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Study of The Effect of Variation of Zirconium Content and Ageing Through Precipitation Hardening Process on Mechanical Properties of Aluminum Alloys (Al-Zr)

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Abstract. Precipitation hardening is a heat treatment process to increase the strength of aluminum alloys with solution heat treatment, quenching and aging processes. This literature study aims to determine how aging from the precipitation hardening process affects aluminum zirconium alloy material on mechanical properties with varying temperature and aging time. The analysis was carried out using secondary data obtained from research published before in various journals. The research material is aluminum zirconium alloy with 0.1-0.4% zirconium composition and above 99.5% aluminum composition. The temperatures used in this study were 375^{0}C, 400^{o}C, and 425^{0}C, and the aging time was up to 400 hours. Based on studies from various literature, it is found that the aging process gets an increase in the hardness value of aluminum alloy materials. The results of this study will be one of the references in further research. Keywords: precipitation hardening, aging, aluminum, zirconium, hardness.

INTRODUCTION

Aluminum is the most consumed non-ferrous metal globally, with current annual consumption reaching 24 million tons. About 75% of this total volume, or 18 million tons, is "primary aluminum," that is, aluminum extracted from ore instead of secondary aluminum from scrap metal processing [1]. Aluminum is one of the many materials that are widely used in industry. Aluminum has its advantages, such as being lightweight but having good ductility, corrosion resistance, and good electrical conductivity. Aluminum has an important role in the industrial world because of its availability and versatility as a material for aircraft, ships, automotive, household appliances, and construction.

Aging is a term that includes precipitation hardening processes that can occur at room temperature (natural aging) or at higher temperatures that require special heating (artificial aging). In the late stages of aging, dissolution may occur due to changes in the structure and distribution of the previous hardening phase [1]. Aging carried out at lower temperatures will have better strength. Merica et al. postulated that age hardening occurs in alloys where the solubility of solids increases with increasing temperature, thus allowing new phases to form at lower temperatures by precipitation from solid solutions [2]. Artificial aging treatment is designed to produce optimal size, distribution, constitution, and morphology of the precipitate and the amount of solute in solid solution. Hardening is often obtained from partially coherent deposits [3].

The use of aluminum sometimes requires greater tensile strength or hardness; therefore, aluminum alloys can be aged at a specific temperature to improve the mechanical properties of aluminum alloys. Zirconium is one of the alloys that can be combined with aluminum, an Al-Zr alloy that has advantages of corrosion and resistance to high temperatures. The use of Al-Zr alloy is as a production material for transmission lines, wire rods, and overhead electric power [4].

This research was conducted because of the desire to improve the mechanical properties of aluminum. One way to improve the mechanical properties of aluminum material is by precipitation hardening. In the precipitation

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hardening process, there is an aging process where the process is carried out to eliminate dislocations due to particle precipitation so that the hardness value increases. Only a few materials can do precipitation hardening. The material used in this research is aluminum with a bit of a mixture of zirconium composition. The aluminum zirconium alloy material was chosen because of the precipitation-hardening process. According to Phillip D. Staublin, zirconium added to aluminum in small amounts (0.04-0.2%) allows the material to carry out a precipitation hardening process to increase the strength of the aluminum alloy [5]. In a previous study, Keith E. Knipling, David C. Dunand, and David N. Seidman carried out a precipitation hardening process on Al-0.19Zr material and Al3Zr that increased the hardness value.

METHOD

The research collected secondary data related to aluminum zirconium alloy material aging at a specific temperature. The data obtained will be processed into a graph to compare variables, and analysis will be carried out. The material of this research is aluminum zirconium alloy material where the material has different zirconium composition values, namely 0.1-0.4% and aluminum composition above 99.5%; this is useful to determine the effect of zirconium composition and the effect of aging on the hardness value. The equipment used for this research is a tool to determine the value of hardness and a material heating device for aluminum zirconium. Hardness value was obtained by testing the hardness of the Vickers method, with a load of 1.96 N and a holding time of 5s. The tested specimens were collected 20 times with the averaged results. The results are averaged 20 times, making the data used more accurate.

The aging process in this study is an artificial aging process with temperatures used in this study, namely 375^0C, 400^0C, and 425^0C, using a muffle furnace. The choice of temperature is because the temperature of $300\text{-}400^0$C causes precipitation hardening with the appearance of spherical coherent particles consisting of a cubic phase of Al3Zr with an L12 structure [6]. The aging time in this study was 0-400 h. After the aging process, the quenching process was carried out with water at room temperature. The flow in this study can be seen in Figure 1.

