Mould design optimisation by FEM

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Abstract. Production can be briefly defined as creating something new as a result of effort. There are many different production methods. With the industrial revolutions, the number of these methods has increased, and these methods have developed. Over time, heavy and laborious work that people had to do began to be done by machines. The casting method, which is one of the most common production methods in the world, is to pour the molten metal or its alloy into a mould cavity suitable for the shape of the desired product and remove it from the mould after it solidifies. In this study, firstly, the manufacturing method by casting was mentioned, and the difficulties of mould design in the casting method were explained. Secondly, the benefits of computer-aided simulation programs for casting are explained. As an example, a model was designed and different runners were added to this model. These models, which were prepared afterwards, were cast in a virtual environment with the FLOW-3D CAST program, which is a simulation program. Casting results and casting defects after these castings were compared and interpreted. The results show that it is important for the casting quality to keep the runner diameters as small as possible in runner designs. Two or three times more air voids are formed in the sand mould casting method compared to the permanent mould casting. Additionally, it was observed that the casting material had less shrinkage in the sand mould casting method. It is concluded that sand mould casting is disadvantageous in terms of the parameter of time.

1. Introduction
The casting method is one of the oldest manufacturing methods and involves a gradual process. The first step in these processes is the model geometry design and the selection of the engineering alloy that will provide the required material properties. Although the material selection from these stages is not directly related to the foundry, the main task of the foundry is to control the process from filling the mould cavity with the determined alloy to the completion of solidification and to manufacture solid parts. To obtain a solid casting with the desired properties, several conditions have to be fulfilled, such as selection of suitable casting method, mould design according to the chosen method, preparation of moulds and cores, determination of their properties and control, preparation of the desired alloy, selection of the appropriate melting unit, performing the necessary processes for melting, ensuring that the liquid metal enters the mould in a proper and fluidity and control of nucleation, solidification and hence casting structure are the main parameters. Casting provides an economic advantage for various types of metals and alloys. It has high machinability and resistance to vibration in cast iron. In the case of some light metal alloys, strength and lightness may be only achieved by casting. Better properties to wear can be achieved through metal casting.

Usage of the numerical approach for engineering problems has become widespread with the development of computers. The finite element method is used to solve various problems in engineering
by using FEM software packages. Numerical simulation of solidification facilitates obtaining high-quality castings and minimising product cost and scrap [1–4]. FEM-based software for solving casting problems has high computational capabilities for low operating costs, and advances in simulation methodology have made simulation the most widely used and accepted method in operations research and systems analysis. Rodriguez-Gonzalez et.al. [5–7] used a comparative study for investigating the aluminium alloys casting. [8] The conditions under which simulation should be used have been studied by various authors. Pradhan et.al. reviewed the studies on the effect of the runner system on the mechanical strength of aluminium alloys. Bouzakis et. al. [9] proposed an analytical–experimental method that was introduced to acquire such properties as a function of temperature and flow velocity. Venkatesan et. al. [10] developed a program for finite element modelling of casting solidification. [11] Dou et. al examined the FEM model by using parallel computing techniques to investigate the fluid flow, heat transfer, solidification and defect formation behaviours under different casting conditions. Kabnure [12] used FEM software for the prediction of the location and level of shrinkage. Verma [13] studied the cooling characteristics of LM6 alloy used as a pouring material for manufacturing of thin hollow rectangular section during the solidification process inside the mould by using FEM based software [14]. Briefly, the FEM method is getting attention for solving casting method’s problems and for bringing quality for casting product [15,16].

In this study, nine different models were designed according to runner angles and diameters. The runner angles were selected as 45°, 60°, 90° and the runner diameters were designed as 20mm, 30mm and 40mm. The models were simulated and then analysed by using the “Flow-3D Cast” program for both “continuous casting” and “sand mould casting” methods. The simulation results were compared according to the runner angles and the defects encountered. This study aims to investigate the effect of runner angle and runner diameter on the solidification behaviour and void particles changes of permanent mould casting and sand casting processes.

2. Materials and methods

2.1. Models

The nine different CAD models of different runner angles and diameters were built for the investigation of their effects for two different casting methods. The model consists of the same product the same spherical shape with 80mm for all die variations. The casting model combination is given in Figure 1. The main parameters are chosen as runner angle and runner diameter. The diameter of the runner is represented as “d” and the runner angle as “α” in the study. The FEM study was carried out by using FEM based software named “Flow-3d Cast”. Two different casting method was chosen as the main processes which are sand casting and permanent mould casting. In the FEM study, the casting material was selected as Al-LM4 (A319), process time was selected as 20 seconds, H13 type (DIN1.2344 / X40CrMoV5-1) tool steel has been selected as a material for all mould types; whereas Sand Silica was used for sand casting.

2.2. Analysis of pouring liquid metal and solidification

Solidification, which is the process of transformation of the liquid metal filling inside the mould cavity into a solid-state, begins with the nucleation of atoms in the liquid metal by bonding to form a crystal lattice structure. The kernels that can reach critical size grow larger and form the grains, and with grain growth, the grains contact with each other and form the grain boundaries. Since the solid phase is denser than the liquid phase, shrinkage occurs because the volume of the liquid metal will decrease as it solidifies. Shrinkage can affect the dimensional accuracy and cause defects in the part. Especially in the middle of thick sections, shrinkage gaps may occur due to shrinkage. In this study, solidification analyses were also carried out after casting analyses, and all results were compared for two different casting methods.
3. Results and discussion

3.1. Void particles for permanent mould casting
The void particles obtained from the FEM study was given in Figure 2. It has been observed that as the runner angles increase, the formation of air gaps decrease. However, it was observed that the air gaps occurrence increased as the runner diameters increased.

Figure 1. View of model combination for different die parameters.

Figure 2. FEM results for void particles of permanent mould casting.
3.2. Void particles for sand casting
It has been observed that the formation of air gaps decreases as the runner diameters increase in sand mould casting, figure 3. However, as the runner diameters increased, the occurrence of air gaps has also increased. The results show that higher runner angle and smaller runner diameter give the suitable casting product for the sand casting method. Additionally, sand casting method products have fewer flaws comparing to permanent mould casting.

3.3. Solidification analysis of permanent mould casting
The representation of all models in the last phase of solidification after casting with the permanent mould casting method is shown in Figure 4. It was observed that the solidification time is shorter when the runner angle is 90°. Additionally, it can also be seen from the figure that a higher runner angle causes a better solidification phase for permanent mould casting.

3.4. Solidification analysis of sand casting
The figures of all models in the last stage of casting were given in Figure 5. As can be seen from the figure, the solidification time in the sand-casting method takes more time compared to the permanent mould casting. The solidification trend is similar to the permanent mould casting but in sand-casting, the solidification time is considerably higher compared to permanent mould casting.

4. Conclusions
According to the results obtained from the analyses, it was observed that the formation of air gaps increased when the runner angles and runner diameters increased. From this result, it can be concluded that it is important for the casting quality to keep the runner diameters as small as possible in runner designs. It has been observed that approximately two or three times more air voids are formed in the sand mould casting method compared to the permanent mould casting. Additionally, it can be concluded that the permanent mould casting method is more suitable for obtaining quality casting. When the solidification analysis was examined, it has been observed that the solidification times are much longer in the sand mould casting method. At the same time, it was observed that the casting material had less shrinkage in the sand mould casting method. From this, it is concluded that sand mould casting is disadvantageous in terms of time.

![Figure 3. FEM results for void particles of sand casting.](image-url)
Figure 4. FEM results for solidification of permanent mould casting.

Figure 5. FEM results for solidification of sand casting.
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