Journal of Manufacturing Engineering, June 2011, Vol. 6, Issue 2, pp 69-74

WEAR AND THERMAL BEHAVIOR OF GRAPHITE PARTICLE REINFORCEMENT IN ZA-27 ALLOY COMPOSITES FOR TRIBOLOGICAL APPLICATIONS

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ABSTRACT

The objective of present work is to investigate the effect of macroscopic graphite particles on Wear and thermal behavior of ZA-27 alloy composites. Compo casting technique was used to prepare the composites, in which the graphite particles were used to reinforce ZA-27 alloy .Wear tests were conducted using pin on disc sliding wear testing apparatus under unlubricated conditions at various load and speeds, results indicates that the tribological properties improves with the addition of graphite particle

Keywords: *Metal Matrix Composites, Wear and Microstructure.*

1. Introduction to Wear

A progressive loss of material from its surface is called wear. It is a material response to the external stimulus and can be mechanical or chemical in nature. Wear is unwanted and the effect of wear on the reliability of industrial components is recognized widely; also, the cost of wear has also been recognized to be high. Systematic efforts in wear research were started in the 1960's in industrial countries. The direct costs of wear failures, i.e., wear part replacements, increased work and time, loss of productivity, as well as indirect losses of energy and the increased environmental burden, are real problems in everyday work and business. In catastrophic failures, there is also the possibility of human losses. Although wear has been extensively studied scientifically, in the 21st century there are still wear problems present in industrial applications. This actually reveals the complexity of the wear phenomenon.

Past decades, has resulted in the need for new multifunctional materials that possess characteristics not obtainable from any individual material. Composites possess significantly higher strength and stiffness than unreinforced materials'. Although most composites have anisotropic properties, those reinforced with particles are by and large isotropic, which is an added advantage. Metal-matrix composites (MMCs) are known for their high specific moduli and strength, recently, their wear resistance compared to the conventional metal alloys proved good. Particulate graphite reinforced aluminium alloy MMCs have been reported to have good wear characteristics because of the lubricative properties of graphite'. W.L. Bragg [1] had clearly explained the origin of lubricity in graphite, as follows: "Wear and friction are found greatly reduced in lamellar solids, like graphite, when applied to sliding surfaces, because the crystal structure of this lamellar solid has layers weakly bonded to each other although the bonding within the layers is quite strong." Graphite is, thus, strong in compression but weak in shear, and acts as a solid lubricant. Composite materials with solid lubricants, as particulate dispersions, have been found to possess good anti-seizing properties and low wear rates. Examples are: aluminium-graphite and bronze graphite MMCs, which have been proved to be tribologically superior to their respective matrix alloys. In recent years, considerable work has been done on graphite particle reinforced MMCs, which exhibit low friction, low wear rate and excellent antiseizing properties. Due to its potential use as a solid lubricant, particulate graphite is, therefore, a good choice of reinforcement material for MMCs that need to have a good wear resistance, components such as engine bearings, pistons, piston rings and cylinder liners.

Zinc alloys are feasible matrix materials, and are excellent, inexpensive, low melting point replacements for cast iron, brass or aluminium alloy. They also have excellent pressure tightness, and good tribological properties. (Pressure tightness is the property by which, the material does not allow any leakage of fluids even under high pressures.) Among the zinc-based foundry alloys, the ZA family of alloys has been increasingly used over the past few years in several structural and bearing applications [2]. The members of

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the ZA casting alloys are: ZA-8, ZA-12, and ZA-27. These alloys have many advantages over aluminium-based alloys, namely; high strength, and tribological properties, and low casting temperature. ZA-27 alloy, in particular has been used in bearings and bushing applications, as a replacement for bronze bearings because of its low cost and equivalent or superior bearing performance [3].

Moreover, ZA-27 is classified as (HIDAMETS) high damping material [4] and high strength alloy, with tensile strength substantially higher than that of ordinary cast aluminium alloys. There are several approaches to control noise and vibration, one of which is to manufacture structural and moving components from high-damping alloys [5,6]. In choosing a particular high-damping alloy for a given application, its strength, corrosion resistance, and a whole host of other physical properties must be considered, as well as its intrinsic damping capacity. Usually, high damping capacity is related to those materials with poor mechanical properties, therefore the key problem is in preparing composites for coupling high damping capacity with a tolerable modulus and high strength [7, 8]. The ZA27 alloys have high strength, hardness, and wear resistance, as well as other favorable physical properties. The properties make it an attractive alternative to aluminum, brass, bronze, or iron for the designer of structures and machine parts that can be cast. Therefore, it has obtained more and more applications in industry. Various methods and techniques were used to substantially improve the Wear and damping capacities of Zn-Al alloys without lowering significantly the mechanical properties. In this study an effort is made to understand the influence of graphite particle on the wear behavior of the composite.

