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Effect of Casting Design on Shrinkage Porosity and Microstructure in Hollow Cylindrical Aluminium-4.5% Copper Alloy Casting

Mr. Rajkumar Sreepadapu[1], Dr.Amol A. Gokhale[2]

[1]Head of Mechanical Engineering Section, Sanjay Gandhi Government Polytechnic, Adilabad-Telangana State, India

[2] Scientist-F, Defence Metallurgical Research Laboratory, Hyderabad, Telangana State, India

Abstract: With the increasing use of Aluminium foundry alloys for automotive and aerospace components the Aluminium industry has to focus sharply on the quality and reliability of such components. One of the biggest problems in Aluminium castings is porosity, caused mainly by solidification shrinkage and the evolution of dissolved gases. The presence of porosity is inevitable to a certain extent in any casting, can be very detrimental with respect to the mechanical properties. In general Aluminium alloys solidify over a wide temperature range, and therefore, their solidification mode is of the mushy type. Also, due to good thermal conductivity and high latent heat, it is difficult to maintain steep temperature gradients during casting solidification. When suitably designed, risers can eliminate macroporosity, but may not be effective in preventing microporosity formation in the inter dendritic regions. Other means such as chilling to establish favorable temperature gradients are required to achieve soundness.

In this project, the effects of casting design parameters i.e. section thickness, Taper, risers and chills on microshrinkage porosity and microstructure have been investigated experimentally in a wide freezing range Aluminium- 4.5% Copper alloy. Hollow cylindrical geometry castings, which are widely produced in automotive, aerospace and defence industries were sand cast under different designs. Cooling curves were recorded for different locations in the castings. Castings were subjected to X-ray radiography to evaluate internal soundness over the entire height. Castings were sectioned for density measurement and percent porosity values were calculated from the measured densities. Metallographic observations were carried out to characterize the type of microstructure, size and distribution of porosity. Results from the evaluations were compiled and correlated to the solidification parameters which, in turn were controlled by the casting design variables.

Key Words: Sand Casting, Aluminium Alloy, Cylindrical castings, Porosity.

1. INTRODUCTION & EXPERIMENTAL WORK

It was decided to study the effect of selected design variables on the microstructure and microshrinkage porosity in Al-4.5% Cu alloy hollow cylindrical sand castings made by CO_2 process. The changes in casting design are aimed at changing the fundamental solidification variables such as solidification time, temperature gradient etc. which are known to affect microstructure and porosity. In particular, the effects of four design variables were studied.

They are: casting section thickness, thickness taper, risering with exothermic sleeves and chilling bottom of the casting. Accordingly four types of experiments were planned.

In experiment 1, castings varying in thickness from 5 mm to 20mm which do not have taper, risers or chills were produced. These castings were used to study the effect of section thickness.

In experiment 2, casting with thickness of 5mm at the bottom were produced. One of the castings had no taper, while the remaining two had 1° and 2° tapers, respectively. These castings were evaluated for the effect of taper.

In experiment 3, castings with section thickness and tapers similar to those in Experiment 2 with the inclusion of four exothermic risers on the top were produced. Comparison of the evaluations of experiments 2 and 3 threw light on the effect of exothermic risers.

In experiment 4, castings similar to those in experiment 3 with bottom chills were produced to study the effect of combined risering and chilling.

In each experiment cooling curves were obtained during solidification of castings.

All the castings were subjected to:

*Chemical Analysis (to find the composition of alloy of castings)

*Density measurements (to calculate percentage porosity)

*Radiography (to understand location wise presence of porosity, hot tears, incomplete filling etc.)

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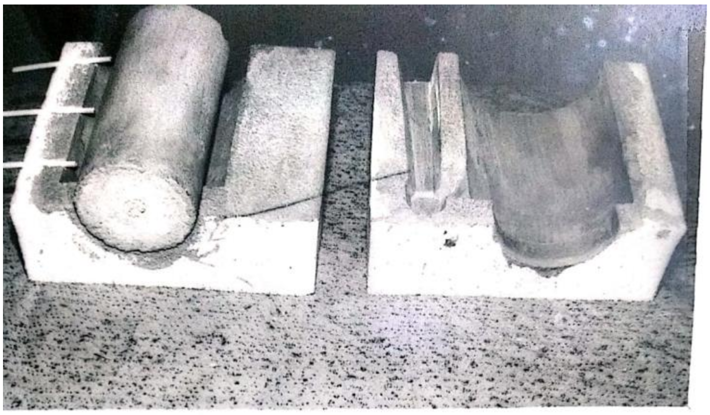
*Metallography (to characterize microstructure size, distribution of porosity).
*Results from these evaluations were compiled to understand the effect of the design variables on the microstructure and microshrinkage porosity.

