International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V71I11P213

Volume 71 Issue 11, 124-128, November 2023

Original Article

The Effect of T6 Heat Treatment on Mechanical Properties of Cast AA6061 Products with Fine Coal Addition

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Received: 16 July 2023 Revised: 11 September 2023 Accepted: 03 October 2023 Published: 04 November 2023

Abstract - *The study aimed to analyze the effect of adding coal powder to the AA6061 liquid, which was re-melted into a steel cylinder tube mold. The results of this addition are then given heat treatment solution treatment and artificial aging. The molten aluminium is poured into a cylindrical tube at a temperature of around 660 °C so that the fine coal is burned and mixed with the aluminium alloy. To determine how significant the effect of adding coal powder was, tensile testing and impact testing were carried out. The addition of coal powder increases the material's tensile strength but decreases the ability of the material to accept impact loads. Heat treatment generally increases the strength of the material, and so does the ability to accept impact loads.*

Keywords - *AA6061, Coal powder, Casting, Tensile strength, and Impact*.

1. Introduction

Aluminium is a metal material whose benefits can be found in almost every human activity. The increasing number of people has also increased the type and amount of aluminium used. Aluminium metal and its alloys are more widely used because they have several advantages compared to other metals and nonferrous metals; aluminium can be recycled. At present and future generations, aluminium recycling management will be very beneficial for energy conservation and other natural resources. For example, recycling aluminium scrap, which in this case includes scrap from the machining process, soft drink cans, electrical instruments, motor vehicle components, old aluminium scrap, household appliances, and others [1]. All alloying elements used for the design of aluminium alloys can be classified into three main groups: basic alloying elements, additives (or dopants), and impurities. Alloy elements Cu, Mg, Zn, and Si are essential alloying elements. Meanwhile, Fe, Ni, Ce, Mn, Sc, Ti, Zr, and Cr include additional alloying elements (dopant). The last group of chemical elements that can enter aluminium alloy components is impurities (impurities). These impurities are obtained during the smelting process (from the mold, using instruments, etc.) [2]. These three chemical elements are added to the aluminium metal as an alloy. The mechanical ability of the aluminium material can accept several types of loading according to needs. Some researchers use fly ash as reinforcement in manufacturing aluminium composite materials. Fly ash, a coal combustion waste is added to molten aluminium metal and stirred in a cylinder [3]. In this case, other elements are physically apart from chemical elements, which can be added to the molten aluminium metal as an alloying material with a reinforcing effect. This study carried out a smelting process using aluminium alloy 6061, then cast into a mold filled with fine coal at the bottom. The mold results will be analyzed to determine whether it affects the material being cast, and on the test, the sample will be characterizing for its mechanical properties.

Some of the properties of aluminium and its alloys that make it widely used and economical include appearance, not heavy, easy to machining, and physical, mechanical and corrosion-resistant properties [4]. It is also understood that compared to ferrous metals, aluminium has a greater strength-to-weight ratio. Apart from that, the corrosion-resistant properties of aluminium are obtained from the oxidation process of aluminium with air. A thin layer of aluminium oxide is found on the skin of the aluminium alloy, which adheres tightly and strongly to the surface. The nature of this layer is stable, can protect the inside, and is resistant to corrosion.

In general, aluminium alloys are categorized into wrought aluminium alloys and cast aluminium alloys, both of which are based on the manufacturing mechanism of the product. Forged aluminium alloy products are products that consumers can use with a solid-state process. Usually formed through several processes, namely through the forging process by being rolled into sheets, strips, or plates, pulled into wire or pressed as bars and others. At the same time, cast alloys tend to have more alloying elements than wrought aluminium alloys. Because it is difficult to remove some of the alloying elements from molten aluminium, cast aluminium alloys are difficult to recycle into anything other than cast alloys [5].

