THERMAL CYCLE MEASUREMENT OF P92 WELDED JOINTS

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Abstract

This paper deals with welded joints carried out by 111 (MMAW) and 141 (GTAW) welding method on the P92 steel. With respect to the small size of each region in the heat-affected zone (HAZ), the suitable simulation technique for estimation of the microstructure and properties needs to be prepared. In order to find out the important values for this simulation it is necessary to measure thermal cycles on real welded joints of P92 steel using the set of thermocouples. From the time-temperature curves the maximum temperature of each cycle and cooling rate $\Delta t_{8/5}$ of the main heat-affected zone regions could be determined. This study is the first part of a large experiment from which mechanical, microstructural and creep properties of significant HAZ regions and the weakest point of the P92 welded joints will be defined.

Keywords: P92 Steel, P92 Welded Joints, Thermal Cycles

1. INTRODUCTION

Modified martensitic heat-resistant steel P92 belongs to very progressive group of 9-12 % Cr steels micro-alloyed with vanadium and niobium, with controlled boron and nitrogen content. P92 has got excellent creep properties. Thanks to its excellent properties it is used very often to build the most exposed parts of supercritical units in steam power plants. These units must resist high temperatures and pressures (temperatures exceeding 600 °C and pressures over 25 MPa). Because the weakest parts of each construction are welded joints theirs research is very important. [1, 2, 3, 4].

In this study the main task is to measure thermal cycles of P92 welded joints obtained by 111 (with electrodes ∅2.5 mm and ∅3.2 mm) and 141 welding method on P92 steel. In first part of this study the determination of heat affected zone of welded joints was made. Based on results gained from metallographic investigation including light microscopy, where the width of heat affected zone for each type of welding was measured, the specimens for main measuring of thermal cycles were prepared. After the thermocouples preparation the time-temperature curves during welding were recorded. In the last part of this study the suitable parameters for simulation of each part of HAZ regions are chosen. These values are important part for thermal cycles modelling at single-layer welding of steel P92. This study is the first part of large experiment from which the mechanical, microstructural and creep properties of significant HAZ regions and the weakest point of the P92 welded joints will be defined.

2. EXPERIMENTAL PROCEDURE

2.1 Material specification

Chemical composition of tested P92 block is shown in **Table 1**.

Table 1 Chemical composition of the P92 steel investigated in the present study (wt. %, * ppm)

C	Mn	Si	P	S	Cu	Ni	Cr	Mo	V	Ti	W
0.093	0.50	0.32	0.020	0.0030	0.10	0.206	8.62	0.517	0.196	<0.004	1.56
Al-c)	Nb	Co	B	As	Sn	Pb	Sb	N	O_2	H*	Bi
0.012	0.064	0.023	0.0021	0.009	0.007	0.003	0.018	0.033	0.004	0.7	<0.003

2.2 Experimental part

Before the main procedure measurement of thermal cycles could be done it was necessary to determinate width of heat affected zone of each welding method. Test weld joints were prepared on P92 block (with dimensions 20x180x185) where the V-notch was made. Before the welding the preheat temperature 250 °C was used. The weld metal was obtained by:

- 111 welding method, electrodes ∅2.5 mm and ∅3.2 mm
- 141 welding method

After the weld fabrication metallographic examination was carried out. Firstly the surface layer affected by process of cutting was removed - the specimens were polished on grinding machine Tegrapol 35. When polishing of both sides was finished and all visible scratches were eliminated, the specimens were rinsed in water and then smear with alcohol to protect them against corrosion. Thus prepared samples were etched and then the heat affected zones were examined by optical microscope Neophot 21. Width of each zone (measured with software QuickPHOTO Industrial 2.2) is in **Fig. 1**.

