# Design and analysis of various cooling conditions of an aluminium wheel mold

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During low pressure casting of aluminum alloy wheels, the cooling conditions affect the mechanical properties directly. Cooling of wheel mold is conducted by an air, water, or mist cooling system. These coolants flow in the cooling channels within the mold to reduce temperature of mold to obtain directional solidification. During the solidification of aluminum alloy wheels, directional solidification starts on outer flange area, continues toward inner flange area, and finishes on spoke and hub areas. Directional solidification helps to reduce risk of material defects in the wheel. One way to ensure directional solidification is modelling cooling channel geometries with a CAD program and then analyzing the cooling effects by a casting simulation software. The aim of this study is to develop a complex design with an amorph cooling channel to obtain a high surface area, hence a higher cooling performance while also keeping the producibility in focus. A 'complexity in design' and 'producibility' are contrary terms in traditional manufacturing methods, on the other hand, non-traditional manufacturing methods such as additive manufacturing can be used to obtain geometrical complexity and together with producibility. In this study, different cooling geometries were modelled and then analyzed. During design iterations, various cooling channels with higher surface areas were considered. After casting simulation, temperature in pre-selected areas, UTS (Ultimate Tensile Strength), YS (Yield Strength) and Elongation (ε%) values of simulated wheels are obtained, and designs are compared.

**KEYWORDS:** ALUMINUM ALLOY WHEELS, CASTING SIMULATION, COOLING CHANNELS, LPDC, MOLD;

## INTRODUCTION

It is common to find aluminum alloys used in many industries due to their lightweight and castability. Automotive and aviation industries are common users of aluminum alloys. With the help of aluminum alloys have the obvious advantage of being easy to cast, various casting techniques have developed for the purpose of improving the soundness and productivity of the outputs and continue to be developed [1]. There are many examples of product such as automobile wheels that manufactured by casting. Automobile wheels can be produced by low pressure die casting technique (LPDC). Since the LPDC technique is profitable if large number of productions will be made. On the other hand, permanent molds can be used in low pressure die casting and it provides relatively fast cooling with the help of cooling channels (cooling circuits). Heat is transferred from the cast metal to the die and ultimately to the environment in that process [2,3].

The cooling stage is significantly important for casting products. If it can be controlled, it would alter the microstructure of the product in a better way. So, the cooling directly influence the mechanical properties. Higher cooling rates can help the modifying eutectic silicon into fibrous

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branched morphology and determine the porosity size in A356 alloys. It allows even large castings to solidify quickly, thereby reducing grain segregation and improving grain refinement. It also provides lower cycle times. However, it is not always easy to increase cooling rate. The cooling rate can be changed by coolant, cooling channel design, mold material, etc. and for the purpose of enhancing a best possible quality, everything must be optimized [4,5,6]. In a case the only variable is coolant, even only cooling channel design and coolant (water and air usually used) could significantly alter the cooling rate. Also, water as a coolant provides better cooling efficiency comparing the air in that case [7].

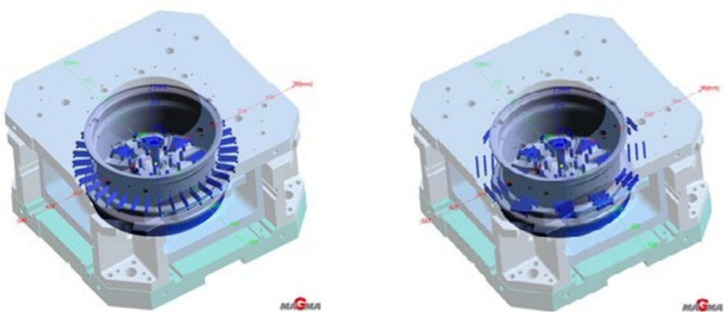
Considering the advantage of calculation times with developing computer technology, numerical simulation technology becomes playing a crucial role in optimizing those cooling parameters. To improve the performance of aluminum alloy LPDC wheels, computer simulation is widely used. Using numerical simulation, the results indicate that casting filling parameters are optimized, and the evolutionary process of casting filling predicted in the study of Zhang L. et al. [8]. The number of cooling inlets and outlets and the pressure of the cooling channel can affect the flow rate in LPDC. The affect can be seen by using computational fluid dynamics software [9]. The software also helps to spot the areas that have possibly casting defects like porosity and give an opportunity to understand defect formation with different casting scenarios. Thus, it could be possible to optimize the parameters in a short time to obtain an almost defect-free casting [10,11,12]. In addition, due to the nature of heat transfer, the change in wall thickness also affects the cooling efficiency. It causes different mechanical properties on different parts of the product. This affair must be considered while cooling channels are designed. The increase in the surface area of the cooling channels can provide a more effective cooling. The purpose is to direct conduction heat transfer away from the molten metal and to solidify it as rapidly as possible. It is difficult to carry out conduction cooling on targeted areas during this process since the solidifying molten metal naturally shrinks away from the mold. In many products like an automobile wheel, directional solidification cannot take place naturally because of its complex geometry with different parts such as the hub, spokes, and the rim. Therefore, it can be controlled by a cooling channel [13]. Numerical and experimental studies were made in recent years and thanks to these studies important results have been achieved. In addition to the geometry and mass flow rate, the cooling water temperature and flow rate are also factoring that influence the quality of the formed region according to some studies [14]. Using different mold materials can change the mold temperature as well as cooling conditions [15].

