

Effect of Heat Treatment of Beverage Cans Remelting on Mechanical Properties

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Abstracts: This study compared the mechanical properties of the repeated melting of beverage cans. From the effects of the first melting, a chemical composition test was held out, which turned out that the aluminum produced was not explicitly admitted in the aluminum alloy series 2xxx, 3xxx, 4xxx or 6xxx. The smelting process I have increased the element Fe, as well as the addition of elements of Pb and Sn. Part of smelting I and II were annealed and quenched at 400°C with a holding time of 2 hours. The highest tensile strength is held from the first smelting product that has received quenching heat treatment, 9.67 kg/mm². After remelting, it decreased to 9.07 kg/mm². Products that have received quenching heat treatment have the most significant impact value, both for the first and second melting products, namely 74.34 BHN and 101.86 BHN. The most significant impact value was obtained from the first smelting product that received annealing heat treatment, which was 0.0388 J/mm², and after receiving quenching heat treatment, the impact value became 0.0379 J/mm².

Keywords: Beverage Cans, Aluminium, Remelting, Mechanical Properties.

1. INTRODUCTION

The use of Aluminium as a metal material began in the 19th century, where it can be said that aluminum has become a competitor in economics and engineering applications, which is the second most abundant metal on earth. Industrial developments continue to emerge by demanding good and consistent material characteristics with the unique qualities of aluminum and its alloys, giving rise to growth in production and new metals. In the development of time, almost every aspect of modern life will be directly or indirectly influenced by the use of aluminum in various applications [1]. In everyday life, aluminum is often found in forms such as cooking utensils, building construction, vehicle parts, and others.

Aluminum plays a vital role in human life, and aluminum is increasing in vehicle transportation. Aluminum is a material that has excellent mechanical properties, especially for machining or structural materials. Also, aluminum has various advantages, including low specific gravity, functional strength, excellent resistance to chemical attack, weather and seawater, good forming ability, high electrical conductivity, and high thermal conductivity [2].

Beverage cans are a product made of aluminum and continue to be widely circulated in people's lives, which over time, will become waste in the environment. Therefore it is necessary to recycle the beverage cans. The process of recycling beverage cans is by melting, namely by heating until it reaches the melting point of the metal, after that it goes through the pouring process. Several small and large scale industries have recycled and made it into new products, including household appliances, building construction, vehicle spare parts, and others. Nevertheless, the quality of castings for small household industries is even so far from those of big manufactures. Moreover, from the results of this recycling process, the residual product is quite large, around eight to 15% is dross [3], which is a loss for the small industry. Aluminum castings resulting from the smelting process of small industrial products need to be improved on their mechanical properties to get qualified to have high selling value.

It is known that there are various methods of smelting, making it easier to choose the manufacturing process. Among them, the smelting capability is used to create complex geometric parts, including external and internal shapes, and some casting methods are quite suitable for mass production. However, there are also disadvantages associated with the various smelting methods, namely limitations in mechanical properties and the presence of porosity [4]. Recycling of beverage cans has also been carried out with a simple furnace using wood charcoal as

fuel [5]. Various kinds of research have been carried out to determine the mechanical properties of recycled aluminum material [6].

It is necessary to carry out a heat treatment process after the smelting process to improve the mechanical properties of aluminum smelting. Heat treatment, in a broad sense, refers to one of the heating and cooling performed to change the mechanical properties, metallurgical structure, or residual stress state of metal products. In general, there are 3 (three) stages of a heat treatment process to increase the strength of aluminum alloys, the first is a solution heat treatment process followed by a quenching process and then age-hardening [7]. Changes in the mechanical properties of heat-treated aluminum alloys have also been carried out by several researchers [8], [9], [10], [11], [12], [13], [14].

The heat treatment process carried out on the results of smelting aluminum is annealing, which aims to remove residual stress and to smooth coarse grains due to the casting process or due to imperfect cooling, then quenching heat treatment to change the mechanical properties of the aluminum material, especially hardness. One way to improve or change the mechanical properties of aluminum is by re-melting it. In this case, it is also possible to consider the heat treatment effect of smelting I and remelting samples. In the smelting process, different melting furnaces can also be used. Different types of furnaces are used for smelting I and II. Also, to get a benefit, research can use beverage cans as an ingredient to be melted.

The remelting research, in terms of tensile strength and hardness, has been investigated [14]. The mechanical and structural properties of remelting aluminum will show a tendency to decrease in mechanical value [15].

