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Filling and Solidification Simulation of Aluminium Casting Process

Suttipong Jumroonrut Sasithon Pitakthapanaphong*
Department of Production Engineering, Faculty of Engineering
King Mongkut's Institute of Technology North Bangkok
1518 Pibulsongkram Road Bangkok 10800
*E-mail: sstp@kmitnb.ac.th

Abstract
Aluminium casting is one of the key manufacturing processes used in various products, especially in automotive industries. The process consists of filling and solidification of molten materials. This work investigates the casting of aluminium via finite difference simulation. A model representing an automotive part is developed. The filling and simulation of aluminium through different designs of moulds and gating system are studied. Temperature distribution, material flow and casting defects development within the work piece are examined. Results are in agreement with trends found from industry. Suggestions on improving the manufacture of cast products are made.

Keywords: Aluminium, Casting, Filling, Solidification, Finite Difference.

1. Introduction

The casting of metals is a complex and common process in industry. The complexity is due to the fact that it involves, at the simplest level, thermal and mechanical phenomena. The thermal phenomenon deals with metal solidification, where different phase changes are produced by the different cooling conditions. The mechanical phenomenon is promoted by the large thermal stresses and the solidification shrinkage [1]. Moreover, all these phenomena are deeply related with the physical properties of the materials.

Casting process consists primarily of the flow of the molten metal into the mould cavity, the solidification and cooling of the metal in the mould and the influence of the type of mould materials. During the process, the materials are subjected to temperature change, which greatly affects their microstructure and composition. Phase changes take place and the significant factors affecting the changes are the type of metal, the thermal properties of both the metal and the mould, the geometric relationship between volume and surface area of the casting and the shape of the mould.

Aluminium and Al-alloys are widely used in applications where weight is of prime concern. This is due to their high strength to weight ratio [2]. In addition they possess high resistance to corrosion by many chemicals, high thermal and electrical conductivity as well as their ease of formability. They can also be easily cast where their strength can be retained. However, the existing of defects within the cast part can reduce their strength substantially and hence undesirable. As a result, extensive efforts are made to improve the casting process to avoid or minimise manufacturing-related defects.

Several numerical studies attempted to investigate the behaviour of aluminium during casting have been published [3-5]. Numerical formulations as well as finite element and finite difference methods have been proposed and used with the aim to understand and be able to model the casting process. Others studied the filling process including the design of moulds and runner systems to optimise the filling of molten aluminium [6-7], the solidification process during casting [8-9], the formation of porosity inside the cast part [10] for instance. Overall the research in this field covers all aspects of casting processes from the start to finished products as well as the properties of the cast materials. With better understanding of the parameters involved in the process and how they influence the quality of the cast parts, more successful manufacturing can be achieved.

This work studies the filling and solidification processes of an aluminium cast product via simulation method with the aid of a commercially available software [11]. Different designs of gating systems are used and the flow of materials and the temperature distribution during filling and defects development during solidification are investigated. Suggestions on the design based on the findings are made.

2. Aluminium casting models

The cast product, which is the center of the study here is a part used widely in automotive industry. Its configuration is shown in Figure 1.

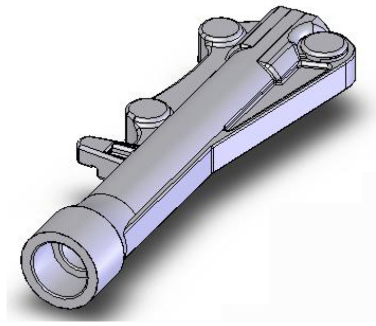


Figure 1. Configuration of the cast product investigated in this work.

Since the quality of the cast product strongly depends on the filling and solidification of the metals which depends greatly on the design of the gating system, three different gating systems are examined in this work. The preliminary designs of the gating system including the shape and sizes of components such as sprue, gate and riser are based on the guidelines given by [12]. They are, if applicable, to have the same dimensions among the three designs. These are shown in Figure 2. All designs allow the molten aluminium to enter the mould through the gate located at the side of the cast. The first design (A) contains no riser when compared to design B. The design C rotates the cast by 180 degree so it is up side down compared to designs A.

