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Effect of post weld heat treatments on fracture frontier and type IV cracking nature of the crept P91 welded sample

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ABSTRACT

The research work explores the microstructure evolution and creeps rupture behavior of the shielded metal arc welded joint of reduced activation ferritic/martensitic P91 steel plate in the as-welded and different states of post weld heat treatment (PWHT). Two types of heat treatments were employed including (i) post weld heat treatment (PWHT) at 760 °C for 2 h and finally air cooled and (ii) re-austenitizing at 1040 °C for 60 min and air-cooled and tempered at 760 °C for 2 h, followed by air cooling (PWNT). The P91 steel plates were received in the cast and forged condition having fully tempered lath martensite with lath blocks, packet boundaries and prior austenite grain boundaries (PAGBs). In this research, microstructural evolution at fracture frontier of crept P91 weld sample, creep rupture life and effect of creep exposure time on microstructure evolution in the fine-grained heat affected zone (FGHAZ) were studied. The results show a dominating effect of PWNT treatment on fracture behavior and creep rupture life of the P91 welded joints. PWNT treatment results in negligible hardness variation across the transverse section of the weld joint. The creep rupture life of PWNT specimen was 594.895% higher as compared to that of PWHT specimen and 142.7% higher than that of the as-welded specimen for the similar condition of creep exposure (620 °C/150 MPa). In PWHT condition, the most common type IV cracking was observed. However, it was eliminated in PWNT specimens and fracture occurred form the base zone. The fracture frontier of crept PWNT specimen showed a higher amount of creep cavities that can be attributed to the formation of Laves phase.

1. Introduction

The modified 9Cr-1Mo steel (P91) was developed in the USA by the Oak Ridge National Laboratory (ORNL) for modern operating nuclear and thermal power plants [1]. The general application of P91 steel is found in the temperature range of 550–650 °C. The enhanced thermo-physical properties and enhanced creep strength of P91 steel makes it attractive material for power plant components [2–5]. The P91 steel was developed by modifying the chemical composition of plain 9Cr-1Mo steel [6]. In Plain 9Cr-1Mo steel, a small addition of V and Nb with N leads to the formation of fine V and Nb-rich MX precipitates having a size in the range of 20–40 nm. The pinning effect resulting from the fine MX type precipitates enhances the creep strength by retarding the dislocation movement [7]. The other attractive properties like low thermal expansion coefficient, high thermal conductivity, high creep rupture strength, high oxidation and corrosion resistance, adequate resistance to cracking and high strength at elevated temperature are also required for the nuclear and thermal power plant components [8–12].

For any high strength steels, welding is an important criteria for their selection. The P91 steel can be welded easily by any of the arc welding process [13]. The major issue that observed in P91 steel weldments is their poor creep rupture life as compared to the virgin base metal. The poor rupture life of the weldment is attributed to the type IV cracking in P91 weldments. The type IV cracking occurs generally in the soft FGHAZ or ICHAZ via a creep mechanism, and results in fractures with relatively little total cross-weld strain [14–17]. The heterogeneous microstructure across the weldments is also attributed to poor creep rupture and mechanical properties to P91 weldments. In virgin state P91 microstructure exhibit the tempered martensite with precipitates that transform into the untempered lath martensite during the weld thermal cycle and different microstructure is observed in a different zone of the P91 weldments [18]. In order to remove the heterogeneity in microstructure across the weldments, post weld heat treatment (PWHT) is performed. PWHT results in softening of martensite and evolution of precipitates [19–21]. A lot of work has been published related to the effect of PWHT on microstructure evolution across the weldments and their effect on the mechanical properties,

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Table 1
Chemical composition of as-received C&F P91 steel, shielded metal arc welding (SMAW) filler rod, and gas tungsten arc welding (GTAW) filler wire, %wt.

Element	Chemical composition, wt%												
	C	Mn	W	S	Si	Cr	Mo	V	N	Ni	Cu	Nb	Ti
C&F P91 steel	0.023	0.689	0.0258	0.019	0.193	8.16	0.710	< 0.005	< 0.02	0.305	0.034	0.05	< 0.02
SMAW filler rod	0.08–0.13	0.40–1.0	–	Max 0.02	0.20–0.50	8–10	0.85–1.1	0.15–0.30	0.03–0.07	0.4–1.0	–	0.04–0.08	–
GTAW filler wire	0.12	0.50	–	0.019	0.30	9.0	0.90	0.20	< 0.02	0.50	–	0.06	< 0.02