2. Experimental Procedure

2.1 Preparation of the composite

In present investigation ZA-27 with chemical composition as per ASTM B 669-82 ingot specification (Al-25%, Cu-2%, Mg-0.01, Zn-% Remainder) was used as the matrix material. The ZA-27/graphite composites were prepared using the liquid metallurgy technique. The alloy is prepared using Zn (99.99%), commercially pure Mg (99.85%) and Al (99.6%). The size of the graphite particles selected was 100-150 µm. The graphite contents of the particle used for the preparation of the composites were 0,4,6 and 8%.this is because graphite composition of above 8% would lead to rejection from the melt.

The addition of graphite into the molten zinc alloy melt above its liquid temperature of 500°C was done by creating a vortex in the melt using a mechanical stainless steel stirrer coated with aluminite (to prevent migration of ferrous ions from the stirrer material into the zinc alloy melt). The melt was agitated at a rotational speed of 500-600 rpm to create the necessary vortex. The graphite particles were preheated to 400°C and added to the melt through the vortex at the rate of 0.1 kg /min. A small amount of magnesium, which improves the wetability of the graphite particles, was added along with the graphite, and the melt was thoroughly stirred and subsequently degassed by passing nitrogen at the rate of 2-3 lit/ min.

2.2 Microstructure

The micrographs of polished composites using optical microscope in accordance with ASTM E-3 are shown in Figs. 1 to 4 for graphite content from 0% to 8%. All the micrographs show uniform distribution of both ZA and Graphite phases with no noticeable isolated areas. General appearance of as cast microstructure is shown in fig1 which is a typical dendrite structure consists of Al rich phase appears as core of the dendrite, which is surrounded by the decomposed Zinc rich phase and dark imaged graphite phase in the interdendritic region.

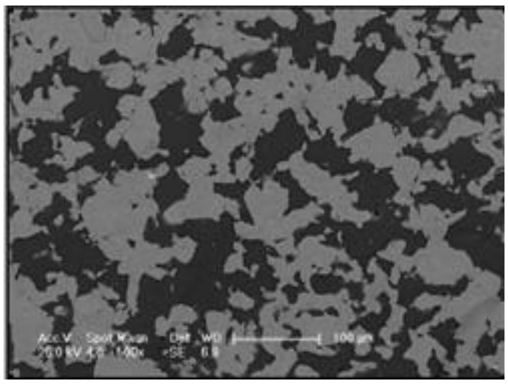


Fig. 1 Microstructure with 0% Graphite

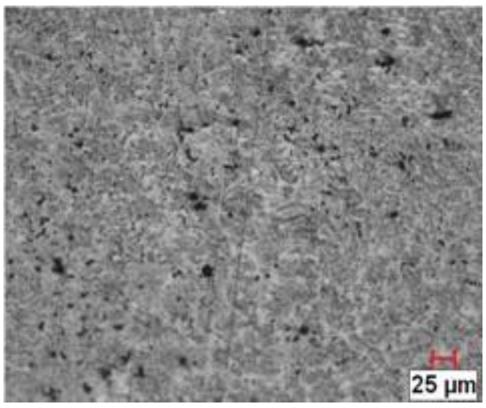


Fig. 2 Microstructure with 4% Graphite

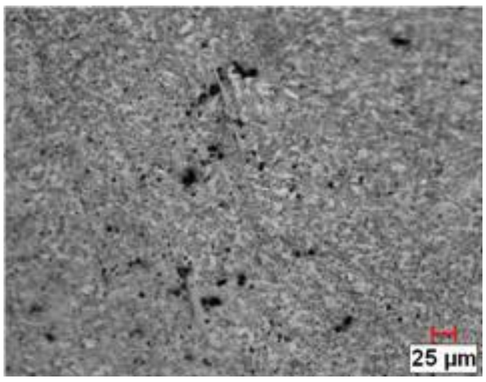


Fig. 3 Microstructure with 6% Graphite

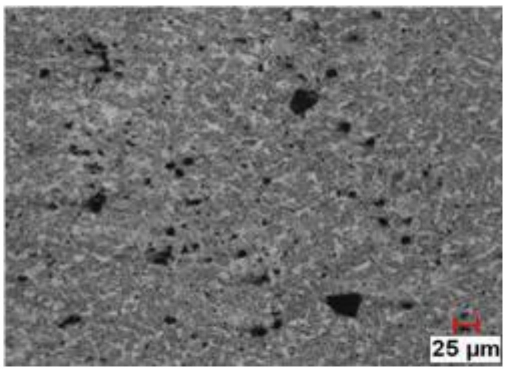


Fig. 4 Microstructure with 8% Graphite

3. Results and Discussion

Wear tests were conducted using pin on disc sliding wear testing apparatus under unlubricated conditions at various load and speeds, details of wear testing machine and its specification are as follows

