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Study on effect of double austenitization treatment on fracture morphology tensile tested nuclear grade P92 steel

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ABSTRACT

Effect of 'conventional normalizing and tempering' (CNT) and 'double austenitization based normalizing and tempering' (DNT) process on microstructure characteristic and mechanical behavior was studied forP92 steel. In CNT heat treatment, P92 steel is normalized at 1040 °C/air cool and tempered with 760 °C/2 h/air cool. In DNT heat treatment, initially normalizing was performed at 1040 °C for 1 h followed by water quenching. After that sample was normalized in the temperature range of 950–1150 °C for 1 h and tempered at 760 °C/2 h/air cool (950 °C-DNT1, 1050 °C-DNT2, 1150 °C-DNT3).Grain size for CNT and DNT1 treatment were measured 17 ± 7 μm and 12 ± 5 μm. A DNT treatment resulted in homogeneous microstructure formation that led to improved mechanical properties as compared to CNT treatment. The DN based heat treatment produced complete martensitic microstructure formation by complete dissolution of carbide precipitates. The optimized room temperature condition was obtained for the DNT 1 heat treatment.

1. Introduction

To overcome the emission of greenhouse gases and enhance the efficiency of the power plants, most of the high temperature operating structural component is made of Cr-Mo low carbon ferritic-martensitic steels [1]. These steels exhibit superior creep rupture strength, high void swelling resistance, and high temperature mechanical properties as compared to the austenitic steel [2]. These steels are used in normalized and tempered (NT) condition and process the martensitic microstructure with carbide precipitates ($M_{23}C_6$ type) along boundaries while fine carbide and carbonitride precipitates inside the intra-lath region. Selection of the proper heat treatment regimes in order to get the optimum microstructure evolution for achieving the good combination of strength, hardness, ductility, Charpy toughness and creep rupture strength is an important task for developing such type of materials. The well-known technique to enhance the strength without impairing the ductility is grain refinement [3]. The various research has been conducted to study the effect of heat treatment process and their time on the mechanical behavior of the creep strength enhanced ferritic (CSEF) steels [4,5]. In CSEF steels, the martensitic structure imparts the strength to the material while ductility and toughness are imparted form the tempering reaction of the martensite. The effect of normalizing temperature on the grain refinement has been already reported by the Barbadikar et al. and Chatterjeeet al. [6–8]. In CSEF steels austenitizing is performed above the upper critical

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temperature (A_{c3}). However, the austenitizing is also associated with substantial grain growth as a result of the dissolution of the precipitates. Hence, to overcome the grain growth in such steels during the austenitizing, double austenitization based treatment have been recommended by the researchers [3,9,10]. In double austenitizing based heat treatment involve the austenitizing above A_{c3} in the first step (similar to conventional normalizing) that results in untempered martensite formation after the cooling that is devoid of carbide precipitates [10,11]. The second austenitizing is generally performed at a temperature below than the A_{c3} that was resulted in a formation of uniform fine grains and ensuring the lath martensite formation. For 9Cr-1Mo steel, Karthikeyan et al. [12] studied the effect of 'Double austenitization based Normalizing and Tempering (DNT)' on grain refinement and toughness and compared it with the 'Conventional Normalizing and Tempering' (CNT) treatment. The DNT has resulted in a uniform fine grain formation with superior toughness as compared to CNT treatment. Grain refinement of material enhances the impact toughness and strength of material while grain refinement might be the cause of poor creep strength especially if it driven by Coble creep mechanism. For dislocation-climb creep mechanism low temperature and high stress), it might be useful [13].

For CSEF steels (P92 steel), microstructure and high-temperature mechanical properties is governed by the Processing history [14]. Thermal aging of P92 steel in the temperature range of 520–650 °C fora long time causes a significant reduction in temperature strength properties [5,15]. For long-term aging, microstructure faces the following change like martensite recovery, precipitation of intermetallic phase (Laves, *Z*-phase), coarsening of $M_{23}C_6$ precipitates, and impurity segregation along the boundaries. These results in detonation of creep and impact toughness of material [16,17]. Reduction in fracture toughness and impurities like P and S based embrittlement were also observed [18,19]. The objective of the current study is to study the effect of conventional normalizing (CN) and double normalizing (DN) treatment on microstructure evolution and strength of P92 steel.

In P92 steel, the martensitic microstructure is mainly composed of lath-shaped martensite crystallites with high dislocation density as a result of normalizing with lath blocks and lath packets within the prior austenite grain boundaries (PAGBs). The tempering of the P92 steel results in diffusion of C from the matrix in form of the carbides while matrix retains the martensitic morphology. The TEM is most commonly used for the study the lath blocks and dislocations morphology [11,20] while SEM and optical microscopy are used for the demarcation of the lath blocks, lath packets, sub-blocks with in the PAGBs [21]. From the literature study, it is clear that the unambiguous identification of martensite feature and their size play an important role in deciding the mechanical behavior of the material. The paper deals with the comparative study of the tensile properties, hardness and microstructure evolution for CNT and varying DNT treatment.

2. Experiments

2.1. Heat treatment

A 20 mm thick steel plate of P92 steel plates were supplied from BHEL Haridwar, India that were in cast and forged (C&F) condition with the chemical composition is listed in Table 1. The plate was subjected to different heat treatment as per Fig. 1.

- ➢ CNT- 1040 °C/1 h/air cool'(CN) and'760 °C/2 h/air cool' (T)
- ➢ DNT1- 1040 °C/1 h//water quench, 950 °C/1 h/air cool'(DN1)and'760 °C/2 h/air cool' (T)
- ➢ DNT2- 1040 °C/1 h//water quench, 1050 °C/1 h/air cool'(DN2)and'760 °C/2 h/air cool' (T)
- ➢ DNT3- 1040 °C/1 h//water quench, 1150 °C/1 h/air cool'(DN3)and'760 °C/2 h/air cool' (T)

2.2. Microstructure characterization and hardness tests

For metallographic characterization, the sample was prepared form the heat-treated plate. The polished and etched (Vilella's reagent) sample was utilzed for the microstructure characterization. Hardness measurement was carried out using Microhardness tester (Omnitech S. Auto) at aload of 500 g for10 s of dwell time. The tensile tests were performed for standard size specimen prepared as per ASTM A370-14 standard [22] on Instron 5982 Vertical Tensile Testing machine. For each condition, three samples were tested. The fracture surface morphology was studied using the field emission scanning electron microscope (FE-SEM Quanta 200 FEG).

3. Results and discussion

3.1. As-received material

The detailed microstructure analysis of P92 steel in C&F condition is discussed in the previous work [23]. As-received material microstructure shows the presence tempered martensite with columnar lath, martensitic blocks and packets and prior austenite grain

Table 1
Chemical composition of P92 steel plate in wt%.

Element	C	Mn	Si	Cr	Mo	V	Nb	W	Cu	Ni	Fe
Wt%	0.10	0.57	0.47	9.10	0.45	0.24	0.08	1.88	0.03	0.40	Rest