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

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Abstract: The decomposition of the coarse primary M₂C 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 M₂C eutectic carbides. The MC is granular and M₆C 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 M₆C carbides change to simple skeleton-shaped ones. The phase transformation refinement of primary M₂C carbides in M2 steel by the decomposition of metastable M₂C carbides at high temperature can be obtained if suitable annealing parameters are applied. The complete decomposition of M₂C to M₆C 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, M₆C, MC and M₂C, occur during the solidification process. MC is blocky, M₆C is lamellar with “fan” or “feather” feature, and M₂C exhibits skeleton shape. M₂C or M₆C 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
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 M2C carbides in M2 high speed steel or other high-Mo high speed steels. M2C is a metastable compound, and can change to M6C and MC during annealing by the phase transformation, M2C+matrix→M6C+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 M2C to M6C and MC, little work was carried out and reported regarding to systematic investigation on the phase transformation refinement of M2C 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 KMnO4 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 M2C 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 M2C carbides. SEM observation shows clearly the three-dimensional shape of M2C 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 M2C 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 M2C carbides, some very small particles were observed by SEM, which suggested the transformation of M2C to M6C and MC occurred.

After the steel was heated at 1 000 °C for 4 h, the amount of decomposition products of the lamellar M2C carbides increased. Nevertheless, most of the primary M2C 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 M2C 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
Fig. 2 Optical (a) and SEM (b) images of eutectic carbides in as-heated M2 steel after annealed at 780 °C for 10 h.

Fig. 3 Optical (a) and SEM (b) images of eutectic carbides in as-heated M2 steel after annealed at 1000 °C for 4 h.

Fig. 4 Optical (a) and SEM (b) (c) images of eutectic carbides after annealed at 1150 °C for 15 min.

time by the phase transformation of $M_2C$ to $M_6C$ and MC. When the steel was heated for 15 min, the decomposition of $M_2C$ to $M_6C$ and MC occurred obviously. On the surface of the lamellar $M_2C$ carbides (Fig. 4(c)), a lot of small particles, the decomposition products of the $M_2C$ carbides, were observed. With the increase of heating time from 15 min to 1 h, the amount of decomposition products, $M_6C$ and MC, increased in the as-heated M2 steel (Fig. 5). From the optical photo as shown in Fig. 5(a), almost the lamellar $M_2C$ carbides were broken up and the phase transformation of $M_2C$ to $M_6C$ and MC seemed to complete. However, a lot of large lamellar $M_2C$ eutectic carbides were observed by SEM on the deep etched samples (Figs. 5(b) and (c)), suggesting that the SEM observation of deep etched samples could reveal the details of the eutectic carbides clearly. It is worthy of noting that no similar SEM investigation of three-dimension morphology was reported on the decomposition of $M_2C$ carbides in high speed steels before. There were two types of decomposition products, granular and peanut-shaped compounds formed, the former was identified as
MC-type carbide and the latter as M$_6$C-type carbide. The amount of M$_6$C in the decomposition products was found to be more than that of MC. In the sample heated for 1 h, the length of M$_6$C was 1–3 μm with the diameter of about 0.5 μm, and the diameter of MC was 0.3–0.6 μm.

![Fig.5 Optical (a) and SEM (b) (c) images of eutectic carbides after annealed at 1 150 °C for 1 h](image)

When the heating duration was increased to 4 h, the primary M$_2$C carbides disappeared, as shown in Fig.6. Most of the eutectic carbides were decomposed to M$_6$C and MC carbides. The diameter of the decomposition products increased with the rise of the heating time. Some M$_6$C carbides changed from peanut-shaped into skeleton-shaped, which were similar to the morphology of M$_6$C eutectic carbides in as-cast high-W high speed steels.

The above results indicate that high temperature annealing at 1 150 °C for 2–4 h is very helpful for the refinement of the primary carbides in M2 steels. Figure 7 shows the microstructure of as-forged and as-tempered M2 steel. It shows that the microstructures of as-forged and as-tempered M2 steel were modified obviously after the steel was heated at 1 160 °C for 3 h before forging.

