Investigation on mechanical properties of hybrid graphene
and beryl reinforced aluminum 7075 composites

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Abstract:
The emerging technologies and trends of present generation requires downsizing the unwieldy structures
light weight structures on one hand and integration of varied properties on other hand to meet the application
demands. In the present investigation an attempt is made to familiarize and best possibilities of reinforcing agent
in aluminum 7075 matrix with naturally occurring beryl (Be) and graphene (Gr) to develop a new hybrid composite
material. A stir casting process was used to fabricate with fixed volume fraction of 6wt% weight beryl and various
volume fractions of 0.5wt%, 1wt%, 1.5wt% and 2wt% of graphene. The properties such as tensile strength,
compression strength, and hardness of hybrid composites were examined. The crystallite size and morphology of
the graphene and beryl particles were analyzed with X-ray diffraction (XRD) and scanning electron microscopy
(SEM) respectively. It was observed that ultimate tensile strength and compression strength of the hybrid composite
increased with increasing reinforcement volume fraction as compared to specimen without reinforcement
additions.
Keywords: Al7075, Beryl, Graphene, Stir casting, Mechanical properties.

1. Introduction
Aluminum is the light weight and second most plentiful metal available on the earth. It has been
most widely used and became an economic competitor in the field of commercial applications such as
mirror frames, house members, serving trays and cooking utensils. Even in the field of engineering
applications, the aluminum and its alloys plays vital role as an automotive and aerospace material of
increasing value because of the it’s properties which includes diverse range of uses are appearance, light
weight and has a density of 2.7 gm/cm³ which is approximately one-third of steel (7.83 gm/cm³). Ease
of fabric ability that is excellent machinability and formability. The most attractive attention
characteristics of aluminum are its adaptability and flexibility [1].The addition ceramic reinforcements
into the aluminum alloys metal matrix leads to development of suitable and comfortable engineering
materials with higher strength to weight ratio [2-4]. The Al MMC’s satisfy many engineering
application and also provides convenient processing because of enough melting point of aluminum. The
aluminum alloy consist of zinc, magnesium and copper as major alloying elements is belongs to 7xxx
series and commonly known as Al7075 which has a high strength, corrosion resistance and hence it is
typically used in aircraft fittings including gears, shafts and various other forms of commercial
transportation, aerospace parts and other highly stressed structural applications[5-11]. Recently the
incorporation of particulate reinforced ceramic hard particles like silicon carbide, boron carbide,
aluminum oxides, beryl (Be₃Al₂(SiO₃)₆), silicide’s such as nickel silicide (Si₃N₄), magnesium silicide
(Mg₂Si) etc. into the Al matrix are enhances its mechanical and physical properties of the composites
and made them a low cost, inherent isotropic and better candidate materials for various engineering
applications. [12-16]. Many researcher worked Al-SiC MMCs and shown limitation such as formation
of Al₄C₃ during high temperature fabrication leads to poor mechanical properties. However a very little
and few research work have been revealed with beryllium aluminum silicate (beryl) and graphene are
being used as reinforcements in Al-MMC. Beryl is naturally occurring material incorporation in Al
MMC exhibit wear resistance and increases hardness [17-20]. William Speer et al [21] have described the applications of aluminum-beryllium metal matrix composites (AlBeMet). The AlBeMet composites are most widely used in aerospace and structural applications. The AlBeMet material has excellent light weight, high strength to weight ratio and thermal properties are outstanding which perfect match for the high temperature applications. AlBeMet material has a low coefficient of thermal expansion, high melting point, high specific heat and high thermal conductivity these properties are favorable for variety space and aerospace application. Graphene has the outstanding mechanical, thermal, electrical properties and because of it has been ideal reinforcement for the Al MMC [22-23]. The many researchers Pradeep Rohatgi, D.M Skibo, S. Balasivanandha Prabhu, Jameel Habeeb Ghazi, Abhilash Vishvanath, Kenneth Kanayo Alaneme, J. Hashim et al, [24-29] has revealed that, stir casting is one of the most economical and widely used for particulate metal matrix composites. In the present study, Al 7075 as matrix and Al7075/Beryl/Graphene MMCs were fabricated by liquid metallurgy route with varying percentage of graphene from 0.5wt% to 2wt% in steps of 0.5 and fixed percentage (6wt %) of beryl. The present study aims to regulate the volume fraction of graphene and beryl addition to liquid aluminum 7075 alloy and also to evaluate the mechanical properties of aluminum-beryl/ graphene (AlBeGr) hybrid composite.

