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MECHANICAL AND METALLOGRAPHIC PROPERTIES OF STEEL NIOMOL 490K SAW-JOINT

MEHANIČKA I METALOGRAFSKA SVOJSTVA EPP ZAVARENOG SPOJA ČELIKA NIOMOL 490K

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- steel NIOMOL 490
- microstructure
- hardness HV
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Ključne reći
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- čelik NIOMOL 490
- mikrostruktura
- tvrdoća HV
- udarna žilavost

Abstract

Bearing in mind the use of fine-grained micro alloyed steel NIOMOL 490K for welded structures exposed to impact loading at low temperatures, the mechanical and metallographic properties of its welded joint obtained by submerged arc welding (SAW), are examined. A filler metal, EPP 2NiMo2 Ø4 mm wire is used, in combination with OP 40 TT flux powder. The final aim of this research is to analyse the behaviour of welded joints under impact load at low temperatures in order to evaluate its fitness-to-service in real operating conditions.

Izvod

Imajući u vidu primenu sitnozrnog mikrolegiranog čelika NIOMOL 490K za izradu zavarenih konstrukcija izloženih udarnom opterećenju na niskim temperaturama, ispitana su mehanička i metalografska svojstva njegovog zavarenog spoja dobijenog postupkom elektrolučnog zavarivanja pod praškom (EPP). Kao dodatni materijal korišćena je žica oznake EPP 2NiMo2 Ø4 mm uz dodatak praška OP 40 TT. Konačni cilj istraživanja jeste analiza ponašanja zavarenog spoja pri udaru na sniženim temperaturama, odnosno, pogodnost za upotrebu u stvarnim radnim uslovima.

INTRODUCTION

NIOMOL 490 K steel, alloyed with Mo, belongs to the second generation of micro alloyed structural steels, with a minimum yield strength of 490 MPa and guaranteed brittle fracture transition temperature of -60 °C /1, 2/. Its pearlite-ferrite microstructure provides sufficient crack resistance, enabling NIOMOL 490K to be used in welded structures operating in aggressive environments, often containing active hydrogen. The mechanical properties of welded joints of NIOMOL 490K depend on the microstructure of the weld metal (WM), heat-affected zone (HAZ), and parent metal (PM), /1-6/.

For this type of steel, the most preferred microstructure in the WM is acicular ferrite, which favourably affects the mechanical properties, /7/. When welding micro alloyed structural steels, the choice of filler material depends on the chemical composition and mechanical properties of the PM, as well as on the welding procedure. The most important chemical elements for welding fine-grained structural steels are nickel (Ni) and molybdenum (Mo) because they significantly affect WM properties. The addition of Ni promotes the formation of acicular ferrite, which increases WM resistance to cracking. Also, Mo in the filler material reduces the grain size in the primary structure of WM, increases the amount of acicular ferrite, and eliminates upper bainite, while thin plates of primary ferrite are maintained at WM base /8, 9/.

The aim of this work is to provide insight into the metallographic and mechanical properties of NIOMOL 490K welded joints produced by submerged arc welding (SAW) process, using laboratory tests such as microstructural and hardness testing. The final goal of this research is to analyse the behaviour of welded joints in operational conditions, under impact loading at low temperatures.

EXPERIMENTAL RESULTS

Plates 30 mm thick, made of NIOMOL 490K steel are butt-welded using the SAW process. The filler metal is EPP 2NiMo2 wire, Ø4 mm, with OP 40 TT flux /10, 11/. Figure 1 shows the dimensions of the V-groove.

For NIOMOL 490K, the V-groove shape significantly affects hardness due to the material's sensitivity to cooling rate. Since the material is prone to martensite transformation in the HAZ, if cooling is rapid, there is a risk of increased hardness in the HAZ. Therefore, a V-groove with a 45° angle is used, as a narrow V-groove without preheating is not recommended for NIOMOL 490K, /10/. Welding parameters (heat input Q, current intensity I, voltage U, and welding speed) are define elsewhere, /12/, whereas the chemical composition is provided in Table 1. Steel NIOMOL 490K microstructure consists of ferrite (grain size 16 μm) and pearlite (grain size 10 μm). Nominal values for mechanical properties of PM are given in Table 2, while the chemical composition of the filler metal and mechanical properties of filler material and WM are shown in Tables 3 and 4, respectively. The test specimens for chemical analysis, the tensile, hardness, toughness, and metallography tests are cut from butt-welded plates as shown in Fig. 2.