In this study, the automobile wheel was produced by low pressure die casting using a numerical simulation. To notice the effect of cooling channel design in the solidification stage, four different cooling channels were designed. Then, these designs were defined in the numerical software. Also, air and water as a coolant were used for observing a difference for each design.

## EXPERIMENTAL

The experimental study started with the designing new cooling channels. Four different cooling channels were drawn by using CATIA V5 as seen in Fig. 1. Then, defined geometric model of the automobile wheel and its mold parts were imported into the Magmasoft commercial casting software. After choosing the AlSi7Mg0.3 alloy and H13 steel for die casting as material data from the Magma database, each design was run with choosing the coolant data water and air. Eventually, in the result section, these 8 cases compared with each other.

**Design 1** **Design 2**



**Design 3** **Design 4**

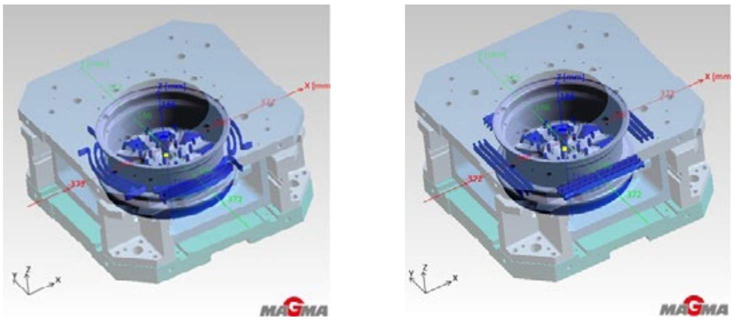
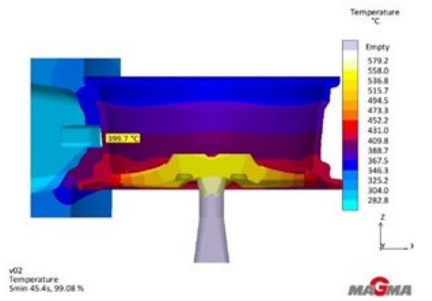
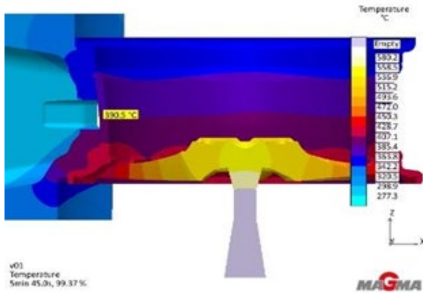
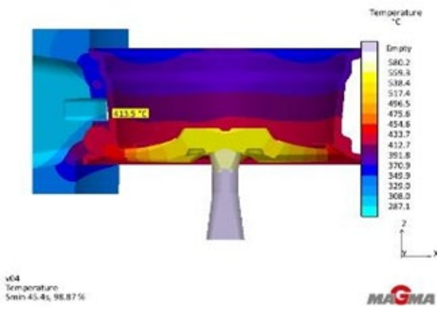
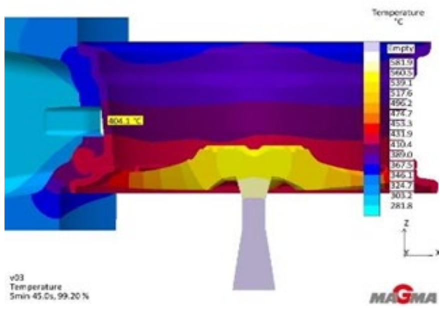
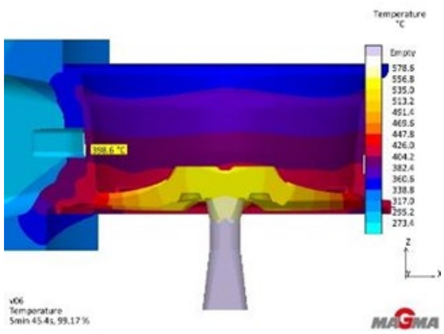
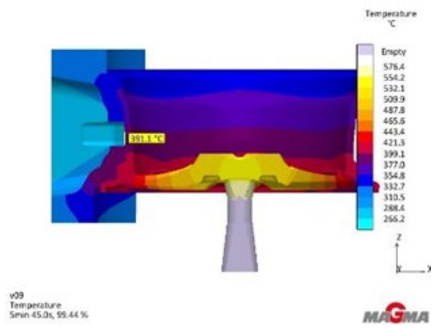
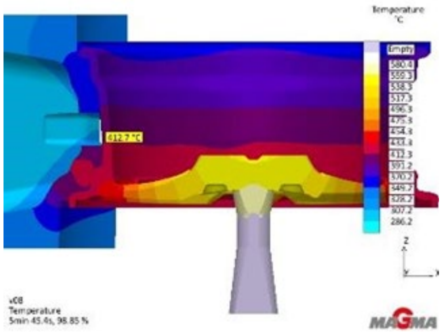
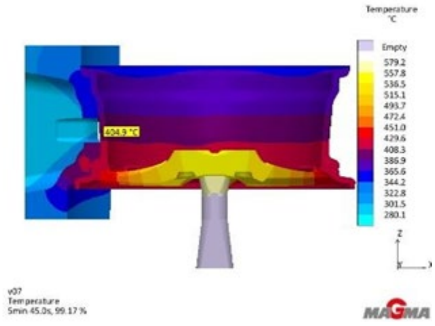


