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Improving aluminum strength with chemical modification based on titanium and boron elements

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Abstract. In general, Al5TiB is added to hypoeutectic Al-Si alloys with Si levels <12%. The addition of Al5TiB grain refiner to hypoeutectic Al-Si alloy has been shown to be effective in increasing the mechanical properties of the alloy. While the addition of Al5TiB grain refiner to the Al-11% Si alloy master has never been done. This study aims to determine the effect of adding Al5TiB grain refiner to the microstructure and mechanical properties of Al-Si eutectic alloys (Si 11%). The mechanical property to be known after the addition of Al5TiB grain refiner is hardness. In this research Al-11% Si material was used. Al5TiB grain refiner added to Al-11% Si material to determine changes in microstructure and the value of violence that occurs. The results showed that the addition of Al5TiB would produce a large number of fine grains with a uniform distribution and shortening the distance between dendrite arms. The results of the hardness test showed that the hardness tended to increase with increasing levels of Al5TiB grain refiner added. The decreasing in the value of hardness in the addition of Al5TiB grain refiner with 0,15% is due to the addition of Al5TiB grain refiner has exceeded its maximum limit.

1. Introduction

Aluminum is one of the elements that has many benefits in human life. Light weight with higher strength value makes aluminum an alternative to the future of wood. In line with this, Indonesia is a very rich area of raw materials that are made of aluminum bauxite based on data from the central bureau of statistics (BPS) in 2014 – 2017. In 2017, the potential for bauxite in Indonesia reached 2.7 metric tons [1] Bauxite is one of the most potentially mining goods in Indonesia.

In 2017, bauxite production reached 1.2 billion tons and decreased when compared to production in the year 2014. Despite the decline in production but still one of the most promising potential in the future. When compared with the potential to export aluminum raw materials to several countries in the world, aluminum raw materials also have a very promising potential. In 2018, Indonesia was able to export aluminum raw materials around 8.6 million tons [2].

In recent years, China is intensively importing aluminum as raw materials which will be used as the main raw material in vehicle manufacturing. Although in the current global economic crisis, it is predicted that there will be a decline in automotive sales, but the development of the automotive industry still making enough progress rapidly [3]. Based on data compiled from trademap.org, it can be seen that the export of aluminum as raw materials from Indonesia, taken as a whole by China. This is in line with data from the CAAM National Bureau of Statistics, Company Reports, Public Sources, CM Group which states that China's total state vehicle production in 2017 reached 31.4 million units which increased by 4.7% from the previous year. Because of the massive increase in vehicle production in



China, the need for aluminum automatically will also increase. In 2017 China's aluminum consumption for vehicles reached 3.9 Metric Tons (MT) and increased by 0.3 MT from before. This shows that there is a tendency for aluminum levels in vehicles to increase due to the many advantages of aluminum. This is arguably an opportunity for the Indonesian state to have abundant natural resources for the aluminum raw material itself.

The increasing use of aluminum in a vehicle can result in a reduction in weight in the vehicle. This will automatically cause the use of fuel in the car will be more efficient. Seeing this fact, it is very clear that the level of aluminum usage will continue to increase every year.

With the many needs for aluminum in the transportation sector, especially for vehicle engine components, it is absolutely necessary to have aluminum with good quality and good characteristics in accordance with needs. However, the use of aluminum alone is not enough to get certain desired characteristics. Therefore, aluminum needs to be combined with silicon because this alloy has good characteristics as vehicle engine components such as pistons and engine blocks.

Although a lot of aluminum used for making automotive products, however aluminum also has disadvantages. So it has limitations in the application like hardness, wear-resistance and strength. This is very important to consider in product manufacturing automotive especially in products that are experiencing loading and experiencing friction with other components. Some aluminum-silicon applications in automotive components with a silicon content of 7% [3]. To complement the properties of silicon aluminum alloys with better quality where the mechanical properties according to needs, there are several parameters that can be used. One way is to add other elements in the silicon aluminum alloy. In this process, aluminum-silicon is combined with certain elements in order to improve the mechanical properties of the product.

