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The Effect of Heat Treatment on Fatigue Testing of Aluminum Cans

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Abstract. Nowadays, Aluminum alloys have been applied to various aspects of daily life due to it has several advantages such as lightweight, corrosion resistant, heat resistant, is an excellent electrical conductor. In this work, the effect of heat treatment on aluminum alloys cans is melted directly and indirectly by fatigue testing will be carried out to determine the mechanical properties of its. The results obtained that these materials have a different cycle and stress values, and the composition test shows that it is a non-homogeneous material. The analysis result has been demonstrated that with direct and indirect casting methods, and subjected to heat treatment and non-heat treatment, these materials have different fatigue resistance and be obtained that the specimens not subjected to heat treatment had better fatigue resistance than specimens subjected to heat treatment.

1. Introduction

Aluminum has a significant effect on environmental pollution problems. Aluminum material utilization is increasing every year, where the aluminum raw material obtained from secondary sources [1–16]. Nowadays, the application of recycled aluminum has been widely implemented [4] and has a significant effect in reducing bauxite, petroleum, and aluminum fluoride usage of reducing environmental pollution due to aluminum mining itself [5].

The physical properties of a material are essential parameters in its application in industrial fields such as automotive and machining, one of that is fatigue resistance. Fatigue Failure is the material failure by stress concentrations caused by repeated loads. The stress concentration occurs due to surface roughness, porosity, dimensional changes, or the other mechanical effects of materials, where 90% of mechanical failure was caused by fatigue.

Mechanical properties of Aluminum Cans have been carried out by Nukman et al., 2017 [17], and obtained different values for the mechanical properties. Pangolon, 2017 has conducted fatigue testing on commercial aluminum and found that it has low fatigue resistance. In 2016, Nukman et al. testing for recycled aluminum and found that the final stress and fracture stress have an increase on repetitive loads.

Usually, melting of aluminum can be done in two ways, that is direct melting where the combustion of fuel is directed directly to the aluminum material, and indirect smelting where aluminum is placed on the outside of the container.

2. Materials and Methods

The smelting is done by repeated smelting. The first melting method, the smelting is done directly (direct furnace-DF) and then indirectly furnace (IDF), while the second fusion is done indirectly and



then followed by an indirect smelting (Nukman 2017). The design of fusion and heat treatment can be seen in figure 1.

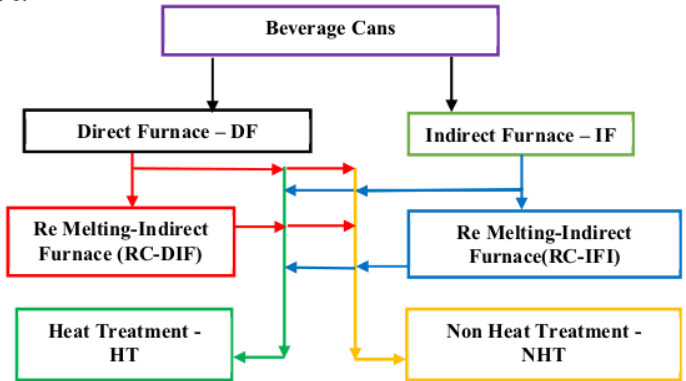


Figure 1. Design of Smelting and Heat Treatment

The furnaces used for both these smelting stages have been designed on a small capacity scale. The fuel used in both phases of melting uses used lubricating oil. On the other side of the material to be melted is aluminum tin former soft drink. From each melt, some samples were tested for fatigue properties.

Regarding the preparation of this sample, the sample is divided into two processes: direct and indirect smelting. Then to get better casting result, hence required heat treatment. So the samples of the two methods must be subdivided. In other words, separated in sample criteria that get heat treatment and do not get heat treatment. The heat treatment is annealed at 330 ° C with a holding time of 60 minutes in the heating furnace.

Fatigue testing has been made sample according to the shape and size as shown in Figure 2. Material test equipment used Torsion Repeated and Bending Fatigue Testing Machine which refers to JIS Z 2273 standard.

In some samples were given heat treatment. Annealing is one method of heat treatment that is often used to aging a material to obtain the best quality of material (Liu and Xiong 2011). As the research has been done by using an annealing method on the test material.

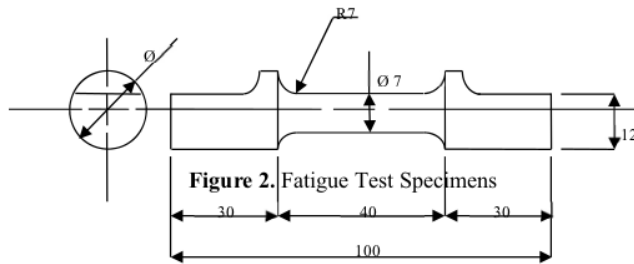


Figure 2. Fatigue Test Specimens

The Fatigue test calculation is done based on the formula in table 1.

