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Effect of beryl and graphene nano platelets reinforcements on the wear behaviour of AL7075-beryl graphene particulate hybrid nano composites

The effect of beryl particles and graphene nano platelets (GNPs) on the wear behaviour of Al7075-beryl-graphene hybrid composites has been studied. The hybrid composites were developed containing Al7075 matrix as matrix materials and 6 weight percentage of beryl and varying 0.5 to 2 weight percentage of graphene by using novel two step stir casting technique and wear behaviour of the newly developed hybrid composites were studied. The dry sliding wear studies conducted using a pin-on-disc tribo-tester under atmospheric conditions revealed that the wear loss of Al7075-beryl-graphene hybrid composites are lower than that of the matrix Al7075 alloy and further with increasing weight percentage of graphene decreased the wear loss of the hybrid composites. The wear studies also showed that the increase in load, sliding speed and sliding distance, the wear loss of the composites increased. The microstructure of the worn out surface revealed that a huge amount of plastic deformation appeared on the unreinforced Al7075 alloy when compared to the reinforced hybrid composites. The incorporation of beryl and graphene into Al7075 showed worn out surface that is not smooth and grooves, scratches and parallel lines were observed. The addition of beryl and GNPs into the matrix reduces erosion and small grooves like structure were noticed in the hybrid composites which leads to a reduction in wear in Al7075-beryl-GNPs hybrid composites

Keywords: Al7075, beryl, graphene, microstructure, wear

1.0 Introduction

The current generation's emerging technologies and trends require that the unfavorable structures (difficult to move because of its size, shape and weight) be reduced to lightweight structures. In the modern era, the growth of metal matrix composites (MMCs) has received wide-reaching consideration because of their greater strength, stiffness wear resistance and creep resistance when compared to wrought alloys. Aerospace, space, marine, and automobile (ground and transportation) industries require advanced engineering materials with better characteristics, high performance, greater efficiency and most important lower production costs [2-4].

Aluminum and its alloys are the utmost extensively used metals in many applications due to their attractive mechanical and physical properties. It has high strength, good ductility, and better corrosion resistance, easily available and low cost. It is light structural material used for different applications with a density of 2.6 g/cc. Many series of aluminum alloys can be made by combining various molecular elements in different percentages. Composites developed with Al metal matrix have been used in high-tech structural and functional applications. Fuselage and stringers are held up as an example where AMMCs make difference in aerospace applications. The greater advantages of using AMMCs in aerospace applications is to achieve weight reduction, greater strength, wear resistance, improved stiffness, improved thermal properties, improved damping capabilities, and corrosion resistance [5].

The research is to satisfy various desired engineering applications by selecting proper reinforcement materials with better mechanical properties. Composites of the Al matrix are usually reinforced with alumina (Al_2O_3), boron carbide (B_4C), titanium carbide (TiC), beryl (BeO), graphene, flyash, basalt, carbon nanotubes (CNTs), silicon carbide, etc. The purpose of adding the reinforcing phase into the matrix phase is to increase strength. It is stronger than the matrix material. Reinforcement material possesses certain characteristics like low density, well compatible with respect to mechanical and chemical, has better thermal stability, high strength, good process ability, and economic efficiency [6].

The wrought aluminum alloys are needed to have high strength and improved hardness before using it in end applications. Wrought aluminum alloys subjected to a heat-

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treatment process to alter the grain structure and thereby increasing the strength and also to relieve the residual stresses. The properties of as-cast Al and its alloys can be improved further after exposing to heat-treatment process. Aluminum alloys are generally classified on the basis of heat treatment and it responds to precipitation hardening, which includes heat-treatable or not heat treatable. The Al alloys like 7XXX, 6XXX and 2XXX are heat treatable and its alloying elements gives improved solubility at a higher temperature than at room temperature [10]. The T6-Solution process of heat treatment gives a greater amount of solute into a solid solution. To preserve the solute in supersaturated solid solution (SSS) the material needs to be quenched after the T6 process. The Al alloys are typically subjected to solution heat treating in ovens for enough large temperature followed by quenching in different media [11].

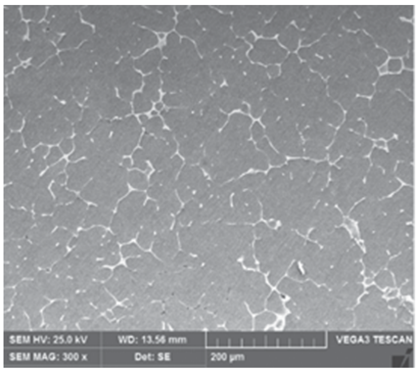
The current investigation includes the development of Al7075-beryl-graphene hybrid composite using liquid metallurgy technique (Fig.1).

