Research on design and technology of aluminium alloy conductor low pressure casting die

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Abstract. Basic principles of aluminium alloy conductor low pressure casting are introduced in the paper. Casting die design and casting system are respectively introduced aiming at the low-pressure casting process of aluminium alloy conductor, the influence of cylindrical riser tube and cone riser tube on liquid rising pressure and liquid rising stability in liquid rising process are analysed in details. It is concluded that the liquid rising pressure for liquid rising process is relatively low during selection of cone liquid rising, and liquid rising process of cone riser tube is more stable. Therefore, cone riser tube is more suitable for liquid rising process of aluminium alloy conductor low pressure casting than cylindrical riser tube. Low pressure casting technological parameters of aluminium alloy conductors are summarized through analysis on low pressure casting technology, thereby providing reference for low pressure casting technique of aluminium alloy conductors.

Keywords: aluminium alloy conductor; low pressure casting; die design; casting system.

1. Introduction
Aluminium alloy conductor has the following advantages compared with conductors made of other materials: rebounding resistance, good bending, corrosion resistance, light weight, etc., therefore its application in the cable system is more and more affirmed, and it gradually replaces copper conductor and becomes a major part of the power transmission system [1]. Aluminium alloy conductors are always produced through low pressure casting mode. Low pressure casting method is a casting technique integrating respective advantages of pressure casting and gravity casting. Relatively low external pressure is utilized for feeding high temperature melting metal from a crucible into cavity, thereby completing component casting. Since relatively low external pressure is used during the casting process, the casting method is called low pressure casting technique [2]. Castings produced through the casting technique has higher casting quality than the casting produced through pressure casting method on the one hand, and complex thin wall structure which can not be produced through gravity casting technique also can be obtained. The original casting method of aluminium alloy has increasingly failed to meet the quality level required by casting, and the low-pressure casting technique has gradually become the most indispensable method for aluminium alloy casting industry with the rapid development of industrial production [3]. Low pressure casting has advantages of simple casting structure, high degree of mechanization and automation, stable filling and high cost performance compared with other casting forms. Therefore, the application of low-pressure casting in aluminium alloy conductor production has been focused more and more widely [4].
2. Basic principles of low-pressure casting

Low pressure casting is a basic theory based on hydrodynamics, it is a casting form developed through combining characteristics of pressure casting and gravity casting. Its basic principles [5] are shown in Figure1.

![Figure 1. Low pressure casting basic principles](image)

It can be seen from the figure that the gas enters crucible from the intake pipe after compression firstly, and it pushes the molten metal inside crucible into the die cavity, thereby finishing the filling process. The air pressure is held until the molten liquid in the grinding tool is clean and solidified secondly. The supercharging pressure is discharged finally, thereby the high temperature molten liquid in the casting cavity and riser tube without crystallization can flow back into the crucible, which can be cooled continuously. Casting is removed, die is cleaned, thereby facilitating casting cycle next time.

3. Design of casting system

The casting system should be designed in accordance with the order of the molten metal solidification in low pressure casting technique. The liquid rising of high temperature molten metal should be as stable as possible in the supercharging process. Materials should be salved, energy consumption should be saved, and the production efficiency should be improved as far as possible under the precondition of ensuring production quality.

3.1. Die introduction

The aluminium alloy conductor die described in the paper [6] is shown in Figure 2. The mold is mainly consists of a sand core and a metal outer mold, wherein the metal outer mold can be used in large batch rather than non-metallic external mold which is mainly used for small batch single production. Aluminium alloy conductor low pressure casting is studied in the paper, wherein the casting production is high, higher requirements are proposed for precision and quality, thereby metal outer mold is selected. The metal outer mold mainly includes a left mold, a right mold and an upper mold, which form an empty cavity. The sand core is installed in the empty cavity, the lower ends of the left mold and the right mold are contacted with cold iron, the cold iron cavity contains an inlet, sprues and ingates, wherein ingates are symmetrically arranged at both ends of the spure top, it is unique advantage of the die, the die also can meet the casting solidification conditions in top-down order, namely the metal is solidified at the farthest position from the ingate, which is followed by the position near the ingate, and the area in the ingate is solidified at last. The advantage of low pressure casting technology can be fully exerted, thereby obtaining casting with dense tissues.
3.2. Design of riser tube

Liquid rising process has important influence on the quality of casting structure and material consumption in low pressure casting process of aluminium alloy. It is required that the riser tube not only can ensure stable liquid rising process, but also can try to meet the requirements of small air filling pressure and air tightness. Figure 3 shows that the liquid rising process is simulated respectively aiming at cylindrical riser tube and cone riser tube in the paper. The liquid rising speed of aluminum alloy liquid is mainly controlled at 0.05m/s in simulation, thereby high temperature molten aluminum can finish filling smoothly, the liquid rising completion time and liquid flow state of each riser tube can be obtained, thereby analyzing liquid rising pressure and liquid rising stability in liquid rising process from the two aspects.

