

Carbide refinement in M42 high speed steel by rare earth metals and spheroidizing treatment

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Abstract: The influence of rare earth metals and heat treatment on the microstructure and performance of M42 steel has been investigated by means of an optical microscope (OM), scanning electron microscope (SEM), energy dispersive spectroscopy (EDS), transmission electron microscope (TEM), electron back-scatter diffraction (EBSD) and X-ray diffraction (XRD). The results show that M_2C is the prevailing type of eutectic carbides in M42 steel. After modification with rare earth metals, M_2C eutectic carbides change from the ordered lamellar structure into a circular structure. Despite different morphologies, the two carbides present the same characteristics of microstructure and growth orientation. Compared with lamellar carbides, M_2C carbides with the circular structure are much easier to decompose and spheroidize after heating, which remarkably refines the carbide dimensions. The refined carbides improve the supersaturation of alloying elements in martensite and increase the hardness of M42 steel by 1.5 HRC.

Key words: high speed steel; rare earth metals; carbide; dimension; spheroidization

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High speed steels are widely used in high-temperature applications. Among them, AISI M42 steel is the most popular. The excellent performance of M42 steel is closely related to a great amount of alloying carbides, the mass percentage of which can reach as high as 20%.

Extensive efforts have been devoted to controlling the dimensions and distributions of carbides in high speed steels, such as forging^[1-2], modification^[3-5] and heat treatment^[6-7]. However, carbides are still too large to sat-

isfy the requirements. This is attributed to the morphologies of eutectic carbides, namely the lamellar morphology, which is unfavorable for carbide spheroidization during heating and deformation.

The present work intends to refine the carbide dimensions in M42 steel by modification and spheroidizing treatment. Misch metal was used to modify eutectic carbides and obtain carbides with the circular structure, which is easier to spheroidize during heating. The microstructure evolution of M42 steel was investigated after modification and heating.

1 Experimental

The material used in this study is AISI M42 steel, the composition of which is listed in Tab. 1. The steel was remelted and cast in a sand mould. Before casting, 0.2% misch metal was added.

Tab. 1 Compositions of AISI M42 high speed steel %

w_C	w_{Si}	w_{Mn}	w_W	w_{Mo}	w_{Cr}	w_V	w_{Co}	w_S	w_P	w_{Fe}
1.05	0.54	0.38	1.60	9.45	3.90	1.15	8.30	0.009	0.025	Balance

The as-cast microstructure was observed by the optical microscopy (OM), using the Murakami etchant, which provided selective etching of M_2C (black), MC (white) carbides without etching the matrix^[8]. The specimens were deeply etched and then observed by the FEI Sirion-400 scanning electron microscope (SEM). The compositions of carbides were measured using Genesis 60S energy dispersive spectroscopy (EDS). The remaining mass percentages of rare earth metals were measured by the MAXx LM15 direct-reading spectrometer (DRS).

The microstructure of the eutectic carbides was investigated by the Tecnai G2 transmission electron microscope (TEM) and electron back-scatter diffraction (EBSD). Samples from ingots were heated at 1 100 °C for 1, 2 and 4 h, respectively. Then, they were analyzed by X-ray diffraction (XRD), SEM and TEM. The samples, which were heated at 1 100 °C for 4 h, were reheated at 1 200 °C for 10 min and then immediately oil quenched. EDS was used to analyze the compositions of the matrix after quenching. Then, the specimens were triple tempered for 1 h at 550 °C, and the Rockwell hardness was measured.

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2 Results and Discussion

2.1 Modification of eutectic carbides by rare earth metals

Fig. 1 shows the typical as-cast structure of M42 high speed steel, consisting of a matrix and coarse networks of eutectic carbides. Eutectic carbides are divided into two types, M_2C and MC, distinguished by the Murakami etchant. It is noted that M_2C eutectic carbides change from the ordered lamellar structure into the circular structure after modification with rare earth metals. The three-dimensional morphologies are illustrated in Fig. 2, from which different characteristics of the two carbides can be clearly distinguished.

