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Computer Simulation and Experimental Investigation of Solidification Casting Process

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Abstract. Computer simulation is widely used and conventional in manufacturing as a way to improve the manufactured goods quality as at same time plummeting invention costs, development time and scrap. In this study, three-dimensional model have been developed to simulate the filling and the solidification pattern in an aluminum casting with "AnyCasting" software. Using this software, solidification of aluminium 11.8% Si alloy in sand and metal mould was simulated and the results were compared with the experimental results. The solidification time and temperature was experimentally determined from thermocouple located at diverse distances. A data logger is used in experiment to gain the temperature division contour during the process of solidification of the aluminium 11.8% Si alloy. Experiments were set up to legalize the simulation results and it is confirm that the results from the two mould methods be in good agreement and the solidification of cast aluminium alloy using copper mould was much faster compared to the one cast sand mould. From this work it is concluded that simulation using AnyCasting software can be use to initially calculate. The simulation shows result that matches with the experimental data qualitatively and therefore the validation procedure is successful.

Introduction

Casting simulation is a new technology that has adopted in industry as a way to reduce scrap, reduce lead times, cut costs, use less energy, has a better final design and to improve the parts design and manufacturing processes. Trial-and-error methods of the past to design casting processes are finding it more and more difficult to compete. This approach is expensive and inflexible because many variable affect the solidification of the metal inside the mold [1, 2]. Using simulation, the behavior of the molten aluminium during the filling, heat transfer and solidification of different casting methods can be studied [3-5].

Casting simulation has the ability to analyze various physical phenomena occurring during casting process. From previous research, the simulation of metal casting about fluid flow, heat transfer and solidification has been treated extensively [1, 5]. It allow researchers to observe and quantify what is not usually visible or measurable during real casting process. Simulation produces a tremendous amount of data that characterize the transient flow behaviour (e.g., velocity, temperature), as well as the final quality of the casting (e.g., porosity, grain structure). It takes good understanding of the actual casting process, and experience in numerical simulation, for a designer to be able to relate one to the other and derive useful conclusions from the results [4].

In this study, the AnyCasting software will be used for investigates the behavior of the molten metal during the melt filling and solidification in casting process. This software is a 3D solidification and fluid flow package used in the die casting industry to model the molten metal flow and solidification in dies. It employs the finite difference method to solve the heat and mass transfer on a rectangular grid. It is a useful tool for simulating molten metal flow in a permanent mould since it can provide useful information about the filling pattern. It also produces reasonable accurate data on casting related features such as premature solidification, air entrapment, velocity distribution, runner and gate effectiveness.

Methodology

The research activity are divided into two parts. The first part explains about the experimental works and the second part explains about simulation works.

Part 1: Material Preparation for Experimental. The aluminium-11.8% silicon alloy or LM6 was used as a matrix in this research. This alloy conforms to British Standard 1490 LM6. LM6 alloy is a eutectic alloy that have lowest melting point that can be seen from Al-Si phase diagram. The mechanical, thermal and electrical properties and the chemical composition of LM6 are shown in Table 1 and 2. In this research, sand and permanent metallic mold was used. The thermocouple was insert at specific measured points for temperature measurement. The process starts when LM6 ingots were cut into small pieces and the process continue by melts the ingots in an coreless induction furnace. The ingots is left to melt until it reaches 750°C. After that, the composite slurry are poured into the sand and permanent metallic mold as shown in Fig. 1 by gravity, and then allowed to solidify. Then the casting is broken out of the mold to complete the process. The casting used in this research is a cylinder shaped. The temperature of the molten metal must maintain while transferring to the mold to ensure the quality of the cast product.

Table 1: Properties of LM6 (wt%) [6]

Physical Properties	**Values**
Density (g/cc)	2.66
Mechanical Properties	**Values**
Tensile strength, Ultimate (MPa)	290
Tensile strength, Yield (MPa)	131
Elongation %; break (%)	3.5
Poissons ratio	0.33
Fatigue strength (MPa)	130
Machinability	30
Shear strength (MPa)	170
Hardness (BHN)	50
Modulus of elasticity (N/sq.mm)	71000
Thermal Properties	**Values**
CTE, linear 20^{o}C (μm/m-^{o}C)	20.4
CTE, linear 250^{o}C (μm/m-^{o}C)	22.4
Heat of fusion (J/g)	389
Thermal conductivity (W/m-K)	155
Melting point (^{o}C)	574
Solidus, (^{o}C)	574
Liquidus (^{o}C)	582
Electrical Properties	**Values**
Electrical resistivity (Ohm-cm)	0.0000044

Table 2: Chemical composition of LM6 (wt%) [7]

Aluminium (Al)	Silicon (Si)	Copper (Cu)	Manganese (Mn)	Tin (Sn)	Iron (Fe)	Nickel (Ni)	Zinc (Zn)	Magnesium (Mg)
88.0%	11.0%	1.0%	0.3%	0.15%	1.3%	0.5%	0.5%	0.1%