2.0 Experimental

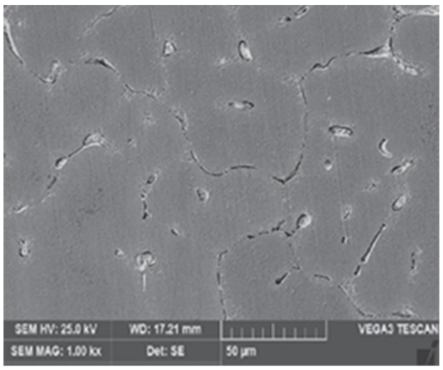
The development of Al7075/graphene/beryl hybrid composites was obtained by stir casting method. The known amount of Al7075 alloy ingots were charged into the electric heating furnace to melt. The furnace temperature set to 800°C to obtain the molten slurry. Thermocouples were used to measure temperature. In order to remove the slag from the molten material a degassing chemical agent hexachloroethane was used. A remi-made mechanical stirrer used for stirring process which was carried out 300 rpm. The stirring process was done for a period of 5 minutes to create the vortex in the molten slurry. At the same time amid the method of stirring the pre-calculated graphene and beryl particulates was included into the vortex in two-stages to guarantee the great wettability. Now the Al7075 alloy along with varying weight percentage of graphene (0.5%, 1%, 1.5% and 2%) and beryl (6 wt. %) were poured into solid cast iron mould to get a composite after solidification.

The composites and the matrix Al7075 alloy were exposed to solutionizing at a temperature of 490±5°C for 2 hours and followed quenching in icy medium and also by artificial aging at 120°C for 6 hours [20].

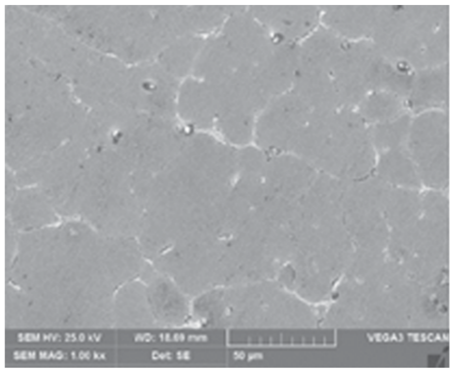
Microstructure characterization are carried out through scanning electron microscopy (SEM). The quantitative phase analysis of developed AMMCs was done by using XRD. The tribological property includes the dry sliding wear behaviour for of as-cast and heat treated hybrid nano composites were studied for different parameters using pin-on disc TR20-LE (Ducom Instruments-Bengaluru) as per ASTM G99.



