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Improvement in effectiveness of diamond in strengthening the porous aluminium composite
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Abstract
In this study, an aluminum (Al) alloy matrix reinforced with uncoated and titanium (Ti) -coated diamond were developed using powder metallurgy technique where polymethylmethacrylate (PMMA) particles were employed as space holders. The weight % of uncoated and coated diamond varied as (0, 6, 9, 12, 15, and 20 wt.%). Microstructural and elemental analysis was examined using scanning electron microscopy and energy dispersive spectroscope, respectively. The relative density and porosity that were in the range of 0.72–0.92 and 31–44% respectively, were measured using Archimedes principle. The compressive properties were measured and correlated with microstructure observations. The microstructure of the composite samples revealed presence of well-defined macro pores with good interfacial integrity. The X-ray diffraction revealed the presence of strengthening phases such as Al2Ti, Mg2Sn, AlB12, Cu5Sn6, Al12Mg17 and MgB2 phases formed as a result of addition of metal additives in Al matrix. Further improvement in the strength was obtained by using Ti-coated diamond particles as reinforcement. As Ti formed a good interface between the Al alloy matrix and the diamond thereby preventing the formation of undesirable carbide phases. There was an improvement in plateau stress and energy absorption capacity of 82 and 88% as compared to unreinforced porous sample. The maximum values obtained for the plateau stress and energy absorption capacity were 45.12 MPa and 13.68 MJ/m3 respectively for 9 wt.% of Ti-coated diamond reinforced composites. Uncoated diamond reinforced composites, on the other hand, reduced the strength of porous Al alloy matrix due to the formation of brittle intermetallic compound such as carbides (Al2C3) at the interface. As a result, the coated diamond particle surface modifies and improves the wettability of the Al alloy matrix and diamond interface. © 2023 The Authors

Author Keywords
Compressive properties; Diamond; Porous aluminium composites; Powder metallurgy

Index Keywords
Additives, Aluminum alloys, Aluminum coatings, Aluminum compounds, Carbides, Diamonds, Magnesium compounds, Metallic matrix composites, Microstructure, Powder metallurgy, Powder metals, Reinforcement, Scanning electron microscopy, Strengthening (metal); Aluminum alloy matrices, Aluminum composites, Coated diamond particles, Coated diamonds, Compressive properties, Energy absorption capacity, Plateau stress, Porous aluminum, Porous aluminum composite, Titania; Binary alloys

References

- Liu, P.S., Chen, G.F.
  Porous materials: processing and applications
  (2014), Elsevier
- Parveez, B., Jamal, N.A., Maleque, A., Yusof, F., Jamadon, N.H., Adzila, S.
  Review on advances in porous Al composites and the possible way forward
  (2021) *J Mater Res Technol*, 14, pp. 2017-2038.
- Atwater, M.A., Guevara, L.N., Darling, K.A., Tschopp, M.A.
  Solid state porous metal production: a review of the capabilities, characteristics, and challenges
  (2018) *Adv Eng Mater*, 20, pp. 1-33.
- Aboraia, M., Sharkawi, R., Doheim, M.A.
  (2011) *Production of aluminium foam and the effect of calcium carbonate as a foaming agent*, 39, pp. 441-451.

- Nakamura, T., Gnyloskurenko, S.V., Sakamoto, K., Byakova, A.V., Ishikawa, R.
Development of new foaming agent for metal foam
(2002) *Mater Trans*, 43, pp. 1191-1196.

- Mukherjee, M., García-Moreno, F., Jiménez, C., Rack, A., Banhart, J.
Microporosity in aluminium foams
(2017) *Acta Mater*, 131, pp. 156-168.

- Jiang, B., Wang, Z., Zhao, N.
Effect of pore size and relative density on the mechanical properties of open cell aluminum foams
(2007) *Scripta Mater*, 56, pp. 169-172.

- Mohd Razali, R.N., Abdullah, B., Ismail, M.H., Ahmad, U.K., Idham, M.F., Rasmli, A.
Mechanical properties of aluminium foam by conventional casting combined with NaCL space holder
(2013) *Appl Mech Mater*, 393, pp. 156-160.

- Krommenhoek, M., Shamma, M., Morsi, K.
Processing, characterization, and properties of aluminum–carbon nanotube open-cell foams
(2017) *J Mater Sci*, 52, pp. 3927-3935.

