EFFECT OF THICKNESS ON MICROSTRUCTURE AND POROSITY OF AL-SI ALLOY IN VORTEX GATING SYSTEM

R. Ahmad and M. B. A. Asmael
Department of Manufacturing and Industrial Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia
E-Mail: roslee@uthm.edu.my

ABSTRACT

The effect of thickness of vortex gating system on microstructure, velocity and porosity of A314 cast alloy was investigated. Three different thicknesses of 20, 25 and 30 mm were simulated and casted. The data of simulation showed the thicker gating reduced the velocity of the melt. In addition, increased thickness in vortex gate contributes to better eutectic interlaminar spacing. The best quality of casting (less porosity) was obtained with large thickness of vortex gating system.

Keywords: vortex gating system, aluminium alloy, microstructure.

INTRODUCTION

Casting is a manufacturing process by which a liquid material is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is also known as a casting, which is ejected or broken out of the mold to complete the process. Casting materials are usually metals or various cold setting materials, that cure after mixing two or more components together such as epoxy, concrete, plaster and clay (Maheswari and Sureshkumar 2013).

Casting is the most often used for making complex shapes, that would otherwise be difficult or uneconomical to make by other methods. Out of all the casting processes created throughout, sand casting stands out in the crowd as being one of the oldest methods of metal casting processes. This is mainly due to its capability of producing moderate to complex parts with low cost consumption. At first, castings produced using sand casting usually exposed to countless defects caused by whether the sand being swept along by the molten metal flow inside the cavity, slow cooling rate of the sand or even low surface finish of the parts. However, that was a thing of the past as sand casting has evolved (Ammen 1979).

The vortex has usually been regarded in foundries as a flow feature to be avoided at all cost and this is because the vortex generally swallowed air, and the air found its way into the molten metal, the vortex flow certainly have to be avoided. Designers of water intakes for hydroelectric power stations are well aware of this benefit. Instead of the water being allowed to tumble haphazardly down the water intake from the reservoir, it caused to spiral down the walls. At the base of the intake duct, the loss of rotational energy allows the duct to back-fill to some extent. The central core of air terminates at the level surface of a comparatively tranquil pool, only gently circulating, near the base of the duct (Campbell 2004).

Vortex gate is a novel design applied in sand casting to deal with the central issue of high liquid velocity running through the runners. Otherwise, high velocity flow that enters the mould will have the tendency to damage the metal. It is considered to be highly effective in reducing the generation of inclusion by surface turbulence at the gate (Dai, Yang *et al.* 2003). In addition, Vortex gate are also designed to absorb energy from the melt flowing through the runners or in other words, it will act like a ceramic foam filter. In vortex gate design, there are not many parameters that had been developed or investigated in order to provide better understanding of the design (Kasala, Pernis *et al.*).

Aluminum alloys have been the primary materials for structural components of military aircrafts, helicopters, amphibians, etc for several decades. This may attribute to the low density of aluminium in mass critical application. The Al-Si aluminium alloys have been widely used in the automotive industry due to its good casting characteristics and mechanical properties (Asmael, Ahmad *et al.* 2014). Producing defect-free Al castings becomes more important (Ahmad, Asmael *et al.* 2014). The most important factors for all casting processes are feasibility, cost factors and quality factors. Quality factors are also important in the selection of a casting process. When applied to castings, the term quality refers to both degree of soundness (freedom from porosity, cracking and surface imperfections) and levels of mechanical properties (strength and ductility). In terms of feasibility, many aluminium alloy castings can be produced by any of the available methods (Ahmad, Talib *et al.* 2013). As reported, the vortex gating system shows an increment of mechanical strength of Aluminium LM25 alloy casting and lower porosity content than conventional gating system (Subhy 2010). For the vortex well design, porosity inside the casting was significantly reduced, while the mechanical strength and reliability of the aluminium casting were further enhanced (Ahmad and Talib 2011).