The process of adding other elements is one of the methods used to obtain good mechanical properties of a liquid metal (aluminum silicon). This process is done by adding grain refiner elements to aluminum alloys. One of the refining elements is a mixture of aluminum, titanium and boron (Al5TiB). Al5TiB alloy acts as a grain refiner in the alloy. Al5TiB grains refiner on silicon aluminum alloys are used to control the grain structure. Grain refiners produce nucleating sites for the formation of primary dendrites and produce large numbers of fine and uniform grains distribution. In Al-Si (aluminum silicon) alloys containing Fe, finer grains will produce smaller intermetallic and more uniform distribution. With the occurrence of grain reduction and uniform distribution, the mechanical properties of the product will be much better than before [4].

2. Materials and methods

2.1 Data and sources of data

The data presented in this study were obtained by conducting research on Aluminum Silicon alloys added with other elements namely Titanium and Boron. The main material in the form of aluminum-silicon eutectic master alloy is Al-11% Si and the temperature used was $\pm 700^{\circ}\text{C}$. Each sample was added Al5TiB content of 0.05%; 0.1%; 0.15%. By doing this research it is expected to know the effect of adding Al5TiB to the morphology of the alloy and its effect on the hardness of the Al-Si alloy. The hardness test specimens and specimens for microstructure testing using HRC (*Mobile Hardness Tester*) machine were made as seen in figure 1. The microstructure was obtained by using SEM (Scanning Electron Microscope) tool. The test results are presented in tabular form and then continued with data analysis related to the test results. In addition, the effect on the microstructure of the alloy was also investigated because the shape of the microstructure is very influential on the strength value of a material or alloy material.

2.2 Data analysis

Data analysis was performed by comparing the results obtained in theory with the results obtained from testing. Then drawn conclusions from the results of testing that had been done. The conclusion obtained

was the effect of giving other elements to an alloy both in the form of altered violence and changes in the morphology of the microstructure.

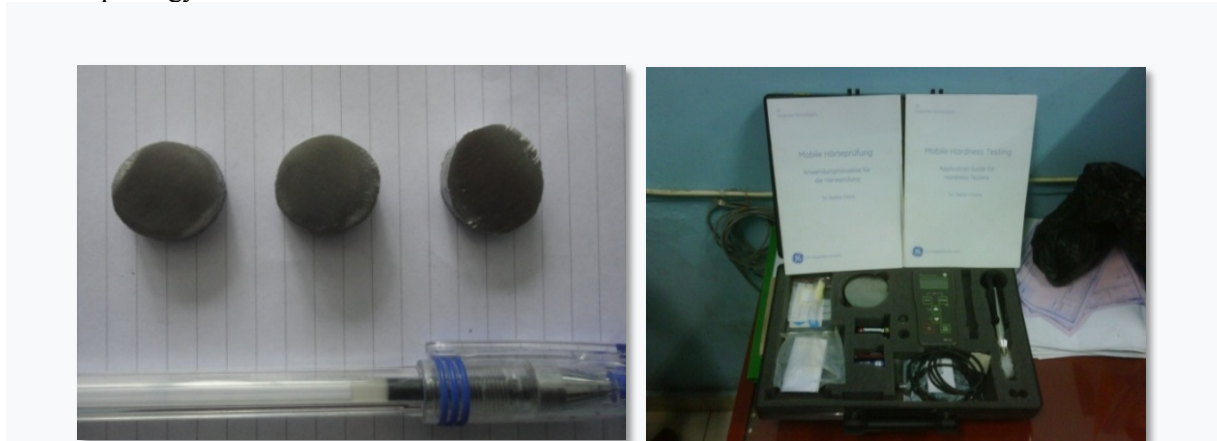


Figure 1. Test specimens for testing mechanical properties.

