Evaluation of Mechanical Properties of Developed Graphite-reinforced- Aluminium Metal Based Composites

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Abstract. Aluminium metal matrix composites have developed for its attractive properties and performances. Graphite-reinforced-aluminium composites have developed with varying the volume percentage (vol. %) of reinforcement, typical variations of graphite have conducted from 2.28\% to 13.19\%. Presence of different phases after sintering have specified by X-ray diffraction (XRD). Surface morphology of each developed metal has studied with scanning electron microscopy (SEM). Ultimate tensile strength (UTS) has computed from the measured hardness as per ASTM A 370-68 standards. Other mechanical properties like tensile strength and young’s modulus (also termed as modulus of elasticity) have found out and reported.

Keywords: Graphite-reinforced-Aluminium, Powder Metallurgy, Surface Morphology, UTS, Tensile Strength, Young’s Modulus.

1. Introduction
Continuous efforts have observed among materials engineers to develop new materials, which can fulfil the requirements of various demands on modern industries. Industries are continuously searching for strong, high strength materials, which can cater the requirements, and having longer lifespan. Aluminium is lightweight, durable metal and is easily available on earth crust. Aluminium has not only good corrosion properties, excellent casting abilities but also has low thermal expansion, wear resistant [1-5]. For this reason, aluminium is being used in different industrial applications like electrical and electronics industries, transport industry including aerospace, aeronautics, automobile applications etc. [1][6-7]. Still low melting point converge the applications of aluminium in limited fields [7-9]. However, this problem can overcome with incorporating suitable second phase into it [2-6] [10-15].

Powder metallurgy is an art or technology by which one can fabricate composites cost effectively with exact size and dimensions [16-17]. Under this fabrication technique, composites can be developed without melting its constituent materials with consequent improvement of properties [16-17]. Authors are tried to develop graphite-reinforced-aluminium metal based composites and also finding out the relevance of incorporating graphite as reinforcement. Study has also tried to visualise the various mechanical properties of developed composites.

2. Experimental procedure
The Graphite-reinforced-aluminium composites have developed followed by conventional 'powder metallurgy' technique maintaining the steps of milling and mixing, compaction and sintering carried
out simultaneously into hot press unit (makes by ‘NascorTechnologies Pvt. Ltd.’, W.B., India). Mixing and grinding was conducted into mortar parcel to produce fine graphite-aluminium powder, having mesh size ~ 250 µm. Various compositions of produced powder have considered separately. Powders of each composition has poured into separate steel die and placed into hot pressing unit towards developing composites with applying 550°C temperature for 1.5 hours maintaining 4.2 ton pressure. After sintering, each sample has cooled slowly into the same furnace unit. After removing from furnace, each composite has polished and considered for further studies.

3. Results and Discussions
Obtained results and corresponding discussions are elaborated below.

3.1. XRD Analysis
To get a thorough insight of the present problem, a transient study is conducted first for a set of typical values of flow parameters (Gr = 10^5, Re = 200, Bi = 1 and Ma = 1000) considering both downward and upward motion of the sidewalls. The corresponding results on the temporal evolutions of flow and thermal fields are analyzed in Figs. 2–3. Non-dimensional time instants are marked by different values of τ ranging from 0.01 to 10. First, the development of flow pattern in terms of XRD pattern for graphite-reinforced aluminium metal based composite has plotted in fig. 1. Aluminium has detected at 2θ angle ~ 38.493°, 44.739°, 65.012°, 78.019°, 82.07° and graphite is found out at 2θ angle of ~ 26.7° with low abundance. Noted that XRD analysis is carried out from 2θ angle of ~ 20° to 80° with scan 5°/minute utilising ‘RigakuUltima III analytical diffractometer’.

![XRD pattern for graphite-reinforced aluminium metal based composite](image)

**Figure 1.** XRD pattern for graphite-reinforced aluminium metal based composite.

3.2. Surface morphology
Surface morphology based on SEM has shown in fig. 2. Graphite has spread in random way into aluminium matrix. The tendency of forming pores has observed with graphite reinforcement. Mentioned that maximum porosity has found out for 13.19 vol. % graphite-reinforced aluminium composite, value only 0.52%.

