Development of High Quality Aluminum Parts using Semi-Solid Die Casting

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Abstract

Generally, die casting is a process of casting metal by forcing molten metal into the mold under high pressure and high velocity. This can result in a possible for mass production of a thin-walled parts compare with sand casting, gravity casting and low pressure casting. Unfortunately, casting defects can be caused by high speed injection and fail to meet reliable parts requirement such as a suspension parts in automobile industry. To serve increased demand for high quality castings, semi-solid die casting[7.3-1] has been developed to overcome those problems. Basically, a casting quality depends on the flow characteristics and solidification phenomena in the cavity. For semi-solid die casting, those characteristics or phenomena differ significantly from the others because of its less liquid phase. In this paper, a quick and easy semi-solid slurry manufacturing process developed by Tohoku University will be introduced. By utilizing this method, a production of high strength parts and pressure tightness parts for motorcycle and others application can be performed with many advantages such as less gas porosity, less shrinkage porosity, and better metal structure can be obtained. Furthermore, the efficiency in production cost and productivity are the advantage of commercialization in die casting process.

Keywords: High Strength Parts, Pressure Tightness Parts, Semi-Solid Die Casting, Cup-Method[7.1-1]

1. Introduction

The study from the beginning of human history until the present shows sand casting is a popular casting method. However, it needs to break down mold for every production batch. Therefore, permanent mold casting was developed to solve a weak point of production by those casting method. Although it still has a problem of melting flow. Then HPDC or high pressure die casting becomes a popular casting method in the present because of theirs high speed and high pressure that resulting in high production capacity, whereas poor mechanical properties and a non heat treatable due to its gas defects are still a problem as shown in Fig.1. Therefore, various special die casting techniques such as vacuum die casting, laminar flow die casting, pore-free die casting, GF die casting and squeeze casting[7.1-2] were developed to solve a problem of the conventional high pressure die casting. Air entrapment and shrinkage porosities can also be solved. But they cannot serve a high quality; furthermore, those methods have difficult in melt handling. At present, semi-solid die casting and semi-liquid die casting were developed to serve high quality with easily production.

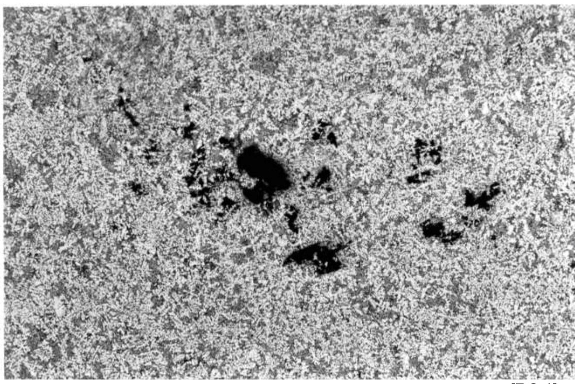

Fig.1 Porosities defect in die casting parts[7.2-1]

2. Conventional semi-solid slurry

In the conventional semi-solid slurry preparation method, with low pouring temperature and low cooling rate, the primary α-Al phase was formed in the spheroidized structures. However, the dendritic structure was formed at high pouring temperature and high cooling rate. For these reasons, semi-solid slurry preparation by the conventional method, it is important to keep a melt temperature higher than liquidus temperature with a low cooling rate. The result is a semi-solid slurry preparation time will longer than a die casting cycle time in finally. To solve those problems, Cup-method gives the fine nucleation with less in both the temperature gradient and result in a uniform quality all along semi-solid slurry as shown in Fig.2. However, Cup-method can provide the spheroidized structure of the primary α-Al phase even if 15 times or 25 times higher than cooling rate.