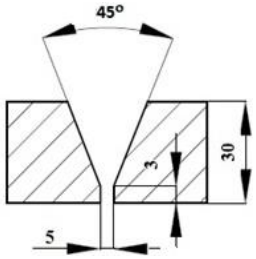


Figure 1. Geometry and dimensions of V-groove.

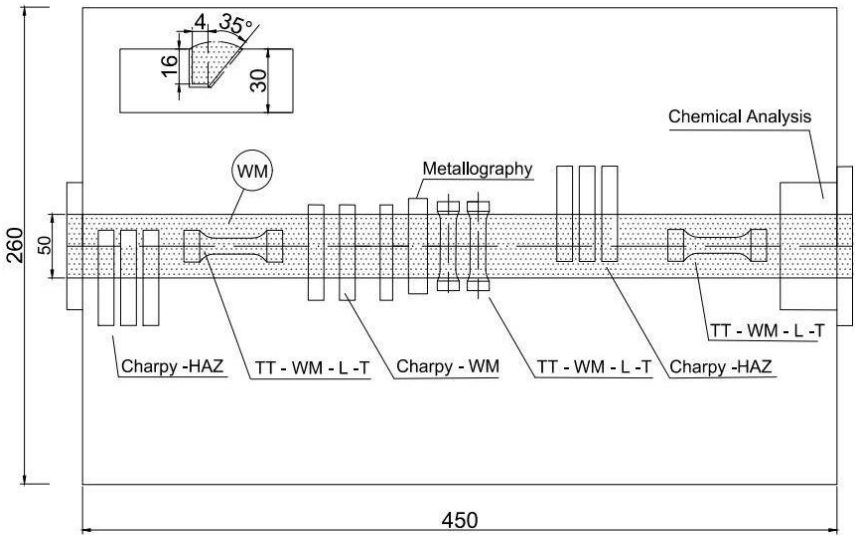


Figure 2. Sampling scheme for testing and metallography, /12/.

Table 1. Nominal chemical composition of steel NIOMOL 490K (wt. %).

C	Si	Mn	P	S	Cr	Cu	Al	Sn	Ni	Mo	As	Nb	N	O
0.09	0.34	1.06	0.009	0.002	0.12	0.17	0.041	0.005	0.19	0.16	0.008	0.006	0.0082	0.0075

Table 2. Nominal values of tensile properties of steel NIOMOL 490K.

R_m (MPa)	$R_{p0.2}$ (MPa) according to thickness (mm)					A_5 (% min.)	Bending angle 180°	
	under 10	11-15	16-25	26-40	41-60		longitudinal	transverse
560-740	490	490	480	470	470	19	D = 2d	D = 2.5d

Table 3. Chemical composition of the filler metal (wt. %).

Designation	C	Si	Mn	Cr	Mo	Ni	S	P	Cu	Ti
EPP NiMo2 Ø4 mm	0.05	0.28	1.09	0.04	/	1.3	0.007	0.009	/	0.07

Table 4. Nominal values of tensile properties of weld metal.

Designation	R_m (MPa)	$R_{p0.2}$ (MPa)	A_5 (%, min.)	Z (%)	KVC -60 °C (J/cm^2)		
EPP 2NiMo2 Ø4 mm	694	596	23	51	67	75	94

Metallography

The parent metal microstructure indicates the material is in quenched and tempered state with approximately 40 % ferrite containing primary carbides and about 60 % of the interphase structure with a bainite base, as expected for the NIOMOL 490K steel /2/.

The photo of the welded sample macrostructure, taken with an optical microscope, is shown in Fig. 3. The HAZ mainly consists of two parts visible to the naked eye which is especially pronounced in flatter areas of the weld.

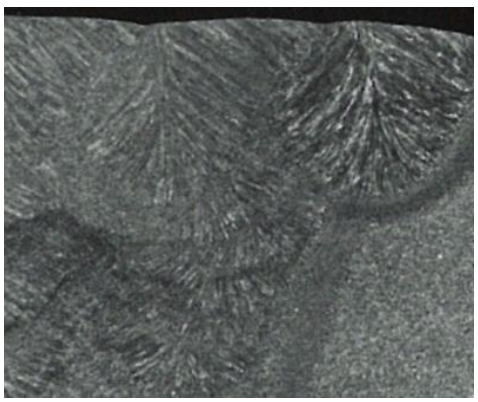


Figure 3. Macrostructure of NIMOL 490K welded joint.

