Study on heat treatment blister of squeeze casting parts

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Abstract: Heat treatment blister is one of the common defects found in squeeze casting parts, which is related to squeeze mode, process and mold. For direct squeeze-casting parts, solution heat treatment can be performed smoothly as long as oil-based paint is not used and air exhaust is well arranged. For indirect squeeze casting parts, solution heat treatment can also be applied when additional factors are taken into consideration, including well designed internal feeding system and strictly controlled liquid metal filling velocity to prevent from inclusions.

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To achieve high mechanical properties, it is necessary to perform solution heat treatment and quenching for squeeze-casting parts. Under general conditions, heat treatment is viable with reasonable die design and proper processes [1]. But in practice, squeeze casting producers are often troubled by the blister problem formed during heat treatment which may even affects their normal production. To a large degree, heat treatment blisters relate with casting method, process and mould structure [2]. Therefore, in this paper, the causes for blister defect and related control methods are studied.

1 Direct causes for heat treatment blister

During the process of mold filling under pressure, liquid metal often traps gas/air and volatile substance/inclusions. For examples, the trapped air and volatile flue may not be exhausted in time; air/gas bubbles that have precipitated in liquid metal do not have time to float and escape; slag and un-dried mold paint/coating containing moisture and volatile grease may be trapped, compressed and sealed in the metal casting during the high pressure solidification. At ambient temperature, these entrapped gas and paint slag are not obvious. However, when solution treated or heated to high temperature, the matrix metal will be softened, and gas and moisture will expand and violate rapidly, creating new blisters in cast parts, or called heat treatment blister. Since gas and slag are easily entrapped underneath the cast surface, and resistance force that blisters need to overcome is relatively small, most blisters are found under the surface of cast parts. Small blisters are grain-sized and large ones are bean-sized, most of which are densely distributed. In fact, blisters can also form in the deep section of cast parts only when exist severe slag/inclusions. In such case, blisters are relatively large.

The characteristics of heat treatment blister can be described as follows. During solution heat treatment (or high temperature heating), blisters appear on the surface of cast parts, and holes are left after the surface of these blisters are shoveled. The inner surface of these holes is smooth and shows trace of contamination, and in more severe case, large pieces of paint/coating slag/inclusions can be found. Blisters damage the appearance of cast parts and the continuousness of material, and the defects can still be seen on the surface even after machining. Therefore, large heat treatment blisters are regarded as one of the serious cast defects, which are not allowed in most cases.

2 Heat treatment blisters in direct squeeze casting

Direct squeeze-casting methods mainly include direct punch squeeze (as shown in Fig. 1) and plunger squeeze (Fig. 2). The characteristics of these methods are pouring liquid metal into mold impression, and applying squeeze force downward to punch or plunger (or column piston). During the entire course of mould matching/closing, liquid metal filling and solidification under pressure, liquid metal stays on the bottom and air on the top of the impression. In this process, liquid metal flows slowly or does not move at all, and it has very limited convection and interflow with air. Besides, air can be exhausted from the clearance between plug and female die. Therefore, it is almost impossible to entrap air in this type of squeeze-casting methods. As long as the paint application and air exhausting process are properly controlled, the products manufactured with this method can be solution treated smoothly.

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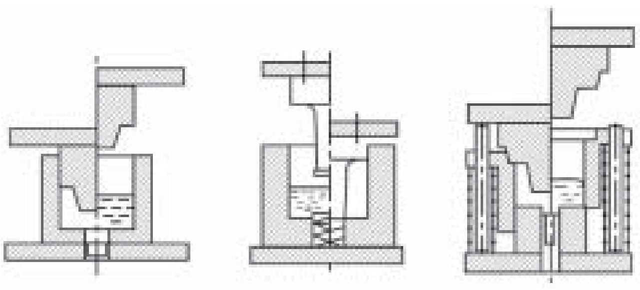


Fig. 1 Sketch of direct punch squeeze-casting method

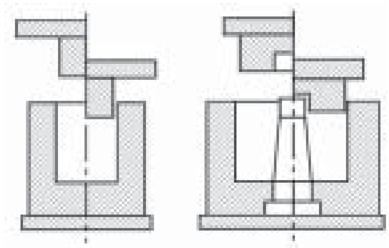


Fig. 2 Sketch of plunger squeeze-casting method

2.1 Effect of paint and spraying process

(1) Paint types

Common paints are classified into two types, water-based and oil-based (including wax-based). The former has good cooling ability and relatively poor lubricity. After it is coated, moisture will evaporate soon and only a layer of dry powder is left inside the impression. The latter has good lubricity, but it is not easy to dry after applied and some oily substance will be left on the impression surface. With water-based paint/coating, some solid lubricating powder may be left on casting surface during the processes of pouring, squeezing-filling and solidification, but blisters are not easy to form in solution heat treatment. Whereas, for parts cast in mold coated with oil-based paint, oil substances have been entrapped into the casting surface, and when heated up during solution heat treatment, they volatilize and expand, very easily leading to formation of blisters. Therefore, for squeeze casting parts that require solution heat treatment, mould impression shall not be coated with oil-based paint or contaminated with grease. Of course, gas-forming properties of different water-oil-based paints are different, and careful comparison is necessary during selection.