Part 2: Simulation. In this research, AnyCasting software was used to predict the filling and solidification characteristics of the LM6 cylinder cast. This software are divided into 3 step. First, the 3-D models of the mold and cast was developed and save as in stereolithography (STL) format and imported to software. The diameter of the cylinder cast is 40mm and the height is 170mm as shown in Fig. 2. The simulation starts with the generation of FDM mesh after reading the CAD data. The FDM mesh is done to devide the geometry into cells or control volumes. In this simulation, about 2,000,000 elements were created for 3-D models. Next, the simulation parameter and specific materials for the mold and casting was set up. In this simulation the mold material is assigned as silica sand and copper and the casting material is aluminium 11.8% silicon alloy. Table 3 shows the assumption parameter were considered in this simulation. Next step was set up the condition of analysis for operating at anySOLVER. Lastly, the filling and solidification results can be viewed in 3-D graphic at anyPOST.

Table 3: The parameter input for simulation

Parameters (LM6)			
Density	2660 kgm^{-3}	Liquidus temperature	582^{o}C
Specific heat	963 $Jkg^{-1}K^{-1}$	Coefficient of thermal expansion	1.824e-008K^{-1}
Thermal conductivity	155$Wm^{-1}K^{-1}$	Latent heat	389000Jkg^{-1}
Solidus temperature	574^{o}C	Volumetrix change of solidification	3.8%

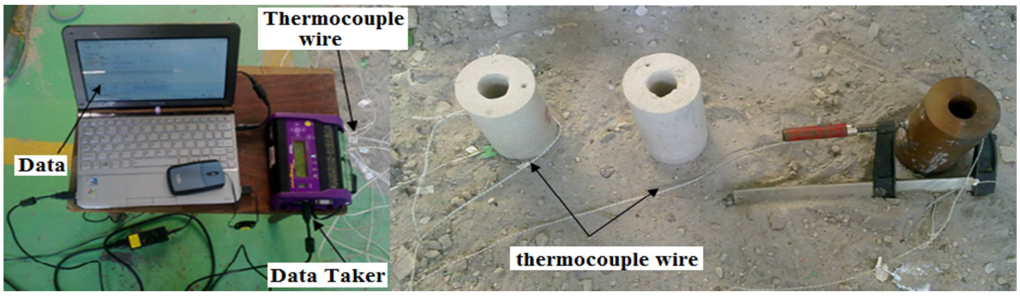

Fig. 1: The mould is connected to datataker data logger using thermocouple wires

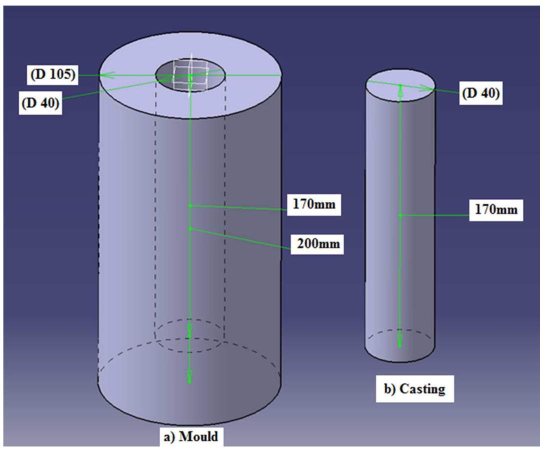

Fig. 2: CAD drawing of mould and casting

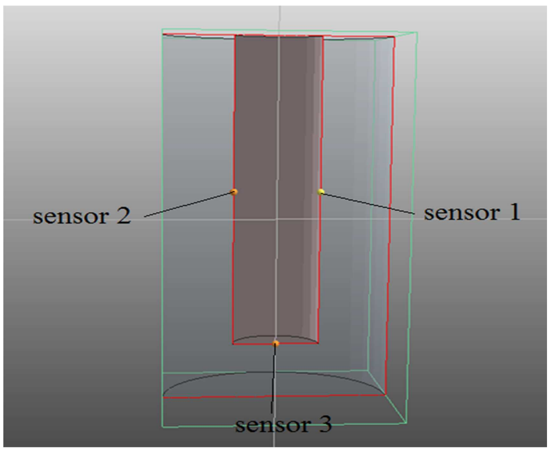

Fig. 3: The location of sensor

Results and Discussion

The visualization of mold filling is shown in Fig. 4 and 5. The duration time for molten metal fill in the mould is about 11.1934 second for sand casting and 11.1937 second for permanent metallic mold. By simulation, the temperatures versus time helps to visualize the temperature contours and the distribution inside the solidifying composites. The verified model based on the experimental observations. The simulations were run by applying the input parameter data as shown in Table 1 and Table 3. From Table 1, the liquidus temperature of LM6 is 574^{o}C and for solidus temperature is 582°C. Fig. 6 shows the solidification process begins near the liquidus temperature at 549.37 °C and ends near the solidus temperature of 520°C.

Fig. 6 to Fig. 8 shows the simulated temperature curve from the simulation of present study and Fig. 7 and 9 shows the cooling curves of the solidification of LM6 from the experimental. The shape of both simulation and experimental are very similar to each other. From the graph, the solidification for the casting using permanent metallic mold (copper) is shorter than using sand casting. Higher thermal conductivity of the copper mold causes faster solidification compare the solidification of sand mold. The molten metal that poured into the copper mold has higher cooling rate than those poured into the sand mold. The thermal conductivity of copper is $401 Wm^{-1}K^{-1}$ and sand is $0.733 Wm^{-1}K^{-1}$.