2. MATERIALS AND METHODS

2.1. Materials

The material used is beverage cans, specifically a product from the coca-cola company, which collects three kinds of beverage products—using this product to avoid different types of cans materials. Previously, beverage cans were cleaned of inherent impurities such as sand, soil, and others, by washing and drying them in the sun. Then flatten it by pounding it so that it becomes even, for easy insertion into the crucible.

2.2. Methods

2.2.1. Melt

The smelting process that has been carried out consists of two stages. The first smelting (Melt I) is the smelting of materials using a direct smelting furnace fueled by used lubricants where the combustion flame is directed directly at the material to be smelted [5]. Then the material is melted for the second time (Melt II) using an indirect furnace that is burned with used lubricants [5], where the fire from the nozzle bursts towards the bottom of the furnace. Remelting is intended as advanced smelting, which means that the material from the first smelting is then melted back in another furnace and other methods of smelting. In contrast, if the first smelting product is used as a machine component or other construction part, which is then used and damaged due to static or dynamic loading, it is melted down again. Part of the melted product I in the form of aluminum blocks is made into mechanical test samples using a machining process. Metal casting is pouring molten metal directly into a mold. Whereas the cast itself is a metal that is heated to a temperature high enough to turn it into a liquid state, then poured into a mold, then cooled and frozen. To make castings, processes such as metal smelting, mold making, preparation, pouring of molten metal into molds, dismantling, and cleaning of castings must be carried out [3]. Smelting II is carried out with material taken from smelting I, and the liquid material is molded into blocks and samples are made as needed.

2.2.2. Heat Treatment and Mechanical Properties Testing

The heat treatment has been carried out using an electric furnace. There are two heat treatment processes used; the first is annealing, a heat treatment process in which the metal is heated under a critical temperature and

cooling it using air slowly to room temperature of approximately 25 to 30 °C which aims to change the mechanical properties. Second, the quenching process is a direct immersion to cool the material quickly, using water as a medium. When an alloy is slowly cooled from high temperature, the alloying elements precipitate and diffuse from the reliable solution to produce grain boundaries, small grains in the solvent particles, dislocations, and other imperfections in the aluminum lattice. To achieve optimal strength, toughness, and corrosion resistance, this diffusion process needs to be inhibited, and the elements in the reliable solution need to be maintained until the alloy hardens. The heat treatment design of the material is shown in Figure 1.

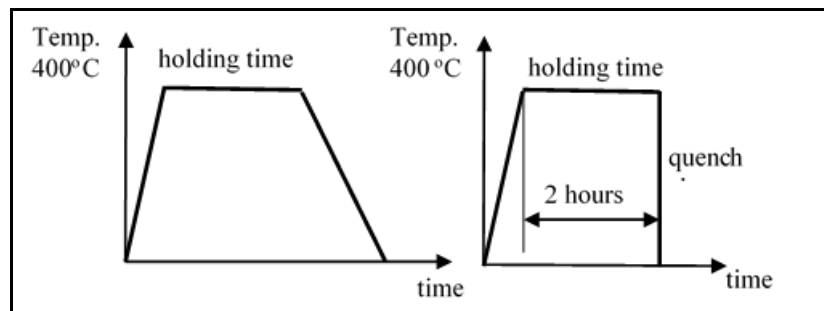


Figure 1. Heat treatment process design

In the study [7], the normalizing process for 6061 aluminum alloy was carried out by heating the metal at a temperature of 400°C with a holding time of 2 hours. For this research, annealing was designed at 400°C [6] with room air cooling, while quenching was carried out at the same temperature, 400°C, with water cooling, with the same holding time of 2 hours. The annealing process results in a softer and more resilient product. Mechanical properties testing will be carried out on samples without heat treatment and heat treatment. The tests carried out include tensile, hardness, and impact tests, as well as chemical composition tests.

The number of samples that have been used for tensile strength testing is 3 (three), which then, from the test results, the average value has been taken. For hardness testing, three steel ball indenter penetrations were carried out for each of 3 (three) samples, and then the average value was taken. The same has been done for the impact test using three samples for each test, and the average value is taken.

The material from the casting process that has received heat treatment or not with heat treatment needs to be tested for its mechanical strength to determine how much influence changes in its mechanical properties will have if the smelting of the material uses used lubricating fuel. Tensile testing is a test that aims to determine the resistance of a material to a static load, which is given slowly; in this case, the static load is a pull. The tensile test method is to apply the tensile force in the opposite direction in a straight line. Through the tensile test, the strain of a material can also be known. Tensile strength testing in this study has used the Torsen Universal Testing Machine made by Tokyo Testing Machine. MFG. CO. LTD, with a standard testing machine using JIS B 7721, and the test sample has been referred to JIS Z 2201[16].

