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Effects of Electromagnetic Stirring on Cast Structure of High-Carbon High-Speed Steel

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Abstract

This thesis focuses on the effect of electromagnetic stirring on the microstructure of casting and morphology of carbides in high carbon and high speed steel for composite roll. The microstructure of casting and morphology of carbides of are studied using the method of metallographic examination, SEM and EDS. The results show that the carbides of high carbon and high speed steel are mainly the MC, M_2C and M_6C carbides. MC carbides distributed mainly by granular, M_2C carbides distributed by strip and massive, and most of the network carbides are M_6C type carbides. With electromagnetic stirring, carbides distributed mainly on the boundary become to distribute dispersively in the grain and along the boundary. And with the increase of the applied current, distribution of carbides are more uniform. With electromagnetic stirring, at cast center, the main carbides are MC type carbides. With an optimal electromagnetic stirring current intensity, 250A for our casting system, rotary electromagnetic stirring can tend to form MC carbides, break network carbides and reduce the size of carbides.

Key words: high carbon high speed steel; electromagnetic stirring; cast structure; carbides

1. Introduction

High-carbon high-speed steel roll containing high carbon and alloy is easy to form a lot of network carbides^[1-3]. This network carbide is hard and crisp, which seriously reduces the performance of roll. The network carbide is difficult to be eliminated by conventional heat treatment. So it is very crucial to modify the carbide size and distribution in high-carbon high-speed steel composite roll during the casting. Electromagnetic stirring has the role of refining grains, reducing macro-segregation and micro-segregation in crystal, and increasing the solubility of elements in the matrix^[4]. Fabrication of high-carbon high-speed steel roll with electromagnetic stirring is expected to obtain better microstructure.

2. Experimental Method

The schematic of experimental device is shown in Fig.1. The high-carbon high-speed steel was smelted in a graphite crucible with refractory lining and cast in a magnesia crucible. The pouring temperature is about 1600°C. The diameter of ingot is 60mm and the height is 100mm. At the section about 40mm apart from ingot bottom, three specimens, with size of 15mm×15mm×20mm, 12mm×15mm×20mm, and 10.5mm×15mm×20mm, were selected and tested, which indicates the regions of ingot center, half-radius, and outer surface. A rotational electromagnetic stirrer was applied during casting. The macro- and microstructure of specimens were examined and analyzed by Leica DMI 5000M metalloscope and SSX-550 scanning electron microscope (SEM) respectively.

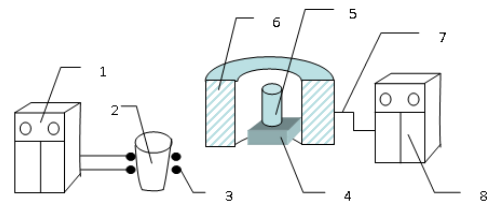


Fig. 1: Schematic of experimental apparatus
1-Power supply; 2-Smelting furnace; 3-Induction coil; 4-Platform; 5-Casting crucible; 6-Electromagnetic stirrer; 7-Cables; 8-Low frequency power

3. Results and Discussion

The cast structure of high-carbon high-speed steel mainly consists of matrix and various carbides. The alloy elements and carbon are apt to form typical alloy carbide, secondary carbide, and eutectoid carbide. As shown in Fig.2, non-equilibrium structure is formed for high-carbon high-speed steel cast structure. Carbide morphology includes lump forms, fish-bone shape, thin strip and granular shape. Carbides distributed both at grain boundary and in grain. Moreover, according to the observation in the SEM, various carbides show different brightness. The bright white carbides are rather concentrated, and locate near grain boundary. But the distributions of gray carbides are dispersed.

As shown from Fig.3, the results of energy dispersive spectrum (EDS) analysis show that, as for gray carbide, its major alloy elements are vanadium. In addition, it includes little elements Mo and W.

Therefore, the gray carbide is mainly composed of MC type carbides. As for bright white carbide, its major alloy elements are W and Mo and it is composed of M_6C type carbides with larger size. In matrix, there is little alloy elements. The results indicate that the formation of bright white fish-bone carbide is related to W and Mo component in alloy. The M_6C carbides would dissolve at $850^{\circ}C\sim 1150^{\circ}C$ in the subsequent heat treatment, even if at $1350^{\circ}C$, the M_6C carbides fail to dissolve wholly. Hence, to improve performance of roller, MC carbides are needed to enhance abrasive resistance and machinability of steel. The results of SEM also indicate that the inhomogeneous distribution of V, W and Mo elements is related to distribution of carbides.

