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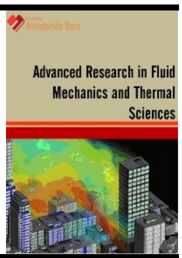

Flow Analysis of Five-Axis Impeller in Vacuum Casting by Computer Simulation

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ABSTRACT

Vacuum casting is a modern technique in the casting technology. It is capable to cast the complex parts with low tooling cost and short time. Thus, in order to achieve the optimum result of casted parts the computer simulation was used in the analysis. So, this paper presents the study to analyze the flow of resin into the mould of five-axis impeller by vacuum casting process. Computer simulation was used to define critical parameters such as casting point location, flow temperature, average, flow velocity, air traps location and filling time. The Moldflow software was used as simulation tool to gain result of analysis. Polyurethane resin has been used as raw material to cast a five-axis impeller. Vacuum casting machine types KLM 1000A was selected and mould is made by silicone rubber mould (Axson-Essil291). Otherwise, pattern for impeller was fabricated by 3D printer type's powder based which is named as Project460. The results from simulation show that the maximum flow temperature in cavity could be 230.1 degree celcius (°C), 0.142 centimetre per second (cm/s) for average flow velocity and 0.5210 second (s) for filling time. Meanwhile, the casting point location could be located at the top of the mould cavity. Therefore, by using computer simulation for flow analysis, it shows that on how the material flows in a cavity, the risk areas, the air trap forming and the suitable position for casting funnel that would be contributed to increase the quality of the part.

Keywords:
Vacuum casting; moldflow; impeller; simulation

1. Introduction

Vacuum casting is an advanced method, one of the most fascinating and greatest technique of Rapid Prototyping models, which has demonstrated its suitability and effectiveness in new product improvement stage. Vacuum casting is a modern technique that allows the manufacturing of pieces in small batches and individual fabrication at minimum price and shorter time and build complicated prototype parts with similar form details and surface quality of the duplicate master model [1].

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MoldFlow package was applied to simulate and predict different scenarios and investigate the optimum tool design and injection parameters [2].

A lecturer from Manufacturing Engineering Centre (MEC) at Cardiff University, said “faster and quicker alternative to investment casting is vacuum investment casting”. He based his argument on the facts that a vacuum casting machine bought for “in-house” use, costs from £80,000 to £300,000 depending on manufacturer and size, and on the ease with which the vacuum casting method is integrated with rapid prototyping [3]. Furthermore, vacuum casting also known as a method to produce small prototypes form RP models. A popular application is the vacuum casting of prototypes in a formulated polyurethane material of a wide variety of physical properties [4]. The process starts from the building of a silicone rubber mould using the RP model, e.g. an SL model, as the positive master. Once the mould is fabricated, is then cut into two halves to remove the RP pattern. Then, two polyurethane resins are mixed and poured into the sealed silicone mould halves and the resin filled mould is de-gassed and placed in an oven. When the process is completed the mould is then opened and the end product is retrieved [5]. The basic advantage of vacuum casting process is the shortening of prototype making time and cost, compared to traditional methods. Whilst, the silicon matrixes permit casting and low-pressure injections of plastics [6]. Moulds made of silicones that have higher resistance to high temperatures may serve for producing single castings of nonferrous metals. Silicon may also be utilized for producing matrices for wax patterns for precision casting [7]. For rapid tooling technology usually the preparation of master model/pattern was done by Rapid Prototyping (RP) method [8-10].

A finite element model has been developed and applied to compute the fluid flow distribution inside the shell in the mould region of a continuous, steel slab-casting machine [11]. Computer simulation software such as MAGMA is a three-dimensional solidification and fluid flow package used extensively in the die casting industry, particularly in foundry applications, to model the molten metal flow and solidification in dies [12-13]. 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 and has strong material properties capability. Computational models to simulate fluid flow phenomena in three dimensions generally start by solving the continuity equation and Navier-Stokes equations for incompressible Newtonian fluids, which are based on conserving mass (one equation) and momentum (three equations) at every point in a computational domain [14].

