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Fracture behaviour of crept P91 welded sample for different post weld heat treatments condition

Chandan Pandey[a,*], Manas Mohan Mahapatra[b], Pradeep Kumar[c], Sachin Sirohi[a]

[a] Department of Mechanical Engineering, SRM IST Delhi NCR Campus Modinagar, Uttrarpradesh 201204, India
[b] School of Mechanical Sciences, Indian Institute of Technology, Bhubaneswar, Odisha 751013, India
[c] Department of Mechanical and Industrial Engineering, Indian Institute of Technology Roorkee, Uttrakhand 247667, India

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ABSTRACT

In the present research work, P91 steel plates of thickness 18 mm were welded using the shielded metal arc welding process. The welded steel plate subjected to different heat treatment condition including post weld heat treatment (760 °C for 2 h, followed by air cooling) and re-austenitizing (1040 °C for 60 min and air cooled) and tempered (760 °C for 2 h, followed by air cooling). The heat treatments were referred as the PWHT and PWNT. The creep sample was prepared to form the welded and heat treated plate. The creep tests were performed at 620 °C for stresses of 150 and 200 MPa. The weld fusion zone and fine-grained heat affected zone of the crept sample were characterized using the field emission scanning electron microscope (FESEM). The fracture surface morphology of crept sample was also studied using the FESEM. The maximum creep exposure time was measured for the PWNT sample as a result of homogeneous microstructure across the weldments.

1. Introduction

Modified 9Cr−1Mo (P91) steel is also designated as ASTM A335 is a well-known member of Cr−Mo steel family and commonly used for power plant and nuclear components as a result of its attractive thermo-physical and mechanical properties [1,2]. P91 steel offers enhanced creep strength as compared to austenitic steel and plain 9Cr−1Mo steel due to presence of strong carbide and nitride forming element which forms the fine MX precipitates in size order of 20 to 40 nm [3,4]. They also offers the low thermal expansion coefficient and high thermal conductivity as compared to austenitic steel [5]. The P91 steel used in normalized and tempered condition that consisted of tempered martensitic microstructure with fine MX and $M_{23}C_6$ [M: Cr, Fe and Mo] precipitates [6]. P91 steel can be welded many of the arc welding process that leads to change in the microstructure [7–9]. The welding cycle leads to the formation of heterogeneous microstructure across the weldments as a results of the varying experienced temperature [10,11]. Heterogeneous microstructure across the P91 weldments results in poor creep rupture life of P91 weldments as compared to as-received virgin metal [12–14]. The poor creep rupture life of P91 welds joint make a serious issue on use of P91 steel [15]. A lot of works has been performed to overcome the heterogeneity across the weldments and post weld heat treatment of the weldments is one of them [16–19]. The PWHT of the welds joint overcome the heterogeneity across the welded joint but heterogeneity is not removed completely. Re-austenitizing and tempering of the welded joint (PWNT) was also performed by the researchers [17,18]. PWNT provides almost uniform microstructure across the weldments that leads to enhanced creep rupture life and mechanical properties [17,18]. However, less work has been reported about the PWNT treatment of the welds and their effect on creep rupture life and

* Corresponding author.
E-mail addresses: chanddme@iitr.ac.in, chandanpandey.j@ncr.srmuniv.ac.in (C. Pandey).

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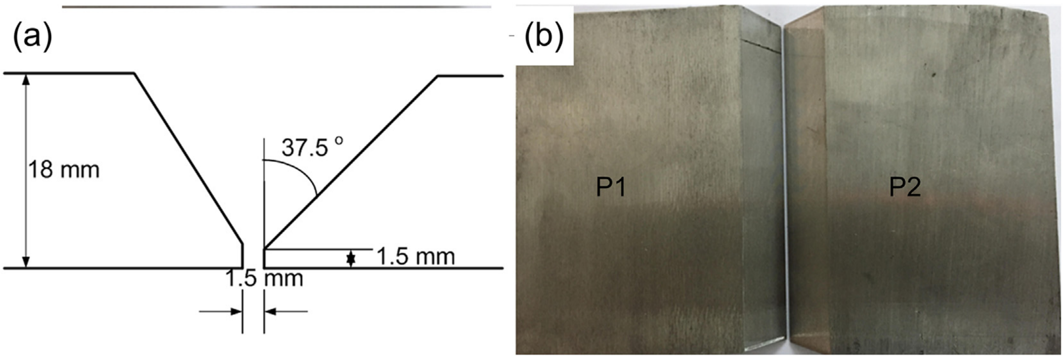

Fig. 1. (a) Weld groove design (b) plate after groove preparation.

mechanical properties. The present research work deals with the study of PWHT and PWNT on creep rupture life and fracture surface morphology of crept sample. The effect of varying heat treatment on microstructure evolution in weld fusion zone was also studied. The creep tests were performed at 620 °C for stresses of 150 and 200 MPa in as-welded, PWHT and PWNT condition.

2. Experimental details

In this investigation, cast and forged (C&F) P91 steel plate of thickness 18 mm was used. Grove design and plate after the groove preparation is shown in Fig. 1(a-b). The plates were welded using the shielded metal arc welding (SMAW) process. The root pass on the both side were carried out using the tungsten inert gas welding process with filler of AWER90S-B9 (9CrMoV-N) with diameter of 1.6 mm and cut length of 1000 mm. For filling pass, SMAW electrode (AWS E9015-B9) of diameter 4 mm was used. The chemical composition of base plate, and TIG filler wire and SMAW filler rod are depicted in Table 1. The 14 filling passes are used to complete the P91 weld joint. For GTAW root pass welding current and arc voltage were maintained in range of 110–120 amp and 12–15 V, respectively. For SMAW filling pass welding current and arc voltage were maintained in range of 140–150 amp and 20–25 V, respectively. The P91 weld joint subjected to heat treatment including post weld heat treatment (PWHT) and post weld re-austenitizing and tempering (PWNT). The PWHT was performed at 760 °C for 2 h just after the welding as per reference [15]. For PWNT treatment, austenitizing was performed at 1040 °C for 40 min followed by tempering at 760 °C for 2 h [10,20]. The creep test specimen were prepared from the as-welded, PWHT and PWNT plates. The dimensions of creep test specimen is given in Fig. 2. The creep test was conducted in three different condition of heat treatment as discussed in Table 2.

3. Results and discussion

3.1. As-received material

The micrograph of the as-received material consists of lath blocks and precipitates along it. The lath martensite direction is observed to be different in lath packet boundaries, as shown in Fig. 3(a). The coarse precipitates are observed along the lath blocks while fine precipitates inside the intra-lath region. Different lath martensite direction is clearly observed in Fig. 3(b). The coarse precipitates in range of 150–200 nm are confirmed as Fe, Mo, and Cr-rich $M_{23}C_6$ type while fine MX precipitates of size in the range of 20–40 nm are V and Nb-rich carbide or carbonitrides [21,22].

3.2. Creep tests

The fractured location for each test condition is depicted in Table 2. In as-welded 2, PWHT 1 and PWHT 2 condition fracture occur from the soft fine-grained heat affected zone and referred as Type IV cracking [15,23]. The creep exposure time related to different creep test condition is shown in Fig. 4. For a high level of applied stress (200 MPa) at 620 °C, the creep rupture life was measured to be 100 h in as-welded condition 1 condition. The fracture occurs in the base zone for as-welded 1 condition. For PWHT 1 condition,

Table 1
Chemical composition of as-received C&F P91 steel, SMAW filler rod and 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