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TGA/DTA Analysis To Calculate The Temperature Of The Heat Treatment Of Smelting Aa6061 Material Blended With Refined Coal

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Abstract. The purpose of this research is to determine the melting point, solidus point, and the amount of activation energy of the aluminum alloy AA6061, which is re-melted by adding fine coal. AA6061, which is commercial Aluminum, is re-smelted as a raw material. Sub-bituminous coal in the form of fine powder is added to the cylindrical tube. The burning of this powder when molten Aluminum is poured into the tube has given some changes to the thermal properties. Melting point temperature for Aluminum without the addition of pulverized coal is slightly in the case of aluminum powder treated with pulverized coal. The solidus temperature point for Aluminum treated with fine coal is slightly lower than for Aluminum not treated with coal.

Keywords: Aluminium, Fine Coal, Thermogravimetry, Solidus

INTRODUCTION

The use of Aluminum is increasing with increasing human activities, including, among others, in the construction sector, the food industry, motor vehicles, and aircraft. The choice to use Aluminum is due to several things that stand out from the properties of this aluminum material, including lightweight, the large ratio between strength and weight, rust resistance, readily available in the market, can be recycled with less melting energy (Stojanovic, Bukvic, & Epler, 2018), (Astika, 2019), (Schmitz, 2014).

Aluminum recycling is an industrial activity carried out by large and small-scale industries, and this can be made possible because it is easy to get used aluminum raw materials, and the smelting system can be done with simple technology or advanced technology. Aluminum from the initial casting can be used directly. However, there are some disadvantages of this casting, namely the problem of non-uniform atomic diffusion, which results in the imperfect arrangement of atoms and ions in the material; also, atoms and ions tend to move in predictable ways to eliminate concentration differences and produce homogeneous compositions that make the material thermodynamic more stable (Askeland, Fulay, & Wright, 2011).

Due to the various uses of this aluminum material, a classification of Aluminum has been made based on the main alloying elements and the primary temper designation (Cayless, 1992). AA6061 is a type of Aluminum with the main alloying elements are Magnesium and Silicon. Where this type of Aluminum has good formability, good weldability, good machining capability, and corrosion resistance, and has medium strength (Cayless, 1992). From the classification that has been made, it has been developed again with the ability of AA 6061 in its ability to receive heat treatment (Cayless, 1992). Where heat treatment is given with the aim of improving the mechanical properties. ASM 1991, states that several types of aluminum alloys from the wrought aluminum alloy classification can receive heat treatment, namely: Commercial alloys whose strength and hardness can be significantly increased by heat treatment including 2xxx, 6xxx, and 7xxx series wrought alloys (except 7072) (Brooks, 1991).

Heat treatment to increase the strength of aluminum alloys has a three-step process, namely: Solution treatment: dissolution of soluble phases, Quenching: development of saturation, age hardening: precipitation of solute atoms either at room temperature (natural aging or elevated temperature (artificial aging or precipitation heat) treatment (Brooks, 1991). Setting the appropriate and appropriate temperature and time will provide heat treatment results in accordance with the desired mechanical properties. Several studies of Aluminum which were given heat treatment to improve the quality of its physical properties have been carried out by adjusting the temperature during the process (Ozturk, Sisman, Toros, Kilic, & Picu, 2010), (Zhang, Zheng, & StJohn, 2002), (Alaneme, Ekperusi, & Oke, 2018), (Tafti, Sedighi, & Hashemi, 2018), (Kilic et al., 2019), (Astika, 2019), (Cui & Roven, 2010), (Wagiman, Mustapa, Asmawi, Shamsudin, & Lajis, 2019), (Akhil, Arul, & Sellamuthu, 2014), (Tan & Said, 2009), (Rady et al., 2019), (Mahmood, Zainulabdeen, Mohmmed, & Oun, 2020), (Jang, Nam, Park, & Park, 2013). Different things were done by (Cagala, Bruska, Lichy, Beno, & Spirutova, 2013) namely compacting to obtain good diffusion bonds between particles at high temperatures for aluminum scrap material. On the other hand, after smelting and in the casting stage, several thermal processes occur in the aluminum material, including diffusion (Askeland et al., 2011) and oxidation (Schmitz, 2014). It is also known that decomposition of the material undergoes heating (Smallman & Bishop, 1999).

