Differences in Pour Temperature Affect Hardness Properties of CuZn Brass Alloy through Metal Casting

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Abstract. The purpose of this study to evaluate the effect of pouring temperature on the Vickers hardness of CuZn brass alloys through metal casting. The pouring temperature varied from 1,060; 1,110; 1,160; 1,210; and 1,260 °C; while metal molds were not given preheat treatment or at room temperature conditions. The results obtained that the maximum hardness is 616 HV shown at 1,210 °C of the pouring temperature, while the minimum hardness is 574 HV can be seen at 1,210 °C of the pouring temperature. The significance of the difference in casting temperature on the hardness of CuZn brass alloy through metal casting was analyzed using one-way ANOVA. Generally, it appears that hardness increases with increasing pouring temperature. The effect of pouring temperature results in differences in solidifying rates and freezing intervals of brass alloys. Furthermore, it affects the grain structure growth of the brass alloy which led to the difference in Vickers hardness.
1. Introduction

The application of brass alloys is very wide in the engineering field, Products that are frequently found such as bolts, nuts, electrical connectors, valve bodies, and hydraulic fittings. Brass alloys have the properties of excellent mechanical strength, high workability, and excellent corrosion and wear resistance [1]. Differences in pouring and mold temperatures can affect the cooling rate of metal alloys [2]. The solidification rate can affect the microstructure of the alloys so that it affects the hardness, tensile strength, percentage elongation, and impact toughness of the metal alloy. Increasing the cooling rate can increase the hardness, tensile strength, percentage elongation, and impact toughness of metal alloys, this can reduce the percentage of porosity and secondary dendrite arm spacing on metal alloys [3]. Research conducted to vary the effect of pouring temperature on the mechanical properties of metal alloys was evaluated in metal casting [4,5].

The hardness of brass alloys with copper (Cu) content of 65.493 wt.pct and zinc (Zn) 34.506 wt.pct and others have been investigated through metal casting, and the Briner hardness value is HB 110.44 kg/mm². [6]. Microstructural evolution investigations have been carried out on brass alloys produced by low-pressure die casting. It has been shown that the fine $\beta$-phase distribution increases the hardness of the alloy [7]. The result shows an increase in the hardness of the alloy from 62 to 156 HBN due to the addition of Sn. Studies on low-pressure die casting brass alloys have been carried out to predict casting defects [8]. The effect of lead content on the microstructure, hardness of cast bronze alloys in permanent molds has been observed. The results showed that the increase in hardness of the bronze alloy was influenced by the initial formation of the spinodal or modulated structure [9]. The hardness of the product shell wall thickness from the rapid casting in brass alloys has been evaluated using three-dimensional printing technology. As a result, the hardness variation obtained from casting brass alloys with shell mold thickness ranges from 84-102 VHN [10]. Several brass alloy castings have been reported for several cases, including shell mold [11], machining applications [12], different gate systems [13].

The microstructure, hardness, and machinability of the alloys have been studied on $\alpha$-brass alloy [14]. The hardness and impact toughness of recycled metal alloys have been evaluated by the metal casting process [15]. The effect of casting temperature on the mechanical properties of metal alloys has been investigated during metal casting [16,17]. ANOVA test has been carried out to optimize the process parameters when squeeze casting of brass alloys [18]. Based on this background, the purpose of this study was to evaluate the effect of casting temperature on Vickers hardness of the brass alloy was evaluated using a one-way ANOVA statistical test.

2. Method and Parameters

CuZn brass alloy casting products with five variations of pouring temperature were used to evaluate the hardness behavior of the alloy. In this experiment, a gravity casting process was carried out to produce cast samples [19, 20, 21]. The metal casting process begins by cutting a cylindrical brass rod with a diameter of 25.4 mm and a length of 609.6 mm into small pieces for easy melting in the furnace. The melting furnace used is a furnace with LPG (liquefied petroleum gas) fuel with additional oxygen for complete combustion. The cast sample for hardness testing is produced in a medium-carbon steel metal mold in a rectangular shape, as shown in Figure 1.