The hardness of a material is a measure that indicates whether the material can be plastically deformed in a particular load. The hardness test of aluminum material has used the Torsen Brinell Hardness Tester made by Tokyo Testing Machine. MFG. CO. LTD, which refers to JIS B 7724. Meanwhile, the standard test sample has been referred to as JIS Z 2243 [16]. The basic principle used as a measure of hardness in this penetration method is the resistance of the material to plastic deformation; in other words, the size of the trace of penetration is a measure of hardness.

Impact testing is a test that aims to determine the brittleness or ductility of a material to be tested by sudden loading of the object to be tested. For testing with the Charpy method, the Impact testing machine according to the JIS B 7722 standard and the standard for the test sample is JIS Z 2202 [16] and the machine that has been used by the Charpy Impact Testing Machine made by Tokyo Testing Machine. MFG. CO. LTD. The Charpy impact test is a

collision test by placing the test sample position on a pedestal in a horizontal position with the opposite loading direction of the notch.

3. RESULTS AND DISCUSSIONS

3.1. Chemical Composition Testing

Testing the chemical composition of aluminum smelting has used the XRF Analyzer. This chemical composition test is useful for determining the percentage of elemental content present in the castings. The results of chemical composition testing on the results of aluminum smelting can be seen in table 1.

Table 1. Chemical Composition Test Results

No.	Elements	Test result (%)
1.	Aluminum (Al)	95.130
2.	Silicon (Si)	1.130
3.	Manganese (Mn)	0.766
4.	Ferro (Fe)	1.100
5.	Cuprum (Cu)	0.295
6.	Zinc (Zn)	0.206
7.	Plumbum (Pb)	0.015
8	Tin (Sn)	0.005

The chemical composition test on aluminum from casting has shown the most dominant elements, among others: Aluminum (Al) 95.130%, Silicon (Si) 1.130%, and Ferro (Fe) 1.100%. Based on the percentage of its constituent elements, this type of aluminum alloy can fall into the category of aluminum alloy type 2xxx, 3xxx, 4xxx, or 6xxx. These four series are dominated by elements Si, Fe, Cu, and Mn [1]. Observing the magnitude of the element Fe in this aluminum material, aluminum is included in aluminum with a high Fe element content [17]. However, in testing the composition, there are elements of Pb and Sn. The Pb element is thought to come from used lubricants [18], which was used as fuel.

In contrast, the Sn element was estimated from the pipe or nozzle of used lubricating fuel. The increase in the element Fe is also estimated from used lubricants [18], [19], [20], or the removal of crucible materials. With the presence of Pb and Sn elements in the aluminum material produced by Melt I, it can be said that the material produced by Melt I is difficult to categorize as a material that can or cannot be heat treated. However, it can be assumed that the material can still be heat-treated [21].

3.2. Tensile Strength Testing

From the measurement results and the tensile and strain test calculations, it can be explained that there has been a change in value due to Melt reset and the effect of heat treatment for the samples. The tensile strength after Melt I was 6.95 kg/mm², increased after Melt II to 7.89 kg/mm², whereas the strain from Melt I of 2.67% also increased to 3% (see Figure 2). This contradicts [15], but it can be understood that in Melt I, melt uses used lubricant as fuel and is sprayed directly into the aluminum material in the crucible. So it can be estimated that the used lubricant has had an influence on the Melt I results. For Melt I results in that received Annealing heat treatment, the tensile strength value increased to 7.19 kg/mm² and the strain increased to 3%. The quenching heat treatment of the samples from the Melt I results experienced a significant increase, namely 9.67 kg/mm², but followed by a decrease in strain by 2%. For Melt II results, due to heat treatment of the samples, the tensile strength increased by 8.93 kg/mm², with the strain also increasing to 3.33%. Heat quenching treatment increased the tensile strength value to 9.07 kg/mm², decreasing in strain to 1.67%. It can be seen that for samples, the Melt II result is more stringent than the Melt I result, which means that Melt II has provided better benefits. In general, it can be said that the quenching heat treatment has increased the strength of the material.

Meanwhile, the heat treatment of annealing has made the material more robust and more reliable. Compared with [17], where several samples had received remelting, the tensile strength was increased and decreased in strain. Likewise, after receiving heat treatment, there was an increase in tensile strength, followed by a decrease in strain. So it can be said that an increase in tensile strength can occur when the sample is heat-treated, and after it is melted back, it is also heat treated. In contrast to the tensile strength of reclaimed aluminum, its tensile strength is decreased when tested at temperatures between 20 to 100 °C [15]. Heat treatment applied to aluminum has also increased tensile strength and decreased strain [8].

