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Effect of Pouring Temperature Variation on Cooling Rate, Hardness and Microstructure of Al-Zn in Aircraft Structures

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Abstract

Al-Zn alloys are widely utilized in industries such as automotive, aircraft manufacturing, and advanced military equipment due to their exceptional strength-to-weight ratio. Among various fabrication methods, metal casting is a commonly used technique for producing structural components from these alloys. However, a significant challenge with metal casting is the reduction in mechanical properties compared to the base material before melting. This reduction highlights the need for research to identify the optimal casting conditions, particularly the casting temperature, which plays a crucial role in maintaining and potentially enhancing the material's mechanical properties. Aluminum alloy 7075, known for its high strength, was selected for investigation. According to the Al-Zn phase diagram, the melting point of aluminum alloy 7075, based on the weight percentage specified by the Standard Aluminum Association, is approximately 660°C. Experiments were conducted by varying the pouring temperature during casting in 30°C increments above this melting point. Specifically, the alloy was melted and cast at three different temperatures: 690°C, 720°C, and 750°C. The mold temperature was consistently maintained at 220°C to isolate the effects of the pouring temperature. Results indicate that increasing the casting temperature significantly affects the alloy's microstructure and mechanical properties. As the casting temperature increases, the cooling rate decreases, leading to a finer grain structure. This finer grain size directly contributes to an increase in hardness, suggesting that higher casting temperatures can enhance the mechanical properties of Al-Zn alloys. These findings emphasize the importance of precise control over casting temperatures to optimize the performance characteristics of aluminum alloy 7075 in high-strength applications.

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1. Introduction

Aluminum alloys find extensive application in the automotive industry, aircraft component manufacturing, and advanced military equipment [1], [2], [3], [4]. For instance, Al–Zn–Mg–Cu represents a high-strength aluminum alloy. These alloys find extensive use in critical aircraft components like stringers, fuselage, and wing skin. The Al–Zn–Mg–Cu alloy belongs to the 7xxx series within the aluminum group, exhibiting properties such as corrosion resistance, high impact resistance, and good thermal conductivity. T6 heat treatment typically enhances the strength and toughness of these alloys [5], [6], [7]. Metal casting involves fabricating structural components, but its drawback lies in reduced mechanical properties compared to the original base material before melting. Research is necessary to determine the optimal temperature, as pouring temperature significantly impacts material properties [8]. The quality of aluminum alloy castings can be enhanced by adjusting casting variables such as mold material and casting temperature. Extensive research has been conducted on the impact of cooling rate on the mechanical properties of aluminum alloys [9], [10]. Studies have explored how cooling rate impacts the microstructure and solidification parameters of the Al−7Si−0.3Mg−0.15Fe alloy. The findings revealed that hardness rises as the cooling rate increases [11].

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Researchers investigated how heat treatment and cooling rate impact the hardness properties of Sr-added alloys A319.1, A356.2, and A413.1 [12]. Two quenching levels were employed to estimate hardness (85 and 110-115 BHN) in commercial alloys. The results show that higher cooling rates result in greater hardness index compared to lower cooling rates. The alloy lacking Sr addition exhibited slightly higher hardness than the Sr-added alloy, and hardness index decreased with Sr addition at both cooling rates. The interaction between Sr, Cu, and Mg elements, which form various intermetallic phases, correlates with reduced hardness values. Additionally, an increase in these elements led to a decrease in the formation volume fraction of precipitation-hardening phases (Al2Cu and Mg2Si) in A319.1 and A356.2 alloys, further lowering hardness.

The Cooling Curve Analysis (CCA) method predicts microstructure, grain refinement, and latent heat solidification. It assesses the thermo-physical properties of the alloy, including latent heat of solidification [13], [14]. This study aims to understand the cooling curve behavior, microstructure, and hardness of Al-Zn alloy under different pouring temperatures. The research is divided into two parts: the first examines cooling rates during solidification, while the second focuses on microstructure and hardness variations.

2. Experimental and Procedures

Ingot from recycled aluminum alloy was supplied by an Indonesian metal caster. These ingots are cut into small pieces, as shown in Fig. 1, which are then melted into the mold in the furnace as depicted in Fig. 3. The pouring temperature is maintained at 690 ± 2 °C, 720 ± 2 °C, and 750 ± 2 °C, while the mold temperature is kept constant at 220 ± 3 °C. The steel molds used during this study were made of EMS/17330 carbon steel (Fig. 2). The chemical composition of casting products is shown in Table 1.