Furthermore, the velocity of the metal fluid flowing through the runner often faces problem of being too high. In most cases the velocity tends to exceed its critical velocity, which offers percentage of inclusions occuring in the melt. Although vortex gate is known to

ARPN Journal of Engineering and Applied Sciences

reduce this conundrum of sand casting, little or limited understanding of its parameters have been provided, whereas parameters of a gating design is essential in designing a gating system and to be successfully applied. Thus, the aim of this research is to investigate the effect of wall thickness of vortex gate design on the microstructure and velocity profile of Al-Si sand casting alloy.

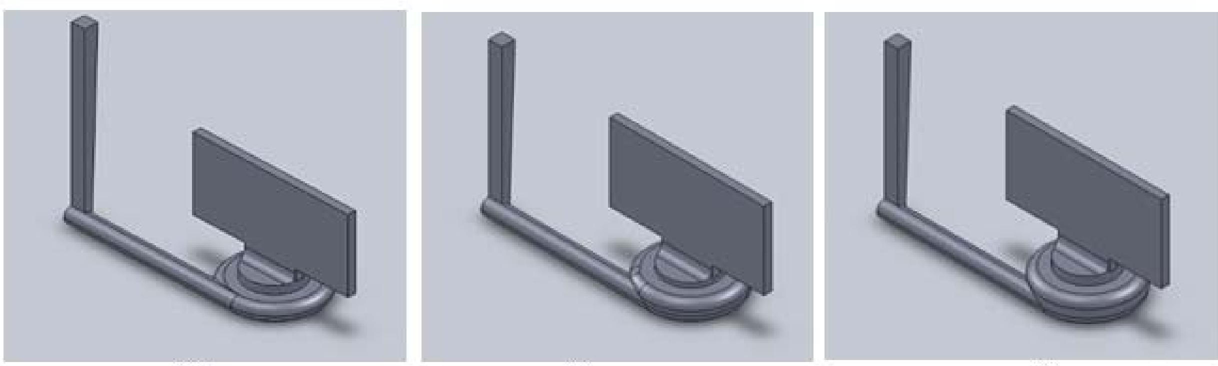
EXPERIMENT PROCEDURE

The A413 casting alloy was used and poured at 700°C into sand mould. The green sand mold was used, with a combination of sand, clay, water and the ratio of sand: clay: water is 7: 2: 1. Three different walls vortex thicknesses are shown in Figure-1. The gating system design will be incorporating the novel vortex gate design in order to apply the variation of thickness to the vortex gate. For this vortex gate design, the proposed experimental thicknesses were 20mm, 25mm and 30mm, while keeping all the components of the gating system such as runners and sprue remain constant.

Therefore, the result from different thickness of vortex gate design was used as the comparison and identification of the effect caused by the thickness parameter. The simulation method was employed in order to obtain prediction data of velocity and microstructure, which improved the understanding of the experimental results. ProCast was used to simulate the fluid flow in vortex gate design. MeshCast software was applied to create a mesh model for the finite element based simulation software. The model consists of two part, which are the casting itself and the mould.

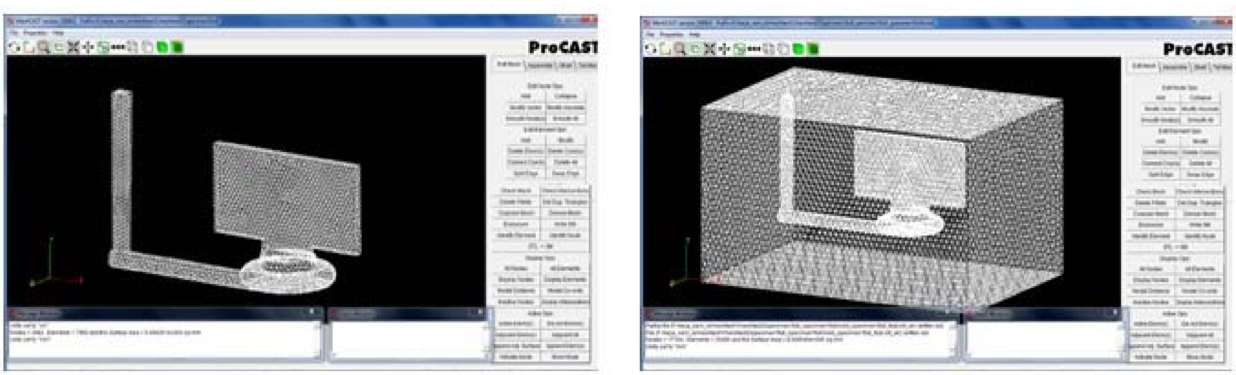
Figure-2 (a) and (b) show the meshed model and the assembled meshed model of the two parts using MeshCast. Precast component software was used to assign material and other parameters employed in this research. Selection of boundary conditions was made according to the studied parameters, such as heat, temperature and velocity as shown in Figure-3. Due to the nature of sand casting, heat was selected as air cooling due to no additional cooling system used after pouring was done.