2. Materials and Methods

2.1 Matrix Material:
In the present work, Al7075 alloy is used as a matrix material, the alloying elements like zinc, magnesium and copper leads to corrosion resistance, high strength and hardness. Al7075 alloy has outstanding properties which leads to wide usage and found in many engineering sector, typically used in aircraft structural parts and other highly stressed structural application. Al7075 alloy were procured from M/s Fenfe Metallurgical, Bangalore. The chemical composition of matrix alloy shown in Table 1.

Table 1. Chemical composition of Al 7075 Matrix alloy (AlZn5.6MgCu)

| Chemical Composition | Zn  | Mg  | Cu  | Cr  | Ti  | Fe  | Mn  | Si  | Al  |
|----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Wt %                 | 5.602| 2.506| 1.598| 0.253| 0.18| 0.106| 0.0014| 0.052| Balance |

2.2 Reinforcing Materials:
In the present study, Beryl and Graphene are used as reinforcing materials. Beryl, commonly known as beryllium aluminum silicate and having chemical formula (Be3Al2 (SiO3)6) which is naturally available mineral. The density of the mineral beryl is 2700-2800 kg/m³ which is quite similar to the aluminum alloy, having hardness of 7.5-8.5 on Moh’s scale and hexagonal crystal structure was used as the reinforcement [2]. The beryl particle size of 60 to 70 microns (µm).

Table 2. Chemical composition of beryl

| Chemical Composition | SiO₂ | Al₂O₃ | BeO | Fe₂O₃ | CaO | MgO | Na₂O | K₂O | MnO |
|----------------------|------|-------|-----|-------|-----|-----|------|-----|-----|
| Wt %                 | 62.12| 18.05 | 8.24| 4.054 | 1.34| 0.48| 0.55 | 0.004| 0.05|
Figure 1. SEM image Beryl particles

Figure 2. XRD image of Beryl

Figure 1 represent the SEM image (scanning electron micrograph) of beryl and Figure 2 shows the XRD analysis of beryl. The presence of beryl and its hexagonal crystal structure was found in XRD analysis.

Graphene is pure carbon, crystalline allotrope of carbon industrial grade greyish black 97% purity 5-10nm with 10 micron lateral dimension 20-30 layers particulate used here as reinforcement, having 480 kg/m³ and anorthic (triclinic) crystal system.

Figure 3. SEM of graphene

Figure 4. XRD image of graphene

Figure 3 shows the scanning electron micrograph of graphene and Figure 4 shows the XRD analysis of graphene. The anorthic crystal structure was found in XRD analysis.

2.3 Methods:

Al 7075, fixed 6wt% of beryl particles and varying weight percentage of graphene reinforcement were fabricated by liquid metallurgy route (stir casting method) by using 6 kW electrical furnace used in the present study as shown Figure 5. Liquid metallurgy route is the most economical process to develop a new composite materials [5]. The specifications of melting electric furnace as shown in Table 3. Al7075 alloy is first melted in the furnace to temperature of 800°C. The preheated graphene and beryl particulates were poured slowly into vortex of molten metal. The vortex was created by using mechanical stirrer for the duration of 10 minutes and the stirring speed maintained was 300rpm. The melt is degassed by passing nitrogen gas. Finally the molten metal is poured into the preheated cast iron molds. The cast samples are subjected to characterization.
Figure 5. Stir casting set up for development of AlBeGr hybrid composites.

