Cooling Rate Investigation and The Influence of Pouring Temperature on Hardness Properties of As–Cast Aluminium Alloys

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Abstract

This experiment investigated the cooling curve behavior and the effect of variation pouring temperature on three aluminum alloy by casting process. Three aluminum alloys are Al–1.37Zn–1.19Si, Al–1.66Si–1.35Zn, and Al–2.81Zn–2.6Si derived from melting and alloying a pure aluminum with ADC12 (Al–Si) ingot. Cooling curve recorded from two alloys are Al–1.37Zn–1.19Si and Al–1.66Si–1.35Zn with pouring temperature at 710 ^{o}C. Pouring temperatures was varied by three variations that are 710, 760, and 810 ^{o}C, while the mold temperature kept constant at 220 ^{o}C. The result shows, a freezing range of Al–1.37Zn–1.19Si is 643–348 ^{o}C and Al–1.66Si–1.35Zn is 621–401 ^{o}C with pouring temperature at 710 ^{o}C for both alloys. Then cooling rate obtained for Al–1.37Zn–1.19Si is 55.56 ^{o}C/S, and Al–1.66Si–1.35Zn is 30.09 ^{o}C/S. The hardness index is increasing first then decrease, with increasing of pouring temperature on Al–1.37Zn–1.19Si and 1.66Si–1.35Zn alloys. While on Al–1.66Si–1.35Zn alloy, the hardness value is improving with increasing of pouring temperature.

Keywords : Metal casting, metallurgy, cooling curve, cooling rate, aluminum alloy, hardness.

Introduction

Aluminum alloys have widely used in automotive manufacturing, aerospace component manufacturing and advanced military applications (Wang, *et al.* 2014). They have a high strength to weight ratio, excellent cast ability, high corrosion resistance, low coefficient of thermal expansion, and good wear resistance (Fang, *et al.*, 2014). 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 (Kaiser, *et al.*, 2013). Foundry variable such as mold material and pouring temperature has affected on increasing casting quality of LM25 aluminum alloy (Kabir, *et al.*, 2014). Study on the impact of cooling rate on solidification behavior in casting Mg−10Gd−3Y−0.4Zr alloy using sand mold has been done by Pang, *et al.* (2015). The influence of cooling rate on mechanical properties of aluminum alloys has been widely investigated (Amin and Mufti, 2012; Akili, *et al.*, 2014). Study on a cooling curve during solidification and hardness during recycled Al–Zn aluminum alloy by metal casting process has been done by Akhyar and Husaini (2016). The effect of cooling rate on microstructure and solidification parameter of Al−7Si−0.3Mg−0.15Fe alloy was investigated (Pang, *et al.*, 2013), 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. 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 (Al_2Cu and Mg_2Si phases) on the A319.1 and A356.2 alloys, subsequently reducing the hardness (Sebaie, *et al.*, 2008).

The literature survey revealed that effect of pouring temperature on metal hardness properties and cooling rate behavior had not been documented. Therefore, the main objective of this study is to investigate the cooling curve behavior on Al–1.37Zn–1.19Si and Al–1.66Si–1.35Zn during solidification. The effect of different pouring temperature ranging from 710–810 °C on hardness material properties of cast sample is discussed. Three alloys, namely Al–1.37Zn–1.19Si, Al–1.66Si–1.35Zn, and Al–2.81Zn–2.6Si are used for producing cast–samples from melting pure aluminum and ADC12 (Al–Si).

Material and Method

Material

Al–1.37Zn–1.19Si, Al–1.66Si–1.35Zn, and Al–2.81Zn–2.6Si alloys were prepared by casting metallurgy process. 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. 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 °C.

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

alloying metal	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 2. Chemical composition of cast–sample (wt%)

Cast–sample	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.

Methods

To characterize the influence of the pouring temperature on the hardness properties, the casting temperature of three alloys were chosen as 710, 760 and 810 °C, respectively. 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 °C. 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).