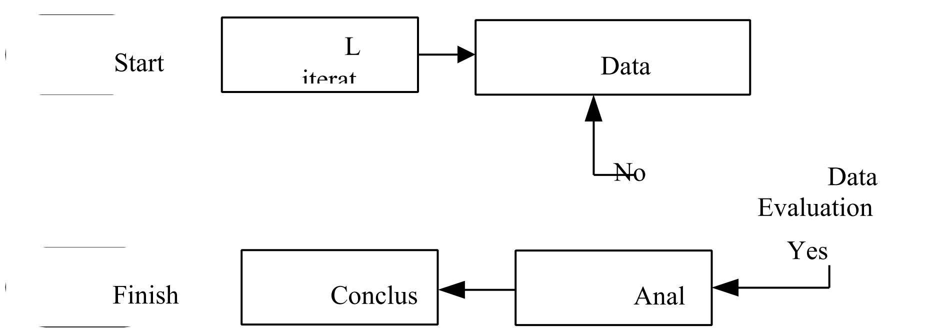

FIGURE 1. Flow Chart of Research

RESULTS AND DISCUSSION

The results of this study are in the form of different hardness values because the variables used are also different. The difference lies in the value of the zirconium composition, aging temperature, and aging time, where these differences can make the resulting hardness value increase or decrease. The results of the hardness values can be seen in Table 1, Table 2, and Table 3.

Table 1. Hardness Test Results with an Aging Temperature of 375°C [7-12]

Specimen	*Ageing time* (h)	*Ageing temperature*	Hardness Number (HVN)
Al-0.1 Zr	Non-Ageing	-	22.09
	1	375⁰C	23.36
	6	375⁰C	31.44
	24	375⁰C	40.78
	100	375⁰C	45.74
	400	375⁰C	46.74
Al-0.19 Zr	Non-Ageing	-	24.00
	1	375⁰C	38.00
	6	375⁰C	64.00
	24	375⁰C	72.00
	100	375⁰C	70.00
	400	375⁰C	68.00
Al-0.2Zr	Non-Ageing	-	24.64
	1	375⁰C	37.81
	6	375⁰C	65.00
	24	375⁰C	72.22
	100	375⁰C	70,89
	400	375⁰C	68.82
Al-0.22 Zr	Non-Ageing	-	24.00
	4	375⁰C	25.78
	12	375⁰C	28.68
	24	375⁰C	34.21
	100	375⁰C	38.15
	400	375⁰C	36.84
Al-0.32Zr	Non-Ageing	-	24.00
	4	375⁰C	36.57
	12	375⁰C	41.57
	24	375⁰C	53.15
	100	375⁰C	53,94
	400	375⁰C	49.73

Table 2. Hardness Test Results with Temperature Aging 400°C [7-12]

Specimen	*Ageing time* (h)	*Ageing temperature*	Hardness Number (HVN)
Al-0.1 Zr	Non-Ageing	-	22.09
	1	400⁰C	25.26
	6	400⁰C	30.52
	24	400⁰C	37.36
	100	400⁰C	41.05
	400	400⁰C	41.57
Al-0.2Zr	Non-Ageing	-	24.64
	1	400⁰C	51.57
	6	400⁰C	61.57
	24	400⁰C	65.26
	100	400⁰C	66.31
	400	400⁰C	63.15
Al-0.4 Zr	Non-Ageing	-	30.00
	3	400⁰C	32.00
	6	400⁰C	32.50
	12	400⁰C	33.50
	24	400⁰C	36.00
	48	400⁰C	35.50

Table 3. Hardness Test Results with Temperature Aging 425°C [7-12]

Specimen	*Ageing time* (h)	*Ageing temperature*	Hardness Number (HVN)
Al-0.1 Zr	Non-Ageing	-	22.09
	1	425⁰C	24.73
	6	425⁰C	26.31
	24	425⁰C	30.00
	100	425⁰C	30.52
	400	425⁰C	30.26
Al-0.19 Zr	Non-Ageing	-	24.00
	1	425⁰C	38.00
	6	425⁰C	52.00
	24	425⁰C	62.00
	100	425⁰C	59.00
	400	425⁰C	54.00
Al-0.2Zr	Non-Ageing	-	24.64
	1	425⁰C	52.63
	6	425⁰C	60.00
	24	425⁰C	61.57
	100	425⁰C	58.42
	400	425⁰C	53.68

The hardness values were taken using a Vickers hardness tester with a load of 1.96 N and a dwell time of 5 s. Of the four specimens, each material has a different zirconium composition, different aging times, and different temperatures, but aging affects the material properties of a material, especially the hardness value. Visualization in graphic form can be seen in Figure 2, Figure 3, and Figure 4.