Furthermore, the pouring temperature condition was at 700 ºC. PreCast and DataCast were used simultaneously to calculate and render the simulation based on the parameter set and the module selected. Datacast creates the necessary constant and file format for the precast to resume the calculation. The microstructure analysis was carried out by Scanning Electron Microscope (SEM).



(a) (b) (c)

Figure-1. The geometry design of the vortex gating system; (a) 20mm thickness (b) 25mm thickness (c) 30mm thickness.



(a) (b)

Figure-2. (a) The meshed model of the casting, (b) Assembled mesh model of casting and mould.

VOL. 11, NO. 10, MAY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

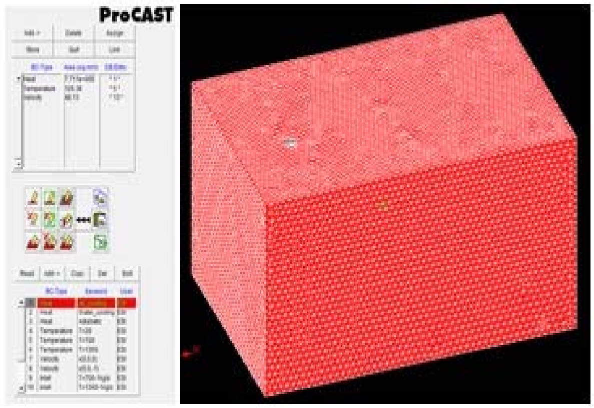


Figure-3. Boundary condition selection in the option side bar.

RESULTS AND DISCUSSION

Microstructure

Figure-3 shows the eutectic interlaminar spacing for the three specimens. The distance of spacing is represented by colors and its value of spacing between each eutectic grains. On the area of the specimen, eutectic spacing consists of only three values, while neglecting the area near the ingate. These values of lesser amount of spacing, which is purple area and larger spacing of grain represented by the blue area, where it determines which specimen has the best interlaminar spacing, which corresponding to its strength. The less amount of spacing indicates the best value of the strength of the specimen.

The first control parameter from Figure-4 (a) shows high distribution of blue area, with small amount of area, which has closer amount of spacing (purple). On the other hand, the two other specimens from Figure-4 (b) and Figure-4 (c) with increased thickness value show larger area of purple and approximately only 20% of blue area in the center, which predicts that the increased thickness in vortex gate contributes to better eutectic interlaminar spacing, in which the grains form closer to each other and creates better strength. By comparing the two thickness values, the 30mm of vortex gate thickness shows more distribution of purple area and the blue area are contained only in the center area of the specimen.

Velocity at step ingate inlet

The velocity at the inlet of step ingate, is to determine the effectiveness of the vortex gate in reducing the flow's velocity, before going through the ingate. The simulation data was obtained in the form of filling simulation snapshots at time step intervals and also the velocity profile at the inlet. Figures-5, 6 and 7 show the molten metal flow at the entrance of the main cavity, which plays a vital role in the production of porosity and oxide entrainment, where it was caused by the surface turbulence.

