Applied Mechanics and Materials Vols. 465-466 (2014) pp 1219-1223
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doi:10.4028/www.scientific.net/AMM.465-466.1219

The Effect of Vortex Well Thickness on Microstructure and Mechanical Properties of Aluminium LM6

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Keywords: Aluminum Alloy Casting, Sand Casting, Vortex Gating System, Weibull Analysis

Abstract. Gating system in a casting mold consists of a series of channels and reservoirs designed to feed molten metal to all parts of the mold cavity. The design of the system is the principle means by which the mold designer can control the rate of the metal flow and promote the desirable temperature distribution of cooling that will take place within the filled cavity. This research was conducted to determine the effects of vortex well thickness on the microstructure and mechanical properties of Aluminium LM6 in sand casting process. The experimental results show that increasing the vortex well thickness leads to a significance improvement on the flexural strength of the cast material. In addition, casting defects such as shrinkage porosity and gas porosity would be minimized as the thickness of the vortex well increases.

Introduction

The molten metal flow into mold during filling process and the cooling characteristics of the metal during solidification process is among the key factors in determining the quality of the casting product. The idea to use a novel runner system, named a "vortex system", for uphill gravity pouring to improve mechanical properties and quality of a casting was being introduced by Campbell [1]. While much research has been done on this system, there is little information available on the effects of vortex gating system to the mechanical properties and microstructure of aluminium alloy casting. The benefits of the vortex action of a sprue in casting were first explored by Campbell and Isawa [2].

The effects of vortex runner systems on the mechanical strength of Al-7Si-Mg alloy castings was investigated through employing different cross sectional shapes of runners by Dai *et al.* [3]. The results from both experiment and simulation support the conclusion that the used of vortex flow runner system can produce castings with fewer oxide film inclusions and more reliable mechanical properties compared with the castings using conventional runner systems. Subhy and Ahmed [4] has investigated the effects on microstructure and mechanical properties of LM25 Aluminium alloy in thin section casting using two different designs of gating system (conventional gating system and vortex gating system). From their study, vortex gating system shows an increment of mechanical strength of LM25 Aluminium alloy casting and lower porosity content than conventional gating system. Other study related to the effect of vortex runner gating system was done by Ahmad and Hashim [5] on the mechanical strength of Al-12Si alloy castings. The experimental results showed that the average bending strength of Al-12Si alloy casting was found to be directly proportional with the increment in the size of the vortex runner diameter. Ahmad and Talib [6] conducted experimental studies of vortex flow induced by a vortex well in sand casting process. The results showed that by optimizing the vortex well design, porosity inside the casting was significantly reduced, while the mechanical strength and reliability of the Aluminium casting were further enhanced. Therefore, this study have been conducted to determine the effects of vortex well thickness on the microstructure and mechanical properties of Aluminium alloy castings. Results of this study may suggest additional information for further research related to the effects of vortex gating system on the mechanical properties and microstructure of casting alloys. These may lead to a broader understanding in designing the vortex gating system in casting process.

Research Methodology

Geometry Design. In this study, vortex well with three different thickness have been used to produce the plate castings. The geometry design (Fig. 1) consists of five separate parts which are sprue (1), well (2), runner (3), ingate (4) and plate (5). SolidWorks Software have been used as a design tool to create the geometry designs of the casting parts in solid model.

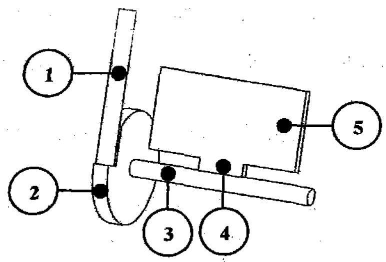


Fig. 1: Casting Geometry Design

Experimental Stage. Experimental works have been conducted at a room temperature approximately 27°C. This process has include several steps, beginning with pattern preparation and ending with casting part finishing works. In this experiment, six castings have been poured, representing the three patterns that have been fabricated at the pattern preparation stage.

Finishing Process. After the molten metal was solidified and cooled at room temperature, casting product was removed from the mold. The casting products were then be machined to separate the ingate and plate area. Then, the plates have been machined vertically and horizontally for the preparation as specimens for 3-Point Bending Test as indicated in Fig. 2.

