Letter to the Editor

Fast predicting the graphite shape of cast iron by surface tension

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Abstract

A new method for fast predicting the graphite shape of cast iron by surface tension has been put forward, and the surface tension can be fast measured by the self-developed device. Through experiments and statistical analysis, the criterion of fast predicting graphite shape by the surface tension has been established. When the surface tension is below 990 mN m^{-1}, between 990 mN m^{-1} and 1108 mN m^{-1}, between 1108 mN m^{-1} and 1283 mN m^{-1}, between 1283 mN m^{-1} and 1385 mN m^{-1}, and above 1385 mN m^{-1}, the graphite shape is all flake, vermicular and flake, vermicular, nodular and vermicular, and all nodular, respectively.

Key words: fast prediction, graphite shape, surface tension, criterion

1. Introduction

Graphite shape has an important influence on mechanical properties of cast iron [1–3]. The larger is the difference of the graphite shape from a perfect sphere, the lower are the toughness and the crack propagation resistance of cast iron, and the higher are the damping capacity and the heat conductivity [4, 5]. As a consequence, graphite shape monitoring is strongly recommended. Up to now, although many methods have been invented or developed [6–9], the most widely used ones are the thermal analysis and the metallographic observation. However, the measuring period of the thermal analysis method is much longer than three minutes [9]. As for the metallographic observation method, not only is the measuring time longer than that of the thermal analysis method, but also the operation is more complicated. Therefore, neither the metallographic observation method nor the thermal analysis method can meet the requirement upon testing speed and operative convenience. Hence, to effectively monitor the graphite shape and thus improve mechanical properties of cast iron, there is a need to develop a new method.

2. Method

Early in 1951, a relationship between the interfacial tension and the graphite shape of cast iron had been found, and then F. H. Buttner had concluded that high interfacial tension of the liquid cast iron could promote the formation of nodular graphite [10], which has been approved by many researches [11, 12]. However, the measurement of the interfacial tension is very difficult, and so the method for predicting the graphite shape by the interfacial tension is unfeasible.

According to the crystal growth theory and the interfacial tension theory [13–16], one of conditions for the graphite growing into nodular shape is that the interfacial tension between the graphite and the liquid cast iron must be higher than between others, and it is the interfacial tension that decides final shape of the graphite. For the graphite's aeolotropy, however, the interfacial tension between various crystal faces and the liquid cast iron is different. After surface active elements such as oxygen and sulphur are adsorbed to the edge plane between the graphite and the liquid cast iron, the interfacial energy and the contact angle will reduce, and the growth speed of the graphite will increase. In the end, the graphite will grow into the flake along the edge plane. Contrarily, because the modifiers have very strong affinities for oxygen and sulphur, surface active elements on the edge plane will be eliminated after they are added. Accordingly, the interfacial energy of the edge plane is much bigger than that of the base plane, and the interfacial tension and the surface tension increase simultaneously. As a res-

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ult, the graphite will grow into vermicular or nodular shape.

Whenever graphite particles occur in the liquid cast iron, there are three tensions among the graphite, the liquid cast iron and the air. Their relationships can be expressed as [17]:

$$\sigma_1 = \sigma_2 + \sigma \cos(180 - \theta). \quad (1)$$

Because the interfacial tension σ_2 retains the same, the change of the interfacial tension σ_1 can be indicated by $\sigma \cos(180 - \theta)$, and the bigger is the interfacial tension σ_1, the greater is the surface tension σ. Moreover, the graphite shape has close relation with the change of the interfacial tension σ_1. Hence, the graphite shape can be fast predicted by the surface tension of the liquid cast iron.

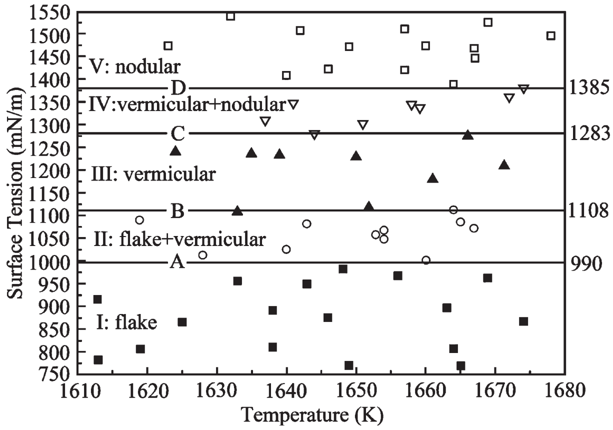

Fig. 1. Relation between the graphite shape and responding surface tension.