**Fig.1** - Four different cooling channel designs.

**Tab.1** - Comparison of designs with different coolants.

RESULTS

| COOLANT<br>DESIGN | AIR | WATER |
|---|---|---|
| **Design 1** | <br>(399.7°C) | <br>(390.5°C) |
| **Design 2** | <br>(413.5°C) | <br>(404.1°C) |
| **Design 3** | <br>(398.6°C) | <br>(391.1°C) |

| | | |
|---|---|---|
| Design 4 | <br>(412.7°C) | <br>(404.9°C) |

## CONCLUSIONS

Mechanical properties like UTS (Ultimate Tensile Strength), YS (Yield Strength), and elongation (ε%) values of simulated wheels were obtained as well as temperature (°C) values for each design.

**Tab.2** - Mechanical properties of all designs.

| COOLANT | WATER | | | | AIR | | | |
|---|---|---|---|---|---|---|---|---|
| **Design** | #1 | #2 | #3 | #4 | #1 | #2 | #3 | #4 |
| **Temperature [°C]** | 390.5 | 404.1 | 391.1 | 404.9 | 399.7 | 413.5 | 398.6 | 412.7 |
| **YS [MPa] (Yield Strength)** | 102.93 | 101.72 | 101.87 | 101.69 | 101.63 | 101.15 | 101.54 | 101.21 |
| **UTS [MPa] (Ultimate Tensile Strength)** | 187.85 | 180.67 | 181.50 | 180.51 | 180.16 | 177.57 | 179.66 | 177.88 |
| **Elongation [%]** | 5.67 | 5.23 | 5.28 | 5.22 | 5.19 | 5.04 | 5.16 | 5.06 |

Water is a better option to cool a mold faster for each design as expected. Design 1 and design 3 are more effective coolant than design 4 and design 2. UTS is the most affected feature compared to the YS and Elongation for each case.

The best UTS, YS, and Elongation value achieved in design 1 water cooling case (187.85 MPa, 102.93 MPa, 5.67%).

But generally, it was observed that YS and elongation values were not affected by designs and coolants like UTS values.

The range of YS values differed between 100 MPa and 103 MPa for each case and the range of Elongation values were almost 5% and 6%.

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