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Effect of Mg and TiB on the Mechanical Properties of A356 Aluminium Alloy Base Materials With Die Casting Process

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Abstract. The development of research on aluminum base materials is very rapid at this time. Aluminum base material reinforced with Mg and TiB particles by the die casting method is the simplest way. The purpose of this study was to see the effect of wt.% Mg and the addition of TiB on the mechanical properties of Al356MgTiB alloy. AlSi was used as a matrix reinforced by Mg with a percentage variation of (3, 4, 5 wt%) and TiB 2 wt%. The method used is die casting. In the casting process, the material is melted down to a liquid state at a temperature of 800 oC. After that the temperature was lowered to a stirring temperature of 640 oC. Then heated again to a pouring temperature of 760 oC. The density value obtained increased with the addition of Mg variation, namely the variation of Mg 4%wt 2.69 g/cm3. The porosity value obtained decreased, namely the variation of the 5%wt Mg element, namely 5.19%. The hardness value of Al356MgTiB alloy increases with the addition of Mg. The highest hardness is achieved at the percentage of Mg 5%wt, which is 65.41 HRB or an increase of 33% from the hardness of the base material. The value of tensile strength increases with the addition of Mg. The highest tensile strength is found in the 4%wt Mg variation, which is 198.4 MPa. The %EL value decreased with the addition of Mg and TiB. The decrease in %EL is accompanied by an increase in the strength of the material. The research was conducted by testing density, hardness testing, and tensile testing.

Keyword: Magnesium, Titanium Boron, Alumunium alloy, Die Casting.

1. Introduction

The development of science and technology is very rapid, this has an impact on the development of transportation technology, especially in the automotive sector. New materials are considered for inclusion in the vehicle design if it has a cost benefit. To achieve the best performance technically and economically, it must pay attention to the relationship between design, materials and production processes in the application of certain components [1-2]. The manufacture of aluminium alloy is a combination of A356 as a matrix with Magnesium (Mg) and Titanium Boron particles as reinforcement because these properties can increase the strength and toughness of a metal. Alloy A356 has advantages such as light weight (density 2.7 g/cm3), tensile strength of 172 MPa and resistance to corrosion, but has a low hardness of 60 HB [3-5]. The addition of magnesium will increase the strength and hardness of the heat-treated Al-Si alloy. The hardening phase was obtained by adding 0.70% Mg. High-strength Al-Si alloys usually have a Mg content of 0.40-0.70%. Al-Mg binary alloys are widely used to improve surface finishing results, good response to chemical finishing, corrosion