The vortex gate of 20 mm, which is the control parameter, shows the splash phenomena occurred as flow exits the ingate, while the vortex gate of thicknesses 25 mm and 30 mm feed the main cavity, with much more controlled velocity and the data shows significant improvement in the velocity entering the cavity. The splash was caused mainly due to the flow exiting the vortex gate with high velocity and with the high energy entering the inlet, it released the energy in the form of splashes as shown in Figure-5. This splashes is what causing porosity and oxide entrainment defects in casting, as the surface folds during the splash, air entrapment occurs and these gasses are engraved into the surface of the casting. The low velocity flow provides the metal into the cavity with more uniform velocity. The energy, which led to the sudden increase in velocity was what causing the splash, but for the vortex gate thicknesses of 25 mm and 30 mm, the splash was not visible. Figure- 8 visualizes the velocity profile data at inlet area of the main cavity, to show the numerical data during the filling process, where the velocity of flow revealed the turbulence and laminar characteristics.

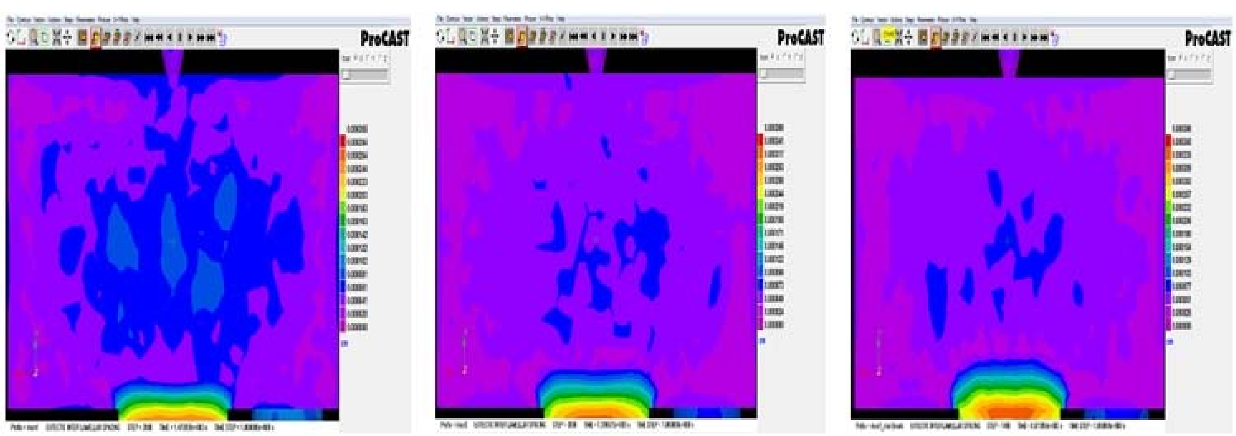


Figure-4. Microstructure simulation for sample with different thickness; (a) 20mm, (b) 25mm and (c) 30 mm.

ARPN Journal of Engineering and Applied Sciences

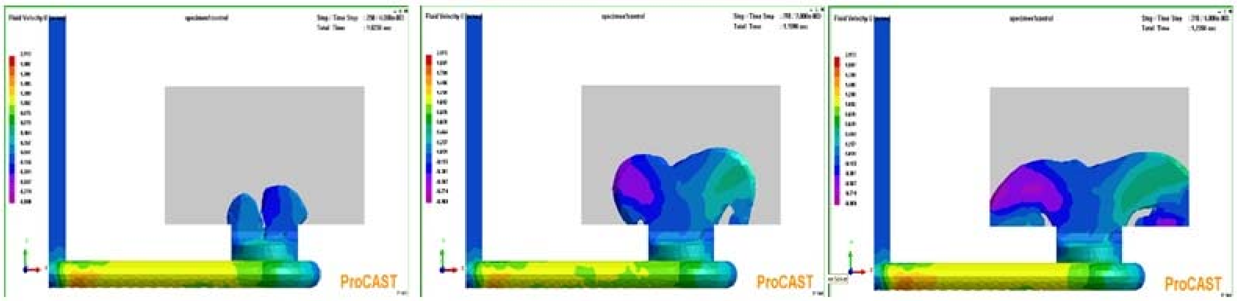


Figure-5. Filling simulation for thickness 20 mm.

