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Identification and Control of Micro porosity for Al-Alloy Wheel Castings

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***Abstract* -The Al-alloy wheel of a motor car made of has to fulfill the quality of cast products directly depends on the quality of molten metal from which the products are cast. Porosity in castings contributes directly to customer concerns about reliability and quality. Controlling porosity depends on understanding its sources and causes. Fine distribution of porosities reduces the effective porosity. If there is no porosity coarser and finer grains will have same strength. Hence porosity determines the strength of the Al alloy castings. The porosity in the specimens was controlling the fatigue life to a greater extent than was the heat treatment. In this paper the analysis was done on Al alloy casting wheel to study the micro porosity by varying the parameters such as metal charge ratio, amount of refiner and degassing time. The grain refinement is done by combined rotary and flux feeding method with 5Ti1BAl (5%Ti, 1%B and Al – Rem.) grain refiner.**

Keywords: Aluminum alloys, micro porosity, refiner, modifier, degassing.

I. INTRODUCTION

The wheel of a motor car is an important component which has to fulfill a variety of technical requirements such as strength, elongation, pressure tightness etc. Aluminum wheels improve driving comfort by reducing the un-sprung mass and also lower brake disc temperatures, due to better heat conductivity. During wheel design aluminum casting processes give the greatest freedom. Low pressure die casting has become the most commonly used casting process for producing aluminum wheels in economic large scale production. Even though higher initial material cost as compared to steel can be compensated by the higher recycle value of aluminum. The main advantages by the use of aluminum in automobiles are the gasoline savings by light weighting and the excellent recycling properties of aluminum [1]. Al castings continuingly replacing the steel and other metals due to weight reduction, vibration absorption capacity, ductility, higher strength/weight ratio, crack resistance and slow crack progression, high thermal conductivity, low heat capacity, corrosion resistance, easy recycling etc. in automobile and other engineering applications [2-5] .Si is the most important element to be combined with Al since it imparts the progressive increase in the fluidity [6-8]. Pure Si is extremely hard and brittle. It is essentially insoluble in Al at room temperature. In cast alloys (A356) free Si is in the form of plates or needles. If the size is relatively large, the Si particles will rip and tear from their soft Al matrix causing many problems during machining. It is to note that the porosity increases with decreasing the degassing time and depending on the application, the size and/or quantity of porosity to be allowed may vary considerably. High performance aerospace castings will generally allow none, while commercial automotive cylinder heads will have critical requirements in areas like the combustion face, and noncritical automotive parts [9]. Studies have demonstrated that whenever present at or near the specimen surface, these defects can cause rapid crack initiation and crack growth will dominate the fatigue behavior [10].Porosity in castings have been classified by the size of the pores as macro porosity and micro porosity and by the cause for the pores forming as shrinkage porosity and gas porosity [11-12]. Micro porosity is a familiar defect in long freezing range alloys and/or when the temperature gradient is low. These conditions create an extensive and uniform pasty zone which is favored by metals of high conductivity, such as aluminum alloys, high mould temperatures, as in investment casting, thermal conductivity of the mould, as in sand, investment or plaster low moulds [13-14]. In such cases, towards the end of solidification, there will be a 'pasty' or 'mushy' zone consisting of a forest of dendrites enclosed in the remaining liquid. Fig. 1 shows a simple bar-shaped casting with a feeder at one end [15].

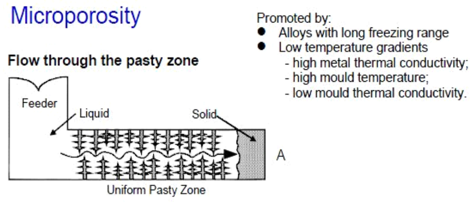

Fig 1: Formation of micro porosity [15]

II. PRODUCTION OF ALUMUNIUM CASTING

This work was carried out in Synergies Castings Ltd., Visakhapatnam. The casting under consideration was automobile Al-alloy wheel casting is being used for world class passenger cars. Fig 2 shows the flow chart for production of wheel castings.