Generally, decomposition is associated with the reduction of mass from one composition to another. So it is possible for a material to be melted and molded to undergo several phase changes such as: decomposition where there is a reduction in mass of the impurities in the melted material, diffusion where the material undergoes a solidification phase where the atoms make up the crystal structure, but sometimes this arrangement occurs in a vacancy known as interstitial. or simplified as the movement of atoms to empty atoms in adjacent locations (Smallman &

Bishop, 1999), then the process of melting the material at high temperatures (Hasani, Panjepour, & Shamanian, 2012), and finally the oxidation process of the reaction between oxygen and the shell of the aluminum material forming Aluminum Oxide (Liu, Ren. H, & Jiao, 2017).

Thermal analysis is carried out in various ways following the form of the thermal process that occurs, starting from melting to pouring. Thermal analysis is defined as the analysis of changes in the properties of the sample, which are related to changes in the applied Temperature (Brown, 2004). The amount of mass of impurities and dross that cannot be eliminated in the casting is estimated to be calculated. It can also be taken into account the temperature range at which the heat treatment to improve the mechanical properties of the material is processed. The melting temperature can be calculated when the phase change starts from solid to liquid. Thermal analysis can also take into account the start and end of oxidation. Apart from that, the activation energy which is the energy needed for the thermal process to occur can be calculated. Thermogravimetry Analysis and Differential Thermogravimetry Analysis are two analyzes used to account for the four thermal analyzes. Thermogravimetry Analysis studies the kinetics of metal oxidation in air or oxygen (Smallman & Bishop, 1999), (Bottom, 2008). The oxidation of aluminum powder at high temperature heating rates has been investigated (Schoenitz, Patel, Agboh, & Dreizin, 2010). Changes in the mass of aluminum powder that undergo oxidation are measured in a thermal analyzer has been investigated by (Trunov, Schoenitz, & Dreizin, 2006), where the degree of difference in oxidation depends on temperature.

According to the results of DSC-TGA (Soltani, Seifoddini, Hasani, & Shahreza, 2020), the oxidation process of the Al-Mg powder mixture is divided into two stages. Phase analysis revealed that only the magnesium powder particles were oxidized during the first step of the process. During the second oxidation stage, the protective oxide layer on the surface of the aluminum particles is broken, and a spinel phase (MgAl2O4) is formed due to the contact of the aluminum melt with the magnesium oxide (MgO) formed in the first stage. Oxidation analysis of Aluminum particles was carried out (M, Panjepour, & Shamanian, 2013), the heating temperature was carried out up to 1400oC, there were 5 five regions for the oxidation process. The oxidation mechanism of aluminum powder particles was studied by simultaneous TG-DTA analysis (at atmospheric air) at different heating rates (10, 20, and 30 °C/min). Also, the oxidation reaction rate (weight gain rate; RTG) was obtained by the weight gain differentiation curve (TGG).

Thermogravimetry analysis can provide data on the amount of activation energy. Research on composite materials using TGA has been carried out (Rehman, Akram, Kanellopoulos, Elmarakbi, & Karagiannidis, 2020) by calculating the weight loss during the decomposition process. In addition, research on initial oxidation at low temperatures (600 to 90oC) has taken into account the activation energy by (Nie, Schoenitz, & Dreizin, 2016).

