Study of Solidification and Mechanical Properties of Al-Sn Casting Alloys

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Abstract

Al-Sn alloys have a very long history to be used as bearing materials. These alloys provide a good combination of strength and surface properties. This study aimed to investigate solidification and mechanical behavior of Al-Sn alloy against both the molding conditions and tin content (20 % ¸ 30 % ¸ 40 % Sn). A metal mold with a different diameter was prepared to study the solidification rate; tribological experiments have been carried out by using a pin on disc machine to investigate the effect of the alloying element content and the molding conditions on the wear resistance and microstructure of the alloys. The results showed with the increasing of tin content the solidification time decreased, as also a decrease of the liquidus temperature was observed and then increased with increasing Sn %. However, decrease of both the ultimate tensile strength and the hardness is obtained by the increase of the tin content also the wear rate decrease with increase of tin content.

Keywords: Solidification, Aluminum, tin, strength wear.

Introduction

Aluminum based alloys are widely used as journal bearing materials in tribological applications [1,2]. Al - Sn alloys, which have high resistance and excellent surface properties, have been used as the bearing materials for a long time. The compatibility of Al - Sn alloy is close to the tin - based white metals; and the fatigue strength of white metals is higher. Sn is found as Al and Sn composition zones in the aluminium alloys. In Al - Sn composition zones, free Sn grains disperse in the aluminium matrix [3].

Al-Sn alloys have been used for many years for the production of self-lubricant bearing materials [4,5]. These alloys provide a good combination of strength and surface properties. The fatigue strength of cold worked and heat treated Al - 20% Sn - 1% Cu alloy having reticular structure is close to that of Cu -30 % Pb alloy with higher seizure resistance[6]. Other additions are made to the Al - Sn alloys i.e. Cu and Si. Copper additions influence the solidification process and promote coarser tin particles in the metastable reaction whilst silicon remains in solution [7]. The conformability of Al – 40 % Sn alloy is comparable to tin-based white metal but its fatigue strength is superior. High tin - aluminum alloys are used as linings bonded to steel - backing strip. Aluminum - tin alloys have good mechanical properties with conformability but these are quite costly. A low modulus of elasticity is required in a bearing alloy to ensure good compatibility with the journal surface [6]. Friction and wear are of considerable importance in most of the structural components, particularly in bearing applications. The typical structure of tough matrix with soft tin inclusions in Al-Sn alloy determines the tribological behavior of the bearing [8].

In general, homogeneous and dispersed distribution of fine Sn which is lubrication phase in Al matrix is beneficial to friction and wears behavior [9]. Furthermore, strength and microstructure of alloy are also very important factors influencing wear properties [10]. Al - Sn alloys are completely miscible only above the liquidus line. In conventional casting, if such a homogeneous single phase liquid is cooled below the liquidus line, it transforms into two liquids, namely aluminium rich and tin rich. The minor 'Sn' rich phase segregates out. If the homogeneous single Al-Sn liquid phase is rapidly cooled, then the minor phase is dispersed uniformly in aluminium rich matrix [8]. Al - Sn is an immiscible binary alloy system with a solid solubility of Sn in Al below 0.09 wt. % at room temperature [11,12,13].The growing importance of Al - Sn based alloys as materials for engineering applications necessitates the development of uniform microstructures with improved performance [9]. Due to the immiscibility of Al - Sn system and big density difference between Al and Sn, there is very strong sedimentary tendency in the casting of Al - Sn alloy. Therefore, homogeneous distribution of Sn in Al matrix could not be easily obtained. Different preparing methods, including stircast, rapid solidification [14,15,16] ,physical vapor deposition [17,18,19],electro deposition[20], powder metallurgy [21,22] , severe plastic deformation [23], and mechanical alloying [24], have been used to improve microstructure homogeneity and refine the size of Sn phase in Al - Sn alloys.

The solidification condition significantly affects the microstructures and properties of the alloy. It is considered useful to determine the relationships between the solidification conditions and their corresponding microstructures and properties. The main objectives of the present study are to characterize the microstructure, mechanical properties and wear properties of AL- Sn alloys cast at different solidification condition, and correlate the microstructures with the mechanical and wear properties.