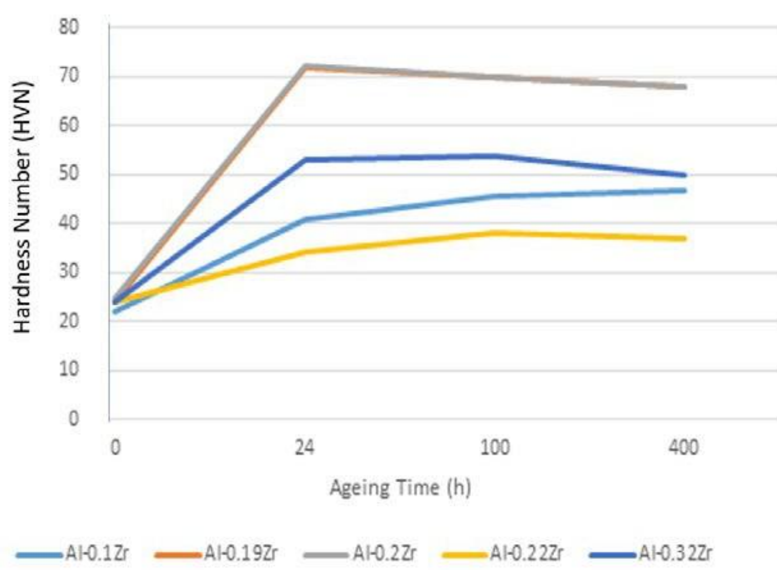

FIGURE 2. Graph of Hardness Test Results with Temperature Aging 375⁰C

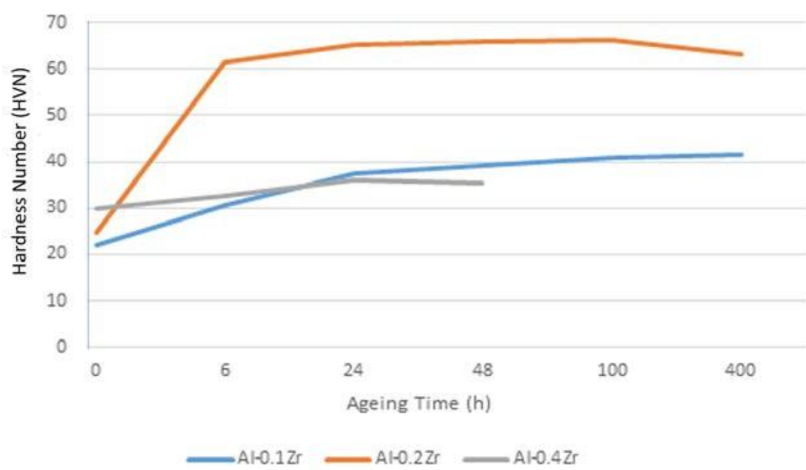

FIGURE 3. Graph of Hardness Test Results with Temperature Aging 400^{0}C

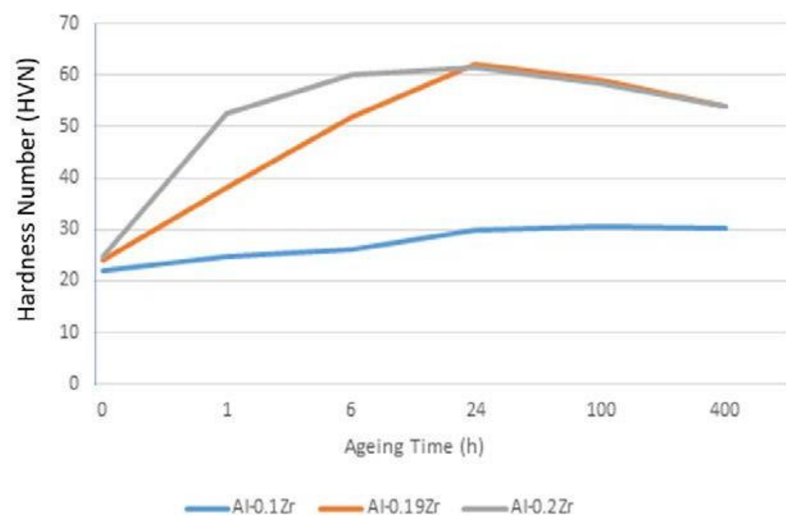

FIGURE 4. Graph of Hardness Test Results with Temperature Aging 425^{0}C

If seen from the graph above, all specimens experienced increased hardness values after the aging process. The hardness value varies depending on the amount of Zr composition and the aging temperature. If seen from the graph above, specimens that underwent an aging process for too long will experience an over-aging period. In this period, the hardness value will decrease so that aging can be used to reduce the hardness value of the specimen.

The results above show that the highest hardness value is obtained during the aging process using a temperature of 375^{0}C. The hardness value can also be increased when using a temperature of 400^{0}C and 425^{0}C, but the hardness value obtained is lower than 375^{0}C. At 375^{0}C, the over-aging process is longer than that at temperatures of 400^{0}C and 425^{0}C. Therefore, the highest hardness value is obtained at a temperature of 375^{0}C. The aging process is done at higher temperatures to reduce the hardness value. The greater the temperature, the hardness value will be lower, and the over-aging will be faster.