There are several types of impurities in recycled aluminum metal liquids, including paint, ink, organic materials, and other metals carried during smelting and also black dross (Soares & Espinosa, 2003). Apart from that, white dross and saltcake also result from the primary aluminum smelting process (Soares & Espinosa, 2003). All components of this dirt must be removed. On the other hand, to obtain a composite material made from Aluminum, several other materials are added. Aluminum material can be mixed with ash from burning fuels such as coal (Nukman, Saloma, Sahim, & Saleh, 2020). The ash from this combustion is not included in the category of impurity because the ash is intentionally added to the liquid aluminum material to get a material with specific mechanical and physical properties.

From this discussion, a decision can be made, namely measuring the temperature of the aluminum material, which contains additional material. Measurements are made for each phase change of the material from solid to liquid. This temperature is needed as a temperature limit for the selection of aluminum material to be heat treated.

EXPERIMENTAL PROCEDURE

The Material

The material that has been used for this research is AA6061 aluminum alloy, which is a commercial aluminum alloy. The aluminum cylindrical rod has been cut to 30 cm, and this has been done because the height of the container is 30 cm, and this has been considered a recycling simulation of the AA6061 aluminum chip produced by the machining process. Saat penuangan ke dalam cetakan tabung silinder berukuran 30 sm dengan diameter 50 mm, pada bagan dasar tabung telah The amount of fine sub-bituminous coal added to each mould cylinder was 12.5; 25; and 37.5 grams. In comparison, melted Aluminum has been poured without adding fine coal (Nukman et al., 2020). The foundry aluminum bars are cut and scraped using a hacksaw. To avoid the presence of ferrous metal from the saw band, a piece of magnetic iron is affixed to the scraping results to separate the iron and aluminum metal.

Thermogravimetric analyzer (TGA)

The thermogravimetry analyzer used is branded DTA/TGA Exstar SII 7300. This tool can measure temperatures up to 1200 ^{o}C. The tool will be set up with an oxygen atmosphere, with a heating rate of 10 ^{o}C/min, while the mass of the material is adjusted to the amount of material that can be loaded into the pan, about 8.5 to 9.3 mg. TGA operating temperature starts from 30 to 900 ^{o}C. Mass or mass percent is usually plotted as the ordinate (Y-axis) and temperature or time as abscissa (X-axis). The mass percent has the advantage that results from different experiments can be compared on a normalized set of axes. When time is used as the abscissa, the second curve of temperature versus time needs to be plotted to show the temperature program used (Brown, 2004). The amount of activation energy can be calculated using the Arrhenius equation (Askeland et al., 2011).

RESULTS AND DISCUSSION

Measurements that have been carried out using TGA produce four main relationship graphs, namely for each aluminum alloy without mixture (WOC), Aluminum with a mixture of coal as much as 12.5 grams (AC12.5), 25 grams (AC25), and 37.5 grams. (AC37.5). The relationship that has been formed is the relationship between the reduction or addition of mass and temperature to the length of heating time.