(2) Spraying process

Paint shall be sprayed uniformly, and moisture on the impression surface shall be dried before casting, and no accumulated water or surplus wet paint is allowed on the surface. Special attention shall be paid during manual paint brushing.

2.2 Effect of gas exhaust

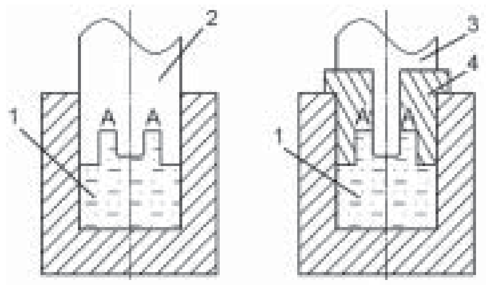
(1) Matching clearance

During direct squeeze-casting, air in the mould shall be exhausted from match clearance between female die and plug (plunger), so clearance size is important. If the gap is too small, air cannot be exhausted smoothly; if too large, liquid metal will be sprayed out. In normal condition, for aluminum or magnesium alloy, H7/e8-H7/d8 is adopted for match clearances between plunge, core rod, female mould and trepan boring, and matching length (or seal height) is 20-50 mm. To enhance air exhaust, several 0.05-0.1 mm deep and 10-30 mm wide exhaust slots can be machined on the match surface of plunger or core rod.

(2) Mould structure

Figure 3 shows the mould design of a cast part with convex. When integrated punch is applied (Fig. 3a), air cannot be exhausted because of the convex (position A), creating a high likelihood for blister formation and misrun during pouring-filling. If the above structure is changed to that shown in Fig. 3b, air in convex (position A) of cast part can be exhausted from the gap between plunger (part 3) and press plate (part 4).

Therefore, for these issues, relative measures shall be taken in mould design.



a. Design with obstructed exhaust   b. Proper design for air exhaust

1-Cast parts; 2-Integrated punch; 3-Punch; 4-Press plate

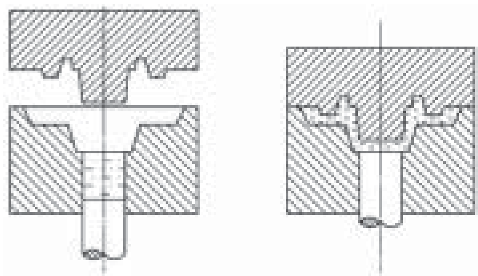
Fig. 3 Mould design with different exhaust methods

3 Heat treatment blisters in indirect squeeze casting

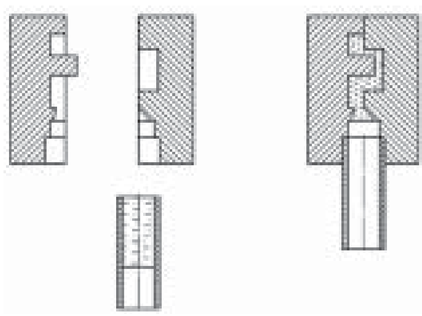
Bottom squeeze method (as shown in Fig. 4a & 4b) and upwards squeeze method (Fig. 5) are two common methods used in indirect punch squeeze casting process. As compared with the direct squeeze casting, indirect squeeze casting process has longer flow distance for liquid metal and often deals with castings of more complex shapes, which makes it more difficult to solve the heat treatment blister defects.

However, compared with die casting, most indirect squeeze casting process is to fill the liquid metal from lower to upper position of the mould with large ingate and wide runner, offering relatively low liquid metal filling velocity. Therefore, this process substantially reduces the chance to form heat treatment blister defect. With proper mould design and suitable process parameters, it is absolutely possible that indirect squeeze casting parts can be treated by solution and quenching.