2-Expermintal works.

The pure aluminum matrix and pure tin with a purity of 99.99 %.The alloy were prepared by melting the pure aluminum in graphite crucible by electric furnace and the required amount of tin was added to the molten aluminum at 750 C°. The prepared alloys were poured in a step metal mold with different diameters of 20, 30, and 40 mm; three sets of the casting alloys were prepared with different tin content, (20 % , 30 % , and 40 % Sn). The measuring of mold temperature is performed using infrared radiation pyrometer is able to measure temperature up to 1200 C°. The ultimate tensile strength and percentage elongation of the cast aluminum alloys were measured using a universal testing machine with a load capacity of 4 KN at the lower speed of 2mm/min. Emery paper was used to grind the surface of the specimens before testing. All the measurements were conducted on a Vickers hardness-testing device at a load of 30 kgf, for 15 seconds loading time. Tribological experiments were carried out using a wear tester, shown in figure (1). The wear apparatus consists of motor with constant revolution speed (500 rpm).Steady state wear rates per unit sliding distance were evaluated from weight loss measurements. A total running time of 30 min was found adequate to generate steady state condition in the bearing pressure rang (60 - 315) KPa and relative interface sliding speed 500 rpm. Wear specimens were machined from ingot and cut according to ASTM specification (20 mm) length and 10 mm diameter.

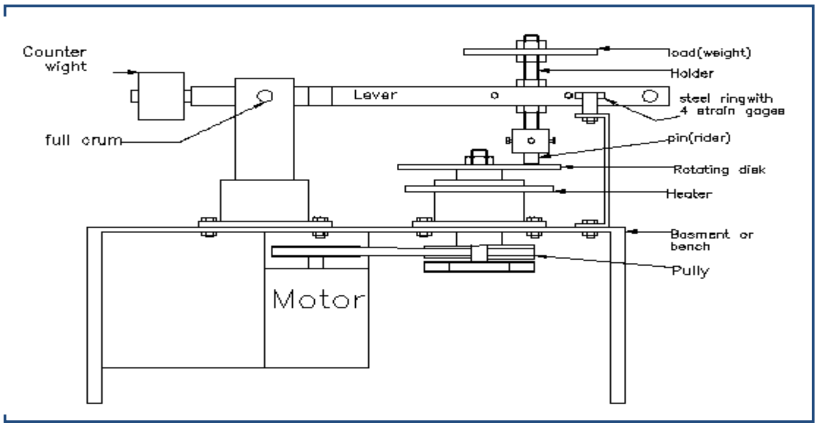

Figure (1): The pin-on-disc wear apparatus

3. Result and discussions.

3.1. Solidification.

The cooling curves obtained during solidification of the Al - Sn casting alloys with different tin content and different mold thicknesses are shown in figures (2 and 3). Typical cooling curve of Al - Sn casting alloys with different tin content are shown in figure (2). It can be seem that the tin content has pronounced effect on the cooling rate, whenever with the increase of tin content the solidification time decreased and a decrease in the liquidus temperature. It is related to the liquidus temperature according to Al - Sn binary phase diagram. Typical cooling curve of Al - Sn castings alloys for a different mold thickness are shown in figure (3). It can noticed that with the longer solidification time was obtained with a case of a mold thickness of 40mm, while in case of a mold thickness of 20 mm give the solidification time was minimum. It could be attributed to the increase of the surface area of the casting mold.