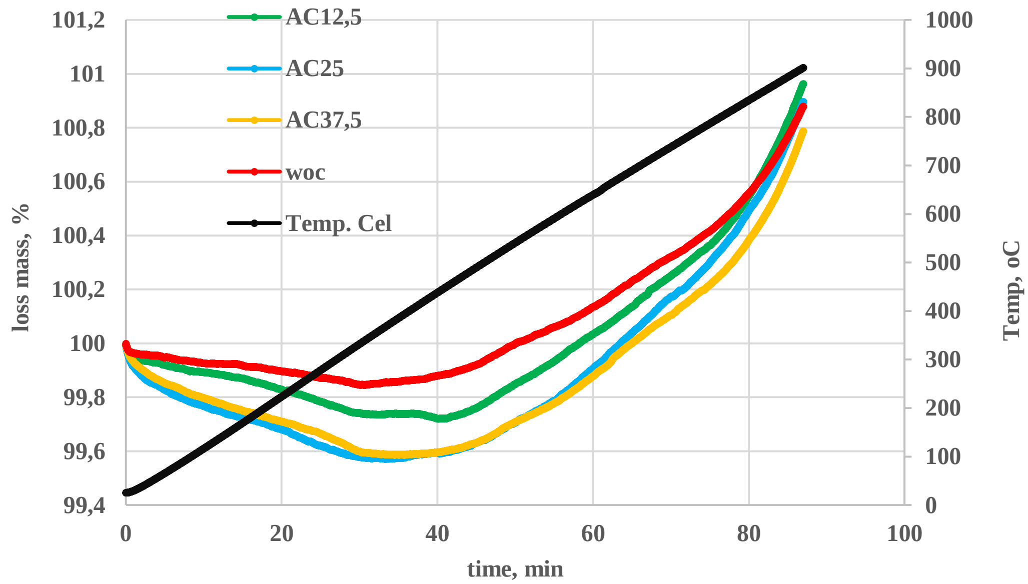


FIGURE 1. Thermogram

From the figure 1, it can be seen that there has been a decrease in mass for all samples, whether or not the samples were treated with coal powder. However, each final temperature for this process is different in magnitude and the time required for the decomposition process. From the thermogram, it can be seen that the mass reduction occurred up to 40 minutes or before the temperature of 450 oC. Seeing the thermogram formed, it can be estimated that there has been a phase change from solid to liquid. Thus the amount of activation energy can be calculated.

In the thermogram, the oxidized aluminum powder can be divided into five different levels from room temperature to 1500℃ (Hasani et al., 2012). The aluminum powder oxidation process can also be divided into four different stages, which are measured by temperature Thermograms can also be formed in terms of the relationship between loss mass (%) and temperature.

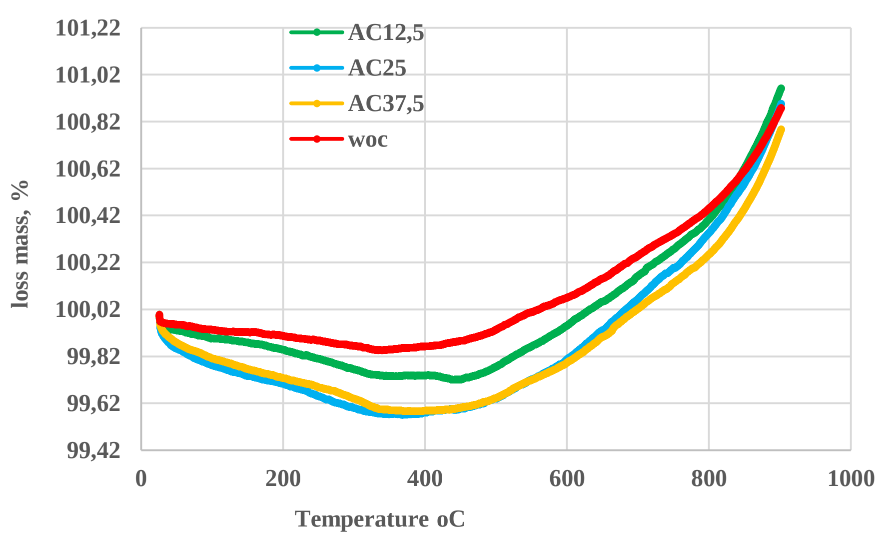


FIGURE 2. TGA vs Temperature

From Figure 2, it can be seen that the decrease in mass percent for the four samples has occurred starting at room temperature so that it reaches a temperature of around 400 oC, except for sample AC12,5, which still has a decrease in mass up to a temperature of 450 oC.