The HAZ typically has a normalised microstructure since it was exposed to temperatures above A_{C3}. In this area, grain recrystallisation occurred, resulting in significantly smaller grains (size 12 according to ASTM) than in the unaffected parent metal, where the grain size is 9. The microstructure of the normalised zone is ferritic-pearlitic. In the region of the HAZ where temperatures were much higher, close to or partially equal to the melting point of the steel, significant grain growth occurs, accompanied by an increase in hardness (about 10 %) and, consequently, an increase in strength. This is the HAZ region where brittleness increases due to reduced toughness and plasticity. However, these two regions of the HAZ are not easy to distinguish. The width of this HAZ region varies from 0.2 to 1 mm, with an average of about 0.4 mm. With an optical microscope it was not possible to determine precisely whether the large crystal grain originated only from the PM or if it formed by mixing the base- and filler metal.

If such a welded joint is to be repaired, heat treatment would be required. Due to the high temperature, the crystals are elongated - longitudinal. Refinement of crystal grains occurred in the middle of the WM, i.e., the grain has recrystallised, but in the HAZ the crystal grain grew. The ratio of grain size at the top and in the middle of the WM is 1:5. At

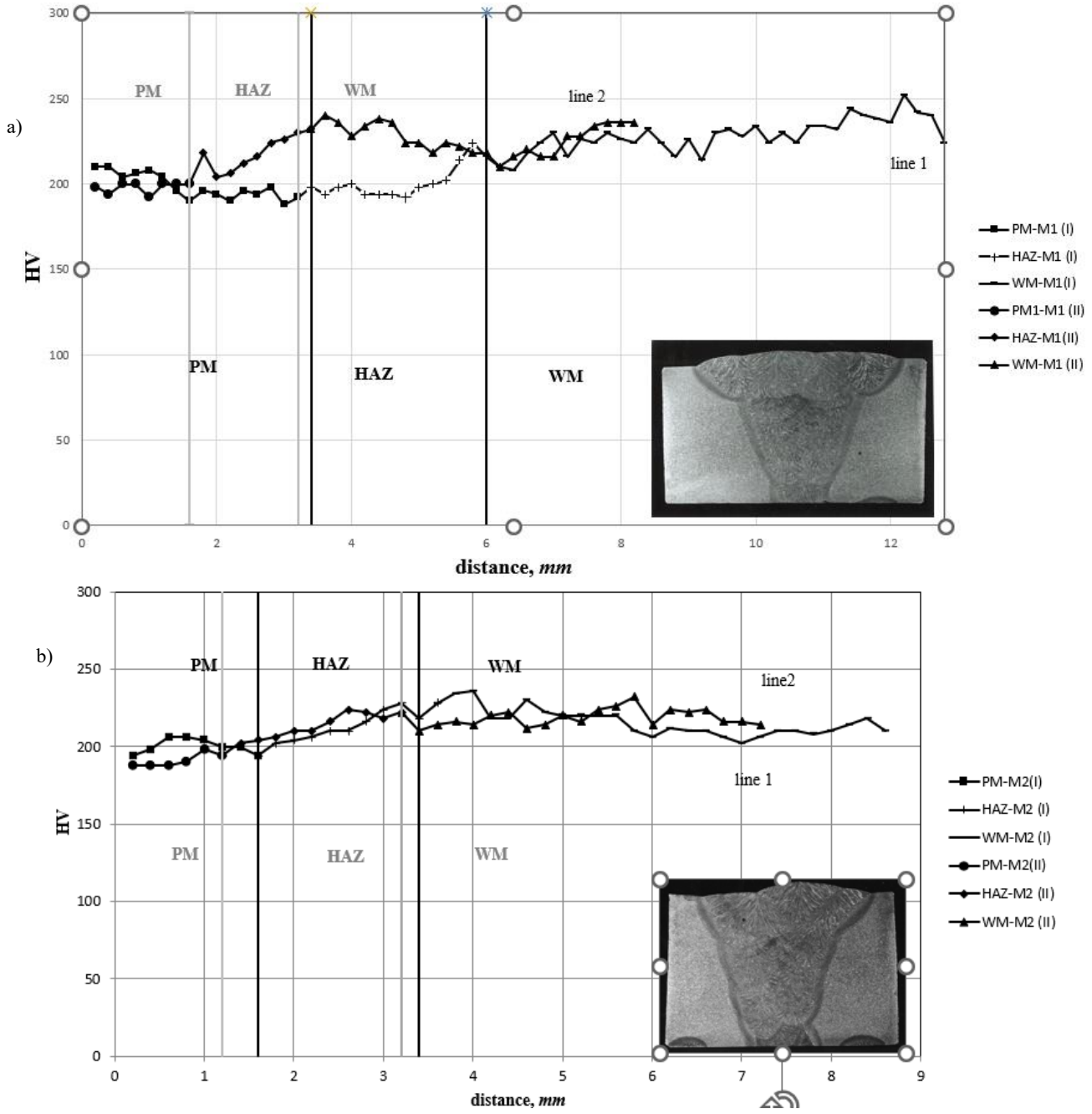
the root of the WM, slight grain growth is observed again, but the grain is half the size of that in the HAZ.

