Cooling Rate, Hardness and Microstructure of Aluminum Cast Alloys

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Abstract: This experiment investigated the cooling curve behavior, hardness and microstructure of two aluminum alloys produced by casting process. There are Al-1.37Zn-1.19Si and Al-1.66Si-1.35Zn derived from melting and alloying a pure aluminum with ADC12 (Al-Si) ingot. Cooling curve recorded from both those two alloys with pouring temperature at 710 oC and the mold temperature kept constant at 220 oC. The result shows, a freezing range of Al-1.37Zn-1.19Si alloy is 643–348 oC and Al-1.66Si-1.35Zn alloy is 621–401 oC. Then cooling rate obtained for Al-1.37Zn-1.19Si is 55.56 oC/S, and Al-1.66Si-1.35Zn is 30.09 oC/S. TThe higher hardness is 40.42 BHN at Al 1.66 Si-1.35Zn, while the lower value is 34.62 BHN on Al-1,37Zn-1,19Si alloy. The hardness value found higher when cooling rate is shorted. The number of silicon present on microstructure is highest in Al-1.37Zn-1.19Si alloy but the hardness value decreases. This is caused by the distribution of the silicon content in the alloy is irregular. It was found that the solidification rate had an effect on hardness, where the freezing rate obtained a high hardness value.
Keywords: Metal casting; metallurgy; cooling curve; cooling rate; aluminum alloy; hardness

1. Introduction

Aluminum alloys have widely used in automotive manufacturing, aerospace component manufacturing and advanced military applications[1]. They have a high strength to weight ratio, excellent castability, high corrosion resistance, low coefficient of thermal expansion, and good wear resistance[2]. Metal casting is a process for fabricating structure components, but a disadvantage of this technique is lower mechanical properties than base material before melted. Pouring temperature is one of the casting parameters that affecting on material properties[3]. Foundry variable such as mold material and pouring temperature has affected on increasing casting quality of LM25 aluminum alloy[4]. Study on the impact of cooling rate on solidification behavior in casting Mg−10Gd−3Y-0.4Zr alloy using sand mold has been done[5]. The influence of cooling rate on mechanical properties of aluminum alloys has been widely investigated[6,7]. Study on a cooling curve during solidification and hardness during recycled Al–Zn aluminum alloy by metal casting process has been done[8]. The effect of cooling rate on microstructure and solidification parameter of Al−7Si−0.3Mg−0.15Fe alloy was investigated[9], the result shows hardness enhances with the increased cooling rate.

Influence of mischmetal as a modifier, heat treatment and cooling rate on hardness properties of non-modified and modified by Sr for A319.1, A356.2 and A413.1 as-cast alloys has been studied[10]. There are two cooling rates were used to estimate hardness levels (~85 and ~110–115 BHN) in commercial alloys. The result displayed hardness indexes were higher at high cooling rates if compared with low cooling rates of the as-cast alloys. Non-modified or no Sr addition alloys showed slightly higher hardness levels beside the Sr modified alloys, and the hardness index also decreased with added mischmetal for both cooling rates. An interaction between mischmetal with the alloying elements Cu and Mg were forming the various intermetallic phases may be attributed reducing the hardness values. Increasing of those elements followed by decreasing the formation volume fraction of the precipitation-hardening phases (Al2Cu and

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Mg2Si phases) on the A319.1 and A356.2 alloys, subsequently reducing the hardness.

The Cooling Curve Analysis (CCA) method can predict microstructure, grain refinement, and determine the latent heat of solidification[11]. The solidification of metal alloys can be observed through Computer-Aided Cooling Curve Analysis (CA-CCA). It can determine thermo-physical properties of metal alloys, latent heat from solidification[12,13]. Al-Si-Zn alloy has been applied to filler on brazing joint the 6061 aluminum alloy, and as sprayer on a plaster substrate[14-16]. The main objective of this experiment is to investigate the cooling curve behavior, microstructure and hardness on Al-1.37Zn-1.19Si and Al-1.66Si-1.35Zn during solidification. The study was divided into two parts, the first part was observed cooling rate when the solidification of Al-1.37Zn-1.19Si and Al-1.66Si-1.35Zn alloys. The second part is to observe the microstructure and hardness in both materials.

2. Materials and Methods

2.1 Material

Al-1.37Zn-1.19Si and Al-1.66Si-1.35Zn alloys were prepared by casting metallurgy pro-cess. Pure aluminum and ADC12 were taken as the starting raw material as shown in Table 1. The chemical composition of the alloys, analyzes by spectroscopy’s metal standard. The chemical compositions (wt.%) of the alloys used in this experiment are shown in Table 2.