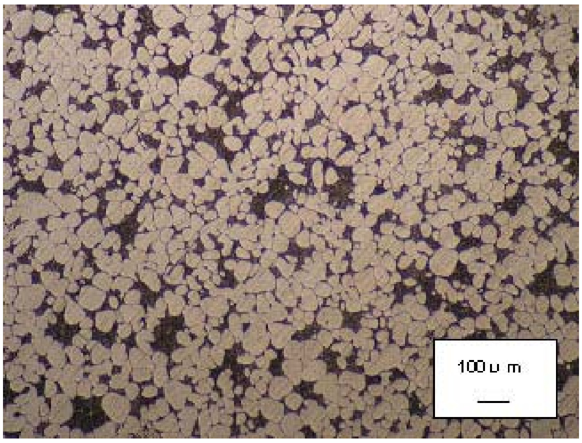

Fig.2 Microstructure of semi-solid alloy (AC4C)

3. Cup-method

Semi-solid slurry preparation by "Cup Method" can be carried out easily like pouring water into a cup. When molten aluminum is poured into a metallic cup, a heat of melt started transfer to a metallic cup as shown in Fig.3.

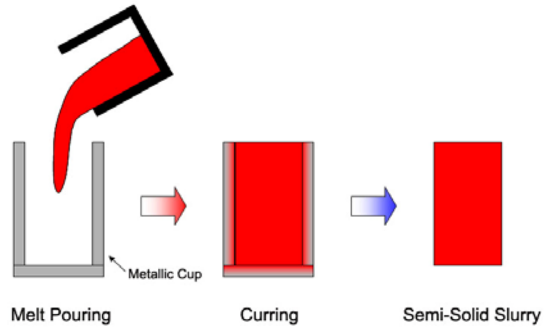

Fig.3 The schematic drawing of Cup-method

Therefore, the initial temperature of aluminum will decrease below than T_c. On the others hand, the initial temperature of a metallic cup will increase from T_m. Finally, the temperature of a metallic cup and a molten aluminum will be balanced without heat transferred during a cup and a melt. At this stage, an equilibrium temperature (T_{eq}) can be calculated by the below equation[7.2-2, 7.2-3, 7.2-4].

$$T_{eq} = \frac{T_c + \gamma T_m + H_f' f_s}{1 + \gamma} \qquad (1)$$

Where as, T_c is initial temperature of a molten aluminum, T_m is initial temperature of a metallic cup, f_s is fraction of solid and H_f' is latent heat of solidification divide by a specific heat.

When T_{eq} is reached, semi-solid state will be kept. Fig.3 shows the schematic drawing of Cup-method.

Fig.4 Semi-solid slurry (AC4C)

3. Semi-solid die casting

The apparatus of manufacturing facility is shown in Fig.5. The manufacturing facility is comprised of 250 tons horizontal cold chamber pressure die casting machine and semi-solid slurry manufacturing stationary by Cup-method. The utilized cup has 50mm in diameter and can produce semi-solid slurry up to 800g aluminum.

Fig.5 250t DCM with Cup-method stationary

4. Industrial applications in die casting

4.1 Pressure Tightness Parts

Fig.6 shows the example of a pressure tightness parts. It has vary in thickness up to 30 mm and weight in 330 grams (machined parts). The pouring weight 0.8 kg casting (AC4C) was cast by 250 tons horizontal cold chamber pressure die casting machine as shown in Fig.5 with cycle time is less than 30 sec.

Fig.6 Pressure tightness parts (AC4C)

Squeeze casting process was used to form this part. However, leakage defect was found and caused in poor mechanical property. This type of defect can be found easily in squeeze casting product due to pressure from intensification period cannot transfer to internal cavity because of rapid solidification of gate. Therefore, impregnation process is required for filling holes in products and causes in expensive cost with bad working environment.

After changing process to semi-solid die casting, soundness casting was obtained as shown in Fig.7, porosities are not found as result shown in color-check testing. Furthermore, usually gas content in melt up to 1cc/100gAl is allowed after melt cleaning process. Therefore, gas content 1.11cc/100gAl in this case shows that almost gas content in casting parts in this case is come from original melt. Furthermore, no need to do impregnation treatment anymore.

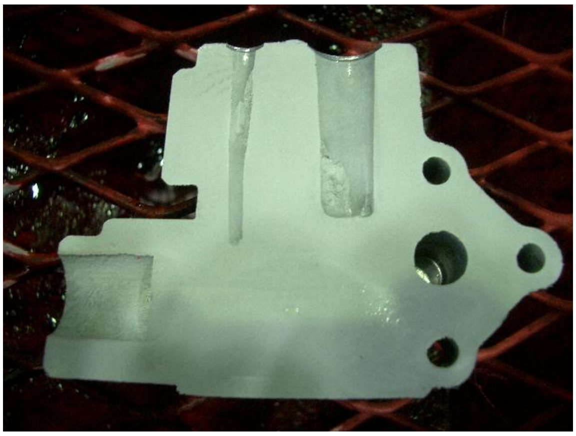

Fig.7 Color-check testing result (As-Cast)

Table.1

Weight (g)	Gas Volume (cc)	Gas Content (cc/100gAl)
725	8.02	1.11

*Weight and gas volume in Table.1 are counted from 2 pieces of casting.