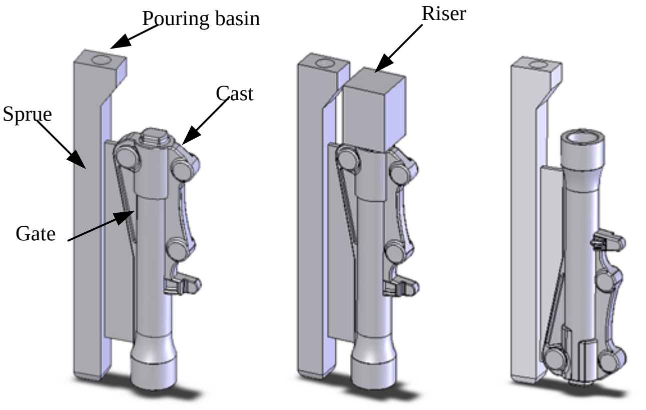


Figure 2. The three designs of the gating system examined in this work.

The aluminium used is the cast aluminium A355 at the pouring temperature of 700°C. The mould, made of white iron, is heated and kept at 350°C. Filling time is chosen to be approximately 7 seconds for all designs, These parameters are chosen so that the simulation represents as close as possible to the actual casting carried out in industry.

3. Filling simulation

The filling simulation starts by the pouring of molten aluminium into the pouring basin and finishes when all the parts involved are filled up. The flow of the aluminium and the temperature distribution of all three designs at different intervals are shown in Figures 3-5.

It can be seen from Figure 3 that aluminium enters the mould with little turbulence (stage (2)). The temperature of the aluminium inside the sprue is generally lower than the rest. The aluminium near the gate sustains highest temperature due to the continuous influx of the molten aluminium. The cast is filled up vertically upwards. The temperatures of the thick and thin section of the cast (labelled A and B, respectively) are similar at the end of the filling process.

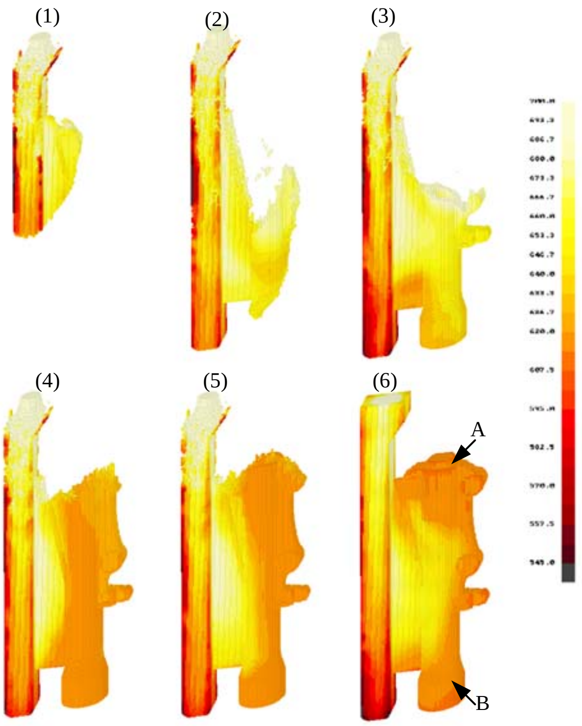


Figure 3. The flow and the temperature distribution of aluminium during filling of casting design A

Figures 4 and 5 show somewhat similar trend of the temperature distribution during the filling. Small turbulence in the aluminium flow is observed. This is partly due to the fact that filling is done in a vertical position. No significant temperature difference between the thick and the thin sections of the cast exist.

