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Investigation of Morphology and Compressive Properties of Diamond Reinforced Porous Aluminium Composites

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Abstract: *In the present work, porous aluminium composite with varying diamond particles content (4, 8, 12, and 16 wt. %) were developed via powder metallurgy technique. Porosity was attained by using 30 wt. % Polymethylmethacrylate particles as a space holder. The effects of varying content of diamond on the morphology, densities, porosities, compressive properties as well as energy absorption were studied. Morphology of the porous Al composite demonstrated the formation of closed- cell macro pores that were uniformly distributed within the Al matrix regardless of different content of diamond particles. However, increasing diamond content was found to alleviate un-wetting phenomenon between Al matrix and diamond particles leading to increased porosities from 34.8% to 26.2%. The compressive properties also declined however maximum values for plateau stress (7.50MPa) and energy absorption capacity 1.7(Mj/m3) were acquired at 8wt.% diamond content.*

Keywords: Porous Al; PMMA; sintering; wettability; closed-cell macro pores; Diamond

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1. Introduction

Porous composites, particularly those based on aluminium (Al), provide a unique characteristics like low density, high stiffness, strength, and energy absorption capability (Kondoh, 2012). Porous Al composites are primarily used in packaging, energy absorption and dissipation, and passive safety systems. Even with a higher weight per volume unit, these materials have a better rate of energy absorption than polymeric foams (Tan et al., 2016). The various methods of foaming these porous materials are casting, powder metallurgy, and metal deposition. The powder metallurgical process has been today's most popular manufacturing method. As the physical and mechanical properties of porous materials are influenced not only by their composition but also by cell structure.

Typically, hydrides are used as foaming agents to obtain porosities in the porous materials. However, due to their hazardous effect on human health such as skin, eye and respiratory tract irritation, also because of their high flammability and higher cost, they are not recommended (Cambronero et al., 2009). In the current study, foaming agent was replaced by space holders Polymethylmethacrylate (PMMA) particles, which decompose during the sintering process, leaving a negligible residue(Jamal et al., 2016). The PM foaming method is quick, with expansion occurring in a matter of minutes, yielding a usable cellular structure of porous material (Asavavisithchai & Kennedy, 2012). In this study, porous Al composites were developed by employing powder metallurgy technique. The porosities were acquired by using PMMA space holder particles. The characterization and compression tests were performed to evaluate the performance of the material under compression.

2. Methods and Material

The materials used in this study are Al, magnesium (Mg), tin (Sn), PMMA, and diamond powder. The metallic powders (Al, Mg, and Sn) of purity 99.9% were supplied by Nova Scientific resources Malaysia Sdn Bhd. PMMA was utilized as space holder particle and was fixed at 30 wt. % in all composites. Porous Al composites were fabricated using powder metallurgy technique, it involves mainly three stages as shown in Table 1. The microstructure, densities, composition, and compression behavior of porous Al composite was observed using (JEOL JSM-6300F) Scanning Electron Microscopy (SEM), Archimedes principle, X-ray diffractometer (PAN analytical empyrean 1032) operated at 40kV and 40 mA in the range of 20°-80° and universal testing machine (Shimadzu Autograph AGX 10 kN) at 10 kN with crosshead speed 0.5 mm/min respectively.

Table 1: Processing parameters

Procedure		Parameters
Mixing	Metallic mix (MM)	225rpm, 12 hours
	Mixing (PMMA and diamond +MM)	800rpm,2hrs
Compaction		250 MPa
Sintering		580°C, 2 hrs (argon atmosphere)

3. Result and Discussion

3.1 Morphology

The microstructure of the porous Al composite with varying content (4, 8, 12 and 16 wt. %) of diamond particles Figure 1. The porous Al composite reinforced with diamond particles are composed of closed macro-pore's structure regardless of varying diamond content. The closed macro-pores are also interconnected thereby forming a cellular structure. Also, the porous Al composites consists of spherical shapes of pores of average size 150µm, same as that of PMMA particles used, indicating that porosities replicate the shape and size of PMMA particles, thus porosities can be tailored.

