STUDY OF EFFECT OF COOLING RATE ON MECHANICAL AND TRIBOLOGICAL PROPERTIES OF CAST Al-6.5Cu ALUMINUM ALLOY

S.Ilangovan[1], SaiKrishna Viswanathan[2], Gopath Niranthar K[3]

[1]Assistant Professor (SG), Department of Mechanical Engineering Amrita School of Engineering, Amrita Vishwa Vidyapeetham Coimbatore, Tamil Nadu, India
[2]Third Year B.Tech, Department of Mechanical Engineering, Amrita School of Engineering, Amrita Vishwa Vidyapeetham Coimbatore, Tamil Nadu, India
[3]Third Year B.Tech, Department of Mechanical Engineering, Amrita School of Engineering, Amrita Vishwa Vidyapeetham Coimbatore, Tamil Nadu, India

Abstract

Solidification time is known to have a large effect on the microstructure of cast Aluminium alloys and hence its properties. This study is conducted to quantify how the mechanical properties of Al-6.5 Cu alloy vary with respect to the solidification time. The solidification time is varied by varying the diameter of the cast rod; this is based on the Chvorinov's rule which gives a relation between solidification time and surface area, volume of the specimen. Mechanical properties such as Ultimate Tensile Strength, Micro- hardness are observed by experimentation and change in microstructure for all the different specimens are also studied and inferred. It is observed that as the solidification time increases, the mechanical properties tend to decrease. Further the coefficient of friction is independent of the hardness and weight loss is dependent on hardness of the alloy.

Keywords: *Solidification time, Chvorinov's rule, grain structure, hardness, Ultimate Tensile Strength.*

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1. INTRODUCTION

The wide variety of properties (appearance, light weight, fabricability, physical properties, mechanical properties, and corrosion resistance) possessed by aluminium makes it an automatic choice for several industrial applications. It is widely used in almost all industries [1]. Since pure aluminium has poor mechanical properties, to enhance the properties, aluminium is generally alloyed with other metals like copper, zinc, magnesium and manganese. Aluminium alloys have been used as substitute materials in automobile industries. Grey iron has been substituted by aluminium alloy for better fuel economy [2]. Aluminium copper alloys are widely used and have major role in aerospace and light weight applications [1].

The ultimate physical and mechanical properties of the cast metal will depend upon both intrinsic factors (chemical composition, cooling rate during solidification and heat and mechanical treatment after solidification) and extrinsic factors (metal cleanliness, additives for microstructure control, casting design, riser and gating design, solidification rate control, and temperature control subsequent to solidification) present in each casting event and in the processing events subsequent to casting [3,4].

Out of the several methods that have been experimented to improve the properties of Al-Cu alloys it was studied that the rapid cooling technique increase the mechanical and tribological properties of the alloys as desired [5].

Cooling rate can be determinant of material properties. Areas of casting that tend to cool rapidly have better mechanical properties as compared to the slowly cooled ones. For the ones with rapid cooling rate, the deposition of partially soluble compounds at the boundaries is very less; hence these areas have better mechanical and tribological properties [6].

The microstructure and lattice structures may vary depending on the temperature and rate at which cooling occurs. The subtle changes produce a marked effect on the properties of cast component [7].

Some mathematical equations have been developed to get relationship between cooling rate and the mechanical and tribological properties of casting [8]. One such relation is Chvorinov's rule. Therefore the purpose of this work is to show the effects of cooling rate on mechanical and tribological properties of Al-6.5Cu alloy on the basis of Chvorinov's rule.

2. EXPERIMENTAL PROCEDURE

2.1 Melting and Alloying

Moulds of different sizes (varying diameter from 15 to 35 mm with the increment of 5 mm and keeping the height constant as 150 mm) are made to obtain different cooling rates (based on

Chvorinov's rule). Commercially available aluminium AA1100 is melted and alloyed with electrolytic pure copper in a crucible furnace. The melt is poured into sand moulds. After solidification the cast rod is tested for its composition using spectroscopic analysis. Figure 1 shows the cast rods of the alloy.Table-1 shows the composition of the cast alloy.

Fig – 1: Cast alloy rods

Table - 1: Composition of the Al-Cu alloy

Element	**Al**	**Cu**	**Fe**	**Si**	**Zn**	**Mn, Sn, Ni**
% Comp	92.2	6.52	0.52	0.519	0.114	Traces

2.2 Specimen Preparation

The sand cast alloy rods are machined to specimens for hardness testing, microscopic examination and tensile testing. Appropriate ASTM standards are used for the preparation of the specimens.