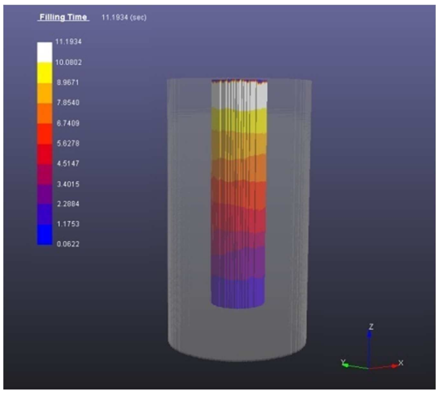

Fig. 4: The filling time (sand casting)

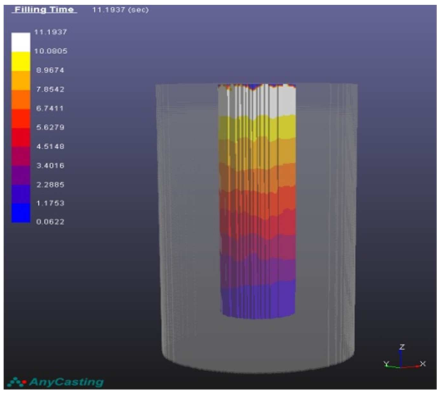

Fig. 5: The filling time (permanent metallic mold)

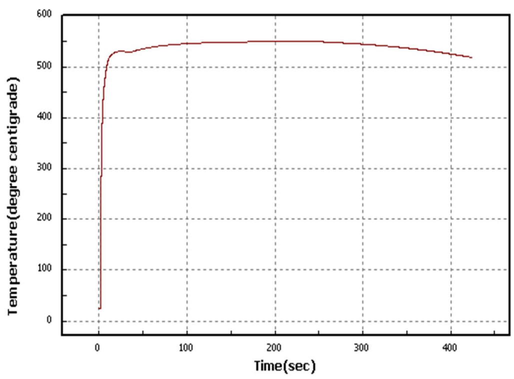

Fig. 6: Temperature curve from LM6 simulation for sand casting methods

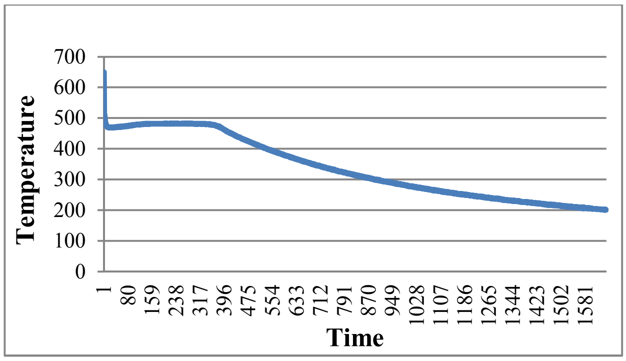

Fig. 7: The cooling curves using sand casting method

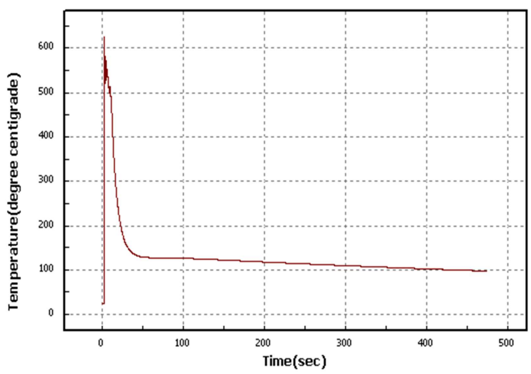

Fig. 8: Temperature curve from LM6 simulation for sand casting methods

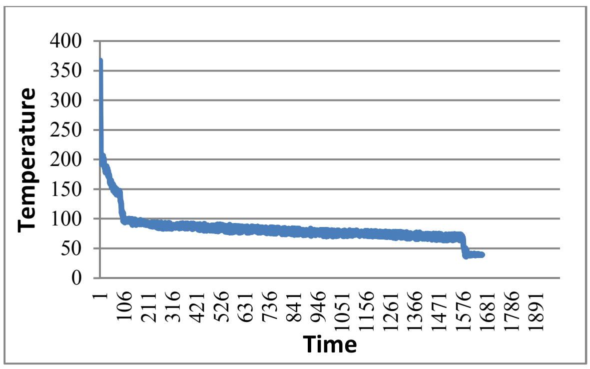

Fig. 9: The cooling curves using permanent metallic methods

Summary
A 3-D model has been developed for the simulation of casting solidification using sand and permanent metallic mold. The effects of the mold on the solidification time have been investigated using this model. Solidification and cooling rate using permanent metallic mould are higher than sand mold and the value of thermal conductivityis influence the results. The solidification and the cooling rate of simulation is very similar to the experimental results.

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