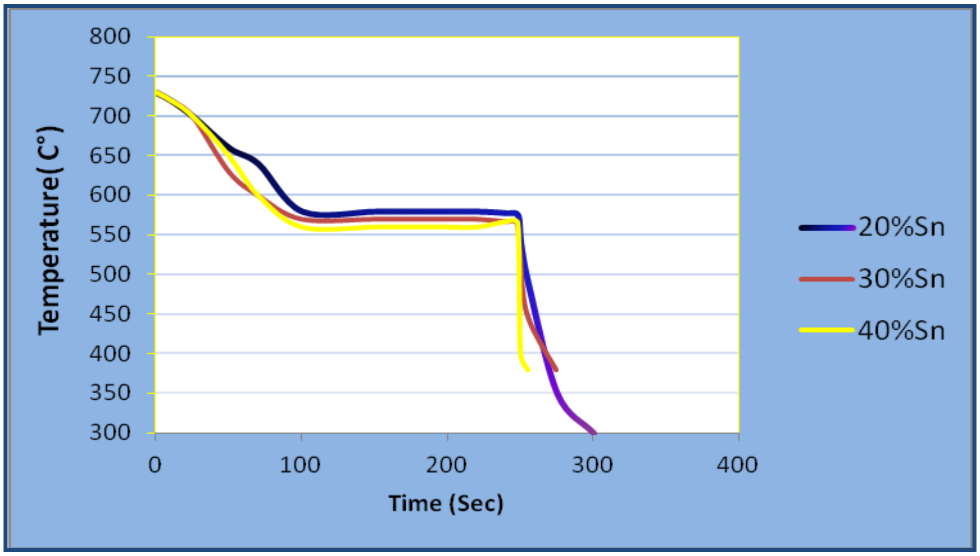

Figure (2): Cooling curve of Al-Sn alloys with different tin content.

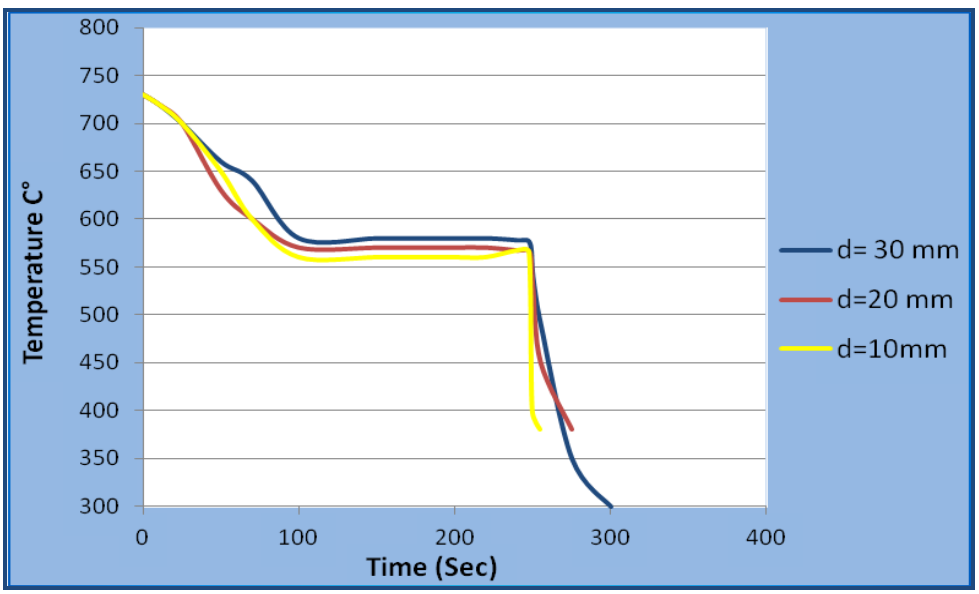

Figure (3): Cooling curve of Al-20%Sn casting alloys for a different molding thickness.

