Effect of Lanthanum on micructure and properties of a chilled iron camshaft

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Abstract: Inoculation can reduce the chill depth of a chilled iron, and therefore influence the microstructure and properties of the iron. In this paper, the effect of rare earth Lanthanum (La) on the microstructure and properties of a chilled iron camshaft was studied. The results show that the La addition efficiently enhances the mechanical properties, yet with the unfavorable effect of decreasing the chilled depth and hardness. Moreover, La promotes graphite concentration and results in large graphite size, as well as A-type graphite. It is also found that excessive La destroys the interconnection and directivity of ledeburite. According to the experimental results, the optimum adding content of La should be no more than 0.02 wt. %.

Key words: chilled iron; camshaft; rare earth La; chilled depth and hardness

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Camshaft is one of the most important parts in the motor. With the increasing demand on engine power, the camshaft quality has become a critical issue for engine performance. Because of the large contact stress and high relative sliding speed between cam and tappet at high temperature during the mechanical movement, the occurrence of some cam surface defects, such as scratch, pointed corrosion, abrade and desquamation, can cause catastrophic cam failure [1-2]. Although strength and toughness are important to a camshaft, high quality camshaft also requires good abradability, high resistance to impact and resistance to contact fatigue [3-4].

Among many kinds of materials to make the camshaft, chilled cast iron has been used as a new material for its special microstructure, less metal allowance and low cost [5]. To produce high quality chilled cast iron camshaft with demanded chilled depth and hardness is challenging [6]. Inoculation can improve the microstructures and properties of chilled iron camshaft [6-7]. In this paper, the effect of rare earth La on the microstructure and properties of chilled iron camshaft is studied.

1 Technical requirements

The semi-chilled cast iron used for making camshaft is HT250, and its composition is shown in Table 1. The hardness should be greater than 48 HRC at cam, and in the range of 220 to 302 HB at the bearing locations. The chilled depth is around 5 to 12 mm. Chilled layer has a combined microstructure of ledeburite, spiculate carbide and fine pearlite with some graphite. The matrix is of fine or lamellar pearlite with some fine graphite. The metallurgical structure of intermediate zone is the typical combined microstructure of ledeburite, pearlite and carbide with a little lamellar pearlite.

### Table 1: Chemical composition of experimental cast iron HT250 (wt. %)

<table>
<thead>
<tr>
<th>Element</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>3.3-3.7</td>
</tr>
<tr>
<td>Si</td>
<td>1.6-2.1</td>
</tr>
<tr>
<td>Mn</td>
<td>0.5-0.8</td>
</tr>
<tr>
<td>S</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>P</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Ni</td>
<td>0.15-0.25</td>
</tr>
<tr>
<td>Cr</td>
<td>0.4-0.7</td>
</tr>
<tr>
<td>Mo</td>
<td>0.15-0.25</td>
</tr>
</tbody>
</table>

2 Experimental procedures

The raw materials used were Q14 pig iron, 45 scrap steel, returns, ferromanganese, ferromolybdenum, nickel, and chrome. The alloy was smelted in a medium-frequency induction furnace, whose capacity is 0.5 t. The rare earth La was added at 1,450 °C, and the pouring temperature was around 1,400 °C. The temperature of the melt was measured and monitored by a portable IR thermometer during mould filling process.

Four castings with rare earth La content of 0.01%, 0.02%, 0.03%, and 0.04% (by weight) respectively, were prepared by resin bonded sand mould with some chills were used in the cam region. The samples were taken from two different locations (i.e. cam and bearing locations) on the camshaft, as schematically shown in Fig. 1. Figure 2 illustrates the points of interest on the samples for microstructural analysis and hardness measurements. The samples were first etched by 4% nital for microstructural observation, and were further etched by a mixed solution of 1 g copper chloride, 4 g magnesium...
Chemical composition was quantified using optical emission spectroscopy (OES) technique, and an Olympus metallographic microscope was used to analyze the microstructure. Rockwell hardness tester was used to measure the hardness, and the chilled depth was measured using wedge test-piece. An universal material testing machine was used to test the mechanical properties of the camshaft.

3 Results and discussion

3.1 Effect of La on microstructure

The variation of hardness at different positions of the samples taken from cam and bearing locations as a function of rare earth La addition is listed in Table 2. It can be seen from Table 2 that with the increase of rare earth La the hardness at P1 of cam consistently decreases. The highest hardness value is 51 HRC with 0.01% La addition or without La. In contrast, the hardness measurements at the bearing location are in the range of 234 to 255 HB with little La dependency. It can be concluded from Table 2 that the rare earth La only affects the chill tendency at the chilling region, while has little effect on the basal body.

The effect of La on the graphite morphology and size of cam is shown in Fig. 3. Compared with the sample without La addition as shown in Fig. 3(a), the alloy with 0.01% La is featured with short graphite and some newly formed E-type graphite, which can be seen in Fig. 3(b). As La increases from 0.02% to 0.03% and then 0.04% [Figs. 3(c) to (e)], the short graphite evolves into longer graphite with more homogeneous distribution. The uniformly distributed long graphite is a favorable microstructure in this alloy for camshaft application.