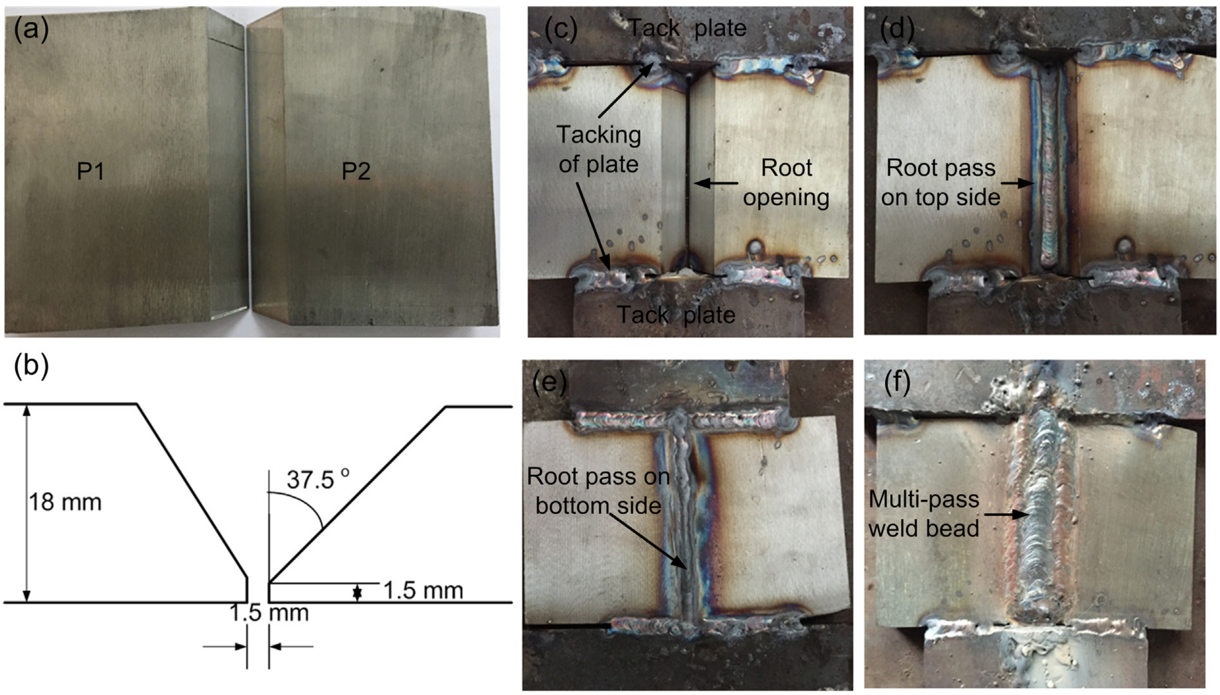

Fig. 1. (a) Machined and grooved plate, (b) Groove design, (c) Plate after tacking, (d) After root pass on top side, (e) After root pass on bottom side, (f) Plate after completion of filling pass.

Table 2
Welding process parameters for root pass and filler pass [33].

Sample 1	Current (amp)	Voltage (volt)	Time (s)	Travel speed (mm/s)	Efficiency (η)	Heat input (KJ/mm)
Root pass 1	115–120	14–16	70	2.14	0.60	0.494
Root pass 2	110–115	12.0–14.0	70	2.14	0.60	0.410
1	140	22.0–23.0	45	3.20	0.80	1.177
2	144	21.6–22.8	44	3.40	0.80	1.195
3	144	22.5–23.6	28	5.36	0.80	1.240
4	144	21.8–23.3	33	4.55	0.80	1.213
5	144	22.8–23	39	3.85	0.80	1.232
6	144	21–22.8	35	4.29	0.80	1.178
7	144	21–23	35	4.29	0.80	1.184
8	144	21.5–23	36	4.17	0.80	1.197
9	144	21.5–23	30	5.00	0.80	1.197
10	144	21–23	31	4.84	0.80	1.184
11	148	23.3–24	40	3.75	0.80	1.308
12	151	22–25.6	30	5.00	0.80	1.343
13	151	22–24.5	30	5.00	0.80	1.312
14	151	21.2–24	29	5.17	0.80	1.275

residual stresses and creep rupture behavior of the P91 welded joints [13,22–29].

In recent years, researchers are focused on the post weld normalizing and tempering treatment in place of the PWHT to overcome the microstructure and hardness heterogeneity across the weldments. Abd El-Salam et al. [1] studied the PWNT effect on mechanical properties of the P91 welded joint and compare it with subsequent PWHT.PWNT treatment results in a uniform hardness across the weldments, higher Charpy toughness and higher creep rupture life of the welded joint as compared to PWHT. Abd El-Salam et al. [6] also studied the effect of PWNT treatment on microstructure evolution in P91 weldments and compared it with the PWHT process. The formation of the softδ-ferrite zone as a result of ferrite stabilizer (V, Nb, Cr,and Mo) is also a serious issue for P91 weldments. The higher content of the ferrite stabilizer results in poor Charpy toughness and tensile strength [30,31]. Wang et al. [32] studied the effect of ferrite on creep rupture behavior of P91