The chemical composition of the brass alloy (CuZn) used in this experiment is as shown in Table 1. Figure 2 shows a binary phase diagram of a brass alloy at equilibrium. Referring to the phase diagram and chemical composition of the brass used in this experiment, it can be identified that the melting point is around 980 °C [22]. Then five variations of pouring temperature were selected, namely 1,060; 1,110; 1,160; 1,210; and 1,260 °C or liquidus + 80, liquidus + 130, liquidus + 180, liquidus + 230, and liquidus + 280 °C which were carried out in this experiment. Hopefully, the solidifying interval can affect the hardness of the cast-sample. The longer solidification interval provides a greater opportunity for the formation of metal alloy microstructure. Where the microstructure morphology of the alloy can affect the Vickers hardness value of the brass alloy.
Figure 1. Schematic of a plate-shaped metal mold (in mm).

Table 1. Chemical composition of the brass alloy (wt.%).

| Element | Cu | Zn  | Pb  | Sn  | Fe  |
|---------|----|-----|-----|-----|-----|
| Bal.    | 28.7 | 2.09 | 1.33 | 1.16 |     |

Figure 2. Binary phase diagram of Cu-Zn alloy at equilibrium [22].
The chemical composition test of the cast samples was carried out using the Spectrolab Jr CCD Spark Analyzer. The surface of the cast-sample was grinding and polished and observed through a scanning electron microscope (SEM). The Vickers hardness test on cast samples follows the ASTM E92 standard with ten test points each. Hardness analysis data obtained from experiments with five variations of pouring temperature were tested through one-way analysis of variance (ANOVA).

3. Result Analysis
The hardness value is one of the mechanical properties of an alloy which indicates the metal's resistance to indentation deformation. The brass alloy hardness value was evaluated against five variations of pouring temperature, as shown in Figure 3.

![Figure 3](image-url)

**Figure 3.** Vickers hardness of CuZn alloy with five variations of pouring temperature.

The results of the Vickers hardness test are shown in Figure 3, that differences in pouring temperature can affect the Vickers hardness of cast brass alloys. In general, based on the trend line, the hardness decreases with increasing pouring temperature. The minimum hardness value is 574 HV obtained from the pouring temperature at 1,260 °C, while the maximum hardness value is 616 HV obtained from the pouring temperature at 1,210 °C. The hardness value of the cast-sample in this experiment was higher when compared to the thick-shell mold of the brass alloy which had a value of 102 VHN [10].

The solidification interval can affect the growth of metal grains in metal alloys. A higher pouring temperature results in a larger solidification interval and causes a longer freezing time. High-temperature pouring can make the grain size enlarge and the phase distribution grows more evenly in the phase matrix. This is almost the same as the sintering conditions of Cu-Zn brass alloys, where the sintering time causes grain growth which causes the number of liquid phases, and the adjustment of the atomic diffusion conditions [23]. The alloy surface morphology was observed through SEM imaging with 500x magnification against five differences in casting temperature during the metal casting process as shown in Figure 4.
Figure 4. Surface morphology of cast samples with different pouring temperatures: (a) 1,060 °C; (b) 1,110 °C, (c) 1,160 °C, (d) 1,210 °C, and (e) 1,260 °C.

The hypothesis in this experiment was tested using one-way ANOVA. Homogeneity and normality tests were performed as statistical prerequisite tests. It was found that the subjects with different pouring temperatures came from normally distributed populations and homogeneous groups of Vickers hardness values (Table 2).
Table 2. Results of the hardness experiment.

| No. | Pouring Temperature (°C) |
|-----|--------------------------|
|     | 1,060 | 1,110 | 1,160 | 1,210 | 1,260 |
| 1   | 595.27 | 595.27 | 588.58 | 657.03 | 664.92 |
| 2   | 591.91 | 598.66 | 608.99 | 634.18 | 657.03 |
| 3   | 660.96 | 578.76 | 572.35 | 626.83 | 572.35 |
| 4   | 605.52 | 582.01 | 689.47 | 697.96 | 626.83 |
| 5   | 602.07 | 702.26 | 578.76 | 702.26 | 572.35 |
| 6   | 575.54 | 657.03 | 582.01 | 657.03 | 752.32 |
| 7   | 619.60 | 608.99 | 689.47 | 637.90 | 894.29 |
| 8   | 591.91 | 572.35 | 776.87 | 605.52 | 578.76 |
| 9   | 595.27 | 818.71 | 598.66 | 612.50 | 1309.51 |
| 10  | 637.90 | 980.84 | 598.66 | 619.60 | 697.96 |

