Biomedical and Mechanical Engineering Journal (BIOMEJ)
e-ISSN: 2776-1983, p-ISSN: 2829-5242
Vol. 3, No.1, October 2022, pp 1-8

Investigation of wt.% Si and Heat Treatment on the Mechanical Properties of Al6063 Aluminum Alloy by the Casting Product Propeller Shaft Model

E.I. Bhiftime[1,*]

[1] Mechanical Engineering Department, Indonesia Defense University, IPSC Area, Sentul, Bogor, West Java 16810, Indonesia

*Corresponding e-mail: eka.bhiftime@idu.ac.id

Abstract. Shaft propeller is one of the most important parts of ship propulsion installations. To produce a good quality shaft propeller, the ship propeller designer must consider various parameters, in order to produce the type and size of the propeller that has the value of effectiveness and high propulsion efficiency. Shaft propellers are usually made of steel but, in this study the propeller shaft model is made of Aluminum Alloy base material. So the material must have good mechanical properties. The purpose of this study is to see the mechanical properties of the sheller propeller with aluminum alloy base material with the addition of silicon elements and magnesium by going through the heat treatment process. The main base material used is 6063 aluminum alloy, with variations in the addition of Si (1, 2, 4 wt%). The addition of Mg can improve the mechanical properties of the casting. Alloy Al6063 is heated to a temperature of 790°C to reach a complete liquid state. Then the temperature is lowered to 645°C, then the Si element is inserted into the heating furnace and stirred. Then the temperature is lowered to 615°C, then the Mg element is added, then stirred thoroughly by a mechanical stirrer. The rotational speed of the stirrer is 70 rpm and the stirring time is 240 seconds. Then heated to a pouring temperature of 670°C. The mold is heated to a temperature of 265°C. Then poured into the mold and pressed 7 MPa. After that, it was allowed to stand for 600 seconds, and then removed from the mould. The cast propeller shaft is cooled at room temperature. Then the propeller shaft was heat treated with a solution treatment temperature of 485°C for 3600 seconds and then quenched using a fluid. After that, the casting products were treated with artificial aging. The results of the study are, Porosity will decrease along with the addition of Silicon elements. The lowest porosity level is in addition of 3% wt Silicon that is equal to 1.15%. Tensile test with the addition of 1% wt Silicon ie, 106.882 MPa, in addition of 2% wt Silicon that is, 128.713 MPa, and in addition of 3% wt Silicon ie 132.668 MPa. So the highest tensile stress value is at 3% wt. Hardness values will increase with the addition of Silicon elements. The highest hardness value found in the variation of 3% wt Silicon ie, 69.9 HB. While in the variation (0, 1, 2% wt) that is, 43.75 HB, 51.24 HB and 56.45 HB. So this study, proving that the addition of silicon elements can improve the mechanical properties of the shaft propeller.

Keyword: Aluminum, Alloy, Magnesium, Silicon, Shaf propeller, Die casting.

1. Introduction

The propeller shaft is one of the most important parts of the ship propulsion installation. The engine rotation is transmitted to the propeller through a shaft which is hereinafter referred to as the propeller shaft. The propeller shaft is made in such a way that it can transfer power from the transmission to the propeller smoothly without being affected by rotational speed and load size. To produce a propeller shaft with good quality, the shaft propeller design must consider various parameters to produce a propeller shape, type and size that has a high value of effectiveness and efficiency. [1,2].

In selecting the material for the propeller shaft, it is certainly influenced by several aspects, one of which is the characteristics of the material. The material used must have good mechanical strength, in addition, the cost of the material and the machining process should be affordable. Currently the propeller shaft for large cargo ships is mostly made of medium carbon steel. [1,2,8]. The propeller shaft is usually made of steel, but in this study the propeller shaft model is made of Aluminum Alloy as the basic material. The material must have good mechanical properties and corrosion resistance. In this study, the physical and mechanical properties as well as the microstructure of the propeller shaft with the base material of aluminum alloy with the addition of silicon (Si) elements will be examined, through the High Pressure Die Casting process. Tests to be carried out include density, hardness, tensile strength tests [1,2,8]. The propeller shaft can be seen in Fig 1 below.

Figure 1. Shaft Propeller

The propeller shaft is usually made of steel, but in this study the propeller shaft model is made of Aluminum Alloy as the basic material. The material must have good mechanical properties and corrosion resistance. In this study, the physical and mechanical properties as well as the microstructure of the propeller shaft with the base material of aluminum alloy with the addition of silicon (Si) elements will be examined, through the High Pressure Die Casting process. Tests to be carried out include density, hardness, tensile strength tests.