Table 3. Specification of aluminum melting furnace

| Particulars          | Description                                          |
|----------------------|------------------------------------------------------|
| Maximum Temperature  | 12000 °C                                             |
| Crucible size (melting capacity) | 5 kg                                    |
| Heating element      | Silicon Carbide (6 Nos)                             |
| Electric Furnace Controller | Thyristerized PID Temperature-6 kW with power pack |
| Crucible material    | Graphite                                             |
| Power                | 230 Volts, 6 kilo Watts                             |
| Mechanical Stirrer   | 50-1000 rpm, Remi made                              |

The extent of combination of graphene and beryl in the Al 7075 alloy is shown in Table 4.

Table 4. List of composites prepared

| Sample | Al 7075 (wt %) | Beryl (wt %) | Graphene (wt %) |
|--------|----------------|--------------|-----------------|
| S1     | 100            | 0            | 0               |
| S2     | 93.5           | 6            | 0.5             |
| S3     | 93             | 6            | 1               |
| S4     | 92.5           | 6            | 1.5             |
| S5     | 92             | 6            | 2               |

The prepared (AlBeGr) hybrid composites and the base matrix material were subjected for machining to obtain tensile, compression and hardness. The tensile test was carried out on as cast hybrid and matrix materials as per ASTM-E8 standard and compression test was carried out on samples according to ASTM-E9 by using UTM. The hardness tests were carried out as per ASTM-E10 standard. The hardness tests were conducted on three different places of the hybrid composite and matrix test specimens to stand the chance of indenter resting on reinforcement, which may result in desired expected value. The scanning electron micrograph (SEM) tests were carried out on all the test specimens.

3 Results and Discussions:

3.1 Morphology
The microstructure of Al 7075 and hybrid Al7075/ Beryl / Graphene are shown in Figure 6 (a), (b), (c), (d) & (e). The microstructure study clearly reveals that, distribution of graphene and beryl
particles in the matrix are fairly uniform along with increased filler contents with minimal porosity in the hybrid composite. Further, from tests results it is inferred that an excellent bonding between both the Al7075 alloy and reinforcement.

Figure 6(a). Al7075 alloy

Figure 6(b). Al7075/6wt%Be/0.5%Gr

Figure 6(c). Al7075/6wt%Be/1%Gr

Figure 6(d). Al7075/6wt%Be/1.5%Gr

Figure 6(e). Al7075/6wt%Be/2%Gr

Figure 5. SEM morphologies of Al7075, Beryl and Graphene composites
3.2 Tensile Strength:
The results of ultimate tensile test of Al7075 & AlBeGr (hybrid composite) cast specimens are tabulated in Table 5.

| Sample  | Sample Designation                          | Ultimate Tensile Strength (MPa) |
|---------|---------------------------------------------|---------------------------------|
| S1      | Al7075                                      | 122.49                          |
| S2      | Al7075 + 6wt% Beryl + 0.5wt% Graphene       | 215.154                         |
| S3      | Al7075 + 6wt% Beryl + 1wt% Graphene         | 216.627                         |
| S4      | Al7075 + 6wt% Beryl + 1.5wt% Graphene       | 199.574                         |
| S5      | Al7075 + 6wt% Beryl + 2wt% Graphene         | 197.13                          |

The tensile strength of specimen of Al7075 and developed MMC were determined by using UTM. It is inferred from the test results that, the tensile strength of hybrid MMC increases with increasing percentage of reinforcement and optimum tensile strength is achieved for 1% of graphene. This is because, the graphene and beryl particles acts as barriers to the dislocations when the external load applied. Further incorporation of brittle and hard ceramic particles in a ductile matrix [2]. The hybrid composites attains peak strength on addition of 6wt. % of beryl particles and 1% of graphene (sample 3). The hybrid composites having 6wt. % of beryl particles and 1% of graphene showed enhancement of 76.84% as compared to Al7075 matrix material. The bonding, closer packing and smaller inter-particle spacing of reinforcement into the Al 7075 matrix alloy leads to increase in strength. However the tensile strength begins to drop when the Graphene exceeds 1%, it may be due to poor wettability and agglomeration which is unwanted lumping of particulate reinforcement. The tensile strength for
6wt. % of beryl particles and 2wt. % of graphene showed enhancement of 60.93% as compared to matrix material.

