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Progress in Natural Science: Materials International 21(2011) 180−186

Progress in Natural Science: Materials International

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Phase transformation refinement of coarse primary carbides in M2 high speed steel

Fu-sheng PAN[1, 2], Wei-qing WANG[1], Ai-tao TANG[1], Li-zhi WU[3], Ting-ting LIU[1], Ren-ju CHENG[1]

1. College of Materials Science and Engineering, Chongqing University, Chongqing 400030, China;
2. Chongqing Academy of Science and Technology, Chongqing 401123, China;
3. Quality Department, Heye Science and Technology Co., Ltd., Shijiazhuang 050031, China

Received 10 February 2011; accepted 11 April 2011

Abstract: The decomposition of the coarse primary M_2C carbide in M2 high speed steel was investigated by using optical microscope, scanning electron microscope, energy dispersive spectrometer and X-ray diffraction analysis. It is indicated that the SEM observation using deeply etched samples can clearly reveal the details of the decomposition products of primary M_2C eutectic carbides. The MC is granular and M_6C is peanut-shaped in the decomposition products, and the decomposition products are found to be very small in the size. With the increase of annealing temperature and duration, part of the peanut-shaped M_6C carbides change to simple skeleton-shaped ones. The phase transformation refinement of primary M_2C carbides in M2 steel by the decomposition of metastable M_2C carbides at high temperature can be obtained if suitable annealing parameters are applied. The complete decomposition of M_2C to M_6C and MC will occur when (1 100 °C, 4 h) or (1 150 °C, 2 h) annealing treatment is employed in M2 high speed steel.

Key words: high speed steel; carbides; decomposition; phase transformation refinement; morphology

1 Introduction

High speed steel has been widely used in various fields[1−3]. Although many new types of tool materials have been developed in the past decades, high speed steel is still a very important tool material today. It is well known that the mechanical properties and mechanical behavior of high speed steels strongly depend on the type, shape, size, amount and distribution of carbides. Primary carbides constitute one of the most important microstructural features of high speed steels. They contribute to the hardness and wear resistance, and affect the toughness of high speed steels. The dissolution of primary carbides during austenitizing enriches the matrix with alloying elements, resulting in an exceptional as-quenched hardness and the ability to undergo secondary hardening by tempering precipitates. The undissolved carbides after austenitization remain in tempered steels. They could contribute to the wear resistance, however, the undissolved carbides damage the toughness property if the size of remained carbides is too large or the remained carbides have nonuniform distribution. The dissolution degree of primary carbides, the size and distribution of the remained carbides strongly depend on the size and distribution of primary carbides. Therefore, it is very necessary to control the size, shape and distribution of primary carbides, specially their size.

There are a lot of carbides forming elements in high speed steel, such as W, Mo, Cr and V, which form coarse primary carbides during the solidification process[4−5]. Normally, three types of primary carbides, M_6C, MC and M_2C, occur during the solidification process. MC is blocky, M_2C is lamellar with “fan” or “feather” feature, and M_6C exhibits skeleton shape. M_2C or M_6C exists normally in the coarse eutectic structure. In order to break up the eutectic carbides, multi-step hot deformation processes are often employed. However, the coarse primary carbides are apt to form uneven carbide bands or remain large size after a substantial amount of hot processing[6]. In addition, modern industry needs more and more big-section parts made of high speed steels. A large amount of hot deformation for these parts

Foundation item: Project (50725413) supported by the National Natural Science Foundation of China; Project (2008DFR50040) supported by the Ministry of Science and Technology of China; Project (2010CSTC-BJLKR) supported by the Chongqing Science and Technology Commission, China
Corresponding author: Fu-sheng PAN; Tel: +86-23-65112635; E-mail: fspan@cqu.edu.cn

is very difficult. Another way to solve this problem is to modify eutectic carbides by additions of other elements. However, most of alloying elements employed in the high speed steels are not enriched on the earth or have high cost although the addition of some alloying elements could refine the coarse primary carbides[7−18]. Moreover, it is still very difficult to make an effective refinement of primary carbides for the big-section parts.