Alloy	**Si**	**Fe**	**Cu**	**Mn**	**Ti**	**Cr**	**Pb**	**Sn**	**Ni**	**Zn**	**Al**
Pure Al	0.24	0.53	0.13	0.07	0.01	0.004	0.7	0.01	0.007	1.65	97.26
ADC12	10.56	0.78	1.71	0.15	0.02	0.029	0.05	0.19	0.05	0.83	85.6

Table 1. Base materials used for alloying metal (wt.%)

Alloy	Si	Fe	Cu	Mn	Mg	Ti	Cr	Ni	Zn	Al
Al-1.37Zn-1.19Si	1.19	0.62	0.3	0.06	0.01	0.02	0.006	0.009	1.37	Bal.
Al-1.66Si-1.35Zn	1.66	0.71	0.39	0.07	0.01	0.02	0.008	0.011	1.35	Bal.
Al-2.81Zn-2.6Si	2.6	1.41	0.87	0.09	0.01	0.02	0.013	0.029	2.81	Bal.

Table 2. Chemical composition of cast-sample (wt%)

2.2 Methods

Induction furnace used for melting aluminum alloys and cast into a permanent mold with the diameter is 9.5 mm. A steel mold was preheated with temperature of 220 oC. Temperature release from molten to air was recorded. A thermocouple K-type was inserted into steel mold for recording cooling temperature during solidification of Al-1.37Zn-1.19Si and Al-1.66Si-1.35Zn alloys with pouring temperature at 710 oC. The cast samples were grind using SiC paper and polished using a standard technique. Hardness value from the alloys was performed using a Brinell test on a section perpendicular of cast sample with five point indentations (Figure 1). The diameter of the ball indentor is 2.5 mm, the load is applied at 249 N, and the indentation time is 30 seconds. Hardness value is obtained from the general formula BHN[4].

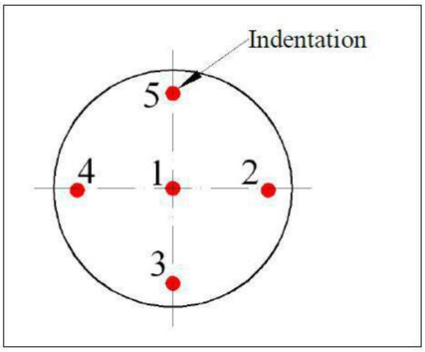


Figure 1; Five location indented on cross section of cast-sample.

3. Results and Discussion

3.1 Cooling Curve/Rate

Figure 2 and **Figure 3** show cooling and first derivative curve on Al-1.37Zn-1.19Si and Al-1.66Si-1.35Zn alloys for pouring temperature at 710 oC[17]. The solidification curves indicate that thermocouples data recorded from a particular range of Solidification. The first peak of derivatives curve shows the liquidus temperature about 643 oC (primary α-Al formation). The second peak on derivatives curve denotes the solidus temperature around 348 oC. The liquidus temperature is 621 oC, and the solidus temperature is 401 oC from cooling and first derivative curve with pouring temperature at 710 oC on Al-1.66Si-1.35Zn alloy, as shown in Figure 3. The freezing range for Al-1.37Zn-1.19Si with casting temperature at 710 oC ranges about 643 – 348 oC and freezing range for Al-1.66Si-1.35Zn with pouring temperature at 710 oC ranges from 621 to 401 oC. Cooling rate for Al-1.37Zn-1.19Si is 55.56 oC/S and Al-1.66Si-1.35Zn is 30.09 oC/S. Cooling rate as a thermodynamic parameter is significantly affected by the pouring temperature, and it would decrease with increasing of pouring temperature[5].

