Characteristics of Magnesium/B₄C Reinforced Composite Fabricated by Stir Casting Method

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Abstract. At present the development of magnesium composites is increasingly being carried out, this is due to the main advantages of magnesium which has the lowest density when compared with other metals so that it can save fuel use when applied as a constituent of an automotive product yet still has great mechanical properties. In this research, magnesium composite is fabricated by mixing magnesium as composite matrix and micro B₄C as reinforcement particle with 2, 4, 6, and 8 Vf-% by stir casting method. The magnesium reinforced B₄C particles has improved the mechanical properties of the composite. The best mechanical properties of magnesium composite are shown by the addition of 8 Vf-% B₄C particles. These values increase up to 73 HRH for the hardness and 64 MPa for the UTS as well as, 0.11 J / mm² for the impact value. The wear rate also reduced to 0.0023 mm³/m. The mechanical properties of magnesium composite are increased due to the increasing number of B₄C particles that caused new interfaces which will block dislocation movement and dispersed B₄C particles will also act as load restraint elements. Composite characterization was also carried out by using SEM-EDS and XRD test to find out the compounds and phases formed from the fabricated composites - then it was known that the possible compounds formed from the composites produced were MgB₂, MgO, B₄C, and Mg₂B₄O₅ respectively.

Keywords: Magnesium composite, B₄C particles, stir casting, mechanical properties

1. Introduction
At this time car is the main transportation mode that is often relied on by humans in meeting various needs every day. According to data from the central statistics agency, the number of four-wheeled vehicles that have been circulating throughout the Indonesian territory has reached up to more than 20 million[1]. However, the increasing number of circulation of four-wheeled vehicles is not supported by the availability of fuel oil which continues to soar every year. One solution to improve the efficiency of using fuel oil in a vehicle is by using lightweight metal as the material of the vehicle.

The use of lightweight metal as the basic material in vehicles can reduce the fuel oil needs of vehicles because with the mass of vehicles getting lighter, the vehicle engine only requires less fuel to drive the vehicle [2]. In this case, Magnesium is one of the most promising metals. Magnesium is one of the lightest metals on the face of the earth, with a specific gravity of only 1.74 g / cm³, where this density is 36% lighter than aluminum, 74% lighter than zinc, and 79% lighter than steel. However, there are limitations in the use of pure magnesium as an application of automotive parts because of the low mechanical properties of magnesium, so it is necessary to mix magnesium with other materials
(ceramics) in order to form magnesium composites which have far better mechanical properties than pure magnesium.

The Composite material is a combination of two or more different components, this is done in order to obtain certain physical and mechanical properties that are better than the properties of each of the constituent components. In this study, the composite matrix used was pure magnesium metal while the amplifier used as boron carbide (B₄C) ceramic particles with micron-size 2, 4, 6, and 8 Vf-%. With the addition of macro-sized B₄C ceramic particles, magnesium composites that have low density, high rigidity, high hardness and high wear resistance [3] will be obtained. The fabrication method used is stir casting, this is done because the method is relatively simple and only requires a relatively low cost in the process.

2. Materials and Methods

2.1 Materials
In this research, the composite was fabricated by using magnesium as the matrix with addition of micro-sized B₄C particle with variation of 2, 4, 6 and 8 Vf-% supplied by Shanghai Xinglu Chemical Co., Ltd, China.

2.2 Experimental Methods
Magnesium ingot was sawn into small block form using bend saw machine, after that small block of magnesium was cleaned with soap and alcohol in order to remove the inclusion particle and oil that might be left on the surface. Before magnesium inserted into the furnace, crucible and mold were coated by zircon and thinner to prevent the chemical reactions that may happen during magnesium were melted. After that, before turn on the furnace, a vacuum pump was used to take out any gasses in the furnace and then furnace has flowed with argon gas until all of the magnesium fully melted. While waiting for magnesium to melt completely, micro-sized particle B₄C was pre-heated at 950°C in the muffle furnace to remove the moist of that reinforce. After the pre-heat process of reinforcing done, reinforce was inserted to molten magnesium and then stirred for 2 minutes with a metallic stirrer to get a homogenous mixture. Then after the stirring process complete, the molten composite was poured to mold and solidified completely in 3 minutes. Finally, a composite sample was ready to be used for further mechanic and chemical characterization.

