Materials Science & Engineering A 699 (2017) 165–175

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

The evolutions of microstructure and mechanical properties of 2.25Cr-1Mo-0.25V steel with different initial microstructures during tempering

Zhonghua Jiang[a,b], Pei Wang[a,b,*], Dianzhong Li[a,b], Yiyi Li[a,b]

[a] Shenyang National Laboratory for Materials Science, Institute of Metal Research, Chinese Academy of Sciences, 72 Wenhua Road, Shenyang 110016, China
[b] School of Materials Science and Engineering, University of Science and Technology of China, 72 Wenhua Road, Shenyang 110016, China

ARTICLE INFO

Keywords:
Cr-Mo-V steel
Martensite-austenite constituents
Bainite
Tempering
Mechanical properties

ABSTRACT

The evolutions of microstructure and mechanical properties during tempering at 700 °C, of normalized and oil-quenched 2.25Cr-1Mo-0.25V steel samples to simulate the central and surface parts of the industrial heavy wall forgings, respectively, have been investigated. It is found that the normalized sample has a granular bainite microstructure and the oil-quenched sample has a lath bainite microstructure. After 0.5 h of tempering, the normalized sample has a higher strength and ductile-to-brittle transition temperature (DBTT) than the oil-quenched sample because of the strengthening effect of the undecomposed martensite-austenite (M-A) constituents and the presence of coherent tiny VC type precipitates in granular bainite. However, when the tempering time is increased from 0.5 to 128 h, the strength as well as the DBTT of the normalized sample decreases more pronounced than that of the oil-quenched sample. This is attributed to the synergistic effect of the decomposition of M-A constituents, growth of VC type precipitate in the normalized sample, and the increase in the effective grain size in the oil-quenched sample.

1. Introduction

In view of their high strength at elevated temperature and resistance to oxidation and hydrogen embrittlement [1,2], low alloy Cr-Mo and Cr-Mo-V steels are extensively used in the manufacture of pressure vessels for electricity generating and oil refining industry [3–6]. Today, larger and thicker pressure vessels are increasingly employed to obtain higher processing efficiencies [7–9]. Generally, the heat treatment of Cr-Mo and Cr-Mo-V steel heavy forgings is composed of quenching and tempering. Therefore, microstructures at different positions in a heavy forging may be significantly different because of the different cooling rates during quenching. In general, the continuous cooling transformation diagram can be constructed and the relationship between cooling rate and microstructure is easily established. However, the effect of quenching cooling rate on the mechanical properties of the material is still difficult to determine directly because of complex microstructural evolution during the subsequent tempering. Thus, in-depth research on the evolutions of the microstructure and mechanical properties of low alloy Cr-Mo and Cr-Mo-V steels with different quenched microstructures is necessary. Results from such studies will help to improve the reliability of pressure vessel components.

The microstructure and mechanical properties of Cr-Mo and Cr-Mo-V steels may change remarkably during tempering and these changes are influenced by the initial quenched microstructure. Li et al. [10,11] have found that the fracture behavior of G18CrMo2-6 steel with granular bainite as the quenched microstructure is significantly affected by the cracking of coarsened carbides and/or their de-bonding from the bainitic matrix. And the precipitation and coarsening of the carbides occur predominantly during tempering rather than during quenching. Jiang et al. [12] have pointed out in 2.25Cr-1Mo-0.25V steel having a granular bainite microstructure, the decomposition of martensite-austenite (M-A) constituents and the softening of bainite ferrite occur simultaneously during tempering and the synergistic effect between these two processes determines the impact toughness of the processed material. Tao et al. [13] have found that carbides present in a normalized 2.25Cr-1Mo steel are coarsened gradually during tempering at 700 °C, which weakens the effect of precipitation strengthening and decreases the hardness of the material. Norris et al. [14] have found that the fracture behavior of low alloy Cr-Mo steel is closely related to the mean diameter and distribution of carbides, which are predominantly controlled by the time of tempering. These studies confirm that in Cr-Mo and Cr-Mo-V steels, a complex evolution of both microstructure and mechanical properties occurs during tempering. However, much of this research has been carried out on materials with a specific quenched microstructure and did not consider the influence of the quenched microstructure.

* Corresponding author at: Shenyang National Laboratory for Materials Science, Institute of Metal Research, Chinese Academy of Sciences, 72 Wenhua Road, Shenyang 110016, China.
E-mail address: pwang@imr.ac.cn (P. Wang).

http://dx.doi.org/10.1016/j.msea.2017.05.095
Received 17 February 2017; Received in revised form 25 May 2017; Accepted 25 May 2017
Available online 26 May 2017
0921-5093/

Certainly, many researchers have realized that it is necessary to investigate the essential effect of quenched microstructure on the changes in microstructure during the subsequent tempering treatment [15–18]. Zhang et al. [15] have investigated the effect of quenched microstructure on the evolution of carbides in a 2.25Cr-1Mo-0.25V steel during tempering at 700 °C. It is found that the types of carbides are identical in the quenched and normalized samples during tempering. However, M_3C and $M_{23}C_6$ carbides are more stable in the normalized sample than in the quenched sample during the early stage of tempering. Dunlop et al. [16] have also studied the effect of initial microstructure on the microstructural evolution of a Cr-Mo-V steel during tempering. The results show that the resistance to over ageing of VC precipitate depends on the matrix and decreases in the order: ferrite, bainite, and martensite. These differences are induced by differences in dislocation densities and the number of interfaces in the original microstructure. Although these studies illuminate the influence of the initial microstructure on the precipitation behavior of carbides in Cr-Mo-V steels, the relationship between the mechanical properties and microstructures of 2.25Cr-1Mo-0.25V steels having different quenched microstructures during subsequent tempering is still not clear.

