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The Effect of Variation of Nano SiC Reinforcement Particle Addition to Mechanical Properties of Mg/Nano SiC Composite by Stir Casting Method

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Abstract. Composites are advanced material which is being developed that contains of two materials or more in order to improve the mechanical properties. Magnesium composite is a suitable material beside aluminium and its alloy to be applicated as vehicle body structure due to its lightweight and its low density. Thus, the vehicle body structure with lightweight and good mechanical properties can be achieved. In this research, magnesium composite is fabricated by mixing magnesium as composite matrix and nano SiC as reinforcement particle with the variation of the volume fraction 0.05 $\%v_f$, 0.10 $\%v_f$, 0.15 $\%v_f$, 0.20 $\%v_f$, and 0.25 $\%v_f$ with stir casting as fabrication methods. To characterize the composite product, several testing were done, which were chemical composition characterization, metallographic observation, SEM-EDS characterization, XRD characterization, hardness testing, wear testing, and impact testing. The result of this research shows that with nano SiC addition as reinforcement particle will increase mechanical properties of magnesium composite. The best mechanical properties of magnesium composite is shown by the addition of 0.15 %vf nano SiC. The result shows the brinnel hardness number of this composition is 39 HB and 0.0052 mm3/m wear rate. Mechanical properties of magnesium composite are increased due to several strengthening mechanism such as grain size reduction and Orowan strengthening mechanism.

Keywords: Magnesium composite, nano SiC, stir casting

1. Introduction

Fuel efficiency on the vehicle is one of the most developed subject in automotive technology. By improving fuel efficiency, the fuel consumption of a vehicle will be lower so as to reduce the costs incurred for fuel and can save the natural resources to fuel the vehicle. The mass of vehicles plays an important role towards the value of fuel efficiency. The higher the mass of the vehicle, the engine will require more fuel to drive the vehicle. Reduction of 10% vehicle load can reduce fuel usage by 6-8%. [1]. Car frame is one part of the vehicle whose mass can be reduced.
Magnesium is a metal that has the lowest density. Since magnesium density is only 1.74 g / cm^3 [2], magnesium can be used as a lighter car frame than a car-made aluminium and steel frame. So in terms of lightness, magnesium is a metal that is suitable to be used as raw material for car

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frame with high fuel efficiency. Moreover the availability of magnesium in nature is very abundant because magnesium is the most abundant element of the sixth order on earth (2.7% of the earth's crust composition is magnesium) [3].
To create a car frame with better mechanical properties, magnesium composite can be used instead of magnesium because magnesium composite has the better hardness, stiffness, and wear rate [4]. In composites, there are at least two types of materials used. Both materials act as matrix and reinforcement. The matrix is magnesium. One of the reinforcement that can be used is the nano-sized silicon carbide ceramic particles (SiC) [5]. Ceramic reinforcement has isotropic properties, excellent mechanical properties, chemical inertness properties, stable at high temperatures, and its expansion coefficient can be controlled [6] so that ceramic particles are considered attractive for metal matrix composite fabrication.

2. Materials and Methods

2.1.Materials

In this research, pure magnesium was used as the matrix and nano sized SiC particles with 0.05, 0.10, 0.15, 0.20, and 0.25% volume fraction were used. The term to be used for composite sample according to the volume fraction is sample 1, 2, 3, 4, and 5. The pure magnesium that used in this research were containing 99.8 % magnesium and another element. The other element composition that contained in the pure magnesium can be seen at Table 1.

Table 1. Chemical Composition of pure magnesium ingot

Al (%)	**Be (%)**	**Cu (%)**	**Mn (%)**	**Zn (%)**	**Ag (%)**	**Ca (%)**	**Cd (%)**	**Sn (%)**	**Sr (%)**	**Mg (%)**
<0.005	0.0001	<0.001	0.0466	0.0377	<0.001	0.0023	<0.001	0.0421	0.0007	Bal.

2.2.Experimental Methods

Pure magnesium and nano SiC particle are cleaned in order to remove inclusion particle. After being cleaned, pure magnesium is weighted and inserted into tilting furnace at 800 oC temperature. In parallel, nano-SiC are preheated in order to remove H20 from the powder. Preheating process are being done at muffle furnace at 1000 oC in one hour temperature. Crucible and mold are also being preheated in muffle furnace at the same temperature in thirty and two minu tes in order to avoid thermal shock. After preheat process, insert nano SiC particle into molten magnesium and then stir it for 1 minutes to get homogenous mixture. Then, pour the molten composite into the crucible and then transfer the molten composite into the mold which has been preheated before. Open the mold after the composite are solidified. Solidified composite sample is being used for characterization.