Alloy elements added to pure aluminium liquid have been able to change mechanical properties, such as the addition of Cu elements [6], adding lithium (Li) elements [7], added Fe (Iron) [8], and added alumina [9]. Besides that, other elements, such as fly ash, added to aluminium alloys have also been able to change some of the mechanical properties of the aluminium [3]. Furthermore, refined coal elements have also affected the hardness and wear of aluminium alloy materials [10].

Some commonly used mechanical properties of materials are tensile strength, hardness, impact, and wear. The ability of the material to accept dynamic loads is included in the fatigue or fatigue testing of the material. Several researchers have carried out mechanical testing of aluminium alloy materials [11-14].

The addition of fly ash carried out by [3] and [15] was processed by mixing the fly ash into liquid aluminium and then stirring. This kind of process produces composite materials. Meanwhile, in this research, fine coal was put into a steel cylinder and poured with liquid aluminium. In this way, due to the high temperature of the aluminium liquid, burning coal and the combustion ash are trapped in the aluminium liquid, which will cool further and form a casting. The two processes are clearly different, although they will produce aluminium mixed with ash.

Thus, the addition of certain alloying elements into aluminium and aluminium alloys will affect the mechanical properties of the aluminium alloy material. On the other hand, the effect of heat treatment has been carried out by several researchers, which helps improve some of the mechanical properties of the material [16], [12], [6], [17], [18], [11], [19].

2. Material and Methods

2.1. Preparation of Materials and Tools

Aluminium Alloy 6061 (AA6061), the primary material obtained from the commercial market, is cut 25 to 30 cm short to be melted. The coal added to the casting is in coal powder measuring 80-100 mesh (passing the 80, 90 and not passing the 100-mesh size. The coal used comes from PT. Batubara Tanjung Enim (Persero), South Sumatra.

For smelting, a crucible furnace with a capacity of 30 kg is used, fueled by wood charcoal, with temperature control using an infrared thermometer. The mold is a steel cylindrical tube with a diameter of 5 cm and a height of 30 cm. Tensile Test Equipment used in the mechanical testing process serves as a tool to obtain the tensile strength value of the test sample, the Gotech brand tensile testing machine GT-7000 model. The sample used refers to ASTM E8/E8M – 11-the Charpy brand Gotech model GT-7045 method of impact testing tests the impact load. The specimen used refers to ASTM E23-18 (Standard Test Methods for Notched Bar Impact Testing of Metallic Materials). The number of samples for tensile and impact tests for each heat treatment was 4 (four) samples, and so were sampled without heat treatment.

2.2. Heat Treatment Process

The heat treatment carried out on the samples was T6, a series of heat treatment solutions followed by artificial aging. There are 2 (two) kinds of heat treatment processes, namely:

2.2.1. Solution Heat Treatment

Samples made according to mechanical testing will then be heated using a furnace at a temperature of 510 ^{o}C with a holding time of 5 hours, followed by rapid cooling (quenching) in a water medium at room temperature (see Fig. 1).

2.2.2. Artificial Aging Process

In this process, the samples that have passed the quenching stage are then allowed to stand for 24 hours in room air and then reheated in the furnace at a temperature of 150 C, With holding times of 3, 5, and 7 hours, for each sample, tested, after that the sample is quenched into the water.

For AA6061, it is determined that T4 = 510 ^{o}C and T6 = 150 ^{o}C [20]. This temperature selection is still within the limits of the value of 530 ^{o}C and T6 at 180 ^{o}C [21].

3. Results and Discussion

The results of testing the chemical composition of samples that did not receive additional coal are shown in Table 1.