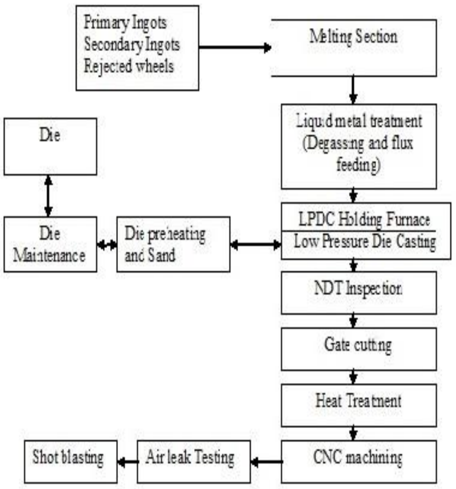

Fig 2: Foundry Flow Chart for production of wheel castings

Sr. No.	Parameters	Quantity required
1	Rotor Speed	400-450 RPM
2	Flux flow rate	40-60 g/min
3	Argon gas flow rate	4-5 kg/cm^2
4	Degassing time (a) Argon gassing + Fluxing Sr-modification + Argon gassing (for machined wheels) (b) Argon gassing + fluxing Argon gassing + Sr – modification (for chrome painted wheels)	8 min. 2 min. Total time - 10 min 10 min. 10 min. Total time- 20 min
5	Grain modifier Al-Sr-5 Al-Sr-10	800g/400 kg of molten metal 480g/400kg of molten metal

TABLE II: Operation parameters for degassing and feeding

TABLE I: The Specifications and chemical composition of Al-5Ti-1B

Ti	B	Fe	Si	V	K	Al
4.79	0.99	0.11	0.05	0.10	0.04	remaining

The normal Charge Ratio: 70:30 (Primary ingots: Rejected Wheel: Secondary ingots) and sometimes 100% (only primary ingots) is used for wheel production. The Primary Ingots are the charge material in the form of ingots having narrower composition range of one or more of the elements all within the composition limit. The secondary ingots produced from melting of machined chips and scrap in scrap melting furnace

III. MELTING OPERATION

Medium frequency coreless induction furnace of 1.2 Ton capacity was used for melting. Before start of melting, melting tools used in processing the melt were given the desire coating to avoid contamination of the liquid metal. The molten bath was covered with a flux called coverall-11 to remove the oxides and to prevent excessive oxidation. After reaching the melt temperature to 745±5^{0}C and required composition (checked by means of spectrometer), molten metal was tapped into a preheated (400) ladle.

IV. MELT TREATMENT

Just before tapping the molten metal into preheated ladle (Capacity- 400 kg Al) for grain refinement, 0.8 kg of 5Ti1BAl (5%Ti, 1%B and Al – Rem.) grain refiner was added into the empty ladle. It is done to produce a finer, equiaxed grains during solidification. The combined rotary and flux feeding method is used for this purpose. Table 2 lists the operation parameters for degassing and feeding. The combined degassing and fluxing Fig. 2 was done for effective removal of dissolved hydrogen and the oxides from the melt respectively. The graphite rotor was cleaned in order to ensure that the gas passages were not clogged with the solid particles. The preheated ladle with molten Al was placed on the platform of degassing machine. Argon gas at a required pressure with a metered supply of flux powder was made to pass through the melt for 8 minutes and 10 minutes respectively in case of machined wheel and chrome plated wheel, while the shaft is rotating at a speed of 400-450 RPM. After completion of this cycle the dross formed was skimmed. Then the molten metal was modified with Sr and Argon gas was allowed to pass for the next 2 minutes and 10 minutes respectively in case of machined wheels and chrome plated wheels and the shaft is rotating at a speed of 400 RPM. The dross formed was skimmed away.

V. EXPERIMENTAL PROCEDURE

The micro porosity formation on spoke portion of the wheel casting was identified and a sample of spoke portion was taken for microscopic examination. The charge ratio, % Ti-B-Al addition/% of Sr-addition and degassing time maintained for the production of above wheel casting was noted down.

Metal charge ratio: 70:30(primary ingot rejected wheels)
5Ti-B-Al addition: 1.1kg (at the melting stage)
0.9kg/tap (at the holding furnace)
Al-Sr-addition : 400g
Degassing time : 10+5 = 15min (degassing + fluxing) + (degassing)

Now maintaining other process parameters melt temperature and pressurization stages and cooling parameters in LPDC machine as earlier, some changes have been made in the charge ratio, % of grain refiner/modifier addition and degassing time.

2nd stage changes

Metal charge ratio: 100% primary ingots
5Ti-B-Al addition: 1.1kg (as in previous stage), 1.5kg/tap (increased from 0.9 to 1.5kg)
Al-Sr-addition: 800g (increased from 400g to 800g)
Degassing time : 10+10 = 20min (degassing + fluxing) + (degassing)

After these changes the control of micro porosity on spoke portion was being observed visually and through microscopic examination. Again by making some changes in degassing time and Sr-addition (modifier addition) the micro porosity on spoke portion was observed both visually and through microscopic examination.