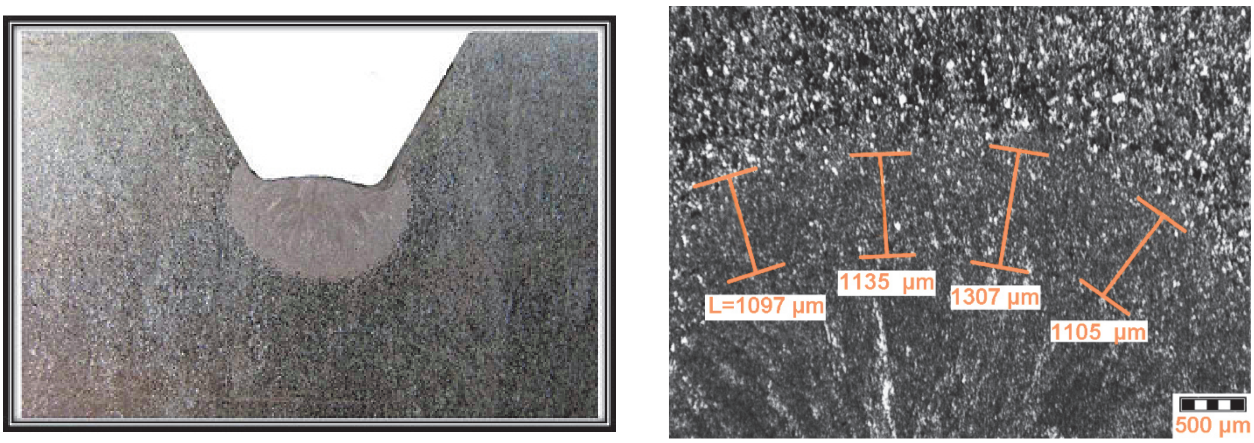

Fig. 1 Example of heat-affected zone width measurement, welding method 111, electrode ∅3.2 mm

Comparing the received values there was determined, that the largest heat-affected zone (HAZ) was obtained in the case of 141 welding method with the average measured value 1313.8 µm. In the case of 111 welding method with electrode ∅2.5 mm there was measured the average value 1161 µm. The smallest heat-affected zone was obtained in the case of 111 welding method with electrode ∅3.2 mm with average measured value 1071.3 µm.

After the determination of heat-affected zone width for each of the welding method two specimens prepared for thermal cycles measurement were machined to dimensions 310x180x20 mm. After the machining on the one of specimen's side a V-notch was made, on the opposite side 16 holes ∅8 mm were drilled according **Fig. 2**. The depth of holes was stated from determination of heat affected zone from 7.45 mm to 8.5 mm on one side and from 6.95 mm to 8 mm on the other side.

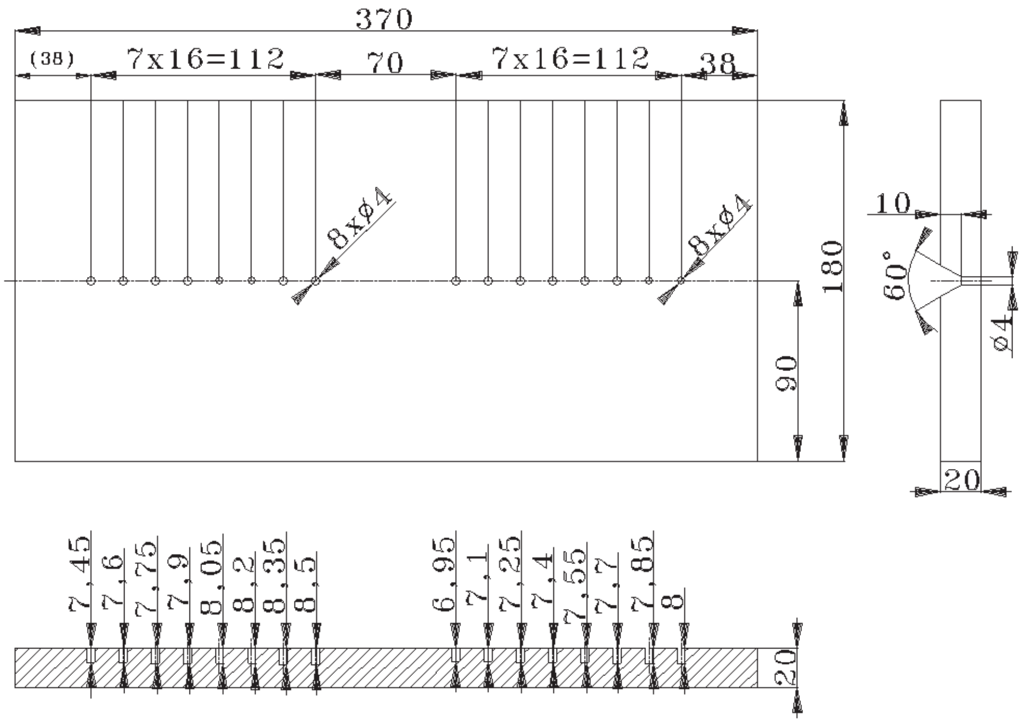

Fig. 2 Dimensions of specimens prepared for thermal cycles measurement

Table 2 Welding parameters used for fabrication the welded joints

Welding parameters				
Welding current (A)	**Arc voltage (V)**	**Polarity**	**Welding speed (cm.min^{-1})**	**Heat input (kJ.cm^{-1})**
111 welding method, electrode ∅2.5				
92-96	21-25	DC/+	4.62	0.49
111 welding method, electrode ∅3.2				
115-120	22-26	DC/+	4.61	0.52
141 welding method				
160-162	11-14	DC/-	0.98	0.92

After thermocouples preparation they were welded to the end of flat holes by capacitor discharge welding process while the very important thing was to ensure as smallest area of thermocouple contact with measured place as possible. The second end of thermocouple was connected to the compensation line (with small resistance) ensuring the connection with measuring station. The time-temperature curves were recorded with software Personal DaqView. The welding parameters are given in **Table 2**.