3.3. Hardness and UTS
Hardness survey has carried out using ‘Leco Micro-hardness tester, model LM248SAT’ and obtained hardness values are reported in table 1. Hardness has seen to be improved with graphite reinforcement. Ultimate tensile strength (UTS) has computed utilising theoretical conversion [18-19] and plotted in fig. 3. UTS has also improved with graphite reinforcement into graphite-reinforced aluminium metal based composites as shown in fig. 3.
Figure 2. Surface morphology (SEM) of (a) 2.28 %, (b) 4.537 %, (c) 6.017 %, (d) 7.484 %, (e) 8.933 %, (f) 10.37 %, (g) 11.789 %, (h) 13.19 % (based on vol. %) graphite-reinforced-aluminium metal based composite.
3.4. Determination of tensile strength and modulus of elasticity

Tensile Strength and the modulus of elasticity can be calculated from the rules of mixture for composites. Modulus of elasticity is considered as 69 GPa and 9.6 GPa for aluminium matrix and graphite reinforcement respectively [20-24]. The obtained results for developed composites are demonstrated in Table 2. Tensile strength has taken 90 MPa and 10 MPa for aluminium and graphite respectively from reputed articles [20-24].

![Variation of ultimate tensile strength (UTS) with reinforcement.](figure3)

**Figure 3.** Variation of ultimate tensile strength (UTS) with reinforcement.

**Table 1.** Hardness for graphite-reinforced aluminium composites.

| Composition                                      | Hardness in MPa |
|--------------------------------------------------|-----------------|
| Sintered aluminium                               | 283.3           |
| 2.28 % graphite-reinforced-aluminium composite   | 332.5           |
| 6.017 % graphite-reinforced-aluminium composite  | 334.9           |
| 8.933 % graphite-reinforced-aluminium composite  | 325.0           |
| 13.19 % graphite-reinforced-aluminium composite  | 306.6           |

**Table 2.** Young’s modulus and tensile strength for graphite-reinforced aluminium composites.

| Composition                                      | Young’s modulus in GPa | Tensile strength in MPa |
|--------------------------------------------------|------------------------|-------------------------|
| 2.28 % graphite-reinforced-aluminium composite   | 67.784                 | 88.365                  |
| 3.04 % graphite-reinforced-aluminium composite   | 67.200                 | 87.568                  |
| 3.79 % graphite-reinforced-aluminium composite   | 66.740                 | 86.959                  |
| 4.537 % graphite-reinforced-aluminium composite  | 66.309                 | 86.367                  |
| 6.017 % graphite-reinforced-aluminium composite  | 65.428                 | 84.642                  |
| 7.484 % graphite-reinforced-aluminium composite  | 64.553                 | 83.998                  |
| 8.933 % graphite-reinforced-aluminium composite  | 63.689                 | 82.790                  |
| 10.37 % graphite-reinforced-aluminium composite  | 62.839                 | 81.704                  |
| 11.789 % graphite-reinforced-aluminium composite | 61.988                 | 80.559                  |
| 13.19 % graphite-reinforced-aluminium composite  | 61.159                 | 79.439                  |
4. Conclusions
Significant conclusions based on this study have noted below.
- Successful development of graphite reinforced aluminium composites have observed cost effectively through power metallurgy technique.
- Graphite reinforced aluminium composites are much lighter in weight. Mentioned that these composites are weight saving even pure aluminium.
- Improvement of hardness, hence UTS, has found out with graphite reinforcement.
- Tensile strength and the modulus of elasticity for developed metals are slightly affected with graphite reinforcement.
- These developed metal based composites can be used to design the outer shell of an automobile body, fabricating various engine parts in automobiles/ aerospace industries. Mentioned that these types of metals having tolerable amount of pores may be appreciated for designing gearwheel arrangements.