2. Experimental Method

Metal casting with Die Casting method is a casting method by injecting liquid metal into the mold cavity with a certain speed and pressure. This casting process basically combines the casting process and the forging process due to pressure. The mold used is a permanent mold made of carbon steel. The influence of each of these parameters will affect the physical and mechanical properties of the object being casted [5,6]. The main base material used is 6063 aluminum alloy, with variations in the addition of Si elements (1, 2, 4 wt%). The addition of Mg can improve the mechanical properties of the casting. The following is Table 1. Composition of materials.

Table 1. Chemical composition of materials

Materials	Chemical composition (%)						
	Si	Mg	Al	Fe	Cu	Mn	Other

Al6063	0.387	0.515	98.50	0.370	0.064	0.0884	1.017
Si	99.94	0.002	-	0.004	-	0.003	0.014
Mg *(ingot)*	0.013	99.93	0.22	0.003	-	0.012	0.020

The first step is to prepare the materials used. These materials are cut and weighed according to the mixing weight ratio. The cutting and weighing processes are carried out to obtain the mixing composition settings. 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%)	Al 6063 (gram)	Si (gram)	Mg (gram)	Total (gram)
Al 6063 + Mg 2% + Si 0%	490	-	10	500
Al 6063 + Mg 2% + Si 1%	485	5	10	500
Al 6063 + Mg 2% + Si 2%	480	10	10	500
Al 6063 + Mg 2% + Si 4%	470	20	10	500

The next process melts the material into the heating furnace. Alloy Al6063 is heated to a temperature of 720°C to reach a complete liquid state. Then the temperature is lowered to 645°C, then the Silicon element is inserted into the heating furnace and stirred. Then the temperature is lowered to 615°C, then the Mg element is added, then stirred thoroughly by a mechanical stirrer. The rotational speed of the stirrer is 70 rpm and the stirring time is 240 seconds. Then heated to a pouring temperature of 680°C. The mold is heated to a temperature of 265°C. Then poured into the mold and pressed 7 MPa. After that, it was allowed to stand for 600 seconds, and then removed from the mould. The casting propeller shaft is cooled at room temperature. Then the propeller shaft was heat treated with a solution treatment temperature of 485°C for 3600 seconds and then quenched using a fluid. After that, the casting product was treated with artificial aging at a temperature of 150°C for 4 hours and then cooled [9,10]. The schematic display of die casting casting can be seen in Fig 2.

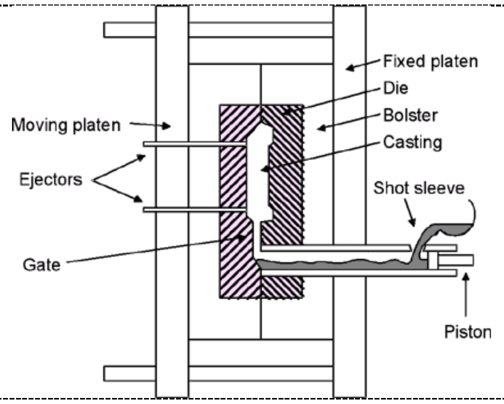

Figure 2. Die Casting Schematics.

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3. Results and Discussions

3.1. Density and Porosity

The results of density testing and porosity calculations of Al 6063 + Mg + Si are shown in Tables 3 and 4 below.

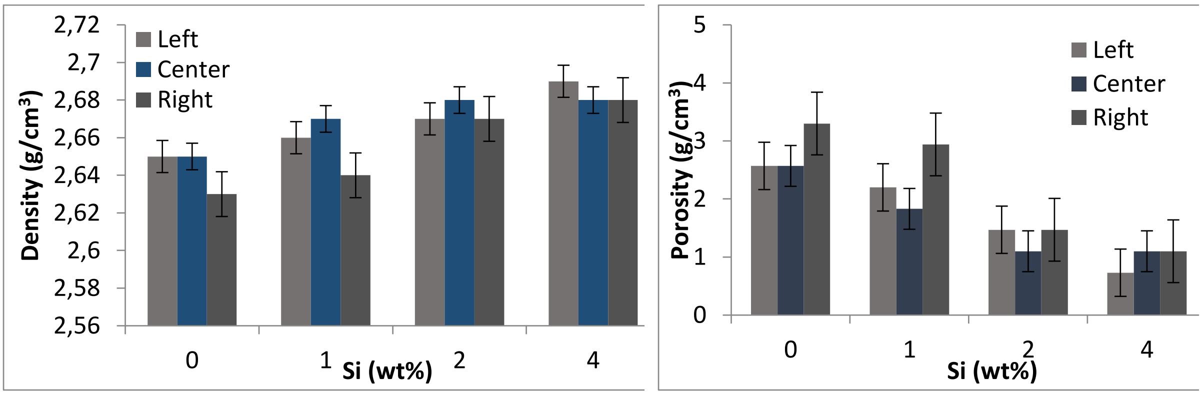
Table 3. Density at the top, middle, bottom of the casting