- Tan, P.P., Mohamad, H., Anasyida, A.S.
Properties of porous magnesium using polymethyl methacrylate (PMMA) as a space holder
(2018) *J Phys Conf Ser*, 1082.

- Bi, Y., Zheng, Y., Li, Y.
Microstructure and mechanical properties of sintered porous magnesium using polymethyl methacrylate as the space holder
(2015) *Mater Lett*, 161, pp. 583-586.

- Li, B.Q., Wang, C.Y., Lu, X.
Effect of pore structure on the compressive property of porous Ti produced by powder metallurgy technique
(2013) *Mater Des*, 50, pp. 613-619.

- Jamal, N.A., Maizatul, O., Anuar, H., Yusof, F., Nor, Y.A., Khalid, K.
Preliminary development of porous aluminum via powder metallurgy technique
(2018) *Mater Werkst*, 49, pp. 460-466.

- Yang, K., Yang, X., He, C., Liu, E., Shi, C., Ma, L.
Damping characteristics of Al matrix composite foams reinforced by in-situ grown carbon nanotubes
(2017) *Mater Lett*, 209, pp. 68-70.

- Yang, X., Hu, Q., Li, W., Song, H., Zou, T., Zong, R.
Compression-compression fatigue performance of aluminium matrix composite foams reinforced by carbon nanotubes
(2020) *Fatig Fract Eng Mater Struct*, 43, pp. 744-756.

- Wang, J., Yang, X., Zhang, M., Li, J., Shi, C., Zhao, N.
A novel approach to obtain in-situ growth carbon nanotube reinforced aluminum foams with enhanced properties
(2015) *Mater Lett*, 161, pp. 763-766.

- Alizadeh, M., Mirzaei-Aliabadi, M.
Compressive properties and energy absorption behavior of Al-Al2O3 composite foam synthesized by space-holder technique
(2012) *Mater Des*, 35, pp. 419-424.

- Chung, C.Y., Chu, C.H., Lee, M.T., Lin, C.M., Lin, S.J.
  Effect of titanium addition on the thermal properties of diamond/Cu-Ti composites fabricated by pressureless liquid-phase sintering technique
  (2014) *Sci World J*, 2014, pp. 1-8.

- Che, Z., Li, J., Wang, L., Qi, Y., Zhang, Y., Zhang, H.
  Effect of diamond surface chemistry and structure on the interfacial microstructure and properties of Al/diamond composites
  (2016) *RSC Adv*, 6, pp. 67252-67259.

- Wang, L., Li, J., Che, Z., Wang, X., Zhang, H., Wang, J.
  Combining Cr pre-coating and Cr alloying to improve the thermal conductivity of diamond particles reinforced Cu matrix composites
  (2018) *J Alloys Compd*, 749, pp. 1098-1105.

- Hamdi, A.A.
  Effect of magnesium and tin as sintering additives on microstructure and compressive properties of porous aluminum
  (2018),

- Sercombe, T.B.
  Non-conventional sintered aluminium powder alloys
  (1998),

- Ali, S., Rani, A.M.A., Altaf, K., Baig, Z.
  Investigation of Boron addition and compaction pressure on the compactibility, densification and microhardness of 316L Stainless Steel
  (2018) *IOP Conf Ser Mater Sci Eng*, 344.

- Sánchez de la Muela, A.M., García Cambronero, L.E., Malheiros, L.F., Ruiz-Román, J.M.
  New aluminum syntactic foam: synthesis and mechanical characterization
  (2022) *Materials*, 15.

- Li, Y.G., Wei, Y.H., Hou, L.F., Guo, C.L., Yang, S.Q.
  Fabrication and compressive behaviour of an aluminium foam composite
  (2015) *J Alloys Compd*, 649, pp. 76-81.

- Yang, B., kang, Y.J., Chen, C.
  Microstructure and thermal expansion of Ti coated diamond/Al composites
  (2009) *Trans Nonferrous Met Soc China (English Ed*, 19, pp. 1167-1173.

- Zhang, C., Cai, Z., Wang, R., Peng, C., Qiu, K., Wang, N.
  Microstructure and thermal properties of Al/W-coated diamond composites prepared by powder metallurgy
  (2016) *Mater Des*, 95, pp. 39-47.