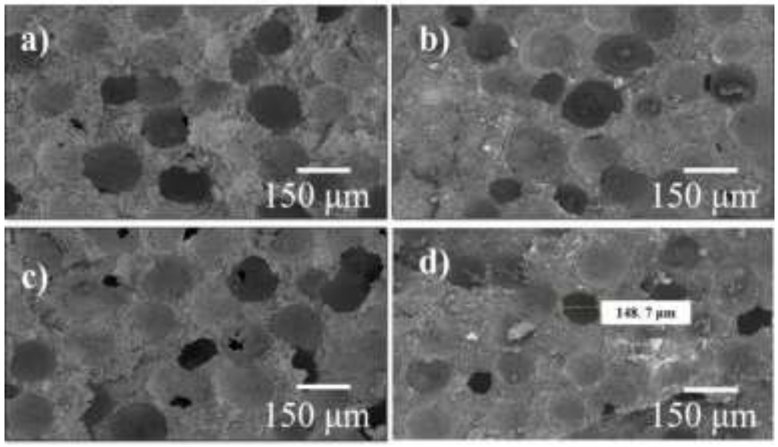

Figure 1: Morphology of sintered porous Al composite with diamond content of a) 4, b) 8, c) 12 and d) 16 wt.%

Figure 2 reveals that the porous Al composites reinforced with diamond particles exhibits micro-pores and cracks in the cell wall and uniform distribution of diamond particles. The presence of porosities may be due to un-wetting phenomenon resulting into the formation of pores at the interfaces of Al matrix and diamond particles during processing (Chung et al., 2014) which becomes more significant with increase in diamond particle fraction.

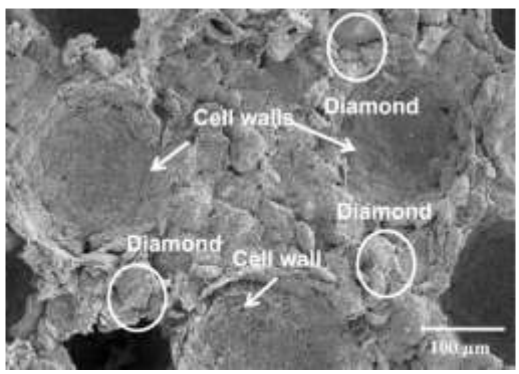

Figure 2: SEM micrography of cell wall of the porous Al composite with 8wt. % of diamond

3.2 Density and Porosity

The sintered densities of diamond reinforced porous Al composite at different diamond contents (4, 8, 12 and 16 wt. %) are shown in Figure 3(a). The densities of diamond reinforced porous Al composite were found to increase from 1.687 g/cm^3 to 1.908 g/cm^3 with increase in the diamond contents. On the contrary, the porosities of composite were found to reduce from 34.8 % to 26.2 % with increase in diamond content. Although the amount of PMMA particles (space holders) were fixed to 30 wt. % in the current study, thus an average of 30% porosity was expected. However lesser porosity values can be attributed to the incomplete removal of PMMA particle during sintering due to agglomeration of diamond particles in composites with higher diamond content, causing difficulty of PMMA decomposition hence PMMA particles (Kwon et al., 2011). Thereby leading to increase in the densities of porous Al composite while as decreasing the porosities with increasing diamond content.

3.3 X-Ray Diffraction (XRD**)**

Figure 3(b) shows the XRD pattern of diamond reinforced porous Al composite at varying diamond content. Apart from the four typical Al peaks at 38.5°, 44.7°, 65.1° and 78.2° representing the planes (111), (200), (220) and (311), respectively, a low intensity of the diamond peak was detected at 43.9° representing plane (111). As evident from 3(b), the peaks of aluminum carbide (Al_4C_3) were detected indicating reaction occurred between Al and diamond particles during sintering. Also from Figure 3(b), the intensities of the main peaks of all samples were found to decrease with increasing diamond content, confirming decreased sintering effectiveness owing to poor wetting of diamond particles by Al matrix at higher diamond content.