Table 1. Chemical composition of the sample without the addition of coal powder

Fe	Cr	Mn	Si	Ni	Cu	Mg
0,523	0,040	0,062	0,938	0,015	0,260	0,207
Pb	**Sn**	**Ti**	**Zn**	**V**	**Al**	
0,047	0,084	0,016	0,235	0,011	97,5	

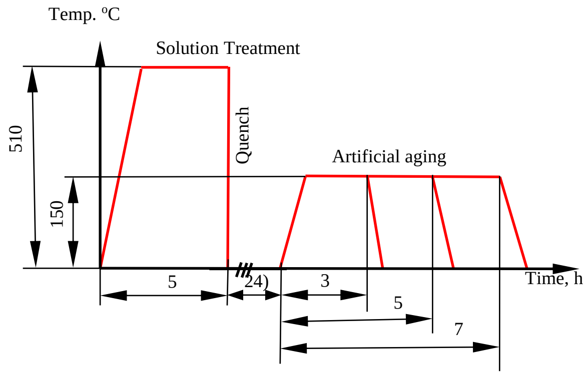

Fig. 1. Holding time heat treatment stage

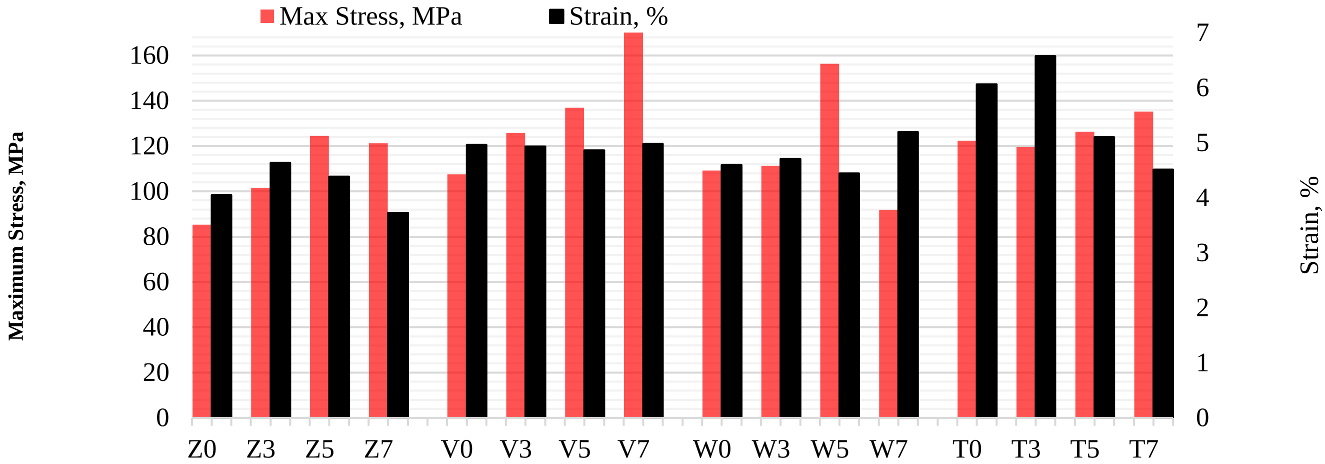

Fig. 2 Maximum stress and strain

The codification given to the sample is: sample Z is aluminium material without coal powder, sample V material with the addition of 12.5 grams of coal powder, and samples W and T, respectively, get 25 and 37.5 grams of coal powder.

3.1. Tensile Test

In this tensile test, 4 (four) samples were used for each material that received additional coal powder and did not receive additional holding times of 3, 5, and 7 hours in the aging treatment stage. The average value is taken and then made an image, as shown in Fig. 2.

Two main treatment categories are given to the castings from which these tensile test samples are made. First, coal powder with 80-100 mesh was added in 12.5, 25 and 37.5 grams. Second, most samples were given heat and solution treatments for 5 hours, followed by quenching with water media. After 24 hours, the sample cooled and was given heat treatment foraging for 3, 5, and 7 hours. The measured tensile test values were compared with samples that did not receive heat treatment (Z0, V0, W0, and T0). The relationship between tensile strength and strain shows stiffness, which results in the brittleness or plasticity of the material; the greater the value of tensile strength with low strain, the more the material is rigid [22].

