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EFFECTS OF RUNNER DIAMETER ON THE MECHANICAL STRENGTH AND POROSITY DISTRIBUTION OF THIN SECTION CASTINGS

Mohd Yussni Hashim, Azriszul Mohd Amin and Vijay R. Raghavan
Faculty of Mechanical and Manufacturing Engineering
University Tun Hussein Onn Malaysia

ABSTRACT

This study was aimed to determine the effects of runner diameter on mechanical strength and porosity distribution pattern of thin section Al-12Si alloy castings which were casted through sand casting process. Computational fluid dynamic (CFD) modeling was used to identify the flow behavior during the filling process. X-ray radiography test was used to examine the general distribution of defects in the castings from different runner diameters. 3-point bending test was applied to measure the flexure strength. The scatter of flexure strength results was quantified by Weibull statistics. The casting defects existing on the fracture surface of the casting specimens were observed by scanning electron microscope (SEM). Simulation results show that predicted porosity location moved to ingate and runner area when the size of runner diameter is increased. This gives good agreement with experimental results, which showed that the casting product with a larger runner diameter leads to the improvement of average flexure strength and reduction of porosity defects. Both results support the conclusion that the use of runner with a larger diameter size can produce casting product with more reliable mechanical properties and fewer porosity defects. An area ratio of unity is recommended in some cases.

Keywords: Aluminum casting, Runner system design, Casting defect, Weibull statistic

INTRODUCTION

Throughout a casting operation, mould filling plays a very significant role in casting quality control. Due to the importance of mould filling, many extensive research efforts have been made in attempts to study the effect of gating design on the flow pattern of melt entering the mould (Esparza et al.,2005; Masoumi, 2005; Babaei, 2006). It has been shown that an optimum gating system design could reduce the turbulence in the melt flow; minimize air entrapment, sand inclusion, oxide film and dross (Hu, 2002; Dai et al., 2003).

The formation of various casting defects could be directly related to fluid flow phenomena involved in the stage of mold filling. For instance, vigorous streams can cause mold erosion; highly turbulent flows could result in air and inclusions entrapments; and relatively slower filling might generate cold shuts (Attar et al., 2005). Furthermore, porosity which is a common defect in casting also could result from improper design of gating system (Lee, 2001; Katzarov, 2003). The existing of porosity defect could decrease the mechanical properties of the product. Greater the amount of porosity in a casting, greater will be the deterioration in mechanical properties. For aluminum alloy castings, the decrease of its mechanical properties are closely related to the area fraction of defects like porosity and oxide films in the fracture surface of the casting sample. Campbell (2003) has indicated that the runner system design is an important influence on the tensile strength of aluminum cast alloy. This fact is consistent with the study carry out by Dai et al. (2003) who indicated that vortex flow runner system can produce castings with fewer oxide film inclusions. The mechanical properties or specifically flexure strength of casting plates produced by vortex flow runner system is more reliable compare with the casting plate produced by conventional runner system. However, the effect of the different runner diameter size used in gating system toward the mechanical strength of casting alloys was not discussed in their research.

The purpose of this project is to determine the effects of runner diameter on mechanical strength and porosity distribution patterns of Al-12Si alloy castings which are cast using sand casting process. This study focuses on the relationships among the liquid aluminium flow behavior, porosity distribution pattern in cast plate, microstructure of defects and ultimate strength. Computational fluid dynamics (CFD) modelling is used to investigate the liquid metal flow behavior and porosity distribution for different gating systems. X-ray radiography and scanning electron microscopy (SEM) are then used to identify the macro- and micro-structure of casting defects. The Weibull statistics method is employed to quantify the effects of three different runner diameter sizes used in this study on the strength and reliability of castings.

Statistical Analysis Of The Mechanical Strength Of Aluminium Castings

The Weibull distribution is an indicator of the variability of strength of materials resulting from a distribution of flaw sizes. This behavior results from critical sized flaws in materials with a distribution of flaw size. The term “flaw” refers to features such as small pores (holes), inclusions or micro crack (Askeland & Phule, 2003). In cast metals, the Weibull distribution, as a statistical description of metal strength properties, was originally used to analyze the yield strength and fatigue behavior of steel alloys (Dai et. al, 2003). For aluminum castings, the two parameter form of Weibull distribution is widely adopted and it can be expressed as:

$$F_p = 1 - \exp\left[-\left(\frac{\sigma}{\sigma_0}\right)^m\right] \qquad (1)$$

where F_p is probability of specimen failures (in the bending test); σ is the variable being measured; σ_0 is the characteristic stress (often assumed to be equal to the average stress) and m is the Weibull modulus. The Weibull modulus, m is a measure of the variability of the strength of the materials. For pressure die castings, a Weibull modulus is often between 1- 10, whereas for many gravity filled casting it is between 10 and 30 (Campbell, 2003).