Table 3 shows the calculation results of sample number for each pouring temperature (Count.), the total Vickers hardness value of all samples per pouring temperature (Sum), the average Vickers hardness value of all samples per pouring temperature (Mean), the variance of the Vickers hardness value of all samples per pouring temperature (Variance), the sum of squares of the Vickers hardness value of all samples per pouring temperature (SS), standard error of each pouring temperature (Std. Err.), lower and upper limits of each pouring temperature. Table 4 shows the results of the one-way ANOVA calculation including the Mean Square (MS) value between Group, Within Group and Total, degrees of freedom (df).

Table 3. Description of hardness experiments.

| Groups (°C) | Count. | Sum    | Mean   | Variance | SS     | Std Err | Lower | Upper |
|-------------|--------|--------|--------|----------|--------|---------|-------|-------|
| 1,060       | 10     | 6075.95 | 607.60 | 640.94   | 5768.45| 38.6984 | 520.0536 | 695.1372 |
| 1,110       | 10     | 6694.87 | 669.49 | 17771.44 | 159942.97| 38.6984 | 581.9450 | 757.0285 |
| 1,160       | 10     | 6283.81 | 628.38 | 4554.64 | 40991.79| 38.6984 | 540.8388 | 715.9224 |
| 1,210       | 10     | 6450.80 | 645.08 | 1125.59  | 10130.33 | 38.6984 | 557.5378 | 732.6214 |
| 1,260       | 10     | 7326.31 | 732.63 | 50785.56 | 457070.02 | 38.6984 | 645.0889 | 820.1725 |

Table 4. ANOVA calculation results.

| Sources      | SS      | df       | MS      | F       | P value | F crit   |
|--------------|---------|----------|---------|---------|---------|----------|
| Between Groups | 92772.38 | 4       | 23193.0954 | 1.548722042 | 0.204424772 | 2.578739184 |
| Within Groups | 673903.56 | 45      | 14975.6346 |         |         |         |
| Total        | 766675.94 | 49      | 15646.4477 |         |         |         |

Conclusions can be built from the calculated F value whether greater or less than the F table. If $F_{\text{Count}} < F_{\text{Table}}$, then $H_0$ is accepted, which means that the influence of pouring temperature on the Vickers hardness value is not significant at the critical alpha limit $\alpha$ ($> 0.05$). Conversely, if $F_{\text{Count}} > F_{\text{Table}}$ then $H_0$ is rejected, which means that the effect of pouring temperature on the hardness value is significant at the critical alpha limit $\alpha$ ($< 0.05$). In the results of this experiment, the hardness value shows a significant probability at $\alpha < 0.3$ to variations in pouring temperature. From the ANOVA data, the calculated F value is greater than the F table ($2.5787 > 1.5487$) and it can be concluded that the increase of the pouring temperature can reduce the Vickers hardness value when casting brass alloys.
4. Conclusions

Vickers hardness evaluation on brass alloys with five variations of pouring temperature has been carried out in this experiment with the metal casting process. Based on the results and discussion, it can be concluded that variations in pouring temperature can affect the hardness value of brass alloys. The Vickers hardness value appears to decrease with increasing pouring temperature. The maximum Vickers hardness value is 616 HV obtained in cast samples with a pouring temperature of 1,210 °C, while the minimum value is 574 HV at a pouring temperature of 1,260 °C. The higher pouring temperature causes the cooling rate (time) to be wider, thus causing the grain growth to be larger than the rapid solidification time. From the ANOVA test, it can be concluded that there is a significant influence between the pouring temperature and the Vickers hardness value.

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