In a vacuum casting technique, the de-aerated slurry from the mixture bowl is pulled through the feed line into a vacuum chamber by application of vacuum. The slurry flows as a very thin layer and as it travels down gets de-aerated [15]. The resin flow in vacuum casting process could be described by Darcy’s Law. However, the fluid here under consideration is resin, whose viscosity is several hundred times than that of water (the object of Darcy’s Law), so the viscosity term should be separated as Eq. (1)

$$\vec{V} = \frac{\overline{\overline{K}}}{\mu} \cdot \nabla P \tag{1}$$

$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = -\frac{1}{\mu} \begin{bmatrix} K_{xx} & K_{xy} & K_{xz} \\ K_{yz} & K_{yy} & K_{yz} \\ K_{zx} & K_{zy} & K_{zz} \end{bmatrix} \begin{bmatrix} \frac{\partial P}{\partial x} \\ \frac{\partial P}{\partial y} \\ \frac{\partial P}{\partial z} \end{bmatrix} \tag{2}$$

where, the V is the Darcian Velocity, K is the tensor of permeability, μ is the viscosity of resin and ∇P is the gradient of pressure. Eq. (2) describes the relation between the permeability and fluid velocities in three directions.

Some of the resins used in development of composite parts such as urea formaldehyde resin (UF), phenol formaldehyde resin (PF) and epoxy [18-19]. Radu *et al.,* [16] in his study uses four types of wax which are 863 Pink, 864 Red, 865 Green, and 866 Blue in development of part by vacuum casting process. The most famous problems or error in the casted part was short shot. Paul *et al.,* [20] has found that the casted part of die casting process was experienced short sot with 25% volume fill. Therefore, in order to eliminate or reduce the error on casted part, this study are recommended to use the Moldflow software to do the analysis and at the same time the Moldflow can help engineer to anticipate the material flow in cavity.

2. Methodology

The mould design of five-axis impeller was designed by SolidWorks, Dassault Systems as shown in Figure 1. Firstly, core and cavity of the mould have to be designed with comply with the international standard in mould design. The best parting lines and parting surface were set towards impeller part model. The parting lines were defined on the body of the mould so that it will make easy in splitting process of the core and cavity.

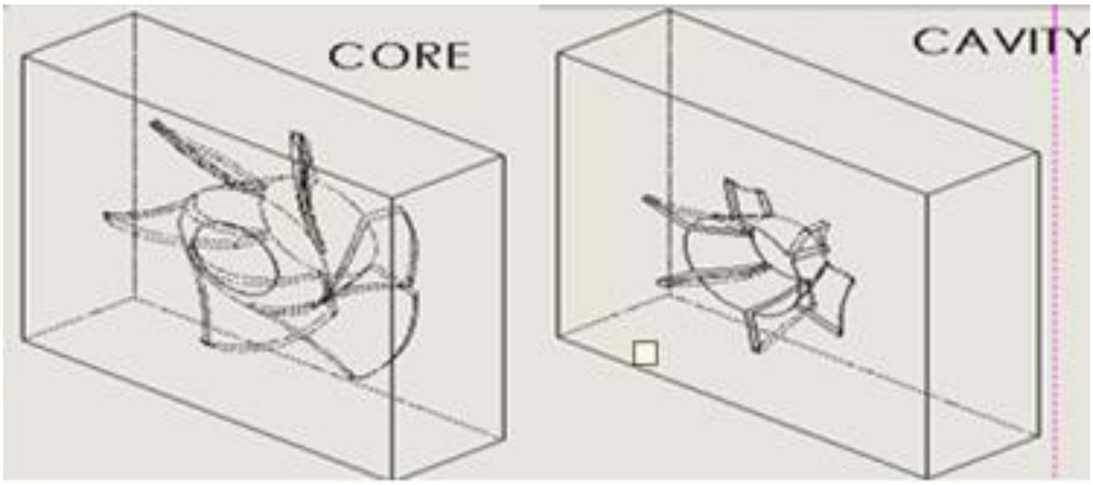


Fig. 1. Core and cavity for five-axis impeller

The MoldFlow software was used in the casting process to analyse the material flow and stages progression. At this progression, the type analysis and material have been chosen from the database software. The simulation process of involves as importing a model, meshing, setting up analysis and run the analysis as shown in Figure 2. For the material, it was chosen from software database, which is named as Acrylonitrile-Butadiene-Styrene-ABS (6230) or Polypropylene (8045) resin. Then, the type of analysis in computer simulation was selected as Flow/Filling analysis software [16].