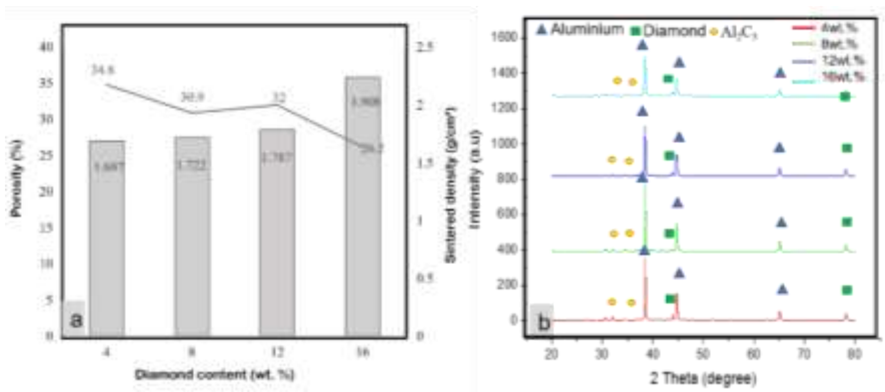

Figure 3: (a) Sintered densities, porosities, and (b) XRD patterns of diamond reinforced porous Al composites

3.4 Compressive Behavior

The deformation behavior of diamond reinforced porous Al composites with varying diamond content (4, 8, 12 and 16 wt.%) were presented in Figure 4. The stress strain curves display all the three regions: elastic, plateau as well as densification region (Aly, 2007; Sahu et al., 2014); a linear elastic region as the first stage of deformation, then a plateau region where stress remains nearly constant over a wide range of strain, and then finally rapid increase in stress with strain forming a densification region. The stress strain curves indicate brittle behaviour exhibiting severe variations during the plateau region. Such fluctuations were also observed by other researches that have used ceramic reinforcements (Hakamada et al., 2005; Mondal et al., 2009) and CNT's(Yang et al., 2017).

Also, from Figure 4, the plateau strength of diamond reinforced porous Al composite initially increased with increase in diamond content from 4 to 8wt.% however beyond this it decreased. This implies that at lower diamond content, Al matrix and diamond particles are well bonded however the wettability of diamond particles by Al matrix reduced with increasing diamond content as confirmed by SEM analysis and XRD analysis in Figure 1 and Figure 2 respectively. Thus, the maximum values of plateau stress of 7.50 MPa was obtained at 8 wt. % diamond content and the minimum values of 5.30 MPa was acquired at 16 wt.% diamond content.

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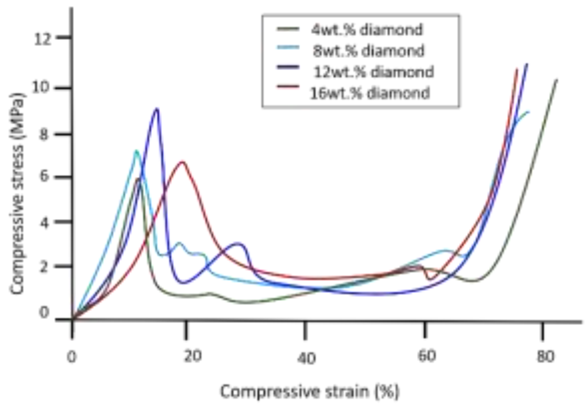

Figure 4: Stress-strain curve of diamond reinforced porous Al composite at varying diamond content

3.5 Energy Absorption Characteristics

The energy absorption capability of the composites with diamond particles was obtained from the area under the curve of the plateau region. The energy absorption capacity first increases on addition of diamond content upto 8wt.% then decreases on further addition. Also, the maximum value of energy absorption capacity of 1.7Mj/m^3 was attained at 8 wt. % diamond content and minimum value of 1.3Mj/m^3 was attained at 16wt.% of diamond content. It is the energy absorbed during bending cell walls in plateau region(Alizadeh & Mirzaei-Aliabadi, 2012). At higher diamond particle content poor mechanical bonding between Al and diamond particles due to un-wetting phenomenon contributed to the presences of cracks and pores in the wall that regulated collapse of cell walls thereby offering low bending deformation resistance hence reducing their ability to resist deformation as well as to dissipate impact energy (Chung et al., 2014).

4. Conclusion

Powder metallurgy technique was implemented in the current study to develop diamond reinforced porous Al composite with varying diamond content whereas PMMA (space holder) content was fixed at 30 wt. %. Morphology of the porous Al composites were composed of closed-cell macro-pores that were homogeneously distributed within the Al matrix however with increased diamond content pores and cracks appeared on the cell wall due to insufficient wetting diamond particles by Al matrix. XRD patterns revealed the main peak intensities of all specimens were found to decrease with increasing diamond content. The plateau stress and energy absorption capacity increased upto 8wt.% beyond that it decreased due to poor cell wall strength. The maximum values of plateau stress and energy absorption capacity of porous Al composite was recorded as 7.50 MPa and 1.7MJ/m^3 for 8 wt. % of diamond reinforcement. Since, the interfacial bonding seems to the greatest challenge in achieving better properties, thus the properties can be further enhanced by varying the processing parameters and by applying coating on diamond particles.

