Effects of gating design on the mechanical strength of thin section castings

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Abstract—Gating system design in casting process is one of the crucial factors to produce good quality of casting product. This study is aimed to determine the effects of runner gating design on mechanical strength of thin section Al-Si7-Mg alloy castings which are cast using sand casting process. The runner design used in this study is Radius bend shaped and L shape design. Flow behavior of filling process is identified by using the ADSTEFAN simulation software. 3-point bending test was applied to measure the flexure strength and its scatter is quantified by Weibull statistics. Simulation results found to be in good agreement with the experimental results. It is observed that radius bend shaped design leads to the improvement of average flexure strength and reduction of porosity defects compared with L shape design.

***Keywords*:** Aluminum casting, runner design, casting defect, Weibull statistic

I. Introduction

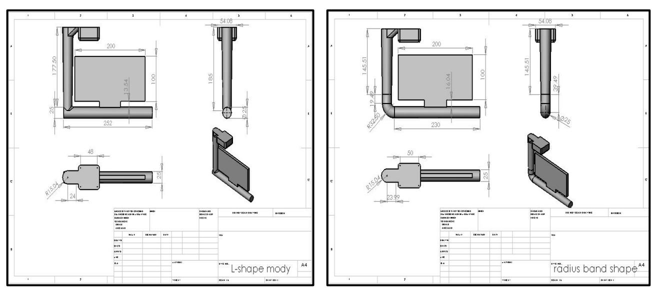
One of the critical elements that have to be considered for producing a high quality in sand casting product is the gating design. Many extensive research efforts have been made in attempts to study the effect of gating design on the flow pattern of melt entering the mould [1]-[3]. It has been shown that an optimum gating system design could reduce the turbulence in the melt flow; minimize air entrapment, sand inclusion, oxide film and dross [4].

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 could cause mold erosion; highly turbulent flows could result in air and inclusions entrapments; and relatively slower filling might generate cold shuts [5]. Furthermore, porosity which is a common defect in casting also could be result from improper design of gating system [6],[7]. The existing of porosity defect could decrease the mechanical properties of the product. Therefore, runner system design plays an important rules on determining the tensile strength of aluminum cast alloy [8],[9]. This fact also has been support by Jolly on his study on gating design which found that radius band shape runner in gating system could maintain velocity in the range of 0.3-0.4 m/s and it could obtain a greater reliability on mechanical strength [10]. However, this study was only based on computational fluid dynamic results and no experimental studied was conducted. Thus, the purpose of this study was to determine the effects of runner diameter on mechanical strength of alloy castings. This study focused on relationships among the liquid aluminum flow, microstructure defects and ultimate strength. ADSTEFAN simulation software was used to investigate the liquid metal flow behavior and porosity distribution for different gating system. The Weibull statistics method was employed to determine the effects of two different runners which is radius band shape and L shape on the strength and reliability of castings product.

II. Procedure

Runner Design

Two different runner designs was discussed in this studied which is L shape runner and radius band shape runner. The detailed dimensions of these two ingate systems are in 'figure 1' below. Each gating system includes a sprue, a runner, ingate, a mould cavity and a pouring basin.



L shape runner   Radius band shape

Figure 1: Dimensions of two runner systems

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Simulation

ADSTEFAN software was used to simulate filling process in different runner design. Casting simulation and results analysis was done to predict the molten metal behavior inside the mould.

Mould Material and Casting Aluminum Alloy Preparation

The green sand was used as a mould. The master pattern was made by 3D printer machine. Commercial LM25 aluminum alloy (Al-7Si- Mg) was used as a casting material. The chemical compositions of these alloys are shown in table 1. Pouring temperature was approximately 720 ^{0}C ~ 730 ^{0}C. Time required to fill the mould was approximately 10 ~ 15 seconds. Four 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.

Si	Fe	Cu	Mn	Mg	Ni	Zn	Pb	Sn	Ti
7,3	0,41	0,05	0,17	0,47	0,00	0,06	0,01	0,00	0,02

Table 1: Chemical Composition of Al-7Si- Mg Alloys

Three Point Bending Test

All the castings plate were machined and cut into horizontal and vertical plate as indicated in figure 2. Three point bending test was carried out to obtain the mechanical strength of Al-7Si- Mg alloys casting. The three point bend tests were conducted following ASTM E290 standard.