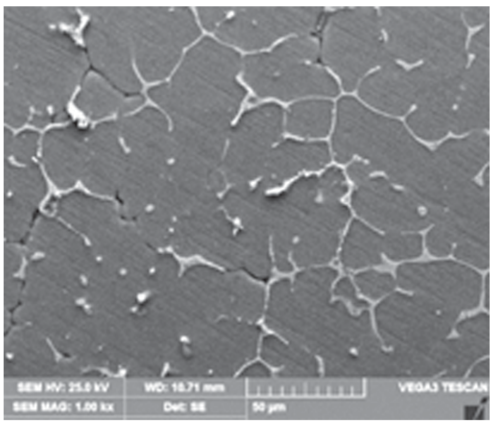
(a) Al7075



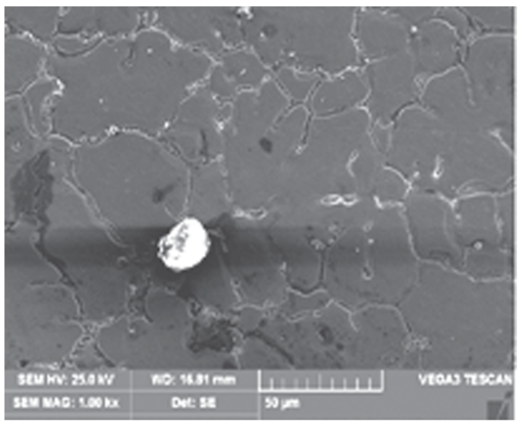
(b) Al7075/0.5Wt.% GNPs/6wt.% Be



(c) Al7075/1Wt.% GNPs/6wt.% Be

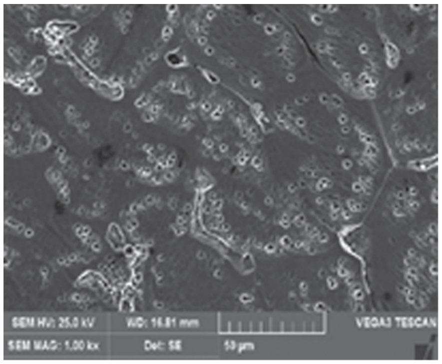


(d) Al7075/1.5Wt.% GNPs/6wt.% Be

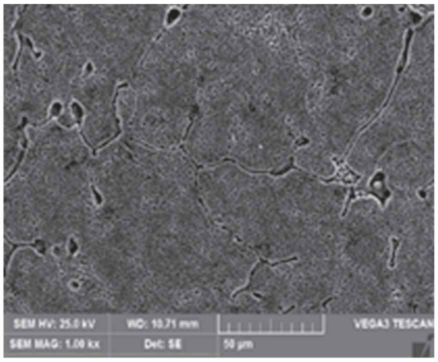


(e) Al7075/2 Wt.% GNPs/6wt.% Be

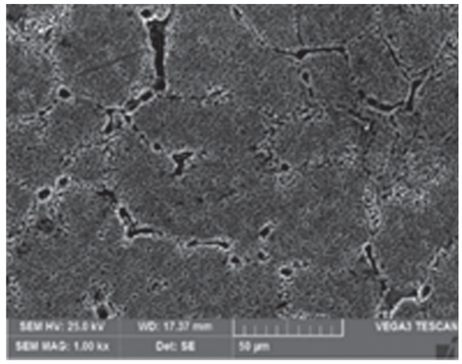
Fig.1: SEM image of Al7075 and its hybrid composites



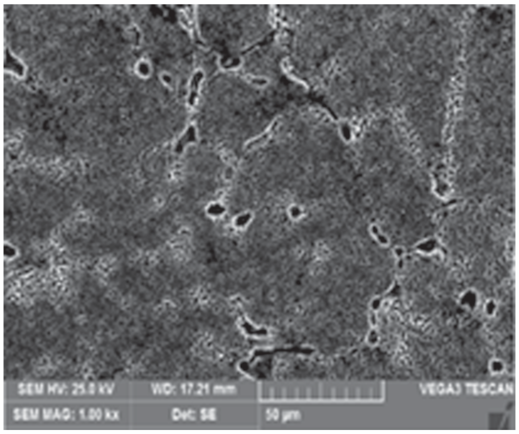
(a) Al7075+6Wt.% Be+1.5Wt.% GNPs



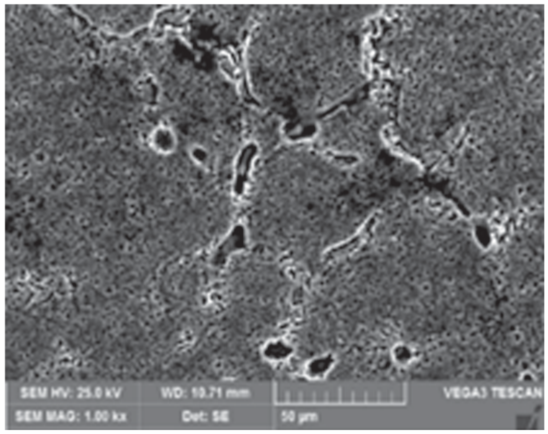
(b) Al7075/0.5Wt.% GNPs/6Wt.% Be



(c) Al7075/1Wt.% GNPs/6Wt.% Be



(d) Al7075/1.5 Wt.% GNPs/6Wt.% Be



(e) Al7075/2Wt.% GNPs/6Wt.% Be

Fig.2: SEM micrographs of ice quenched Al7075 and its hybrid composites

3.0 Result and discussion

3.1 Microstructure Studies

The SEM microstructural analysis was performed on solutionized ice-quench and age hardened Al7075 and its hybrid composites. Fig.2 represents SEM micrographs of solutionized (T6) ice quenched-age hardened Al7075 and its hybrid composites. From the microstructural analysis, it is inferred that grain structure of heat-treated, ice quenched Al7075 are plenty distributed precipitates of $MgZn_2$ intermetallic phases in Al7075 matrix is depicted in Fig.2(a). The age hardening leads to the reduction of micro-segregation and formation of intermetallic phases. The ice quenching media produces and stabilized the intermetallic phase $MgZn_2$ and enhanced bonding between reinforcements and matrix due to lower temperature [11]. The presence of more grain boundaries than the as-cast composites there is more barrier to dislocation wave during deformation and hence enhancement in the material properties. Fig.2 (b-e) represents SEM images of Al7075-beryl-GNPs nano composites. SEM analysis results of hybrid composites are inferred that elimination of micro shrinkage cavities, porosity and formation precipitates of C, Mg, Zn, Fe-rich and secondary phases such as Al-Be-Cu, $AlFe_3$, SiC phases. Complete elemental composition analysis was studied through EDS analysis.

