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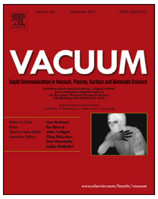

Short communication

The influence of different vacuum degree on the porosity and mechanical properties of aluminum die casting

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ABSTRACT

AlSi9Cu3 alloy castings were produced by the vacuum-assisted high pressure die casting (HPDC) process under three different absolute pressures: 500 mbar, 200 mbar and 100 mbar. The influence of absolute pressure in the die cavity on the porosity, microstructure and mechanical properties of die castings were investigated. It shows that as the absolute pressure decreases, the average porosity and pore sizes reduce from 4.8% to 2.8%, 8.65 μm–5.61 μm respectively, and the tensile strength and elongation is improved markedly by 13%, 25.2% respectively. The specimens contain larger pores under higher absolute pressure. Meanwhile, it discovers that the shape of pores is also an important factor affecting the mechanical properties. The pores with sharp corner present are much more in the castings as the absolute pressure increases. As a whole, high vacuum degree contributes to reduce the porosity that would be the basis for subsequent heat treatment and improve mechanical properties.

In the automotive industry, aluminum alloys are the optimum choice for parts manufacture where they offer significant advantages of light weight, attractive appearance, excellent processability and high corrosion resistance [1,2]. In particular, the aluminum-silicon-copper (Al-Si-Cu) cast alloys is widely used in different application fields because of their good castability. High pressure die casting (HPDC) technology has been extensively applied in producing aluminum castings, which provides high productivity, forming capability of complex shapes castings with fine grain microstructure as well as defect-free surfaces and excellent dimensional accuracy [3–5]. However, the turbulent flow during filling process is an inherent problem which can lead to gas porosity in the castings due mainly to the entrapment of air during the molten metal injected into the die cavity [3,6]. The presentence of gas porosity affects adversely the mechanical properties and pressure tightness of the castings [6]. Various solutions are used to decrease the porosity of pressure castings [6,7]. The application of vacuum device in HPDC process can significantly reduce gas porosities since the reduced back pressure by vacuum can avoid most gas entrapment and improve the deficiencies of filling capacity [8,9]. Hence, the vacuum-assisted HPDC method is deemed to possess advantages for producing aluminum castings. Yet the influence of different absolute pressure in the die cavity on the formation and shape of pores isn't paid attention it deserves. In the present paper, it describes that the effect of different absolute pressure on porosity, mechanical properties and microstructure of the Al-Si-Cu cast alloys through the vacuum-assisted HPDC method. It shows the mechanical properties of the die castings can be further improved by enhancing vacuum pressure.

Experiments were performed on engine block of the standardized AlSi9Cu3. Engine block was produced by the cold chamber die casting machine Buhler Evolution. The machine was equipped with a vacuum system consisting of a vacuum pump and vacuum valves, which can exhaust the air contained in the mold cavity and the shot sleeve. To determine the influence of absolute pressure on the porosity of castings, the engine block was produced under three absolute pressure (500 mbar, 200 mbar and 100 mbar respectively). The experiments were performed at the following constant process parameters: pouring temperature 640 °C die temperature 150–250 °C, slow shot speed 0.2 m/s, fast shot speed 5 m/s, maximum wall thickness $d_1 = 30$ mm, minimum wall thickness $d_2 = 3.5$ mm.

After casting, the microstructure analysis, tensile testing and fracture analysis were carried out on the specimens. The microstructure and morphology of the samples was observed by

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AXIOVERT 40 MAT optical microscope (OM) and TESCAN VEGA II scanning electron microscope (SEM) equipped with an energy dispersive spectroscopy (EDS). A Nano Measurer1.2 software was used to do statistics analysis of the number and size of the pores on the surface of the samples, using the maximum diameter as the diameter of each pore. The tensile strength of the castings was determined using an Instron tensile test machine at room temperature.

To obtain high resolution and clearly resolve the porosities by software, 16 microscope images are montaged to cover the whole metallographic section of samples. Fig. 1 shows the statistics data distribution (the number and size of pores) of the specimens under 500 mbar, 200 mbar and 100 mbar, respectively. It observes that the pore size under three different absolute pressure are mainly distributed at 4–8 μm. Obviously, the number of large pores (>8 μm) decreases with the decrease of absolute pressure. It indicates that this vacuum pressure can only reduce markedly the size of large pores but cannot be enough to compress effectively the small pores (<8 μm). Table 1 shows the result of the porosity measurement of casting. It is seen that the average size of pores decreases in a proportional manner with the decrease of the absolute pressure. The minimum average size (about 5.61 μm) occurs under the absolute pressure of 100 mbar. Comparing the extreme values of absolute pressure, one can find that the reduction of pressure by 400 mbar results in the significant decrease in the average size of pores, exceeding 3 μm. Meanwhile, the maximum diameter as well as minimum diameter and quantities of the pores also increase as the absolute pressure increases.