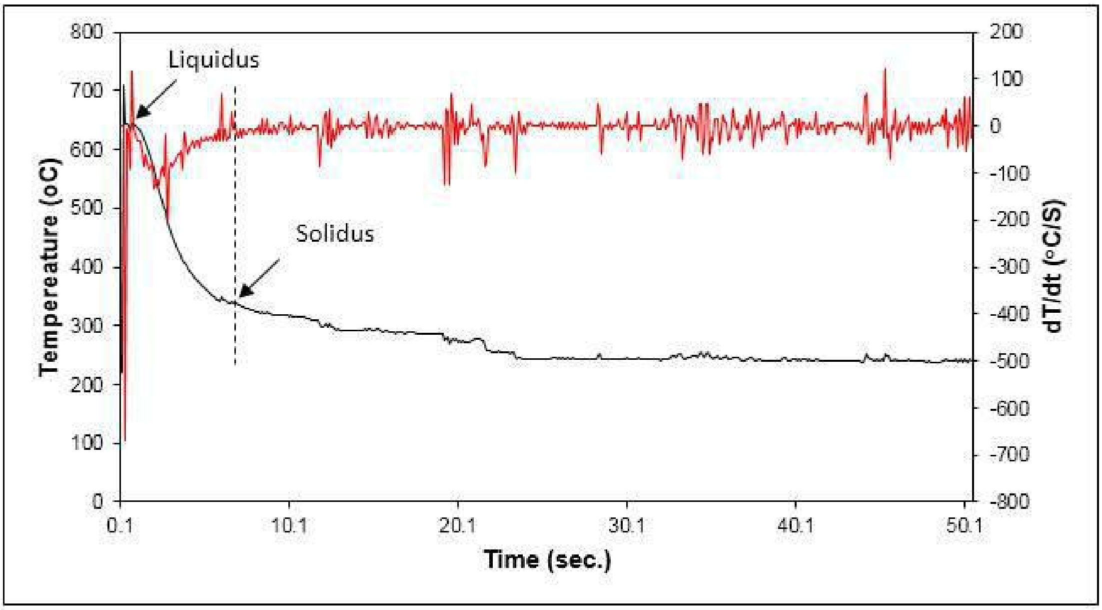


Figure 2; Cooling curves and the first derivative on Al-1.37Zn-1.19Si alloy with poured at 710 °C.

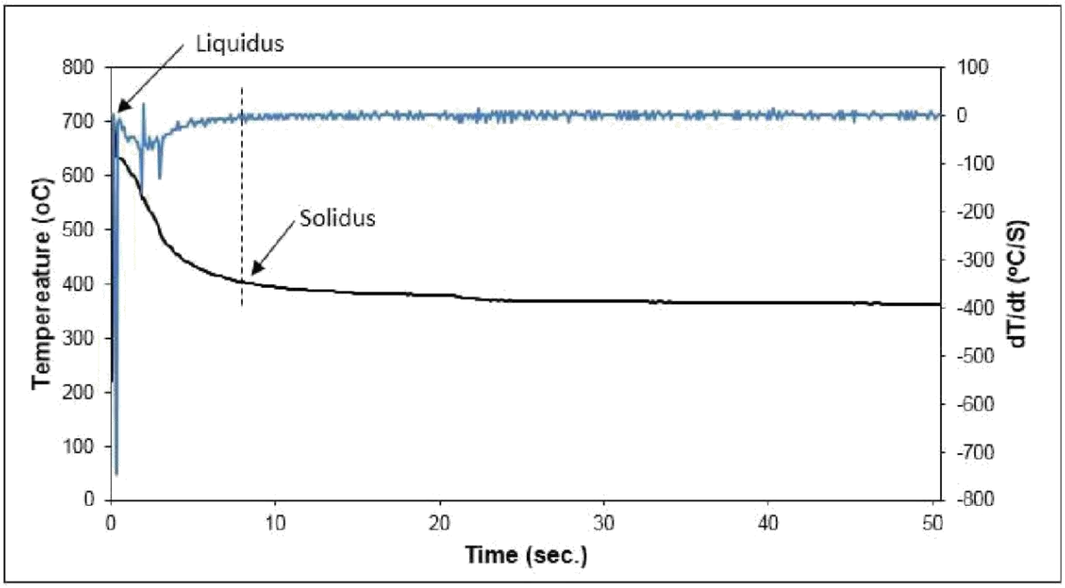


Figure 3; Cooling curves and the first derivative on Al-1.66Si-1.35Zn alloy with poured at 710 °C.