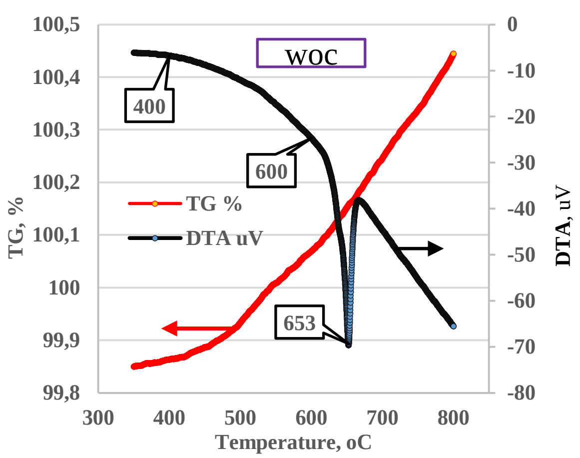
From this thermogram, it can be seen that there was a trend of decreasing mass of less than 0.50% at the beginning of the oxidation process. Fine coal cannot be said to have a full effect on this mass loss. Because the sample without the addition of coal powder also experienced a decrease in mass. Some components that burn during the coal decomposition process are water content, volatile matter, and tethered charcoal. However, most of the decomposition process at temperatures below 360 oC is the loss of water content and the burning of most of the volatile matter (Kok, 2003), (Speight, 2005). The decrease in mass in the sample without the addition of fine coal is due to the presence of impurities in the form of dross and water content and volatile matter in aluminum particles. The most significant mass decrease occurred in samples AC 25 and AC37.5, and this mass was estimated to be a mixture of unburned fine coal when poured into unburned cylindrical molds with moisture and volatile matter content. The decrease in mass at the beginning of oxidation occurs due to the presence of impurities in the aluminum material, which is following what was discussed previously (Nukman, Yani, Arifin, & Ms, 2018).

Melting Point Temperature

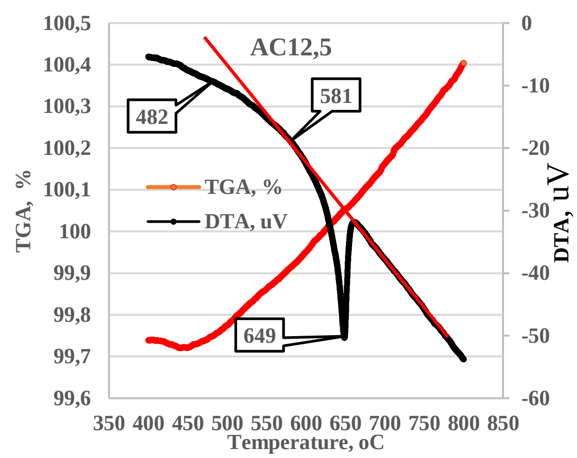
The melting point of Aluminum material is around 600 to 700 ^{o}C. For this reason, the melting point temperature analysis will use the image relationship between TGA and DTA (Differential Thermal Analysis), with a temperature range of 350 to 800 oC. The peak temperature of the DTA curve for the measured sample is the liquid Temperature of the Aluminum (Brown, 2004). From the four figures, it can be seen that the curve tends to form a similar peak. The WOC temperature measured here is 652 oC. This temperature is greater than that of Aluminum which has been mixed with coal powder. The melting Temperature of Aluminum for a mixture with 37.5 grams is 648 oC, and this is not much different from a mixture of 25 grams of coal powder which has a melting point temperature of 646 oC, while for a mixture of 12.5 grams, the temperature obtained is 649 oC. This means that the addition of coal powder has decreased the melting point temperature of the aluminum material. This temperature difference is obviously not very significant, but this nominal figure has proven that the added coal powder has an effect on the melting point of Aluminum. This achieved temperature can be used as a reference in heat-treating Aluminum. Solution treatment at 540 oC was carried out by (Zhang et al., 2002). Also, solution treatment before natural aging was carried out by (Tafti et al., 2018) at a temperature of 493 oC. The same thing was done by (Kilic et al., 2019), who carried out treatments at temperatures at 500 oC, which was similar to what was done by (Astika, 2019) at 500 oC for AA2024. Heat treatment at a temperature of 537 oC is treated with A356 material by (Akhil et al., 2014), while for AA6061 material, which has received T6 heat treatment, it is carried out at temperatures around 500 to 550 oC (below solidus 595 oC) by (Tan & Said, 2009). This indicates that the heat treatment is carried out well below the melting point temperature of the Aluminum, and this is usually done on the solidus line of the material.

