Quality Control Study on High Pressure Casting Based on Magma and Ultra-red Simulation

TANG Jianmin¹,3,*, WU Laijie²,b, LIU Haijun¹, c, LI Bo¹, d, ZENG Dejun³, e

¹Neijiang Vocational & Technical College, Neijiang, Sichuan China
²China University of Geosciences, Wuhan, Hubei, China
³Chongqing Creation Vocational College, Yongchuan, Chongqing, China
⁰email: 1054164659@qq.com, bemail: 1039298796@qq.com, cemail: 978155017@qq.com, demail: 1017713164@qq.com, eemail: 18875014819@qq.com,
*Corresponding author: 1054164659@qq.com

Abstract: The temperature control of high-pressure die casting mold is one difficult problem in die industry. The inner quality of product is greatly affected by mold temperature. Taking the automobile gearbox parts as an example, by the combination of waterproof thermocouple and TP700-16/TP700-40 multi-channel temperature tester, one set of device for monitoring mold real-time temperature is developed. The high pressure casting die and mold temperature field simulation are carried out using Magma software. By simulating analysis and reducing process parameter interval of Magma, the ideal mold temperature is obtained and the quality problem of die casting is solved after the simulation parameters are copied to the die casting machine. The practical results show that the instability of die casting is decreased, the time cost of die casting is decreased by increasing die casting Overall Equipment Effectiveness (OEE), the risk of personal accident is reduced and the product scrap rate can be effectively reduced. Finally, the future research directions are pointed out.

1. Introduction
The shell structure of automobile transmission is complex. The higher waste rate or up to 30% may result because the mold temperature can not be accurately detected and controlled during high pressure casting, which the normal production and economic benefits of enterprises are seriously affected. Therefore, the common concern of enterprises and researchers is to fully grasp the change effect of the temperature field of the transmission box in order to reduce the rejection rate. The automobile gearbox model is constructed by UG software and carried into the Magma software to simulate the analysis.

1.1. Research status of the temperature influence on die casting
The mold preheating temperature, punching speed and time on the forming process were researched. The results show that the main reasons of caused casting defects are the mold preheating temperature, metal flow rate and metal pouring temperature. Zhang, al.¹¹ calculated and compared the effects of pouring temperature and mold preheating temperature on the temperature field of magnesium alloy, aluminum alloy die casting and die casting mold, the distribution of temperature field of die casting magnesium alloy was obtained. Han, al.¹² studied the distribution of thermal stress field of die casting die for aluminum alloy based on ProCast. Zeng, al.¹³ carried out the numerical simulation of die casting process of A356 aluminum alloy based on ADINA. Yu , al.
According to the domestic and foreign research on high pressure casting, most of the scholars have already put forward the importance of temperature control on the casting process, but the corresponding temperature measuring device has not proposed. The automobile gear box shell is shown in Fig. 1.

![Figure 1: Solid pictures of automobile gear box](image)

1.2. Research status of the temperature measuring system

According to the temperature distribution characteristics of the mixing speed and stirring time about the pharmaceutical processing, Jin [4] designed the temperature monitoring system and control system based on infrared temperature sensor. Wang [5] studied the fiber-optical temperature and displacement measurement system, and the changes of temperature and displacement were monitored by using the precise instrument. If the temperature and displacement exceed the normal operating range, the alarm can be issued immediately.

We can know from above mentioned, the method of infrared temperature measurement and microwave temperature measurement are usually adopted for the real-time monitoring system. These two methods can only measure the surface temperature and the supporting role of temperature measuring surface cannot be formed. These systems are difficult to be used in high pressure casting system. Therefore, it is very important to study the real-time temperature measurement system of high pressure casting in order to solve the problem of temperature control.

