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Surface characterization of the ceramic coating process on aluminum matrix composite reinforced particulate

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Abstract. Particulate-reinforced aluminum matrix composite for automotive components are developed since they have light density, high strength, and hardness, wear-resistant properties also low heat expansion coefficient compared to ferrous metals. An important factor that influences the composite characteristics is the condition of the interface area between the particle and the aluminum matrix with optimal wettability and minimal cavity defects. This research aims to improve hardness on particulate-reinforced aluminum composite which produces by a squeeze casting manufacturing process and ceramic coating process. Steps of this research include the development of an aluminum matrix composite manufacturing processes, which is followed by a ceramic coating process. Matrix composite material made of Al-7Si-9Zn-6Mg matrix with strengthened of 10% alumina (Al₂O₃) and 10% silicon carbide (SiC) particles, while for coating materials using Chromium Oxide, Aluminum Oxide, and Ez Zirconium. The results of the hardness test without the ceramic coating process are an average of 71 HRB (127 HV). After the coating process, an obtained hardness value of 163 HV for coating material of Chromium Oxide, 373 HV for Aluminum Oxide, and 338 HV for Ez Zirconium. The wear resistance test results in abrasion values of 2.222 x10⁻⁶ mm²/kg for coating materials of Chromium Oxide, 1.633 x 10⁻⁶mm²/kg for Aluminum Oxide, and 7.021 x 10⁻⁶mm²/kg for Ez Zirconium.

1. Introduction

Development of the transportation industry and machinery in Indonesia is increasing which is quite significant, both in terms of growth production and technology improvement. Many industries are still experiencing some obstacles include not yet all supporting industries such as raw materials and components made domestically. One of the efforts that can be done is by using the component raw material can be produced independently in the country. The material must have the requirements adequate such as good quality, production costs which is cheaper, and lighter material so that fuel use is more efficient. Use of steel material in several components certain is not efficient anymore, considering the weight of relatively heavy steel material. To reduce weight, the vehicle can be done through several alternatives, such as (1) design changes, or (2) the development of lighter materials.

The development of lighter materials, such as aluminum matrix composites is an alternative to ferrous metal replacement materials for automotive components. Aluminum matrix composites also have low density, corrosion resistance and have better elasticity. Besides, Aluminum matrix composites have properties tailorability, so that its mechanical properties desired can be modified depending on matrix combination, reinforced and conditions on the area of the interface (ASM Handbook, 1992; F.L. Matthews and Rawlijns, R.D, 1994). Excellence this is the basis for researchers



to develop aluminum matrix composites as an alternative to conventional materials. In some countries, both on the Asian continent as well Europe, aluminum matrix composites have been used commercially on machine components such as a piston, connecting rod, brake system, and cylinder line. Also tactical vehicles military uses matrix composite materials for body material and door.

The composite manufacturing process becomes something important factors that determine characteristics composite. One method used is with a special casting process that is with squeeze casting technology. Squeeze process casting is a special casting technique combines the advantages of High Pressure Die Casting and forging technology (T.R. Vijayarayam et al., 2006). The resulting advantage is eliminating the amount of gas trapped inside cast results and reduces the amount of depreciation caused solidification.

In previous studies, it was successfully developed composite manufacturing process strengthened alumina particles to produce a composite in the form of plates (D. Rahmalina, et al., 2014), with Al-Si-Zn-Mg matrix reinforced 10% alumina volume fraction, and precipitation hardening process is carried out. From the research was obtained from violence maximum of 86 HRB at Zn 9 wt.%. The technology used in the study has some weaknesses from things temperature stability during pressure and the provision of compressive force so that it requires the development of modifications and mold design and provision of heaters on the mold. In addition, the mold condition is very dependent on the shape and dimensions of the cast product that will be produced. In that study also carried out a thermal spray process with coating material Tungsten Carbide-Cobalt (WC-Co) with a composition of 88WC-12Co. From the ballistic test, it showed that the composite plate with surface hardening has good ballistic resistance to 9 mm caliber bullets (type II), but for a higher ballistic test that is 7.62 mm caliber (type III) the composite plate has not been able to withstand penetration so that cracks occur.