2.3 Characterization

2.3.1 Chemical Characterization. Chemical characterization was carried out by using Optical Emission Spectroscopy (OES) to find out what chemical elements are present in magnesium composite with the addition of 2, 4, 6 & 8 Vf-% micro B₄C samples.

2.3.2 Mechanical Properties Characterization. Mechanical properties characterization was carried out by using tensile, impact, hardness, wear, and porosity & density testing. GoTech machine was used in tensile testing with JIS Z2241 standard, impact test was tested using Charphy method, hardness test was tested using Rockwell machine with HRH standard, pin-on-disk Ogoshi machine was used to wear test with 100m sliding distance, and density test was carried out using DahoMeter machine based on Archimedes Theory.

2.3.3 Microstructural Characterization. Microstructure characterization was carried out on each variable, the first step before testing was to mount all the sample variables and then grind it using abrasive paper with an elevated number of grit, then polishing using selvyt-cloth and kovac liquid. After that, an observation is made on all variables to view each microstructure that obtains on each variable. SEM-EDX testing was used too on one sample which had optimum mechanical properties value to know what elements are contained which can then be analyzed for any possible phase in this sample. XRD testing also carried out to prove the formed phase based on the results of the SEM-EDX test.
3. Result and Discussion

3.1 OES Observation

The results of testing the chemical composition of pure magnesium and pure magnesium composite reinforced B\textsubscript{4}C can be seen in Table 1.

| Element | As-cast (%) | 2 Vf-% | 4 Vf-% | 6 Vf-% | 8 Vf-% |
|---------|-------------|--------|--------|--------|--------|
| Mg      | 99,8        | 99,2   | 96,3   | 99,3   | 99,0   |
| B       | -           | 0,0026 | 0,0016 | 0,0017 | 0,0019 |
| Al      | < 0,005     | 0,527  | 0,599  | 0,570  | 0,574  |
| Be      | 0,0001      | < 0,0005 | 0,00007 | 0,00009 | 0,00052 |
| Cu      | < 0,001     | < 0,00010 | < 0,00010 | < 0,00010 | < 0,00010 |
| Mn      | 0,0466      | 0,0022 | 0,0031 | 0,0031 | 0,0032 |
| Zn      | 0,0377      | 0,0061 | 0,0059 | 0,0024 | 0,294  |
| Ag      | < 0,001     | 0,00011 | 0,00011 | < 0,0010 | < 0,00010 |
| Ca      | 0,0023      | 0,00082 | 0,00056 | 0,00064 | 0,00051 |
| Cd      | < 0,001     | < 0,00010 | < 0,00010 | < 0,00010 | < 0,00010 |
| Sn      | 0,0421      | 0,0055 | 0,0080 | 0,0113 | 0,0118 |
| Sr      | 0,0007      | 0,00017 | 0,00012 | < 0,00010 | < 0,00010 |

Based on the data shown in Table 1, the percentage of magnesium in each variable is above 99%, ideally, the percentage of magnesium contained in each composite variable is at the number below 98%, the high percentage of magnesium content in each variable is due to a large amount of leftover magnesium remaining in the crucible which is used to melt magnesium where the remaining magnesium in the crucible wall dissolves into the molten metal liquid. The presence of magnesium remnants in the crucible is due to the oxidation of the molten metal from the previous melting, the oxidation of the molten metal then forms hard Magnesium Oxide (MgO) rocks [4] and is difficult to remove from the crucible.