2.3 Micro-Hardness

Micro-hardness of the alloy specimens are measured in HV scale by applying a load of 100 gram force for 20 seconds using a diamond indenter. Micro-Hardness is randomly measured at 6 points. The average of the 6 readings is taken to get the value of hardness of the specimen. The effect of cooling rate on micro-hardness is inferred based on the results. Figure 2 shows the Mitutoyo make micro-hardness tester.

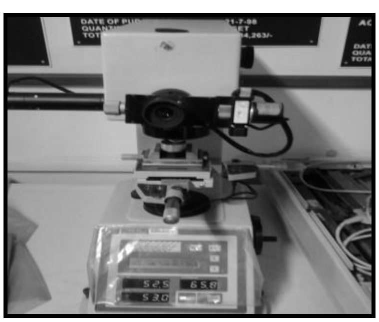

Fig – 2: Micro-hardness tester

2.4 Tensile Test

Tensile test of the machined alloy is performed on a Universal Tensile Testing Machine. The stress versus strain graph of the specimen is plotted and the ultimate tensile strength is found out from the plot. The effect of cooling rate on tensile strength is inferred based on the results. Figure 3 shows the tensile specimen of the alloy. Figure 4 shows the tensile test specimen machined out from cast rods.

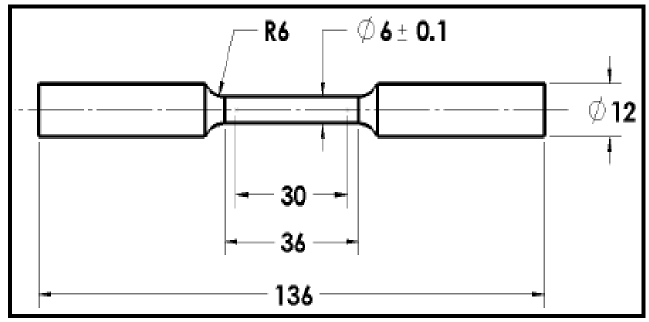

Fig – 3: Drawing of tensile specimen

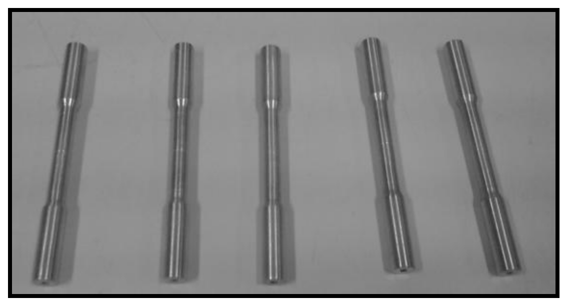

Fig – 4: Photographic image of tensile test specimen

Figure 5 shows the experimental setup of the tensile test

Fig – 5: Universal testing machine

2.5 Microstructure

Metallographic specimens are prepared using standard grinding and polishing procedures. For microstructure analysis, the specimen is etched with HF solution and Kellers reagent. The effect of cooling rate on microstructure is inferred based on the results.

2.6 Wear Test

The wear test is carried out using DUCOM make pin-on-disc wear tester. The specimen is machined to size diameter 10 mm and length 40 mm. The test parameters used are: Speed-236 rpm; Velocity-1 m/s; Load-20 N; Track Radius- 40 mm; Sliding Time-10 minutes.

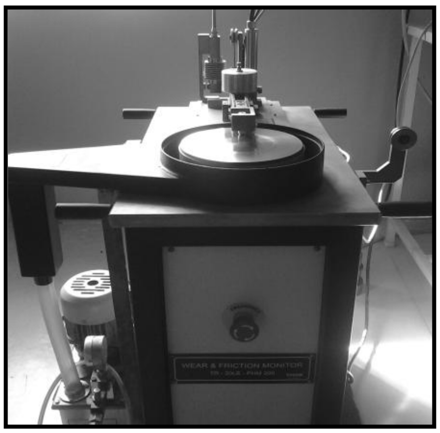

Fig-6: Wear and Friction monitor

3. RESULTS AND DISCUSSION

3.1 Variation in Cooling Rate

It is well known that Chvorinov's rule gives a relation between solidification time and surface area and volume of a casting as defined by the following equation (1).

$$T = B*(V/A)^n \text{ -------------- (1)}$$

where, B = Mould Constant
n = constant
V = Volume of casting
A = Surface Area of casting
T = Solidification time

This relationship gives the liberty to vary the diameters of the castings (keeping height constant) to obtain different cooling rates.