On the other hand, a material with a low tensile strength value with a significant strain indicates that the material is pliable. From the picture, the material without adding Z0 coal powder has a tensile strength value of 91.8244 MPa with a Strain of 4.7168 %. Heat treatment was given to sample Z0 with aging for 3 hours, which slightly increased the tensile strength value but was followed by a decrease in strain. This condition leads the material to tend to become stiffer. Likewise, when given the aging heat treatment for 5 hours, there was an increase in the tensile strength value followed by a decrease in the Strain value. It also shows that the sample without adding coal powder is stiffer.

In other words, the addition of other elements to aluminium influences the tensile strength of the material [7], [23], [9], [8]. Aging heat treatment for 7 hours has slightly decreased the tensile strength value compared to the 5-hour aging sample, but the strain decreased very significantly; with conditions like this, it can be said that the material will be stiffer when given a longer aging treatment. Adding coal powder into the aluminium casting material as much as 12.5 grams (sample V0) has increased the tensile strength value; sample V0 also shows a significant increase in strain. Thus, it can be said that the sample V0 is stronger than the sample Z0.

This indicates that coal powder combustion has occurred in the cylindrical tube when the aluminium melt is poured into the cylindrical tube. So that further heating occurs when the fire continues to burn for a while. In sample V0, which was given heat treatment, aging has increased the tensile strength but was followed by a significant decrease in strain. Sample V5, with a comparison between increasing tensile strength and decreasing strain, has shown that the material is getting stiffer; in other words, the material is increasingly able to withstand greater loads but with the risk of breaking quickly when tested in tension. Basically, for aluminium materials that are heat-treated T6 with aging temperatures below 160 ^{o}C, if the holding time is longer, the tensile strength will increase [16], with a holding time of 5 hours [17], at a temperature of 175 ^{o}C for aging there has been an increase in tensile strength [19], [14].

3.2. Impact Test Results

Impact testing is carried out with the same number of samples as the tensile test. The calculation results have made an Impact Value image (see Fig. 3).

From Fig. 3, the cast material without the addition of fine coal (Z0), when given a solution treatment heat treatment of 5 hours, then quenched in water media and was given an artificial aging heat treatment for 3, 5, and 7 hours each, (Z3, Z5, and Z7), the level of the material's ability to accept impact loads decreases. By increasing the aging time from 3 hours to 5 hours, it is seen that there is a decrease in the ability to accept impact loads. Likewise, when the aging heating resistance time is increased to 7 hours, there is a decrease in the ability to accept impact loads or a decrease in toughness. This is what was stated by [12] for aging temperatures below 240 ^{o}C.