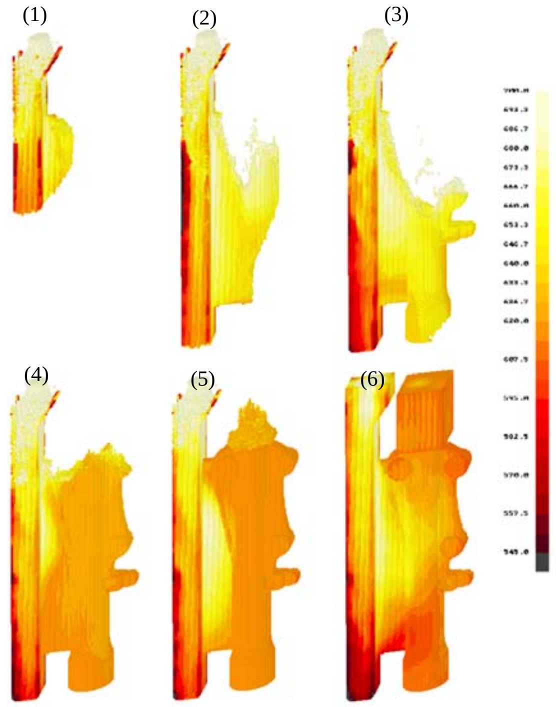


Figure 4. The flow and the temperature distribution of aluminium during filling of casting design B

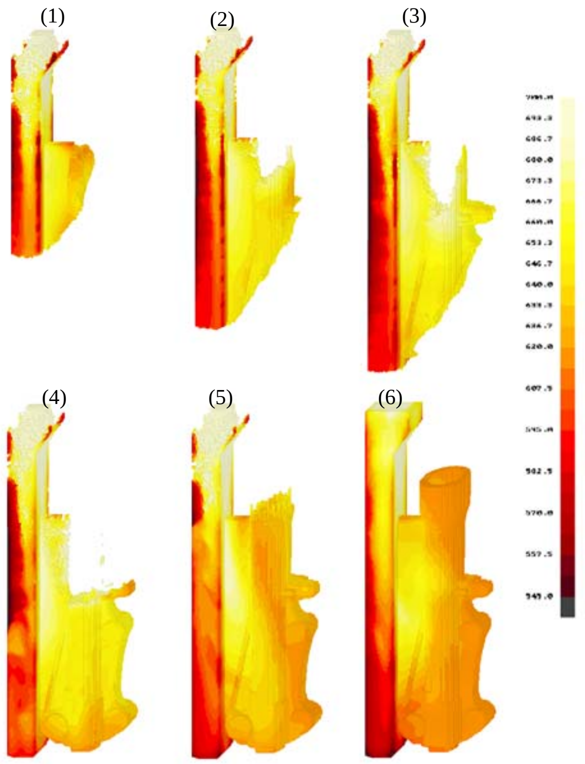


Figure 5. The flow and the temperature distribution of aluminium during filling of casting design B

4. Solidification simulation

Once the mould is filled up, solidification starts. The time taken for the solidification to complete varies from one design to another. In design A, B and C, it takes approximately 113, 201 and 98 seconds, respectively, for the models to completely solidified. The longer time taken for design B is due to its higher volume as a result of the additional riser.

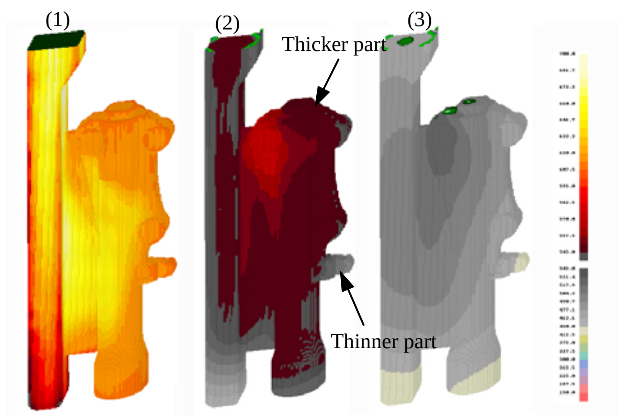


Figure 6. Temperature distribution of aluminium during solidification of casting design A

Figure 6 shows the temperature distribution of the design A at different stages during solidification. It can be seen that cooling down and hence solidification starts from the lower part of the cast where it is thinner and spreads upwards. The thinner parts tend to cool down first, due to its high surface to volume ratio. The thickest part, which is at the top, solidifies last, leaving shrinkage, which is discussed in details later.