3.2 Hardness and Microstucture

Hardness properties of the cast-sample were observed, it shown in Figure 4. The higher hardness value presented on Al-1.66Si-1.35Zn alloy is 40.42 BHN. The Al-1.37Zn-1.19Si alloy has lower index, it is 36,2 BHN. Primary silicon appear in Al-1.66Si-1.35Zn alloy spread evenly on the entire surface of microstructure, while for Al-1.37Zn-1.19Si primary silicon present alloy accumulate in the middle of microstructure Figure 5a[18]. Hardness values also seen higher in Al-1.66Si-1.35Zn alloys when compared with to Al-1.37Zn-1.19Si alloys, this is influenced by the silicon distribution in cast-sample. The percentage amount of silicon on microstrcuture is obtained with the highest value in Al-1.37Zn-1.19Si alloys through calculated by using ImageJ Software (Table 3). The freezing rate of the Al-1.66Si-1.35Zn alloy is shorter so that the hardness value is high in the alloy. The hardness increase in alloy with increasing cooling rate during solidification. Hardness average value is rising from 490 Hv at slow cooling rates to 520 Hv for metal casting with rapidly cooled. The process of freezing metal alloys was significantly affects to the microstructure and mechanical properties[3]. The Influence of cooling rate on Al-18% aluminum alloy can be affected to the microstructure and material hardness. High Solidification rate causes microstructure more finer. High solidification rate is seen to affect the microstructure. Silicon surface area of the material can lead to increasing hardness as seen in the microstructure[7]. The freezing range of a metal alloy may cause the material to be susceptible to defects, either shrinkage porosity or hot tearing defects[6].

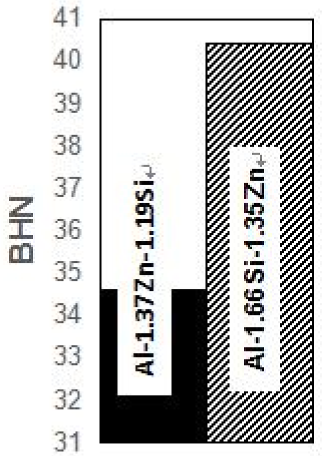
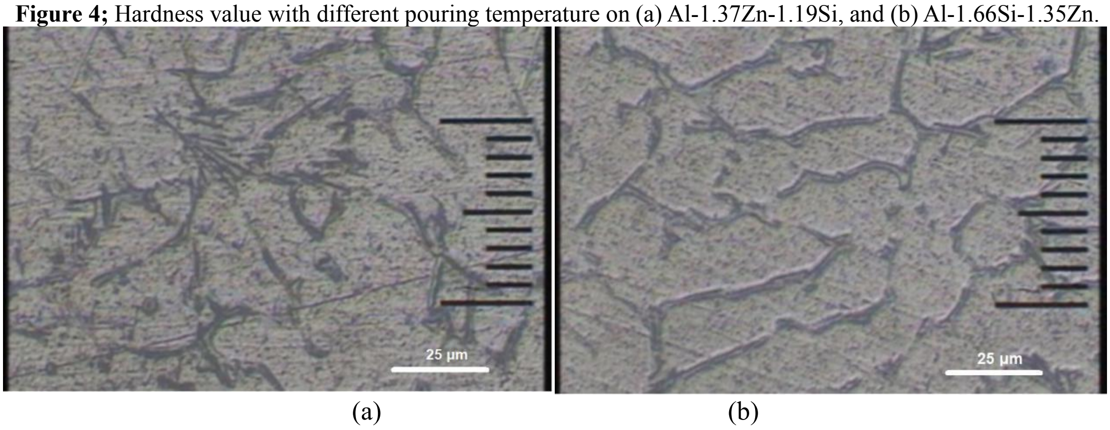


Figure 4; Hardness value with different pouring temperature on (a) Al-1.37Zn-1.19Si, and (b) Al-1.66Si-1.35Zn.



(a) (b)

Figure 5; Microstructure of cast-sample, (a) Al-1.37Zn-1.19Si, and (b) Al-1.66Si-1.35Zn.

Alloys	**Primary silicon (µm²)**	**Total Area (µm²)**	**Silicon (%)**
Al-1.37Zn-1.19Si	5,838.705	18,549.296	31
Al-1.66Si-1.35Zn	2,873.405	11,306.744	25

Table 3. Average primary grain surface silicon

4. Conclusion

The conclusion of this experiment show, the freezing temperature of Al-1.37Zn-1.19Si is starting from 643oC until 348 oC with pouring temperature at 710 oC, while freezing range of Al-1.66Si-1.35Zn is starting with 621 oC to 401 oC at 710 oC of pouring temperature. However, the cooling rate could define for Al-1.37Zn-1.19Si is 55.56 oC/S and Al-1.66Si-1.35Zn is 30.09 oC/S. The higher hardness value presented on Al-1.66Si-1.35Zn alloy is 40.42 BHN. The Al-1.37Zn-1.19Si alloy has lower index, it is 36,2 BHN. Short cooling rates produce high hardness values, but silicon content shows low in the Al-1.66Si-1.35Zn alloy. The low silicon content in alloys still shows a high hardness value. According to microstructure indicates that the distribution of silicon content is spread evenly in the alloy, resulting in high hardness values.

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