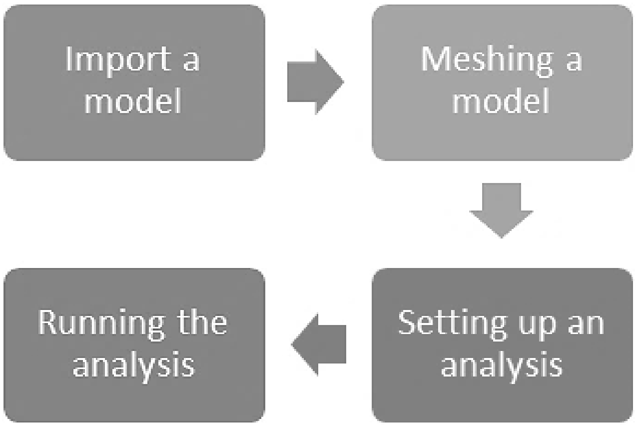


Fig. 2. Simulation process flow

An impeller model must have established first before proceed with importing a model. The model has developed by CAD software with six vanes, 103 mm for width and 45 mm for height as shown in Figure 3. This simulation also selected KLM1000A vacuum casting machine and casting parameters are set. The silicone rubber Essil 291 (produced by Axson Technologies) is chosen as mould material. The study has been focused on the following aspects: temperatures analysis, filling time, determination of the optimal casting point positions, and vent positioning.

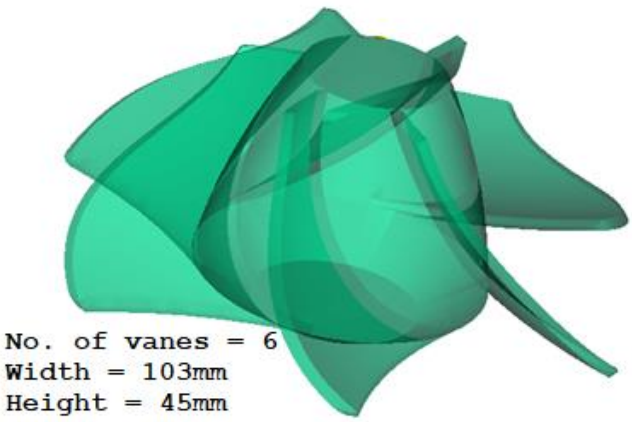


Fig. 3. Overall dimension of 5-axis impeller

For mesh element, it was necessary to be calculated for such parameters like the mesh, temperature, pressure and velocity of the flow. Representations of the whole model are the cumulative effect. There are different types of mesh available which are mid plane, dual domain mesh and 3D mesh. Once the visual inspection of the mesh density looks right then uses the mesh statistics report to determine the quality of the mesh. It is needed to be checked either is acceptable or not. If not the mesh need to repair until meshing process is successful. Many errors especially in areas of fine detail. It is due to the interface between separate surfaces that could be misinterpreted while importing or meshing a part. Figure 4 shows the successful of mashing process of impeller model. It shows that the triangular surfaces were developed nicely by meshing process.