3.2 Microstructure

Based on microstructural observations shown in Figure 1. Microstructure observations on reinforcement compositions of 2%, the presence of brownish-white base identified as pure magnesium phase and also blue-blackish grains scattered in the magnesium matrix, where the grains the blue-black colored grain is then identified as the B\textsubscript{4}C phase, there are blue-black grains that clump in one area, clumping of the grains in one area is then called the agglomeration phenomenon[5].Then in the microstructure observation of the second composition, the number of blackish areas was identified as porosity. Furthermore, on the observation of the third composition, the B\textsubscript{4}C particle agglomeration phenomenon was found to be greater than the other composition microstructure. Then, on the fourth composition observation, it was seen that B\textsubscript{4}C particles were dispersed evenly throughout all parts of the pure magnesium matrix, and there was no visible porosity and agglomeration in the microstructure.
Observation of X-Ray Diffraction (XRD) on magnesium-reinforced B₄C particle composites was carried out on samples with a particle composition of 8 % B₄C, where this was done based on the results of testing mechanical properties, 8 % B₄C/magnesium composite had better mechanical properties than all other compositions.

In the graph of the obtained XRD testing in Figure 2, magnesium phases are seen at all peak points, this indicates that magnesium as the matrix is the most dominant phase in the composite sample tested. In addition, the other highest phase is MgO with a score of 16 and MgB₂O₅ with a score of 2. The number of MgO and MgB₂O₅ phases formed is due to the fact that magnesium elements are very reactive and easily react with Oxygen to form MgO as a compound that is very much found and is at each peak of the test results. In addition, there are also B₄C and Boron phases at the peak points of the test results, although in small amounts, this indicates that the distribution of reinforcing particles is quite good and evenly distributed on all parts of the pure magnesium matrix in pure magnesium composite B₄C particle reinforced.

Figure 1. Microstructure of magnesium composite with addition of (a) 2 Vf-%, (b) 4 Vf-%, (c) 6 Vf-%, (d) 8 Vf-% B₄C.

3.3 XRD Observation

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Figure 2. The XRD result of Mg/Micro B₄C8Vf-% Composite.

3.4 SEM-EDS Test

SEM-EDS testing is carried out on Magnesium composites with the addition of 8 Vf-% B₄C particles which have the best mechanical properties compared to each other variable.

Based on the test results represented in Table 2, it can be seen that the elements contained are Mg, B, C, and O. Then based on the elements contained, it is predicted that the phases formed are MgO, MgB₂O₅, and MgB₃. Points 35, 36, 37 and 42 which are gray areas surrounded by black dots represent that the gray areas and black accents contain Mg and MgO phase. The formation of the MgO phase is caused by the element Mg which is very reactive with the surrounding environment, which in the surrounding environment contains oxide gases which then bind to molten metal molten magnesium and form a compound of Magnesium Oxide (MgO) [6].

Figure 3. SEM Results of Mg/Micro B₄C8Vf-% Composite.
Table 2. EDS Results of Mg/Micro B₄C8VF-% Composite.

| Point | Element (%) | Possible Formed Phase |
|-------|-------------|-----------------------|
|       | Mg          | B                     | O       | C      |                        |
| 35    | 94,71       | 2,72                  | 2,46    | 0,12   | Mg, MgO               |
| 36    | 90,53       | 6,76                  | 2,23    | 0,47   | Mg, MgO               |
| 37    | 91,35       | 5,80                  | 2,36    | 0,49   | Mg, MgO               |
| 38    | 79,19       | 12,78                 | 6,44    | 1,58   | MgO, B₄C             |
| 39    | 59,72       | 27,94                 | 4,37    | 7,97   | B₄C, Mg₂B₂O₅          |
| 40    | 78,28       | 17,04                 | 1,74    | 2,94   | MgO, MgB₂, MgB₂O₅     |
| 41    | 88,67       | 7,71                  | 2,70    | 0,92   | MgO, B₄C             |
| 42    | 90,49       | 6,30                  | 2,47    | 0,74   | Mg, MgO               |

Then at points 38, 39, 40 and, 41 there are bright white dots which indicate the presence of boron with a high enough percentage, the high level of boron added with the presence of Mg, C and O elements is predicted to form compounds B₄C, MgB₂O₅ and MgB₂ [7]. The formation of the MgB₂ and MgO phases is due to the presence of Mg and O bonds which then react with the B₄C amplifier [8].

3.5 Tensile and Elongation

Based on the results of the tests that have been done, the maximum tensile strength values are obtained in Figure 4(a).