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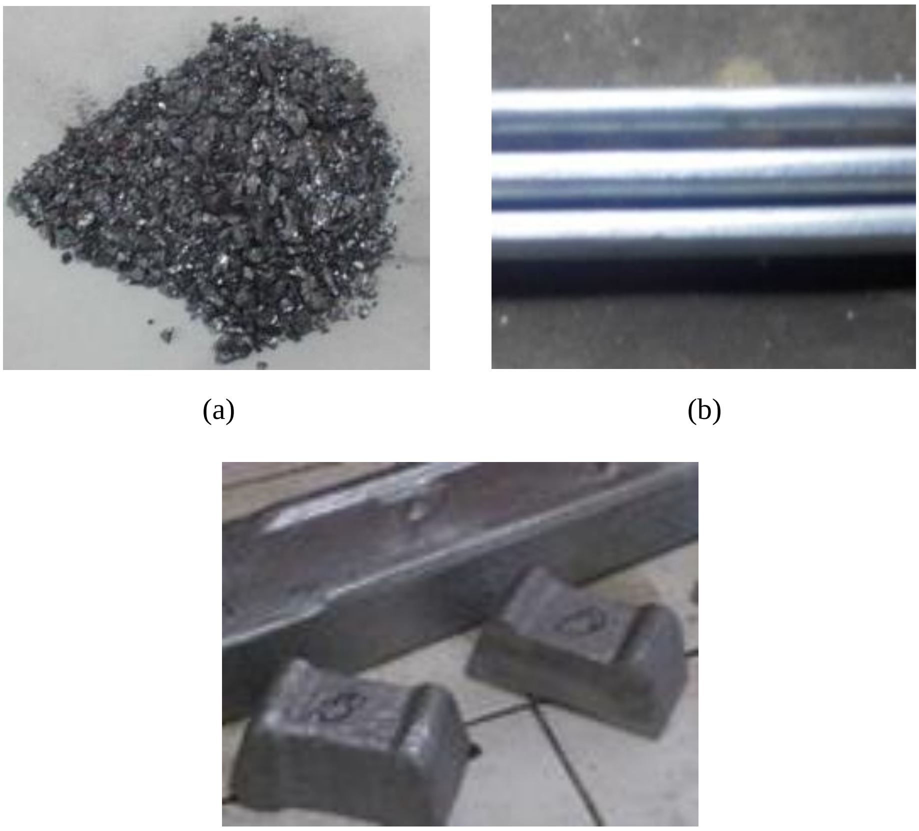
resistance, and a good combination of strength and ductility, namely in the composition of 4-10% Mg. Research on AlTiC and AlTiB with variations of 0.2%, 0.5%, 1% got the result that with the addition of 1% TiB the grain size was getting smaller [6-8]. Alloy Al7178 with variations of TiB (1, 2, 3, 4 wt.%) obtained the result that the addition of TiB between (1-4 wt.%) the grains decreased significantly in the mining of TiB (1 wt.%) which was 140 m , at (4 wt.%) to 55 m [9-10]. The study used master alloys AlTiB with a variation of 0.03% to 0.15% with the results of the study being that the smallest grain size was 50 m, achieved at a variation of 0.13% TiB [8]. The addition of silicon with a certain level can improve fluidity, heat crack resistance, and feed characteristics in the machining process. For castings with slow cooling rates such as plaster molds, investments, and sand, the Si content is 5-7%, for permanent molds the Si content is 7-9%, for die casting the Si content is 8-12%. Silicon combines with Mg to form Mg_2Si in a heat-resistant alloy. Silicon also reduces the specific gravity and coefficient of thermal expansion [11,4]. In this study, the effect of the addition of Mg and TiB on mechanical properties using Al356 as a base material with the die casting process will be investigated. Tests to be carried out include density test, hardness test and tensile test.

2. Experimental Method

The research is viewed from the mechanical properties, the results of the casting using the die casting process. The main material used is aluminum alloy Al356, with variations in the addition of elements Mg (3, 4, 5) wt% and TiB 2 wt%. The addition of Mg and TiB can improve the mechanical properties of the castings. Here is Fig 1 of the materials used, and Table 1 is the composition of the ingredients.



(a) (b)

(c)

Figure 1. Materials used in casting (a) Mg, (b) TiB, (c) Al356.

The following is Table 1 The composition of the ingredients.

Table 1. Chemical composition of materials

Materials	Chemical composition (%)						
	Si	Mg	Al	Fe	Cu	Mn	Other
Al356 (ingot)	10.34	0.27	85.41	0.87	1.81	0.16	1.017
Mg	0.013	99.93	0.022	0.003	0.012	0.012	0.018
TiB	0.16	-	93	0.16	-	-	0.05

The first stage of this process is to prepare the material to be melted. These ingredients are cut into small pieces according to the ratio of the mixing weight. This is done to simplify the process of setting the mixing composition. Each material is weighed to obtain the mass composition according to the variation of casting. The results of weighing materials for each variation are shown in Table 2.

Table 2. Variations in the composition of foundry

Materials (wt%)	Al356 (gram)	TiB (gram)	Mg (gram)	Total (gram)
Al356+TiB 2% Mg 0%	500	-	-	500
Al356+TiB 2% Mg 3%	450	20	30	500
Al356+TiB 2% Mg 4%	440	20	40	500
Al356+TiB 2% Mg 5%	430	20	50	500

In the next process, the material melts into the heating furnace. First Al356 is heated to a temperature of 800 °C to reach a complete liquid state. Then the temperature is lowered to 640 °C, then Mg and TiB are put into the heating furnace. It is then thoroughly stirred by a mechanical stirrer. The rotational speed of the stirrer is 200 rpm and the stirring time is 120 seconds. Then it must be heated again to a pouring temperature of 760 °C. The mold metal is also heated to a temperature of 250 °C, then poured into the mold. Then allowed to stand for 360 seconds, and released from the die casting mold. After that, the casting is cooled at room temperature. Furthermore, the casting results are cut into pieces according to the test specimen. Here is Fig 2. casting results.

Figure 2. Casting results, and dividing the test area boundaris.

