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Microstructure and Mechanical Properties of Ductile Cast Iron in Lost Foam Casting with Vibration

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Abstract: The microstructures and mechanical properties of the ductile cast iron (DI) specimens obtained by lost foam casting (LFC) with and without vibration were investigated. The results indicate that the number of the graphite nodule increases from 175 mm^{-2} of the specimens produced by LFC without vibration to 334 mm^{-2} of the specimens produced by LFC with vibration, and the thickness of the ferrite shell increases. Meanwhile, the amount of the carbides decreases in the specimens produced by LFC with vibration and the granule structure then forms. These are mainly attributed to the "crystal shower" caused by the vibration. In addition, the tensile strength and elongation of DI specimens produced by LFC with vibration are improved due to the dispersion-strengthening of refined carbide and pearlite colony, uniform distribution of the graphite nodule, and increase of the amount of dimples and tearing edges.

Key words: ductile cast iron (DI); microstructure; mechanical property; mechanical vibration; lost foam casting (LFC)

Ductile cast iron (DI) is widely used in the automobile parts due to its excellent mechanical properties and good castability. Due to the complicated structure of the automobile parts, it is difficult to produce these castings using traditional casting methods. The lost foam casting (LFC) is a kind of near net-shape forming technology, through which the foamed polymer patterns of the desired shape are coated with a water-based refractory coating, dried and embedded in unbonded sand. The molten metal is then poured directly on the patterns[1]. In the past few decades, LFC had been widely researched due to its numerous advantages such as the ability to produce complex shapes, no need for mold parting line or cores, and reduced labor in the foundry practice[2]. Therefore, LFC has been applied to produce DI casting[3].

However, the pouring temperature of molten metal with LFC is about 30—50 ℃ higher than that of traditional cast pouring temperature. In addition, the heat transmission capability and the cooling rate of the dry sand used are low. As a result, the mechanical performance of the castings produced by LFC is compromised due to the presence of the coarse grains. Therefore, for the further development of the DI LFC, the coarse grains of the specimens have to be refined to improve the microstructures and properties of the casting.

The methods of refining grain size usually include mechanical and ultrasonic vibration, modifying treatment as well as increasing undercooling degree[4-7]. Relative to the other three methods, imposed mechanical vibration in LFC process has many advantages, such as simple operation, lower demand of equipment precision and improvement of the castings quality. So imposing vibration is a cheap and an efficient method for refining grains and improving the performance of casting produced by LFC.

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Previous experiments on the Al or Mg alloy using LFC suggested that mechanical vibration could help to refine the microstructure of casting[8,9]. When mechanical vibration is imposed to the solidifying molten metal, microstructural transformations occur as follows: grain is refined, homogeneity is increased and segregation is reduced. However, the cast iron is a complex system and its solidification process includes stable and metastable transformation. How the vibration affects the microstructure and other properties of DI produced by LFC is still unclear. The microstructures and properties of DI produced by lost foam casting with mechanical vibration were investigated in this study.

1 Experimental Procedure

1.1 Materials, melting and casting

In the lost foam casting process for producing the DI, expanded polystyrene (EPS) with a density of 20 kg/m^3 was used as the foam material. The foam was cut by a wire cutting machine, and it was then assembled into a pattern with Y-type. The thickness of effective portion of the Y-type pattern is 50 mm. The Y-type patterns are coated with a refractory coating, then dried and embedded in unbounded sand.

Experimental melts was produced in an electric induction furnace of intermediate frequency in a 15 kg capacity. Firstly, the casting pig iron and scrap steel were put into the furnace as raw materials. Secondly, base cast iron was treated by $FeSiMg_8RE_3$ alloy for spheroidization followed by inoculation with 75Fe-Si in a casting ladle. In the process of spheroidization and inoculation, 1.4% of an Fe-Si-Mg-RE alloy and 0.4% of a 75Fe-Si were added. Finally, the molten metal at 1460 ℃ was poured with the amplitude of 3 mm and vibration frequency of 0 and 50 Hz, respectively. The imposition of vibration started before pouring and stopped at 1200 s after pouring. The vibration direction is perpendicular to vibration generator.

1.2 Metallography examination

After solidification, specimens for metallographic examination were taken from the middle of the sample. After the specimens were polished, their graphite morphology was observed using an optical microscope. These specimens were then etched by a solution of 4 mL nitric acid and 96 mL ethanol and the microstructure observation was conducted by the optical microscopy (OM) and scanning electron microscopy (SEM). Then the interlamellar spacing and pearlite colony size were measured by a linear intercept method in scanning electron micrographs[10].

1.3 Tension test

The tensile tests were carried out using a SHIMADZU AG-IC tester at a constant crosshead velocity of 1 mm/min and at room temperature. Nonstandard plate tensile specimens with dimensions shown in Fig. 1 were machined along vibration directions from the central part of the DI. The average ultimate tensile strength (UTS) value was obtained from three samples for each specified condition. The tensile fracture surfaces were investigated by SEM.

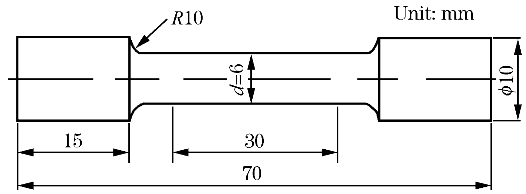

Fig. 1 Dimensions of the specimens for tensile tests

2 Results and Discussion

2.1 Microstructure and microanalysis of the ductile cast iron

Fig. 2 shows the unetched microstructures of specimens produced by LFC with and without vibration. It can be seen that the amount of the graphite nodule in the specimens produced by LFC with vibration was larger than that of the specimens without vibration. The count of graphite nodule increased from 175 mm^{-2} of the specimens produced by LFC without vibration to 334 mm^{-2} of the specimens produced by LFC with vibration. In addition, the size of nodules graphite of the specimens produced by LFC with vibration was smaller than that of without vibration.

Constituent fluctuations were induced due to dissolving or growing of the small size graphite nodule while the solidification temperature decreased. Meanwhile, the number of heterogeneous nucleation was increased due to the presence of the residual spheroidizing agent; thus, the nucleation of the graphite nodule was promoted.

The other reason of the increase of the graphite nodule number is that the "crystal shower" formed caused by the vibration. The "crystal shower" increased the nucleation of the graphite nodule and inhibited the growth of graphite nodule. Therefore, although the number of nuclei of the graphite nodule in the specimens produced by LFC with vibration was