Energy Dispersive Spectroscopy (EDS) analysis carried out while conducting a SEM analysis of Al7075-beryl-GNPs as-cast hybrid composites. EDS analysis spectrum reveals that the presence of aluminum as the highest element followed by carbon (GNPs), Zn, Mg, Cu, and Si, as other elements. Fig.3 depicts the EDS spectrum analysis of Al7075-6Wt. % Beryl-2 wt. % GNPs hybrid composites. Table 1 represents the spot EDS composition of Al 7075-beryl-GNPs hybrid composites in weight percentage.

The occurrence of graphene found at 26.2°. The greater heights peak dose could not be obtained due to nano size and low content of carbon in the matrix materials [15].

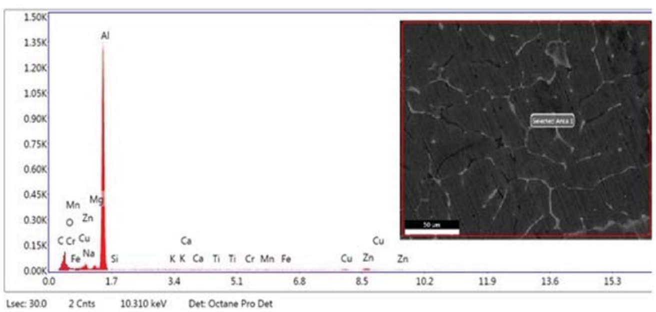


Fig.3: EDS spectrum analysis of Al7075 6 wt. % Beryl-2 wt. % GNPs hybrid composites

Table 1: EDS (Spot) spectrum analysis of Al7075 - 6wt. % beryl–2wt. % GNPs

Elements	Weight %	Atomic %
C	15.50	33.29
Na	0.05	0.06
Mg	3.03	3.22
Al	51.25	49.01
Si	0.48	0.44
K	0.34	0.22
Ca	0.16	0.10
Ti	0.30	0.16
Cr	0.33	0.16
Mn	0.29	0.14
Fe	0.50	0.23
Cu	16.03	6.13
Zn	6.28	2.48

Table 2: Ice quench elemental composition of Al7075 and its nano-composites in wt. % by EDS analysis

Elements	Al7075 Matrix		Al7075+6Wt.%Be+2Wt.%GNPs	
	Wt. %	Atomic %	Wt. %	Atomic %
C	0	0	12.39	14.84
Mg	2.39	2.45	2.48	2.54
Al	82.25	90.74	58.22	63.75
Ti	0.45	0.29	0.48	0.37
Si	0	0	0.98	0.95
Cr	0.54	0.28	0.47	0.17
Mn	0.41	0.19	0.31	0.16
Fe	2.74	2.42	11.68	6.34
Cu	1.95	0.94	3.32	2.81
Zn	5.24	3.15	5.45	3.88

Fig.4 shows the EDS spectrum analysis of solutionized-ice quenched and age hardened Al7075 matrix. From EDS analysis, it confirms the presence of solubility of solute atoms other Al, such as Mg, Zn, Cu, Fe and are represented in Table 2

3.2 XRD analysis of Al 7075-GNPs-beryl nano composites

The developed nano MMCs are exposed to XRD analysis. Fig.5 illustrates the XRD patterns of Al7075 and Al7075-GNP-beryl composites.

XRD analysis test results inferred that intensity of Al7075 decreases and GNPs intensity increases as the GNPs content in Al7075 alloy. It is also observed from X-ray concentrations the peaks are greater at 38°, 65°, and 78°-2θ angle, demonstrating the presence of aluminum phase. The occurrence of beryl phase indicates at 11.6°. The presence of GNPs found at 26.2°.