2. Mold design

2.1. Main instruments of the temperature control

The installation positions of thermocouples are processed in the corresponding parts of the mold, and the distance between the thermocouple temperature measuring point and the mold surface is 25 mm (the mold erosion strength can be ensured) and are contacted with the mold without clearance. The thermocouples are connected to the TP700-16/TP700-40 multi-channel temperature tester through the sensing line and the temperature data are stored. There are two displaying ways for the device. The first one is digital display, which the temperature can be visually shown in seconds. The second one is curve display, which can be combined with the movement of the mold and the temperature of certain state for die casting is visually expressed. Some of the equipment used in the experiment is shown in Fig 2 and Fig 3.

![Figure 2: Thermocouple probe, sensor temperature tester](image)

![Figure 3: TP700-16/TP700-40 multi-channel](image)
2.2. Setting die cavity working condition

The initial process parameters for testing are as follows:

- Die casting model: LK3000 T
- Punch diameter: 140mm
- Die number: 40#
- Mold material: DIACER
- Cup length: 1017
- Product material: A380
- Product weight: 11.36 kg
- System weight: 6.2 kg
- Punch stroke: 985 mm
- Cake thickness: 35~45 mm
- Average wall thickness: 3.5 mm
- Slow speed: 0.20 m/s
- Quick start position: 600 mm
- Fast speed: 5.5 m/s
- Boost start position: 700 mm
- Die casting aluminum liquid temperature: 660±10 ℃
- Casting pressure: 700 bar
- Simulation material: AlSi9Cu3
- Punch stroke: 985 mm
- Vacuum degree: 145 mbar
- Simulated aluminum liquid temperature: 650℃
- Simulated die initial temperature: 170℃
- Simulated punch initial temperature: 170℃
- Vacuum starting position: 150 mm
- Safety factor of press: 30%

The original parameters of the gearbox shell die casting are shown in Table 1. The runner and cooling arrangement is shown in Figure 4 and the blue pipe is cooling water pipe. Zhang Henghua [6] had in detail studied the process parameters of induction heating temperature field for aluminum alloy blank, these parameters include heating power, frequency, heating time, holding time and sample size, etc. and the corresponding parameter ranges are obtained. Iwata, al. [7] studied the effect of melting temperature and pouring temperature on the forming defects of aluminum alloy die castings and the corresponding temperature control ranges were given.

2.3. Working principle

The working principle of the test is shown in Fig 5. The thermocouple is fixed on the screw sleeve and connected to the mold through the screw thread and the thermocouple probe is ensured just contacting with the mold surface. The thermocouple compensation feeder is concentrated in waterproof quick inserting plug and the male connector is used at mold end. The detection positions can be distinguished by marked number on the shell of insert core and the temperature recorder is connected to the female ferrule corresponding number. The induction temperature of thermocouple is transmitted to the temperature monitor in the form of radio waves by the compensation feeder. The temperature signal received is processed digital signal and displayed. When the temperature is higher or lower than the set temperature the signal will be feedback to the alarm device. ZHou [8] pointed out that the distribution of
The temperature field of die casting die is the key factor to influence the quality of die casting and die life. The degree of thermal stress, the tendency of deformation and crack are determined by the temperature field of the die. Through the research progress of numerical simulation and application of temperature field of die casting die, the finite element method of temperature field numerical simulation and the mathematical model relation method were be introduced and the mold temperature field influence of pouring temperature, mold preheating temperature, cooling water temperature, diameter of cooling water pipe, position of cooling water pipe, etc. were quantitatively studied by comparison.

The distance between the thermocouple probe and the molding surface is 25 mm and the temperature difference exists. Therefore, the temperature of the molding surface is directly detected by the other thermocouple or the hand-held infrared thermometer after the die casting. By contrast with the displayed temperature of temperature meter, the temperature difference is 20-30 °C. The displayed temperature is very close to the true value after the 25 °C temperature compensation is set.

2.4. Sketch of Instrument Terminal Connecting Wire

In figure 6, identification 1 is the moving die plug and identification 2 is the fixed die plug, the connection should pay special attention to its direction. The thermocouple feeder is entered the stainless steel bellows. The number 1-9 are respectively inserted the numbers 1-9 of identification 3 and the numbers 10-12 are respectively inserted the numbers 10-12 of identification 4.