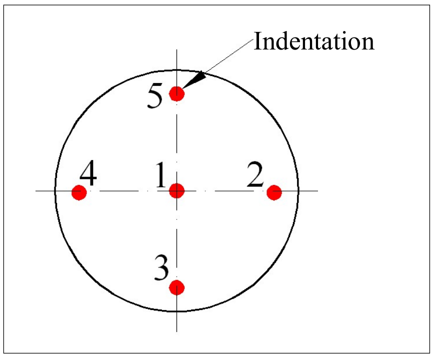

Figure 1. Five location indented on cross section of cast–sample

Results and Discussion

Cooling Curve/Rate

Figure 2 shows cooling and first derivative curve on Al–1.37Zn–1.19Si alloy for pouring temperature at 710 °C. The solidification curves indicate that thermocouples data recorded from a particular range of solidifications. The first peak of derivatives curve shows the liquids temperature about 643 °C (primary α–Al formation). The second peak on derivatives curve denotes the solidus temperature around 348 °C. The liquids temperature is 621 °C, and the solidus temperature is 401 °C from cooling and first derivative curve with pouring temperature at 710 °C 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 ^{o}C ranges about 643 – 348 ^{o}C and freezing range for Al–1.66Si–1.35Zn with pouring temperature at 710 ^{o}C ranges from 621 to 401 ^{o}C. Cooling rate for Al–1.37Zn–1.19Si is 55.56 ^{o}C/S and Al–1.66Si–1.35Zn is 30.09 ^{o}C/S. Cooling rate as a thermodynamic parameter is significantly affected by the pouring temperature, and it would decrease with increasing of pouring temperature (Pang, *et al.* 2015).

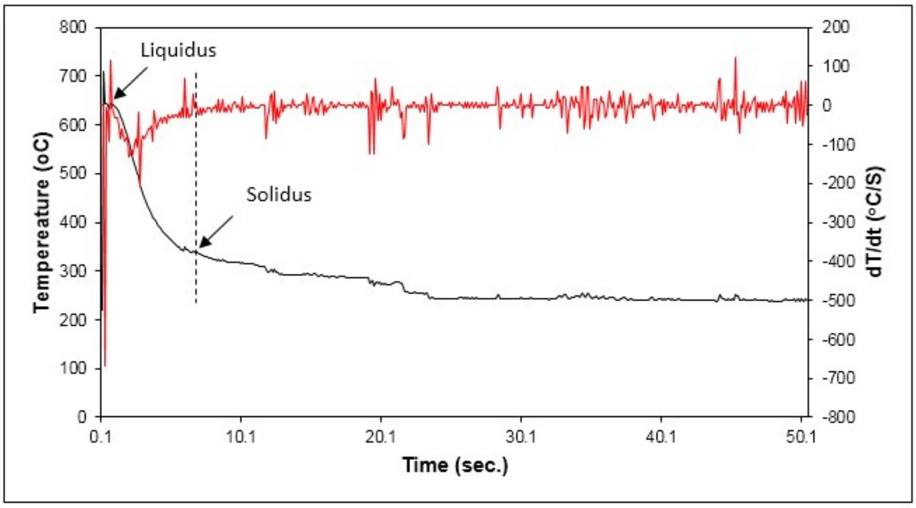

Figure 2. Cooling curves and the first derivative on Al–1.37Zn–1.19Si alloy with poured at 710 ^{o}C.

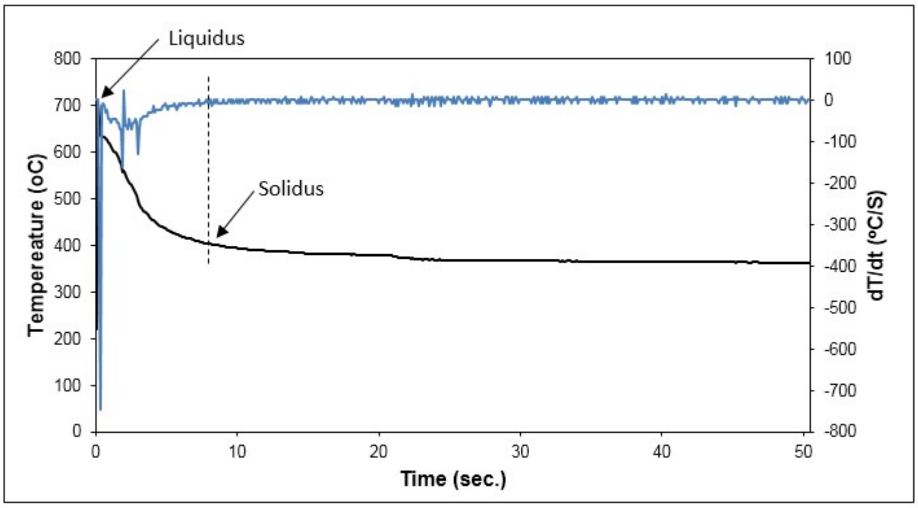

Figure 3. Cooling curves and the first derivative on Al–1.66Si–1.35Zn alloy with poured at 710 ^{o}C.