3. Results and discussions

Hardness testing was carried out on the test specimen with the aim to see the effect of chemical modification on the strength increase of aluminum material. The strength aspect that was seen was the value of the hardness of the test specimen. Before testing the effect of the added elements, a hardness test for each test sample that had not yet been added was executed first. It aimed to get the value of violence due to the influence of the addition of these other elements.

Hardness testing values for each sample can be seen in table 1. For each sample, hardness testing was performed as many as 8 points for each specimen that was carried out randomly, then the average hardness value was taken. Hardness testing was performed for all four variables (0% Al₅TiB, 0.05% Al₅TiB, 0.1% Al₅TiB, and 0.15% Al₅TiB), all four variables were tested using Hardness Mobile Tester. From the hardness test data obtained, then plotted in the form of graphs of Al₅TiB levels versus hardness values (HRC). The graph obtained is seen in figure 2, while microstructure of hardness values for each Al₅TiB addition variable describe in figure 3.

Table 1. Testing values for sample hardness after adding Al₅TiB.

Al ₅ TiB levels	Hardness rating for each test point (HRC)								Hardness average
	I	II	III	IV	V	VI	VII	VIII	
0%	24.4	26.1	29.8	20	29.5	21.3	27.8	24.3	25.4
0.05%	25.4	28.5	28.2	24.3	22.4	28.4	27.3	24.4	26.1
0.10%	25	25.6	22.1	29.1	28.4	27.9	28	26.8	26.6
0.15%	22.3	21.8	21.3	23.1	23.5	22.9	25	25.7	23.2

There was clearly an increase in the value of hardness after the addition of other chemical elements into the alloy. The chemical elements of Titanium and Boron are believed to be able to improve the morphology of the microstructure of aluminum and silicon alloys. The results obtained from the test are in accordance with the theory that the Al₅TiB alloy acts as a grain [4].

Grain refiners produce nucleating sites for the formation of primary dendrites and produce large numbers of fine and uniform grains distribution. In Al-Si alloys containing Fe, finer grains will produce smaller intermetallic and more uniform distribution. With the occurrence of grain reduction and uniform distribution, the mechanical properties of the product will be much better than before [4].

The test results were plotted in graphical form to show the improvement of mechanical properties that had occurred in the study. Figures 2 and 3 show that as the aluminum and boron elements increased

in silicon aluminum alloys, the grain structure would become smaller and increase the hardness value. But there was a maximum level that limits the number of alloys which, if achieved, would actually reduce the hardness of the alloy.

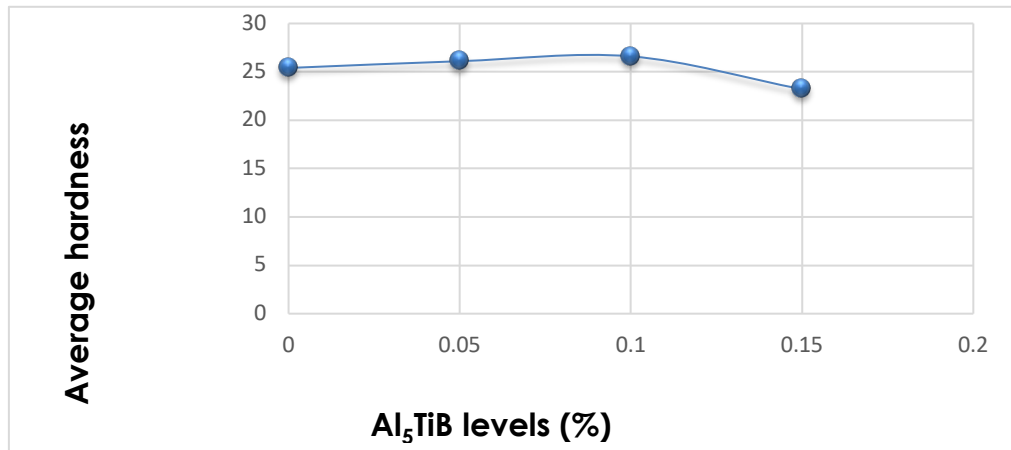


Figure 2. Hardness values for each Al₅TiB addition variable.

