Defects caused by air bubbles during casting filling process: A review

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Abstract

In casting process, there always arises a chance of entrapment of air bubbles and formation of oxides which are the primary causes of defects in it. Poor design of filling system and high velocity of metal flow are the main reasons behind the air gap and oxide formations. The presence of air and oxides usually decrease the mechanical strength of the cast material. The defects like bubble trail are due to presence of larger air gaps. Due to the oxide formation, cracks are developed in the casting. It is possible to pour the molten metal without forming oxides and avoiding air aspiration by the development of improved filling system. It has been found that by the usage of submerged gate casting method, the gate velocities are managed so as to minimise for a turbulence free flow.

Keywords

Casting defects, Air bubbles, Oxides, Filling system , Submerged gate

1. Introduction

Casting is the oldest and mostly used manufacturing process among all other processes. For making fundamental products from raw materials, casting is the most economical technology [1]. Any kind of material whether it is ferrous or non-ferrous can be easily cast. As the molten metal flows into a small section in the mould, any shape can be made by the casting process. Sand casting is the oldest casting process, dating back at least 2000 years. Sand casting is a versatile process and can cast various complex shaped products. The size of casting can vary from a few grams to several tones.

With complex and complicated mould cavity, there are chances of defects within the casting. The complicated solidification and filling process can induce defects within the casting. The defects can arise due to improper design of mould, filling process, moulding material and some metallurgical defects. It is essential to complete a casting process without defects. The defects like blowholes, openholes, air inclusions are seen due to air bubbles and moisture content in the moulding sand, while other defects like shrinkage cavity are due to the improper design of the mould cavity. The pouring temperature of molten metal also causes defects like misrun, coldshut, etc. Defects due to entrainment of solid film results in cracks of thickness few nanometre which is invisible to most of inspection techniques. As per Campbell [1], all defects can be minimized by going through the fundamental causes of defects.

2. Defects caused by air inspiration

The folding-in mechanism of liquid surface causes entrainment defects. The entrapment of air bubbles during filling of molten metal causes the defects like air inclusion and pin holes. Small air bubbles are source of microporosity in casting. While the larger bubbles having diameter larger than 5 mm have enough buoyancy to overcome the oxide layer and form bubble trail. Due to the air gap, a void space is created inside the cast part and it adversely affects the strength of the casting. The metals like aluminium and aluminium alloys are very prone to make oxides when comes in contact with air. Improper design of filling system causes higher metal flow velocity which causes the surface turbulence. With the turbulence of molten metal small air pores use to get entrapped within the casting forming own oxide layers as shown in Fig. 1. The smaller bubbles don't have enough buoyancy to burst its own oxide layer and oxide layer of the casting surface. The smaller bubbles rest in depth under the surface while the larger bubbles with diameter 1 to 5 mm have enough buoyancy to burst and come out of the casting. The oxides trapped inside during pouring are the young oxides which creates new front for the solidification, thus disturbing the directional solidification. The mixture of bubbles and oxide bubble trails are known as bubble damage. Bubble damage is most common in casting process and it causes 80% of casting defects.

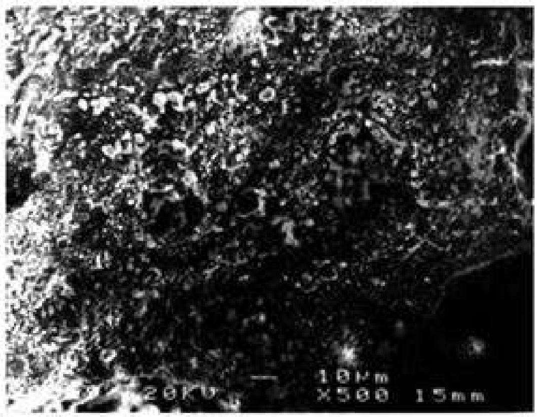

Fig. 1 Granular oxide inclusion

The design of sprue and runner should be such that the air gap during filling of molten metal should be avoided. The metal should flow without creating gaps between the layers. During gravity filling system, there is a chance of increasing the velocity causing incomplete flow and flow separation. Air presents between the layers go to the deep inside the casting and can't escape before the metal freeze. Some of the bubbles which burst at the surface affect the surface roughness of the casting (Fig. 2).

Fig. 2 Gas porosity

During sand casting, the moisture content in the moulding material causes the defects like blow holes and open holes. Due to the high temperature of molten metal, the moisture content gets evaporated and trapped inside the casting. The open holes are seen on the surface of the casting while the blowholes are present inside the casting (Fig. 3), which can't mix with the molten metal and creates a free space within the casting. It is a very time-consuming process to remove or repair these oxide defects. These oxide defects affect machining and mechanical properties of the cast parts which leads to the casting rejection [2].

Fig.3 Blow holes

3. Defects due to sand inclusion

Surface turbulence folded in the surface forms high flow velocity causing turbulence, so there is a chance of sand wash in sand casting. With insufficient ramming of sand mould, the sand particles could not bond with each other. The sand particles move with the molten metal and get inside the casting. Some of the particles react with the metal creating hard brittle like structure (Fig. 4). The presence of oxide layer acts as a mechanical barrier for the sand grains. It is not easy to find out how minute sand grains enter the surface against the repulsive action of surface tension. Sand inclusions are the sign of poor design of filling system. These defects can be avoided by providing sprue base where heavier sand particles get trapped and don't enter into the casting.