3.3 Wear behaviour of Al7075-GNPs-beryl nano composites

Application of load is one of the important parameters

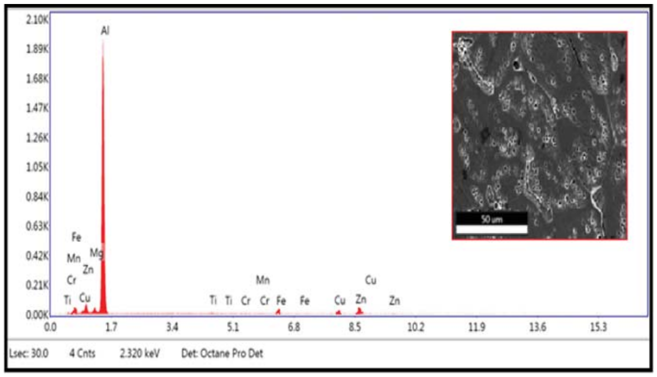


Fig.4: EDS of T6 ice quench Al7075 matrix

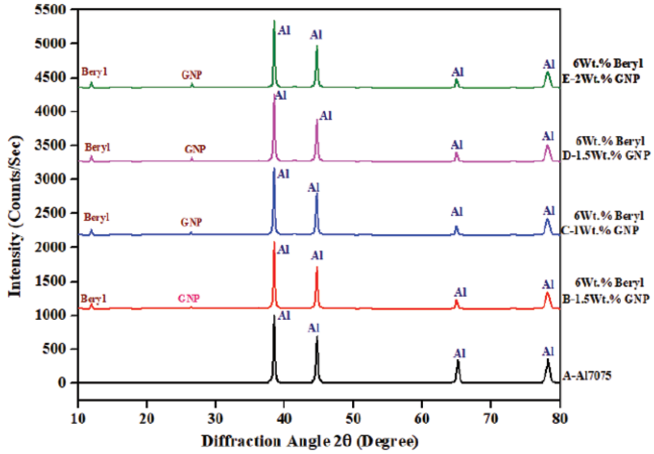


Fig.5: X-Ray diffraction patterns of Al7075 and its composites

play a crucial role in wear loss of the material. Wear loss of Al7075 alloy and its hybrid composites are indicated elsewhere (ref. to authors). In the present research, wear behaviour of the developed as-cast composites are studied at various loads viz., 10N, 20N, and 30N.

Wear test results revealed that wear loss increases due to increase in applied load on Al7075 matrix alloy and Al7075-beryl-GNPs hybrid composites. Wear loss of as-cast Al7075 alloy is highest in all the different loading conditions and it is depicted in Fig.6. Wear loss of hybrid composites consisting of Al7075-beryl–GNPs reduced with an escalation in wt. % of GNPs in Al7075. The highest reduction in wear and increase in wear resistance is for the Al7075- 2 wt. % GNPs and 6 wt.% of beryl. This is due to incorporation of high hardness and homogeneous dispersion of GNPs and beryl particulates into the Al7075. GNPs and beryl particulates act as a barrier and a strong impact on the augmentation of wear resistance.

The force required to separate beryl and GNPs from the Al7075 alloy is more and owing to adhesiveness between Al7075 and beryl is more compared to Al7075. Further hybrid reinforcements particles repel the deformation of the Al7075 and diminish the interaction between pin and disc. The reduction wear loss of 67.17% is found for Al7075– 2 wt.% GNPs 6 wt.% of beryl when compared to Al7075 at 10 N load.

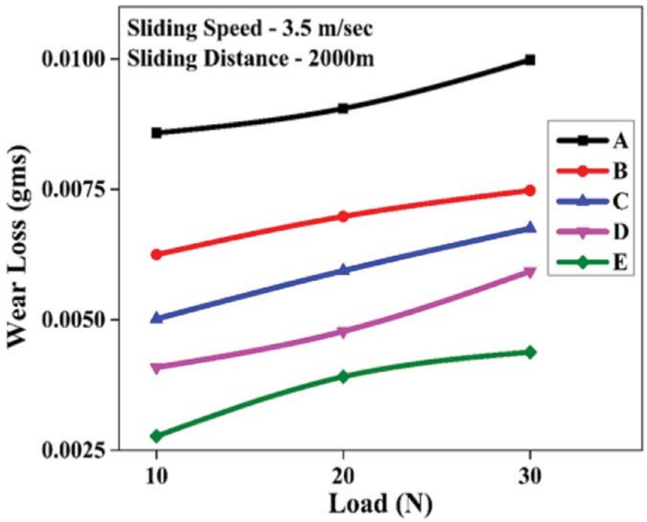


Fig.6: Wear loss of as-cast Al7075 and its hybrid composites at different loads

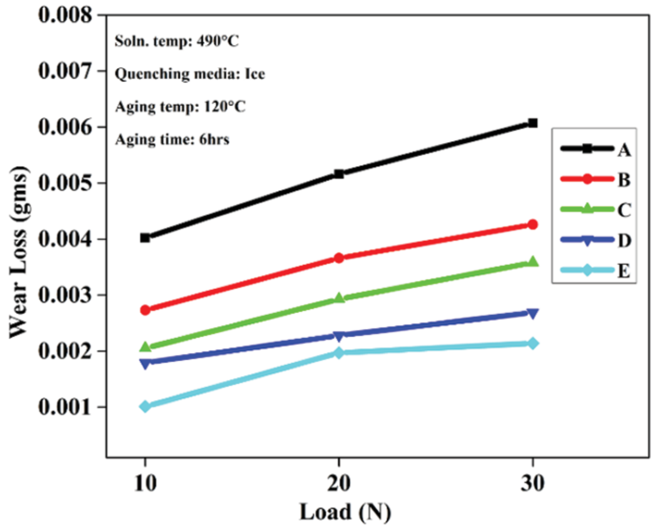


Fig.7: Variation of wear loss of heat-treated ice-quenched Al7075 and its hybrid composites at different loads

The reduction wear loss of 56.79% is found for Al7075– 2 wt.% GNPs 6 wt.% of beryl when compared to Al7075 at 20 N load. The reduction wear loss of 56.11% is found for Al7075– 2 wt.% GNPs 6 wt.% of beryl when compared to Al7075 at 30 N load. The percentages are calculated when compared to base Al7075 matrix material. Bhaskar et al [18] have concluded that addition of beryl content to Al2024 enhances the resistance for the wear of the composites. Tanwir et al [19] claim that wear loss of nanocomposites is increased by increasing the applied load on the A356-nano SiC composites.