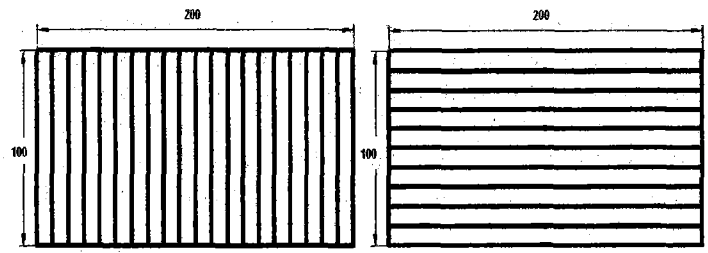


Fig. 2: Cutting Methods of Samples for 3-Point Bending Test

3-Point Bending Test. 3-Point Bending Test has been performed using Universal Testing Machine at room temperature. This test have been conducted with reference to the Standard Test Methods for Bending Test of Material for Ductility – ASTM E290-97a.

Microstructure Analysis. Microstructure analysis was conducted in this study to examine the microstructure of selected casting specimen produced from different vortex system. There were two types of equipment that have been used for microstructure analysis, which are Optical Microscope equipment and Scanning Electron Microscopic (SEM) machine.

Weibull Distribution Analysis. The Weibull distribution is an indicator of the variability of strength of materials resulting from a distribution of flaw sizes. The term "flaw" refers to features as small pores (holes), inclusions or micro crack. It does not refer to atomic level defects such as vacancies or dislocation. For aluminum castings, the two parameter form of Weibull distribution is widely adopted and it can be expressed as Eq. 1:

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

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.

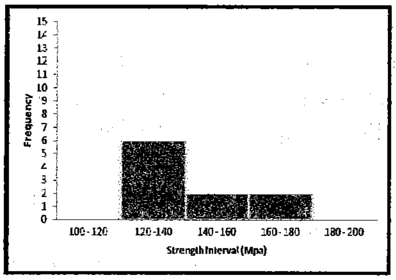
Data Analysis and Results

3-Point Bending Test Result. The results of 3-Point Bending test for horizontal and vertical sampling method are shown in Table 1. An average of bending strength values from both sampling methods indicate that when the thickness of the vortex well increases, the average bending strength of the casting alloy will gradually increase.

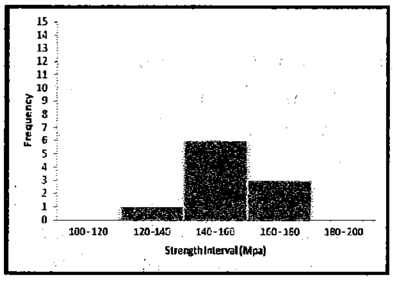
Table 1: 3-Point Bending Test Results

Vortex Well Thickness	20mm	25mm	30mm
Average Bending Strength [MPa] - Horizontal Sampling Method	138.123	152.451	166.348
Average Bending Strength [MPa] – Vertical Sampling Method	139.574	150.878	168.046

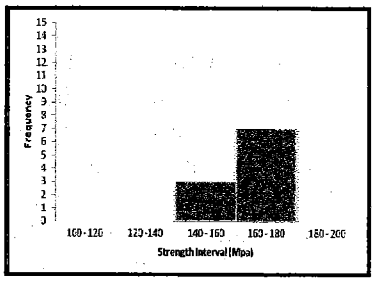
Based from the data observed, frequency histograms of the bending strength for both horizontal and vertical sampling methods are plotted and presented in Fig. 3 to visualize the scatter of strength range. The results show that the mean range of strengths in the Aluminium casting alloy were improved, as the thickness of the vortex well increases.



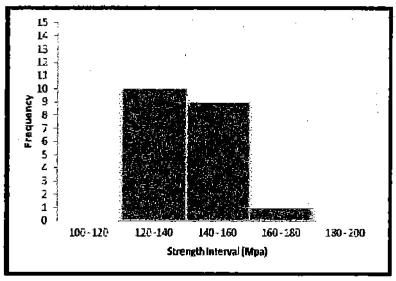
(a) Horizontal Sampling Using 20mm Vortex Well Thickness



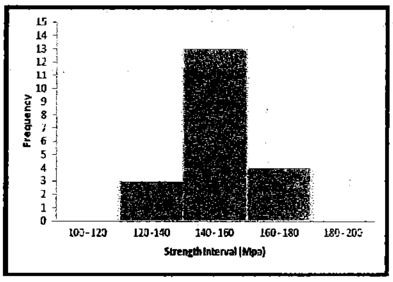
(b) Horizontal Sampling Using 25mm Vortex Well Thickness



