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EXAMINATION OF WEAR RESISTANCE AND MICROSTRUCTURAL CHARACTERISTICS RESULTING FROM THE INCLUSION OF SIC IN CYLINDER BLOCK CASTINGS

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ABSTRACT

Casting of cylinder block metal with SiC is a material manufacturing process by melting metal at a certain temperature. The purpose of this process is to increase the wear resistance of the specimen surface. In this study, the addition of SiC into melted cylinder block was carried out in furnace with temperature of 1012°C by varying the mixture percentages: pure cylinder block (without mixture), 95%-cylinder block with 5% SiC, 90%-cylinder block with 10% SiC, 85%-cylinder block with 15% SiC. As the result the lowest rate of weight loss was obtained in the variation of the cylinder block mixture of 85% with 15% SiC with an average weight loss value of 0.020 gr. The lowest wear volume was obtained in the variation of the cylinder block mixture of 85% with 15% SiC with an average wear volume value of 0.006 m3, and the lowest wear rate was obtained in the variation of the cylinder block mixture of 85% with 15% SiC with an average wear rate value of 2.23 x 10-6 m3/s. From test it iwas obtained that SiC can improve the wear resistance of cylinder blocks due to its superior physical and mechanical properties. Its extremely high hardness makes the surface more resistant to scratches, abrasion, and repeated friction that typically occur between the piston and cylinder wall. From microstructure observations, in pure block specimens there were α Al and β Si structures, while for SiC it was only found in specimens with variations that had been added with SiC mixture. Chemical composition tests of pure block specimens and cylinder blocks with SiC mixture that had been carried out shown an increase in mass and atoms for the Si element.

INTRODUCTION

The metal casting industry has grown along with the development of casting techniques and methods and various models of cast products that have flooded the domestic market. Cast products are widely used in everyday life, from household furniture, automotive components, water pumps to ship propellers. The market demand for prospective and broad cast metal products is not balanced with an increase in product quality (Slamet et al., 2010).

Metal casting is very important in supporting industrial development in the world. To reduce the entry of imported goods into the country, large-scale and small-scale products can be developed through the metal smelting process itself. The most commonly found metal waste is iron, steel, and aluminum waste because these types of metals are widely used by humans. Metals are very possible to be recycled. Scrap metal is collected and then converted into new quality materials in smelting. Scrap metal collected for recycling is material that does not have to be managed as waste. This is a valuable resource that is converted into added value (Tan et al., 2021).

The metal casting used is permanent casting, where permanent casting is the process of pouring metal using a metal mold. This mold is usually made of steel/cast iron. The mold cavity has a gating system. The gating system is a channel where the molten metal flows into the die cavity which aims to ensure smooth and complete flow from the ladle to the mold cavity. Metals commonly used in the casting process with this mold include aluminum, magnesium, copper alloys, and cast iron (Iqbal, 2014). Permanent molds are not used for metals with very high liquid temperatures because the mold is not made of refractory material. In general, if motorbike experiences scratches on the piston which eventually causes smoke on your motorbike, it can be overcome by boring and replacing the piston with a larger diameter, unlike some types of Yamaha motorbikes, for instance. Some motorbikes cannot be bored on the motorbike when there are obstacles so that they have an impact on the amount of cylinder block waste in workshops or homes. The Yamaha cylinder block liner material is usually called Diasil (Die Casting Aluminum Silicon), which is a liner made from an alloy of aluminum and silicon (Eze et al., 2022).

The result of metal casting is the new metal compound with different new unique mechanical properties such wear resistance. Wear resistance is an important material mechanical properties characteristic, which depends on the hardness and fracture toughness (Evans et al., 1976) and (Białobrzeska et al., 2023). To have the more reliable data, as in the case of hardness, the wear-resistance studies for novel superhard and ultrahard materials were conducted in comparison with known materials (Popov et al., 2014) and (Blank et al., 2002). Wear resistance was determined from the wear tracks made by a rotating brass disc with diamond powder (Xiangjun et al., 2024), (Sulima et al., 2024) and (Victor et al., 2015).

