The Impact of Copper on the Mechanical Properties of Cast Motorcycle Cylinder Blocks

Salman[1*], Sinarep[2], Paryanto Dwi Setyawan[3], Hendry Sakke Tira[4], Muhammad Nur Mahadika[5]

[1,2,3,4,5]Departement of Mechanical Engineering, Faculty of Engineering, University of Mataram, Majapahit Street, No. 62, Mataram, Indonesia

***Email:** salman@unram.ac.id

Abstract

Enhancing the mechanical properties of cast products can be achieved by adding other elements. This research investigates the effect of copper (Cu) on the mechanical properties of cast motorcycle cylinder blocks, verified through microstructure analysis. Experiments were conducted by adding varying amounts of copper (Cu) at 5%, 10%, and 15%, with a casting temperature of 1010°C using a metal mold. Data collection included hardness testing, tensile strength testing, and microstructure analysis.The results showed that increasing the percentage of copper (Cu) in the cylinder block casting led to significant improvements in mechanical properties. The highest Vickers hardness was achieved with the addition of 15% Cu, measuring 229.23 HV. Similarly, the highest tensile strength was observed with the 15% Cu addition, reaching 104.218 MPa. Microstructure analysis revealed that the casting results predominantly consisted of α Al+θ ($CuAl_2$)+βSi phases, which were smaller compared to the α Al phase.

Keywords

Copper, Cylinder Blocks, Mechanical Properties, Microstructure

1. Introduction

The cylinder block is an integrated structure consisting of the cylinders of a reciprocating engine and some or all of the associated surrounding structures (cooling parts, intake and exhaust parts, joints, and the crankcase). The term engine block is often used in conjunction with "cylinder block" although technically a distinction can be made between monobloc engine cylinders as discrete units compared to block designs with more integration consisting of the crankcase as well.

The cylinder block is a static tool on a motorbike whose function is as a place for the piston to move in carrying out the motor's work process. Cylinder block and how to deal with cylinder block damage. 4 stroke motorbike cylinders do not have any holes in the cylinder wall. 2 stroke motorbike cylinders have holes in the inside of the cylinder wall. Damage that often occurs to the cylinder block is scratches/wear/enlargement of the cylinder hole, consequently this can result in the piston becoming damaged/crazy/loose in the cylinder.

The substantial problem in material development is determining the value of

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mechanical strength and physical properties of the material whether it is optimum in order to resistance to corrosion and wear can be achieved optimally. The development of the national material and metallurgy industry is also growing rapidly in Indonesia, for example, the national steel industry is also growing from year to year. In 2015 alone, there was an increase in national steel production capacity of up to 4 million tons. This continues to grow from year to year with the opening of several new factories such as PT. Krakatau Posco and others (Awali et al., 2018). The automotive industry is currently experiencing rapid development with the result components that have mechanical properties are needed to support quality vehicle product components (Fauzi et al., 2016).

The addition of copper (Cu) to the aluminum silicon alloy will make this alloy have a good response to heat treatment. Several researches had studied the presence of Cu to the aluminum alloys. Silva et al., (2008) analyzed the effect of casting A206 Al–Cu alloy in a mold that forces a solidification gradient to study its effect on the microstructure and solidification reactions taking place in the material. It was found that the temperatures for liquidus, solidus and solvus were affected by the solidification rate, although the two former ones to a lesser extent. Longfei et al., (2022) studied the distribution of microstructure, chemical composition, and hardness of Al-Cu-Mg alloy along the radial direction of casting. Sezonenko et al., (2024) analyzed composite material based on aluminum by additional pressure on the melt during crystallization, its structure and properties were studied. It is shown that in terms of properties the obtained alloys can compete with modern industrial foundry alloys. Zhan et al., (2023) observed the Mg and Cu additions for a new Al-Si-Cr type die casting alloy to achieve the desired tensile properties without using T7 heat treatment. It was found that Cu addition should be avoided, as it is not effective in enhancing strength while degrading tensile ductility. Mg addition is very effective in improving strength and has minor impact on tensile ductility.