In this work, tempering experiments of different durations ranging from 0.5 to 128 h have been carried out on normalized and oil-quenched 2.25Cr-1Mo-0.25V samples, having granular bainite and lath bainite with the aim to simulate the central and surface parts of industrial heavy wall forgings, respectively. The microstructural evolution of these materials has been examined by scanning electron microscopy (SEM), transmission electron microscopy (TEM), and electron back scattered diffraction (EBSD). The mechanical properties have been evaluated by tensile tests at room temperature and Charpy impact tests carried out at different temperatures ranging from −130 °C to room temperature. Finally, the correlation between the mechanical properties and microstructural evolution during tempering has been discussed.

2. Materials and methods

2.1. Material and heat treatments

The experimental material used in this study was taken from a forged thick plate used in the production of heavy hydrogenation reactor vessel. The chemical composition is listed in Table 1. Blocks sized 60 mm × 40 mm × 13 mm were machined from the thick plate by wire electrical discharge machining for subsequent heat treatments. In order to simulate the real conditions of the central and surface regions of a heavy ~ 300 mm thick plate, the experimental steel blocks were heat treated in two different conditions: one group of blocks was cooled in air after being normalized at 940 °C for 2 h to simulate the cooling of the central region under real conditions, and the other group of blocks was oil-quenched after austenization at 940 °C for 2 h to simulate the cooling of the surface region. And then, the normalized and quenched steel blocks were tempered at 700 °C, which is commonly used in the manufacture of heavy forgings. In order to investigate the evolutions of microstructure and mechanical properties during tempering, the time of tempering was varied from 0.5 to 128 h. For convenience, the samples are named 0.5–128NT (normalized and tempered) and 0.5–128QT (oil-quenched and tempered) to label their quenching conditions and tempering time. For example, the sample name 8NT denotes that the sample is normalized at 940 °C for 2 h and tempered at 700 °C for 8 h.

Table 1
Chemical compositions of the investigated 2.25Cr-1Mo-0.25Vsteel (wt%).

C	Cr	Mo	V	Mn	Si	P	S	Fe
0.14	2.46	1.00	0.28	0.59	0.05	0.006	0.002	Bal.

2.2. Tensile and Charpy impact tests

Tensile tests using rod type tensile samples with a diameter of 5 mm and a gauge of 25 mm were carried out at room temperature using Zwick Z050 tensile testing machine. The yield stress and ultimate tensile stress were obtained. Charpy impact tests were carried out to evaluate the impact toughness of the sample subjected to various heat treatments. All the samples were machined to standard Charpy V-notch samples with dimensions of 10 mm × 10 mm × 55 mm (orientation: transverse). The Charpy impact tests were performed in the temperature ranging from −130 °C to room temperature by a Zwick RKP-450 impact tester.

2.3. Microstructure analysis

Metallographic samples were ground, polished, and etched with 4% nital for 10–15 s. Observation was carried out using FEI Inspect F50 SEM. The initiation and propagation of micro-cracks were also investigated by analyzing the fracture surface and cross-section of the fractured sample using SEM. Effective grain size of the tempered samples were analyzed by EBSD (step size: 0.5 μm).

Thin foils for TEM observation were obtained by mechanical grinding and twin-jet electro-polishing with a solution containing 10% perchloric acid and 90% ethanol with 18 V voltage at −25 °C. TEM observations were performed using a Tecnai G2 20 TEM operated at 200 kV and equipped with an energy dispersive X-ray spectrometry (EDS) detector.

3. Results

3.1. Mechanical properties

The measured yield strength (YS) and ultimate tensile strength (UTS) of the normalized sample are 925 MPa and 1164 MPa, respectively, which are slightly lower than the corresponding values for the oil-quenched sample (YS: 961 MPa, UTS: 1197 MPa). Over the entire range of tempering times used, the strengths of both the NT and QT samples decrease with increasing tempering time monotonically (as shown in Fig. 1). However, certain differences are observed between the NT and QT samples. Although the YS and UTS values of the normalized sample are lower than those of the oil-quenched sample, both these values are higher for the 0.5NT sample than for the 0.5QT sample. Nevertheless, along with the tempering time increasing from 0.5 to 128 h, the decrease in the strength is more pronounced for the NT samples than for the QT samples. After 8 h of tempering, the 8NT and 8QT samples have almost the same YS and UTS. And after 128 h of tempering, both YS and UTS of the 128NT sample are lower than those of the 128QT sample.

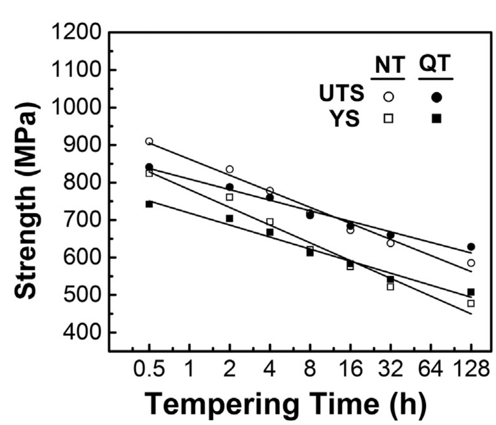

Fig. 1. The variation in yield stress and ultimate tensile strength with the tempering time for the NT and QT samples.