CONCLUSION

After analyzing the aging process of aluminum zirconium alloy, all specimens tested have an increase in hardness values, starting from the smallest amount of composition, namely 0.1-0.4%. The hardness values obtained also vary depending on the composition and temperature. The greater the zirconium content, the greater the hardness value before aging, proving that zirconium helps increase the hardness value. However, specimens containing zirconium greater than 0.2% have an aging result that is not better than those containing only 0.1-0.2% zirconium. The highest hardness values of 0.22Zr, 0.32Zr, and 0.4Zr are not greater than those of 0.1Zr, 0.19Zr, and 0.2Zr. The best temperature of aging is 375^{0}C because, at 400^{0}C and 425^{0}C, over-aging occurs more quickly. The results of this study are in accordance with the purpose of this study, namely increasing the hardness value of the aluminum material where all specimens subjected to aging have increased hardness values.

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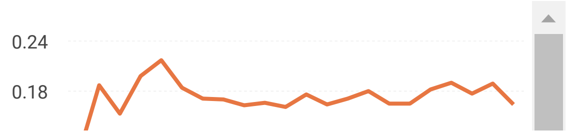

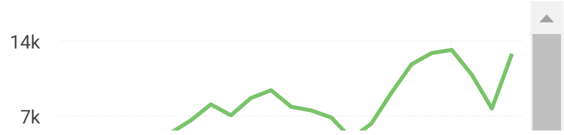

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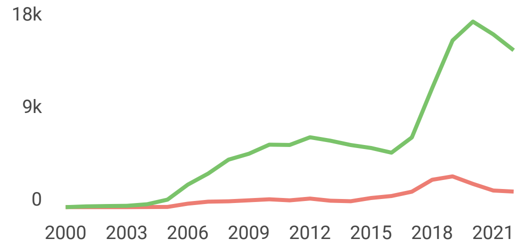

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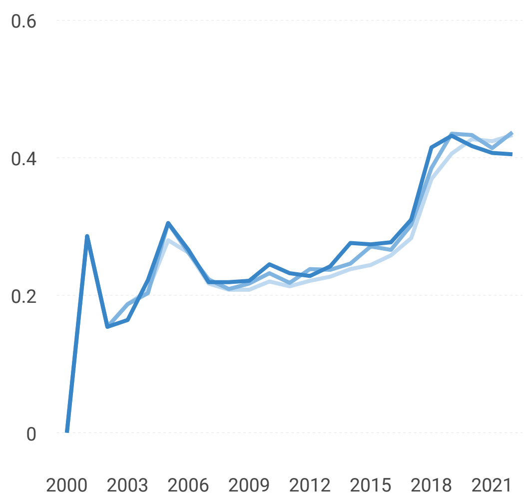

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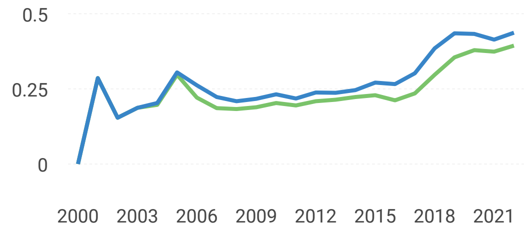

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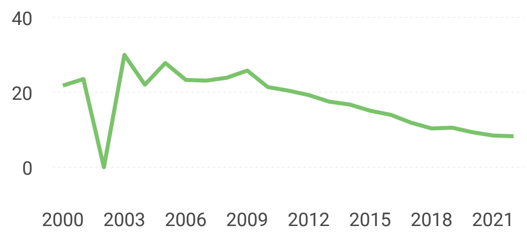

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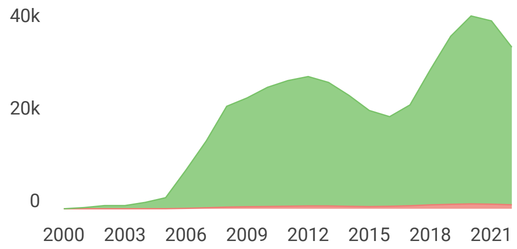

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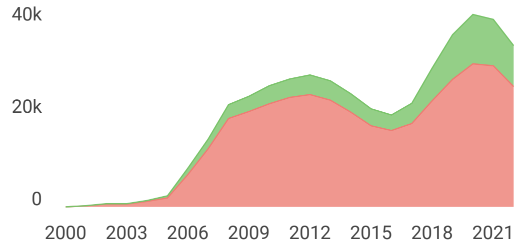

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