Table 1. Fatigue test calculation

| Moment Inertia Polar (m ⁴) | Modulus of Shearing (MPa) | Maximum Shearing Stress (MPa) |
|---|--|---|
| $J = \frac{\pi \cdot d^4}{32}$ | $G = \frac{T \cdot L}{\theta \cdot J}$ | $\tau = \frac{R \cdot G \cdot \theta}{L}$ |

Where:

T = Torque (19.62 N-m), G = Shear Modulus (11,400 MPa), θ = Maximum twist angle (15 °),

L = Length of specimen (40 mm), R = Radius of specimen (3.5 mm)

Electric motor rotation = 50 rev/sec.

3. Results and Discussion

The results of calculations based on measured data and research design (figure 1) as shown in table 2.

Table 2. Fatigue Test Calculations

| NON HEAT TREATMENT | | | | |
|---------------------------|-----------|--------------|--|--------------|
| DF (Direct Furnace) NHT | | | RM-DIF (Re Melting–Direct Furnace) NHT | |
| Angle | N (Cycle) | Stress (MPa) | N (Cycle) | Stress (MPa) |
| 1° | 18300 | 1943,14 | 279700 | 1943,14 |
| 2° | 4250 | 3886,39 | 75550 | 3886,39 |
| 3° | 2450 | 5830,53 | 3950 | 5830,53 |
| IF (Indirect Furnace) NHT | | | RM-IFI (Re-Melting–Indirect Furnace) NHT | |
| Angle | N (Cycle) | Stress (MPa) | N (Cycle) | Stress (MPa) |
| 1° | 75500 | 1943,14 | 188750 | 1943,14 |
| 2° | 46050 | 3886,39 | 36750 | 3886,39 |
| 3° | 11750 | 5830,53 | 22900 | 5830,53 |
| HEAT TREATMENT | | | | |
| DF (Direct Furnace) NHT | | | RM-DIF (Re Melting–Direct Furnace) NHT | |
| Angle | N (Cycle) | Stress (MPa) | N (Cycle) | Stress |
| 1° | 47500 | 1943,14 | 16800 | 1943,14 |
| 2° | 7150 | 3886,39 | 2950 | 3886,39 |
| 3° | 2850 | 5830,53 | 600 | 5830,53 |
| IF (Indirect Furnace) NHT | | | RM-IFI (Re-Melting–Indirect Furnace) NHT | |
| Angle | N (Cycle) | Stress (MPa) | N (Cycle) | Stress (MPa) |
| 1° | 29000 | 1943,14 | 87400 | 1943,14 |
| 2° | 5200 | 3886,39 | 43550 | 3886,39 |
| 3° | 2400 | 5830,53 | 550 | 5830,53 |

A. The Effect of Re-melting

The calculation results in table 2 can be illustrated as in Figures 3 and 4.

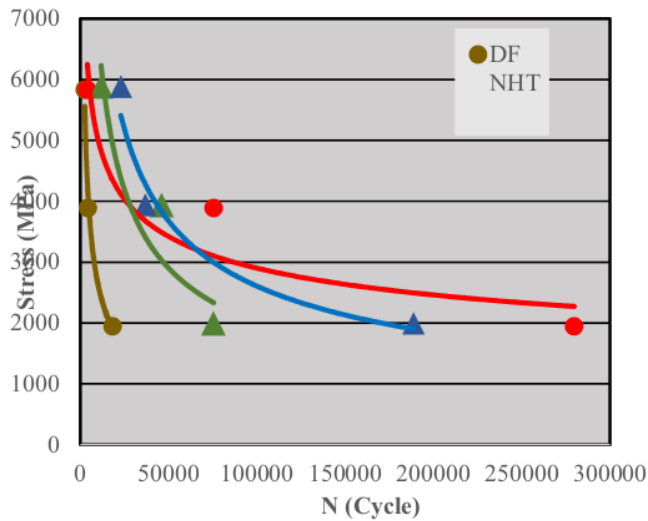


Figure 3. The Effect of Fixed Repeat on Repeated Loads

Re-melting of previously melted material in the Direct Furnace (DF NHT) to Indirect Furnace Re-melting (RM-DIF NHT) has increased the re-loading sample in larger cycles (see Figure 3). Its happens because more impurities are burned because of the oil content of used oil as fuel in the Direct Furnace process. The presence of some dirt on spent fuel oil is the cause of this low value of the N cycle [17]. The detected compounded fired element is capable of burning and reducing the number of impurities in the aluminum castings.