Table 1. Al-Zn chemical composition

Element	(wt%)
Si	0.2411
Fe	0.5275
Cu	0.13.10
Mn	0.0705
Mg	0.0081
Ti	0.0104
Cr	0.0043
Pb	0.0754
Sr	0.0109
Ni	0.0072
Zn	1.6542
Al	Balance

Figure 1. Al-Zn aluminum alloy

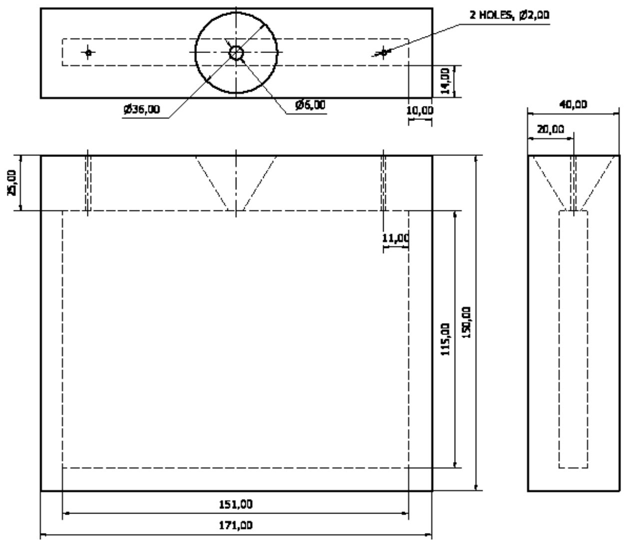

Figure 2. Trapezoidal mold for testing specimens

Molten aluminum was poured into a 10mm permanent metal mold and allowed to cool to room temperature. The steel molds used in this study were made of EMS/17330 carbon steel, chosen for its ability to hold liquid aluminum due to its higher melting point compared to aluminum alloy. Cooling temperature was monitored using a chromel-alumel (type K) thermocouple during solidification. The hardness of the Al-Zn alloy specimen was tested using the Brinell method with a 2.5 mm steel ball indenter and a 612.9 N load for 10 seconds. The average hardness value was determined from six tests. Metallographic specimens were prepared by grinding with SiC paper, followed by polishing and etching using a solution of 2 ml HF and 100 ml H_2O.

Figure 3. Furnace

3. Results and Discussion

3.1. Cooling rate

Fig. 4, Fig. 5, and Fig. 6 show the cooling and first derivative curves for Al-Zn alloy with variations in pouring temperature. The cooling curve shows the difference in cooling time at each pouring temperature. The temperature decreases due to variations in pouring temperatures (690 °C, 720 °C, and 750 °C) and a mold temperature of 220 °C. The illustration indicates that the temperature simultaneously drops from 690 °C to 550 °C in 90 seconds, from 720 °C to 550 °C in 150 seconds, and from 750 °C to 550 °C in 200 seconds. The cooling rate for a pouring temperature of 690 °C is 1.55 °C/S, 720 °C is 1.13 °C/S, and 750 °C is 1.05 °C/S. The cooling rate, as a thermodynamic parameter, is significantly affected by the pouring temperature and decreases as the pouring temperature increases [11].