3.3 Compression Strength:
The results of compression test on the hybrid cast specimens are tabulated in Table 6. The relationship between compression strength of the fabricated composites with different weight fractions of graphene and beryl particles are shown in Figure 8. From the compression strength test results, it is clearly revealed that the compression strength of hybrid MMC increases with increasing percentage of Graphene content. This is because the beryl being hard material which in turn increases the compression strength of the hybrid composite. The hybrid composites attains peak strength on addition of 6wt. % of beryl particles and 2% of graphene (sample 5). The hybrid composites having 6wt. % of beryl particles and 2% of graphene showed enhancement of 7.064% as compared to Al7075 matrix material. The observed enhancement in compression strength of the hybrid composite is attributed due to the presence of hard beryl (ceramic) particles. The effect of elastic behavior of the reinforcement prevent the plastic deformation of aluminum 7075 alloy matrix resulting in compressive strength [30].

| Sample | Sample Designation | Compression Strength, MPa |
|--------|--------------------|--------------------------|
| S1     | Al7075             | 656.64                   |
| S2     | Al7075 + 6wt%Beryl + 0.5wt% Graphene | 661.99                   |
| S3     | Al7075 + 6wt%Beryl + 1wt% Graphene  | 677.94                   |
| S4     | Al7075 + 6wt%Beryl + 1.5wt% Graphene | 681.99                   |
| S5     | Al7075 + 6wt%Beryl + 2wt% Graphene  | 703.03                   |

Figure 8. Variation of compression strength for different test samples

3.4 Hardness
The results Brinell hardness number test on the hybrid cast specimens are tabulated in Table 7.
Table 7. Brinell hardness test results

| Sample | Sample Designation                        | BHN   |
|--------|-------------------------------------------|-------|
| S1     | Al7075                                    | 90.7  |
| S2     | Al7075 + 6wt% Beryl + 0.5wt% Graphene     | 101   |
| S3     | Al7075 + 6wt% Beryl + 1wt% Graphene       | 104   |
| S4     | Al7075 + 6wt% Beryl + 1.5wt% Graphene     | 94.4  |
| S5     | Al7075 + 6wt% Beryl + 2wt% Graphene       | 93.9  |

The relationship between Brinell hardness number of the fabricated composites with different weight fractions of graphene and beryl particles are shown in Figure 9.

It is inferred from the test results that, the hardness of hybrid MMC increases with increasing weight percentage of reinforcement. The hybrid composites attains peak hardness on addition of 6wt.% of beryl particles and 1% of graphene (sample 3). The hybrid composites having 6wt.% of beryl particles and 1% of graphene showed enhancement of 14.66% as compared to Al7075 matrix material. However the hardness begins to drop when the graphene exceeds 1%, it may be due to poor wettability. The hardness for 6wt. % of beryl particles and 2wt. % of graphene showed enhancement of 3.52% as compared matrix material. This is occurs due to increases in surface area of the matrix and the reduced grain size and beryl particles are harder than Al7075 [2].

4. Conclusions:
1. Al7075-Beryl-Graphene hybrid composites specimens are successfully prepared with fairly uniform distribution of beryl and graphene particulates using stir casing technique.
2. The mechanical (Tensile strength test, compression strength test, hardness) properties have been investigated for both the Al7075 and AlBeGr hybrid MMC.
3. The microstructure through SEM observation of the hybrid composites reveals the fairly uniform distributions of beryl and graphene into the base matrix material.

4. Tensile strength of Al7075-beryl-graphene composites show a peak strength of 216.62 MPa at 6 wt.% of beryl and 1 wt.% of graphene particulate showing improvement of 76.84% when compared to Al7075 matrix material without addition of reinforcement.