Zhou et al., (2023) investigated the microstructures and mechanical properties of Al-9Si-0.5Mg-xCu alloys to elucidate the effect of Cu content on the evolution of their mechanical properties. It was found that the increase of Cu level results in difference of the type, number density, and morphology of the nanoscale precipitated phase. Mathias and Salar (2020) evaluated the alloys based on the characterization of their mechanical properties and the analysis of their microstructures. It was found that the application of a modified heat treatment method clearly show the potential of AlZnMg(Cu) die-cast alloys for future industrial use.

The addition of copper to the aluminum silicon alloy can provide hardness when hot. Aluminum alloys containing copper elements above their solubility limit will combine with aluminum to form hard and brittle CuAl2 deposits. After heat treatment, this property will become ductile and not brittle, this is because the CuAl2 deposits will dissolve when the heat treatment temperature is reached and will re-form more homogeneous and more even properties during cooling (Setyawan, 2006). The increasing need for components and material parts therefore that used cylinder blocks are recycled with the addition of copper variations using metal casting methods to improve characteristics and quality. Quality is a problem that is very important in the production process, process and development of a component. To produce good cast products, everything must be planned and carried out carefully in such a manner it can predict various quality conditions.

2. Methodology

Cylinder casting at a temperature of 1010°C for 1 hour 30 minutes (90 minutes), with copper variations of 5%, 10%, 15% and cylinder block variations of 85%, 90%, 95%. After casting, it was then cooled with air cooling. Experimental by testing the same specimen, namely the differences in specimen testing on surface hardness, tensile strength and microstructure.

Analyze the research data carried out in the laboratory by considering existing research.

Preparation of Media and Metal Casting Test Objects

- The casting media used in this study was a solid medium, with a predetermined composition as determined in the problem limitations.
- Cylinder blocks were collected as needed and cut.
- Copper was collected and cleaned and then cut.
- Making tensile test specimens with ASTM E8-E8M and hardness test specimens with ASTM E92-17 standards.

Preparation Before Metal Casting

- The cast sample was cleaned of dust and rust.
- Preparation of metal casting media includes weighing the cylinder block and copper with a weight or mass fraction divided into 5%, 10%, 15% copper with 85%, 90%, 95% cylinder block.
- In crucible the composition started from mixing the cylinder block and copper.
- The sample that had been placed into a crucible with a capacity of 10 kg with a thickness of 2 cm.
- After everything was ready, it was then heated in a heating furnace.

In this study, the specimen testing process carried out was surface hardness testing using the Vickers method, tensile strength testing and microstructure observation.

3. Result and Discussion

Variations	*P* (kg)	d_1 (mm)	d_2 (mm)	Hardness (HV) (kg/mm²)	Average of hardness (kg/mm²)
		0,97	0,97	118,32	
		0, 97	0,98	117,11	117,11
100% *Cylinder Block* 0% Cu	60	0,98	0,98	115,91	
		0,97	0,98	117,11	
		0,98	0,97	117,11	147,10
		0,88	0,87	145,40	
		0,87	0,88	145,40	
95% *Cylinder Block* 5% Cu	60	0,87	0,87	147,08	
		0,88	0,86	147,08	
		0,86	0,86	150,52	179,75
		0,78	0,79	180,65	
		0,79	0,78	180,65	
90% *Cylinder Block* 10% Cu	60	0,80	0,79	176,14	
		0,78	0,79	180,65	
		0,79	0,78	180,65	229,23
		0,70	0,69	230,47	
85% *Cylinder Block* 15% Cu	60	0,69	0,70	230,47	
		0,70	0,71	223,98	

	0,71	0,70	223,98	225,87
	0,68	0,69	237,25	

Table 1. The average of hardness of cylinder block with varied percentage of Cu.