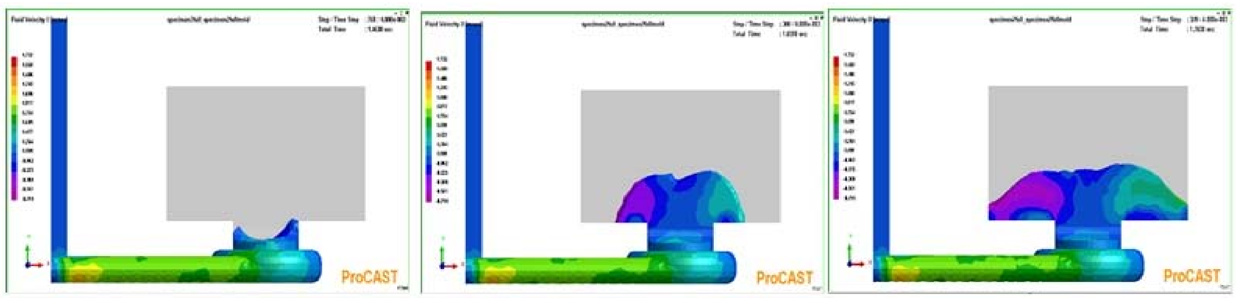


Figure-6. Filling simulation for thickness 25 mm.

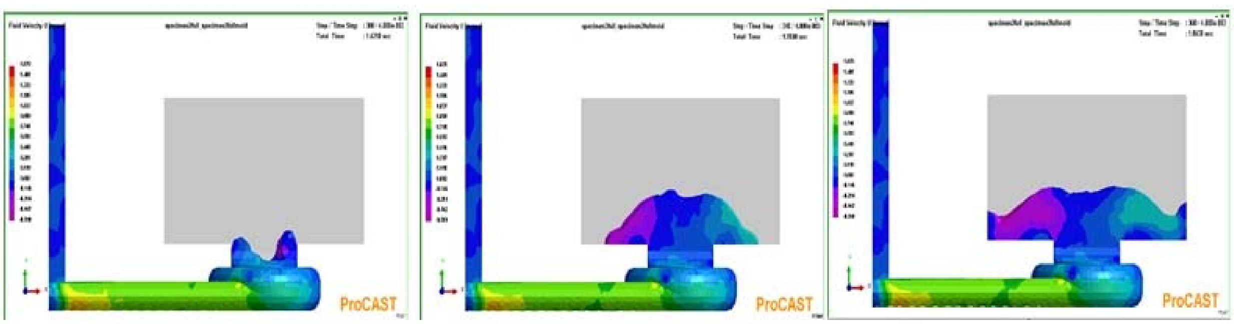


Figure-7. Filling simulation for thickness 30 mm.

The flow velocity at node located in the center of the step ingate inlet for the control thickness of 20mm is shown in Figure- 8(a), where it clearly shows that the velocity at the early stages of entrance is 0.3, where the flow exiting the vortex was at high velocity. Furthermore, the velocity for the elapsed time until the filling was completed was high in magnitude, in which for the whole time during the pouring occurred, the velocity at the step ingate was almost constantly high. For the second thickness setting (25 mm), the velocity during the filling process was contained by the duration of the flow inside the vortex gate, thus affecting the velocity by a large margin. As shown in Figure-8 (b), only at the end of the process where the velocity rose at 0.3 m/s. This is caused by the flow, which is consisted of high velocity, as it leaves the vortex gate and it is insufficient in slowing the flow. Furthermore, the overall trend of velocity data shows improvement in velocity reduction by the vortex gate. In Figure-8 (c), it is evident that the vortex gate thickness of 30 mm provides better controlled velocity profile compared to the other two thicknesses of 20 mm and 25 mm. the velocity of the flow was kept below 0.2 m/s for the whole duration of filling and the reduction of velocity is sufficient as there are no drastic increase in velocity, when it enters the ingate. This is caused by the molten metal flowing into the gate with induced vortex for a longer time, thus reducing the high velocity for a longer duration then the 20mm and 25mm vortex for a longer time, thus reducing the high velocity for a longer duration then the 20mm and 25mm thickness settings, before it enters the main cavity and producing lower porosity in the specimen. Clearly the thickness of 30mm is sufficient in order to provide controlled pattern of velocity into the ingate. Thus, the velocity, which is considered to be turbulence are at 0.3 and above. The SEM images obtained show a significant difference between the three thickness variations as shown in Figure-9.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