2.3.Characterization

In order to characterize the composite product, several testing were done. There were physical characterization which contain hardness testing, impact testing, and wear testing. Characterization like chemical composition characterization, metallographic observation, SEM-EDS characterization, and XRD characterization were also being conducted.

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3. Result and Discussion

3.1.Chemical Composition

OES (Optical Emission Spectrometry) was performed to analyze the elements contained in the material quantitatively. The purpose of the test is to identify and know the chemical composition contained in the magnesium as-cast sample and the magnesium nano SiC composite sample to know the effect of the casting process on the metal characteristics of the casting. SiC were not observed because SiC is a compound. OES characterization can only observe an element.
According to characterization result, there are some additional elements in the materials tested. This is because in the casting process are not completely clean of impurities so that elements other than magnesium are mixed into the matrix.

Table 2. Chemical compotition of pure magnesium as a matrix and Composite Materials

Elements	Content (Vf%)					
	As-cast	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Mg	99.8	99.8	99.8	99.7	99.8	99.8
Al	< 0.005	0.0177	0.0162	0.0169	0.0126	0.0146
Be	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002
Cu	< 0.001	0.0139	0.0148	0.0131	0.0077	0.0059
Mn	0.0466	0.0347	0.0341	0.0462	0.0452	0.0449
Zn	0.0377	0.076	0.048	0.0410	0.0411	0.0419
Ag	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Ca	0.0023	0.0021	0.0023	0.0028	0.0025	0.0023
Cd	< 0.001	0.0014	0.0014	0.0015	0.0014	0.0016
Sn	0.0421	0.0640	0.0644	0.0639	0.0632	0.0635
Sr	0.0007	> 0.0008	> 0.0008	> 0.0008	> 0.0008	> 0.0008

3.2.SEM and EDS

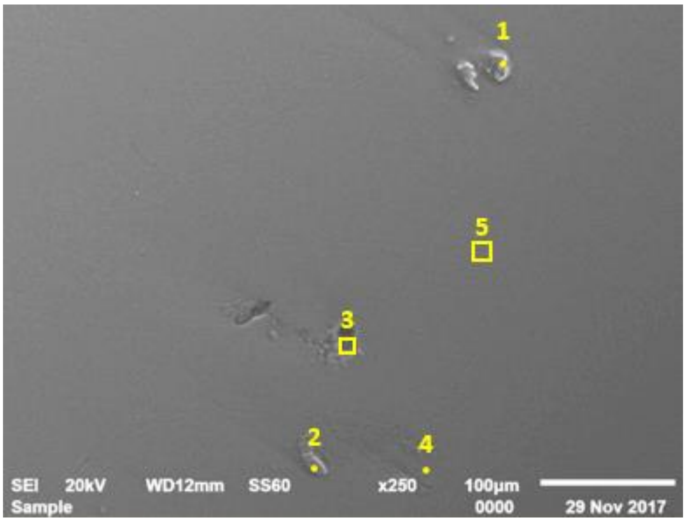

Figure 1. SEM observation result of composite material

SEM and EDS tests were conducted using magnesium composites sample 3 to represent all of the magnesium composite samples. At 250x magnification SEM image was being taken in five locations and can be seen in Figure 1.

Table 3. Chemical composition of phase based on SEM-EDS examination

Location	Content (wt%)					Possible Phase
	Mg	Al	Si	C	O	
1	18.53	0.28	39.46	32.08	9.55	MgO, SiC
2	57.80	1.81	0.73	4.37	35.10	MgO
3	23.26	11.33	0.11	38.26	26.54	MgO, Al_2O_3
4	16.60	0.55	26.40	36.76	19.27	MgO, SiC
5	97.21	0.00	0.00	1.74	0.83	Mg

Location 5 of the EDS test results is the magnesium matrix due to the high magnesium levels at that point and on the SEM result image, the magnesium matrix are represented with grey area. Magnesium content at location 1, 3, and 4 are low when compared with location 5. At location 1 and 4 there are high amounts of Si and C. High levels of Si and C it is possible that at that point there is a SiC thereby which mean there is a SiC content in this sample.
In addition there is an element of oxygen at most of the locations which indicates the creation of rust in the form of MgO. This is because magnesium is a highly reactive metal and very easily oxidized. There are some Al2O3 compound that observed in location 3 which indicates there are some contamination from casting process.