Figure 7 shows the solidification stages of design B. It is shown that the additional riser sustains higher temperature compared to the rest of the cast. This is advantageous in the way that the riser will be cooled down last. In design C, the cool down starts from the top part which is thin and spread downwards to the thick section as shown in Figure 8.

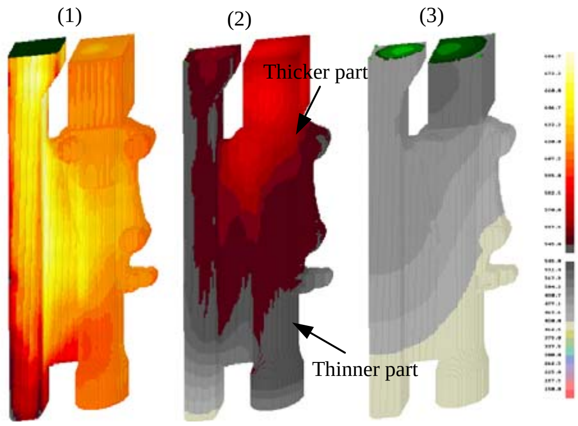


Figure 7. Temperature distribution of aluminium during solidification of casting design A

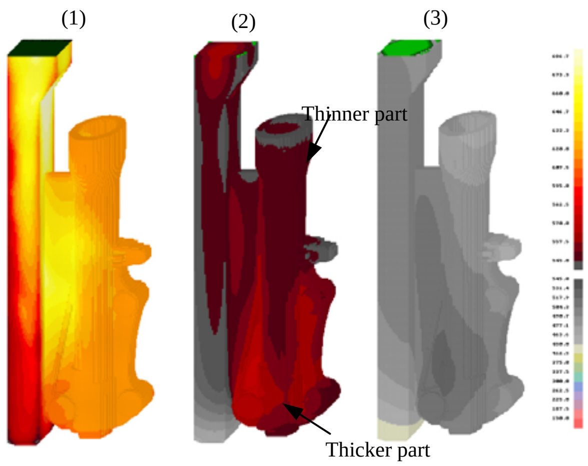
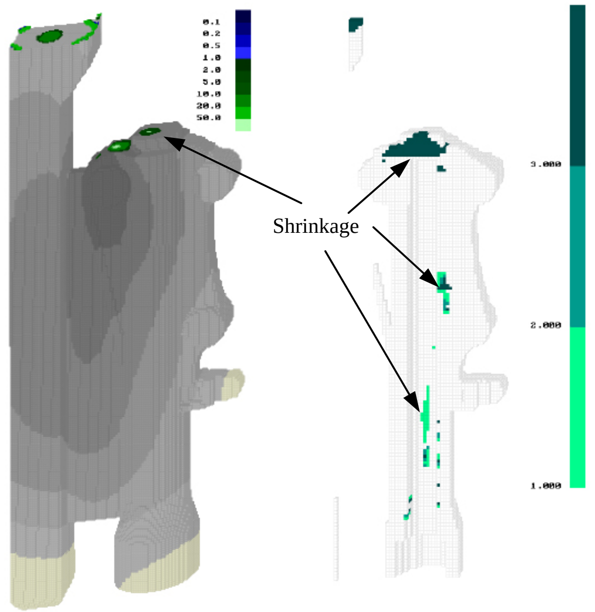