Another study for matrix composites aluminum reinforced with alumina and silicon carbide has also been carried out, however without the coating process being carried out hardening (Hendri Sukma et al., 2015). From the results this study obtained the maximum hardness value from the composite plate is 60.28 HRB. Picas, Josep A, et al. in 2005, had researched thermally sprayed coating on aluminum matrix composites, with CrC-NiCr and WC-CoCr coating materials, for analyzing microstructure of the type of material coating and thermal spray process parameters.

Increasing surface characterization Al-3Si9Zn-6Mg aluminum matrix composite 10% alumina (Al₂O₃), with thermal sprayed coating technology through High-Velocity Oxy-Fuel (HVOF) method with a variety of coating material composition is 20Ni80Cr, 88WC-12Co, and 86WC-10Co4Cr was examined (Hendri Sukma et al., 2017). The results showed that wear resistance with abrasion specification values of 5.2×10^{-9} mm² / kg for coating material 20Ni80Cr, 1.2×10^{-9} mm² / kg for coating materials 88WC-12Co, and 1.6×10^{-9} mm² / kg for coating material 86WC-10Co4Cr.

Sachin Jadav N and Anil Kumar C, in the year 2014 conducted research on ceramic coatings on Aluminum 6061T6 with the Plasma method Spraying, which produces 121 HV hardness for Ez Zirconium coating material, 317 HV for Titanium Dioxide-40% coating material Zirconium, 776 HV for coating material Titanium Dioxide.

Confidently this research can be obtained highest value of hardness and wear resistance with a variation of types of ceramic coating materials. The results of this study are also expected to contribute to strengthening the system national innovation in the field of material engineering that can be applied in the automotive field and other machinery industry products.

2. Research Methodology

To achieve the development of aluminum matrix composites reinforced with alumina and silicon carbide with good mechanical characteristics, and ceramic coating processes to improve surface hardness and wear resistance, the research was designed to follow a flow diagram as shown in figure 1 below.

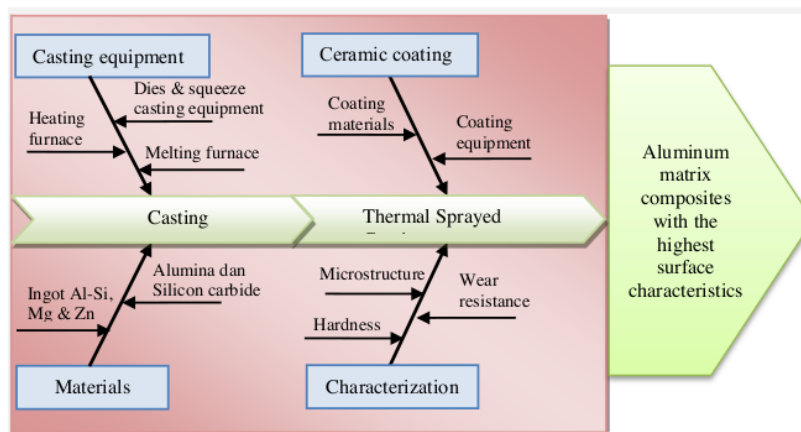


Figure 1. Research flow chart

The initial material used is pure Aluminum ingots and alloyed with Si 7% wt Zn 9% wt, Mg 6% wt (Al-7Si-9Zn-6Mg) also reinforced with 10% alumina (Al_2O_3) and 10% silicon carbide (SiC) particles. The process of making aluminum matrix composites with alumina and silicon carbide reinforcement, with the following stages:

- Heating of alumina and silicon carbide strengthening particles at a temperature of 1000°C.
- The process of melting aluminum ingots and their alloys namely silicon, magnesium and zinc is carried out in an electric melting furnace with a melting temperature of 850°C.
- Mixing of alumina reinforcing particles and silicon carbide with aluminum alloy is carried out at a temperature of 850°C.
- The casting process using squeeze-casting method is carried out to produce aluminum matrix composites with alumina and silicon carbide particles with the pressure of 30 MPa.

The process of ceramic coating with the method of Flame Powder Coating using Chromium Oxide, Aluminum Oxide, and Zirconium coating materials.