3.2. Mechanical properties.

Results of the mechanical tests are presented graphically, the variations in tensile strength, hardness and elongation. Figure (4) shows the effect of tin content on the ultimate tensile strength of Al-Sn casting alloys. It can be noticed that the increase of tin content from 20 % to 40 % gives a slightly decrease in the ultimate tensile strength have been obtained in case of 30 and 40 mm mold thickness. In the case of 20 mm mold thickness the ultimate tensile strength increased with the increase of tin content; it might be related to the solidification rate change. The effect of tin content on the elongation % is shown in figure (5). Which can noticed that the elongation % increase gradually related to the tin content increase and reach its maximum value at 40 % Sn the minimum elongation % produced at 10mm mold thickness, which 40mm mold thickness produce the maximum elongation %. It may be related to the effect of solidification rate. The variations of hardness against the tin content for a different mold thickness are shown in figure (6). It can be noticed that, a significant decrease of hardness with the tin content increased. There was pronounced effect of the mold thickness on the hardness. It might be related to the presence of tin as separate phase in form of reticular (network) structure in aluminium matrix, which obtained by the increase of tin content. The microstructure of the as-cast Al-Sn alloys depends on the tin percentage. Alloy with tin 20 - 30 % showed aluminum matrix with semi-continuous network distributions of tin on the grain boundaries (figures 7 and 8). The bonding between the tin and matrix was improved at higher tin content (40 %). On other hand, increasing the tin content resulted in continuous increasing of bonding between Al and Sn. It is essential to noted that the shape, distribution and the bonding between the tin and aluminum matrix depend highly on the tin percentage. This type of structure shown in figure (9) consist of irregular islands of tin interconnected along trigonal aluminum grain boundaries to form a three dimensional net of tin throughout aluminum matrix .This result is consistent with the previous observations by the Forrester [25].

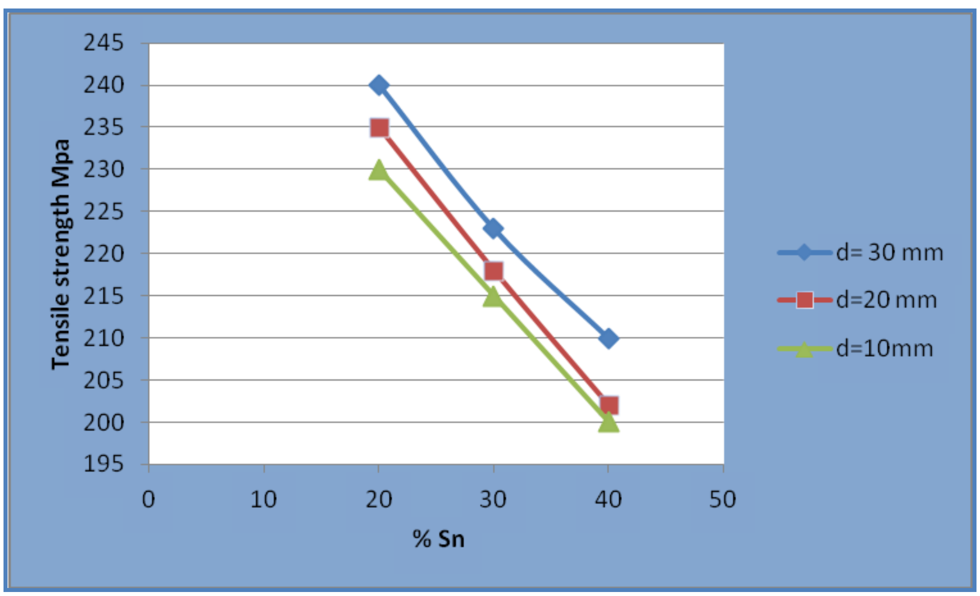

Figure (4): Effect of tin content on the tensile strength of Al-Sn casting alloys