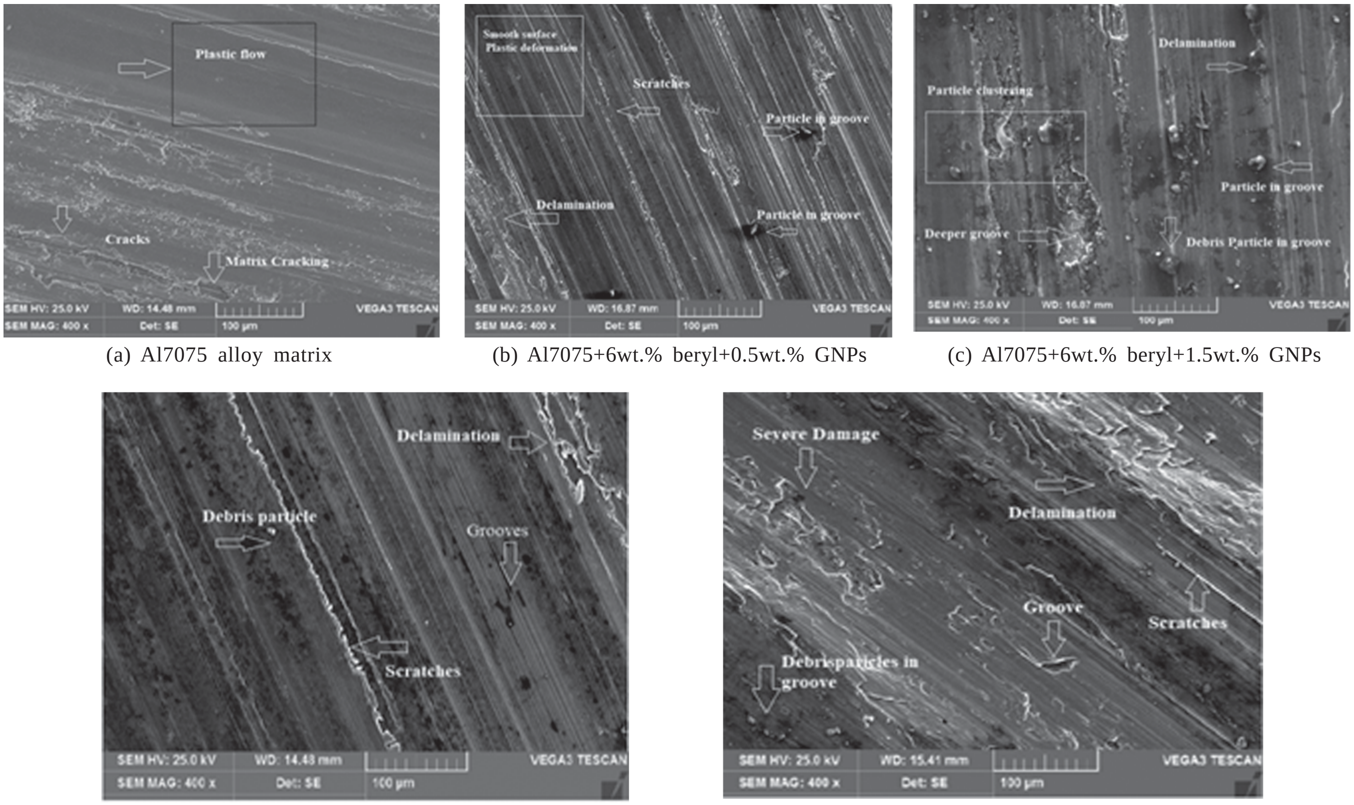
3.4 Effect of load on ice quench of hybrid composites

Wear loss of heat-treated ice quenched Al7075 and its hybrid composites at different loads depicted in Fig.7. Wear studies are done varying load from 10N to 30N, whereas other two parameters sliding speed and sliding distance are 3.5m/sec and 2000m respectively are kept constant. Composites were subjected to T6 solutionizing process. Composites wear loss increases with load increment. Heat treatment on Al7075 and its hybrid composites have a major influence on dry sliding wear behaviour. Wear loss of hybrid heat-treated composites is lesser than heat-treated Al7075. Heat-treated hybrid composites exhibit better resistance to wear owing to composites hardness increment. Formation of solid solution and sequence of precipitation causes a reduction in wear loss of heat-treated composites. Further hybrid reinforcements particles repel mobility in Al7075 and diminish interaction between composites and counterpart. GNPs particles act as a lubricant (solid) and increase resistance to wear.

