Mold Design and Casting of an Impeller Using MAGMASoft

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***Abstract*— The use of computer simulations has significantly increased in modern metal casting over the past few years. With these simulations, the prediction and minimization of casting defects has become very convenient without following the conventional trial-and-error method of metal casting. This study presents the utilization of simulation tools in predicting two important casting defects, hotspots and porosity. An aluminum impeller with a moderately complex geometry is selected for which the initial and modified casting layouts are simulated using MAGMASoft. Hotspots and porosity are predicted and minimized using simulations and the impeller is cast based on the modified casting layout with minimal defects. Simulations and experimental results are found to be in good agreement. It is concluded that a casting process can be accurately modeled using simulations together with defect prediction and minimization. Moreover, the predicted high quality of castings can be achieved if the process is done in a controlled manner while exactly matching the parameters used in simulations.**

***Index Terms*— manufacturing, metal casting, mold design, simulation, quality**

I. Introduction

Metal casting is one of the oldest method of manufacturing near net shape products. The process requires a mold cavity (normally made up of sand or metal) of the shape to be cast where molten metal is poured and solidified to get the final product. The flow of molten metal in the mold cavity is through a pouring basin followed by runner and gating system which allows its adequate supply during filling. During solidification, most metals experience shrinkage which is compensated by providing additional metal through risers or feeders. Besides gates, runners, and risers, often auxiliary components such as sleeves, chills, cores etc. are used in mold to obtain high quality products with minimum defects (sand inclusions, slag, cracks, hotspots etc.).

Casting simulations are now considered as an integral part of the process because they offer significant reduction in manufacturing cost and product development time. These simulations are viewed as a tool to shift from conventional trial-and-error approach to a proof-of-concept approach in obtaining robust mold designs for producing high quality castings. Casting defects can be accurately predicted and minimized, if not eliminated, at a much earlier stage which ensures high quality and performance of the cast part in service. The use of simulations in casting industry is not a new idea, instead, a lot of work has been done in the past to obtain high quality defect-free castings by developing an in-depth understanding of the areas such as (a) design of runner and gating systems [1]–[3] (b) design of feeding systems (locations and number of risers) [4], [5] (c) filling and solidification sequence [6]–[8] (d) casting process parameters (thermo-physical data, injection parameters, etc.) [9], [10] (e) stress distribution in cast products [11], [12] and (f) quality control and assurance of the cast products [13].

This paper is based on casting an impeller having a moderately complex geometry as shown in Fig. 1 using simulations. Since, the selected part is a rotating component subjected to very high forces during operation, it is important to minimize/eliminate any casting defects for proper functionality and a longer service life. Therefore, this study first provides the casting process simulations of impeller using MAGMASoft, where, casting defects such as hotspots and porosities are predicted and minimized. Following the casting simulations, the casting of impeller is physically done using the simulation based finalized mold design. Although, the ultimate goal is to determine the mechanical performance of impeller with minimal defects, this part of the study is focused on obtaining a nearly defect-free mold followed by its experimental validation. The details of materials, modelling and simulation in MAGMASoft, casting process, and mapping of

Manuscript received May 24, 2020; revised November 4 , 2020.

doi: 10.18178/ijmerr.9.12.1579-1583

simulation and experimental results are provided in the forthcoming sections.

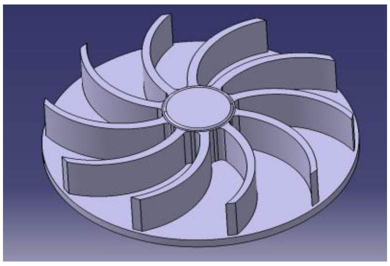

Figure 1. CAD model of impeller.

II. Materials

The selected material for impeller is an aluminum alloy ($AlCu_4TiMg$) which is widely used in general purpose castings subjected to higher loads. Also, it provides outstanding machinability and very good polishing properties. The chemical composition and mechanical properties of $AlCu_4TiMg$ are presented in Table I. The mold material used in simulations and casting process is green sand. Table II lists the properties of mold material.

TABLE I. Cast Material Specification

Chemical Composition (Wt. %)						
Si	Fe	Cu	Mn	Mg	Zn	Ti
0.15	0.15	4.2 – 5.0	0.1	0.20 - 0.35	0.07	0.15 – 0.25
Mechanical Properties						
Yield Strength (MPa)		Tensile Strength (MPa)			Elongation (%)	
180 - 220		240 - 280			5 - 15	

TABLE II. Mold Material Specification

Mold Material	Green Sand
Base Materials	Silica Sand
Binder	Bentonite
Water Content	3.50%
Initial Temperature	40 ℃
Erosion Properties	
Reference Velocity	2.25 m/s
Reference Time	4.5 sec
Sand Inclusion Parameters	
Sand grain diameter	240 µm
Sand grain density	2650 kg/m3

