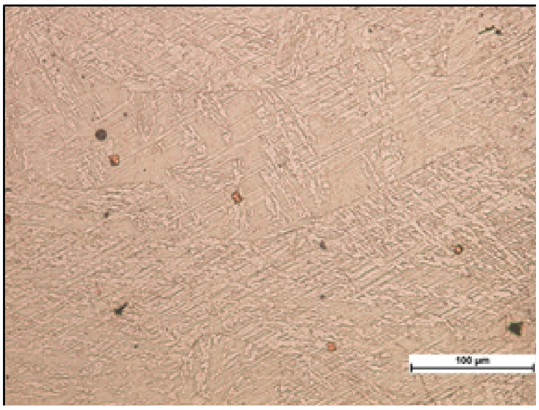
Fusion line (mag. 100x)	Weld (mag. 200x)
	
Weld (mag. 500x)	HAZ (mag.200x)
	

Fig. 2. Microstructure of the joint made in steel 7CrMoVTiB10-10 after heat treatment at a temperature of 600°C

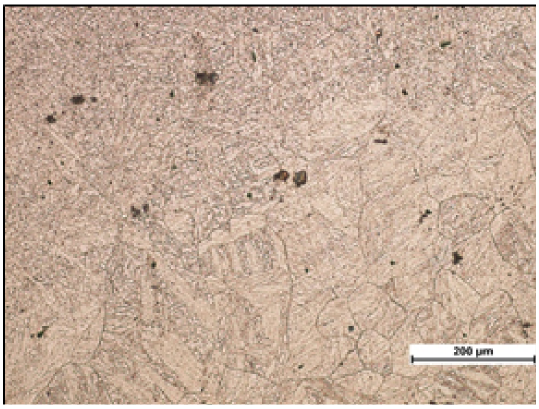
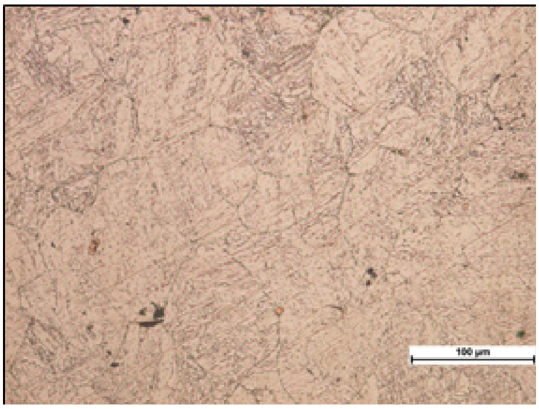
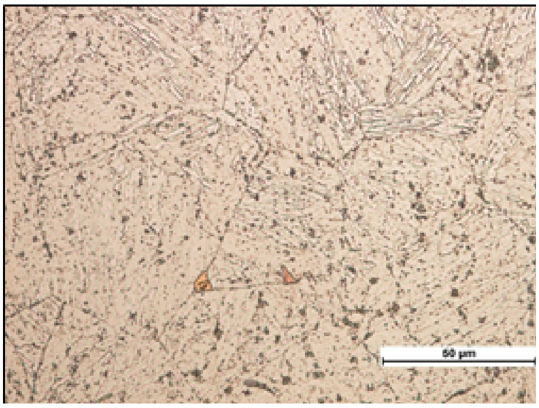
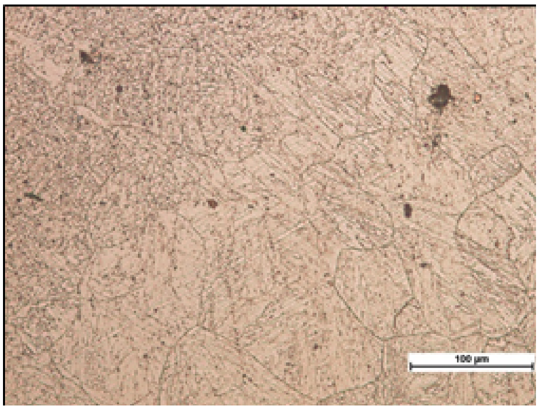
Fusion line (mag. 100x)	Weld (mag. 200x)
	
Weld (mag. 500x)	HAZ (mag.200x)
	

Fig. 3. Microstructure of the joint made in steel 7CrMoVTiB10-10 after heat treatment at a temperature of 750°C

heat treatment at a temperature of 750°C contained the tempered martensitic-bainitic structure.

The test specimens were subjected to HV0.1 hardness measurements from the weld face to the weld root and across the weld (see Fig. 4). The hardness measurement results are presented in Table 3.