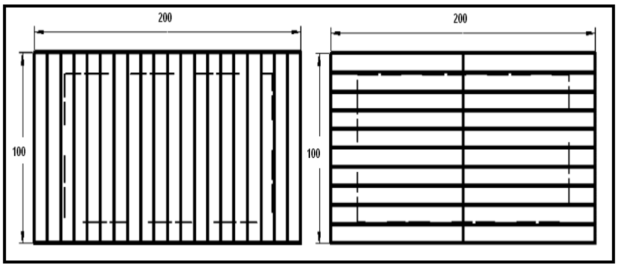


Figure 2 : The cutting methods of casting samples and the produced specimens will subjected to 3 point bend test

Analysis of the Mechanical Strength of Aluminum 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 [11]. 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. 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 [8].

III. RESULT & DISCUSSION

Simulation Result

From mould filling simulation result, it shows that the molten metal flow in radius band shape runner take are less time to fill the mould compare with L shape runners design. The molten metal behavior in radius band shape during filling the plate cavity was quickly, smoothly and less fluctuated without showing any splash compared to L shape runners. This can be seen in figure 3. On the other hand, predicted porosity distribution and location on radius band shape was less compared to L shapes design. This can be explained due to the improvement of gating design in radius shape which produces less turbulence flow during entering mould cavity. Decreasing of turbulence flow inside the mould could prevent the possibility of porosity defect to occur due to air and inclusions entrapments during filling process. Predicted porosity distribution is shown in figure 4.