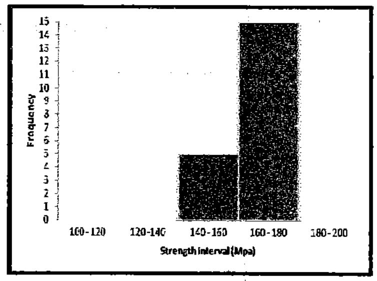
(c) Horizontal Sampling Using 30mm Vortex Well Thickness



(d) Vertical Sampling Using 20mm Vortex Well Thickness



(e) Vertical Sampling Using 25mm Vortex Well Thickness



(f) Vertical Sampling Using 30mm Vortex Well Thickness

Fig. 3: Frequency Histogram Plots of Bending Strength

Weibull Distribution Analysis. The sampling data was restructured to ascending orders. The Failure Probability, F_p is the numerical rank divided by n+1, where n is totals number of specimens. In this case, total number of specimen were 10 for horizontal samples and 20 for vertical samples. Further calculation was made base on Eq. 1. By eliminating the minus sign and taking natural logarithm twice, Eq. 1 becomes;

$$\ln\left[\ln\left(\frac{1}{1-Fp}\right)\right] = m\ln(\sigma) - m\ln(\sigma_0) \quad (2)$$

where m represent the Weibull modulus. The Weibull plot was plotted as a straight line by plotting the graph of ln [ln(1/1-F_p)] versus ln(σ) with slope m and intercept at -$m$ln(σ_0). Fig. 4 depicts the

Weibull plots of horizontal and vertical casting specimens sampling. The Weibull modulus of each vortex well thickness in horizontal and vertical sampling is shown in Table 2.

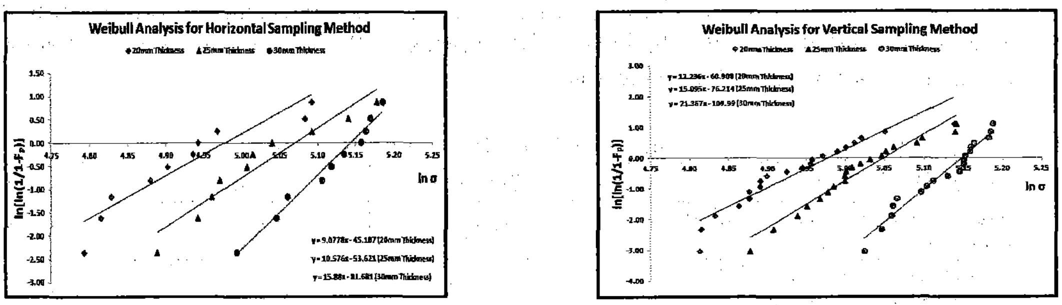


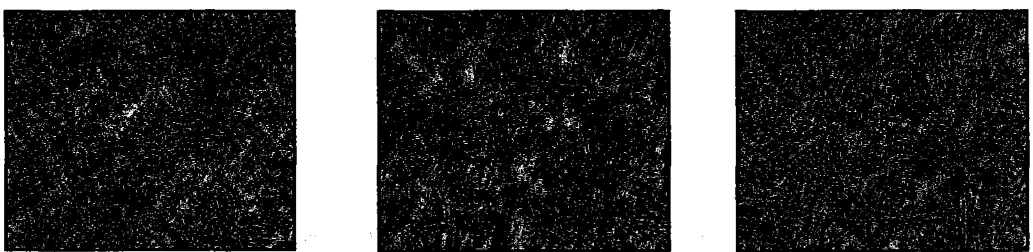
Fig. 4: Weibull Plots of All Casting Specimens (Aluminium LM6)

Table 2: The Weibull modulus of Aluminium LM6 (Al-12Si) Casting Alloys

Vortex Well Thickness	20mm	25mm	30mm
Weibull modulus (*m*) - Horizontal Samples	9.078	10.576	15.880
Weibull modulus (*m*) - Vertical Samples	12.236	15.095	21.367

The Weibull modulus values for both sampling method shows that when the vortex well thickness increases, the *m* value will also increase. This indicates that, the strength variability of specimens produced by 30mm vortex well thickness was smaller compared to specimens produced by 25mm and 20mm vortex well thickness.