The typical cam microstructures with different La content are shown in Fig. 4. It has been reported\(^{[8]}\) that rare earth La could suppress or decrease the degree of supercooling and therefore leads to smaller chilled depth. Due to the small supercooling, the alloy with 0.01% La [Fig. 4(b)] has more ledeburite in comparison with the unmodified alloy [Fig. 4(a)]. These ledeburites interconnect with each other and align accordingly. As shown in Table 3, the chilled depth of the alloy with 0.01% La is about 7 mm. With the increase of La addition up to 0.02% [Fig. 4(c)], the amount of ledeburite decreases, however the ledeburite still exhibits the feature of entanglement and directional alignment. When the content of La increases to 0.03% [Fig. 4(d)], the amount of ledeburite
Table 3: Effect of La addition on chilled depth

<table>
<thead>
<tr>
<th>No.</th>
<th>Inoculation temp. (°C)</th>
<th>Adding content of La</th>
<th>Pouring temp. (°C)</th>
<th>Chilled depth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1446</td>
<td>0%</td>
<td>1,400</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>1450</td>
<td>0.01%</td>
<td>1,408</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>1445</td>
<td>0.02%</td>
<td>1,410</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>1453</td>
<td>0.03%</td>
<td>1,405</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>1448</td>
<td>0.04%</td>
<td>1,409</td>
<td>3</td>
</tr>
</tbody>
</table>

As shown in Fig. 4(e), the interconnection and the directivity of ledeburite are completely destroyed and the chilled depth decreases obviously to 3 mm (see also Table 3). The decreased ledeburite is also one of the reasons causing hardness decrease. So in order to obtain acceptable camshaft, materials specification limits La to be no more than 0.02%, otherwise the chilled depth is too thin to meet the technical requirement.

3.2 Effect of La on stereo morphology of ledeburite

The effect of rare earth La on stereo morphology of ledeburite is shown in Fig. 5. Figures 5 (a) & (b) and Figs.5 (c) &

![Fig. 4: Variation of microstructure of cam as a function of La addition: 0% (a) 0.01% (b), 0.02% (c), 0.03% (d), 0.04% (e)](image)

![Fig. 5: Stereo morphology of ledeburite of 0.01% La (a) and (b), 0.04% La (c) and (d) with different magnifications](image)
(d) show the morphology of ledeburite with La addition of 0.01% and 0.04%, respectively. It can be seen from Fig. 5 that the ledeburite morphology varies largely with different concentrations of La. In the alloy with La content of 0.01%, the ledeburites are mainly spiculate, blocky and netted and their dimension is over 10 μm. As La increases to 0.04%, the ledeburites are mainly spiculate and blocky and the average length is no more than 5 μm. Otherwise, the content of ledeburite decreases and pearlite increases with the increase of La addition amount, which also explains the reason of hardness decrease. The network structure of ledeburite is no longer existed with high La content, this is due to the inoculation effect of rare earth La which promotes the graphitization and decreases the amount of ledeburite.

3.3 Effect of La on tensile strength of camshaft

The change of tensile strength of camshaft as a function of La addition is shown in Fig. 6. As a reference, the tensile strength of an unmodified alloy is 251 MPa, and one can see that a significant strength increase is observed for the alloy with 0.01% La addition (i.e. 295 MPa, an increment of 17.5%). However, further increase of La addition causes a consistent decrease of the tensile strength. Yet, the tensile strength of the alloy with La addition up to 0.04% is still greater than 280 MPa (about 30 MPa higher than the unmodified alloy). The efficiency of La inoculation on enhancing the tensile strength is due to the relatively higher volume of pearlite and carbides formed, and the refined microstructure.

![Fig. 6: Variation of tensile strength of camshaft as a function of La addition amount](image)

4 Conclusions

The effect of rare earth La on the microstructures and mechanical properties of camshaft materials have been studied and the following conclusions are made.

1. The addition of La suppresses supercooling. The hardness varies greatly with the different radius positions at the cam location, however little variation was found for the sample taken from the bearing locations. Thus, it can be concluded that rare earth La only affects the chill tendency at the chilling region and has little impact on the basal body.

2. The inoculation decreases the chilled depth. With increasing La content, the chilled layer thickness continuously drops, and the interconnection and directivity features of ledeburites weaken gradually. Due to the fact that rare earth La can effectively enhance the tensile strength of the camshaft, a compromise has to be made in order to meet both mechanical and the chilled depth requirements. As a rule of thumb, a La concentration of 0.02% is recommended for this particular application.

3. La addition has obvious effect on tensile strength of camshaft. With the increase of La addition amount, the tensile strength of camshaft increases at first, and then decreases. The tensile strength reaches the maximum value of 295 MPa when 0.01% La is added.

References


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