3.2 Micro-Hardness

Figure 7 is plotted between hardness value and the diameter of the specimens. It is observed that as the diameter of the specimen increases, the hardness value decreases. The reason for the variation is due to the fact that as the diameter increases, the time for solidification of the casting increases. Further, as the diameter increases, larger grain structures are formed due to slow cooling and hence giving a declining trend in mechanical properties [9]. The variation of hardness value with diameter is shown in Table 2.

Table - 2: Variation of hardness with diameter

Diameter (mm)	15	20	25	30	35
Hardness (HV)	87.4	83.9	79.6	75.8	71.6

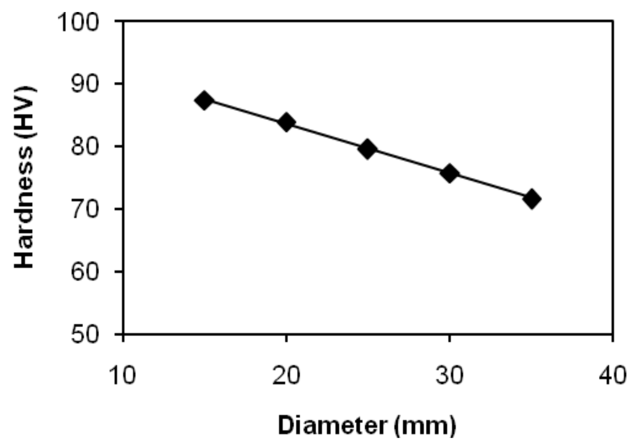

Fig - 7: Plot of variation of micro hardness with diameter

3.3 Tensile Test

Figure 8 is plotted between ultimate tensile strength (UTS) and diameter of the specimens. From the plot it is observed that the UTS value decreases as the diameter increases. It is due to lower hardness observed in the larger diameter specimen as compared to smaller diameter. As a general rule, UTS is function of hardness of the alloy. That is if hardness decreases, the UTS also proportionally decreases. The nature of fracture observed in this study is brittle fracture because of cast specimen. Table 3 shows the UTS value of the alloy for different diameters.

Table - 3: Variation of UTS with diameter

Diameter (mm)	15	20	25	30	35
UTS (MPa)	107	104.2	99.8	90.3	88.1

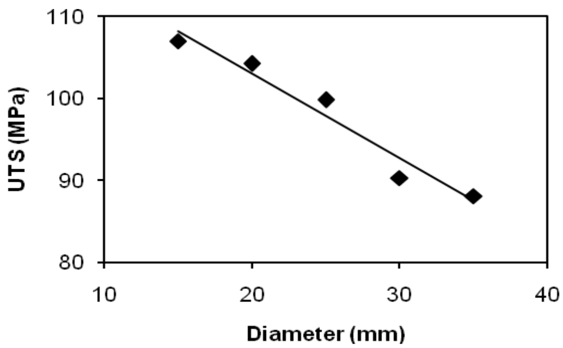

Fig – 8: Plot of variation of UTS with diameter

3.4 Microstructure

The microstructure of the specimens of the alloy castings of diameter 15, 25 and 35 mm (Figures 9-11) is chosen so as to find a significant difference in grain structure. By comparing Figures 9 and 11, it is observed that for 15 mm diameter casting the grain size is very small as compared to 35 mm diameter casting. This is due to the fact that for smaller diameter, the cooling rate is very high which leads to smaller grain size and for larger diameter it is low and forming large grain size. Microstructure showed a marked shift from large sized dendrites to finer dendrites this is in accordance with previous report [10].