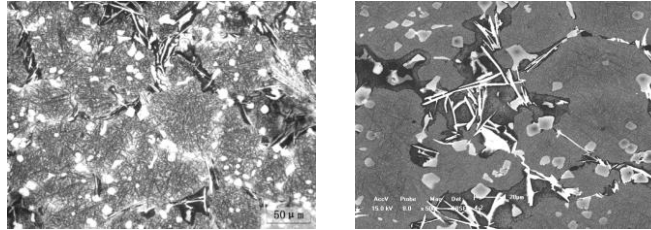


Fig.2: Carbides of high-carbon high-speed steel (2.2%C, 5%V, 9%W)

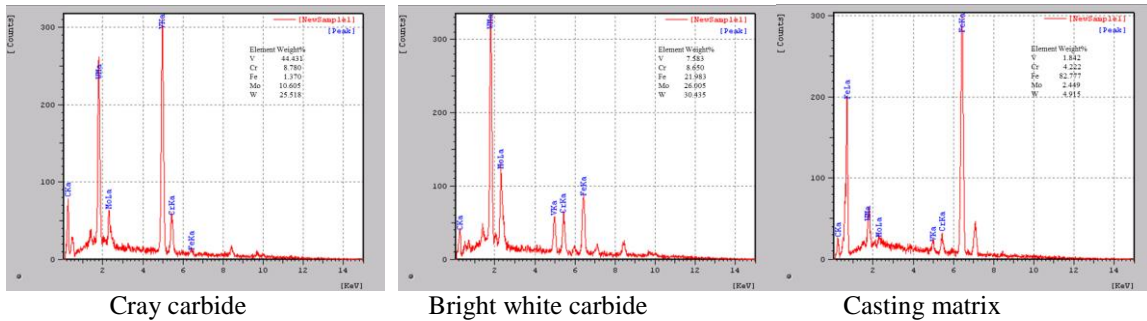


Fig. 3: EDS curve of carbides (2.2%C, 5% V, 9% W)

Fig.4 shows the solidification structure of high-carbon high-speed steel without EMS, with forward and backward EMS (250A, 10Hz, mixing time 10s, reversing time 5s), and with rotational EMS (250A, 10Hz). It indicates that without EMS, the carbides are granular and fish-bone shape, and mainly distribute along grain boundary. With forward and backward EMS, the major carbides are granular shape besides a little fish-bone shape carbide. The granular carbides distribute at the whole section. After applying rotational EMS, the major carbides is granular shape, and the distribution of carbides is more uniform.

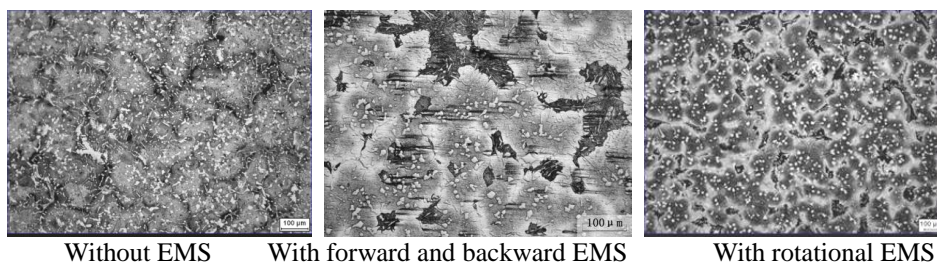


Fig. 4: Carbides with and without EMS (2.2%C, 8% V, 5% W)

The SEM and EDS analysis results for carbides of Fig.4 show that for forward and backward EMS, the major elements of MC type carbides is V, while W and Mo element locate in the fish-bone shape carbides. However, V, W and Mo elements can be found in the MC type carbides in the specimens cast with rotational EMS and without EMS. Moreover, with rotational EMS, the amount of MC type carbides is much more than that without EMS, and there is a lot of W and Mo element in the MC type carbides besides much V element. As a result, the fish-bone shape carbides containing much W and Mo are restrained. That is the reason why there is little fish-bone carbides in the specimens made by rotational EMS.

As we know from literature [5], during solidification of high-carbon high-speed steel, MC type carbides firstly precipitate form molten steel, then with temperature reduction, other carbides would precipitate. Therefore, the EMS enhances steel flow, which accelerates the heat dissipation of molten steel. As a result, during the solidification process

that V element combines with carbon to form MC type carbides, the W and Mo elements would also be promoted to participate in to form MC type carbides. Hence, with EMS, there is not enough W and Mo elements to form M_6C type carbides, and the fish-bone carbides and strip carbides would be restrained.