5. The compression strength of Al7075-beryl-graphene composites show a peak strength of 703.03 MPa at 6 wt.% of beryl and 2 wt.% of graphene particulate showing improvement of 7.064% when compared to Al7075 matrix material without addition of reinforcement.

6. The hardness of Al7075-beryl-graphene composites show a maximum hardness of 104 BHN at 6 wt.% of beryl and 1 wt.% of graphene particulate showing improvement of 14.66% when compared to Al7075 matrix material without addition of reinforcement.

7. The XRD analysis given the crystal structure and composition of beryl and graphene particulates.

Acknowledgements:
One of the author (Mr. Shanawaz Patil) express heartful thanks to management of Ghousia College of engineering and REVA University for their encouragement in carrying out this work.

References
[1] ASM International: Handbook, Properties and Selection: Nonferrous Alloys and special purpose materials, vol 2 (1990)
[2] K.R. Suresh, H.B. Niranjan, P. Martin Jabraj and M.P. Chowdaiah, “Tensile and Wear Properties of Aluminum Composites, Wear, Vol. 225, No. 1-6, 2003, pp. 638-642. Doi:10.1016/S0043-1648(03)00292-8
[3] D.M. Aylor, Metals Handbook V-13, vol. 9, ASM Metals Park, OH, 1982, pp. 859-863.
[4] Mater. Sci. Eng. A, 245 (1998) 165–172.
[5] Mohammed Imran, A.R. Anwar Khan, Sadananda Megeri, Shoaib Sadik, “Study of hardness and tensile strength of Aluminum 7075 percentage varying reinforced with graphite and bagasse-ash composites”, ELSEVIER, Resource Efficient Technologies 2, 2017, pp. 81-88, http://dx.doi.org/10.1016/j.refit.2016.06.007.
[6] A. Baradeswaran, A. Elaya Perumal, Wear and mechanical characteristics of Al 7075/graphite composites, Compos. Part B Eng. 56 (2014) 472–476.
[7] A. Baradeswaran, A. Elaya Perumal, Study on mechanical and wear properties of Al 7075/Al2O3/graphite hybrid composites, Compos. Part B Eng. 56 (2014) 464–471.
[8] I.A. Ibrahim, F.A. Mohamed, E.J. Lavernia, Particulate reinforced metal matrix composites – a review, J. Mater. Sci. 26 (5) (1991) 1137–1156.
[9] S. Kumar, M. Chakraborty, V. Subramanya Sarma, B.S. Murty, Tensile and wear behaviour of in situ Al–7Si/TiB2 particulate composite, Wear 265 (2008) 134–142.
[10] R. Kumar, S. Dhiman, A study of sliding wear behaviors of Al-7075 alloy and Al-7075 hybrid composite by response surface methodology analysis, Mater. Des. 50 (2013) 351–359.
[11] S. Suresha, B.K. Sridhara, Effect of silicon carbide particulates on wear resistance of graphitic aluminium matrix composites, Mater. Des. 31 (9) (2010) 4470–4477.
[12] R. Deaquino-Lara, N. Soltani, A. Bahrami, E. Gutiérrez-Castañeda, E. García-Sánchez, M.A.L. Hernandez-Rodriguez, “Tribological characterization of Al7075–graphite composites fabricated by mechanical alloying and hot extrusion”,ELSEVIER, Materials and Design 67, 2015, pp 224-231, http://dx.doi.org/10.1016/j.matdes.2014.11.045
[13] Lloyd D. Particle reinforced aluminium and magnesium matrix composites. Int Mater Rev 1994; 39:1–23.
[14] Deaquino-Lara R, Estrada-Guel I, Hinojosa-Ruiz G, Flores-Campos R, Herrera-Ramírez J, Martínez-Sánchez R. Synthesis of aluminium alloy 7075–graphite composites by milling processes and hot extrusion. J Alloys Compd 2011; 509:5284–9.