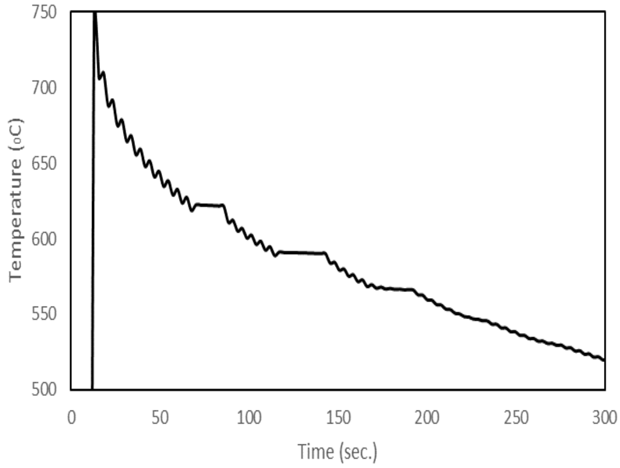

Figure 4. Pour temperature cooling curve 750 °C

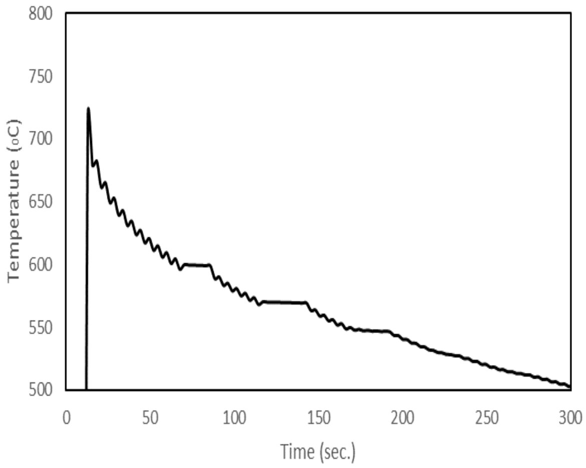

Figure 5. Pour temperature cooling curve 720 °C

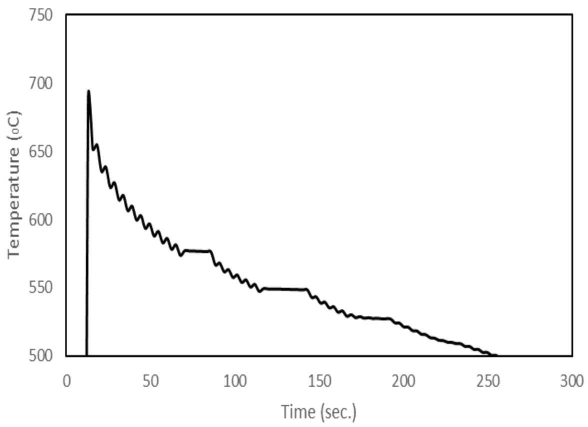

Figure 6. Pour temperature cooling curve 690 °C

3.2. Hardness and microstructure

Figure 7 shows that the average hardness values of the Al-Zn alloy specimens were determined from six test points using the Brinell test. The hardness values at pouring temperatures of 690 °C, 720 °C, and 750 °C were 59.65 BHN, 60.63 BHN, and 60.7 BHN, respectively. These values are higher than the hardness value reported Akhyar et al. [15], which was approximately 38.43 BHN. Hardness increases with increasing pouring temperature which is influenced by grain size. An image of the grain size can be seen in Fig. 8. The higher the pouring temperature, the smaller the grain size.

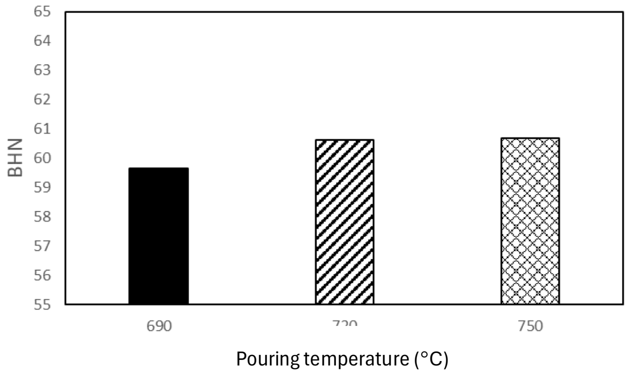

Figure 7. Brinell test with three variations of pouring temperature

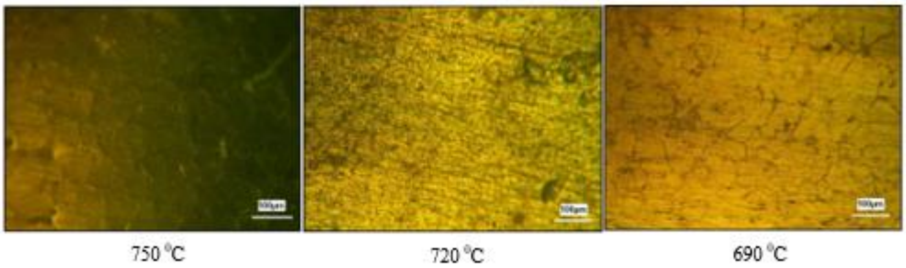

Figure 8. Microstructure with three variations of pouring temperature

4. Conclusions

The Al-Zn alloy specimens analyzed in this study closely mirror the chemical composition of the 7xxx series aluminum alloys (Al-Zn-Cu-Mg), which are extensively utilized in the automotive, aerospace, and military sectors due to their exceptional mechanical properties. These alloys are particularly valued for their high strength-to-weight ratio, corrosion resistance, and durability under extreme conditions, making them ideal for critical structural applications.

At a casting temperature of 690°C, the maximum cooling rate observed was 1.55°C/s, indicating a relatively rapid solidification process. This rapid cooling is crucial as it influences the microstructure, particularly the grain size, which in turn affects the mechanical properties of the alloy. The study reveals a direct correlation between the pouring temperature and the hardness of the alloy. Specifically, as the casting temperature increases, the hardness of the Al-Zn alloy also increases, with the highest hardness value recorded at 750°C, reaching 60.7 BHN (Brinell Hardness Number).

The observed increase in hardness with rising pouring temperature is largely attributed to the reduction in grain size. As the temperature increases, the cooling rate decreases, promoting the formation of finer grains within the alloy's microstructure. Finer grains contribute to higher hardness values, enhancing the overall mechanical properties of the alloy. This finding underscores the importance of precise control over casting temperatures in optimizing the performance characteristics of Al-Zn alloys.