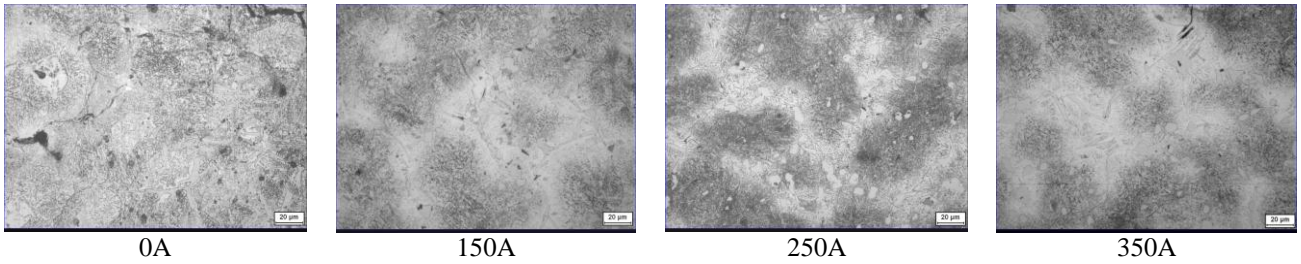


Fig. 5: Forms of carbides with different stirring current (1.6%C, 5%V, 5%W)

With different stirring current, the forms of carbides of specimens are shown in Fig.5. As shown from Fig.5, it clearly indicates that with stirring current increasing, the fish-bone shape carbides change to strip and granular carbides. At 250A, the strip carbides decrease, and the granular carbides gradually increase. However, at 350A, some strip carbides appear at the grain boundary once again besides granular carbides. The SEM analysis results also show that without EMS, W and Mo elements locate near the strip carbides, and V mainly distribute on the grain boundary with the forms of reticulation. After imposing EMS, V element distributes in the grain with the forms of granular carbides. The results show that for this casting system, the optimal stirring current is about 250A, and more granular carbides can be obtained. The optimal stirring current maybe relates to the size of casting.

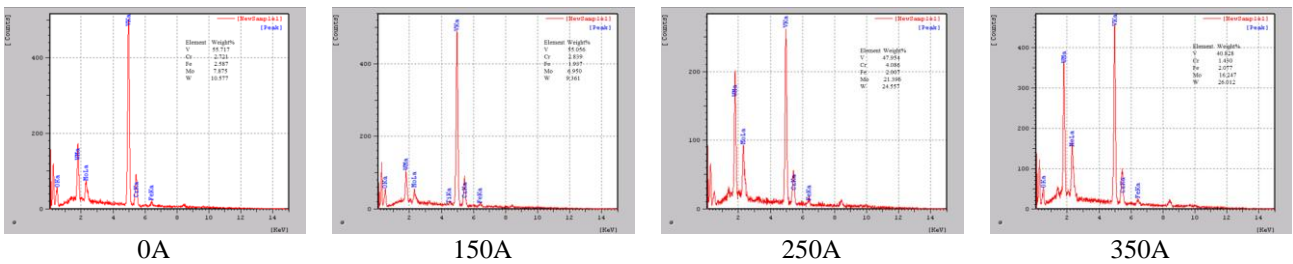


Fig. 6: EDS curve of granular carbide in specimens in Fig.5 (1.6%C, 5%V, 5%W)

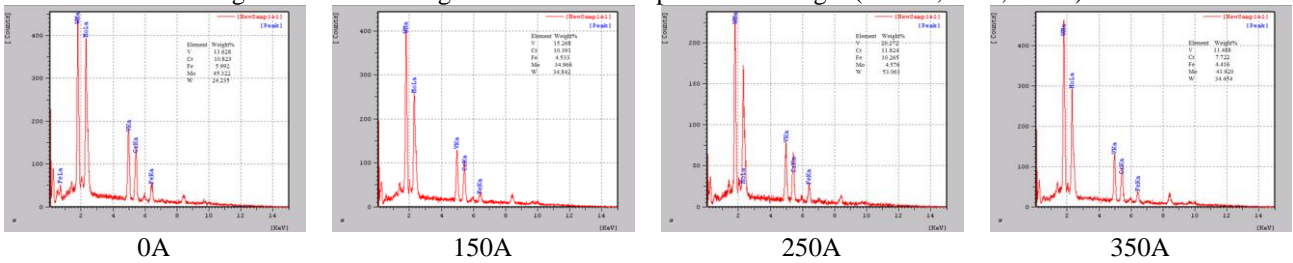


Fig. 7: EDS curve for strip carbide in specimens in Fig.5 (1.6%C, 5%V, 5%W)

Fig. 6 and Fig. 7 are the EDS analysis results for granular carbides and strip carbides respectively. Although the main composition of granular carbides is V element, as show from Fig.6 and Fig. 7, with stirring current increasing, the component of V element decrease and the component of W and Mo increase in the granular carbides. In the strip or fish-bone shape carbides, the component of Mo element has the trend to decrease firstly and then increase with stirring current. However, the component of W element has reverse tendency.