- Ma, S., Zhao, N., Shi, C., Liu, E., He, C., He, F.
  (2017) *Mo 2 C coating on diamond: different effects on thermal conductivity of diamond/Al and diamond/Cu composites*, 402.
  Elsevier B.V.

- Suleiman, M.J., Ahmad, M.A., Mohamed, N., Mohamad Junus, Y., Ibrahim, R., Mohamad, M.
  Effect of atmosphere on the sintered titanium alloy produced by metal injection molding (mim) technique
  (2013) *J Ind Technol*, 21, pp. 9-17.

- Dong, Y., Zhang, R., He, X., Ye, Z., Qu, X.
  Fabrication and infiltration kinetics analysis of Ti-coated diamond/copper

composites with near-net-shape by pressureless infiltration
(2012) *Mater Sci Eng B Solid-State Mater Adv Technol*, 177, pp. 1524-1530.

- Zhang, C., Cai, Z., Wang, R., Peng, C., Feng, Y.
Enhancing densification capacity and properties of Al/diamond composites by partial liquid hot pressing
(2017) *Surf Coating Technol*, 313, pp. 347-354.

- Abyzov, A.M., Kruszewski, M.J., Ciupiński, Ł., Mazurkiewicz, M., Michalski, A., Kurzydłowski, K.J.
Diamond-tungsten based coating-copper composites with high thermal conductivity produced by Pulse Plasma Sintering
(2015) *Mater Des*, 76, pp. 97-109.

- Parveez, B., Nur Ayuni, J., Abdul Aabid, M.B., F, Y.
Experimental analysis and parametric optimization on compressive properties of diamond-reinforced porous Al composites
(2023) *Materials*, 16, p. 91.

- Sun, Y., Zhang, C., He, L., Meng, Q., Liu, B.C., Gao, K.
Enhanced bending strength and thermal conductivity in diamond/Al composites with B4C coating
(2018) *Sci Rep*, 8, pp. 1-12.

- Kovarik, O., Cizek, J., Yin, S., Lupoi, R., Janovska, M., Cech, J.
Mechanical and fatigue properties of diamond-reinforced Cu and Al metal matrix composites prepared by cold spray
(2022) *J Therm Spray Technol*, 31, pp. 217-233.

- (2006) *ASTM C373-14 standard test method for water absorption, bulk density, apparent porosity, and apparent specific gravity of fired whiteware products*, 88, pp. 1-2.
Astm C373-88

- Luecke, W.E., Ma, L., Graham, S.M., Adler, M.A.
Repeatability and reproducibility of compression strength measurements conducted according to ASTM E9
(2009), p. 39.

- Baumeister, J., Banhart, J., Weber, M.
Aluminium foams for transport industry
(1997) *Mater Des*, 18, pp. 217-220.

- Bekoz, N., Oktay, E.
Effects of carbamide shape and content on processing and properties of steel foams
(2012) *J Mater Process Technol*, 212, pp. 2109-2116.

- Yang, K., Yang, X., Liu, E., Shi, C., Ma, L., He, C.
Elevated temperature compressive properties and energy absorption response of in-situ grown CNT- reinforced Al composite foams
(2017) *Mater Sci Eng, A*, 690, pp. 294-302.

- Chu, K., Jia, C.C., Liang, X.B., Chen, H.
Effect of sintering temperature on the microstructure and thermal conductivity of Al/diamond composites prepared by spark plasma sintering
(2010) *Int J Miner Metall Mater*, 17, pp. 234-240.

- Yang, X., Zou, T., Shi, C., Liu, E., Chunnian He, N.Z.
Effect of carbon nanotube (CNT) content on the properties of in-situ synthesis CNT reinforced Al composites
(2016) *Mater Sci Eng, A*,

- Al-Maharma, A.Y., Patil, S.P., Markert, B.
Effects of porosity on the mechanical properties of additively manufactured components: a critical review
(2020) *Mater Res Express*, 7.

- Orlova, Y., Maekawa, K., Rack, H.J.
Structure formation during preparation of variable porosity titanium foams by solid state replication
(2010) *Key Eng Mater*, 436, pp. 165-170.

- Mizuuchi, K., Inoue, K., Agari, Y., Morisada, Y., Sugioka, M., Tanaka, M.
Processing of diamond particle dispersed aluminum matrix composites in continuous solid-liquid co-existent state by SPS and their thermal properties
(2011) *Compos B Eng*, 42, pp. 825-831.