Hardness testing

The hardness test was performed according to standards EN 9015-1 (Destructive testing of welded joints in metallic materials - Hardness testing - Part 1: Hardness testing of arc welded joints) and EN 1043-2 (Plastics - Symbols and abbreviations - Part 2: Fillers and reinforcing materials), /13/. The Vickers method HV10 is used. Indentations are made in the WM, HAZ, and PM to obtain and record the value ranges in the welded joint, as shown in Fig. 4. Hardness is measured on four different types of samples intended for determining tensile properties (designated as M1 and M2) and fracture mechanics testing (M3 and M4). The measured hardness values HV for samples marked M1-M4 are shown in Fig. 4 a-d. Measuring line 1 indicates the weld face, while the measuring line 2 indicates the weld root. The number I next to the symbols PM, WM, and HAZ indicates the hardness measured at the weld face, while the number II indicates the hardness measured at the weld root. The same symbols are used in all four diagrams in Fig. 4 a-d. The results of the hardness measurements are shown in Table 5.

Fracture toughness testing

Fracture toughness testing was performed in the previous research, as shown in details in /14/. Although this research was done on welded joints made by shielded metal arc welding (SMAW), results are shown here in Table 6, to enable a broader view on NIOMOL 490K behaviour and crack resistance.



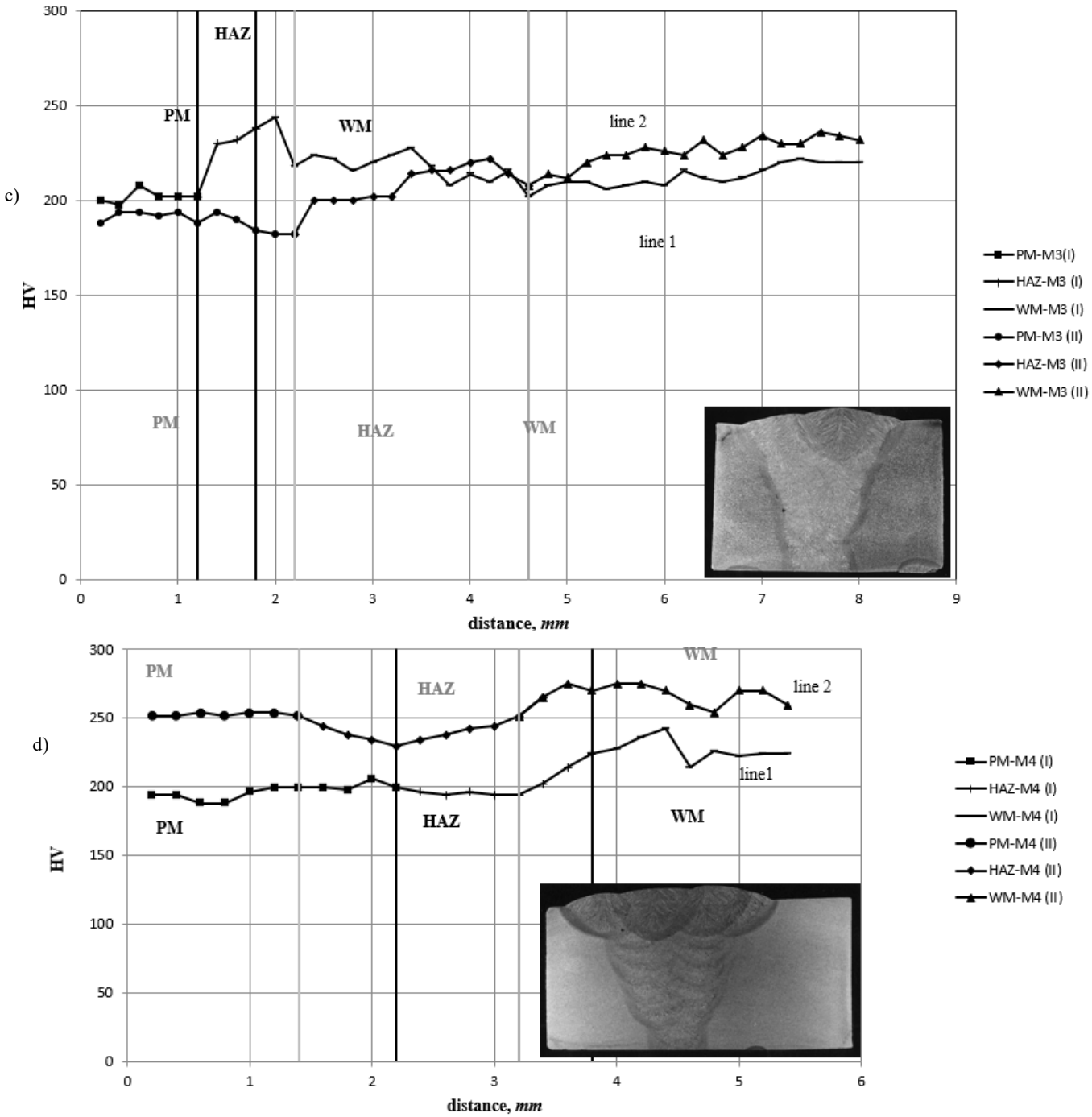


Figure 4. Vickers hardness distribution along the welded joint in 4 cross-sections for specimens: a) M1; b) M2; c) M3; and d) M4.

Table 5. Hardness measurement results.

Base metal	Filler metal	Welding process	Heat input Q (kJ/cm)	Hardness (HV)			
				Specimen design.	PM	HAZ	WM
NIOMOL 490	SAW 2NiMo. Ø4 mm	SAW	13.9	M1	188-210	192-232	210-244
				M2	188-206	202-228	208-236
				M3	182-208	200-238	202-244
				M4	194-254	194-252	214-275

Table 6. Values of fracture toughness and stress intensity factor, /14/.

Testing temperature (°C)	a (mm)	Δa (mm)	J_{Ic} (kJ/m^2)	K_{Ic} (MPa·m$^{1/2}$)
RT	11.617	0.414	222	226
-20	10.519	0.391	147	184
-30	10.982	0.312	118	165

DISCUSSION