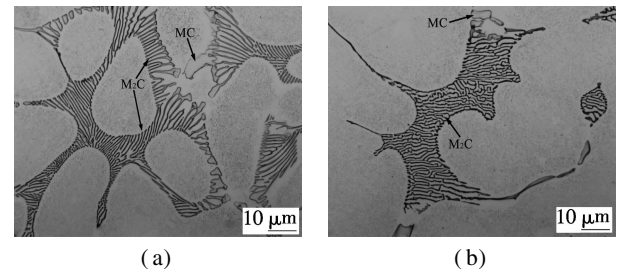


Fig. 1 As-cast structure of M42 ingots. (a) Unmodified ingots; (b) Modified ingots

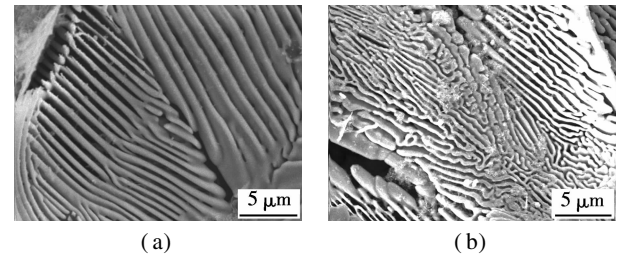


Fig. 2 Three-dimensional morphologies of eutectic carbides. (a) Unmodified ingots; (b) Modified ingots

Tab. 2 shows compositions of M_2C carbides. The amount of alloying elements, such as Mo, V and Cr, is lower in M_2C carbides with the circular structure. Rare earth metals are rarely detected by EDS, either in the matrix or carbides, although the remaining amount is approximately 0.01% in total of modified M42 ingots. This suggests that the majority of rare earth metals have been burned out and the remaining mostly exist in inclusions. It is expected that the trace amount of rare earth metals might be distributed on the interface of M_2C /matrix, although the amount is too small to be detected by EDS. This theory was proved in previous studies in which Ce was detected on the surface of eutectic carbides by EPMA or ion bombardment^[9–10].

Fig. 3 shows the microstructure M_2C eutectic carbides.

Tab. 2 Chemical compositions of M_2C eutectic carbide %					
Morphology of eutectic carbide	w_{Mo}	w_V	w_W	w_{Cr}	w_{Fe}
M_2C with the ordered lamellar structure	59.8	7.1	8.7	6.9	5.1
M_2C with the circular structure	49.2	6.5	11.1	5.9	14.8

The two carbides are both the M_2C type with a hexagonal close-packed structure. This indicates that rare earth metals change only the morphology rather than the crystal structure of eutectic carbides. Crystal defects have been rarely detected in the two carbides. This is quite different from the lamellar M_2C in M2 steel where micro-twinning and stacking faults were observed^[11].

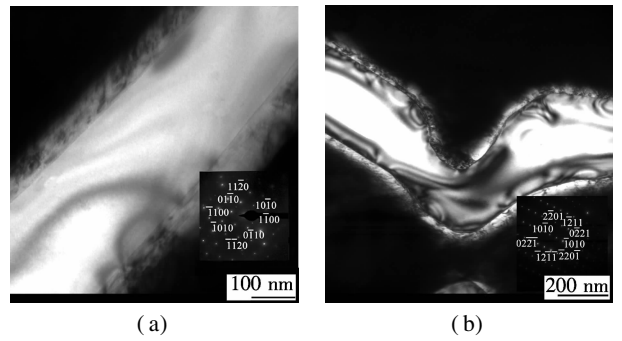


Fig. 3 Bright field images and diffraction patterns of the eutectic carbides. (a) M_2C with the ordered lamellar structure; (b) M_2C with the circular structure

Fig. 4 illustrates the Kikuchi patterns of M_2C carbides. The Kikuchi patterns rotate very little in different regions of the eutectic carbides, indicating that the two carbides both have a single crystal orientation. It is inferred that rare earth metals influence the growth rather than the nucleation of M_2C . It should be pointed out that the growth of M_2C in M42 steel may be different from that of lamellar M_2C in M2 steel, which presents a polycrystal orientation^[11].