3. Experiment and Analysis

3.1. Location Selection of the Detection Points

Through a lot of experiments, as well as the summary of the automotive engine casing in early production, the points 10, 11, 12 of the fixed mold are the key monitoring positions as shown in Fig 7.

3.2. Simulation of the temperature field of the fixed mold

Liu simulated the temperature field of die by using MAGMA software and pointed out that the mold surface temperature is the highest when the casting die is unloaded, the temperature is the lowest after spraying finishing agent. The mold heat flow is from the alloy surface to the inside during fill finished to casting unloaded, but the mold heat flow is from the center to the surface and cooling water runner during other cycles.
3.2.1. Acquisition temperature of the fixed mold (before spraying)

From Fig.8 and Fig.9, the overall temperature difference is small by comparison, the minimum is 1.4 ℃. The simulation temperature of the fixed mold is very close to the actual temperature before spraying.

3.2.2. Acquisition temperature of the fixed mold (after spraying)

From Fig.10 and Fig.11, the overall temperature difference is not large, the maximum is 122 ℃ and the minimum is 3 ℃. The spraying time and location of simulation should be changed from the above analysis. Because the temperature difference of the green square is obvious, it should be confirmed that the cooling water is used or not.

3.3. Analysis of filling temperature and quality

The initial temperature of liquid aluminum is 660±10 ℃. The aluminum liquid temperature begins to decrease while the aluminum liquid is poured into the barrel. The aluminum liquid should have a suitable temperature in the die casting filling, which affects the quality of casting products. The temperature is too high to produce sintering, foaming, die casting running water, etc. The temperature is too low to lead to cold shut, porosity and slag hole, as shown in Fig.12, It corresponds to the identification in Figure 13.
The liquid aluminum is above the liquid limit 578 °C. The black circle mark is 620 °C and it is lower than the temperature of aluminum liquid. It is not at the filling product end and the liquid aluminum solidifies early, which leads to cold shut and porosity.

The cooling is late in square frame position, and the liquid around has already solidified and the liquid island is formed. The shrinkage cavities are formed when the casting pressure and the casting’s feeding are not obtained during solidifying.

The area with the darker color is the area with high temperature in the die casting and can be analyzed by freezing temperature. The temperature of the mold is relatively high where hot spot exists as shown in Fig.15.

4. Accuracy Verification

The temperature of each point is shown on the panel, as shown in Fig.16, in which the temperatures of the fixed mold (CH10, CH11, CH12) are 182.89 °C, 209.80 °C and 148.80 °C, respectively. The temperature of the thermocouple measurement is very close to the temperature of the thermal imaging instrument after compensation, which is a true reflection of the temperature change process of the mold.
The comparison of production quantity, internal waste rate and external waste rate is shown in Table 1.

| Test method       | Production quantity (weekly) | Internal waste rate | External waste rate |
|-------------------|-----------------------------|---------------------|---------------------|
| Thermocouple method | 4752                        | 7.8                 | 10.3                |
| Ultra-red method  | 4730                        | 3.4                 | 5.2                 |

Fig.16 is taken by the thermal imaging instrument while the die casting needs to be suspended, each need about 5 min. The waste of time will be avoided by using thermocouple monitoring, the utilization rate of device is improved and the OEE is increased by 2.5%. Moeller, al.\textsuperscript{[10]} studied the deformation processes of the Al-Mg-Si-(Cu) alloy considering the longer temperature control time (five days) of die casting. The improved temperature control mode is obtained and the die casting time is greatly reduced.

The staff will be immediately reminded of alarm when the mold temperature does not meet the requirements due to the thermocouple real-time monitoring. The problem of mold temperature can be timely found and the stability of die casting may be guaranteed. Through Table 2, the inside and outside waste from the above data, the inside waste can be increased by 4.4% and the outside waste can be increased by 5.1%. The qualified rate of products is effectively improved and the production cost is reduced.