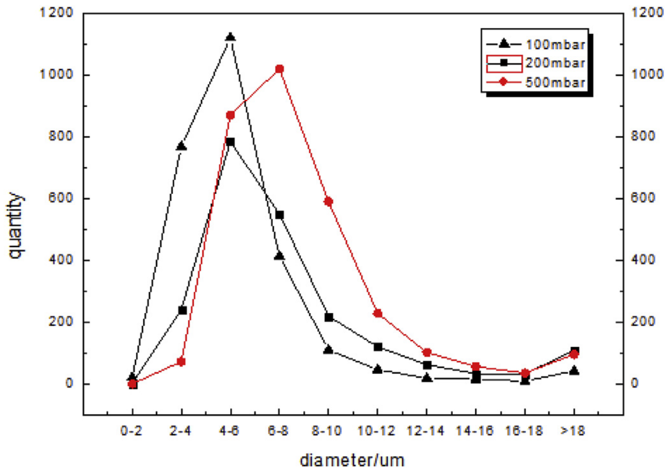

Fig. 1. The statistics of the number and size of pores.

Porosity of castings was assessed according to the standard BN-75/4051-10. Hydrostatic weighing was carried out [10]. All specimens were weighted in air and in water respectively, and then their densities were determined according to the following formula:

$$\rho_p = \frac{m_1}{m_1 - m_2} \cdot \rho_w \quad (1)$$

where: ρ_p and ρ_w is respectively the density of the specimen and water; m_1 and m_2 is the mass of the specimen in air and in water respectively. Next the porosity of the examined specimens was calculated from the following relationship:

$$P = \left(1 - \frac{\rho_p}{\rho_{wz}}\right) \cdot 100\% \quad (2)$$

where: ρ_{wz}-true density, equal to 2760 kg/m^3 for the EN AB 46000 alloy in accord with EN1706.

The results of measurements detailed in Table 1 show that the lowest porosity (about 2.8%) occurs under the absolute pressure of 100 mbar, while the highest porosity (about 4.8%) occurs under 500 mbar. It can be concluded that the establishment of high vacuum degree in the cavity is beneficial to decrease porosity, and the reduction of porosity may be mainly accomplished by reducing air or gas entrapment in the melt.

Observations of microstructures were carried out by OM and SEM. Fig. 2 presents microstructures, morphology and representative defects in castings under the absolute pressure of 500 mbar, 200 mbar, or 100 mbar. The observation area was selected according to the pores with the highest occurrence frequency on the 25 mm^2 surface of specimens. A number of pores with sharp corners are found in Fig. 2a while most of the pores are round or oval in Fig. 2b and c (indicated by the red slashed circle). It is found that large pores of irregular shape and random distribution result from the occlusion of gaseous phase during the filling of the die cavity. Pores also occur when the absolute pressure reaches 200 mbar, but both the number and the size of pores are significantly reduced. Further decreasing the absolute pressure to 100 mbar restricts the nucleation and growth of gas pores even more.

Table 1
The result of the porosity measurement of casting.

Absolute pressure/mbar	Quantities	Average size/μm	Average porosity (P)/%	Maximum diameter/μm	Minimum diameter/μm
500	3298	8.65	4.8	142.3	2.24
200	3080	8.12	4.4	127.59	1.98
100	2572	5.61	2.8	111.9	1.44

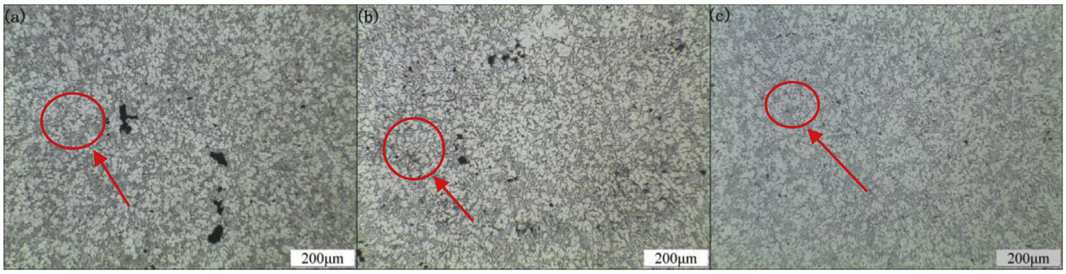

Fig. 2. Metallographic structure of engine block under three different absolute pressure; (a) 500 mbar, (b) 200 mbar, (c) 100 mbar.