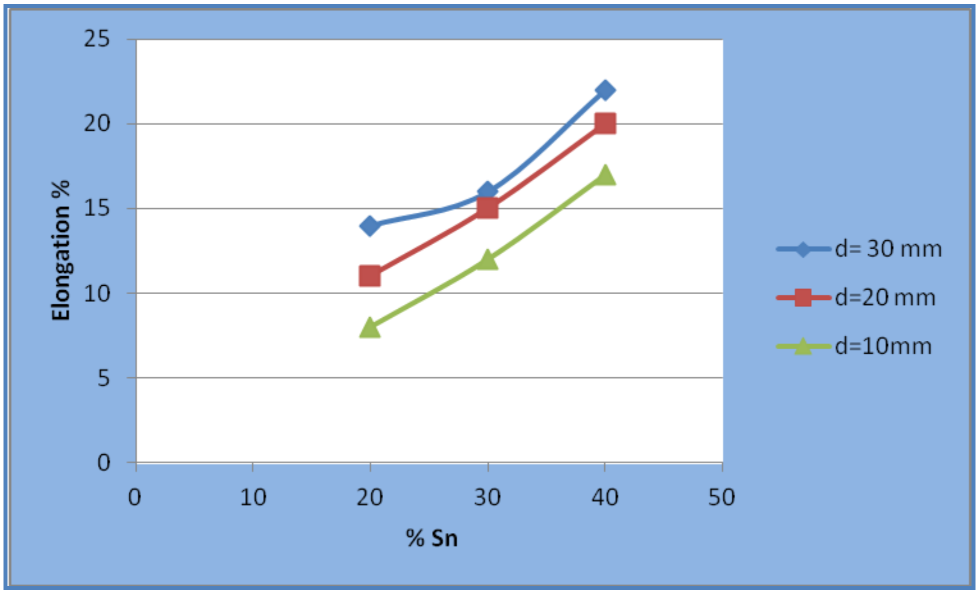

Figure (5): Effect of tin content on the elongation of Al-Sn casting alloys

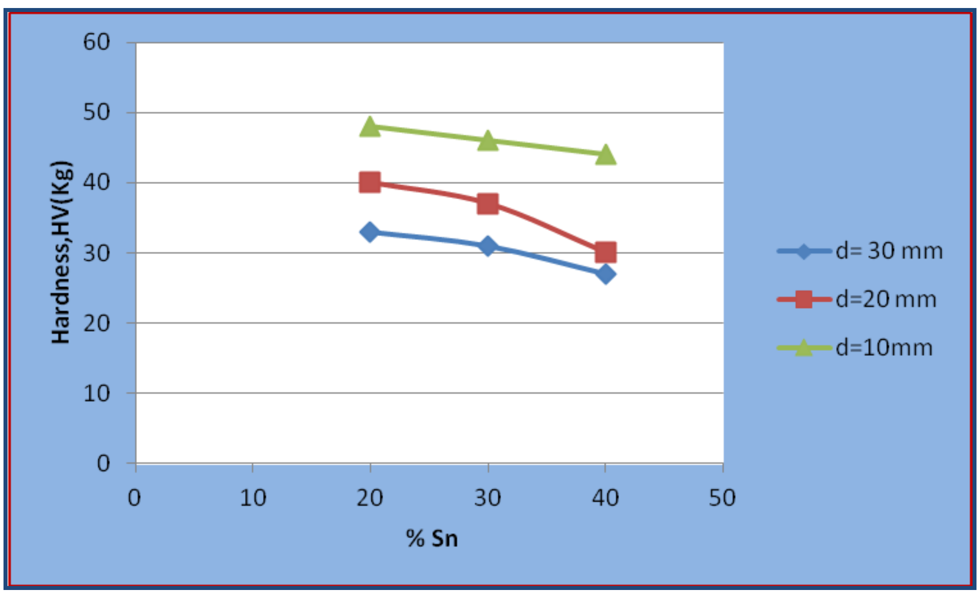

Figure (6): Effect of tin content on the hardness of Al-Sn casting alloys.