Figure 8. Temperature distribution of aluminium during solidification of casting design A

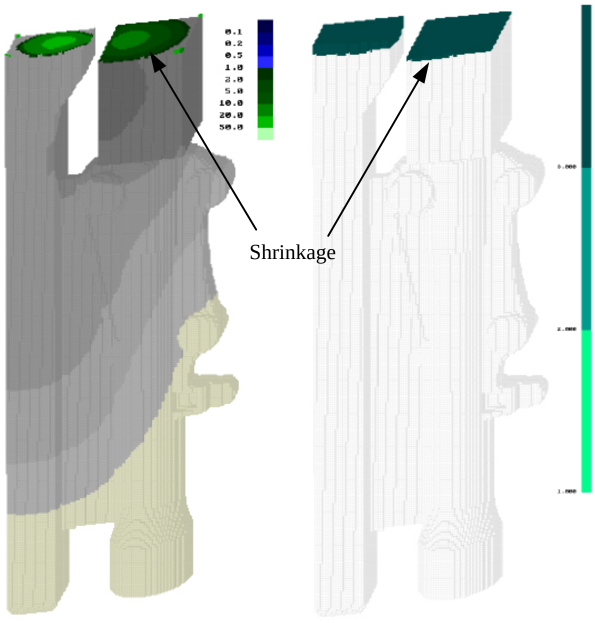
After the cast is completely solidified, defects such as shrinkage can be seen. Figure 9 shows the surface and internal shrinkage expected in design A. It is found in the thick section at the top of the cast where the molten aluminium is drawn to other parts while cooling takes place. Also some shrinkage can be seen by taking the cross-section view of the cast as shown in Figure 9(b). This shrinkage is undesirable since it can reduce the strength of the cast.

In contrast to design A, by using the riser as in design B, the shrinkage can be controlled and contained within the riser (Figure 10). Since the riser cools down last, the molten aluminium within the riser can be drawn to the cast while solidification occurs. In design C, no surface shrinkage is seen in the cast (Figure 11(a)). All the shrinkage takes place inside the cast as shown in the cross-section view (Figure 11(b)).



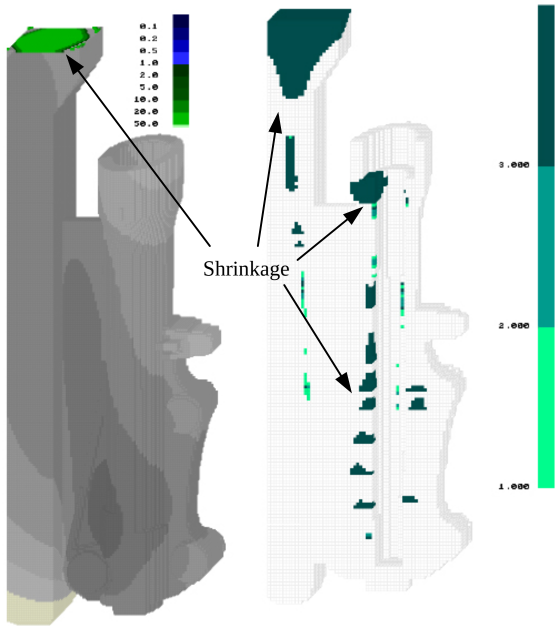
(a) (b)

Figure 9. Shrinkage development in casting design A



(a) (b)

Figure 10. Shrinkage development in casting design B



(a) (b)

Figure 11. Shrinkage development in casting design C

5. Conclusions

This work investigates the casting process of an aluminium automotive part via simulation method. Three different designs of gating system are studied. It is found that the design of the gating system has strong effects on the filling behaviour of the molten aluminium and the solidification process, hence the quality of the cast product. By using the riser, the undesirable defects such as shrinkage can be controlled, leaving the cast defect-free and maintaining its strength. These findings can be used as guidelines in designing the casting process parameters in industry.

Acknowledgments

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