RESEARCH METHODOLOGY

CFD Modelling

CFD modelling was used in order to investigate the molten metal flow during filling process inside the mould. Initially, Unigraphics software version NX2 was used to draw the casting geometry design and then converted to stereo lithography (STL) format. Magmasoft software package version 4.0 provided by SIRIM Berhad (RAMET) was used to perform casting simulation and results analysis.

Runner Design

Vortex flow runner system with 3 different diameters was used to produce plate casting. A cone shape sprue design was used to improve the molten flow movement during filling process as shown in FIGURE 1. The geometry of the design consists of 4 separate parts which are sprue, runner, ingate and plate. All of these geometry sizes are the same except for the size of runner diameter. This arrangement allows for a direct comparison of the liquid metal flow behavior and performance of the castings acquired by using different runner diameter.

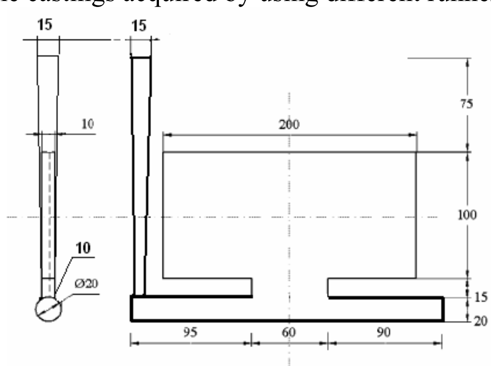


FIGURE 1 : Gating System With Different Runner Size (15mm, 20mm & 25mm)

Mould Materials and Aluminium Alloys Preparation

The green sand was used as a mould. Sand fineness was AFS 200. Material used was Al-12Si or LM6 alloys. The chemical compositions of these alloys are shown in TABLE 1. Pouring temperature was approximately 650 ^{0}C ~ 660 ^{0}C. Time required to fill the mould was approximately 9 ~ 11 seconds. Six castings were poured, two for each runner. After casting, all the samples were subjected to solidification at room temperature without heat treatment or quenching process.

TABLE 1 : Chemical Composition Of Al-12Si Alloys

Comp.	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti	Al
(%)	0.1	0.1	10.0 ~ 13.0	0.6	0.5	0.1	0.1	0.1	0.05	0.2	Remainder

X-Ray Radiography

X-ray radiography test was performed to investigate the porosity distribution in plate casting. FIGURE 2 shows the distribution of porosity in the casting samples obtained using different runner diameter size. The plates then were machined vertically and horizontally using band saw machine for three-point-bending specimen preparation as indicated in FIGURE 3.

3 Point Bending Test

3 point bending test was carried out to obtain the mechanical strength of Al-12Si alloys casting. This test was selected due to the brittle characteristics of casting specimens resulting from the silicon morphology, which developed during eutectic solidification. Unmodified alloys contained coarse acicular silicon that results in low ductility.

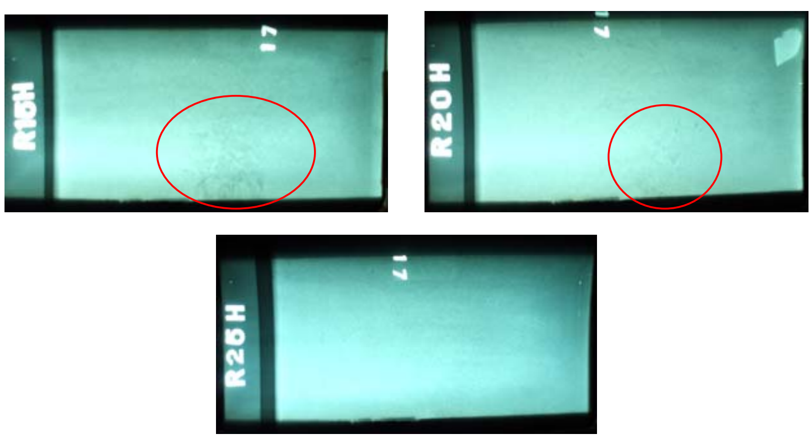


FIGURE 2 Porosity Distribution In Casting Plate Using Different Diameter Runner System. (Circle Area Indicate the Porosity Location)