3.3.XRD

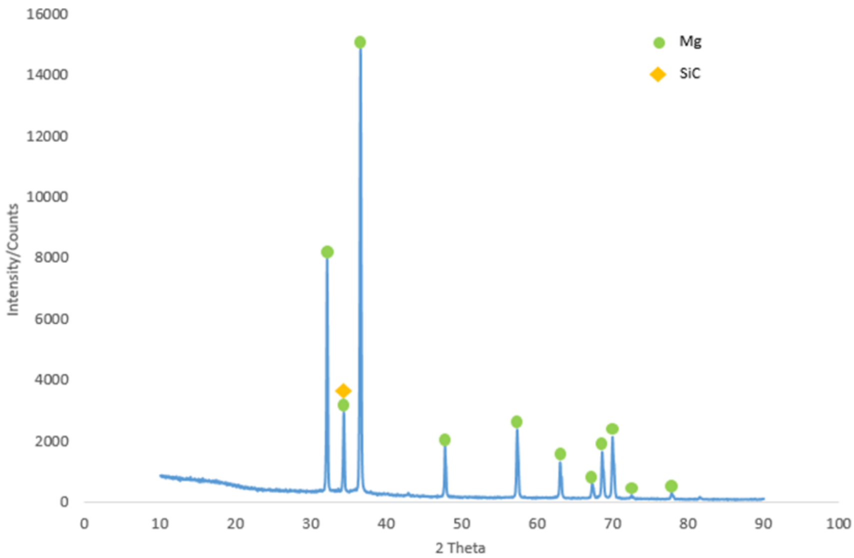

Figure 2. XRD observation result of composite material

XRD test was conducted magnesium composites sample 3 to represent all of the magnesium composite samples. From the data processing, there were 11 peaks at 02θ *i.e.* 32.0974, 34.3334, 36.5434, 47.7494, 57.3434, 62.9594, 67.2754, 68.6014, 69.9264, 72.4754, and 77.9354 can be seen at Figures 2. In the graph of XRD data reading, the magnesium phase is observed in all peaks. This indicates that magnesium as the matrix is the dominant phase in the magnesium composite. Nano SiC reinforcement particle is also seen at the second peak at XRD reading result. The presence of reinforcement particles in magnesium composites will make magnesium composites much better than as-cast magnesium.