Wear refers to the degradation and displacement of the contact surface of a material during interaction, which significantly contributes to the reduction of a machine's service life and results in economic losses (Hutchings et al., 2006) and (Findik, 2014). Based on the characteristics of surface damage, wear can be categorized into several types: abrasive wear, adhesive wear, fatigue wear, and corrosion wear. The mechanisms of wear are closely linked to the properties of the materials involved and the conditions of contact, such as load, speed, temperature, and lubrication (Benarbia et al., 2024) and (Jiang et al., 2023). In industrial applications, research on wear primarily focuses on components produced through conventional manufacturing techniques. Prior to the application of parts created through direct metal laser sintering in industrial settings, extensive investigation into their wear mechanisms is essential. Furthermore, wear in orthopedic implants poses significant challenges for replacement, making it a critical area of research within the biomedical field. Nevertheless, there is a scarcity of studies addressing the friction and wear characteristics of parts produced by powder bed fusion methods. This is largely due to the fact that method components are typically utilized as structural elements, where enhancing material density and strength takes precedence over minimizing wear. Additionally, wear resistance does not necessarily correlate with the density of the component. Ultimately, wear resistance is more influenced by the specific application and material properties than by density alone.

Several researchers have attempted to improve the mechanical strength properties of metal materials particularly wear resistance by adding certain metal alloy elements or compounds. Silicon carbide (SiC) for instance is one of compound which was added to the casting metal.

The SiC is a type of ceramic material with characteristics such as good mechanical, chemical and thermal conductivity resistance, making it widely applied in various applications. Silicon carbide has several advantages such as having very good properties, being able to conduct heat and electricity well, and being strong against oxidation. Silicon carbide has superior characteristics, namely: anti-oxidation, high hardness, good mechanical strength, good elastic modulus, anti-erosion, and light density. The ability of SiC to resist corrosion can be seen through the presence of coal ash, acid slag and neutral slag when this material is used. Silicon Carbide is classified as a hard and strong material against abrasives, SiC raw material is relatively friendly, and can be formed into something diverse, which can be done with a conventional fabrication process.

Due to the important role of SiC in metal alloys, Liu et al. (2023) demonstrated the direct correlation of microstructure and content of SiC with the performance parameters of SiC ceramics. How silicon carbide (SiC) reinforcement affected the microstructure and wear properties of Mo5SiB2-based alloy was investigated by Islak et al. (2024) fabricated by powder metallurgy. The results assessed the wear performance of the samples that indicated the wear performance SiC-reinforced sample with a coefficient of friction and wear rate values. The SiC was also used as filler material. Sridhar et al. (2019) study of the effect of SiC as filler material on the banana carbon fibers reinforced hybrid composites. The results mechanical properties like tensile, flexural, impact and hardness are improved by the addition of the SiC to the banana carbon fiber composite laminate.

Therefore, further research is needed to analyze the effect of adding SiC to used cylinder blocks on surface wear, chemical composition, and microstructure observations.

EXPERIMENTAL METHOD

Experiments conducted different tests on the same types of specimens namely, chemical composition testing, wear test and microscopic test. Data analysis analyzed data from experiments and research carried out in the laboratory.

1. Tools

The tools and materials were used in this study are as follows the melting furnace was used to heat raw materials used to make metal casting needs. Crucible is used to melt metal that is resistant to a certain temperature so that the metal casting process can run. Pliers were used to clamp and hold the crucible during melting. Digital scales were used to weigh silicon and cast-iron materials that are ready to be mixed. Molds are used to print specimens that have been melted so that the specimens are neatly shaped as desired. Tachometer used to measure rotation on the wear test tool. Thermometer used to measure the temperature of the melting furnace.
SEM

2. Materials

The used materials were:

a. Cylinder block is the main material that will be mixed with silicon in this study.
b. Silicon carbide is a ceramic material that has high hardness (Sharma et al., 2024).

3. Experimental Procedure

The stages of testing were as follows:

a. Preparation of media

The media used in this study is a solid medium, with a predetermined composition as determined in the problem limitations. The cast iron is cleaned and then cut according to needs.

SiC powder and iron block pieces are weighed according to variation. Making wear test specimens and SEM test specimens.

b. Preparation before metal casting

Preparation of metal casting media includes weighing the cylinder block and silicon carbide powder with weights divided into 0%, 5%, 10%, and 15% Silicon, 100%, 95%, 90%- and 85%-Cylinder block. In the furnace, the arrangement starts from mixing the cylinder block and silicon. The sample that has been placed in the crucible with a capacity of 5 kg with a thickness of 2 cm. After everything is ready, it is then heated in the heating furnace.

c. Wear testing

Figure 1. Wear resting tool.

d. The wear test tool consists of several components, including a frame, a single-phase AC motor, a load, a specimen holder, and a 20 cm diameter disc (see Figure 1).

e. SEM testing

SEM testing is used to determine the micro image of the specimen surface. The SEM machine used is the Hitachi Tabletop Microscope TM3000. The resolution displayed is higher than an optical microscope, namely 15-30,000 times to the depth of penetration, has a size that is not too large and does not take up much space, only this tool must be placed in a room with a temperature between 15 – 30^{o}C.