Hardness Material

Hardness properties of the cast–sample that produced with different pouring temperatures were observed, the result shown in Figure 4. The hardness value maximum on Al–1.37Zn–1.19Si alloy is 42.88 BHN at 760 ^{o}C of pouring temperature. The hardness index has a maximum on Al–1.66Si–1.35Zn alloy is 50.04 BHN at 760 ^{o}C of pouring temperature. It can be seen that the hardness index is increasing first and then decrease with increasing of pouring temperature. A Slightly difference on Al–2.81Zn–2.6Si alloy, the hardness index is increased with increasing pouring temperature and reach maximum at 62.83 BHN at 810 ^{o}C of pouring temperature. According to Kaiser, *et al.* (2013), the hardness increase in alloy with increasing cooling rate during solidification. Hardness average value is rising from 490 H_v at slow cooling rates to 520 H_v for metal casting with rapidly cooled.

According to the result shows that pouring temperature has affected on hardness material properties. Moreover, the variation of metal compositions has effected to the hardness index. Increases cooling rate would be increasing hardness properties of material. Increases cooling rate frequently change grain microstructure become finer, and that would follow by increasing the solid solubility in solid solution. If the solid solubility alloying elements is weak, then the grain size become smoother so increased hardness metal. A regular structure has better of hardness properties than random structure, and this is because of higher internal stress. That internal stress is inversely proportional to mechanical properties. A high pouring temperature frequently increases the nucleation spots in the superheat melt and refine the microstructure (Kabir, *et al.* 2014). The refined microstructure improved the hardness of the alloy, implying that SDAS of cast–sample have an influence on hardness (Hu, *et al.*, 2012).

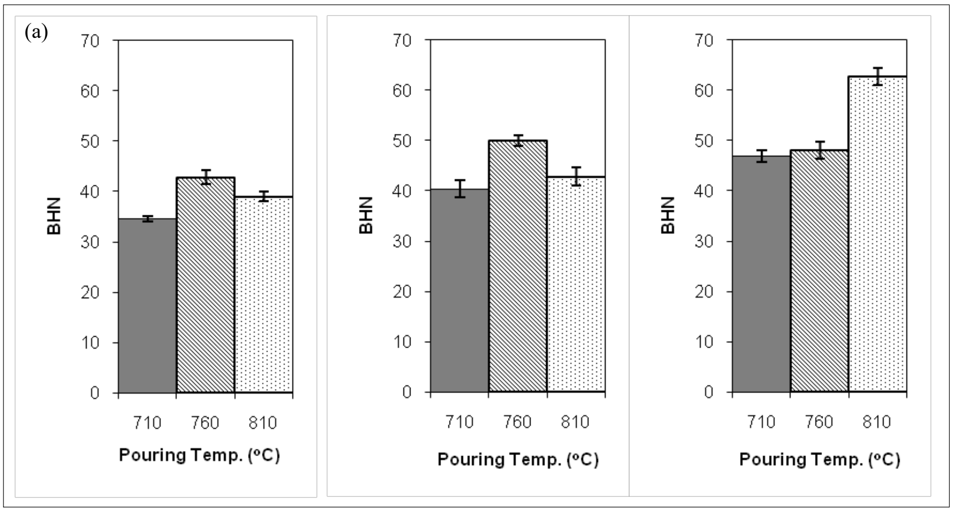

Figure 4. Hardness value with different pouring temperature on (a) Al–1.37Zn–1.19Si; (b) Al–1.66Si–1.35Zn; and (c) Al–2.81Zn–2.6Si alloys.

Conclusions

The conclusion of this experiment show, the freezing temperature of Al–1.37Zn–1.19Si is starting from 643 ^{o}C until 348 ^{o}C with pouring temperature at 710 ^{o}C, while freezing range of Al–1.66Si–1.35Zn is starting with 621 ^{o}C to 401 ^{o}C at 710 ^{o}C of pouring temperature. However, the cooling rate could define for Al–1.37Zn–1.19Si is 55.56 ^{o}C/S and Al–1.66Si–1.35Zn is 30.09 ^{o}C/S. The hardness value is increasing first then decrease, with increasing of pouring temperature on Al–1.37Zn–1.19Si and 1.66Si–1.35Zn alloys. The slight difference with Al–1.66Si–1.35Zn alloy, the hardness value is increase with increasing of pouring temperature.

Acknowledgements

This publication was made possible by a Grant from the Indonesia National Research Fund (Dikti, No.:090/UN11.2/LT/SP3/2015; No.: 035/SP2H/PL/Dit.Litabmas/II/2015); the financial support is greatly appreciated. We would like to thank Dr. Suyitno and Prof. Husaini for support during this research.

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