III. Casting Simulations

In order to simulate the casting process, a casting layout is designed based on the standards, in-house experience, and the expertise of foundrymen. Gate-runner configuration of the mold is used, however, two in-gates are provided for an adequate supply of molten metal into the mold cavity. The overall casting layout consists of pouring basin, sprue, runners, gates, castings and the risers as shown in Fig. 2. This casting layout is modeled in Solidworks which is then imported to casting simulation software MAGMASoft. MAGMASoft uses finite difference method (FDM) to solve heat and mass transfer on a rectangular grid which is reflected by the rectangular cubes on the outer side of the model. Besides the filling behavior in the mold, it also provides information about casting related features such as pre-mature solidification, air entrapment, velocity distribution, gating and runner system effectiveness etc. The fastest practicable pouring time was determined by, $t = S\sqrt{W}$, where, t is the pouring time in seconds, W is the weight of liquid metal poured, and S is the coefficient based on the casting wall thickness. The values of S are 1.63, 1.85, and 2.20 for a casting thickness range of 2.5-3.5 mm, 3.5 to 8 mm, and 8 to 15 mm respectively [14]. With a total casting weight of ~10 kg and S value of 1.85, the pouring time was found to be 5 seconds. The casting layout is discretized using a cubical mesh. The materials properties, all modes of heat transfer i.e. conduction, convection, and radiation, and solvers used in simulations are already implemented/coded in the development of the software [15]. All properties such as heat transfer coefficients, density and kinematic viscosity at temperature of the melt, sand and core material properties are based on the embedded database in MAGMASoft. The initial temperature of the melt and the mold were 720 ℃ and 20 ℃ respectively. The simulation is run for filling, solidification, and prediction of casting defects, especially, porosity and hotspots.

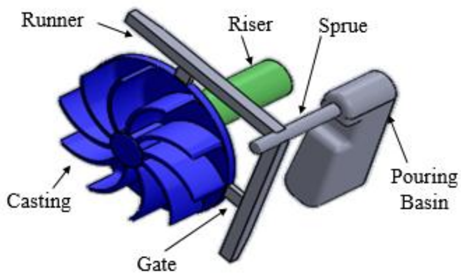

Figure 2. Isometric view of casting layout for impeller.

The initial simulation results are presented in Fig. 3. A hotspot is observed in the impeller body as shown in Fig 3 (a) and porosity is also observed in impeller body at the casting and riser junction as shown in Fig. 3 (b). Therefore, it is decided to modify the casting layout. The diameter of the riser is increased to provide more molten metal during the solidification so that the shrinkage porosities can be avoided. Also, an exothermic sleeve is added to delay the solidification in the riser which can help in shifting the hotspot from impeller body to the riser. The modified casting layout is then simulated again and the results are presented in Fig. 4. It can be observed that the hotspot is completely shifted to the riser and there is no porosity observed in the impeller body. Hence, this casting layout is finalized to prepare the mold for casting the impeller body.

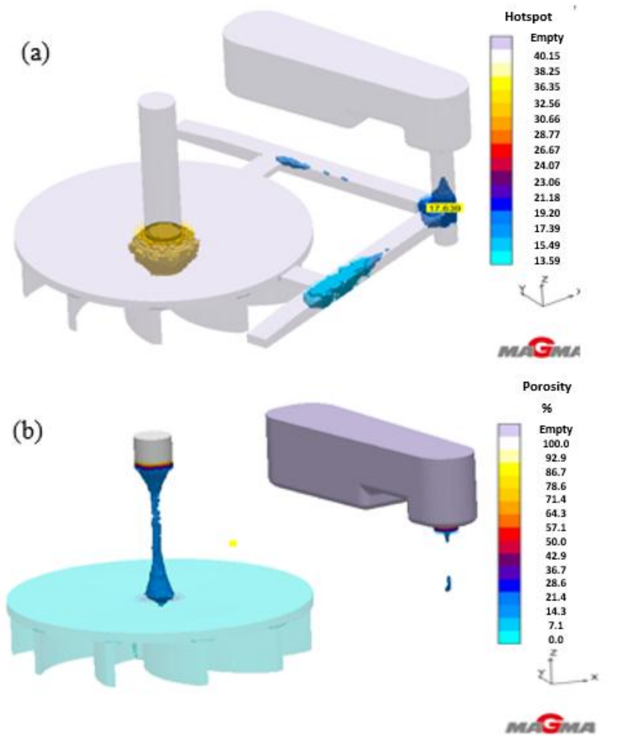

Figure 3. Initial simulation results (a) Hotspot and (b) Porosity in Impeller Body.