The steps of SEM testing are conducted by placing material on the stand and measure its height, so that it does not hit the optics when inserted into the SEM tester.

4. Data Analysis

The data analysis is stage to find the variables of the wear test which are calculated by:

a. Weight loss (ΔW) is expressed by the difference between the initial weight of specimen (W_0) compared with the specimen after (W_1) (Hutching et al., 2006).

b.
$$\Delta W = W_0 - W_1 \quad (1)$$

c. Wear volume (Vw) is shown by the ratio between ΔW and mass density of specimen (ρ):
$$V_w = \frac{\Delta W}{\rho} \quad (2)$$

d. Wear rate ($\bar{v}$) is expressed as the ratio between (V_w) and time (t):
$$\bar{v} = \frac{V_w}{t} \quad (3)$$

5. Statistical Analysis

Statistical analysis in this study focuses on the wear test of each mixture variation, where the wear test is carried out to determine the wear value of the material in each variation of the specimen mixture. The analysis of variance used in this study is one-way ANOVA which aims to compare more than two averages. While its use is to test the ability of generalization. The meaning of the significance of the research results. If proven different, it means that the sample data is considered to be able to represent the population. ANOVA is better known as the F_{test} (Fisher Test), while the meaning of variation or variant originates from the concept of "Mean Square" or mean square (KR), the systematic formula: Determining the testing criteria: if $F_{count} \geq F_{table}$, then reject H_0, meaning it is significant.

RESULTS AND DISCUSSION

Table 1. Results of wear test data analysis.

No	SiC Variation %	ρ (gr/ml)	t	W_0 (gr)	W_1 (gr)	ΔW (gr)	$\overline{\Delta W}$ (gr)	n (rpm)	r (cm)	K (m^3)	C $n\,t$	V (m^3)	$\bar{V}$ (m^3)	S mm	v_w x 10^{-5} (m^3/s)	$\bar{v}$ x 10^{-5} (m^3/s)
1		2,93	300	17,6249	17,5933	0,032		210	7	44	63.000	0,010		2772	3,3	
2		2,72	300	16,3880	16,3340	0,054	0,041	210	7	44	63.000	0,019		2772	6,33	
3	0	2,44	300	14,7051	14,6674	0,038		210	7	44	63.000	0,015	0,014	2772	5	4,876
1		2,63	300	15,8353	15,8073	0,028		210	7	44	63.000	0,010		2772	3,3	
2		2,39	300	14,4275	14,3977	0,030	0,027	210	7	44	63.000	0,012		2772	4	
3	5	2,00	300	12,0485	12,0246	0,024		210	7	44	63.000	0,012	0,011	2772	4	3,766
1		3,70	300	14,8361	14,8138	0,022		210	7	44	63.000	0,005		2772	1,66	
2		2,87	300	14,3766	14,3560	0,021	0,022	210	7	44	63.000	0,007		2772	2,33	
3	10	2,32	300	13,9457	13,9229	0,023		210	7	44	63.000	0,009	0,007	2772	3	2,33
1		3,23	300	16,2013	16,1815	0,020		210	7	44	63.000	0,006		2772	2	
2		2,85	300	17,1775	17,1563	0,021	0,020	210	7	44	63.000	0,007		2772	2,33	
3	15	2,86	300	14,3471	14,3273	0,020		210	7	44	63.000	0,006	0,006	2772	2	2,11