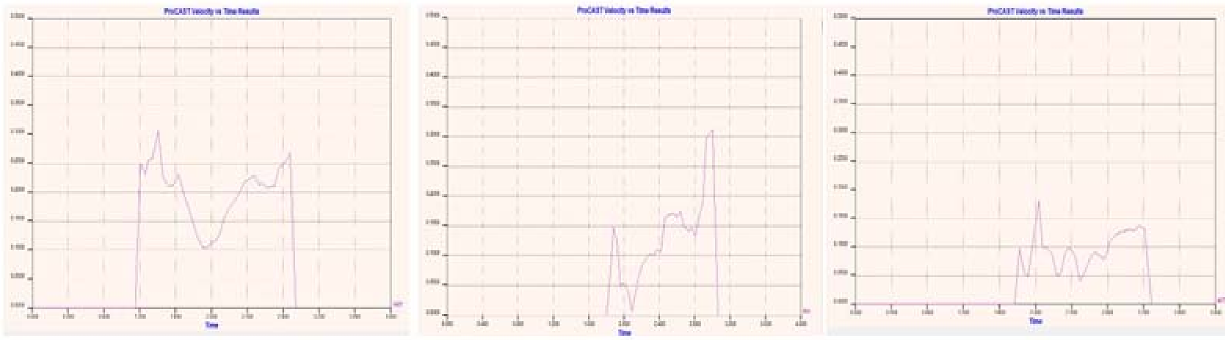
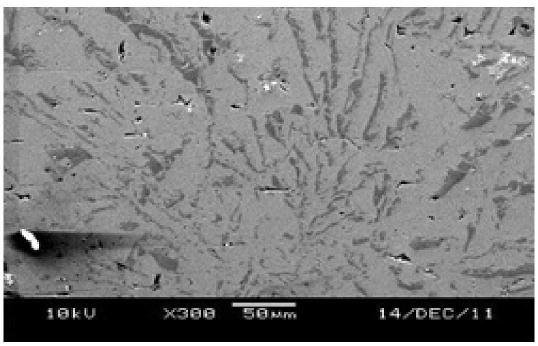
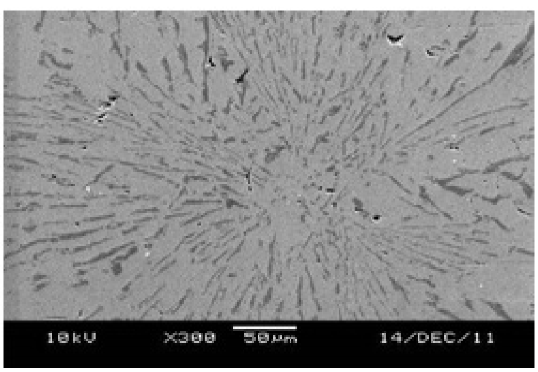


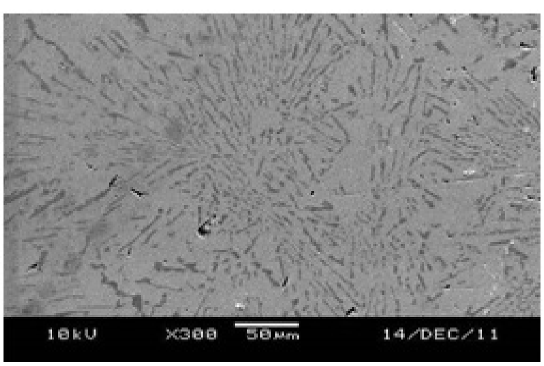
Figure-8. Velocity profile at ingate for vortex gate with thickness; (a) 20mm, (b) 25mm and (c) 30 mm.



(a)



(b)



(c)

Figure-9. SEM images of the samples (a) 20mm (b), 25mm and (c) 30mm.