It must be pointed out that during indirect squeeze, the blister formation probability is different between bottom squeeze method (Fig. 4) and upper squeeze method (Fig. 5). Blister problem can be solved easily in the former case because of good condition for air exhaust and slag blocking. In the later case, due to the horizontal ingate design, liquid metal will interflow easily with air in reservoir; liquid metal near reservoir wall may chill to form crust; and surface slag will be inevitably flushed into mould cavity (without slag-blocking feature) during squeeze-filling. Thus, in the later case, it is more difficult to avoid blister.



a. Horizontal joint mould



b.Vertical joint mould

Fig. 4 Sketch of indirect squeeze casting method (bottom squeeze)

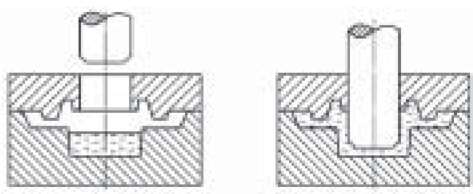


Fig. 5 Sketch of indirect squeeze casting method (upward squeeze)

3.1 Control of liquid metal filling velocity

Liquid metal is filled by the press of squeeze punch, and the filling velocity depends on the squeeze velocity of the punch. If filling velocity is too high, vortex may occur in liquid metal and air will be entrapped easily, which may result in heat treatment blisters. If filling process is too slow, liquid metal will freeze too early, resulting in misrun condition. Therefore, the filling velocity of liquid metal is an important factor. According to theoretical analysis and experiments, to avoid vortex in liquid metal, the filling velocity shall be controlled under 0.8 m/s. In direct squeeze casting process, the filling velocity is mostly controlled by the squeeze velocity. For heavy sectioned casting, the squeeze velocity can be lowered and controlled at about 0.1 m/s, while 0.2-0.4 m/s for thin or small cast parts. In indirect squeeze casting process, the filling velocity is usually controlled by calculating the flowing velocity of liquid metal at the ingate or the narrowest position of the cast part. The filling velocity shall be controlled within 0.5-1 m/s for thick cast parts, and 0.8-2 m/s for thin cast parts.

In order to prevent from vortex in flowing liquid metal, it should be considered during mould design (especially ingate design), to minimize direct impact of liquid flow on mould core and impression wall, to increase corner radius of casting and even to place additional flow passages.

3.2 Control of paint and oxide slag

Paint and oxide slag in cast parts are also two causes for heat treatment blister. If there's no moisture, grease and other volatile substances in such slag, no blister will be created. However, with the increase of trapped moisture and grease, blister problem will become more severe.

(1) Approaches of slag entrapping

a. Paint and slag on the surface of impression may be entrapped, which is similar to that in the direct squeeze casting process.

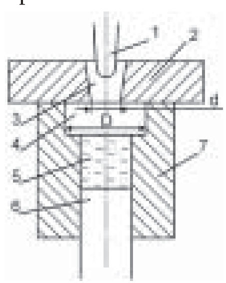
b. Paint on the wall of material tank (reservoir) may be entrapped. When liquid metal is filled into the material tank, it will contact with tank wall and quickly create crystal incrustation (or formation of thin solid shell). When material is squeezed into the mould, incrustation with paint will be crushed and flow into the mould impression through ingate. References [3] discussed specially on this issue.

c. The slag and grease substances floating on the surface of liquid metal may be entrapped. When liquid metal is filled into the material tank, oxide slag may remain in upper surface of metal, grease and paint in material tank will also float. If slag cannot be completely removed, it will be entrapped in liquid metal during later part of the squeeze/filling process.

(2) Measures to control slag entrapping

Beside the requirements described for direct squeeze casting parts such as that paint shall be uniformly applied fully dried, and oil-based paint shall be prohibited, following measures shall also be taken:

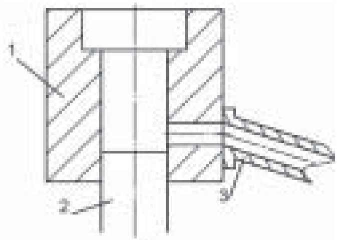
a. Design a slag collection cavity on the top of material tank, and the diameter (d) of ingate 3 shall be smaller than that of slag collection cavity (D) (as shown in Fig. 6), so that when squeeze punch pushes liquid metal upward to fill the mould, most fragments of the crushed incrustation (solid layer) will be accumulated around the inlet of slag collection cavity, and be blocked by ingate with smaller diameter (d) and be kept remaining in material pie.