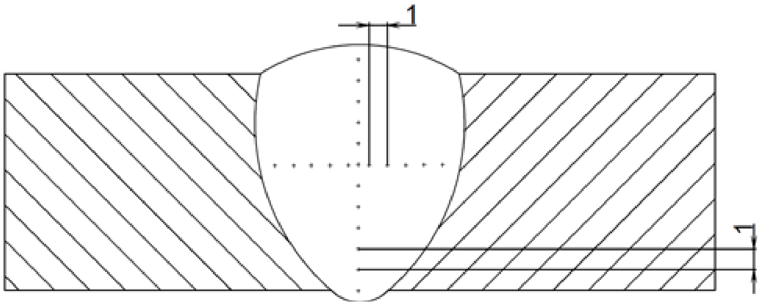


Fig. 4. Method used in hardness measurements

Analysis of test results

The tests involved the making of three joints using welding consumables recommended for the welding of steel 7CrMoVTiB10-10 (filler metal Union S P 24 and flux UV 305). Each welding process involved the drying of the flux (to prevent humidity) as well as the use of run-on and run-off plates and ceramic backing strips (to ensure the proper formation of the weld root). The visual and penetrant tests of the welded joints did not reveal the presence of any welding imperfections. The presence of micro-porosity (characterised by the globular shape and the diameter not 20 μm) was observed by means of a light microscope (Fig. 1–3).

All of the welds contained titanium nitrides. Because of its higher chemical affinity for titanium, nitrogen (during welding) combines with titanium, forming titanium nitrides. Titanium nitrides are characterised by very high hardness as well as low toughness and plasticity, potentially increasing the risk of crack formation in welds. With reference to the chemical composition of the consumables used in the process it was noticed that, as a result of welding, titanium forming the titanium nitride (TiN) "moved" from the base material to the weld area. The observation of the plane of metallographic specimens revealed that, in addition to cavities and TiN, the surface of each weld also contained fine precipitates of carbides. The structure of the weld in the as-made state did not change after heat treatment performed at a temperature of 600°C. In both cases the

Table 3. Hardness measurements of the individual welds

Hardness [HV0.1]					
Measurement from the face to the root			**Measurement across the weld**		
Specimen 1 (as-welded state)	Specimen 2 (600°C)	Specimen 3 (700°C)	Specimen 1 (as-welded state)	Specimen 2 (600°C)	Specimen 3 (700°C)
331	369	246	-	-	-
325	365	244	325	-	247
324	362	248	318	-	246
325	355	253	316	368	240
321	359	254	321	359	248
320	356	245	309	356	239
324	357	250	311	364	242
326	361	249	315	369	247
324	360	249	314	371	249
328	368	246	327	-	251
323	367	254	328	-	250
321	368	251	-	-	-

structure was martensitic-bainitic. The structure of the weld exposed to a temperature of 750°C was tempered.

The hardness measurements of the welded joints made in steel 7CrMoVTiB10-10 revealed that their mean hardness in the as-welded state amounted to 321 HV0.1. Heat treatment performed for 30 minutes at a temperature of 600°C increased hardness up to 363 HV0.1. In turn, heat treatment performed for 30 minutes at a temperature of 750°C reduced the weld hardness to 248 HV0.1. Although the tempering of steel is usually associated with a decrease in hardness, the tests revealed the occurrence of the phenomenon referred to as secondary hardness (where the mean weld hardness value after tempering at a temperature 600°C was by 42 HV0.1 higher than that of the weld measured directly after welding). The above-presented phenomenon could be ascribed to the presence of carbide precipitates as well as to the fact that steel T24 is provided with additions of strongly carbide-forming chemical elements.

The overview of related reference publications and the results of the tests led to the conclusion that, because of the operating temperature of steel T24, welded structures made of the aforesaid material initially increase their brittleness through hardening. The lack of post-weld heat treatment combined with very high welding stresses and the presence of hydrogen during the start-up and operation of hardness as well as the occurrence of secondary hardness may lead to the formation of cracks in the welds. Because of this, the post-weld heat treatment of joints at a temperature of approximately 750°C is inevitable. Related tests demonstrated that tempering performed at temperature lower than that of 750°C may lead to secondary hardness and lead to a decrease in hardness.

Concluding remarks

1. The tests revealed that heat treatment performed at a temperature of 600°C did not affect the structure of the welds made in steel T24. The structure of the welds subjected to heat treatment performed at a temperature 750°C was tempered.
2. The tests also revealed the “passage” of titanium from the base material to the weld (manifested by the presence of numerous TiN precipitates on the surface of the metallographic specimens in all of the specimens).
3. Heat treatment performed at a temperature 600°C increased the hardness of the welds by 42 HV0.1, indicating the susceptibility of steel T24 to secondary hardness. Heat treatment performed at a temperature of 750°C reduced the hardness of the welds by 115 HV0.1.
4. To prevent welded structures from cracking, the welding of joints in steel 7CrMoVTiB10-10 must be followed by heat treatment performed at a temperature of 750°C.

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