3rd stage changes

The above changes were continued as they influenced in controlling the micro porosity.

Metal charge ratio: 100% primary ingots
5Ti-B-Al addition: 1.1kg (as in previous stage), 1.5kg/tap (as in previous stage)
Al-Sr-addition : 1200g/tap (increased from 800 to 1200g)
Degassing time : 20+10 = 30min (degassing + fluxing) + (degassing)

VI. RESULTS AND DISCUSSION:

The micro porosity formed on spoke portion was controlled by adopting effective melt treatments and charge quality.

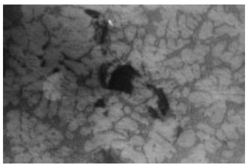

Fig 4(a): 1st Stage

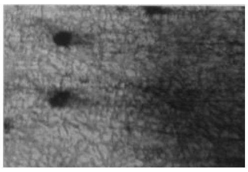

Fig 4(b): 2nd Stage

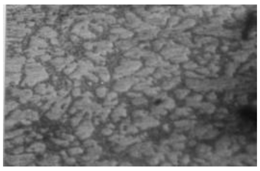

Fig 4 (c): 3rd Stage

Fig 4: As cast Microstructures of micro porosity in spoke region of A356 Aluminum wheel produced by Low pressure permanent mold at 3 stages; 100X.

It has been observed from Fig. 4 that the micro porosity is controlled from 1st stage to 3rd stage in addition the refinement of α - dendrites in 2nd stage due to increased grain refiner/modifier and the coarsening of grains in 3rd stage due to increased degassing time is observed.

A. *CAUSES IDENTIFIED FOR MICRO POROSITY*

The causes of micro porosity can be due to keeping the holding furnace ideally up to the finish of die maintenance, there will be some moisture (i.e. hydrogen) pickup in the holding furnace due to air entrapment. The other reasons can be before arrival of the molten metal ladle to the holding furnace, there is also some moisture pickup, but it is inevitable, the variation of Dew point temperature (DPT) in the Drier form standard value of 3.5 to 4.5^{0}C, moisture pickup by the charging ingots from atmosphere, the variation in the temperature of the molten metal from 745±5^{0}C, due to poor control at the melting furnace, difficulty in feeding the solidification shrinkage upon solidification of the wheel casting. The micro porosity is formed as a consequence of two mechanisms and are Micro shrinkage; due to difficulties in interdendritic feeding and Gas porosity; due to hydrogen segregation to the last portion of liquid. Especially long freezing range alloys develop dendrite solidification and propitiate micro porosity and surface sink defects.

B. *EFFECT OF GRAIN REFINEMENT ON MICRO POROSITY*

As the solidification progresses, the impingement of various dendrites leads to the formation of a rigid inter connected network is known as the dendrite coherence point. After the coherence point the solidifying mass looses the characteristics of a viscous liquid and becomes a solid paste, like butter or ice cream. The mobility of the liquid beyond this point is very reduced, since the metal has to flow through the dendrite network to feed the solidification shrinkage. As a consequence the potential to micro porosity formation grows with the solidification progress since the interdendritic permeability has been reduced. It is surprising that dendrite coherency occurs for small solid fraction, such as 19% in A356 alloy. At higher solid fraction, the dendrite permeability becomes lower and the mechanical strength of dendrite network higher, so both feed mechanisms interdendritic feeding (flow of the melt inter dendritically), Burst Feeding (The rupture of the dendritic network opening channels through which the melt flows easily) fail, developing internal defects such as micro porosity and shrinkage cavity. So that to improve the feeding characteristics for compensating the solidification shrinkage the grain refinement is used. The higher solid fraction to the dendrite coherency obtained in the grain refined condition promotes the better feeding condition and lower micro porosity size, since the mass feeding performance is extended. The grain size reduced by refinement avoids the difficulty of interdendritic feeding because the feeding distance is short.

C. EFFECT OF GRAIN MODIFICATION ON MICRO POROSITY

Sr – modification is often associated with an increased in porosity above that of unmodified alloy and also a redistribution of porosity from macroscopic shrinkage porosity to well dispersed micro porosity. The solidification temperature range is increased due to the under cooling effect by the Sr addition and feeding resistance by dendrites is expected to increase. However the modified eutectic – liquid interface becomes more planer. Therefore feeding through the channels of modified eutectic grains would be less restricted than through unmodified grains, resulting in less porosity in modified castings. The distribution of pores was controlled by the relatively smaller number of large modified grains.