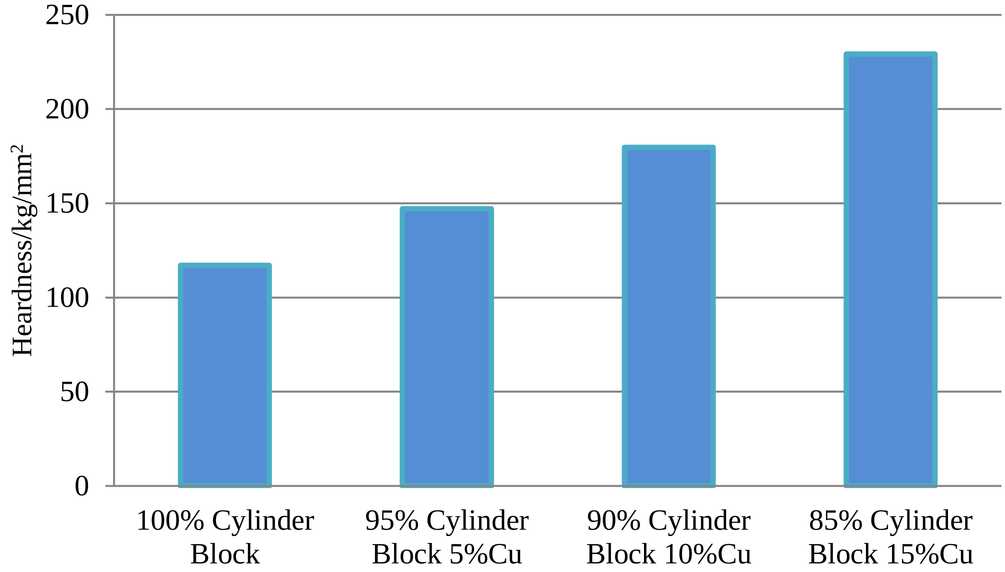

Figure 1. The values of hardness of cylinder block regarding to Cu percentage.

Table 1 and Figure 1 show the average hardness above shows that the highest hardness value is in the variation of Cu addition of 15%- and 85%-cylinder block with a hardness value of 229.23 kg/mm^2. And the lowest hardness value is without a mixture of Cu which is 100%-cylinder block with a hardness value of 117.11 kg/mm^2, in this way it can be concluded that the more variations of Cu are varied, the higher the hardness value on the surface obtained.

Table 2. The Tensile Strength, Strain and Elastic Modulus of Varied Speciments.

Variations	Experiments	F (N)	A_0 (mm^2)	σ (MPa)	L_0 (mm)	ΔL (mm)	$\mathcal{E}$ (%)	E (MPa)
100% *Cylinder Block* 0% Cu	1	1499,2	36	41,6	40	0,6196	1,549	5339,2
	2	1120,8	36	35,5	40	0,4843	0,983	4098,2
	3	1576,5	36	43,8	40	0,6284	1,760	5088,3
	Average	1498,8	36	41,6	40	0,6108	1,551	5208,7
95% *Cylinder Block* 5% Cu	1	1944,8	36	54,0	40	1,1388	2,847	4574,6
	2	1998,2	36	55,5	40	1,2540	3,135	4495,1
	3	2002,6	36	55,6	40	1,3356	3,339	4379,4
	Average	1981,8	36	55,1	40	1,2428	3,107	4483,0
90% *Cylinder Block* 10% Cu	1	3107,9	36	86,3	40	1,1997	2,999	3325,9
	2	3069,3	36	85,3	40	1,1027	2,702	3245,3
	3	3221,2	36	89,5	40	1,2056	3,014	3185,7
	Average	3132,8	36	87,0	40	1,1693	2,905	3252,3
85% *Cylinder Block* 0% Cu	1	3358,2	36	90,7	40	1,2450	3,180	3104,2
	2	3274,5	36	91,0	40	1,2347	3,025	3256,4
	3	3491,1	36	97,0	40	1,2721	3,327	3178,5
	Average	3374,6	36	92,9	40	1,2506	3,177	3179,7