1.1. SELECTION OF CASTING PROCESS

Sand is the principal moulding material in the foundry shop where it is used for all types of castings, irrespective of whether the cast metal is ferrous or non-ferrous. This is because it possesses the vital properties for foundry purposes. The most important characteristic of sand is its refractory nature due to which it can easily withstand the high temperature of molten metal and does not get fused. Secondly, moulding sand has chemical resistivity. It does not chemically react or combine with molten metal and can therefore be used again and again. Thirdly, sand has a high degree of permeability. It allows gases and air to escape from the mould when molten metal is pored without interfering with the rigidity and strength of the mould.
The degree of strength, hardness and permeability can be adjusted, as desired, by varying the composition of the ingredients of the sand. Such flexibility is extremely difficult to achieve with any other moulding material. Intricate parts can be cast easily with this process.
In this investigation, CO_2 process is used for mould and core preparation. It is a quick process. The mould is prepared with a mixture of sodium silicate and sand and then treated with carbon dioxide to get sufficent hardness.



Moulds prepared by CO_2 process.

Pouring of molten metal in to the mould

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Exothermic Risers, Mild steel Chills used in experiments. Also seen samples of microstructure and samples of density measurement.

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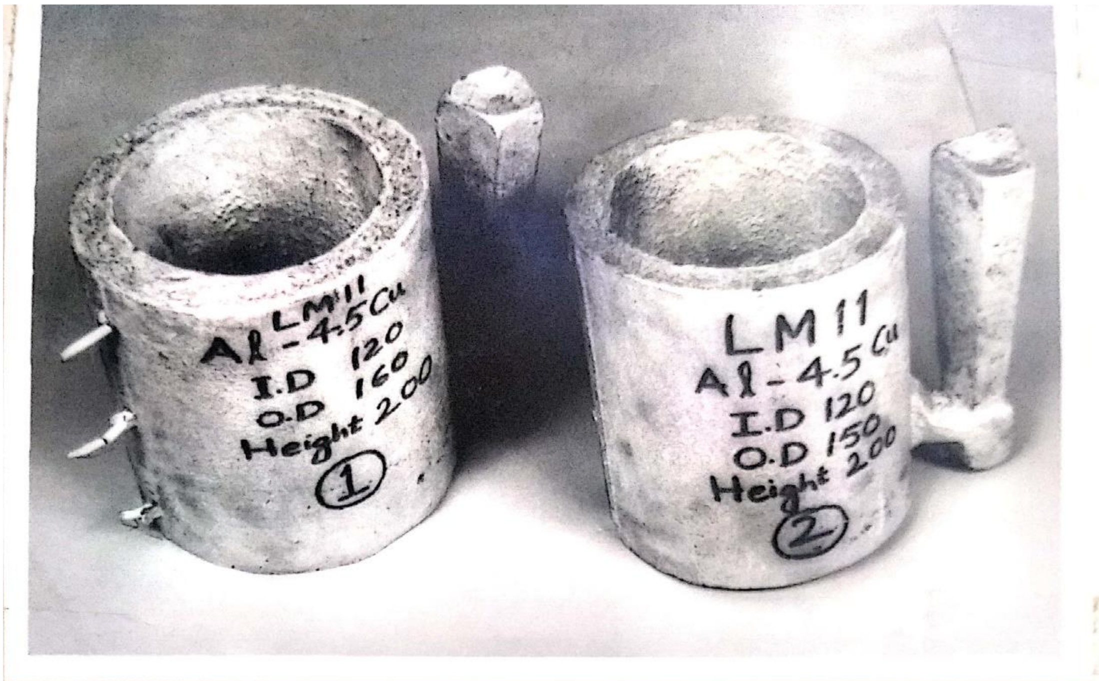

Castings of 15mm and 20mm thick and 200mm height produced without ta
risers or chills.

Castings of 10mm and 5mm thick and 200mm height produced without tap
risers or chills.