2.3 Results

The important values obtained from thermal cycle measurement are given in **Table 3**.

Table 3 Important values obtained from thermal cycles measurement

111 welding method with electrode ∅2.5 mm		
Thermocouple:	**The peak temperature:**	**Cooling rate $\Delta t_{8/5}$**
Thermocouple 2	969 °C	13 s
Thermocouple 3	857 °C	7s
Thermocouple 2 was situated in fine-grained region of HAZ Thermocouple 3 was situated in inter-critical region of HAZ		
111 welding method with electrode ∅3.2 mm		
Thermocouple:	**The peak temperature:**	**Cooling rate $\Delta t_{8/5}$**
Thermocouple 2	1028 °C	13.95 s
Thermocouple 8	1161 °C	10.85 s
Both of thermocouples were situated in fine-grained region of HAZ		
141 welding method		
Thermocouple:	**The peak temperature:**	**Cooling rate $\Delta t_{8/5}$**
Thermocouple 6	1240 °C	28.35 s
Thermocouple 6 was situated in fine-grained region of HAZ. In cooling branch (time t=70 s) some deviation can be seen. It was caused by arc extinction and theirs re-ignition.		

Measured thermal cycles are given in **Fig. 3**.

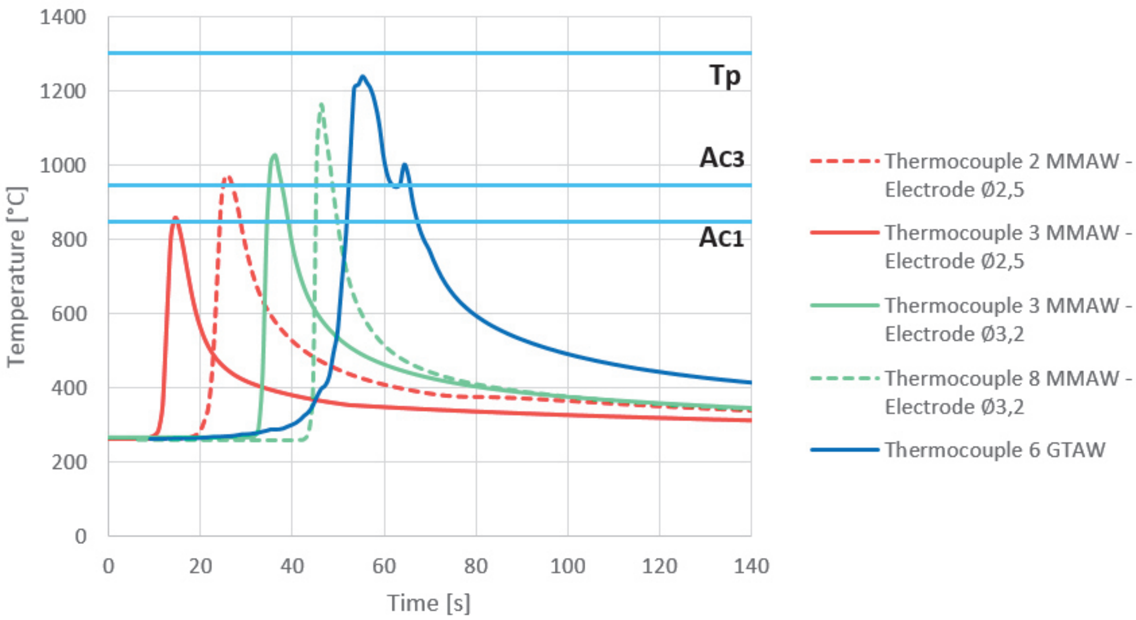

Fig. 3 Thermal cycles measurement of P92 welded joints

After the thermal cycle measurement the metallographic investigation of welded joints was done and the distance between the place where the thermocouple was welded and the end of fusion line was measured (**Fig. 4**).