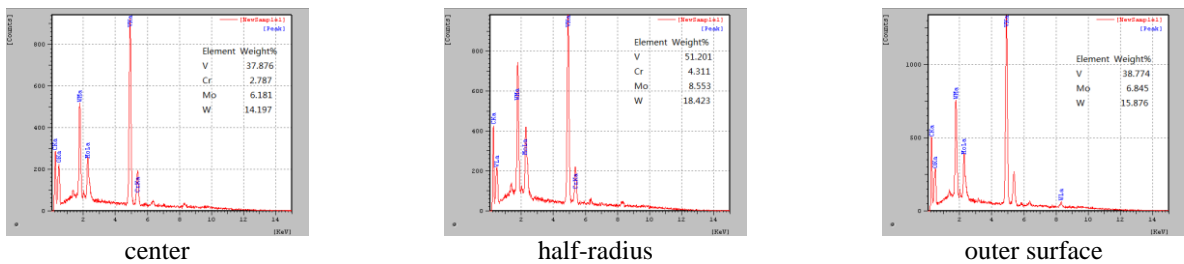


Fig. 8: EDS curve for granular carbide at different positions without EMS (1.6%C, 8%V, 5%W)

Without EMS, Fig.8 is the EDS analysis results of granular carbides in specimens located at center, half-radius, and the outer surface of casting. The results show that at the half-radius of casting, the component of V element in granular carbides is higher than that in center or at the outer surface. In the conventional solidification process, solidification rate at outer surface of casting is higher than that in inner region. MC type carbides precipitate firstly at outer surface region, and the V element supplements continuously from inner due to the steel flow and diffusion. As a result, the component of vanadium in inner region decreases. Because of sharp cooling rate at outer surface region, the solidification is too rapid to supplement of V element. At the half-radius region, the solidification rate slows down, and there is enough time for V element supplement from inner. Therefore, in half-radius region, the component of V element in MC type carbides is higher than that at outer surface and in center region.

With EMS, the EDS analysis for granular carbides at different positions is shown in Fig.9. It clearly shows that in the center region of ingot, the component of V element is very higher in MC type carbides. In the outer surface region, the component of elements is almost unchanged for the casting condition with EMS and without EMS. Comparing with Fig.8, the distribution of V element indicates that the EMS maybe changes the temperature distribution and the MC type carbides firstly precipitate in the center region of specimen. Therefore, controlling the temperature distribution and cooling rate would be appropriate measures to get more MC type carbides.

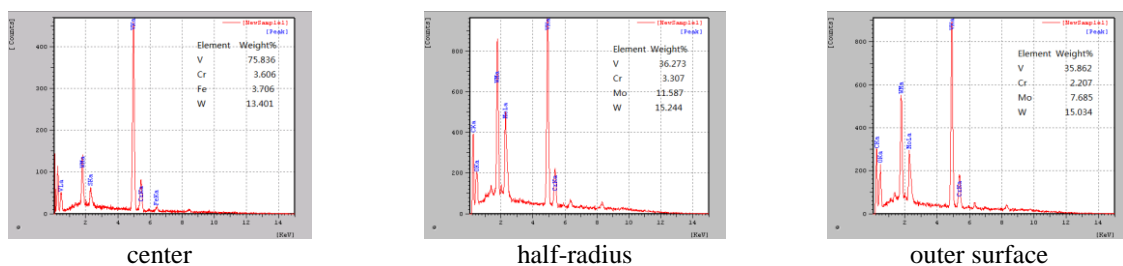


Fig. 9: EDS curve for granular carbides at different positions with EMS (1.6% C, 8% V, 5% W)

4. Conclusions

With electromagnetic stirring, carbides distributed mainly on the boundary become to dispersively distribute in the grain and along the boundary. And with the increase of the applied current, distribution of carbides are more uniform. Rotary electromagnetic stirring tends to promote to form MC type carbides, break reticulation or strip carbides and reduce the size of carbides. There exists an optimal electromagnetic stirring current intensity. EMS can affect the type of precipitated carbides. With electromagnetic stirring, at cast center, the main carbides are MC type carbides.

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