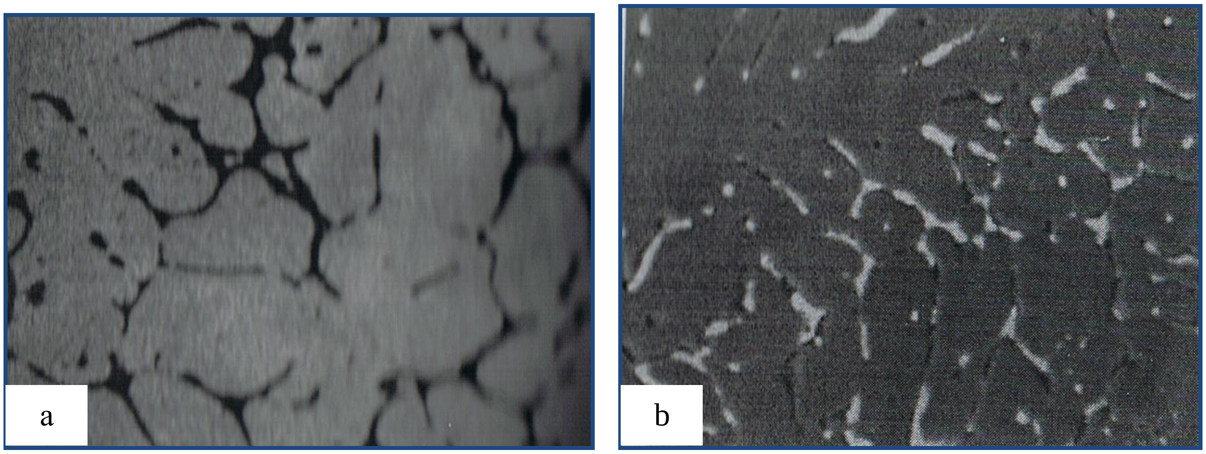

Figure 7: Micrographs revealing the microstructures of Al20Sn1Cu.
a) Scanning electron microscope. b) Optical microscope.

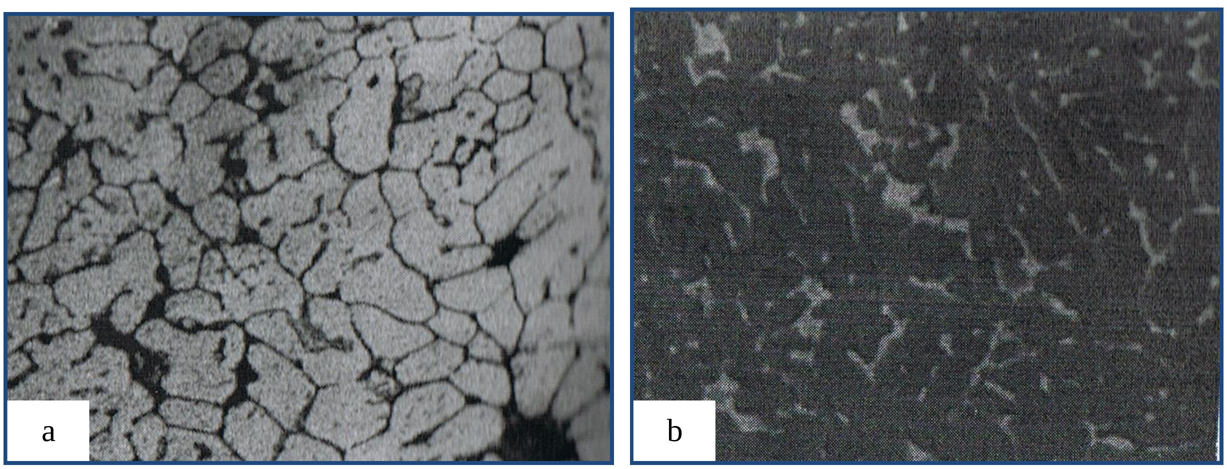

Figure (8): Micrographs revealing the microstructures of Al30Sn1Cu.
a) Scanning electron microscope. b) Optical microscope.