- Kwon, H., Leparoux, M., Heintz, J.M., Silvain, J.F., Kawasaki, A.
Fabrication of single crystalline diamond reinforced aluminum matrix composite by powder metallurgy route
(2011) *Met Mater Int*, 17, pp. 755-763.

- Tan, Z., Ji, G., Addad, A., Li, Z., Silvain, J.F., Zhang, D.
Tailoring interfacial bonding states of highly thermal performance diamond/Al composites: spark plasma sintering vs. vacuum hot pressing
(2016) *Compos Part A Appl Sci Manuf*, 91, pp. 9-19.

- Liu, K., Bai, Y., Zhang, L., Yang, Z., Fan, Q., Zheng, H.
Porous Au-Ag nanospheres with high-density and highly accessible hotspots for SERS analysis
(2016) *Nano Lett*, 16, pp. 3675-3681.

- Zhang, Z., Ding, J., Xia, X., Sun, X., Song, K., Zhao, W.
Fabrication and characterization of closed-cell aluminum foams with different contents of multi-walled carbon nanotubes
(2015) *Mater Des*, 88, pp. 359-365.

- Novak, B., Tschope Apr, K., T, G.
Fundamentals of aluminium carbide formation
(2012) *Light Met*, pp. 1-1407.

- Tan, Z., Li, Z., Fan, G., Kai, X., Ji, G., Zhang, L.
Fabrication of diamond/aluminum composites by vacuum hot pressing: process optimization and thermal properties
(2013) *Compos B Eng*, 47, pp. 173-180.

- Kleiner, S., Khalid, F.A., Ruch, P.W., Meier, S., Beffort, O.
Effect of diamond crystallographic orientation on dissolution and carbide formation in contact with liquid aluminium
(2006) *Scripta Mater*, 55, pp. 291-294.

- Edtmaier, C., Segl, J., Rosenberg, E., Liedl, G., Pospichal, R., Steiger-Thirsfeld, A.
Microstructural characterization and quantitative analysis of the interfacial carbides in Al(Si)/diamond composites
(2018) *J Mater Sci*, 53, pp. 15514-15529.

- Monje, I.E., Louis, E., Molina, J.M.
Aluminum/diamond composites: a preparative method to characterize reactivity and selectivity at the interface
(2012) *Scripta Mater*, 66, pp. 789-792.

- Ruch, P.W., Beffort, O., Kleiner, S., Weber, L., Uggowitzer, P.J.
Selective interfacial bonding in Al(Si)-diamond composites and its effect on thermal conductivity
(2006) *Compos Sci Technol*, 66, pp. 2677-2685.

- Zhang, Y., Wang, X., Jiang, S., Wu, J.
Thermo-physical properties of Ti-coated diamond/Al composites prepared by pressure infiltration
(2010) *Mater Sci Forum*, 654, pp. 2572-2575.
656

- Pal, U., Sandoval, A., Madrid, S.I.U., Corro, G., Sharma, V., Mohanty, P.
Mixed titanium, silicon, and aluminum oxide nanostructures as novel adsorbent for removal of rhodamine 6G and methylene blue as cationic dyes from aqueous solution
(2016) *Chemosphere*, 163, pp. 142-152.

- Jiang, M.G., Xu, C., Nakata, T., Yan, H., Chen, R.S., Kamado, S.
Development of dilute Mg-Zn-Ca-Mn alloy with high performance via extrusion
(2016) *J Alloys Compd*, 668, pp. 13-21.

- Guan, M., Hu, Y., Zheng, T., Zhao, T., Pan, F.
Composition optimization and mechanical properties of Mg-Al-Sn-Mn alloys by orthogonal design
(2018) *Materials*, 11.

- Amore, S., Ricci, E., Borzone, G., Novakovic, R.
Wetting behaviour of lead-free Sn-based alloys on Cu and Ni substrates
(2008) *Mater Sci Eng, A*, 495, pp. 108-112.

- Jiang, Q.C., Wang, H.Y., Ma, B.X., Wang, Y., Zhao, F.
Fabrication of B4C participate reinforced magnesium matrix composite by powder metallurgy
(2005) *J Alloys Compd*, 386, pp. 177-181.

- Matan Cafri, N.F.
Boron carbide/magnesium alloys composites : processing, microstructure and properties
(2012),

- Mota, J.M., Martinez, M.A., Velasco, F., Criado, A.J.
Preparation of aluminium boride by powder technology
(2004) *Ceram Int*, 30, pp. 301-306.