[15] Soltani N, Pech-Canul M, Bahrami A. Effect of 10Ce–TZP/Al2O3 nanocomposite particle amount and sintering temperature on the microstructure and mechanical properties of Al/(10Ce–TZP/Al2O3) nanocomposites. Mater Des 2013; 50:85–91.

[16] Soltani N, Bahrami A, Pech-Canul M. The effect of Ti on mechanical properties of extruded in-situ Al–15 pct Mg2Si composite. Metall Mater Trans A 2013; 44:4366–73.

[17] N.J. Krishna Prasad, K.R. Suresh, H.B. Niranjan, K.V. Venkateswarlu, “Effect of copper addition on the sintering behavior and mechanical properties of powder processed Al/Beryl composites”, Procedia Materials Science 2014, pp 1148-1154.

[18] Hosur Nanjireddy Reddappa, Kitakanur Ramareddy Suresh, Hollakere Basavaraj Niranjan, Kestur Gundappa Satyanarayana, “Studies on Mechanical and Wear Properties of Al6061/Beryl Composites”, Journal of Minerals and Materials Characterization and Engineering, 2012, 11, 704-708.

[19] Bhaskar H.B, Abdul Sharief, “Effect of Solutionizing On Dry Sliding Wear Of Al2024-Beryl Metal Matrix Composite”, Journal of Mechanical Engineering and Sciences, Dec 2012, Vol 3, pp. 281-290, DOI: http://dx.doi.org/10.15282/jmes.3.2012.4.0026

[20] V. Bharat et al 2016 IOP Conf. Ser.: Mater. Sci. Eng. 114 012103

[21] Z. Hu, G. Tong, D. Lin, C. Chen, H. Guo, J. Xu & L. Zhou (2016): Graphene reinforced metal matrix nanocomposite, a-review, Materials Science and Technology, http://dx.doi.org/10.1080/02670836.2015.1104018

[22] S. F. Bartolucci, J. Paras, M. A. Rafiee, J. Rafiee, S. Lee, D. Kapoor, and N. Koratkar: ‘Graphene–aluminium nanocomposites’, Mater. Sci. Eng. A, 2011, 528, (27), 7933–7937.

[23] Pradeep Rohatgi “Cast Aluminium – Matrix Composites for Automotive Applications” JOM 1991 springer

[24] [3] D.M. Skibo, D.M. Schuster, L. Jolla’ Process for preparation of composite materials containing non-metallic particles in a metallic matrix, and composite materials made by, US Patent No. 4 786 467, 1988.

[25] S. Balasivanandha Prabu, L. Karunamoorthy , S. Kathiresan , B. Mohan “Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composite” Journal of material processing technology 171 2006: 268-273

[26] Dr. Jameel Habeeb Ghazi “Production and Properties of Silicon Carbide Particles Reinforced Aluminium Alloy Composites” International Journal of Mining, Metallurgy and Mechanical Engineering 2013; 1: 2320-4052

[27] Abhilash Viswanath, H. Dieringa, K.K. Ajith Kumar, U.T.S. Pillai, B.C. Pai,” Investigation on Mechanical properties and creep behaviour of stir cast AZ91-SiCp composites”, Journal of Magnesium and Alloys 2015 ; 3 : 16-22

[28] Kenneth Kanyo Alaneme , Olusola Joseph Ajayi, “Microstructure and Mechanical behaviour of stir cast Zn-27Al based composites reinforced with rice husk ash, Silicon carbide and graphite”, Journal of King Saud University- Engineering Sciences 2015

[29] J. Hashim, L. Looney, M.S. J. Hashmi “Metal matrix composites: production by the stir casting method” Journal of Materials Processing Technology 1999; 92-93: 1-7

[30] Munnun Baumik and Kalipada Maity “Fabrication and Characterization of the Al6063/5%ZrO2/5%Al2O3 composite”, IOP conference series: Material Science and Engineering 178 (2017) 012011