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S.No.	TABLE 1: EXPERIMENTAL WORK DONE DESCRIPTION	EXP-1 (Thickness Variation) (5,10,15,20mm)				EXP-2 With 0°,1°,2° taper (5mm thick)			EXP-3 With taper & Riser (5mm thick)			EXP-4 With taper, Riser & Chill (5mm thick)		
1.	Geometry of castings	Hollow Cylindrical				Hollow Cylindrical			Hollow Cylindrical			Hollow Cylindrical		
2.	Casting dimensions (mm)	5	10	15	20	5 ◦ 0	5 1°	5 2°	5 ◦ 0	5 1°	5 2°	5 0°	5 1°	5 2°
3.	Casting SYMBOL	C11	C12	C13	C14	C21	C22	C23	C31	C32	C33	C41	C42	C43
4.	Inner Dia. (cm)	12	12 -	12	12	12	12	12	12	12	12	12	12	12
5.	Outer Dia (Top) (cm)	13	14	15	16	13	13.7	14.4	13	13.7	14.4	13	13.7	14.4
6.	Outer Dia Bottom (cm)	13	14	15	16	13	13	13	13	13	13	13	13	13
7.	Height(cm)	20	20	20	20	20	20	20	20	20	20	20	20	20
8.	Vol.of casting (cc)	392	814	1271	1751	392	538	688	392	538	688	392	538	688
9.	Surface area of Casting(cm2)	1611	1720	1837	1960	1611	1633	1690	1611	1633	1690	1611	1633	1690
10.	Weight of Casting(Kg)	1	2.3	3.6	5	1	1.5	2	1	1.5	2	1	1.5	2
11.	Casting Modulus (Vol./S.A)	0.24	0.47	0.69	0.89	0.24	0.33	0.41	0.24	0.33	0.41	0.24	0.33	0.41
12.	Chemical analysis of casting(%Cu)	4.8 (EXP-1)				4.8 (EXP-2)			4.46 (EXP-3)			4.4 (EXP-4)		
13.	Dimensions of Exothermic riser (mm)	-							O.D 40 I.D 25 Height 50			O.D 40 I.D. 25 Height 50		
14.	Riser modulus	-							6.25			6.25		
15.	**Dimensions of Mild Steel Chills (mm)**	**-**							-			**Length 10 Width 10 Height 70**		
16.	**Location of Chills**	**-**				-			-			**Around core at the bottom.**		
17.	**Room Temp.**	**34°C**				**33°C**			**27°°C**			**28°C**		
18.	**Mould Temp. before pouring**	**63°C**				**65°C**			**58°C**			**38°C**		
19.	**Pouring Temp.**	**725°C**				**725°C**			**725°C**			**725°C**		

TABLE : EXPERIMENTAL WORK DONE AND CASTING DESIGN PARAMETERS

2. RESULTS & CONCLUSIONS

On the basis of experiments conducted and analysis of the results, the following conclusions have been drawn:

1. Tapering, Risering and Chilling resulted in achieving positive thermal gradient towards top of the castings.
2. Inside of the hollow castings has coarser structure compared to outside due to the lower cooling rates at the inner surface.
3. In most of the castings the tapering, risering and chilling shifted the maximum porosity to the top.
4. As the cooling rate decreased the grain size and dendrite arm spacing (DAS) increased causing coarse porosity.
5. The use of chills increased the cooling rate and resulted in clear separation of cooling curves at different locations, thus resulting in progressive directional solidification.

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6. To achieve porosity free castings the control of directional solidification as well as controlling of other parameters like sufficient heating of mould, grain refinement, degassing etc. is required.
7. The experimental work should be carefully planned, in particular variations in molten metal treatment and moulding conditions should be minimized. The grain refinement and the level of dissolved gas will have a significant effect on the amount and distribution of microporosity. The pouring of all test castings at the same time with the same melt minimize the differences.

3. LIMITATIONS

During the experimental investigation, the following limitations restricted the area of the present work.
1. Due to limited number of channels (only four) in temperature recorder, cooling curves could not be obtained from all castings simultaneously.
2. Separate melts caused variation of percentage of copper and other conditions.
3. The time taken to conduct each experiment took long time due to the involvement of human efforts.
4. Degassing could not be standardized due to the lack of availability of liquid metal Hydrogen gas analyzer.
5. Seasonal effects on humidity: More humidity cause more absorption of hydrogen which results in increased porosity.
6. Mould temperatures before pouring varied from one experiment to another experiment.
7. The microstructural observations are localized. More statistical data should be collected from a large number of samples for better reliability and reproducibility.

4. FUTURE SCOPE OF WORK

1. Computer simulation can be done with the observations obtained in these experiments.
2. The experiments can be conducted with increasing risers size and changing the chill material and distance from the casting.
3. Experiments can be conducted with controlled Hydrogen content in the melt.
4. Temperature recorder with more number of channels can be used to record thermal history of all the castings for better comparison.

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