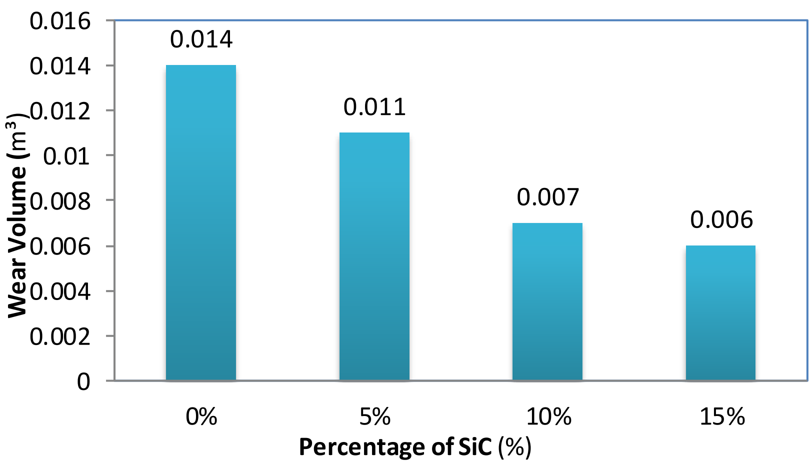

Figure 2. Material wear volume

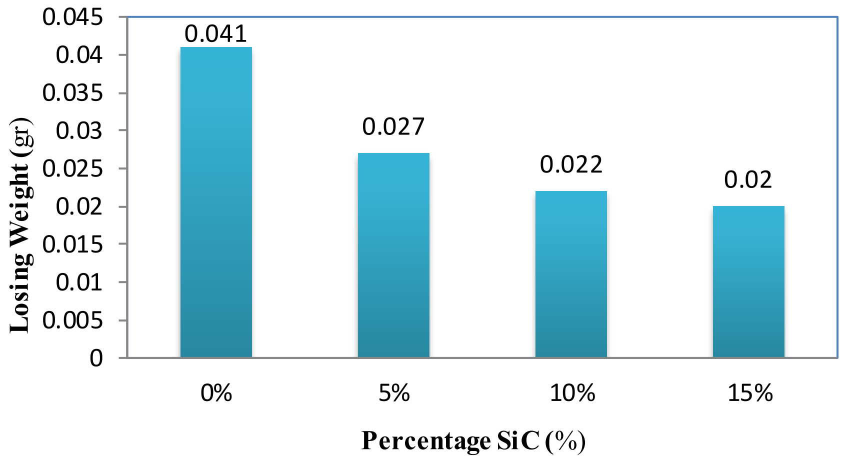

Figure 3. Losing weight

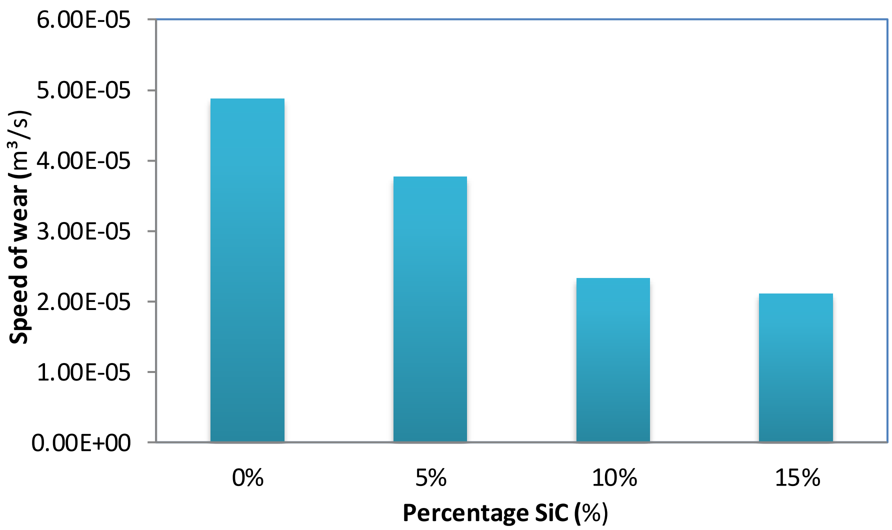

Figure 4. Material wear rate

The wear volume was obtained on each specimen variation is different depends on the percentage of SiC, as shown in Fig. 2. In the first variation (100%-cylinder block and 0% SiC/pure block without mixture) is 0.014 m^3. The second variation with a mixture (95%-cylinder block and 5% SiC) is 0.011 m^3. The third variation with a mixture (90%-cylinder block and 10% SiC) is 0.007 m^3. The fourth variation with a mixture (85%-cylinder block and 15% SiC) is 0.006 m^3. The specimens with mixture variation of 100%-cylinder block and 0% SiC (pure block without mixture) have the highest wear volume with a value of 0.014 m^3. The lowest wear volume value is shown in the variation with a mixture of 85%-cylinder block and 15% SiC with a value of 0.006 m^3.