3.4. Microsturcture

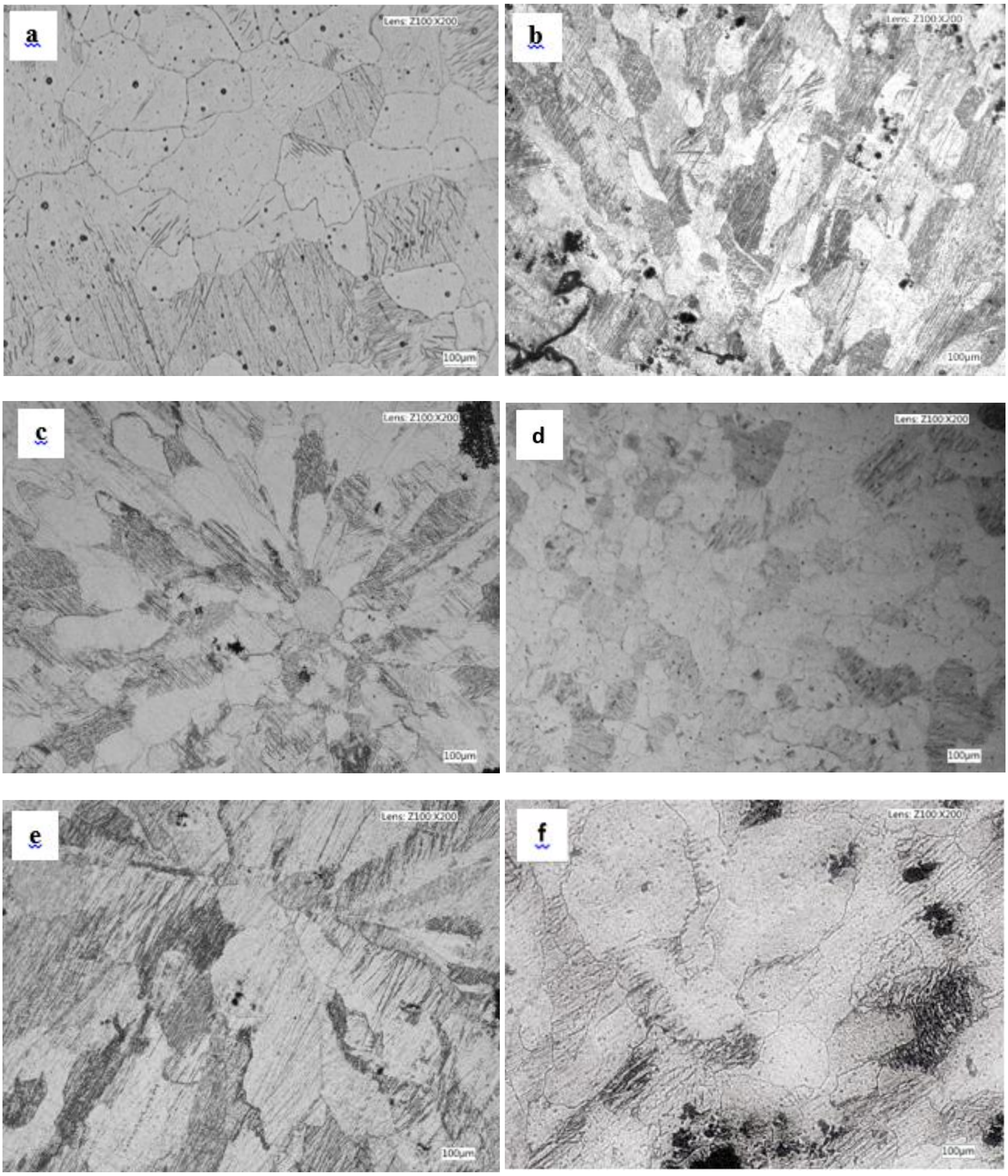

Figure 3. Microstructure images of (a) as-cast, (b) sample 1, (c) sample 2, (d) sample 3, (e) sample 4, and (f) sample 5 of magnesium composites

Microstructural observation of magnesium magnesium composites are being conducted by using digital optical microscopes with magnification 200 times The addition of nano SiC reinforcement particles will lead to a decrease in magnesium grain size as the volume fraction is added [7]. Because the nano SiC reinforcement particles act as a grain refiner. nano SiC reinforcement particles will usually occupy the grain boundary of magnesium and will cause pinning effect which will cause grain growth obstruction due to the presence of reinforcement particles so that the magnesium grains will be smaller [8].
The average grains size of sample 1, 2, 3, 4, and 5 are 201 µm, 198 µm, 174 µm 248 µm, and 264 µm. In this study there is a decrease in grain size on the sample of 1 to 3. However, in sample 4 and 5, the size of the grains become re-enlarged. This could be happened because the greater the addition of volume fraction of reinforcement particles, then the possibility of the reinforcement particle experiencing agglomeration will be greater. Agglomeration of reinforcement particles causes uneven distribution of reinforcing particles in the composite so that the pinning effect of the reinforcing particles against magnesium grains will not be optimal [8].