Fig.4 Sand Inclusion

4. Casting filling process

The above discussed defects can be partially eliminated by improving the filling process. During sand casting, the filling process is generally gravity filling system. In this system, the velocity at the gate is generally higher as compared to that of the pouring velocity. Due to high velocity, the fluid exhibits turbulent flow and gives rise to formation of oxide layer [3] and air get trapped within it. The filling process is crucial to casting quality industry.

Inclusion defects are significantly affected by free surface condition, gate velocity and the flow distribution during filling.

As per Wang and Yao [4], top gate filling system causes sand inclusion while decreasing the pouring time. While bottom gate filling system allows smooth free surface which is beneficial to reducing film inclusions for larger casting [5]. The flow condition near the gate is the key factor affecting the inclusion defects. It is also important to fill the mould before the molten metal gets freezed. So the pouring time should be less while the velocity should be higher to counter it. So it is required to have a higher flow velocity while slowing down at the ingates. The kinetic energy of the fluid at the ingates is so high causing sand inclusions. If some part of the kinetic energy is converted to some other energy forms, then the required velocity will be low and will allow a smooth surface flow.

Wang et al. [6] designed the submerged gate casting method which is useful to eliminate turbulent flow. In this method, the surface of the molten metal is stable and the flow is laminar. Air bubbles don't go to the deepest, so it is easy for air bubbles to come out of the molten metal. The defects like air inclusion are shown nearer to the gate (Fig. 5).

Fig.5 Casting produced by submerged gate casting method

Young oxide layer formed during casting are due to the turbulence flow of the metal and contact of the metal with the air. By the elimination of turbulent flow, the oxide formation is limited to only in the ladle. The stable feeding enables a directional solidification and complete filling of the mould, thus shrinkage cavity is avoided.

It is always desired to keep the liquid metal velocity under a critical value. To keep low velocity, non-pressurised gating system is chosen. But the formation of clockwise vortex flow pushes the liquid metal with high velocity into the mould. So it is concluded that both non-pressurised gating system and bottom gate filling system can avoid turbulence [7]. As per Campbell and Green, the mechanical strength depends upon the surface turbulence during casting which is due to crack formation within the casting [8].

5. Discussion

From the present study, it has been found that for better casting, it is required to have a smooth surface flow and stable feeding. Wang et al. [6] describes that by improving the filling condition using submerged gate will reduce the inclusion up to some extent. With the advancement of technology like CAD/CAE, process technology, control engineering, inspection technology; it is possible to investigate the fundamental causes of defects in casting.

The research on principle of gating done by Grube et al. [9] showed that dross formation during pouring of molten metal is owing to entrainment of air. Divandari and Campbell [10] found that chemical interaction between the molten metal and the mould or core materials leads to fine subsurface precipitated pores.

6. Conclusions

The fundamental cause for defects like blow holes, open holes, oxide formation is due to the nature of the fluid flow. Generally, the flow nature in gravity filling condition is turbulent which enhances the distributed surface of molten metal causing air inclusions. The turbulent region is restricted to a small zone as compared to gravity filling system in case of submerged gate system. By changing the flow direction, the impact velocity at the mould wall reduces and thus it decreases sand wash defects. As the gap between the free surface and the gate remains relatively small, the low density slags and air bubbles come to the surface by drag force and buoyancy. It helps in reducing the air bubbles inside the casting.

References

[1] Campbell, J. (2003). Castings. Second ed. Burlington: Butterwworth-Heinemann.
[2] Melendez, A. J., Carlson, K. D., Beckermann, C., (2010) Modeling of reoxidation inclusion formation in steel sand casting: Cast metals research, 23, 278-288.
[3] Dai, X., Yang, X., Campbell, J., Wood, J. (2004). Influence of oxide film defects generated in filling on mechanical strength of aluminium alloy castings. Mater Sci Technol; 20: 505–513.
[4] Wang, T., Yao, S. Shen, W.,(2015). A submerged gate casting method.
[5] Cox, M., Wickins, M., Kuang, J.P., Campbell J. Effect of top and bottom filling on reliability of investment castingin Al, Fe, and Ni based alloys, Mater Sci Technol 2000;16:1445-52
[6] T. Wang, S.Yao, Q. Tong, L. Sui. Improved filling condition to reduce casting inclusions using the submerged gate method: 2017.
[7] N. R. Green and J. Campbell: Investigation of molten metal flow pattern during the vertical ingate filling in non-pressurized bottom gating system in A356 alloys: AFS Transaction, 94, 341– 347, 1994.
[8] J. Campbell, N.R Green, Influence in Oxide Film Filling Defects on the Strength of Al-7si-Mg, Transactions of the American foundry society, 114,341 -347,1994.
[9] N. R. Green and J. Campbell: Investigation of molten metal flow pattern during the vertical ingate filling in non-pressurized bottom gating system in A356 alloys: AFS Transaction, 94, 341– 347, 1994.
[10] Divandari, M., J. Campbell: Mechanisms of bubble damage in castings. PhD Thesis, University of Birmingham, 2001