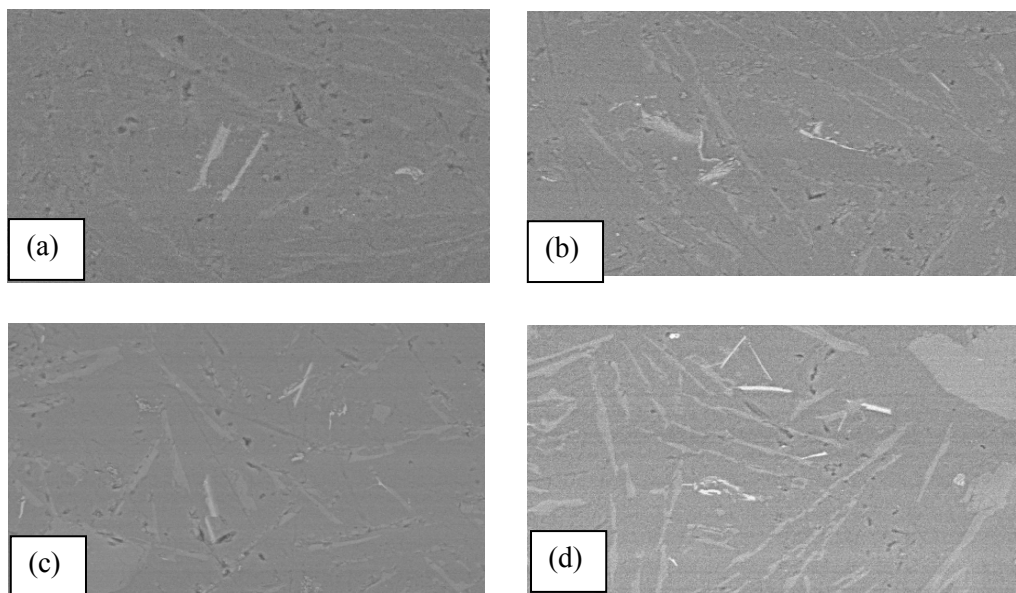


Figure 3. Microstructure of Hardness values for each Al₅TiB addition variable
 (a) microstructure Al₅TiB level 0, (b) microstructure Al₅TiB level 0.05,
 (c) microstructure Al₅TiB level 0.1 and (d) microstructure Al₅TiB level 0.15.

The hardness value would tend to increase with increasing levels of Al₅TiB in the alloy. These data are in accordance with the research conducted by Suhariyanto which stated that the results of the hardness test showed that Ti was quite influential on the mechanical properties of the alloy, namely the increase in the value of the hardness. Titanium combined with boron or carbon is an Al-Si alloy element that serves to refine grain (grain refiner) in cast aluminum, because Ti C or TiB can be the core of aluminum alloys. This is what affects the changes in mechanical properties and microstructure [5].

With the finer grain, the propagation of the blockage will be more difficult, so it has greater resistance, because it requires more energy to damage the fine grain, this is indicated by the increase in

tensile strength and hardness. Besides that, grain refiner can also reduce hot tearing and porosity, and can tighten grain pressure.

In the SEM test results, the difference was seen between silicon crystals without the addition of Al5TiB with the addition of Al5TiB of 0.05%. This can be seen in figure 4.