The weight loss was obtained on each specimen variation is different depends on the SiC ingredient as well as shown in Fig. 3. Where in the first variation (100%-cylinder block and 0% SiC / pure block without mixture) is 0.041 gr. The second variation with a mixture (95%-cylinder block and 5% SiC) is 0.027 gr. The third variation with a mixture (90%-cylinder

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Table 2. Table of wear values with one-way ANOVA.

SiC Variation %	ΔW	V	$\bar{v}$ x 10^{-5}
	0,032	0,010	3,30
0	0,054	0,019	6,33
	0,038	0,015	5,00
	0,028	0,010	3,30
5	0,030	0,012	4,00
	0,024	0,012	4,00
	0,022	0,005	1,66
10	0,021	0,007	2,33
	0,023	0,009	3,00
	0,020	0,006	2,00
15	0,021	0,007	2,33
	0,020	0,006	2,00

block and 10% SiC) is 0.022 gr. The fourth variation with a mixture (85%-cylinder block and 15% SiC) is 0.020 gr. The specimens with mixture variation of 100%-cylinder block and 0% SiC (pure block without mixture) have the highest weight loss value with a value of 0.041 gr. Whereas the lowest weight loss value is shown in the variation with a mixture of 85%-cylinder block and 15% SiC with a value of 0.020 gr.
The wear rate was obtained in each different specimen variation, also depends on the percentage of SiC as shown in Fig. 4. Where in the first variation (100%-cylinder block and 0% SiC / pure block without mixture) is 4.876 x 10^{-5} m^3/ s. The second variation with a mixture (95%-cylinder block and 5% SiC) is 3.766 x 10^{-5} m^3/s.

The third variation with a mixture (85%-cylinder block and 15% SiC) is 2.11 x 10^{-5} m^3/s. It shows that specimens with mixture variation of 100%-cylinder block and 0% SiC (pure block without mixture) have the highest wear rate value with a value of 4.876 x 10^{-5} m^3/s. and the lowest wear rate value is shown in the variation with a mixture of 85%-cylinder block and 15% SiC with a value of 2.11 x 10^{-5} m^3/s.

Based on the results of observations and data analysis (see Table 1) for the wear test above, it can be concluded that the higher the mixture of SiC in the metal casting process with a cylinder block, the lower the wear value obtained by the material.

In Sharma et al., (2024) research on the Characteristics of AC8H/SiC Aluminum Composites with the Stir Casting Process, it shows that with the addition of 5%, 10%, and 15% SiC reinforcement to the Al/SiC composite in as-cast conditions, the wear rate values are 3.24E-06, 2.14E-06 and 1.99E-06, respectively. Meanwhile, after undergoing the T6 treatment process, the wear rate value decreased to 2.16E-06, 2.08E-06, and 1.77E-06 for the addition of reinforcement of 5%, 10% and 15% wt. The higher the reinforcement content in the composite, the lower the wear rate value of the material. Similar research has also been conducted by Dagale et al., (2023) with the result that the wear rate of aluminum composites decreased along with the addition of the weight fraction of SiC reinforcement. However, this wear rate value has a certain limit in relation to the clustering and interface of SiC in the composite, which is actually the addition of SiC continues to be carried out, the wear rate value actually increases.

For the analysis with one-way ANOVA that has been carried out on the wear rate and wear volume values, it can be concluded that $F_{count} > F_{table}$, therefor H_0 is rejected and H_1 is accepted, which means that there is a significant effect on each variation of the SiC mixture on the wear volume and wear rate (see Table 2).

1. Chemical Composition Test Results

Chemical composition testing was carried out on the surface of the specimen, the specimens that were tested for chemical composition were specimens with variations of pure block mixtures without mixture (Table 3), 95%-cylinder block with 5% SiC (Table 4), 90%-cylinder block with 10% SiC, and 85%-cylinder block mixture specimens with 15% SiC.

Table 3. Results of chemical composition tests of pure block specimens without mixture.

Display	Standard	Quantification	Result
SiC_0%	Standardless	ZAF	Metal
Element	Line	Mass%	Atom%
C	K	2.20±0.12	4.98±0.28
Mg	K	0.28±0.02	0.32±0.02
Al	K	70.19±0.26	70.68±0.26
Si	K	22.80±0.22	22.05±0.21
Fe	K	0.52±0.06	0.25±0.03
Cu	K	4.00±0.23	1.71±0.10
Total		100.00	100.00
SiC_0%		Fitting ratio 0.0070	

Table 4. The results of the chemical composition test of the specimen with a mixture of 95% cylinder block and 5% SiC.