3.5. Mechanical Properties

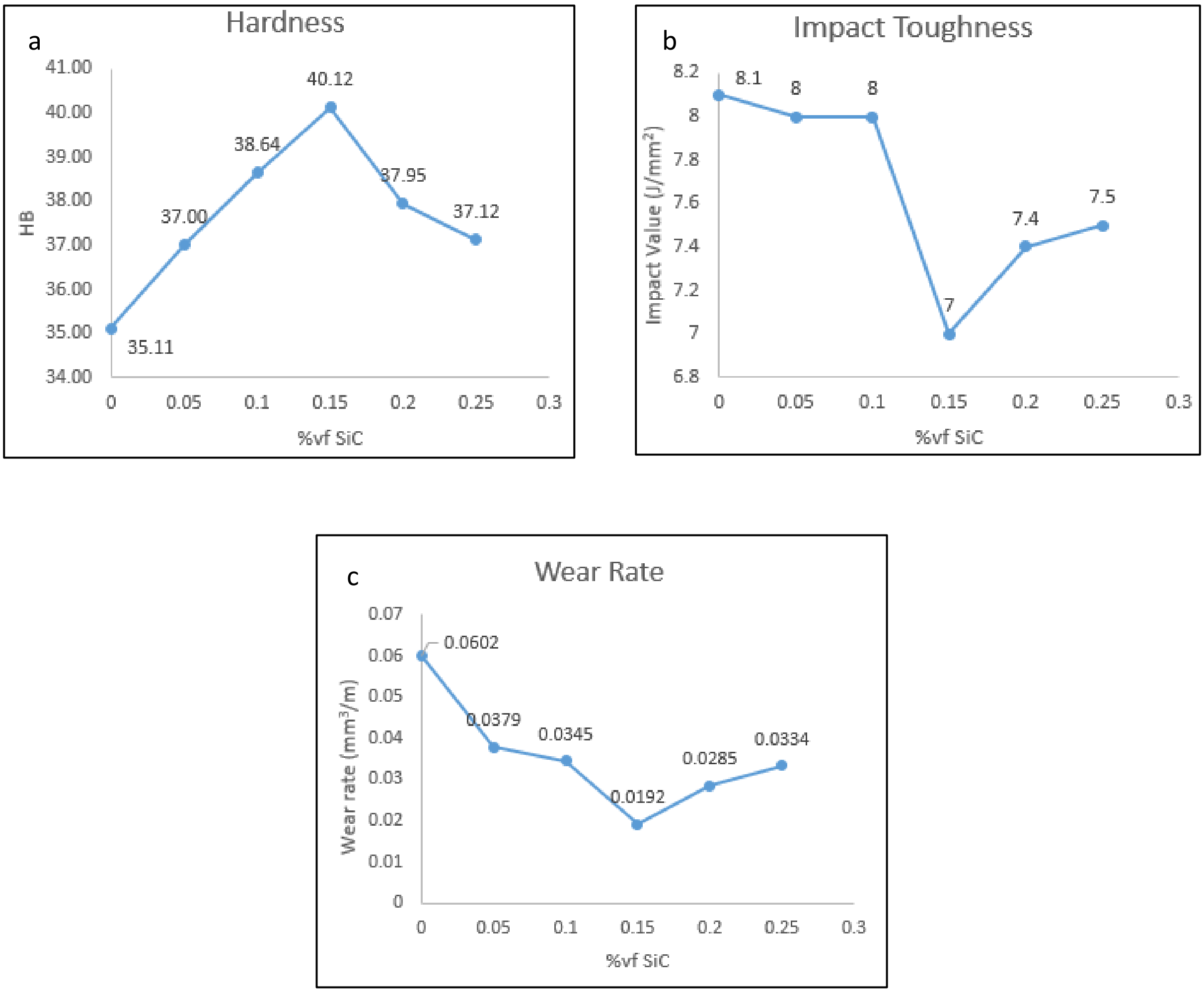

Figure 4. Effects of nano SiC particles addition on the (a) hardness, (b) impact toughness, (c) wear rates characteristics of composite materials

In this experiment, there is an increase in the hardness value of magnesium as-cast to magnesium composites. In magnesium composites, the more reinforcement particles increase the hardness value of the composite. This is because the higher levels of reinforcement particles, the grain size on the matrix will decrease because magnesium matrix grain growth were increased by reinforcement particles.
The smaller the grain size of the matrix then the compressive resistance will be increased. Additionally, the added nanoparticles increase the area of the amplifier so that the matrix bonds will become larger and give rise to Orowan defense mechanism where the deformation resistance will be better because the reinforcing particles act as a barrier to deformation [9]. The optimum hardness value is in sample 3 with 40.12 HB but the value will be decreased in sample 4 and sample 5 due to nano SiC agglomeration. Nano SiC in composites with larger volume fraction of reinforcement particle are easier to be agglomerated [10]. Agglomeration of the reinforcing particles causes a decrease in interface strength between the matrix and the reinforcement particles. Thus, the composite hardness will be decreased [11].
The addition of the nano SiC volume fraction will make the material harder. As the hardness increases, the material properties tend to change from ductile to brittle as a result of decreased ductility [12]. The more material gets brittle then it can decrease the energy that can be absorbed when fracture occurs. This results in a decrease in impact strength because the material will break as less energy is absorbed. The impact toughness value can be seen at figure 4 where sample 3 have the lowest impact toughness with 7 J/mm^2 impact resistance because sample 3 have the highest hardness if compared with another sample.
The reduction of the wear rate occurs with the addition of the nano SiC reinforcement particle to magnesium because reinforcement particles have a contribution in increasing the hardness of the material. The optimum wear rate is in sample 3 with 0.0192 mm^3/m wear rate because the harder the material will result in less abrasion to that material [13]. Increasing the volume fraction of the reinforcement particles can also increase the protection of the matrix surface from contact with other materials because the interface between the matrix and reinforcement particles are increased thus the strength of the interface will prevent the composite from peeling due to the friction of other materials [14].

4. Conclusion

Nano SiC reinforcement particles addition to magnesium matrix shows that magnesium composites have the better mechanical properties expecially in hardness value and wear rate. Nano SiC particles addition to magnesium composite will increase composite hardness with optimum value in sample 3 with 40.12 HB hardness value because the distribution of reinforcing particles are evenly distributed in the matrix which can increase deformation resistance and reduce the grain size. There is a decrease in hardness value in sample 4 and sample 5 due to the agglomeration of reinforcing particles. The hardness value affects the impact toughness and wear rate of magnesium composite. The sample with higher hardness value will have the lower wear rate and impact toughness.

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