Materials	Mg wt%	Si wt%	Density (g/cm^3) Left	Center	Right	Average
Al 6063	2	0	2.65	2.65	2.63	2.64
Al 6063	2	1	2.66	2.67	2.64	2.64
Al 6063	2	2	2.67	2.68	2.67	2.67
Al 6063	2	4	2.69	2.68	2.68	2.68

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

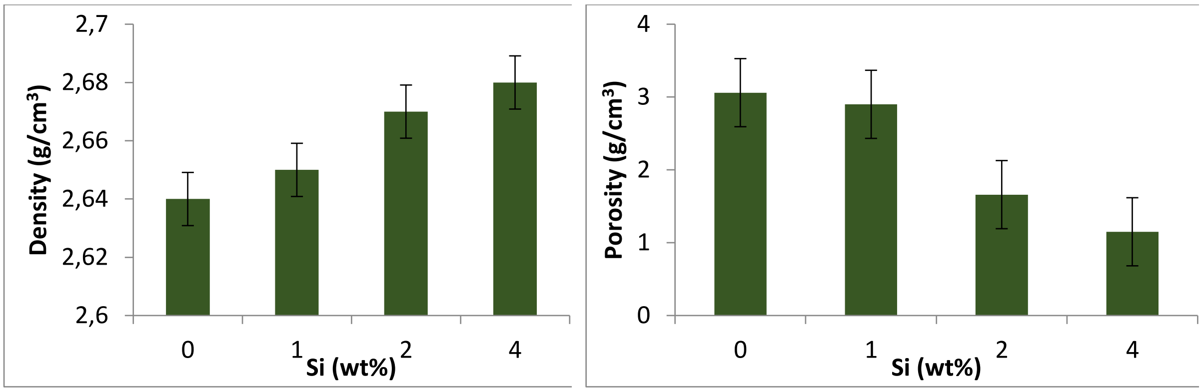
Materials	Mg wt%	Si wt%	Porosity (g/cm^3) Left	Center	Right	Average
Al 6063	2	0	2.57	2.57	3.30	3.06
Al 6063	2	1	2.20	1.83	2.94	2.90
Al 6063	2	2	1.47	1.10	1.47	1.66
Al 6063	2	4	0.73	1.10	1.10	1.15

The density and porosity graphs of the top, middle, and bottom castings of Al 6063 + Si are shown in Fig 3.



(a) (b)

Figure 3. Distributions Graph (a) density, (b) the level of porosity Al 6063 alloy



(a) (b)

Figure 4. Graph (a) density, (b) the level of porosity Al 6063 alloy

The results of the density and porosity test showed that the density with the largest value was found in the 3% Si variation of 2.69 g/cm3 and the smallest density was found in the 0% Si variation no 3 of 2.63 g/cm3. From the data obtained, it can be seen that the distribution of particles can be evenly distributed. Homogeneous is due to the casting method so that aluminum and silicon are evenly distributed and the amount of porosity in each variation has decreased.

3.2. Hardness Test

Hardness testing was carried out using the Rockwell Hardness Tester Model HR-150A using an F (HRF) scale, loading 60 kgf and using a 1/16" steel ball pendent. Then converted to Briell units (HB) following the ASTM E140-05 standard. The test is carried out on the center of the specimen from right to left as shown in Fig 5.