4.2 High Strength Parts

Fig.8 shows another application in high strength parts that has vary in thickness up to 50 mm and weight in 400 gram (machined parts). The pouring weight 0.8 kg casting (AC4C) was cast by 250 tons horizontal cold chamber pressure die casting machine as shown in Fig.5 with cycle time is less than 30 sec.

Because of this part is designed to be installed in 1,400 cc motorcycle that required more than 300MPa tensile strength and more over 10% elongation. To obtain those requirements, forging process was chosen to manufacturing this parts. However, the limitations of forging process cannot form an undercut shape in one time. Therefore, 7 forging dies is required to form this shape that make an expensive cost.

Next, squeeze casting was adopted to produce this parts in one shot casting. Unfortunately, the weak point of squeeze casting as mentioned before is it cannot solve a problem of shrinkage porosity completely due to a rapid solidification at gate. Furthermore, melting temperature for squeeze casting is very high that causes a short die life and results in increasing cost.

Fig.8 High strength parts (AC4C)

Finally, semi-solid die casting was applied to produce this parts. It was found that gating system of conventional squeeze casting cannot use with semi-solid die casting. Therefore, wide and thick gating system and cooling system of die casting die were modified for proper mold filling and solidification phenomena of semi-solid slurry. High quality die casting parts can be produced with near net shape casting and the mechanical properties requirements such as UTS and elongation also investigated and confirmed that have the excellent values.

Fig.9 and Fig.10 show testing apparatus and testing result respectively. A casting can be loaded over requirement valve of 55kN that means the quality of semi-solid die casting by Cup-method is the same as the quality of forging process.

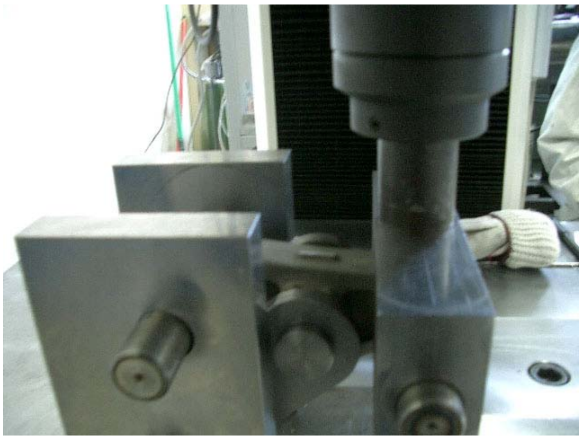

Fig.9 Testing method

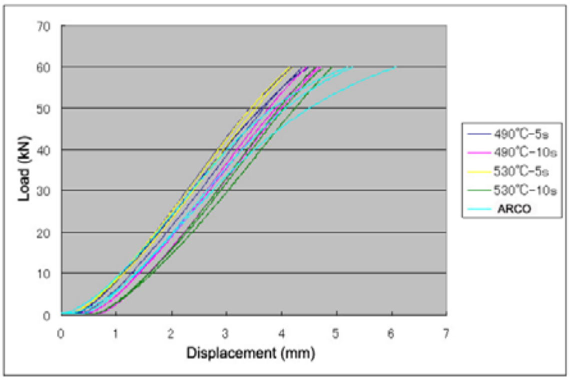

Fig.10 Load testing result

Table. 2

Weight (g)	Gas Volume (cc)	Gas Content (cc/100gAl)
807	14.07	1.74

*Weight and gas volume in Table.2 are counted from 2 pieces of casting.

5. Conclusions.

Semi-solid die casting by Cup-method can improve the following characteristics; High mechanical properties such as strength, toughness and pressure tightness with refined microstructure characteristics compared to the conventional die casting process.

6. Acknowledgement

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