References

[1] Akhyar, P. T. Iswanto, R. Syaputra, and A. Farhan, "Experimental investigation on hardness, tensile strength, and microstructure of Al-3,1Cu Cast-Alloy after T6 - tempered," *Metalurgija*, vol. 61, no. 3–4, pp. 616–618, 2022.

[2] P. T. Iswanto, Akhyar, and A. Pambekti, "Heat treatment T4 and T6 effects on mechanical properties in Al-Cu alloy after remelt with different pouring temperatures," *Metalurgija*, vol. 59, no. 2, pp. 171–174, 2020.

[3] L. P. McDonnell et al., "Superposition of intra- and inter-layer excitons in twistronic MoSe2/WSe2 bilayers probed by resonant Raman scattering," *2d Mater*, vol. 8, no. 3, 2021, doi: 10.1088/2053-1583/abe778.

[4] Y. Otani and S. Sasaki, "Effects of the addition of silicon to 7075 aluminum alloy on microstructure, mechanical properties, and selective laser melting processability," *Materials Science and Engineering: A,* vol. 777, p. 139079, 2020, doi: 10.1016/j.msea.2020.139079.

[5] S. Y. Zhou, Y. Su, H. Wang, J. Enz, T. Ebel, and M. Yan, "Selective laser melting additive manufacturing of 7xxx series Al-Zn-Mg-Cu alloy: Cracking elimination by co-incorporation of Si and TiB2," *Addit Manuf*, vol. 36, 2020, doi: 10.1016/j.addma.2020.101458.

[6] E. Georgantzia, M. Gkantou, and G. S. Kamaris, “Aluminium alloys as structural material: A review of research,” *Eng Struct*, vol. 227, p. 111372, 2021, doi: 10.1016/j.engstruct.2020.111372.

[7] L. Li, R. Li, T. Yuan, C. Chen, Z. Zhang, and X. Li, “Microstructures and tensile properties of a selective laser melted Al–Zn–Mg–Cu (Al7075) alloy by Si and Zr microalloying,” *Materials Science and Engineering: A,* vol. 787, no. April, p. 139492, 2020, doi: 10.1016/j.msea.2020.139492.

[8] K. He et al., “Effect of pouring temperature during a novel solid–liquid compound casting process on microstructure and mechanical properties of AZ91D magnesium alloy parts with arc-sprayed aluminum coatings,” *J Mater Sci*, vol. 55, no. 15, pp. 6678–6695, 2020, doi: 10.1007/s10853-020-04437-5.

[9] M. Aniolek, T. Smith, and F. Czerwinski, “Combining differential scanning calorimetry and cooling- heating curve thermal analysis to study the melting and solidification behavior of Al-Ce binary alloys,” *Metals (Basel),* vol. 11, no. 2, pp. 1–17, 2021, doi: 10.3390/met11020372.

[10] J. Li, J. Feng, Y. Li, F. Dong, and G. Geng, “Cooling curve thermal analysis, phase constitution, and solidification characteristics of cast Mg–5Gd–2Y–xNd–Zr alloys,” *J Therm Anal Calorim,* vol. 142, no. 4, pp. 1429–1435, 2020, doi: 10.1007/s10973-020-09515-z.

[11] S. Pang et al., “Effect of cooling rate on the microstructure and mechanical properties of sand-casting Mg-10Gd-3Y-0.5Zr magnesium alloy,” *Materials Science and Engineering: A*, vol. 562, pp. 152–160, 2013, doi: 10.1016/j.msea.2012.11.016.

[12] O. El Sebaie, A. M. Samuel, F. H. Samuel, and H. W. Doty, “The effects of mischmetal, cooling rate and heat treatment on the eutectic Si particle characteristics of A319.1, A356.2 and A413.1 Al-Si casting alloys,” *Materials Science and Engineering: A*, vol. 480, no. 1–2, pp. 342–355, 2008, doi: 10.1016/j.msea.2007.07.039.

[13] A. V. Anil, V. Vijayan, B. Sachin, P. K. Rai, and M. Rao, “Computer aided cooling curve analysis (CACCA) of ADC-12 alloy,” *Mater Today Proc,* vol. 46, pp. 2591–2595, 2021, doi: 10.1016/j.matpr.2021.02.129.

[14] N. H. Husain, A. H. Ahmad, and M. M. Rashidi, “Thermal analysis of 6061 wrought aluminium alloy using cooling curve analysis-computer aided (CCA-CA) method,” *IOP Conf Ser Mater Sci Eng,* vol. 788, no. 1, 2020, doi: 10.1088/1757-899X/788/1/012018.

[15] H. Akhyar and Husaini, “Study on cooling curve behavior during solidification and investigation of impact strength and hardness of recycled Al-Zn aluminum alloy,” *International Journal of Metalcasting*, vol. 10, no. 4, pp. 452–456, 2016, doi: 10.1007/s40962-016-0024-8.