3. Fast measurement of surface tension and establishment of criterion

A new method is used to fast measure the surface tension of the liquid cast iron. Its measuring period is shorter and the operation becomes easier than that of the maximum bubble pressure method and the basic principle is as follows [18]. Pressurized gas is blown in the liquid cast iron through a capillary and bubbles will generate and vanish continuously at the speed of 2–3 bubbles per second. The dipping depth of capillary can change at the range of 10–20 mm. During the course of blowing gas, the pressure in the bubble is monitored by a high precision data acquisition system and the pressure curve recorded by computer is a sine wave. According to the Laplace's formula, the amplitude and the period of the sine wave reflect the additional pressure caused by the surface tension and the speed of generating bubbles, respectively. To simplify the calculation, the period of the sine wave is replaced by the number of bubbles in five seconds. In addition, the temperature of the liquid cast iron and the capillary diameter will affect the calculation of the surface tension, but they can also be measured automatically. Therefore, if the amplitude ΔP, the number N of bubbles in five seconds, the capillary diameter ϕ_x, and the temperature T of the liquid cast iron are fast measured, the surface tension σ can be calculated instantly by the following equation:

$$\sigma = 1.6641\Delta P + 19.5022 \cdot N + \\ + 0.2038 \cdot (\phi_x - 600) - 0.3581 \cdot T + 292.9447. \quad (2)$$

We have constructed a device [18], by which the surface tension of the liquid cast iron can be fast measured automatically in five seconds. Many experiments on Al-Si alloys and graphite cast iron have showed that the values of the measured surface tension have very small deviation from the reference values.

Materials for experiments are pig iron Z14, modifier 1RETiMg10-5 and inoculant 75 % FeSi. The composition of the liquid cast iron after modification is as follows: C 3.7–4.2 %, Si 2.2–3.0 %, Mn 0.3–0.5 %, P < 0.06 %, S < 0.02 %, Re > 0.035 %, Ca < 0.02 %.

To obtain the liquid cast iron with different surface tension and different graphite shape, the melting craft as follows is adopted. Pig iron is melted in a high frequency induction furnace. Over the 1773–1793 K temperature range, the liquid cast iron is spheroidized by the modifier, and the mass fraction of the modifier is varied from 0.0 % to 3.0 % in 0.05 % steps. Then the liquid cast iron is inoculated by 75 % FeSi. After the inoculation treatment, the surface tension of the liquid cast iron is fast measured by the self-developed device over the 1613–1683 K temperature range. At the same time, the metallographic samples are poured and standard graphite shape can be obtained by observing the microstructure.

When the temperature of the liquid cast iron alters over the 1613–1683 K temperature range, its surface tension will change slightly [19]. Furthermore, the temperature range of spheroidization is very small and its influence on the surface tension has been taken into consideration when the surface tension is fast measured by the self-developed device. So, the temperature can be neglected when the criterion of fast predicting the graphite shape is established. According to this craft, many experiments have been performed, and the relation between the graphite shape and the surface tension of the liquid cast iron is shown in Fig. 1.

Figure 1 is divided into five sectors according to different graphite shape. With the increase of the surface tension, the graphite will change from flake to nodular shape. In sector (I), the modifier is not added to the liquid cast iron or a small quantity is added,

Table 1. Criterion of fast predicting graphite shape by surface tension

Surface tension (mN m^{-1})	Graphite shape
$\sigma \leq 990$	flake
$990 < \sigma \leq 1108$	vermicular(small amount) + flake(large amount)
$1108 < \sigma \leq 1283$	vermicular
$1283 < \sigma < 1385$	nodular(small amount) + vermicular(large amount)
$\sigma \geq 1385$	nodular

although the surface tension increases, the graphite shape is still flake. From sector (II) to sector (IV), the surface tension increases continuously with the increase of the modifier, and the graphite will change from flake to vermicular shape. When the modifier continues to be added, the graphite will change from vermicular to nodular shape, as shown in sector (V), and the surface tension will change from the minimum to the maximum.

Through detailed comparison and statistical analysis between the graphite shape and corresponding surface tension, the criterion of fast predicting the graphite shape by the surface tension has been obtained, which is shown in Table 1. When the surface tension is below 990 mN m^{-1}, the graphite is all flake, when the surface tension is between 990 mN m^{-1} and 1108 mN m^{-1}, the graphite is flake and vermicular, when the surface tension is between 1108 mN m^{-1} and 1283 mN m^{-1}, the graphite is all vermicular, when the surface tension is between 1283 mN m^{-1} and 1385 mN m^{-1}, the graphite is vermicular and nodular, and when the surface tension is above 1385 mN m^{-1}, the graphite is all nodular. According to this criterion, as long as the surface tension of the liquid cast iron is fast measured, the graphite shape after solidification can be fast predicted by the surface tension before being poured. Therefore, it has provided an effective means for fast predicting the graphite shape and thus scientifically guiding the production of cast iron.

4. Conclusions

A new method of fast predicting the graphite shape of cast iron by the surface tension has been brought forward. In this method, the surface tension can be fast measured by self-developed device in five seconds. By experiments and statistical analysis, the criterion of fast predicting the graphite shape by the surface tension has been obtained, according to which the graphite shape of cast iron can be fast predicted.

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