It is well known that the predominant eutectic carbides are M_2C carbides in M2 high speed steel or other high-Mo high speed steels. M_2C is a metastable compound, and can change to M_6C and MC during annealing by the phase transformation, M_2C+matrix→ M_6C+MC[17−22]. In the present study, as a potential way, the phase transformation refinement of primary carbides in high speed steels was investigated. Although some previous work mentioned the phase transformation of M_2C to M_6C and MC, little work was carried out and reported regarding to systematic investigation on the phase transformation refinement of M_2C primary carbides.

2 Experimental

As one of the most commercial materials, M2 high speed steel was selected in the present work. The chemical compositions are 0.92% C, 6.17% W, 4.79% Mo, 4.00% Cr, 1.85% V and 0.3% Si (mass fraction) by chemical analysis. The M2 high speed steel cast ingot was produced by electroslag remelting process. The cast ingot was annealed at 780 °C for 10 h, and then heated to 950, 1 000, 1 050, 1 100 and 1 150 °C, respectively. The heating duration lasted for 15, 30, 60, 120 and 240 min, respectively. Part of the as-forged specimens were quenched at 1 200 °C in salt-bath furnace and tempered at 540 °C. The specimens were etched by alkali saturated $KMnO_4$ solution after grinding and polishing, and then observed on an OLYMPUS optical microscope. The deeply etched specimens were examined directly on a scanning electron microscope (TESCAN VEGAII LMU) to obtain the spatial morphology of the carbides in the high-speed steels investigated. The compositions of carbides were determined by energy dispersive X-ray spectrometer attached to SEM. The Japan/MAX−1200 X-ray diffractometer was used to identify the types of carbide phases.

3 Results

3.1 Decomposition of primary M_2C carbides at 780 and 1 000 °C

Figure 1 shows the microstructure of as-cast M2 high speed steel. It is seen that the eutectic carbides in the steel are lamellar with “fan” or “feather” feature. X-ray analysis and composition measurement identify the eutectic carbides to be M_2C carbides. SEM observation shows clearly the three-dimensional shape of M_2C carbides (Fig.1(b)). The distance between the lamellar carbides was 2−5 μm, the width was up to 50 μm and the length up to 100 μm. No small particles formed on the surface of M_2C carbides were observed. When the steel was heated at 780 °C for 10 h, the optical morphology of the eutectic carbide remained unchanged, as shown in Fig.2. However, on the surface of M_2C carbides, some very small particles were observed by SEM, which suggested the transformation of M_2C to M_6C and MC occurred.

After the steel was heated at 1 000 °C for 4 h, the amount of decomposition products of the lamellar M_2C carbides increased. Nevertheless, most of the primary M_2C carbides remained unchanged, which existed in the coarse lamellar shape, as shown in Fig.3.

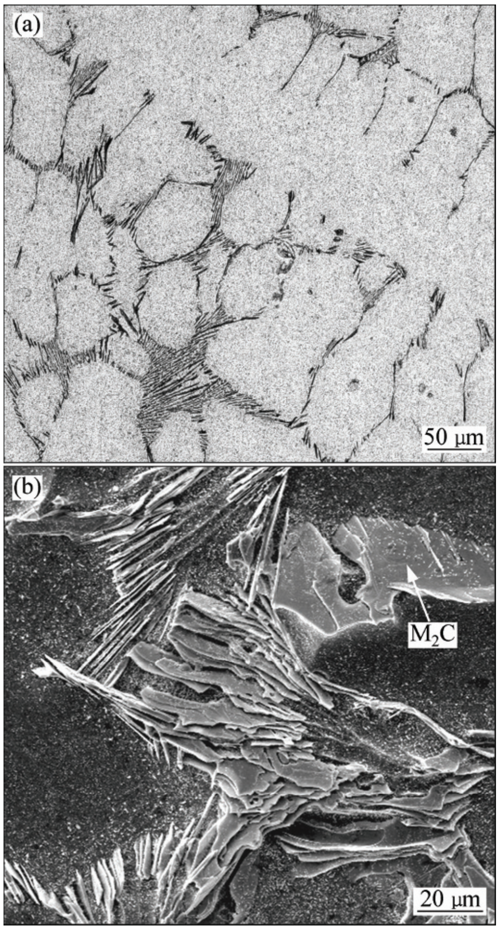

Fig.1 Optical (a) and SEM (b) images of eutectic carbides in as-cast M2 steel

3.2 Decomposition of primary M_2C carbides at 1 150 °C

Figures 4, 5 and 6 show the changes of eutectic carbides in M2 steel at 1 150 °C for different annealing