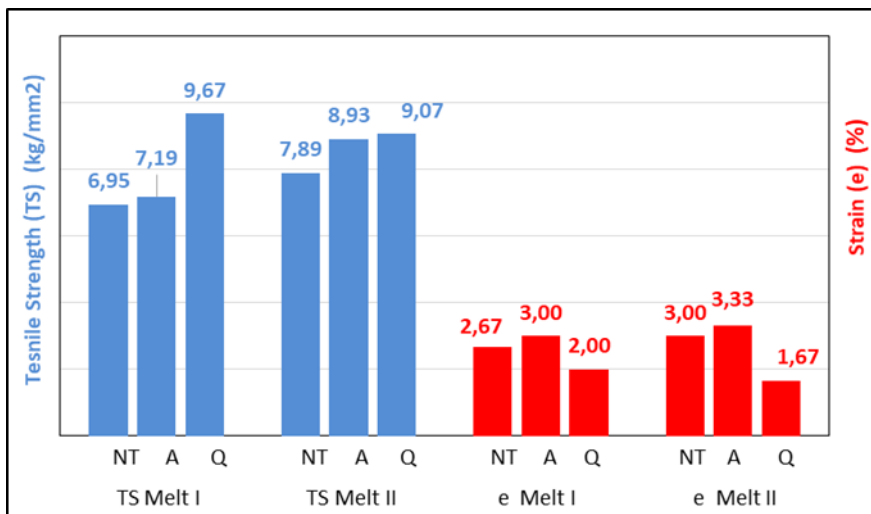


Figure 2. Relationship between Tensile Strength and Strain for Melt I and II

3.3. Hardness Testing

From Figure 3, it can be seen that the hardness of the Melt I samples has a value of 62.18 BHN, and this value is higher than the Melt II sample result, which is 59.74 BHN. This shows that there has been a better melt, where most of the remaining impurities due to Melt I have been burned after Melt II. In this case, it can be said that the granules of fused II are better. The decrease in the value of this hardness is by what was stated by [6] [15]. Some of the samples from the Melt I and II results were subjected to annealing and quenching heat treatment. The temperature that has been used for these two sample groups is 400 °C and is only distinguished by the cooling treatment. The results of the annealing process for both Melt I and II groups have decreased. Material from the Melt I group that received annealing heat treatment decreased to 60.66 BHN, down from 62.18 BHN. Likewise, the Melt II group experienced a decrease in the value of hardness. There was a decrease in the value of hardness from 59.74 BHN to 54.16 BHN, the same thing happened to several samples [17], which decreased, but there was an increase in hardness after heat treatment. The sample group that received quenching, where the results of the hardness measurement had experienced a significant increase in size. There has been an increase to 73.44 BHN from the previous 62.18 BHN from the untreated samples. The increase in hardness value for samples that received quenching from Melt I samples was 74.34 BHN, and for samples from Melt II results, there was a more significant increase, from 59.74 BHN to 101.86 BHN. The relatively significant increase of this quenching sample group when compared to those that received annealing heat treatment is understandable because, due to the rapid cooling of the quenching process with water media, the aluminum material becomes harder. Also, [15] said that aluminum material, which is recycled up to 3 times melting, had decreased the hardness value, but for the result of smelting the fourth time, the hardness value increases. Increased hardness also occurs for heat-treated aluminum material [9], [10]. Compared to heat treatment in aging, the aluminum material that is treated with artificial aging has a higher hardness value than natural aging, wherein artificial aging, water media is used [11], this is analogous to rapid cooling with water media. The material under test increases in hardness. The same thing happened to decrease the hardness value of the aluminum material after heat treatment. [12].