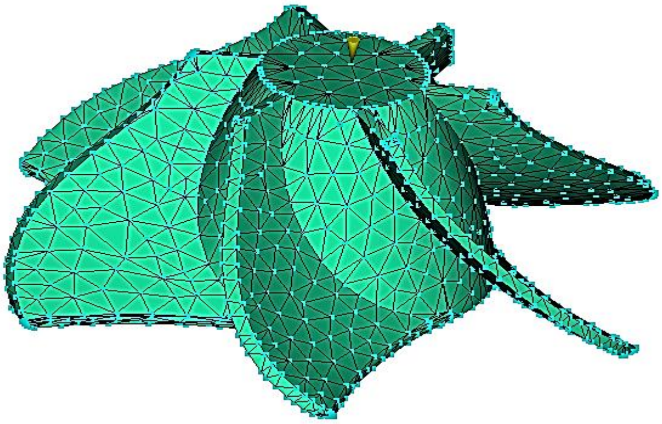


Fig. 4. Mesh of five-axis impeller

3. Results and Analysis

The observation of the marginal layer in the mould, it seems to be thicker and lower heat shear. The shear is less means the warmth had incurred. During the flow in the casting gate, the molten materials were lost the some amounts of heat. The flow becomes slow because the increment of the marginal layer thickness away from the casting funnel. Filling resistance of mould cavity might be causes by such a flow casting speed [17].

Figure 5(a) demonstrates the flow front position at standard interval during filling material into cavity. The same colour indicates the mould zone which were filled at the simultaneously by the contours represented. From the simulation the results show that the maximum flow temperature in cavity is 230.1 °C. Meanwhile, the silicone rubber mould speed and flowing mode by plastic is shown in Figure 5(b) and the value of average speed of flow is 0.142 cm/s. The orientation of macromolecules of material during the vacuum casting process was determined of physical and mechanical properties of the part are largely. By analysis the filling time of mould is 0.5210 s as shown in Figure 5(c). Obviously, the material filling at the farthest focuses from the surface of the casting keeps going the longest. Throughout the process of casting, the air inclusions could be happened due to the air bubbles accumulated through melting and mixing of material and it would not be evacuated before casting process. Converging polymer melt fronts or because it failed to escape from the hold mold vents it becomes trapped and air traps are caught inside the mold cavity. Types of defect for air bubbles will happen such as shown entrapped air will result in voids and bubbles inside the molded part, incomplete fill (short shot) or surface defect. Solving this defect, a proper position of vent is required. In this case study, resulting come up the position air trap occurred, from that position is a suitable for the vent positioning as shown in Figure 5(d).

The expected defect of shot fill was occurred on the casted part because of the lack in venting system and inappropriate viscosity of the material as shown in Figure 6.

On the other hands, it was too difficult to make a decision to determine the location of air vent and how many numbers of them should be. Whilst, by implementing the simulation by Moldflow the location and numbers of air vents can be determined easily.