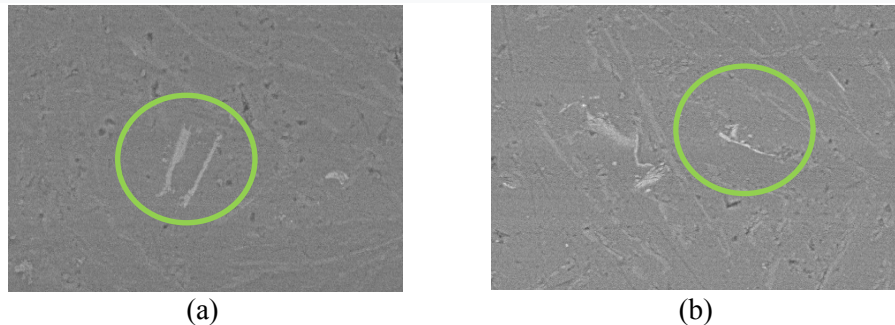


Figure 4. Al-11% Si microstructure changes a) Without the addition of Al5TiB
b) With the addition of 0.05% Al5TiB.

From the picture above it can be seen that there was a change in the microstructure of Al-11% Si alloy. The addition of 0.05% Al5TiB content reacted in the alloy to produce a finer and more evenly distributed grain structure. The crystalline silicon, which was originally shaped as long and very coarse needles, had become finer and shortened. This was the reaction given by Al5TiB as an item refiner.

The fine graining element reacted by wrapping silicon crystals to prevent grain growth from becoming rough. This can be interpreted that the fine graining element can act as an element that can control the amount of grain structure produced [4]. Al5TiB refiner grains on aluminum-silicon alloys were used to control the grain structure. Grain refiners produced nucleating sites for the formation of primary dendrites and produce large numbers of fine and uniform distribution grains. This has led to an increase in the value of violence.

On the addition of 0.1% Al5TiB levels there was also an increase in the value of violence. This was very reasonable considering the increase in Al5TiB content in the alloy so that it reduced the grain structure and had an effect on the price of violence which also rose. This can be seen in figure 5.

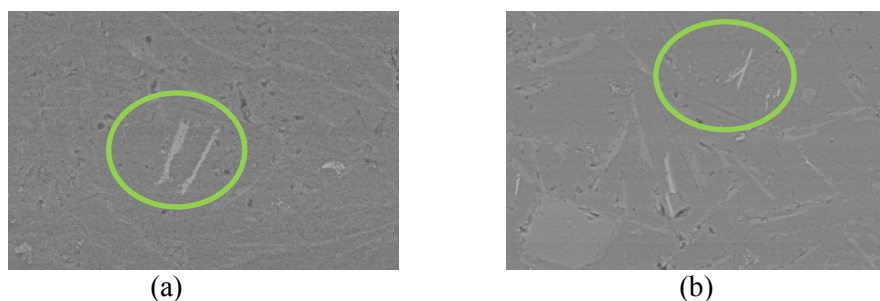


Figure 5. Al-11% Si microstructure change a) Without the addition of Al5TiB
b) With the addition of 0.10% Al5TiB

From the picture above it can be seen that there was a change in the microstructure of the Al-11% Si alloy. Modified silicon crystals were more and more evenly distributed. The grain structure at the addition of 0.10% Al5TiB became smoother when compared to the addition of 0.05% Al5TiB. This has resulted in an increase in the value of violence from before. This is in line with research conducted by Imanuel Ginting in his journal entitled "Strengthening with the fineness of grains on Al-9.4% Si alloys".

In that study, it was said that along with the addition of grain refiners in the alloy, it would cause the price of violence would increase and the grain structure tends to be smoother [6].

When referring to the value of the DAS (Dendrite Arm Spacing) or the distance between the dendritic arms, the value of this DAS depends on the speed of the freezing process of the casting process. DAS value has a great effect on the mechanical properties of a metal alloy.

Increased arm spacing indicates rough microstructure so that its mechanical properties are not good. While the small DAS value indicates a delicate micro structure with good mechanical properties. In the research conducted by Budi Lesmana, it can be seen that the addition of grain refiner can produce a faster freezing rate. If the freezing rate is fast, the resulting DAS value will be smaller. Therefore, the value of violence is higher than before. So it is very clear that the addition of grain refiner in the alloy is very influential on the value of the DAS which can directly improve the mechanical properties of an alloy [7].