3. Results and Discussions

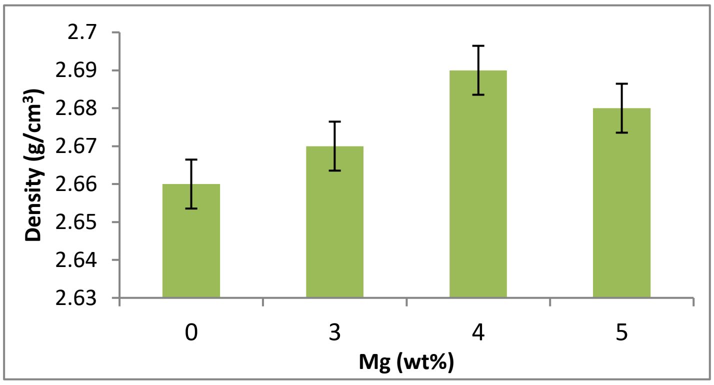
3.1. Density and Porosity

The results of density testing and porosity calculations of Al356MgTiB alloys are shown in Table 3 below:

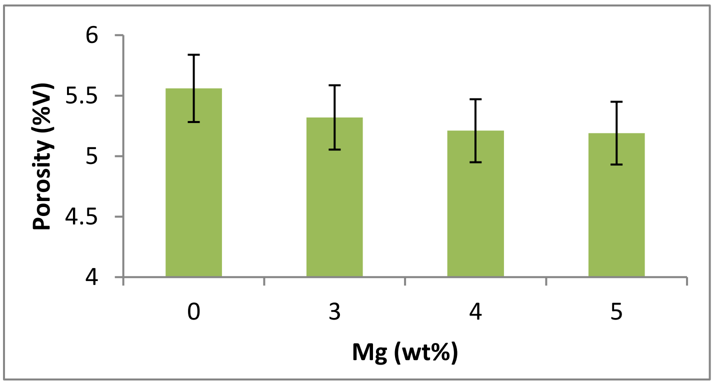
Table 3. Variations in the composition of foundry

Materials	Mg (wt%)	TiB (wt%)	ρ_{actual} (g/cm^3)	$\rho_{theoretic}$ (g/cm^3)	Porosity (%V)
Al356 +Mg+TiB	0	0	2.66	2.85	5.56
Al356 +Mg+TiB	3	2	2.67	2.82	5.32
Al356 +Mg+TiB	4	2	2.69	2.81	5.21
Al356 +Mg+TiB	5	2	2.68	2.80	5.19

The density and porosity graph of the casting results with the percentage of Mg is shown in Fig 3 below:



(a)



(b)

Figure 3. Graph (a) density, (b) the level of porosity Al356MgTiB.

Fig 3. The density value decreases at Mg 0%wt 2.66 g/cm3 and then increases at Mg 3% and 4%, then decreases when the Mg 5%wt element variation is 2.68 g/cm3, but the decrease is not too significant. While the porosity at 0%wt Mg is 5.56% then there is a decrease in porosity in the variation of Mg 3,4,5 %wt. The porosity value is 5.56% at 0%wt Mg. The porosity contained in the casting results has the potential to occur. This is like the results of research Hashim, et al. (1999) which states that the potential for porosity in the casting process is caused by chemical reactions between reinforcing particles and alloys that produce gas, as well as gas trapped during the stirring process.

3.2. Distribution of Density in Casting Result

The density distribution of the casting results shows the level of distribution or dispersion of Mg and TiB particles in AlSi alloys. Furthermore, an analysis of the distribution of Mg elements was carried out on the top, middle, and bottom casting results for each variation of alloy and Mg content. The following is Table 4 density for each part of the casting results.

Table 4. Density at the top, middle, bottom of the casting

Materials	Density (g/cm^3)		
	Top	Center	Battom
Al356+TiB 2% Mg 0%	2.68	2.70	2.71
Al356+TiB 2% Mg 3%	2.70	2.69	2.49
Al356+TiB 2% Mg 4%	2.78	2.49	2.72
Al356+TiB 2% Mg 5%	2.71	2.63	2.60

The density and porosity graph of the casting results with the percentage of Mg is shown in Fig 4 below:

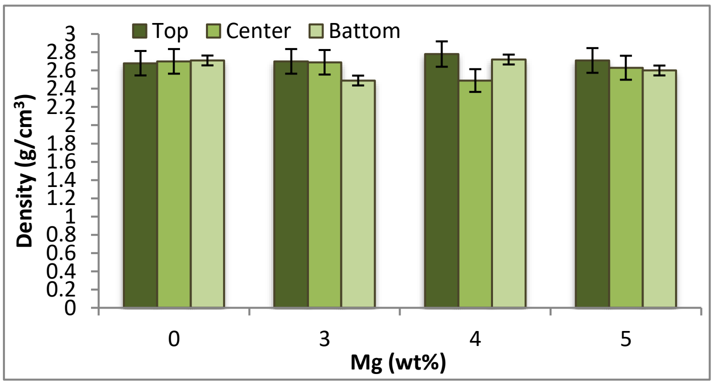


Figure 4. Density distribution of Al356MgTiB.

Fig 4. Shows that the density of alloy castings at the top, middle, and bottom is generally relatively the same. The difference in density between parts is on average 0-1%. This difference means that the lower part of the casting has a higher density than the upper part. Theoretically the lower part has a higher density because AlSi which has a density greater than Mg tends to evaporate. Meanwhile, the upper part is lighter because the part contains less Mg, and the porosity tends to be at the top of the casting results.

3.3. Hardness Test

The hardness test of Rockwell B (HRB) which was based on the standard ASTM E18-11 may produce the data of hardness material shown in Table 5 as follows.

Table 5. Test results density and porosity calculations

Materials	Mg (wt%)	TiB (wt%)	Hardness (HRB)
Al356 +Mg+TiB	0	0	43.39
Al356 +Mg+TiB	3	2	48.67
Al356 +Mg+TiB	4	2	57.56
Al356 +Mg+TiB	5	2	65.41

The relationship graph between the hardness of casting results and the Mg percentage was shown in Fig 5. below:

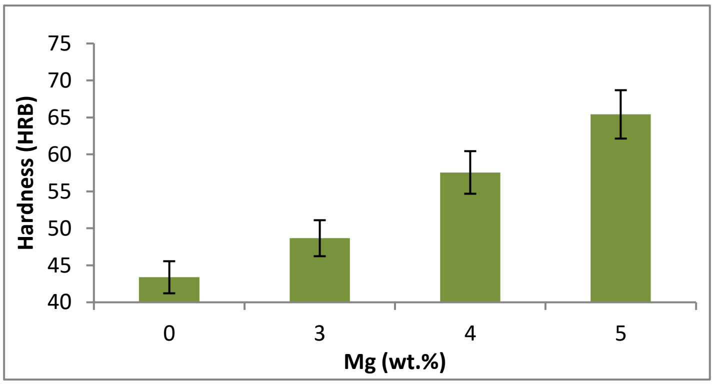


Figure 5. Hardness value on Al356MgTiB

Fig 5. The hardness value of the Al356MgTiB alloy increases with the addition of Mg. The highest hardness was achieved at the percentage of Mg 5%wt. In the Al356MgTiB alloy, the highest hardness is 65.41 HRB or an increase of 33% from the hardness of the initial material. The addition of Mg variations can increase the hardness of the resulting casting alloy. The average composite hardness increased by 7% after the addition of Mg. The hardness of the casting alloy increases because the Mg element functions as a wetting agent, namely that the Mg element is able to increase the hardness and the TiB element has a significant impact because it can help refine grain boundaries and provide a hardness value to the casting results.

3.4. Distribution of Hardness in Casting Result

The hardness distribution of the casting results shows the level of distribution or dispersion of the Mg element in the AlSi alloy. The distribution of Mg at the top, middle, and bottom of each alloy and the Mg content were analyzed by comparing the hardness at the top, middle, and bottom of the casting. The following is Table 6 hardness for each part of the casting results.

Table 6. Hardness at the top, middle, bottom of the casting

Materials	Hardness (HRB)		
	Top	Center	Battom
Al356+TiB 2% Mg 0%	42.25	41.50	45.42
Al356+TiB 2% Mg 3%	48.42	55.83	41.74
Al356+TiB 2% Mg 4%	62.93	55.25	54.50
Al356+TiB 2% Mg 5%	67.33	67.33	62.67

The herdness graph of the casting results with the percentage of Mg is shown in Fig 6 below:

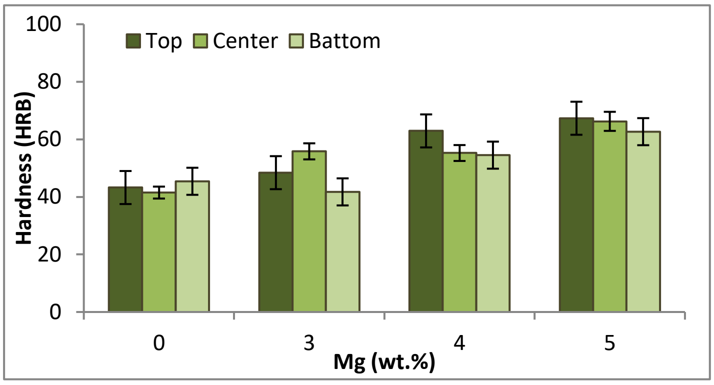


Figure 6. Hardness distribution of Al356MgTiB.

Fig 6. The hardness value of the Al356MgTiB alloy has a tendency to increase with the addition of percent Mg. The hardness of the left, center, and right sections for each alloy and the addition of Mg showed random variations. From this it can be seen that there is no significant deposition rate of Mg particles at the base of the casting alloy. The hardness level of the Al356MgTiB alloy casting is influenced by several things, including the amount of Mg dispersed, the grain size which is affected by the cooling rate. The more Mg dispersed, the harder the casting will be compared to the one without the influence of Mg. The faster the cooling rate, the finer and harder grains formed. In the casting results, the part that is close to the mold wall will experience a faster cooling rate, so that the grains are round and smoother. However, the center of the casting will experience slower cooling and have an elongated and coarse grain shape.

3.5. Tensile Strength and Elongation
The results of the tensile test and calculation of % EL of the Al356MgTiB alloy are shown in Table 7 below.

Table 7. Test results tansil strang calculations

Materials	Mg (wt%)	TiB (wt%)	σu (MPa)	*%EL* (MPa)
Al356 +Mg+TiB	0	0	137.8	2.34
Al356 +Mg+TiB	3	2	189.6	2.26
Al356 +Mg+TiB	4	2	198.4	2.22
Al356 +Mg+TiB	5	2	194.9	2.23

The graph of the tensile test results and the calculation of the elongation of the Al356MgTiB casting results with variations in Mg are shown in Figures 7 and 8 below.