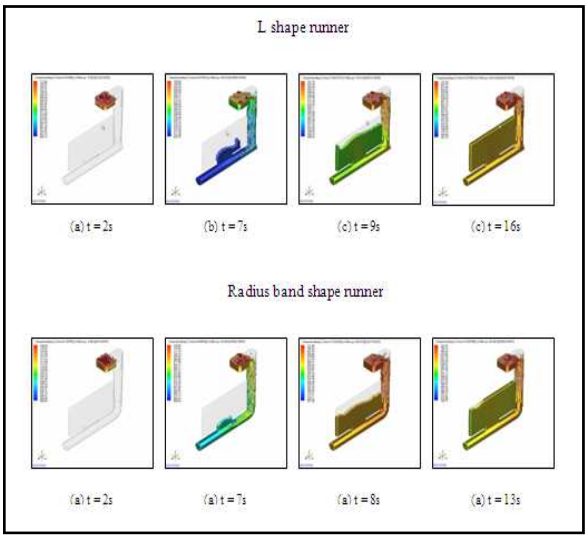


Figure 3: Filling time simulation result

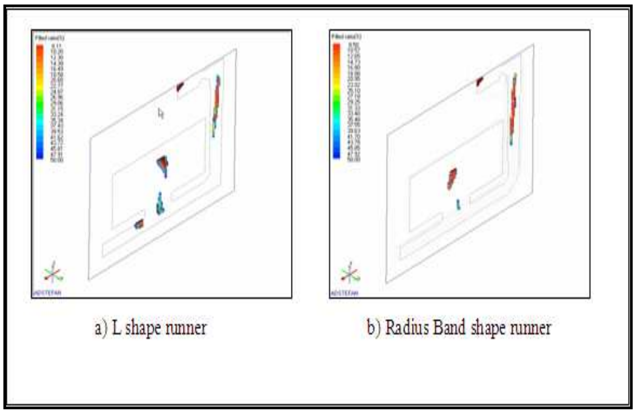
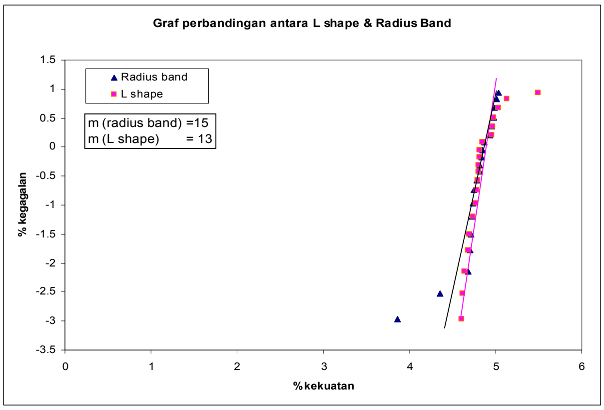
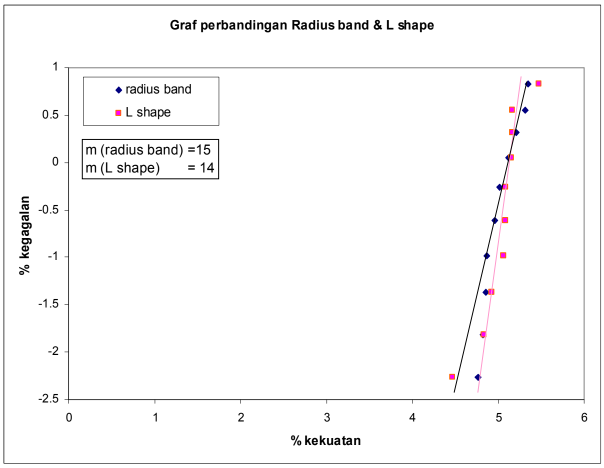


Figure 4: Predicted porosity distribution on runners design



Graph 1: Result on horizontal cut



Graph 2: Result on verticle cut

Three Point Bending Test

The average bending strength values was calculated and shows that the radius band shape design produces a higher bending strength for both horizontal and vertical samples which is 124MPa (horizontal) and 158MPa (vertical) compare with L shape design which is 116MPa (horizontal) and 151MPa (vertical). An average of bending strength values show that the different runner design (radius and L shape) could slightly alter the bending strength of the specimens. 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

Graph 1 and graph 2 represent the horizontal and vertical cut sampling data. Both graph shows the gradient value or Weibull modulus, *m* which indicate the measure of the reproducibility of the data. For radius band shape design, $m = 15$ for horizontal specimens data and vertical specimens data. On the other hand, for L shape runner, $m = 14$ for horizontal specimens data and $m = 13$ for vertical specimens data. The Weibull modulus values for both sampling methods show that *m* value for radius shape runner design was slightly higher then L shape runner design. This indicates that, strength variability of specimens produced by L shape runner was smaller compared to specimens produced by radius band shape runner.

Microstructure Analysis

Figure 5 shows a few types of defects that are observed when polished metallographic section for casting specimen was examined under 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 radius shape runner design was applied, the defect quantity in specimen become less compare to L shape design. The decreasing of defect in radius shape band runner design might be occur due to the possibility of minimizing the turbulent flow inside the mould during filling process. Furthermore, from visual inspection using microscope, it seems that the grain structure of specimen produced using different runner design appear relatively similar. Due to this similarity, it appears that the different in flexure strength value obtained from 3 point bending test was not significantly influenced by the grain structure.

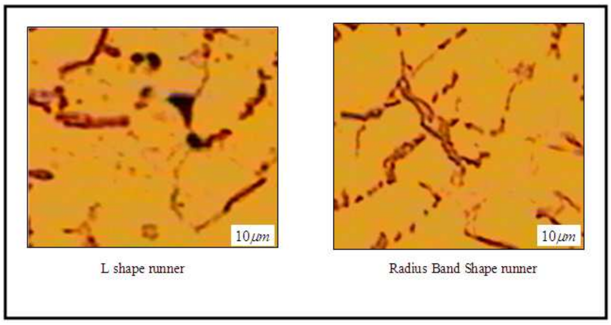


Figure 6: Result from microstructure

IV. CONCLUSION

The correlation of runner design on the mechanical strength of Al-7Si- Mg alloy castings has been investigated by ADSTEFAN simulation and experimental work. Both results support the conclusion that the use of radius band shape runner can produce casting product with more reliable mechanical properties and fewer porosity defects.

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