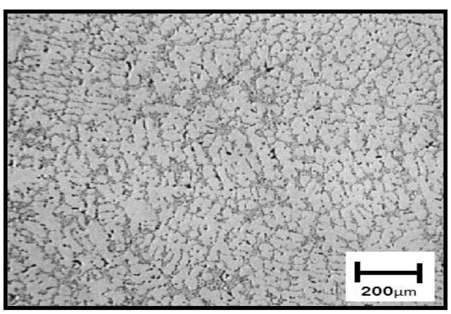

Fig - 9: Microstructure of 15 mm diameter casting showing finer grains

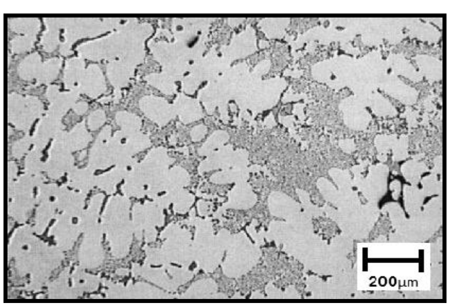

Fig - 10: Microstructure of 25 mm diameter casting showing bigger grains

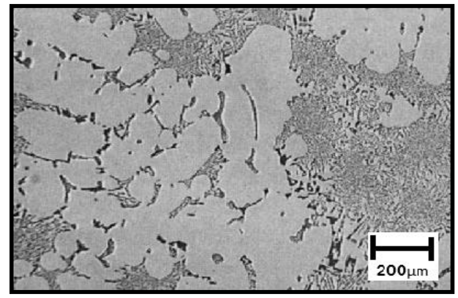

Fig - 11: Microstructure of 35 mm diameter casting showing relatively bigger grains than 25 mm diameter

3.5 Coefficient of Friction

Figure 12 shows the variation of coefficient of friction with hardness of the alloy. From the figure it is observed that the COF value is not varied significantly with hardness of the alloy. This shows COF is independent of the hardness of the alloy. It is in consistence with previous report [9, 11-12].

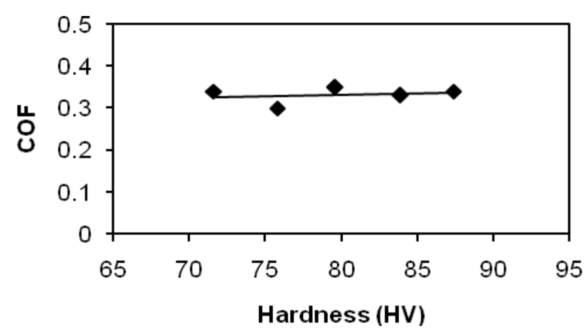

Fig-12: Plot of COF versus Hardness

3.6 Wear

The weight loss is measured by subtracting final weight from initial weight of the specimens. It is expressed in grams. Figure 13 is plotted between weight loss and hardness of the alloy specimens. It is found that weight loss decreases as the hardness increases. Hence it may be concluded that weight loss is function of hardness of alloy.

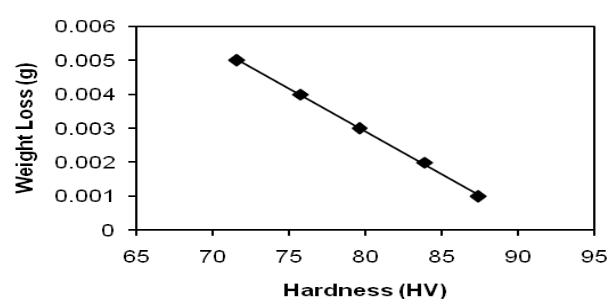

Fig-13: Variation of weight loss with hardness

4. CONCLUSIONS

The effect of cooling rate on mechanical properties of cast aluminium Al-6.5Cu alloy is studied and the following conclusions are derived.

- Hardness of the alloy decreases as the diameter of the cast rod increases, which is due to slow cooling of the larger diameter as compared to smaller diameter.
- Ultimate Tensile Strength decreases with increase in diameter. The reason being, in the case of larger diameter rod, the hardness is less.
- The size of grain structure increases with increase in diameter which is subjected to slow cooling.
- Coefficient of Friction is independent of hardness of the alloy.
- Weight loss is dependent on hardness of the alloy.

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BIOGRAPHIES

Dr. S. Ilangovan has completed his Bachelor’s Degree in Mechanical Engineering and Master’s Degree in Production Engineering. He has fourteen years of experience in industry and sixteen years in teaching. He has also completed Ph.D. in Materials Engineering

SaiKrishna Viswanathan is a third-year Mechanical Engineering student currently pursuing Bachelor of Technology degree from Amrita School of Engineering, Tamil Nadu.

Gopath Niranthar K is a third-year Mechanical Engineering student currently pursuing Bachelor of Technology degree from Amrita School of Engineering, Tamil Nadu.