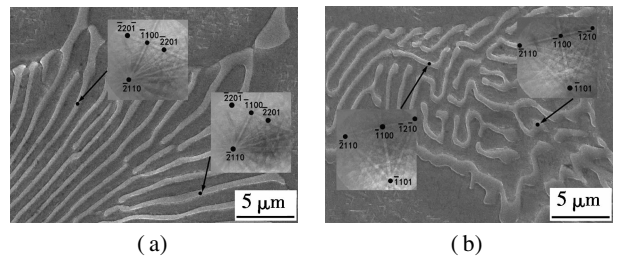


Fig. 4 Kikuchi patterns of eutectic carbides. (a) M_2C with the ordered lamellar structure; (b) M_2C with the circular structure

In high speed steels, M_2C eutectic carbides are created by an eutectic reaction: liquid \rightarrow austenite + M_2C . M_2C and austenite both nucleate from the liquid and grow together at similar rates, thus M_2C forms the lamellar morphology. The three-dimensional networks of eutectic carbides suggest that M_2C grows somewhat faster than the austenite, acting as the leading phase during an eutectic reaction.

During solidification, rare earth metals are severely segregated at the front of the solid/liquid interface, due to the extremely low solubility of iron. It causes high composition undercooling, increasing the growth rates of both austenite and M_2C . As a faceted phase, the increment in the growth rates of M_2C is less pronounced than

that of austenite with a non-faceted interface. To prevent the overgrowth of austenite, M_2C must bend and branch frequently, thus forming the circular structure.

2.2 Microstructure evolution of eutectic carbides during heating

Fig. 5 illustrates the morphology evolution of M_2C carbides in unmodified ingots after heating. M_2C eutectic carbides decompose into M_6C and MC after 1 h. As the heating time is prolonged, they spheroidize in local regions. Nevertheless, the carbide dimensions are still very large. In contrast, M_2C carbides with the circular structure also decompose after 1 h, but the amount of MC carbides is more, as shown in Fig. 6(a). It suggests that the stability of M_2C carbides may change after modification, confirmed by XRD (see Fig. 7). M_2C carbides in modified ingots decompose completely into M_6C and MC whereas there are still some M_2C carbides remaining in unmodified ingots. It demonstrates that M_2C more easily decomposes after modification. With prolonged heating time, circular M_2C carbides spheroidize clearly, which greatly refines the carbide dimensions.

The decomposition of M_2C can be expressed as $M_2C + Fe(\gamma) \rightarrow M_6C + MC$ where the matrix, represented as $Fe(\gamma)$, provides elements for the formation of M_6C and MC ^[12]. Compared with lamellar carbides, circular carbides have bended and cylindrical surfaces with large specific surface areas. It suggests that M_6C and MC may nucleate at more sites at the interface of $M_2C/Fe(\gamma)$, thus accelerating the decomposition of M_2C . In addition, the lower amount of strong carbide forming elements, such as Mo, V and Cr, may also reduce the stability of circular M_2C at high temperatures.

The process of carbide spheroidization is closely related

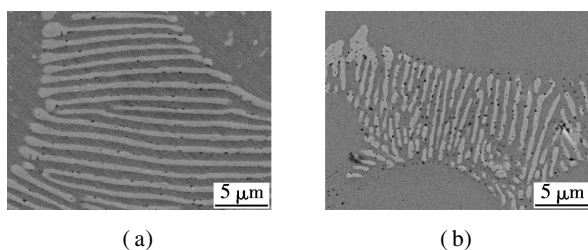


Fig. 5 Morphology evolution of M_2C eutectic carbides in unmodified M42 ingots during heating. (a) 1 h; (b) 4 h

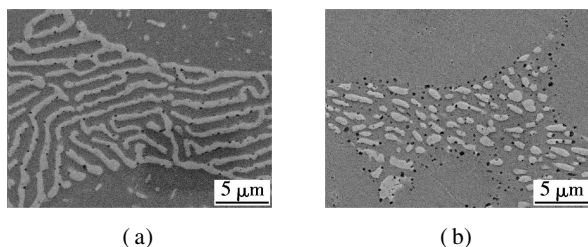


Fig. 6 Morphology evolution of M_2C eutectic carbides in modified M42 ingots during heating. (a) 1 h; (b) 4 h