By way of Indirect Furnace then the big Cycle N becomes more significant than the smelting in the Direct Furnace (DF NHT). Its happens due to the influence of fuel being burned directly to the former aluminum, where some impurities do not have time to burn out.

When the material that has been melted using Indirect Furnace (IF-NHT) is then re-melted in the Direct Furnace (RM-IFI-NHT), then there is an increased mean value of the mean cycle. Under such conditions, it can be said that the reconstitution of DF-NHT to RM-DIF-NHT and from the IF-NHT to RM-IFI-NHT, has been able to increase the material's ability to receive larger recurrent loads.

B. Effect of Heat Treatment

Fig. 4 show that the overall sample of the heat-treated fusion melt reduces the ability of the cycle to receive recurrent loads, except for the smelter with DF-NHT to the increasing DT-HT. Elements of the burning of used fuel oils have provided the ability of the material to receive recurrent loads.

From Figure 4 it can also be seen that a sample capable of receiving the most significant and most repeatable loads is obtained on the RM-DIF-NHT sample, i.e., the samples of the resurfacing by using the Indirect Furnace which is not subjected to heat treatment.

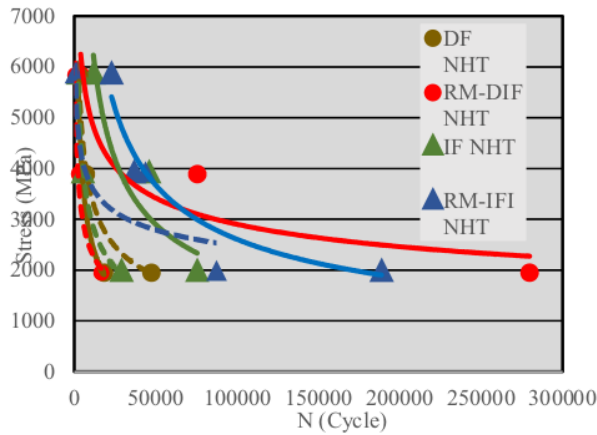


Figure 4. Effect of Heat Treatment on Repeated Expenses

C. Chemical Material Composition

The chemical composition of cast aluminum recycling beverage cans are shown in Table 3.

Table 3. Chemical Composition Test Result

| DF (Direct Furnace) NHT | | | RM-DIF (Re Melting–Direct Furnace) NHT | |
|---------------------------|----------------|-----------------|--|-----------------|
| No | Element | Composition (%) | Element | Composition (%) |
| 1 | Aluminum (Al) | 96,435 | Aluminum (Al) | 94,779 |
| 2 | Silicon (Si) | 1,145 | Silicon (Si) | 1,261 |
| 3 | Manganese (Mn) | 0,777 | Manganese (Mn) | 0,607 |
| 4 | Ferro (Fe) | 1,115 | Copper (Fe) | 1,712 |
| 5 | Copper (Cu) | 0,299 | Nickel (Ni) | 0,031 |
| 6 | Zinc (Zn) | 0,209 | Copper (Cu) | 0,36 |
| 7 | Plumbum (Pb) | 0,015 | Zinc (Zn) | 1,231 |
| 8 | Thin (Sn) | 0,005 | Molybdenum (Mo) | 0,018 |
| IF (Indirect Furnace) NHT | | | RM-IFI (Re-Melting–Indirect Furnace) NHT | |
| No | Element | Composition (%) | Element | Composition (%) |
| 1 | Aluminum (Al) | 96,525 | Aluminum (Al) | 95,326 |
| 2 | Silicon (Si) | 1,082 | Silicon (Si) | 1,153 |
| 3 | Manganese (Mn) | 0,733 | Manganese (Mn) | 0,720 |
| 4 | Ferro (Fe) | 1,115 | Ferro (Fe) | 1,865 |
| 5 | Copper (Cu) | 1,082 | Nickel (Ni) | 0,026 |
| 6 | Zinc (Zn) | 0,317 | Copper (Cu) | 0,463 |
| 7 | Plumbum (Pb) | 0,256 | Zinc (Zn) | 0,436 |
| 8 | Thin (Sn) | 0,015 | Thin (Sn) | 0,009 |

Based on the results of the chemical composition test conducted on each specimen showed that the lowest aluminum content in the RM-DIF sample was 94.779%, while the highest aluminum percentage occurred in the IF (Indirect Furnace) NHT sample of 96.525%. After testing the age of fracture, it turns out that at the lowest aluminum content has a primarily broken cycle, means having a strong fatigue resistance compared to higher aluminum content.

4. Conclusions

From the results, it is obtained in the direct and indirect melting of aluminum cans, then subjected to heat treatment and non-heat treatment have different fatigue resistance. Aluminum that is not subjected to heat treatment has better strength.

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