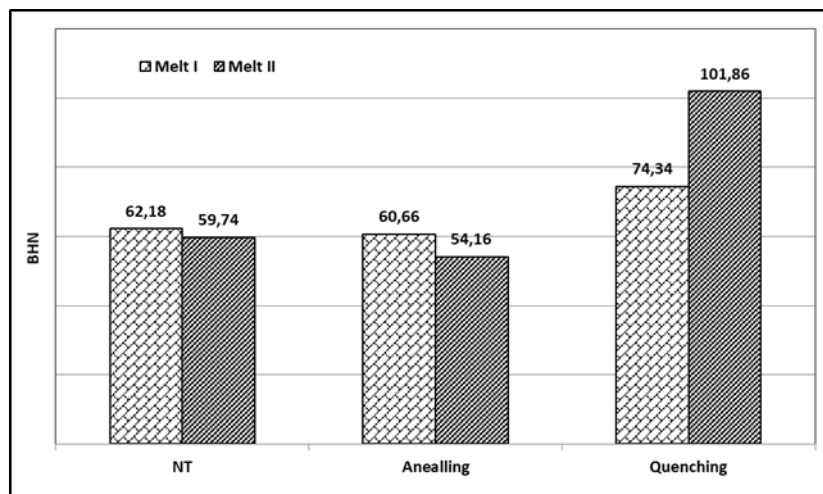


Figure 3. Material Hardness Value for Melt I and II

3.4. Impact Testing

From the impact test that has been done, the impact value has been obtained. The impact test results can be seen in Figure 4. The impact value is calculated based on the striking hammer effect on the sample; the energy magnitude of the unit area is the unit for this impact value. From Figure 4, it can be seen that due to Melt II, the impact value has decreased not so much. Meanwhile, after receiving heat treatment, annealing has increased. On the other hand, quenching heat treatment has increased the impact value is lower than that of annealing heat treatment. For samples from the Melt I results, the impact value increases to 0.0388 J/mm² from 0.0183 J/mm².

Meanwhile, after receiving quench heat treatment, the increase was 0.0379 J/mm². It can be seen that the increase in the impact value due to annealing heat treatment for Melt II became 0.0317 J/mm² from the original 0.0175 J/mm². The increase was more significant than the samples that received heat treatment annealing was more significant than the quenching, which was 0.027 J/mm². In general, it can be said that annealing heat treatment has increased the toughness of the Melt I samples as well as after remelting. Heat treatment of aluminum materials has also increased the impact strength [13].

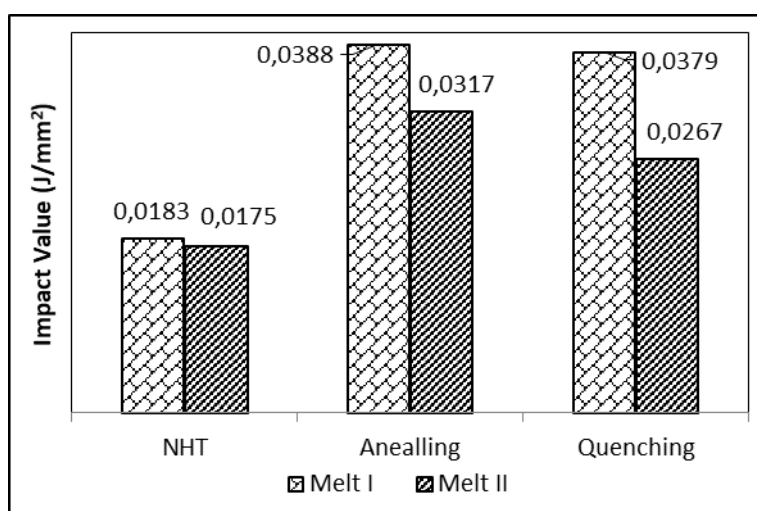


Figure 4. Impact Test values for Melts I and II

CONCLUSIONS

After testing such as chemical composition, tensile strength, hardness, and impact, and then do the analysis, it can be concluded that:

In the chemical composition test of recycled aluminum castings from beverage cans or the result of smelting I, it shows that the material is not included in the aluminum alloy series 2xxx, 3xxx, 4xxx, or 6xxx, due to the addition of Pb and Sn elements. The addition of the Pb element is estimated to be obtained from burning used lubricants, which are used as fuel, which directly melts the aluminum material. While the Sn element is obtained from the erosion of the combustion nozzle, and the increase in the element Fe is also estimated from used lubricants or the removal of crucible materials.

The highest tensile strength value is found in the quenching of Melt I, which was 11.504 kg/mm², and the smallest value is found in the sample without heat treatment of Melt 2, which was 8.677 kg/mm². The most substantial strain value is found in the sample without heat treatment of Melt II, which was 3%, while the smallest value is found in the sample quenched with Melt I, which was 1.6%. The test results show that the result of burning used lubricant sprayed on aluminum beverage cans has shown an increase in tensile strength and strain when the melted material I is Melt II (Remelting).

In the hardness test, it can be seen that the highest hardness value is found in the sample in quenching smelting II, which is 101.86 BHN, while the lowest hardness value is found in the sample without heat treatment of fusion II, which is 59.74 BHN.

The most significant impact value is found in the sample in quenching Melt I, which is 0.0383 J/mm², while the smallest is in the sample without heat treatment of Melt II, which is 0.0175 J/mm².

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