![Figure 2. Die structure](image)

![Figure 3. Riser tube sectional view](image)

3.2.1. Analysis on fluid pressure characteristics in crucible. The liquid rising process of two riser tube structures is simulated, the fluid pressure distribution at four time points of 5s, 10s, 15s and 20s is respectively obtained as shown in Figure 4 and Figure 5. It can be seen from the figure that the position in the riser tube with deeper red color belongs to part with higher pressure, the position with deeper blue color belongs to part with lower fluid pressure, and the deeper blue parts refers to the height of molten aluminum rising. Therefore, the fluid pressure in the crucible is relatively high, the fluid pressure in the riser tube is relatively low, the gas pressure for liquid rising is gradually increased with the increase of
liquid rising height in order to maintain stable rising of high temperature molten aluminum in the riser tube. The gas pressure changes at the stage of liquid rising are shown in figure 6.

**Figure 4.** Fluid pressure characteristics of cylindrical riser tube

![Fluid pressure characteristics of cylindrical riser tube](image1)

**Figure 5.** Fluid pressure characteristics of cone riser tube

![Fluid pressure characteristics of cone riser tube](image2)
It can be seen from figure 6 that the liquid rising pressure in liquid rising process has linear increasing trend. The supercharging pressure for the cylindrical riser tube is larger than the supercharging pressure of the cone riser tube. The energy for cone riser tube at the stage of supercharging is lower than that of cylindrical riser tube. It is obvious that energy consumption can be reduced by cone riser tube to a certain extent.

3.2.2. Analysis on fluid velocity characteristics in crucible. The liquid rising process under the two riser tube conditions is simulated for obtaining the velocity vector diagram of liquid in the crucible and riser tube under the two conditions at 10s as shown in figure 7. Can be seen in the figure, on the other hand, for the gas inlet, cone riser tube inlet in the gas disturbance. The figure shows that the gas disturbance at the air inlet of cone riser tube is relatively high in the aspect of gas inlet on the one hand because the cone riser tube is relatively narrow at the lower portion. The gas at the inlet is inclined to certain extent, the space is increased suddenly, thereby leading to relatively high gas disturbance. Higher gas disturbance shows gas turbulence role at the inlet. Fluid inertia accounts for a major role, thereby forming a thrust to high temperature molten aluminum to some extent, and reducing liquid rising stability of high temperature molten aluminum in the riser tube. In addition, the gas disturbance at the inlet also can not affect the liquid rising stability of high temperature molten aluminum in the cone riser tube. In addition, the vector figure also shows that the gas disturbance above the molten aluminum in the cylindrical riser tube is sharper than the gas disturbance above molten aluminum in the cone riser tube. The gas disturbance above the molten aluminum will affect the stability of liquid rising to certain degree because vortex is formed above the molten aluminum, and the inertia effect is prominent, thereby leading uneven force in all parts of molten aluminum liquid surface, and prominent fluctuation of molten aluminum liquid surface. Strong fluctuation will lead to scattering of molten aluminum, which is not beneficial for supercharging stability of molten aluminum. The above analysis shows that the molten aluminum stability in the cone riser tube is higher than the molten aluminum in cone riser tube during liquid rising process. Therefore, cone supercharging tube better meets the requirements of liquid rising stability.

![Figure 6. Change of liquid rising pressure](image)

![Figure 7. Fluid velocity vector distribution in crucible](image)
4. Low pressure casting technological process

The process of aluminium alloy low pressure casting process mainly includes the follows: (1) assemble metal, riser tube and cast, cover hermetic seal, and reach the effect of pressure holding; (2) feed the compressed air into the crucible through air duct, use constantly fed compressed air to push molten metal into the cavity along the riser tube, keep pressure to solidify molten metal; (3) remove supercharging pressure, thereby non-crystallized high temperature molten metal in the casting cavity and riser tube can flow back into the crucible along the riser tube; (4) take out the casting, and clean the mold for the next casting cycle. The overall technological process of low pressure casting technique is shown in figure 7. The figure shows that the technological process mainly includes four parts: aluminium alloy melting process, mold preparation process, sand core preparation and vibration core removal process.