5. Conclusions
In summary, the equipment utilization rate is improved, the man-made downtime is reduced and the OEE is improved after the technical improvement. The stability of die casting production is effectively improved because the abnormal mold is timely detected in temperature real-time monitoring. The difference of the thermal imager and Magma simulation exists in temperature acquisition point. It may not be completely accurate in the same spot and only may be in a relatively accurate range. Each region of the mold cannot be refined and parameterized in the setting of spraying during Magma simulation, so the temperature difference is larger. But the temperature distribution trend of the Magma simulation and the actual thermal imager is identical. In the real-time temperature monitoring of mold, the process parameter interval can be reduced in advance in Magma, the simulation parameter is copied to the die casting machine and the ideal die temperature is obtained by trimming because of the difficulty in adjusting the parameter.

According to this project, we can know that the following aspects can be further studied in the future:
1. The machining problem of mold assembly hole: There are two kinds of connection ways between thermocouple and die, one is directly connected with the screw thread and the other is connected with the fast inserted method. The assembly precision of the thermocouple may be affected by the larger deviation of hole and inaccuracy screw thread, therefore, the temperature of the point cannot be accurately collected.

2. The quality problem of thermocouple: In the normal condition, the thermocouple must be contacted with the mold and the closer the detection point is, the more accurate the temperature is. The accuracy of domestic thermocouple cannot meet the requirements. When the thermocouple is contacted with die the thermocouple it cannot work, or the difference of the displayed temperature and actual temperature is particularly large and the data have obvious jump. When the thermocouple is away from the mold, the normal temperature can be detected but the temperature value is largely different from the temperature of thermal imaging instrument and it exists a certain fluctuation. The acquisition temperature is relatively stable when the distance between the thermocouple and the mold is 3-4mm, but the air temperature is detected because of the air gap between the thermocouple and the mold. The detection sensitivity of thermocouple is reduced, the temperature cannot be accurately detected by the thermocouple when the overall temperature of the mold or the highly toxic temperature has obvious difference.
Acknowledgments:
Natural Science Foundation of Chongqing, China (NO: cstc2019jcyj-msxmX0521; Science and technology research project of Chongqing city board of education (No. KJQN201805401).

References
[1] Zhang G.M., Zhang J., Wu W. (2017) Study on temperature field distribution of die casting magnesium alloy die based on CAE analysis [J]. Foundry, 07: 559-562.
[2] Han X.W., Li X.X., Chen Z.H. (2011) Numerical simulation of thermal stress field of aluminum alloy die casting die based on ProCast [J]. Special Casting and Nonferrous Alloys, 09: 837-839.
[3] Zeng S.Q., Cheng D.Y., Guo M.J. (2011) Numerical simulation analysis of A356 aluminum alloy die casting die based on ADINA [J]. Hot Working Technology, 23: 54-55.
[4] Jin P.f. (2012) Design of infrared temperature monitoring and control system [D]. North University of China.
[5] Wang X.N. (2017) Theoretical and experimental study on fibre-optical temperature and displacement measurement [D]. Yanshan University.
[6] Zhang H.H. (2004) Forming technology and simulation research on semi-solid aluminum alloy thixoforming [D]. Shanghai University.
[7] Iwata Y., Dong S., Sugiyama Y., (2014) change in molten metal pressure and its effect on defects of aluminum alloy die castings [J]. MATERIALS TRANSACTIONS, 55(2): 311-317.
[8] Zhou Y.H. (2006) Numerical simulation of temperature field of die casting die for automobile hub [D]. Xihua University.
[9] Liu C.S. (2015) Simulation analysis of high pressure die casting of aluminum alloy [J]. Journal of Wuhan University of Science and Technology (Natural Science Edition), 01: 28-31.
[10] MOELLER H., DASWA P., GOVENDER G. (2014) The heat treatment of rheo-high pressure die cast 6xxx series Al-Mg-Si-(Cu) alloys [J]. Aluminium Alloys 2014 - ICAA14, 794-796: 137-142.