As shown in Figure-9, the porosity pore shows the existence of pores from SEM observation. However, this porosity shows a decrease in amount and size as the first specimen. Figure-9(a) contains the largest amount of pores distributed over its surface. This shows the incomplete reduction of velocity, before the entrance of the flow, which causes surface entrainment and lead to the production of oxides entrained in the surface of the metal and the gas entrapment porosity of high magnitudes. On the other hand, for the second specimen as shown in Figure-9 (b), the porosities are less compared to the first specimen. This can be postulated as the effect of added thickness in the vortex gate, which increases the reduction of velocity to be below the critical velocity and correspondingly reducing the pores generated in the main cavity. The specimen from thickness of 30mm in Figure-9 (c) exhibits the best quality with the much less porosity diffusion compared to all other specimen. This is the effect of the sufficient amount of reduction in velocity or energy to avoid turbulence in the main cavity. This result is in agreement with the data from the bending test and the simulation conducted. Furthermore, the SEM images obtained in terms of grains structure are similar to those of the simulation prediction of microstructure.

CONCLUSIONS

The effect of vortex gating system thickness on microstructure, velocity and porosity of A314 cast alloy was investigated and the following can be summarized:

- The effectiveness of the vortex gate is exponentially improved as it decreases the flow velocity on the first specimen to below 0.2 m/s in the 30 mm thickness specimen.
- Large thickness produced a product with less porosity, the vortex gate of larger thickness also improved the solidification process, in which it prevented from any liquid pockets trapped in the area of the product required.
- The solidification of the vortex gate with larger thickness completes in a longer time.

ARPN Journal of Engineering and Applied Sciences

ACKNOWLEDGEMENTS

This research is funded by Fundamental Research Grant Scheme (FRGS), Vot number 1422, Ministry of Education Malaysia.

REFERENCES

[1] Ammen, Cw (1979). The complete handbook of sand casting, Tab Books.

[2] Campbell, John (2004). Castings Practice: The Ten Rules of Castings, Butterworth-Heinemann.

[3] Dai, X, X Yang, J Campbell and J Wood (2003). Effects of runner system design on the mechanical strength of Al–7Si–Mg alloy castings. Materials Science and Engineering: A, 354(1), pp.315-325.

[4] Kasala, J, R Pernis and Ľ Čaplovič Influence of gating system design on tensile properties of AlSi7Mg0. 3 alloy.

[5] Maheswari, K and G Sureshkumar (2013). Die Designing and molten metal flow analysis for intermediate flange. International Journal of Mechanical Engineering and Robotics Research India, 2(4), pp.176-182.

[6] M.B.A. Asmael, R Ahmad, A. Ourdjini and S Farahany (2014). Effect of Elements Cerium and Lanthanum on Eutectic Solidification of Al-Si-Cu near Eutectic Cast Alloy. Advanced Materials Research, 845, pp.118-122.

[7] R. Ahmad, M.B.A. Asmael, R Sadeghi, H Mohamad, Z Harun and Sulaiman Hasan (2014). The Effect of Metallic Addition on Mechanical Property of Aluminum (LM6) Alloy. Applied Mechanics and Materials, 465, pp.958-961.

[8] R. Ahmad and N Talib (2011). Experimental study of vortex flow induced by a vortex well in sand casting. Revue de Métallurgie, 108(03), pp.129-139.

[9] R. Ahmad, M.B.A .Asmael and A. Ourdjini (2014). Effect of High Cerium and Lanthanum on Impact Toughness of Al-11Si-Cu Eutectic Cast Alloy. Applied Mechanics and Materials, 660, pp.195-198.

[10] R. Ahmad, N. Talib and M.B.A. Asmael (2013). Effect of pouring temperature on microstructure properties of Al-Si LM6 Alloy sand casting. Applied Mechanics and Materials, 315, pp.856-860.

[11] Z. A.Subhy, R. Ahmed. (2010). Microstructure and mechanical properties of LM25 aluminium alloy in thin section casting using vortex gate. International Conference on Design and Concurrent Engineering. Universiti Teknikal Malaysia Melaka.