Wear loss of 74.87% reduction was found for heat-treated ice quenched Al7075– 2 wt.% GNPs 6 wt.% of beryl when compared to Al7075 at 10 N load. The reduction wear loss of 61.82% is found for heat-treated ice quenched Al7075– 2 wt.% GNPs 6 wt.% of beryl when compared to Al7075 at 20 N load. The reduction wear loss of 64.74% is found for heat-treated ice quenched Al7075–2wt.% GNPs 6 wt.% of beryl when compared to Al7075 at 30N load. The percentages are calculated when compared to heat-treated ice quenched base Al7075 matrix material. The decrease in wear loss is due to reduction in micro-segregation and micro-shrinkage in heat-treated composites. Heat-treated Al7075 showed more wear loss owing to increase in load on Al7075. Result in commencement of delamination, adhesive and abrasion of Al7075 matrix pin with counterpart. However higher wear loss of heat-treated hybrid composites as the load increases could be mostly because of reinforcement particles severe destruction and particle is drawn out. Variation in wear results of heat-treated ice quenched Al7075 alloy and its hybrid composites for different loads are indicated elsewhere (ref. to authors). Naveed et al [17] have concluded that the addition of graphite and SiC in Al6061 increased the wear resistance. Increase in applied load on the Al6061 and graphite-SiC-Al6061 composites increased wear loss. Effect of solutionizing (T6) followed by ice quenching increased the wear resistance of Al6061-graphite-SiC hybrid composites than Al6061.

3.5 Morphological analysis of worn-out surfaces

SEM analysis is accomplished to investigate the effect of GNPs, beryl (reinforcements), loads, sliding speeds, and sliding distances on wear behaviour of synthesized Al7075 and Al7075-beryl-GNPs nano-hybrid composites. SEM analysis has been done on worn-out surface of Al7075 and its hybrid composites. SEM morphological studies reported that uniformity of GNPs and beryl distributions into Al7075 alloy matrix. The proper distribution and existence of GNPs and beryl in Al7075 lead to more resistance to wear. By increasing the load the surface wear ascends because of extreme increase in debonding. Worn out surface analysis shows that, in a soft ductile matrix, some of broken GNPs and beryl particles are entrapped. Al7075 matrix is softer than the



(a) Al7075 alloy matrix (b) Al7075+6wt.% beryl+0.5wt.% GNPs (c) Al7075+6wt.% beryl+1.5wt.% GNPs

(d) Al7075+6wt.% beryl+1.5 wt.% GNPs (e) Al7075+6wt.% beryl+2 wt.% GNPs

Fig.8: SEM results of worn surfaces at load 30N, sliding distance 2000m, and sliding speed 3.5m/sec

counterpart disk material. The Al7075 has a plastic flow deformation, smooth surface and matrix cracking zone that occurred on the surface. Resulting in a mechanically deformed zone, which leads to high wear loss.

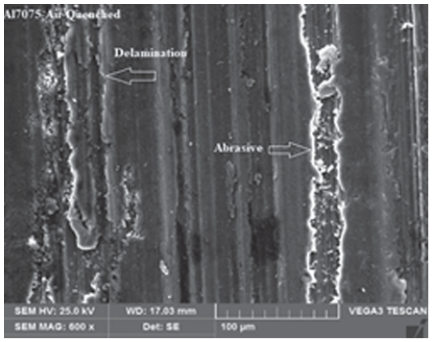
More penetration and amount of grooves are diminished with more content of GNPs in hybrid composites. The incorporation of beryl particles which are hard, and hence resist the wear. Fig.8 (a-e) shows the SEM micrographs results of worn-out surface at 30N load applied, sliding speed of 3.5m/sec, and 2000m sliding distance. The addition of beryl and GNPs into the matrix reduces erosion and hence small grooves like structure noticed in the hybrid composites lead to a reduction in wear in Al7075-beryl-GNPs hybrid composites.

SEM micrographs of worn-out surface of heat-treated Al7075 and its hybrid composites at different load and quenching mediums are presented in Fig.9. Worn out surface analysis of Al7075 alloy subjected to ice quenched shows that, Al7075 has a plastic flow deformation, smooth surface and matrix cracking zone occurred on the surface. Al7075 matrix is softer than the counterpart disk material. Resulting in a mechanically deformed zone that leads to high wear loss.