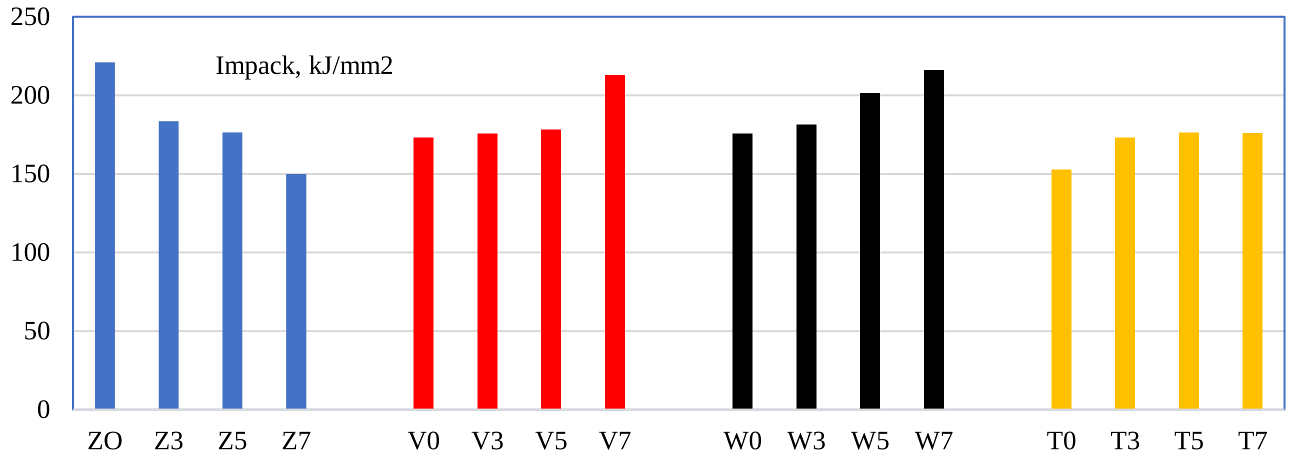

Fig. 3 Impact test values

For the cast, material added 12.5 grams of coal powder (V0), in general, with 5 hours of heat treatment, Solution Treatment, and quenching in water media followed by 3, 5, and 7 hours of aging (V3, V5, and V7), has increased the ability of the material to withstand impact loads. In this case, the amount of coal powder added and burned may have turned into ash.

As for the addition of coal powder in the amount of 25 grams (sample W0), on the other hand, there was a decrease in the ability of the material to accept impact loads. Heat treatment of solution treatment for 5 hours followed by quenching with water has a different effect on sample V. On the other hand, this decrease in impact value resembles the graphic pattern of sample Z, where heat treatment has decreased the impact value on the material.

In contrast, sample T, where the addition of 37.5 grams to the material and then given a solution treatment heat treatment for 5 hours, then quenched in water media and followed by aging for 3, 5, and 7 hours, has given a different pattern of decline with the samples. Samples Z, V, and W. The addition of 37.5 grams of coal powder has reduced the impact value, which is insignificant, where the impact value of Z0 of 220.9438 kg/mm^2 decreased to 218.9574 kg/mm^2 in sample T0. Heat treatment has had a significant effect on this T0 sample. With solution treatment heat treatment for 5 hours and quenched in water media followed by aging for 3 hours, it has reduced the impact value to 204.3483 kg/mm^2. However, there was an increase in the impact value after heat treatment was given solution treatment for 5 hours and then aged for 5 and 7 hours. From Fig. 1, the addition of coal powder has reduced the impact value of the material. With the addition of 12.5 grams of coal powder, the impact value of 220.9438 kg/mm^2 of sample Z has decreased to 203.2639 kg/mm^2. Likewise, the addition of 25 grams of coal powder has reduced the impact value to 216.0305 kg/mm^2. In general, it is said that with the addition of coal powder, there has been a decrease in the value of the impact load. With an estimate that most coal powder burns and becomes ash, the decrease in the value of the impact load will decrease [15], [24].

4. Conclusion

Adding coal powder measuring 80-100 mesh has provided new achievements in tensile strength testing. Adding 12.5 grams of coal powder (sample V) increased the tensile strength to 107.4126 MPa, originally 91.8244 MPa. In comparison, the addition of 25 grams of coal powder (sample W) increased the tensile strength to 104.3344 MPa, which is lower than with sample V. However, the increase occurred and was more significant in sample T, which was 122.3322 MPa. Considering the elongation of sample Z5, where the sample without adding coal powder has high brittleness, this can be seen from the comparison between the magnitude of the tensile strength followed by the slight elongation. At the same time, the sample with the best tensile properties is sample T1, with a low tensile strength value followed by a high elongation.

Adding fine coal powder to the AA6061 melt has reduced the material's ability to withstand impact loads. The lowest value is in sample V, where the magnitude is 203.2639 kg/mm^2 compared to the impact value of sample Z, which is 220.9438 kg/mm^2. However, there was a slight decrease when pulverized coal was added to sample W with an impact value of 216.0305 kg/mm^2 and 218.9574 kg/mm^2 for sample T.

Acknowledgement

Thank you to Sriwijaya University for providing research funding through agreement letter 00245.06/UN9/SB3.LPPM.PT.

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