Display	Standard	Quantification	Result
SiC_0%	Standardless	ZAF	Metal
Element	Line	Mass, %	Atom, %
C	K	2.64±0.14	5.94±0.30
Mg	K	0.18±0.02	0.20±0.02
Al	K	61.61±0.24	61.69±0.24
Si	K	31.69±0.24	30.49±0.23
Fe	K	0.54±0.06	0.26±0.03
Cu	K	3.34±0.21	1.42±0.09
Total		100.00	100.00
SiC_0%		Fitting ratio 0.0069	

2. Microstructure Observation Results

Microstructure testing was carried out on the surface of the specimen, microstructure testing was carried out to determine the microstructure of the pure block melting specimen (without SiC mixture), variations of 95%-cylinder block mixture with 15% SiC, variations of 90%-cylinder block mixture with 10% SiC and variations of 85%-cylinder block mixture with 15% SiC (see Fig. 5).

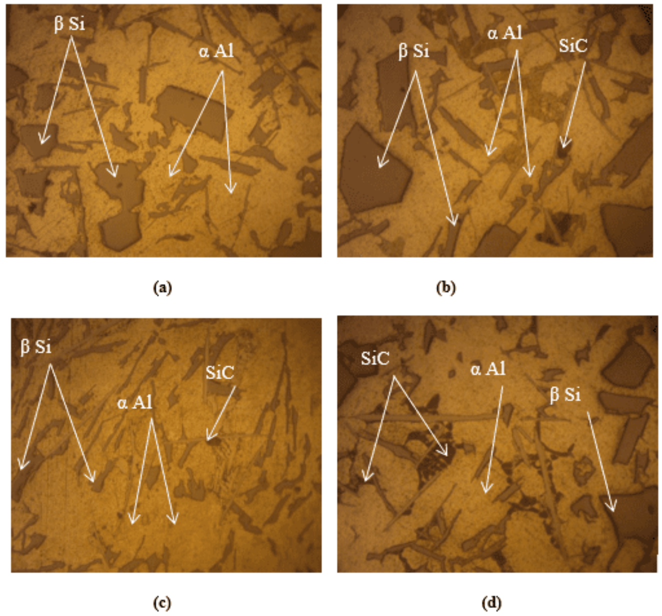

Figure 5. Microstructure photos of (a) pure block specimens without mixture (b) variation of 95%-cylinder block specimens with 5% SiC (c) variation of 90%-cylinder block specimens with 10% SiC (d) variation of 85%-cylinder block specimens with 15% SiC.

There are two areas that can be distinguished by dark and light colors. For the light-colored area represents the α Al structure while for the dark colored structure represents the β Si structure, with the α Al structure more dominant than the β Si structure with a larger α Al size and small β Si. Microstructure in the specimen variation of the mixture of 95%-cylinder blocks with 5% SiC is dominated by α Al with a large shape and a little β Si with a random shape and SiC appears with a smaller size. In the variation of the specimen mixture of 90%-cylinder blocks with 10% SiC α Al with a large shape and β Si with a random shape and SiC appears with a smaller and smaller size.

CONCLUSION

Variation of pure cylinder block specimens (without SiC mixture) from metal casting results obtained the highest wear volume value with an average of 0.014 m^3. While the lowest wear volume value from the specimen variation with a mixture (85%-cylinder block and 15% SiC) with an average wear volume value of 0.006 m^3. Highest weight loss was obtained in metal casting with pure block specimen variations (without mixture) with an average value of 0.041 gr. While the lowest weight loss value was obtained in the specimen variation with a mixture (85%-cylinder block and 15% SiC) with an average weight loss value of 0.020 gr. Highest wear rate was obtained in the pure block specimen variation (without mixture) with an average value of 4.876 x 10^{-5} m^3/s. while the lowest wear rate value was obtained in the specimen variation with a mixture (85%-cylinder block and 15% SiC) with an average wear rate value of 2.11 x 10^{-5} m^3/s. The higher the SiC mixture in the metal casting process with the cylinder block, the lower the wear value obtained by the material.

The results of testing the chemical composition of metal casting with variations of pure block specimens without mixture and variations of mixed specimens (95% pure block with 5% SiC, 90% pure block with 10% SiC and 85% pure block with 15% SiC) show an increase in chemical composition with each addition of SiC in the metal casting process of the cylinder block. The results of microstructure observations show that the specimen is dominated by the α Al and β Si structures and the appearance of SiC is slightly seen in the variation with the addition of SiC.

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