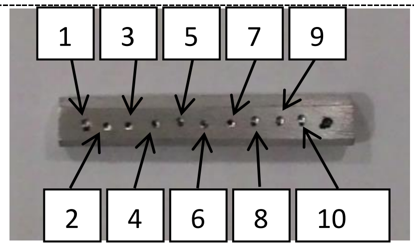


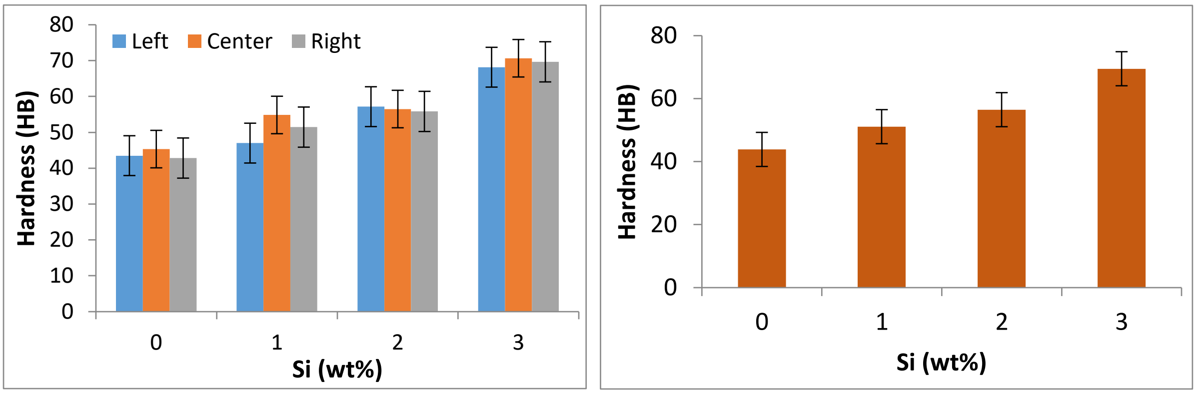
Figure 5. Hardness Testing Point On Specimen

The results of hardness testing on the propeller shaft can be seen in the table 5 below.

Table 5. Hardness values at the top, middle, battom of Al6063

Materials	Mg wt%	Si wt%	Hardness HB			Average
			Left	Center	Right	
Al 6063	2	0	43.50	45.33	42.83	43.88
Al 6063	2	1	47.00	54.84	51.46	51.10
Al 6063	2	2	57.16	56.50	55.83	56.49
Al 6063	2	4	68.16	70.66	69.66	69.49

The graph of the hardness of the upper, middle, and lower parts of the Al 6063 + Si casting is shown in Fig 6.



(a) (b)

Figure 6. Hardness Graph (a) Distributions, (b) The value average hardness Al 6063 alloy

Fig 6 shows that the highest value is shown in the variation of 4 wt% Si, which is 69.49 HB. And the smallest value is shown in the variation of 0 wt% Si, which is 43.88 HB. The hardness value obtained increases with the number of variations of Si given, this proves that the greater the weight percentage of Si, the greater the hardness value.

3.3. Tansile Test

The value of tensile strength and elongation of Al 6063 + Si alloy can be seen in Tables 6 and 7.

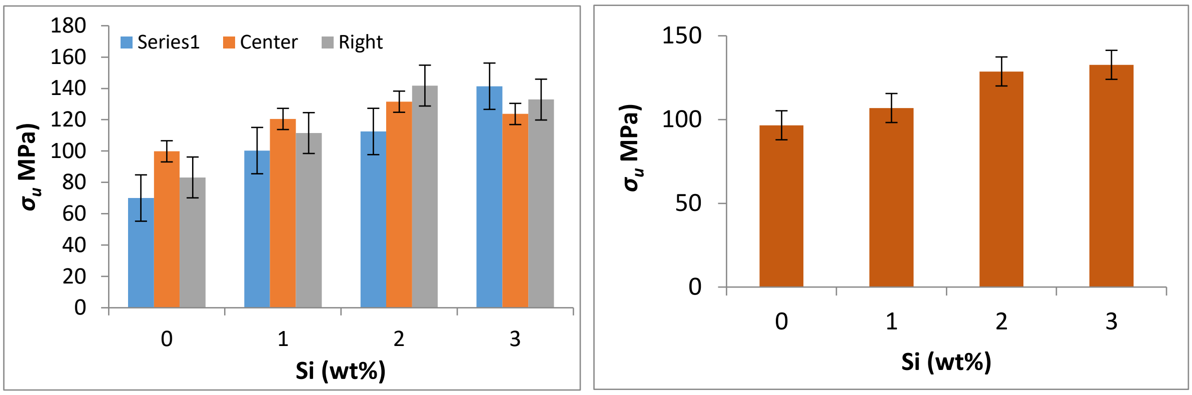
Table 6. Tensile strength values at the top, middle, battom of Al6063