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References

Alizadeh, M., & Mirzaei-Aliabadi, M. (2012). Compressive properties and energy absorption behavior of Al-Al2O3 composite foam synthesized by space-holder technique. *Materials and Design*, *35*, 419–424. https://doi.org/10.1016/j.matdes.2011.09.059

Aly, M. S. (2007). Behavior of closed cell aluminium foams upon compressive testing at elevated temperatures: Experimental results. *Materials Letters*, *61*(14–15), 3138–3141. https://doi.org/10.1016/j.matlet.2006.11.046

Asavavisithchai, S., & Kennedy, A. R. (2012). The effect of oxides in various aluminium powders on foamability. *Procedia Engineering*, *32*, 714–721. https://doi.org/10.1016/j.proeng.2012.02.002

Cambronero, L. E. G., Ruiz-Roman, J. M., Corpas, F. A., & Ruiz Prieto, J. M. (2009). Manufacturing of Al-Mg-Si alloy foam using calcium carbonate as foaming agent. *Journal of Materials Processing Technology*, *209*(4), 1803–1809. https://doi.org/10.1016/j.jmatprotec.2008.04.032

Chung, C. Y., Chu, C. H., Lee, M. T., Lin, C. M., & Lin, S. J. (2014). Effect of titanium addition on the thermal properties of diamond/Cu-Ti composites fabricated by pressureless liquid-phase sintering technique. *The Scientific World Journal*, *2014*, 1–8. https://doi.org/10.1155/2014/713537

Hakamada, M., Nomura, T., Yamada, Y., Chino, Y., Hosokawa, H., Nakajima, T., Chen, Y., Kusuda, H., & Mabuchi, M. (2005). Compressive properties at elevated temperatures of porous aluminum processed by the spacer method. *Journal of Materials Research*, *20*(12), 3385–3390. https://doi.org/10.1557/jmr.2005.0415

Jamal, N. A., Tan, A. W., Yusof, F., Katsuyoshi, K., Hisashi, I., Singh, S., & Anuar, H. (2016). Fabrication and compressive properties of low to medium porosity closed-cell porous Aluminum using PMMA space holder technique. *Materials*, *9*(4), 1–13.

Kondoh, K. (2012). Edited by Katsuyoshi Kondoh. In *Powder Metallurgy*.

Kwon, Y., Im, H., & Kim, J. (2011). Effect of PMMA-graft-silica nanoparticles on the gas permeation properties of hexafluoroisopropylidene-based polyimide membranes. *Separation and Purification Technology*, *78*(3), 281–289. https://doi.org/10.1016/j.seppur.2011.02.014

Mondal, D. P., Goel, M. D., & Das, S. (2009). Effect of strain rate and relative density on compressive deformation behaviour of closed cell aluminum-fly ash composite foam. *Materials and Design*, *30*(4), 1268–1274. https://doi.org/10.1016/j.matdes.2008.06.059

Sahu, S., Goel, M. D., Mondal, D. P., & Das, S. (2014). High temperature compressive deformation behavior of ZA27-SiC foam. *Materials Science and Engineering A*, *607*, 162–172. https://doi.org/10.1016/j.msea.2014.04.004

Tan, Z., Chen, Z., Fan, G., Ji, G., Zhang, J., Xu, R., Shan, A., Li, Z., & Zhang, D. (2016). Effect of particle size on the thermal and mechanical properties of aluminum composites reinforced with SiC and diamond. *Materials and Design*, *90*(June 2019), 845–851.

Yang, K., Yang, X., Liu, E., Shi, C., Ma, L., He, C., Li, Q., Li, J., & Zhao, N. (2017). Elevated temperature compressive properties and energy absorption response of in-situ grown CNT-reinforced Al composite foams. *Materials Science and Engineering A*, *690*, 294–302. https://doi.org/10.1016/j.msea.2017.03.004