![Figure 4](image-url)

Figure 4. (a) Tensile, and (b) Elongation.

In general, there is a significant increase in maximum tensile strength along with the increasing number of B₄C reinforcing particles into the pure magnesium matrix. B₄C particles that are evenly dispersed in a pure magnesium matrix will increase the dislocation density, wherewith increasing dislocation density in the sample, greater energy is needed to deform the material the newly formed grains will block the movement of dislocations during deformation [9]. However, in a B₄C-reinforced pure magnesium composite sample of 4 VF-%, the maximum tensile strength was decreased. This is caused by the high porosity percentage value in the composite sample. The highest elongation rate in this variable occurs because of good grain smoothing before it reaches the critical point of a material. This fine grain smoothing provides a more homogeneous strain distribution and decreases the stress concentration in the material so that the tenacity of the material becomes higher.
3.5.1 Hardness, Wear rate and Impact. Based on the graph shown in Figure 5(a), it can be seen that there is a consistent increase in hardness with the increasing number of added particles B4C. Increased hardness of the B4C reinforced composite is caused by dispersed B4C particle will make more and more interfaces formed between the pure magnesium matrix and B4C reinforce [10] then with the formation of a strong interface, the dislocation movement will be blocked so that the material becomes stronger [11].

![Graph showing hardness, wear rate, and impact](image)

**Figure 5.** (a) Hardness, (b) Wear rate, and (c) Impact value of Mg/B₄C Composite.

There is an increase in wear resistance as the number of boron carbide particles is added, this is due to an increase in the hardness and strength of the composite as more reinforcement is added, this also corresponds to the Archard equation [12] where the wear rate of a material will be inversely proportional to the hardness of the material.

Based on the impact value graph in Figure 5(c), the addition of the B₄C reinforce tends to increase the impact value of the magnesium/B₄C composite. This is because the dispersed B₄C particles will act as a load restraining element which is the process of transferring the load first through the B₄C reinforce which has been dispersed in a pure magnesium matrix so that a larger load is needed to deform the material, hence the toughness of the composite will increase [7]. However, in the composition of 4% the value obtained tends to decrease this is due to the percentage of porosity in the composition is very high.

3.5.2. Density and Porosity. Based on Figure 6 (a), the actual density value obtained in all B₄C magnesium-reinforced composite compositions has a smaller value when compared to the theoretical density value, the smaller actual density value indicates the presence of porosity in the fabricated sample.
The larger difference between the theoretical density value and the actual density value, hence there is more porosity value obtained from the composite sample.

![Graph showing density and porosity of Mg/B₄C Composite](image)

**Figure 6.** (a) Density and (b) Porosity of Mg/B₄C Composite.

Based on the graph in Figure 6 (b). It can be seen that the highest percentage porosity value occurs in samples with the addition of 4% B₄C reinforce. In this composition the porosity percentage value formed is 8.6495%, the highest porosity percentage value in the composite sample occurs due to the length of the stirring is longer than any other fabrication process so with this longer stirring process and dross extraction in the composite [13] sample resulted in contact or contamination of oxygen gas with molten magnesium metal that makes the porosity value is higher than any other composition [14].

4. Conclusion
Magnesium with the addition of B₄C reinforces particle composites has successfully fabricated using a stir casting method. The higher the difference between the actual density and the theoretical density in the tested sample, the higher the porosity percentage in the sample. Addition of reinforce particles B₄C to magnesium composites will increase composite hardness with a maximum value of the composition of 8 Vf-% B₄C which is equal to 72.8 HRH. Increase the composite impact value with the highest value in the composition of 8 Vf-% B₄C which is equal to 0.11 Joule / mm², Reduce the composite wear rate with a minimum value of the composition of 8 Vf-% B₄C which is equal to 0.0023mm³/m. The tensile test results show the optimal value of UTS and % elongation achieved in the composition of 8 Vf-% B₄C which is equal to 64.03 MPa and 26% elongation. XRD results of magnesium composite samples show there are phases of Mg, MgO, MgB₂, B₄C, and MgB₂O₅.

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