Materials	Mg wt%	Si wt%	Tensile strength (MPa)			Average MPa
			Left	Center	Right	
Al 6063	2	0	70.03	136.54	83.18	96.58
Al 6063	2	1	100.30	120.50	99.83	106.88
Al 6063	2	2	112.50	131.51	141.79	128.71
Al 6063	2	4	141.39	123.68	132.86	132.66

Table 7. Elongation at the top, middle, battom of Al6063

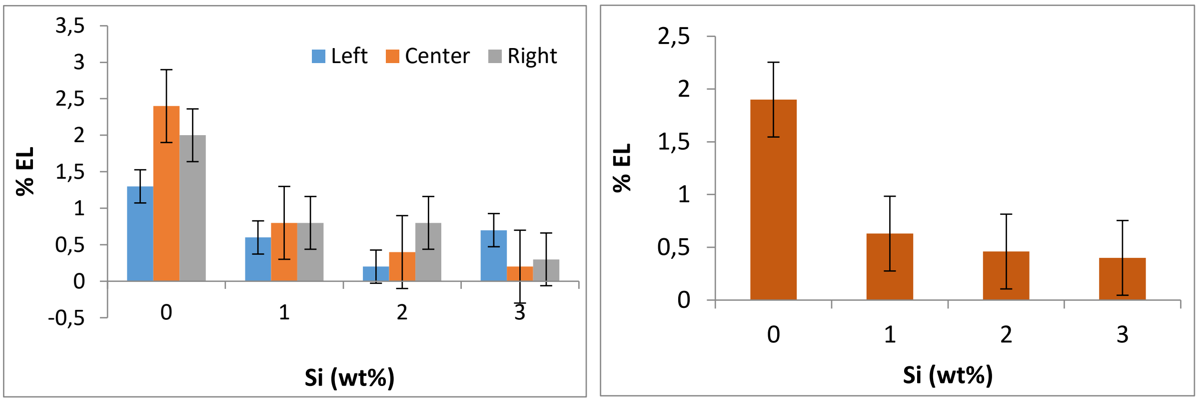
Materials	Mg wt%	Si wt%	Elongation (MPa)			Average MPa
			Left	Center	Right	
Al 6063	2	0	1.30	2.40	2.00	1.90
Al 6063	2	1	0.60	0.80	0.80	0.63
Al 6063	2	2	0.20	0.40	0.80	0.46
Al 6063	2	4	0.70	0.20	0.30	0.40

The graphs of the tensile strength and elongation of the top, middle, and bottom Al 6063 + Si castings are shown in Figs 7 and 8.



(a) (b)

Figure 7. Tensile strength Graph (a) Distributions, (b) The value average tensile strength Al 6063 alloy



(a) (b)

Figure 8. Elongation Graph (a) Distributions, (b) The value average elongation Al 6063 alloy

Fig 7 can be concluded that the tensile strength of the shaft propeller model specimen with 3 wt% Si variation has the highest tensile strength compared to 0 wt%, 1 wt% and 2 wt% Si variations. The shaft propeller model specimen with a variation of 0 wt% Si has a tensile strength of 96.58 MPa. Then, the tensile strength increased at a variation of 4 wt% Si to 132.66 MPa. The increase in the variation of the addition of silicon results in an increase in tensile strength, this happens because the more silicon will increase the fluidity of the casting, so that the casting quality will be better marked by a decrease in the porosity value of the casting. Fig 8 it can be concluded that the ductility of the shaft propeller model specimen decreased with the addition of the percent Si. This means that the greater the percentage of Si added, the ductility of the shaft propeller model specimen decreases or becomes more brittle. On the addition of Si, the variation of 4 wt% has the lowest ductility, which is 0.4%. Meanwhile, the shaft propeller model specimen without the addition of Si has the highest ductility, which is 2.56%.

4. Conclusion

The results of the study can be concluded as follows. Porosity will decrease with the addition of the element Si in the aluminum alloy. The lowest level of porosity is found in the addition of 3% Si, which is 1.15%. While the variations in the addition of 0%, 1%, and 2% were 3.06%, 2.90% and 1.66%. The tensile stress of aluminum at the addition of 1% Si is 106.882 MPa, at the addition of 2% Si it is 128.713 MPa and at the addition of 3% Si it is 132.668 MPa. Meanwhile, without the addition of Mg, it is 96.587 MPa. The hardness of aluminum will increase with the addition of the element Si. The highest hardness was found in the addition of 3% Si, which was 69.9 HB. While the variations in the addition of 0% , 1%, and 2% were 43.75 HB, 51.24 HB and 56.45 HB.

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