Previous results from the broader investigation of NIOMOL 490K behaviour include both impact toughness /11/ and fracture toughness via J_{Ic} /14/, measured at different temperatures up to -60 °C in the first case and up to -30 °C in the second case. The first study is aimed to determine the lowest temperature at which impact toughness values exceed 27 J, i.e., the ductile-to-brittle transition temperature TK27, for all three zones of the welded joint, produced in the same way as in this research. It is shown that the PM and HAZ have TK27 values significantly below -60 °C, as their impact toughness values are 65 J and 44 J at -60 °C, respectively. In contrast, the WM impact toughness at -60 °C is only 22 J, and its TK27 is -35 °C.

For the fracture toughness investigation, results are provided for WM produced by SMAW process /14/ (Table 7). Fracture toughness values are K_{Ic} = 226 MPa√m at 20 °C, 184 MPa√m at -20 °C, and 165 MPa√m at -30 °C. Unlike the WM impact values, fracture toughness values indicate high crack resistance which is attributed to acicular ferrite as the typical microstructure in produced by SMAW with a mixture of shielding gases with oxygen, as shown in /1/.

Hardness measurements presented here indicate *overmatching*, as values obtained in the WM are higher than those in the PM. This is attributed to the presence of a ferrite-bainite microstructure, corresponding to the selected filler metal 2NiMo2. Hardness measured in the HAZ is somewhat lower, while the hardness in the PM is the lowest. More importantly, the differences in hardness values among PM, WM, and HAZ are small. It is also important to emphasize that the hardness values in WM and HAZ do not indicate a detrimental microstructure, such as martensite or upper bainite, that would significantly reduce toughness, even at room temperature.

Finally, it should be noted that these results are influenced by the amount of heat introduced during each subsequent pass of filling the groove, as this leads to normalisation of the previously completed passes, resulting in relatively uniform microstructure and hardness.

CONCLUSIONS

Based on the presented results and previous research, the following conclusions can be drawn:

The hardness and microstructure of the weld metal (WM) and heat-affected zone (HAZ) are relatively uniform due to the multi-pass welding procedure.

Impact toughness is satisfactory in the NIOMOL 490K welded joint made by submerged arc welding (SAW), except in the WM region at low temperatures.

From impact toughness perspective, SAW procedure is not the optimal process for NIOMOL 490K. If low-temperature toughness is of utmost importance, the shielded metal arc welding (SMAW) process should be used instead.

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