Aluminium LM6 (Al-12Si) Grain Structure. Fig. 5 shows the grain structure of unmodified Aluminium LM6 (Al-12Si) alloys produced in this project. The microstructure of specimens (at 5X scales of magnification) produced using different thickness of vortex well appear relatively similar. The structure contained needle like silicon particles and surrounded with aluminum matrix composition. Due to this similarity, it appears that the different in flexure strength values obtained from the 3-Point Bending test was not significantly influenced by the grain structure.

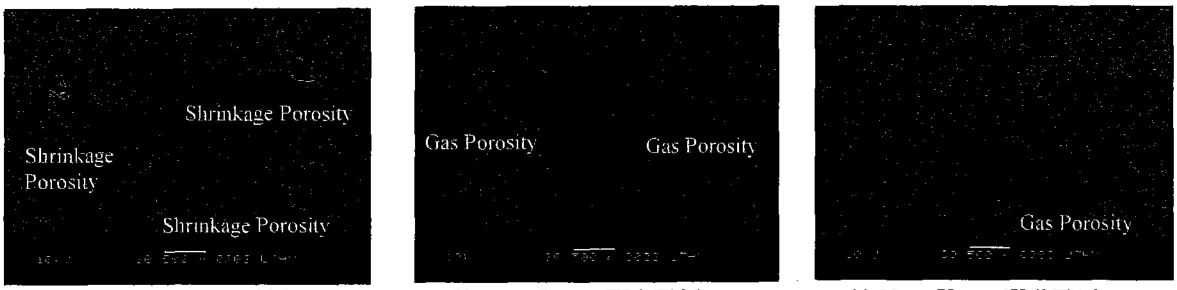


(a) 20mm Vortex Well Thickness (b) 25mm Vortex Well Thickness (c) 30mm Vortex Well Thickness

Fig. 5: Grain Structure of Aluminium LM6 (Al-12Si) Casting Alloys (Scale [μm]: 1:2)

Types of Defects. A few types of defects, recognized as shrinkage porosity and gas porosity (Fig. 6), were observed when polished casting specimen was examined under Scanning Electron Microscopic (SEM) machine. It can be observed that when bigger thickness of vortex well was applied, the quantity and severity of the shrinkage and gas porosity defects in the specimens become less. These results may be explained by the different of time required for liquid metal to solidify in different well size. When the thickness is increase, more time is required for the molten metal to solidify. Thus, the well with larger thickness will act like a riser, continuously supplied the molten metal into the runner, ingate and plate areas during solidification process.

In addition, as the molten metal solidified, the gases trapped inside the metal would further escape via the bigger well areas. This will minimize the possibility of shrinkage and gas porosity defects inside the plate area because the molten metal would be able to feed effectively into the dendrites and the gases would be able to be extracted effectively via the gating system. As a result, less shrinkage porosity and gas porosity defects were found in the casting specimens which used 25mm and 30mm vortex well thickness.



(a) 20mm Vortex Well Thickness (b) 25mm Vortex Well Thickness (c) 30mm Vortex Well Thickness

Fig. 6: Defects in the Specimens of Aluminium LM6 (Al-12Si) Casting Alloys

Conclusion

This project was attempted to determine the significant affects of vortex gating system design, particularly related to the vortex well thickness, on the mechanical properties of Aluminium LM6 (Al-12Si) alloy castings. It also looked into the microstructure and defect pattern in plate casting having different thickness of vortex well. Experimental and testing works have been conducted to investigate the mechanical strength, grain structure and defects pattern of the alloy castings material. The results of this project led to the following conclusions:

i. The thickness of vortex well design was found to have an effect on the flexural strengths of Aluminium LM6 (Al-12Si) alloy castings. The results show that increasing the vortex well thickness would increase the mechanical strength of Aluminium LM6 (Al-12Si) alloy castings.
ii. Casting defects in the part, such as shrinkage and gas porosities, were found to be the major defects that influences the mechanical strength of Aluminium LM6 (Al-12Si) alloy castings. However, the possibility of such defects that occurred due to the turbulence flow can be controlled and minimized by modifying the vortex well design. These may be explained by the differences on the severity and size of the defects found in the casting plate when the well thickness is increased.

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