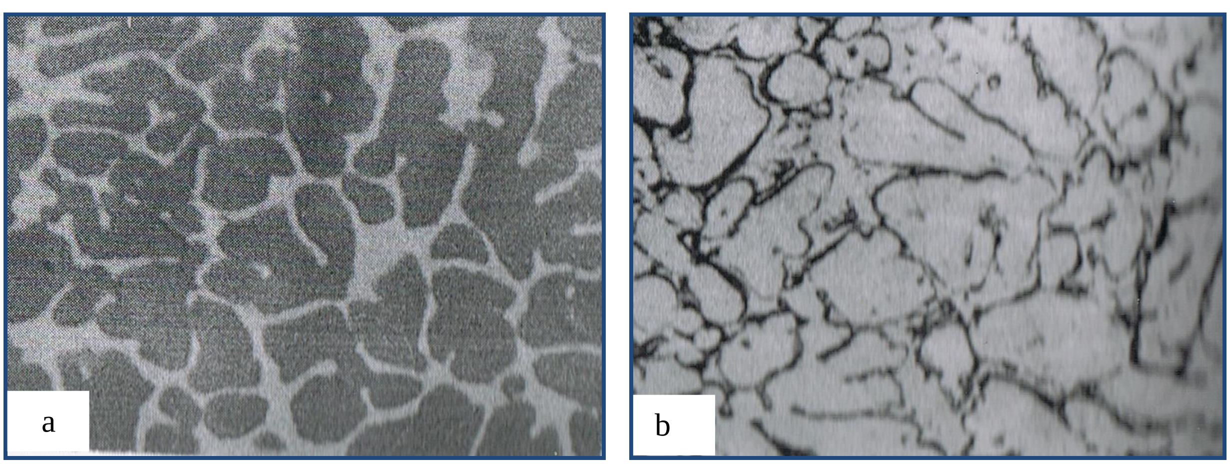

Figure (9): Micrographs revealing the microstructures of Al40Sn1Cu.
a) Scanning electron microscope. b) Optical microscope.

3.3. Tribological properties.

Wear rate of aluminum-tin casting alloys was studied by using a pin-on-disc wear tester. It was observed that, as shown in figure (10) the weight loss decreased down with increasing Sn content. The higher weight loss was produced in the case of 10mm mold thickness, while weight loss in the mold thickness 30mm produced the lower weight loss.

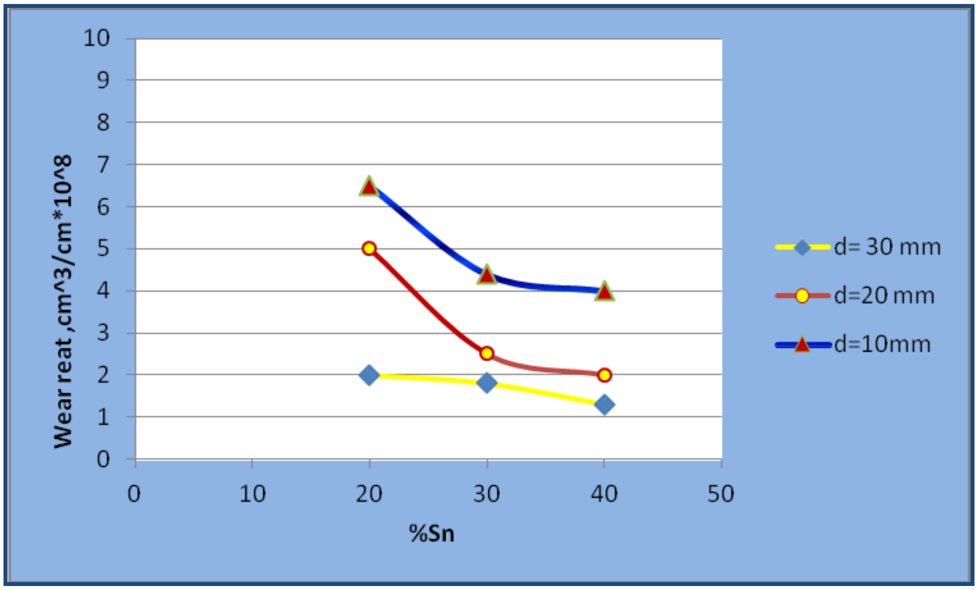

Figure (10): Effect of tin content on wear rate of Al-Sn casting alloys

4. Conclusion.

The understanding of the properties of the Al-Sn alloys will be discussed on the basis of experimental observation. The main conclusions drawn from this study are as follows:

1. With the increase of tin content of the aluminum- tin casting alloys the cooling rate decreased.
2. Decrease of the liquidus temperature was observed with increasing Sn%.
3. Increase the tin content resulted in continuous increasing of bonding between Al matrix and Sn phase.
4. With the increase of tin content the ultimate tensile strength and hardness decrease.
5. High wear resistance was produced with the increase of tin content.
6. The change of mold thickness affected on the cooling rate of aluminum- tin casting alloys so on the microstructure.
7. A pronounced change in the mechanical and tribological properties by the change of mold thickness was obtained.

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