Solidus Temperature and Activation Energy

The solidus temperature is the limit at which the solid + liquid phase separates from the solid phase (Baker, 1992). The heat treatment applied to Aluminum must be below this solidus line. From Figures 3: a, b, c, d, it can be seen that the melting point of Aluminum can be seen from the peak of the DTA curve. Peak base relationships can be linked by the method suggested by (Brown, 2004). On the left side of the line will be tangent to the point of the curve line. When observed, there is a relationship between the maximum temperature points for calculating the activation energy due to the oxidation process. In the woc figure, the temperature of 600 oC is the end of the calculation of the activation energy and this is the point where the tangent to the base of the curve intersects. The solidus boundary temperature point and the amount of activation energy can be described in table 1.



(a)



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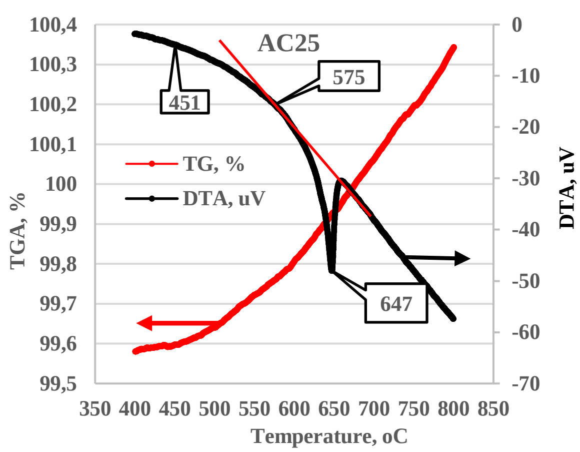

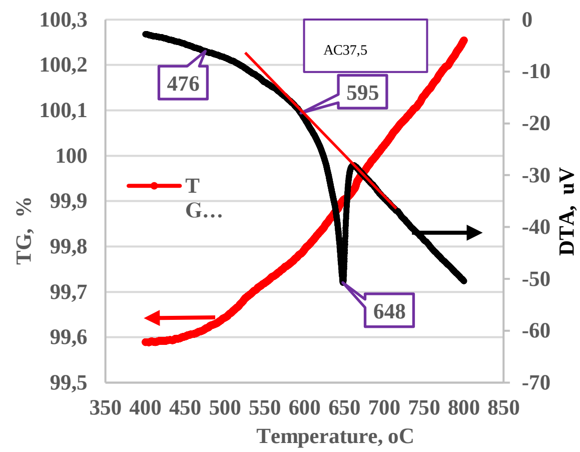

(c) (d)

FIGURE 3. Melting Point Temperature, Solidus Temperature and Activation Energy Temperature

TABLE 1. Solidus Temperature and Activation Energy

Sample	Solidus Temperature °C	Activation Energy Temperature °C	Activation Energy kJ/kg
woc	600	400 - 600	206,91
AC12,5	581	482 -581	465,78
AC25	575	451 - 575	517,30
AC37,5	595	476 - 595	994,01

CONCLUSION

From the analysis, it can be concluded that, by using TGA/DTA analysis, the solidus temperature of aluminum material mixed with coal powder has been obtained. The oxidation that has been carried out has given the results of this solidus temperature data and the results of the melting point of the sample material. The activation energy is calculated after passing through the mass reduction phase until it reaches a temperature point where the material will start to turn into a solid + liquid phase. Applying fine coal to the re-melted AA6061 material has reduced the melting point of the samples AC12.5, AC25, and AC37.5.

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