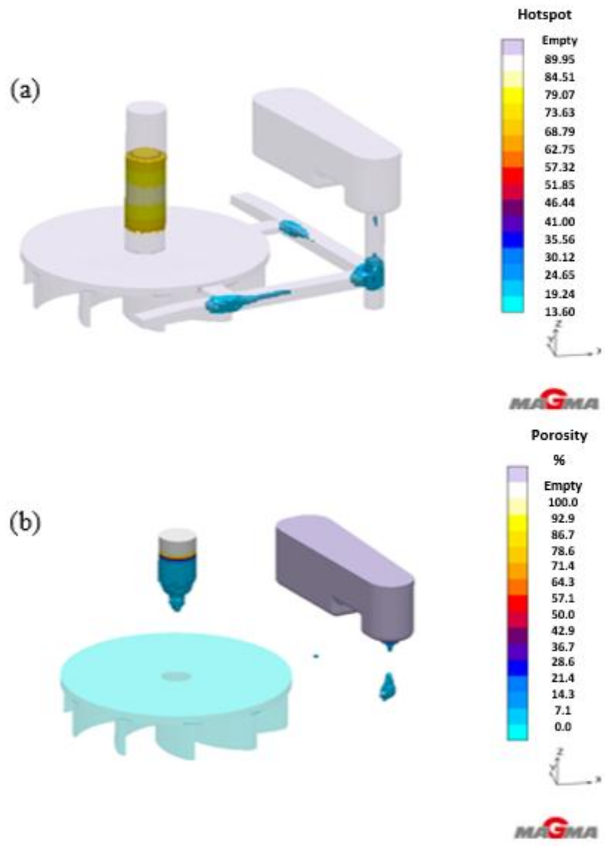

Figure 4. Simulation Results with modified casting layout (a) Hotspot and (b) Porosity.

IV. Experimental Work

A. Pattern Making

The casting of impeller began with the development of a pattern. A pattern is replica of the part to be cast which is used to create the sand mold. In this study, a wooden pattern is prepared using (computer numerical control) CNC milling process. The geometry, tool, and machining strategy are defined using (computer aided manufacturing) CAM. Fig. 5 (a) and (b) shows the profile contouring operation and the final pattern respectively. The gating and riser system for the mold are presented in Fig 6.

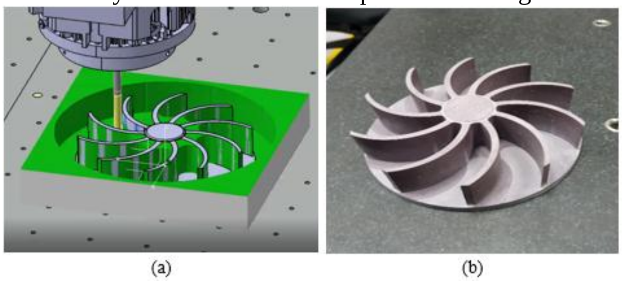

Figure 5. (a) Profile contouring using CAM and (b) Final wooden pattern

Figure 6. Gating and riser system for impeller casting

B. Mold Preparation

The mold is prepared by compacting the sand around the pattern in the flask. The entire casting and runner system is placed in the drag portion of the mold as shown in Fig. 7. An exothermic sleeve is attached around the riser as per the simulated casting layout. Zirkofluid coating is applied on mold to avoid metal penetrations and mold-metal reactions.

Figure 7. Mold for impeller casting

C. Casting and Mapping of Simulation and Experimental Results

The molten metal is prepared and poured into the mold at 720 ℃ at one of the local foundries. It is ensured that same physical condition must be maintained as per the casting simulations. Upon solidification, the cast impeller along with the gating and riser system as shown in Fig. 8 is removed from the mold. After cleaning and finishing operations, the final impeller casting obtained as shown in Fig. 9. A detailed visual examination of the final casting revealed no significant surface porosity which is in good agreement with the simulation results. This suggests the effectiveness of simulations in defect prediction followed by its minimization to produce high quality cast parts.

Figure 8. Cast Impeller with gating and riser system prior to cleaning and finishing

Figure 9. Cast Impeller after cleaning and final machining

V. Conclusions and Future Work

The study presented in this paper is focused on designing a robust mold for an aluminum impeller using MAGMASoft casting simulation software followed by its experimental validation. It is inferred that simulation tools can accurately predict the casting defects such as hotspot and porosities. Moreover, simulations can be repeated to improve the mold design and other parameters until a nearly defect free and high quality cast product is produced.

The study presented in this paper will be extended to study the microstructure of the resulting casting and to analyze the mechanical performance of the impeller with minimum casting defects under actual loading conditions using integrated simulations and experimental testing. With such developments, it is possible to analyze the cast products from mold design to failure in a virtual domain before they actually cast and put into practice.

Acknowledgements

MAGMASoft simulations are done at Rapid Prototyping and Reverse Engineering Lab at KFUPM. The authors would like to acknowledge the support provided by MAGMA in this work. The authors are also thankful to PMU for supporting this research.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Muhammad A. A. Khan conducted the research, simulation and experimental work. Anwar K. Sheikh supervised the research. All authors contributed in writing, reviewing, and approval of the final version.

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