Characterization of aluminum matrix composites;

- Hardness testing
- Wear testing
- Microstructure observation

3. Results and Discussion

3.1. Melting Process

The melting process uses a crucible melting furnace with filaments as a heat source to melt aluminum that carried out at a temperature of 850°C (figure 2). After the aluminum melts, the degassing process with argon is carried out so that the dirt that settles on the aluminum matrix liquid arises to the surface and the impurities that arise on the surface are removed. Next, the mixture of magnesium, silicon, and zinc is mixed. After the alloy material melts, then mixed with alumina and silicon carbide which functions as a reinforced of aluminum matrix composites. Before the mixing process, alumina and graphite first heated on a temperature of 1000°C are then held on the temperature is for 1 hour (figure 3).



Figure 2. The process of aluminum melting.

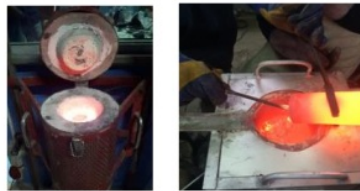


Figure 3. Heating reinforcement particle and mixing on alloy material.

3.2. Casting Process

Before the casting process is carried out, first heating the pouring inlet using a manual heater is done with a burner cutting torch and the mold with a heater which is made as an automatic heater. This treatment was conducted to prevent the liquid metal from freezing quickly in the inlet and not cooling the initial when the molten metal enters the mold. This mold heating process is carried out at a temperature of 300°C. The pouring process is carried out slowly to avoid turbulence in the flow of castings in the mold.

After castings are poured into the mold, then the pressure is applied using a hydraulic system with a compressive strength of 30 MPa in the mold (figure 4). This emphasis is carried out so that the molten metal can fill the entire mold cavity also to minimize the occurrence of void defects and gas porosity due to the melting process.



Figure 4. Casting process and the pressure in the mold

This pressure is applied after the composite liquid is in a semi-solid condition until the metal cools completely. And then dismantling the mold and removing the cast material from the mold (figure 5).



Figure 5. Removing the cast material from the mold.

3.3. Ceramic Coating

The Ceramic Coating process is carried out using the Flame Powder Spray (FPS) method, with a process scheme as shown in figure 6. The equipment and materials used in this ceramic coating process include specimen jigs, spray gun as coating material sprayers, coating room, blasting room, oxygen, nitrogen, propane, compressors, control panels, chillers, as well as some other supporting equipment. The coating material used is in powder form, namely Chromium Oxide, Aluminum Oxide, and Ez Zirconium.

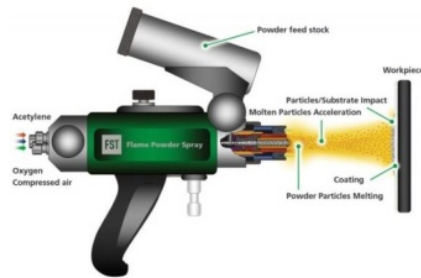


Figure 6. Ceramic Coating Process Scheme

The coating process is carried out in two stages of the process, namely the preparation process and the spraying process. The preparation process includes:

1. Cleaning material using thinner, so that the surface is clean from dirt, oil, and corrosion.
2. Heating material by using a gas fuel flame (LPG) in a short time to remove water and thinner, which may remain in the material.
3. The surface is roughing with grit blasting method — the results of a good blasting process when the surface of the material looks dull and rather rough (figure 7).



Figure 7. (a) Composites before blasting, (b) Composites after blasting

After the blasting process is carried out, the second stage is the process of spraying or the coating process (figure 8). The coating process must be carried out as soon as possible to prevent oxidation that affects the strength of the bonding layer.



Figure 8. Coating process on the surface of the material.

After the coating process is complete, the composite is left to cool to room temperature; then the composite is released from the retaining jig (figure 9).



Figure 9. Composite materials after the coating process.

3.4. Hardness Testing

Hardness testing is carried out to determine the value of surface hardness of the material that has been carried out by the coating process, and to see the difference in the hardness value of different types of coating material. This hardness test uses Micro Vickers test method with reference to ASTM E92 standard (table 1).

Table 1. Vickers Micro Hardness Testing Results

Coating Materials	Hardness (HV)						Average
	1	2	3	4	5	6	
Chromium Oxide	228.7	231.2	173.0	109.0	111.2	126.5	163
Aluminum Oxide	361.9	422.6	331.9	383.0	354.5	382.6	373
Ez Zirconium	491.6	429.6	239.5	299.4	274.3	293.2	338

From the results of the hardness test, the highest hardness value was found in Aluminum Oxide coating material is 373 HV, and the lowest hardness value was found in Chromium Oxide coating material of 163 HV.