D. *EFFECT OF MELT TEMPERATURE AND MELT HANDLING ON MICRO POROSITY*

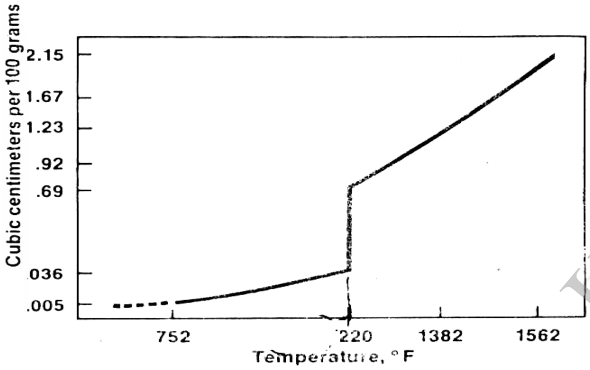

Fig 5: Effect of temperature on the solubility of hydrogen in Aluminum

The temperature of the molten metal determines the amount of hydrogen absorbed. As the temperature rises, the volume of hydrogen taken into solution increases rapidly. Solubility in the solid metal is practically nil; however, it jumps from a very small measurable quantity at just below the melting point to over 0.7cm3/100g when the metal is molten at a little above the melting point. Alloys with a hydrogen content of less than about 0.01cm3/100g remain practically free of gas pores and blisters. The precautions to be taken are: strict control in melting furnace without crossing the 745±5 0C, because at >750t 0C here will be large pickup for hydrogen. So that melt temperature should not exceed 7600C.The molten aluminum surrounds itself completely with a thin envelope of oxide. As long as this oxide layer remains unbroken, the rate at which the gas is absorbed by the melt is quite low. So that agitation should be avoided or at least held to a minimum. Long holding times in the molten state, must be avoided as there will be pick up for hydrogen.

E. *EFFECT OF H2 GAS AND DEW POINT TEMPERATURE ON MICRO POROSITY*

Hydrogen is highly soluble in liquid Al metal; however this solubility drops drastically to a minimum when Al solidifies. The Hydrogen rejected from liquid metal during solidification leads to micro porosity on castings. This can be controlled through careful and effective degassing for the removal of absorbed H2.The air injected from a Drier to the LPDC machine must be controlled to maintain DPT of Dry air not to cross 4.5 to 5 0C. Otherwise there will be larger moisture pickup in the Holding Furnace melt and this absorbed hydrogen in the melt through moisture will leads to micro porosity. To know the effect of grain refiner/modifier and charge quality on micro porosity the other parameters melting temperature, method of melt transfer, effective degassing procedure were maintained as per the standard practical rules. The control in micro porosity from stage to stage was due to increase in grain refiner/modifier addition, charge quality and effective degassing, without affecting the mechanical requirements of wheel castings. With a high degree of grain refining the dendrite morphology is quite round probably with a smaller number of impingements, resulting in a less rigid dendrite network. Which in turn results in effective feeding during solidification and thereby controlled micro porosity is observed. Also the feeding capability was significantly improved by the simultaneous treatment of grain refining and eutectic modification, as the significant reduction in grain size by the use of both modification and grain refinement. This is turn resulted in control of micro porosity. Whereas with high degree of grain modification the micro porosity was controlled from stage to stage as the tendency of redistribution of porosity from macroscopic shrinkage porosity to micro porosity would be more. Now the increase in degassing time from stage to stage was resulted in control of micro porosity as it involves effective degassing for the removal of soluble H2 in the liquid metal. But with the increase in degassing time the loss of Ti, B and Sr will be more, to compensate these losses the grain refiner (Ti-B-Al)/modifier (Al-Sr) additions from stage to stage was increased. As the rejected wheels in the charge would pick up some moisture before they are charging into the furnace, which in turn leads to the generation of H2 gas and thereby micro porosity would be more. With a change in charge quality without using rejected wheels the control in micro porosity was observed.

CONCLUSION

The experiment revealed that micro porosity formed on spoke portion was controlled by adopting effective melt treatments and charge quality. The micro porosity is controlled from 1st stage to 3rd stage in addition the refinement of dendrites in 2nd stage due to increased grain refiner/modifier and the coarsening of grains in 3rd stage due to increased degassing time is observed. The causes that can create micro porosity and the effect of grain refinement, modification,melttemperature,H2gasetc.,havebeenidentified.

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