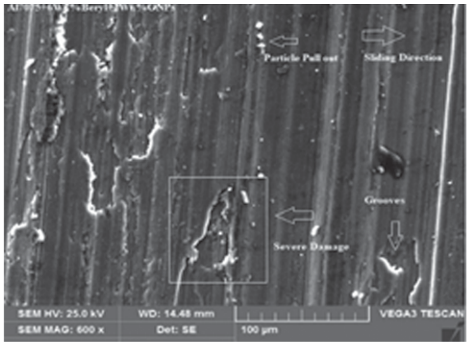
Micrographs show the presence of ridges, grooves, and craters parallel to the direction of sliding, which represents wear is abrasive and crater are evidence of adhesive wear. Hence in Al7075, the wear is due to combinations of abrasive and adhesive wear. The weight percentage of reinforcement increases in Al7075 found to be more resistance to wear for the ice quenching medium. SEM examination represents that the worn-out surface of the Al7075-beryl-GNPs hybrid composites is generally ample coarser than Al7075. At higher load, sliding distance and sliding speed, more scratch, delamination, severe and smaller grooves are noticed through SEM analysis. Increase in wt.% of GNPs, resulting in lubricating film, which in turn prevents direct contact between hybrid AMMCs pin and counterpart disc and leads decrease in wear loss. And also as the percentage of GNPs is increased, the scratches and grooves become narrower and decrease in plastic flow indicating larger wear resistance.

4.0 Conclsions

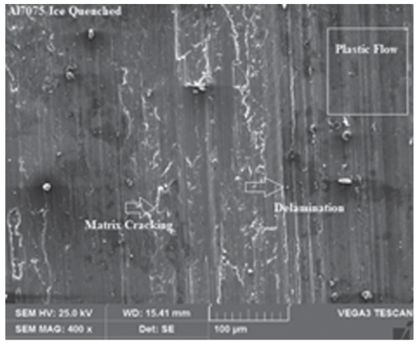
- The liquid metallurgy route was utilized to incorporate the graphene and beryl particulates into the Al7075 matrix successfully. The microstructure study exposes the occurrence of graphene and beryl with less porosity
- The XRD study confirmed the occurrence of graphene and beryl in Al7075
- The effect of the applied load on Al7075-beryl-GNPs composites was studied. The wear loss of the Al7075-beryl-GNPs hybrid composites increases with increase in the loads. And also wear loss of the Al7075-beryl-GNPs



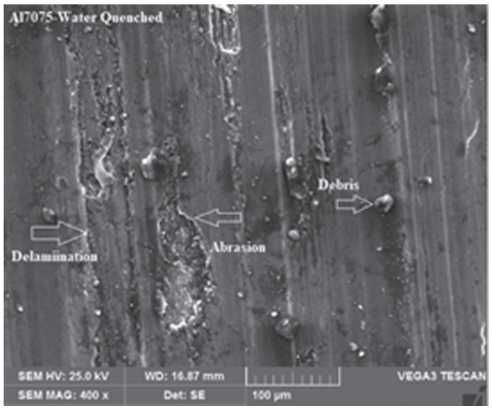
(a) Al7075



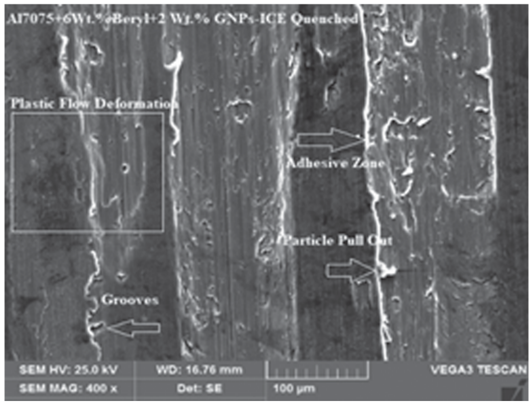
(b) Al7075+6Wt. % Be+0.5 Wt. % GNPs



(c) Al7075+6Wt. % Be+1 Wt. % GNPs



(d) Al7075+6Wt. % Be+1.5 Wt. % GNPs



(e) Al7075+6Wt. % Be+2 Wt. % GNPs

Fig.9: SEM results worn surfaces of heat-treated ice quench at different loads

hybrid composites decreases with increase in weight percentage of reinforcements GNPs in the Al7075 alloy.

- Scanning electron micrographs of solutionized- T6 treated and ice, quenched shown the large enough scattered precipitates of $MgZn_2$ intermetallic phases.
- The heat treatment followed by ice quenching medium has a greater effect on the mechanical and tribological of Al7075-beryl-GNPs hybrid composites.
- Worn out morphology studies of both as-cast and heat-treated Al7075 alloy and Al7075-beryl-GNPs revealed the various wear mechanisms.

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