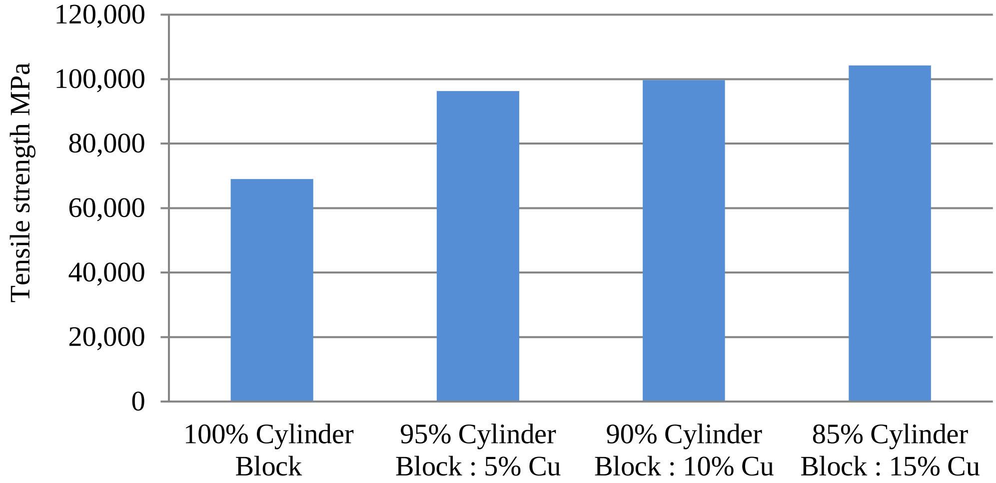

Figure 2. The tensile strength regarding to the percentage of Cu.

Table 2 and Figure 2 show the lowest tensile strength value is in 100%-cylinder block which is 66.658 MPa, while the highest tensile strength is shown in the variation of Cu addition of 15%- and 85%-cylinder block, namely the tensile strength is 104.218 MPa. Therefore, it can be concluded that the higher the variation of Cu given, the higher the tensile strength value.

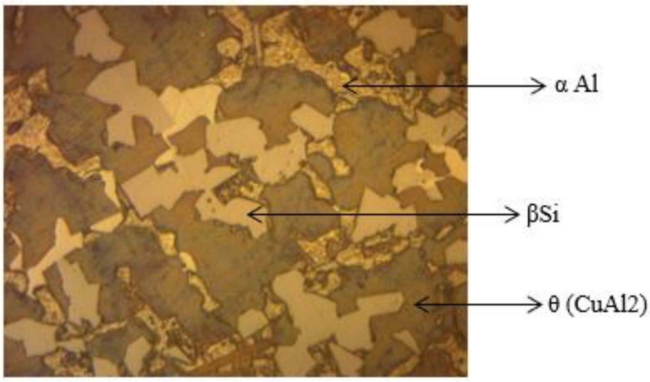

Figure 3. Microstructure of α Al+θ ($CuAl_2$)+βSi 15% Cu 400x Magnification.

The addition of Cu can be seen that the chemical composition as shown in Figure 3 is α Al+θ ($CuAl_2$) + βSi. By using 400x magnification the microstructure shows the presence of the α Al + βSi phase, the dark brown and square-shaped is βSi and the light brown is α Al, in this content aluminum is the main ingredient and βSi is an alloy material with a percentage value of βSi of 14.3%, in this observation where α Al is greater than βSi.

The presence of α Al+θ ($CuAl_2$)+βSi phase, that the golden yellow one is α Al, and the brown one is θ ($CuAl_2$) and the gray one is βSi, in this content α Al is the main material, θ ($CuAl_2$) and βSi are alloy materials with a percentage value of ($CuAl_2$) of 17.7% and βSi 14.3%, in this observation where α Al is greater than θ ($CuAl_2$) + βSi. The boiling point of α Al+Cu occurs at a temperature of 660.452^{o}C when the temperature is lowered below the solidus line of 548^{o}C then the liquid phase will change into a solid phase, the reaction that occurs is L α+ θ, where L is the liquid phase, α is the aluminum phase and θ is the copper phase. Observations and analysis carried out that the greater the variation of copper addition to the casting increases the hardness properties and is proportional to the tensile strength.

The results are compatible with the previous researches such as by Zhan et al., (2023), Zhou et al., (2023), and Mathias and Salar (2020) particularly in explaining the presence of Cu in optimizing the strength of alloys. Nevertheless, the novelty in this study is the difference in the phase reaction effect with the increasing variation of copper addition, where in this observation the content of the α Al+θ ($CuAl_2$)+βSi phase is obtained.

4. Conclusions

The higher the Cu content in the cylinder block casting, the greater the hardness value. The highest hardness was obtained with the addition of 15% Cu, achieving a value of 229.23 HV. Similarly, the tensile strength increased with higher Cu content, reaching a maximum of 104.218 MPa with 15% Cu. Microstructure analysis revealed that with increasing Cu content, the hardness and tensile strength of the cylinder block improved. The observed phases through microscopy included α Al+θ ($CuAl_2$) + βSi, indicating a well-mixed material composition.

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