![Fig.6 Optical (a) and SEM (b) (c) images of eutectic carbides after annealed at 1 150 °C for 4 h](image)

### 3.3 X-ray analysis of decomposition products of metastable M$_2$C carbides

Figures 8 and 9 show the X-ray patterns of the samples after heating at different temperatures for different time. Two types of carbides in as-cast M2 steel were observed, M$_2$C and MC. The experimental results showed that the amount of M$_6$C increased with increasing heating temperature and time. In the samples heated at 780 °C and 950 °C, most of carbides in the steel were M$_2$C carbides although the M$_6$C carbides were observed. Under (1 150 °C, 2 h) treatment, no M$_2$C carbides were observed in M2 steel. In the samples heated at 1 100 °C or 1 150 °C for 4 h, the M$_2$C carbides disappeared completely. The X-ray analysis results are in agreement with the above-mentioned results on the investigation of the microstructure in M2 steel.

### 4 Discussion

A schematic of comparison between the phase
Fig. 7 SEM images of remained carbides in as-forged steel (a) (b) and as-tempered M2 steel (c) (d): (a) (c) Heated at 1160 °C for 1 h before forging; (b) (d) Heated at 1160 °C for 3 h before forging.

Fig. 8 XRD patterns of M2 steel annealed at different temperatures

transformation refinement and deformation refinement of coarse primary compounds is shown in Fig. 10. The deformation refinement of coarse primary compounds can be obtained by the substantial amount of hot processing, but it is very difficult to make an effective refinement of primary carbides for the big-section parts by hot processing. Repeated hot deformation before the final large-section parts are made, of course, can increase the amount of deformation. However, it will result in much higher cost of wrought parts. While the phase
transformation refinement of primary M₂C carbides in decomposition products in M2 steel. Processes and the three-dimension shape of speed steels are M₂C carbides, which can be used for the eutectic carbides in M2 steel or other high-Mo high applied can clearly reveal the phase transformation experimental methods. In the present work, the method morphology, because of the limitation of previous decomposition products, such as the size and temperature. In addition, nobody reported the details of phase transformation refinement is very potential for large-section wrought parts or casting parts, which need to be paid to more attention.

In order to obtain the phase transformation refinement, the primary compounds must be metastable compounds, which may transform into stable compounds during heating. Many research works show that M₆C carbide is a metastable phase, which may decompose into M₆C and MC carbides[17–22]. It is known that the eutectic carbides in M2 steel or other high-Mo high speed steels are M₄C carbides, which can be used for the phase transformation refinement of coarse primary carbides in high speed steels. However, the decomposition of coarse primary M₂C carbides in M2 steel is found to be very difficult when the traditional annealing process is employed because of lower annealing temperature. Although the increase of annealing temperature can accelerate the decomposition of M₂C carbides in M2 steel, very little work was carried out on the decomposition of M₂C carbides at higher temperature. In addition, nobody reported the details of decomposition products, such as the size and morphology, because of the limitation of previous experimental methods. In the present work, the method applied can clearly reveal the phase transformation processes and the three-dimension shape of decomposition products in M2 steel.

The results in the present work show that the phase transformation refinement of primary M₂C carbides in M2 steel by the decomposition of the metastable M₂C carbides at high temperature can be obtained, and the complete decomposition of M₂C to M₆C and MC will occur in the M2 high speed steel when (1 100 °C, 4 h) or (1 150 °C, 2 h) annealing treatment is employed. Because the decomposition products, M₆C and MC, are small, the phase transformation refinement is a very potential way for casting parts and large-section wrought parts of M2 high speed steel and other high-Mo high speed steels which have metastable M₂C eutectic carbides.

5 Conclusions

1) The SEM observation using the deeply etched samples can clearly reveal the details of decomposition products of primary M₄C eutectic carbides. It is indicated that MC is granular and M₆C is peanut-shaped. The decomposition products are found to be very small in the size, and the diameter of the products is normally less than 1 μm when M2 steel is annealed at the temperature of less than 1 150 °C.

2) The phase transformation refinement of primary M₂C carbides in M2 steel by the transformation of metastable M₂C carbides to stable MC and M₆C carbides at higher temperature can be obtained if suitable annealing parameters are applied.

3) Long time annealing (10 h) at 780 °C does not result in obvious decomposition of M₄C eutectic carbides in M2 steel. When annealing temperature is less than 1 050 °C, the decomposition of the primary M₂C carbides in M2 steel is incomplete. The complete decomposition of M₂C to M₆C and MC in M2 steel will occur when (1 100 °C, 4 h) or (1 150 °C, 2 h) treatment is employed.

References