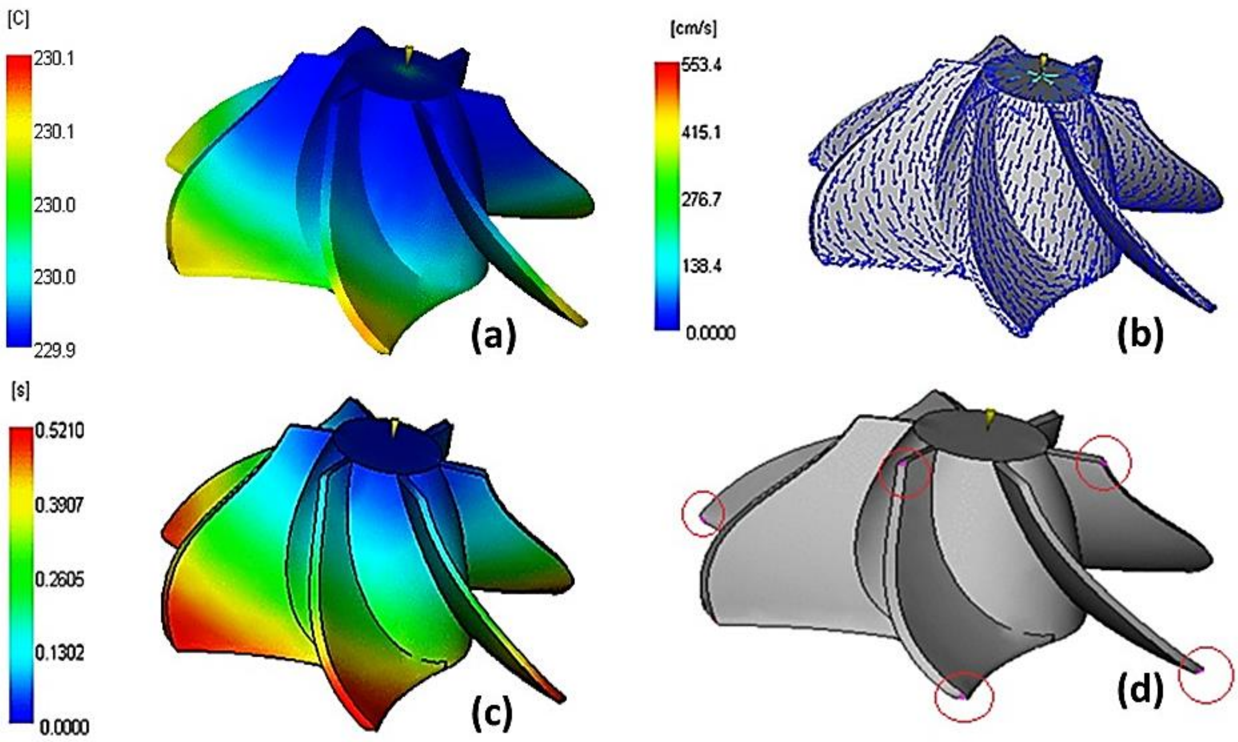
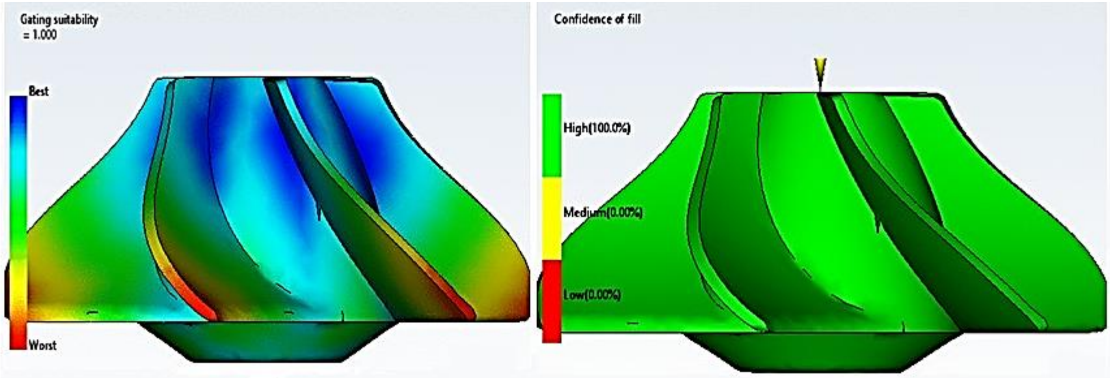


Fig. 5. Simulation results (a) temperature at flow front, (b) average of material flow, (c) filling time, and (d) air traps location

Fig. 6. Expected defect due to lack of venting system

Figure 7(a) shows the optimal casting gate should be set the position on the centre. This design is a form of circle which means that the flow of material can through simultaneously. The use of Autodesk Moldflow software is to do the flow simulation. Figure 7(b) shows the best gating position was on the centre and the worst gating position was on the side part or critical area. The best recommendation for gating system could be applied the sprue gating system. Sprue gate is defined as connecting directly and basically used for single cavity mould. Hence, for Figure 7(a), it is shows the complex part such as impeller can be filled under the vacuum casting process. Thus, the confident level to fill the molten material in the mould of five-axis impeller was the highest.



(a) (b)

Fig. 7. (a) Optimal casting position, and (b) confidence of fill plastic part

4. Conclusions

The most important outcomes of this study were to eliminate possible errors of mould design and its execution was detected by simulation of the vacuum casting. From the simulation results, it is proved that future errors can be predicted by the flow material. The results show the maximum flow temperature in cavity is 230.1 °C, 0.142 cm/s for average flow velocity and 0.5210 s for filling time. Meanwhile, the casting point location could be located at the top of the mould cavity. The application of computer software in vacuum casting process was so significant. In this study, Moldflow software was used to carry out analysis and at the same time Moldflow can help engineer to anticipate the material flow in cavity.

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