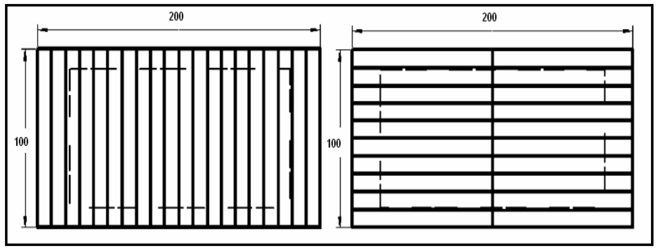


FIGURE 3 : The Cutting Methods Of Casting Samples And The Produced Specimens Will Subjected To 3 Point Bend Test

RESULTS AND DISCUSSION

Simulation Results

Numerical simulations results of filling processes are shown in FIGURE 4-6. It shows that the molten metal flow in 25mm runner fluctuated more compared to 15mm and 20mm runners. In case of 15mm and 20mm runners, the molten metal movement during entry to plate cavity was increased smoothly without showing any splash. Conversely, in 25mm runner, the movement of molten metal shows a slightly fluctuating movement. From ingate velocity calculation, it was found that all the velocity values are below the critical velocity for aluminum casting which is 0.5 *m/sec* (Barkhudarov and Williams, 1995; Sirrell *et al.*, 1996 and Dai *et al*., 2003). This shows that the molten metal flow behavior in this study was not the major factor that contributes to defect occurrence in the cast plate.

$$\boldsymbol{V}_{15}\ [\underline{0.046}\ m/sec] < \boldsymbol{V}_{20}\ [\underline{0.052}\ m/sec] < \boldsymbol{V}_{25}\ [\underline{0.059}\ m/sec]$$

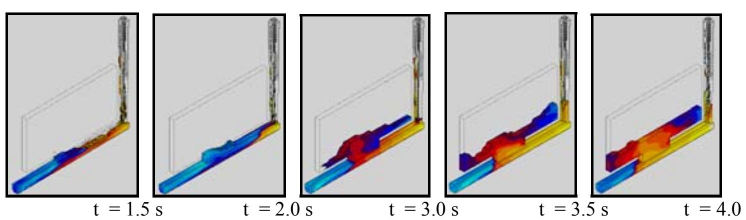


FIGURE 4: Mould Filling Sequence of 15mm Runner System

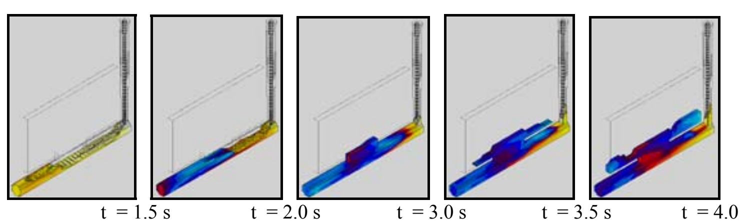
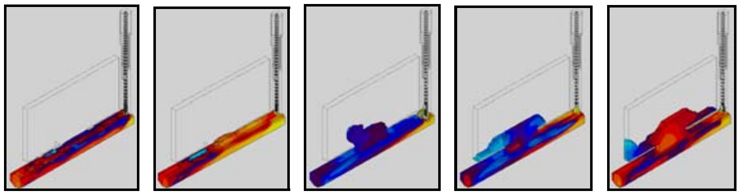