3.5. Wear Resistance Test

Wear testing is carried out by the Ogoshi method according to ASTM G99 standard. The wear rate of composite materials was measured based on material resistance to abrasion. Wear resistance test results can be seen in table 2. The highest value of wear resistance was obtained at the smallest abrasion value, namely in the aluminum oxide coating material, with an abrasion value of $1,633 \times 10^{-6} \text{ mm}^2/\text{kg}$.

Table 2. Results of wear resistance test

Coating Materials	Wear scar width [b] (mm)	Disk Thickness [B] (mm)	Pin diameter [d] (mm)	Sliding Distance [lo] (m)	Load [po] (kg)	Velocity [v] (m/s)	Spesifikasi Abrasi mm^2/kg
Chromium Oxide	3,83	3	30	100	3,18	1,97	$2,222 \times 10^{-6}$
Aluminum Oxide	0,22	3	30	100	3,18	1,97	$1,633 \times 10^{-6}$
Ez Zirconium	0,24	3	30	100	3,18	1,97	$7,021 \times 10^{-6}$

3.6. Micro Structures Examination

Microstructure examination was carried out using the Scanning Electron Microscope/Energy Dispersive X-ray Spectroscopy (SEM/EDS) method, which was carried out according to ASTM F1371 standards. This examination is done to find out the results of coating and wettability of the coating surface on composite samples with different coating material variations. SEM/EDS examination is done from the side to observe the coating bond and the conditions between the base material and coating whether it is attached homogeneously or not, and also to determine the thickness of the coating.

SEM/EDS testing results for ceramic coatings can be seen in figure 10. These figures show good interface area between coating materials and composite with the absence of void and cavity, and the layer is homogeneous, and there is no gap or cavity between the coating material and the base material.

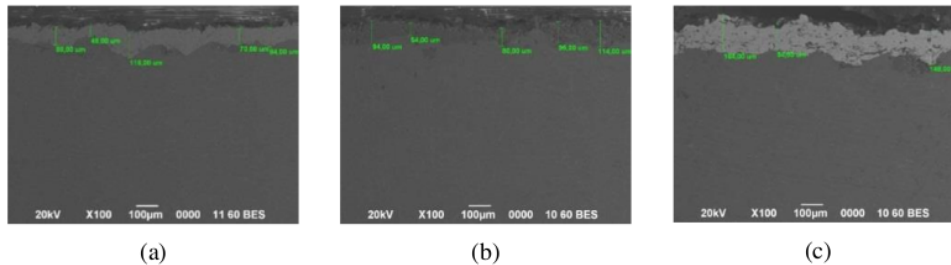


Figure 10. SEM/EDS observations of ceramic coating material; (a) Chromium Oxide (b) Aluminum Oxide (c) Ez Zirconium

The average coating materials thickness is 79.6 μm for chromium oxide, 87.6 μm for aluminum oxide and 135,33 μm for ez zirconium.

4. Conclusion

The results of this research can be summarized as follows:

1. Testing the hardness of the initial composite plate (before coating) obtained an average hardness value of 71.41 HRB or 130 HV.
2. After the coating process, the value of hardness is obtained 163 HV for Chromium Oxide coating material, 373 HV for Aluminum Oxide, and 338 HV for Ez Zirconium.
3. The highest hardness value was obtained from Aluminum Oxide coating material with a hardness value 373 HV, much higher than the initial hardness value before being coated only 130 HV
4. The wear resistance test results in abrasion values of $2,222 \times 10^{-6} \text{ mm}^2/\text{kg}$ for coating material Chromium Oxide, $1,633 \times 10^{-6} \text{ mm}^2/\text{kg}$ for Aluminum Oxide, and $7,021 \times 10^{-6} \text{ mm}^2/\text{kg}$ for Ez Zirconium.
5. The highest wear resistance value was obtained from Aluminum Oxide coating material with an abrasion values $1,633 \times 10^{-6} \text{ mm}^2/\text{kg}$
6. From the results of microstructure observation using SEM/EDS (Scanning Electron microscope/Energy depression X-ray Spectroscopy), the coating process with this thermal spray coating method produces a homogeneous coating layer, and there is no porosity between the coating layer and the base material.

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