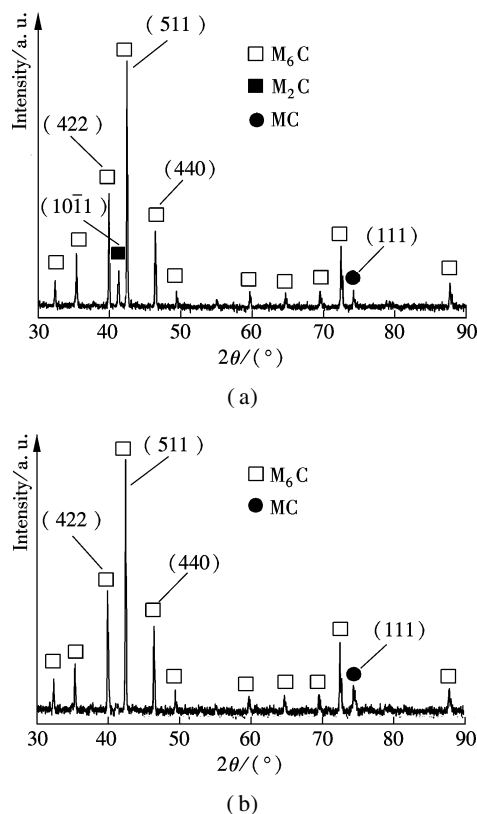


Fig. 7 XRD profiles of carbide powders extracted from M42 ingots after heating at 1 100 °C for 2 h. (a) Unmodified ingots; (b) Modified ingots

to element diffusion at the carbide/matrix interface, depending on the concentration gradient in the matrix^[13]. The element concentration is higher in the matrix adjoining the carbides with a larger surface curvature. Compared with lamellar carbides, M_2C carbides with the circular structure have quite a different surface curvature from one part to another. Thus, the concentration gradient is higher in the matrix adjoining circular carbides, which accelerates the spheroidization of circular carbides.

2.3 Hardness after quenching and tempering

Tab. 3 shows compositions of the matrix after quenching. The amount of strong carbide forming elements is higher in modified M42 ingots, particularly for Mo. It is attributed to those much finer carbides in specimens, which are easier to dissolve into the matrix at high temperatures. As M_2C carbides are enriched in Mo, the amount of Mo increases more remarkably than other elements. The higher supersaturation promotes the precipitation of secondary carbides from the martensite during tempering. It is found that the hardness of M42 steel increases from 61.0 to 62.5 HRC after modification.

Tab. 3 Compositions of the matrix after quenching at 1 200 °C for 10 min

Samples	w_{Mo}	w_W	w_{Cr}	w_V	w_{Co}	w_{Si}	w_{Mn}	w_{Fe}
Unmodified M42 steel	5.4	2.8	4.0	1.1	8.7	0.7	0.8	75.8
Modified M42 steel	9.1	3.7	4.2	1.1	8.4	0.9	0.8	71.1

3 Conclusions

1) After modification with rare earth metals, M_2C eutectic carbides changes from the ordered lamellar structure into the circular structure. Despite different morphologies, the two carbides present the same characteristics of microstructure and growth orientation.

2) Compared with lamellar carbides, M_2C carbides with the circular structure decompose more easily and spheroidize during heating, which remarkably refines carbide dimensions and increases the hardness of M42 steel. Therefore, the method of modification with rare earth metals and spheroidizing treatment is an effective method to improve both the microstructural homogeneity and performance of high speed steels.

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稀土和球化热处理对 M42 高速钢碳化物尺寸的细化作用

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摘要:采用 OM, SEM, EDS, TEM, EBSD, XRD 等分析手段, 研究了稀土和热处理对 M42 高速钢组织和性能的影响规律. 结果表明, M_2C 是 M42 高速钢主要的共晶碳化物类型. 稀土处理后, M_2C 共晶碳化物形貌由规则层片状变为不规则环状. 尽管二者形貌差异明显, 但具有相同的微观结构和晶体取向特征. 与层片状碳化物相比, 环状 M_2C 共晶碳化物热稳定性较差, 高温加热时更易发生分解和球化, 使碳化物尺寸明显细化. 小尺寸碳化物在淬火加热时易于溶解, 提高了淬火后基体中合金元素的固溶度, 使 M42 高速钢硬度增加了 1.5 HRC.

关键词:高速钢; 稀土; 碳化物; 尺寸; 球化

中图分类号: TG142.7