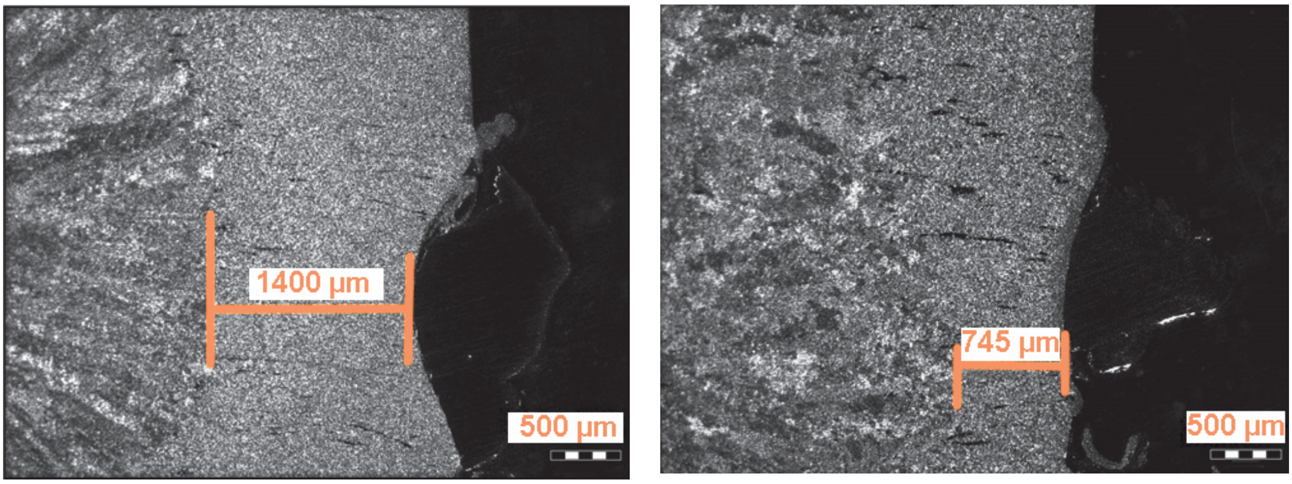

Fig. 4 Metallographic investigation of welded joints obtained by:

a) 111 welding method, electrode ∅2.5 (thermocouple 2) b) 141 welding method (thermocouple 6)

2.4 Discussion

For the simulation of thermal cycles of each zone of HAZ it will be necessary to know the temperatures A_{C1}, A_{C3} a T_p. These key values were determined from CCT diagram of P92 steel: A_{C1} = 845 °C, A_{C3} = 945 °C and overheating temperature T_p = 1300 °C.

Table 4 Average values of each zone of HAZ determined from the experimental study

Welding method	T_{max} (°C)	$\Delta t_{8/5}$ (s)	Time duration at relevant temperatures (s)	
			845 °C (A_{C1})	945 °C (A_{C3})
Inter-critical heat-affected zone				
111, electrode ∅2.5	857	7	1.18	-
Fine-grained heat-affected zone				
111, electrode ∅2.5	1029	12	5	3
111, electrode ∅3.2	1164	10	5	4
	1105	16	5	4
141	1161	30	12	9

Table 5 Characteristic values for modelling of each zone of HAZ

111 welding method, electrode ∅2.5		
	T_{max} (°C)	$\Delta t_{8/5}$ (s)
Fine-grained region	1080	12
Inter-critical region	880	7
111 welding method, electrode ∅3.2		
	T_{max} (°C)	$\Delta t_{8/5}$ (s)
Fine-grained region	1100	16
141 welding method		
	T_{max} (°C)	$\Delta t_{8/5}$ (s)
Fine-grained region	1100	30

CONCLUSION

Modified martensitic heat-resistant P92 steel belongs to very progressive group of 9-12% Cr steels with excellent creep properties. This steel is used to build the most exposed parts of supercritical units in steam power plants. Welded joints are the weakest part of each construction. Welded joints carried out by 111 (MMAW) and 141 (GTAW) were investigated in this paper.

The detailed study performed on the real welded joints is very difficult due to small size of each of the heat-affected zone region. That is why the properties of each of HAZ region cannot be determined using the usual testing methods directly on the real welded joints. The possibility to gain the searched properties is to reproduce the measured thermal cycles on a larger specimen, in order to allow a mechanical properties measurement and microstructure characterization of the previously-identified HAZ regions. This is possible using the simulation technique, where the input values are determined from measured thermal cycles in the HAZ. From this study the basic characteristics of each region of the HAZ (max. temperature, cooling rate ($\Delta t_{8/5}$) and time duration at relevant temperatures) can be determined for the next step of research - simulation technique. This study is the first part of large experiment from which the mechanical, microstructural and creep properties of significant HAZ regions and the weakest point of the P92 welded joints can be defined.

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