In the Al-11% Si alloy added by Al5TiB as much as 0.15%, it can be seen that the results are contrary to previous data. In this condition, there was a decrease in the value of violence from an average of 26.6 HRC to 23.2 HRC. From the microstructure image obtained, it can be seen that the silicon particles were charged after adding Al5TiB of 0.15%. This had become the main cause of the decline in the value of violence found. For more details, can be seen in figure 6.

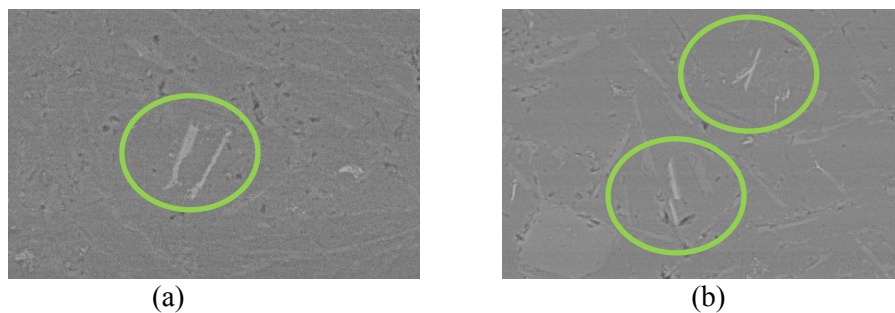


Figure 6. Al-11% Si microstructure changes a) Without the addition of Al5TiB
b) With the addition of 0.15% Al5TiB.

From figure 6 the change in silicon crystals in Al-11% Si alloy can be seen. The structure of silicon which was originally shaped as short needles turned into a structure of longer needles at the addition of 0.15% Al5TiB. Besides that, the grain size tended to be bigger than before. Grain structure that did not spread evenly also had a very large impact on the decrease in the value of the hardness found in the test. This was because the added Al5TiB content had exceeded the ideal limit so that the addition process did not improve the mechanical properties but worsen it.

This is in accordance with research conducted by Ahmad Supriyadi [8], that giving Ti-B more than the right percentage would reduce its mechanical strength because Ti-B inoculants produce impurity. The research also shows that if the addition of TiB is greater than 0.12%, it will reduce the value of violence.

In addition, the decrease in the value of violence can also be explained by research conducted by Dobrzanski [9], who explained that the titanium element has a maximum concentration of 0.14%. If it has passed these numbers, the tendency for the process of imperfect modification will be even greater. This has caused the value of violence to be lower.

4. Conclusion

The addition of Al5TiB grain refiner grading 0.05% caused a significant change in the Al-11% Si alloy microstructure. The effect on the alloy was that the silicon crystal which was originally coarse became finer with the addition of the Al5TiB grain refiner. This change in microstructure caused an increase in hardness of 2.756% of Al-11% Si alloy without the addition of Al5TiB grain refiner. The addition of

Al₅TiB grain refiner grading 0.10% caused significant changes in the microstructure of Al-11% Si alloys. The effect on the alloy was that the crystalline structure of silicon became smoother when compared to the addition of an Al₅TiB grain refiner of 0.05%. In addition, the grains were more evenly distributed than before. This had led to an increase in the value of hardness of 4.724% of Al-11% Si alloy without the addition of Al₅TiB grain refiner. The addition of Al₅TiB grain refiner grading 0.15% caused changes that were contrary to changes in the micro-alloy structure of Al-11% Si. The effect on alloys was that silicon crystals which were originally refined now even experienced uneven distribution and distribution. This happened because the addition of Al₅TiB grain refiner had exceeded the maximum limit. Therefore, the hardness value decreased very dramatically by 8.661% of Al-11% Si alloy without the addition of Al₅TiB grain refiner.

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