- Ebhota, W.S., Jen, T.-C.
Intermetallics Formation and their effect on mechanical properties of Al-Si-X alloys
(2018) *Intermet Compd - Form Appl*,

- Rajak, D.K., Pagar, D.D., Kumar, R., Pruncu, C.I.
Recent progress of reinforcement materials: a comprehensive overview of composite materials
(2019) *J Mater Res Technol*, 8, pp. 6354-6374.

- Yang, D., Hu, Z., Chen, W., Lu, J., Chen, J., Wang, H.
Fabrication of Mg-Al alloy foam with close-cell structure by powder metallurgy approach and its mechanical properties
(2016) *J Manuf Process*, 22, pp. 290-296.

- Parveez, B., Jamal, N.A., Anuar, H., Ahmad, Y., Aabid, A., Baig, M.
Microstructure and mechanical properties of metal foams fabricated via melt

foaming and powder metallurgy technique : a review
(2022) *Materials*, 15, p. 5302.

- Asavavisithchai, S., Kennedy, A.R.
The effect of Mg addition on the stability of Al-Al2O 3 foams made by a powder metallurgy route
(2006) *Scripta Mater*, 54, pp. 1331-1334.

- Jamal, N.A., Yusof, F., Nor, Y.A., Othman, M., Khalid, K., Zakaria, M.N.
The role of tin and magnesium in assisting liquid phase sintering of aluminum (Al)
(2018) *IOP Conf Ser Mater Sci Eng*, 290.

- Parveez, B., Wani, M.F.
Tribological behaviour of nano-zirconia reinforced iron-based self-lubricating composites for bearing applications
(2021) *Tribol Int*, 159.

- Fornaro, O.
Directional solidification of Sn-Cu6Sn5 in situ composites
(2019) *Adv Mater Sci Eng*, 2019, pp. 16-20.

- Kontis, P., Yusof, H.A.M., Pedrazzini, S., Danaie, M., Moore, K.L., Bagot, P.A.J.
On the effect of boron on grain boundary character in a new polycrystalline superalloy
(2016) *Acta Mater*, 103, pp. 688-699.

- Abenojar, J., Martinez, M.A., Velasco, F.
Effect of the boron content in the aluminium/boron composite
(2006) *J Alloys Compd*, 422, pp. 67-72.

- Kaczmar, J.W., Naplocha, K., Morgiel, J.
Microstructure and strength of Al2O3 and carbon fiber reinforced 2024 aluminum alloy composites
(2014) *J Mater Eng Perform*, 23, pp. 2801-2808.

- Trinath, K., Aepuru, R., Biswas, A.
Study of microstructure and mechanical behaviour of Ti2AlC reinforced hypereutectic Al-16Si matrix composites fabricated by induction melting
(2022), pp. 1-10.

- Sun, Y., Li, C., Liu, Y., Yu, L., Li, H.
Intermetallic phase evolution and strengthening effect in Al–Mg2Si alloys with different Cu/Ni ratios
(2018) *Mater Lett*, 215, pp. 254-258.

- Tan, Z., Li, Z., Xiong, D.B., Fan, G., Ji, G., Zhang, D.
A predictive model for interfacial thermal conductance in surface metallized diamond aluminum matrix composites
(2014) *Mater Des*, 55, pp. 257-262.

- Liu, P.S., Ma, X.M.
Property relations based on the octahedral structure model with body-centered cubic mode for porous metal foams
(2020) *Mater Des*, 188.

- Gibson, L., Ashby, M.
Cellular solids: structure and properties
(1999), Cambridge press

- Jamal, N.A., Tan, A.W., Yusof, F., Katsuyoshi, K., Hisashi, I., Singh, S.
Fabrication and compressive properties of low to medium porosity closed-cell

porous Aluminum using PMMA space holder technique
(2016) *Materials*, 9, pp. 1-13.

- Linul, E., Marsavina, L., Ková, J.
Collapse mechanisms of metal foam matrix composites under static and dynamic loading conditions
(2017) *Mater Sci Eng, A*, 690, pp. 214-224.

- Kováčik, J., Orovčík Jj, Ľ.
High-temperature compression of closed cell aluminium foams
(2016) *Kov Mater*, 54, pp. 429-440.

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