FIGURE 5: Mould Filling Sequence of 20mm Runner System



t = 1.5 s t = 2.0 s t = 3.0 s t = 3.5 s t = 4.0 s

FIGURE 6: Mould Filling Sequence of 25mm Runner System

Point Bending Test

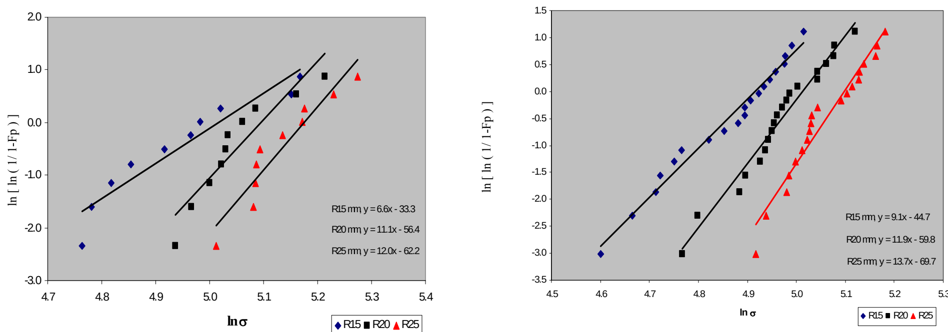
The average bending strength values was calculated in descending order are as follows; 25mm (170.244MPa) > 20mm (156.643MPa) > 15mm (141.366MPa) for horizontal sampling method and 25mm (158.003MPa) > 20mm (144.451MPa) > 15mm (129.791MPa) for vertical sampling method. An average of bending strength values show that when the diameter of runner increased, the average bending strength also increased. In case of horizontal sampling data, the higher strength values were obtained from samples close to the outside surface of plate casting. When the specimens get near to ingate, the observed flexure strength values gradually decreased. On the other hand, for vertical sampling data, the trend of flexure strength values was higher at the beginning and ending area, whereas at the central area, the strength value was slightly reduced. These trends are recognized as "edge effect" where the outside surfaces of the plate casting have a higher mechanical strength than the central area. This is because of higher cooling speeds on the casting surface which result in a finer microstructure which increases the mechanical strength of the parts.

Weibull Distribution Analysis

FIGURE 7 (a) and (b) depict the Weibull plots of horizontal and vertical casting specimens sampling. The Weibull modulus of each runner diameter is shown as follows: Horizontal samples; 15mm : 20mm : 25mm = 6.6 : 11.1 : 12.0 and Vertical samples; 15mm : 20mm : 25mm = 9.1 : 11.9 : 13.7. The Weibull modulus values for both sampling methods show that when the runner diameter increases, the *m* value will also increase. This indicates that, strength variability of specimens produced by bigger runner diameter was smaller compared to specimens produced by smaller runner diameter.

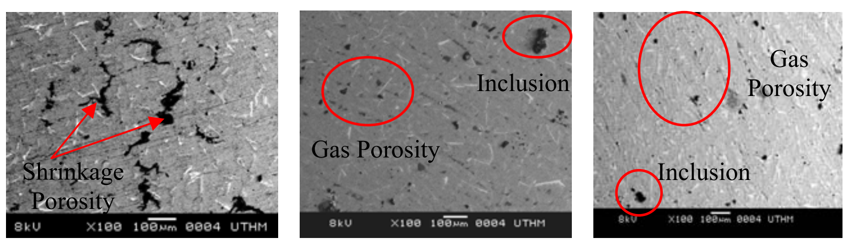
Micro Structure Analysis

Figure 8 (a), (b) and (c) show a few types of defects that are observed when polished casting specimen was examined under scanning electron microscope. Most of the defects were recognized as gas porosity, shrinkage porosity, blow holes and inclusion defect. The formation of shrinkage porosity defect can be explained by existence of hot spot at the center of plate casting. When the outer areas are already solidified, molten metal is often unable to feed effectively into the spaces which form between the dendrites due to the shrinkage which accompanies freezing. These spaces then remain as cavity following the outline of the solid dendrite. It was found that when bigger runner diameter was applied, the defect quantity in specimen become less. These results may be explained by the different of time required for liquid metal to solidify in different runner diameter size. When the diameter is increase, more time is required for molten metal to solidify. Thus, the runner with bigger diameter will act like riser and supplied the molten metal into ingate and plate area during solidification process. This will minimize the possibility of shrinkage porosity inside plate area because the molten metal is able to feed effectively into dendrite. As a result, no shrinkage porosity was found in casting specimen which used 20mm and 25mm runner diameters, as shown in Figure 8 (b) and (c).



(a) (b)

FIGURE 7 : Weibull Plots For (a) Horizontal Samples , (b) Vertical Samples



(a) 15mm (b) 20mm (c) 25mm

FIGURE 8 : Microstructure Analysis In Casting Specimen

CONCLUSIONS

The correlation of runner diameter size on the mechanical strength of Al-12Si alloy castings has been investigated by CFD and experimental work. Both results support the conclusion that the use of runner with a larger diameter size can produce casting product with more reliable mechanical properties and fewer porosity defects. An area ratio of unity is recommended in such cases.

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