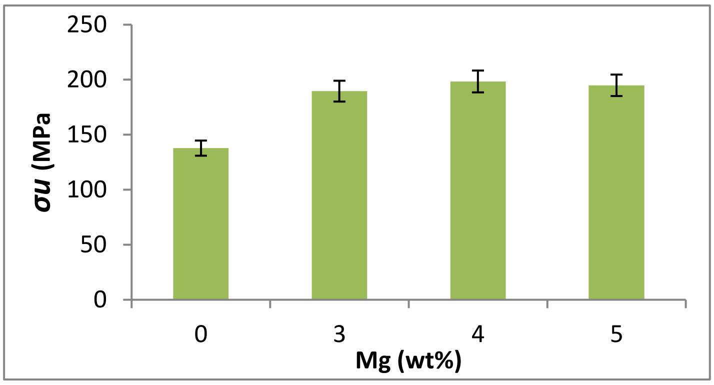


Figure 7. Tensile strength value on Al356MgTiB

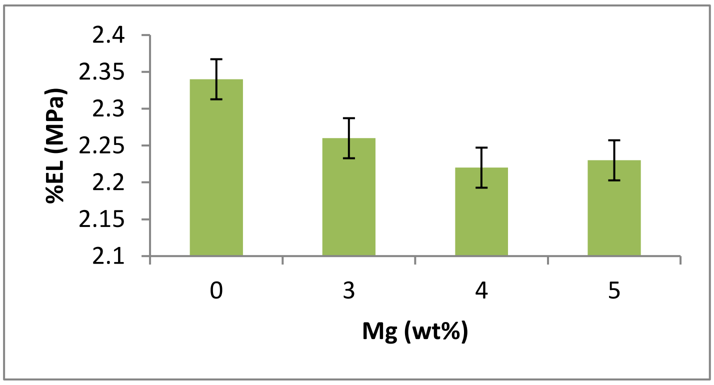


Figure 8. %EL value on Al356MgTiB

Fig 7. It can be concluded that the tensile strength of Al356MgTiB is higher than that of Al356 without the addition of Mg and TiB elements. Al356MgTiB alloy with 3%wt Mg variation of 189.6 MPa experienced an increase in tensile strength with increasing percentage of Mg element variation. The percentage of Mg element variation with the highest tensile strength value is found in the 4%wt Mg variation, which is 198.4 MPa. The addition of Mg and TiB elements can increase the strength of the AlSi material, because the Mg element can increase the wettability between atomic particle bonds. While TiB can improve grain boundaries or refine grain size, so that the value of material strength can increase with changes in grain size. The binding strength increases with the increase in the hardness and density values. While the porosity value is quite small, so that the strength with the addition of Mg and TiB elements increases even though the increase is quite small. Fig 8. The %EL value decreased from 3%wt Mg element variation, which was 2.26% to 5%wt, which was 2.23%. The decrease in %EL is accompanied by an increase in the strength of the material. Because the results of the melting of the Al356MgTiB alloy, the change is more brittle than the base material.

3.6. Distribution of Tensile Strength on Casting Results

The distribution of the tensile strength of the castings shows an even distribution of the Al356MgTiB castings. The distribution of casting results at the top, middle, and bottom of each variation of Mg, by analyzing the value of tensile strength. The following is a Table 8 tensile strength test results in the casting section.

Table 8. Tensile strength values at the top, middle, bottom

Materials	Tensile Strength (MPa)		
	Top	Center	Battom
Al356+TiB 2% Mg 0%	136.82	137.50	138.42
Al356+TiB 2% Mg 3%	188.49	189.33	189.84
Al356+TiB 2% Mg 4%	197.93	198.25	199.50
Al356+TiB 2% Mg 5%	195.33	195.26	196.27

The tensile strength graph of the casting results with the percentage of Mg is shown in Fig 9 below:

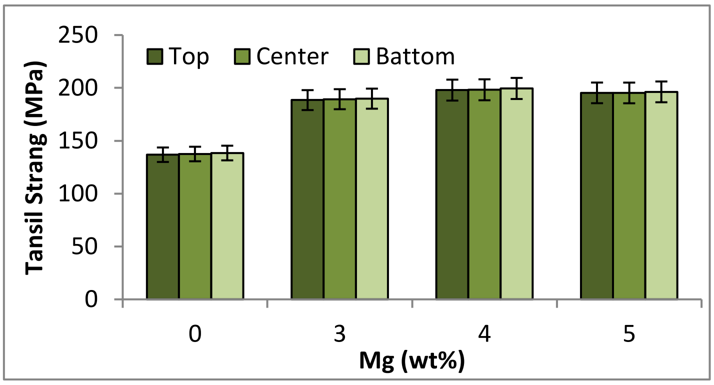


Figure 9. Tensile strength distribution of Al356MgTiB.

Fig 9 The value of the tensile strength of Al356MgTiB alloy has a tendency to increase with the addition of percent Mg. The tensile strength of the top, middle, and bottom of each alloy casting results showed uniform results. The level of tensile strength of Al356MgTiB alloy casting results is influenced by several things, including the percentage of the weight percentage of the dispersed Mg and TiB elements, and the grain size which is affected by the cooling rate. The more Mg dispersed, the stronger the casting results.

4. Conclusion

The results of this study are as follows: The density value increases with the addition of Mg, namely the variation of Mg 4%wt 2.69 g/cm3. Meanwhile, the porosity decreased, namely the variation of the 5%wt Mg element, namely 5.19%. The potential for porosity in the casting process is caused by chemical reactions between reinforcing particles and alloys that produce gas, as well as gas trapped during the stirring process. The hardness value of Al356MgTiB alloy increases with the addition of Mg. The highest hardness is achieved at the percentage of Mg 5%wt, which is 65.41 HRB or an increase of 33% from the hardness of the base material. The average hardness increased by 7% after the addition of Mg and TiB elements. The tensile strength of Al356MgTiB has increased and is more evenly distributed. The highest tensile strength value is found in the 4%wt Mg variation, which is 198.4 MPa. Meanwhile, the decrease in %EL value occurred in the variation of the 3%wt Mg element, namely 2.26% to 5%wt, namely 2.23%. The decrease in %EL is accompanied by an increase in the tensile strength of the material. The addition of Mg and TiB elements can increase the strength and hardness of the casting material. This is because the addition of Mg can increase the wettability between atomic particle bonds. While the TiB element can improve grain boundaries or refine grain size.

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