1-Flow distribution cone; 2-Flow gate collar; 3-Ingate; 4-Slag collection cavity; 5-Liquid metal; 6-Squeeze punch; 7-Material tank

Fig. 6 Design of the material tank and internal flow gate

b. Pipe type equipment for feeding liquid metal from lower to upper position shall be adopted if possible (as shown in Fig. 7), so that gas and slag will be prevented from being entrapped into metal when the liquid metal is poured from high to low with pouring ladle and raw material is turning over in material tank. At present, pipe type of liquid aluminum supply system driven by electromagnetism pump is adopted in DHXV and DXV squeeze casting machines produced by Toshiba Company.

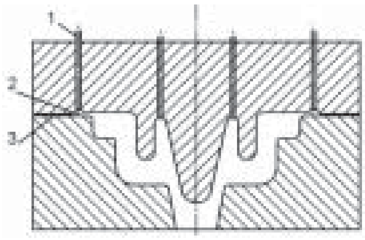


1-Material tank; 2-Squeeze punch; 3-Metal transportation pipe

Fig. 7 Pipe-type liquid metal squeeze equipment (from lower to upper)

c. If spoon pouring method is used, slag on the surface shall be skimmed before squeeze to prevent it from entering the cast parts.

d. Joint (parting) surface of mould, especially at the terminal of liquid flow, is the location of meeting point of two liquid flows. At such locations, slag trap shall be installed with a depth of 3-5 mm, while its size and shape can be adjusted according to casting/design requirement. Normally, a slag trap and a pushing bar shall be installed on moving mould. (as shown in Fig. 8)



1-Pushing bar; 2-Slag trap; 3- Air exhaust passage

Fig. 8 Design of air exhaust and slag collection of mould

3.3 Measures for air exhaust in mould cavity

(1) Exhausting the air with hole on pushing bar

Pushing bar on mould is used to push the cast parts for demoulding. When pushing the cast part, the gap between pushing bar and the hole on it will be cleaned, and the filled material and trash such as paint, metal burr and oxide will be removed so that air can be exhausted smoothly. Therefore, during mould design, pushing bar will be furnished specially for air exhaust, particularly for cast parts not being able to exhaust air from the parting surface (or mould joint face).

(2) Air exhausting through joint face

Joint face on mould is usually installed with air exhaust slot, the recommended size of which is 0.05-0.1 mm deep and 5-20 mm wide. During each squeeze casting procedure, flash and burr may be sprayed into air exhaust slot, so the air exhaust slot shall be designed for easy cleaning. In most cases, air exhaust slot on joint face shall be connected in series with slag trap and work with pushing bar for gas exhaust and slag collection (Fig. 8).

(3) Special air exhaust measures

To exhaust air more completely, special air exhaust measures are usually necessary for cast parts with higher requirement, such as to furnish air exhaust block and valve and to use vacuum pumping system.

Figure 9 shows a kind of concentrated air exhaust structure with a "washboard" air exhaust block. It exhausts air by using wide passage, and prevents spraying of liquid metal by using zigzag passage for barrier and condensation. Air exhaust block and the exhaust passages within the mould cavity shall be connected and kept with open condition at all time so as to improve air exhaust during the filling process of liquid metal. The outlet of air exhaust block may be connected with air suction equipment to exhaust the air more smoothly.

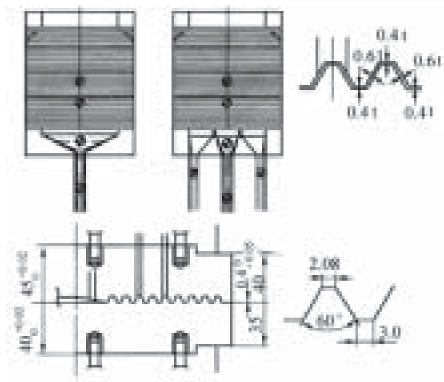


Fig. 9 Air exhaust block

There is a kind of vacuum liquid squeeze casting system [6] which uses a valve handle to control vertical air extraction hole to vacuum the system through a horizontal air extracting hole. The vertical air extraction hole links with mould impression by connecting an air exhaust trench and several air exhausting slots. By using this type of mould, the authors have produced high quality aluminum alloy parts for automobiles and motorcycles with squeeze casting process.

When producing large vehicle aluminum wheels on VSC squeeze casting machine, YBE Japan has also used air exhausting valve system with vacuum pump, and applied for a series of patents. The principle of this structure is that valve is opened and can be used for air extraction when liquid metal flows into the mould. Once liquid metal touches valve core, the valve will close quickly to prevent liquid metal from entering vacuum pump system. This device is also equipped with a set of electric circuit control system.

All major die casting machine manufactures have developed their own vacuum air exhaust devices, while squeeze casting moulds can be referred or directly used in most cases.

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