References
[1] Prasad S V and Asthana R 2004. Aluminium metal matrix composites for automotive applications; Tribological Considerations, Tribology Letters 17(3), pp. 445-453.
[2] Hesabi Z R, Simchi A, Raihani S M S 2006. Structural evolution during mechanical milling of nanometric and micrometric Al2O3 reinforced Al matrix composites, Materials Science and Engineering, A428.
[3] Tong X C and Ghosh A K 2001. Fabrication of in situ TiC reinforced Aluminum matrix composites, Journal of Materials Science 36, pp. 4059-4069.
[4] Magesh M, Baruch L J, Oliver D G 2014. Microstructure and Hardness of Aluminium Alloy-Fused Silica Particulate Composite, International Journal of Innovative Research in Advanced Engineering 1(5), pp. 199-204.
[5] Hamouda A M S, Sulaiman S, Vijayaram T R, Sayuti M, Ahmad MH M 2007. Processing and characterization of particulate reinforced aluminium silicon matrix composite, Journal of Achievements in Materials and Manufacturing Engineering 25(2), pp. 11-16.
[6] Chawla N and Chawla K K 2006. Metal Matrix Composites in ground transportation, Springer-Verlag, New York, pp. 401.
[7] Dixit A 2018. Application of silica-gel-reinforced aluminium composite on the piston of internal combustion engine: Comparative study of silica-gel-reinforced aluminium composite piston with aluminium alloy piston, Composites and Advanced Materials for Industrial Applications, pp. 63-98. DOI: 10.4018/978-1-5225-5216-1.ch004
[8] Usman A M, Raji A, Waziri N H, Hassan M A 2014. Production and Characterization of Aluminium Alloy - Bagasse Ash Composites, IOSR Journal of Mechanical and Civil Engineering 11(4) Ver. III (Jul- Aug. 2014), pp. 38-44.
[9] Wakeel S 2017. Fabrication and Mechanical Properties of Aluminium Composites, Scholarpress, omniscrptum publication group- Germany, ISBN 978-3-639-71638-2.
[10] Bharath V, Nagaral M, Auradi V 2012. Preparation of 6061Al-Al2O3 metal matrix composite by stir casting and evaluation of mechanical properties, International Journal of Metallurgical & Materials Science and Engineering 2(3), pp. 22-31.
[11] Toptan F, Karaaslan A A, Cigdem M, Kerti 2009. Processing and microstructural characterization of AA 1070 and AA 6063 matrix B4Cp reinforced composites, Materials and Design 31, pp.87-91.
[12] Tong X C and Ghosh A K 2001. Fabrication of in situ TiC reinforced Aluminum matrix composites, Journal of Materials Science 36, pp. 4059-4069.
[13] Hembrom S, Roy B N, Khobragade N, Roy D 2016. Studies on Amorphous Alloy Dispersed Aluminium Matrix Composite Prepared by High Pressure Torsion, Journal of Materials Science Research 5(1), pp. 89-96.
[14] Huo H and Woo KD 2006. In situ synthesis of Al2O3 particulate reinforced Al matrix
composite by low temperature sintering, Journal of Materials Science 41, pp. 3249-3253.

[15] Shi Z 2001. The oxidation Of SiC Particles and its interfacial characteristics in Al-Matrix composite, Journal of Materials Science, 36, pp. 2441 – 2449.

[16] Debnath S and Pramanick A K 2016. Development and study on different properties of aluminium- crystalline silica ceramic matrix composites at different sintering temperatures, IJERGS 4(3), pp. 415- 423.

[17] Debnath S and Pramanick A K 2016. Development and Evaluation of Various Properties of Crystalline Silica- Aluminium Metal Based Composites, IJERGS 4(2), pp. 236-245.

[18] Zhang P and Zhang Z F 2011. General relationship between strength and hardness, Materials Science and Engineering: A, ScienceDirect, 529, pp. 62-73. https://doi.org/10.1016/j.msea.2011.08.061

[19] Gaško M and Rosenberg G 2011. Correlation between hardness and tensile properties in ultra-high strength dual phase steels – short communication, Materials Engineering - Materiálové inžinierstvo 18, pp. 155-159. http://fstroj.uniza.sk/PDF/2011/27-2011.pdf

[20] Kumar S S, Bai V S, Rajkumar K V, Sharma G K, Jayakumar T, Rajasekharan T 2009. Elastic modulus of Al–Si/SiC metal matrix composites as a function of volume fraction, Journal of Physics d: applied physics, IOP publishing 42, pp. 1-10. doi:10.1088/0022-3727/42/17/17550

[21] Luis Guilherme Borzani Manhania, Luiz Claudio Pardinib, Flamínio Levy Netoc 2007. Assessment of Tensile Strength of Graphites by the Iosipescu Coupon Test, Materials Research, 10(3), pp. 233-239.

[22] Eung Soo Kim and Chang H Oh 2007. Estimation of graphite density and mechanical strength of vhtd during air-ingress accident, The 12th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-12), Log Number: 185, pp. 1-13, Sheraton Station Square, Pittsburgh, Pennsylvania, U.S.A.

[23] Butt J, Mebrahtu H, Shirvani H 2016. Strength analysis of aluminium foil parts made by composite metal foil manufacturing, ProgAddit Manuf. 1, pp. 93-103. DOI 10.1007/s40964-016-0008-5

[24] Imran M and Sadik S 2016. Study of hardness and tensile strength of Aluminium-7075 percentage varying reinforced with graphite and bagasse-ash composites, Resource-Efficient Technologies, ScienceDirect, 2(2), pp. 81-88.

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