Aluminium alloy melting process is a process of alloy transition from solid state to solid state. The quality of transition process also directly determines the quality of the product and its technological process [7] is mainly divided into four steps: (1) Feed aluminum ingots into melting furnace for melting, do not fill the furnace fully, feed a small amount of aluminum ingots and melt into molten aluminum firstly, feed another part for melting into molten aluminum, etc. until reaching anticipated weight; mix and remove ash during melting; (2) Add silicon after aluminum is melted; note: the aluminum surface should be cleaned before siliconizing, and broken silicon powder should not be added, and the mixture should be mixed suitably during siliconizing; (3) Add a certain amount of aluminum ingot as cooling material after the silicon is siliconized because the temperature will be higher after the silicon is siliconized. The amount of cooling material depends on the temperature required by your casting. (4) Carry out gas removal, refining, metamorphosis, static setting and other refining procedures, and operate according to requirements and equipment of own factory.

Mold preparation process mainly includes mold disassembly, mold inspection, exhaust plug plunger cleaning, cavity blasting cleaning, mold preheating, mold combination, mold installation in the low pressure machine and mold heating.

Sand core preparation process mainly includes hot core technology, cold core technology and shell core technology, wherein the sand core mold is heated during the whole hot core technological process, sand core self-inspection, coating on sand core, sand core drying, sand core baking and sand core inspection are required for the three technological processes, and then they can be warehoused for future use. The sand core preparation also affects the quality of the casting cavity.

Vibration core removal process: vibration core remover is required. Firstly, the casing with the sand core should be installed on the machine for positioning, clamp is used for holding the sand core casting, sand is fallen through vibration, the mold is obtained, and the clamp is cleaned finally for facilitating use in next cycle.

When the casting technological process is designed, the molten metal should be filled on the casting from top to bottom through external application of pressure, and casting can be condensed from bottom to top as far as possible during design of casting technological process during low pressure casting technology. The casting can be gradually solidified from the farthest position of the sprue to the near position of the sprue. The following method is generally adopted in order to solidify the casting in order: (1) The sprue is designed at the position with thicker wall, and the sprue should not be designed near thinner wall; (2) the wall thickness is controlled through leaving allowance in processing, and the parts
can be solidified in order; (2) the conditions facilitating solidification in order is changed during cooling; (4) local cooling treatment method is used in the parts with higher wall thickness.

5. Technological parameter selection for aluminium alloy conductor low pressure casting

Stable liquid rising speed should be controlled as far as possible, and the inertia effect should be low in order to keep molten liquid flowing stability and smooth removal of air in the cast during liquid rising process thereby achieving stable flowing state. The molten aluminum rising speed should be kept at 0.05m/s~0.15m/s aiming at high-temperature molten aluminum liquid rising process, the compressed gas feeding speed of the air duct should be controlled at 12.7mabr/s~17.5mbar/s.

The pressure for pushing molten metal to the top of the cavity is defined as mold-filling pressure. The pressure rising speed above the molten liquid surface is called filling velocity during filling [8].

Mold filling pressure calculation can be expressed as follows according to the empirical formula:

\[ p_2 = \frac{h \rho k}{1020} \]

In the formula, \( h \)- the height for alloy solution rising to the top surface of the casting (cm), \( \rho \)- alloy liquid density (g/cm³), and \( k \)- filling resistance coefficient, \( k \) is 1~1.5 generally, \( k=1 \) under lower resistance, and \( k=1.5 \) under higher resistance.

Filling velocity computation expression is shown as follows:

\[ v_2 = \frac{(p_2 - p_1)}{t} \]

\( p_2 \) refers to mold-filling pressure; \( p_1 \) refers to liquid rising pressure; \( t \) refers to filling time;

When the whole cast is filled with molten metal, compressed gas should be filled continuously, thereby ensuring smooth solidification process of casting, and the casting can be dense, and pressure in the process is called crystallization pressure. The crystallization pressure is within the scope of 1mbar and 2.5mbar under normal circumstances. Higher crystallization pressure is more beneficial for casting crystallization pressure increasing method is not suitable for all circumstances.

Dwell time and cooling time are generally consistent for about 1-2min. The casting temperature of aluminium alloy should be reduced as far as possible under the condition of meeting smooth completion of casting, and it can be changed within the scope of 200 ~ 250 ℃ generally.

6. Conclusion

Casting die and casting technology are analyzed and studied respectively aiming at low pressure casting technique of aluminium alloy conductor in the paper. The results show that:

(1) The die structure described in the paper can give full play to the advantages of low pressure casting technology and obtain dense tissue casting.

(2) The riser tube fluid flow state is analyzed. It is concluded that the liquid rising pressure for liquid rising process is relative low during cone liquid rising, the cone riser tube liquid rising process is more stable, thereby the , cone riser tube is more suitable for liquid rising process of aluminium alloy conductor low pressure casting compared with cylindrical riser tube.

(3) The aluminium alloy conductor low pressure casting technological parameter is analyzed and concluded in the paper, thereby providing reference for aluminium alloy conductor low pressure casting technique.

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