3.1 Effect of graphite content on wear behavior

Wear rate plotted for different graphite content, in weight percent, at different test speeds and for different loads. The graph of wear rate against the graphite content, in weight percent, for rotational wear test speeds of 200, 300 and 400 rpm, are shown in Fig. 5 to 7.In most materials, it is expected that there is an inverse relationship between the wear rate and hardness, in which one increase as the other decreases, and vice versa. However, the composites tested are exceptional because; as the graphite content increases, the hardness drops, accompanied by a decrease in the wear rate (fig 5 to 7). This is obviously due to the lubricating properties of graphite. When the graphite content is low, the interface of the mating parts is largely not covered by a film of graphite, and the tribological properties are almost similar to or only slightly better than those of the matrix materials. As graphite content is increased, the wear rate decreased due to the presence of graphite on the mating surfaces during sliding. The graphite acts as a solid lubricant, which is smeared onto the sliding surfaces, thereby preventing a metal-to-metal contact. Such a mechanism of graphite smearing over the sliding surfaces, has also been observed to operate in aluminum alloy/graphite particulate composites containing up to 50% by volume, of graphite. It is worth noting that when 2% of graphite is added to the unreinforced zinc alloy matrix, the wear decreases spectacularly by about 25% compared to higher percentage of reinforcement. As more graphite is added, it has less effect on the wear rate. This shows that the greatest improvement in the wear resistance of the material is achieved at low graphite contents. Further additions of graphite result only in marginal improvements in the wear resistance, although the hardness continues to fall significantly. Such trends of wear rate can be seen for all the wear test loads and speeds employed. These results are similar to those of Liu et al.[9] and Pai et al.[10] who performed tests on journal bearings made of cast aluminum/ graphite particulate composites containing 1% by weight, of graphite, and discovered that the graphite gets smeared on to the bearing interfaces, thereby lubricating them.

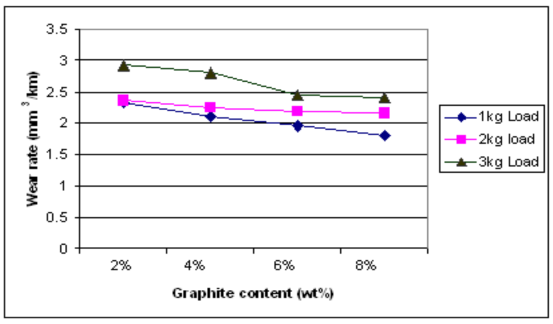


Fig. 5 Wear Rate vs. Graphite Content at 200 rpm

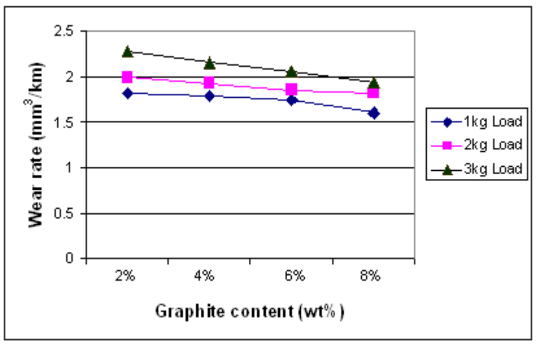


Fig. 6 Wear Rate vs. Graphite Content at 300 rpm

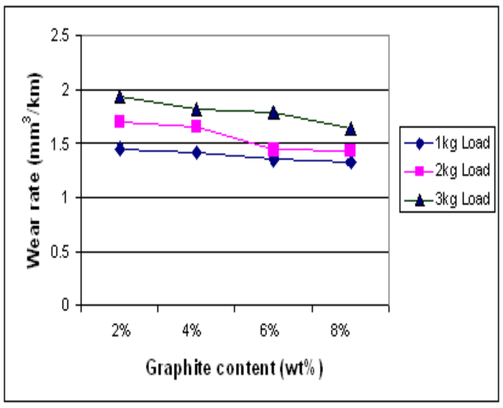


Fig. 7 Wear Rate vs. Graphite Content at 400 rpm

3.2 Effect of wear load on wear behavior

The graph of the wear rate against wear load at different test speed of 200, 300 and 400 rpm, are shown in Figs. 8 to10, It can be seen in each of these graphs the wear rate increases monotonically with load, suggesting an approximate linear relationship between the wear rate and wear load of the Archard type[11] .Again, the significant decrease in wear rate is clearly seen with the addition of even a small amount (2%) of graphite.

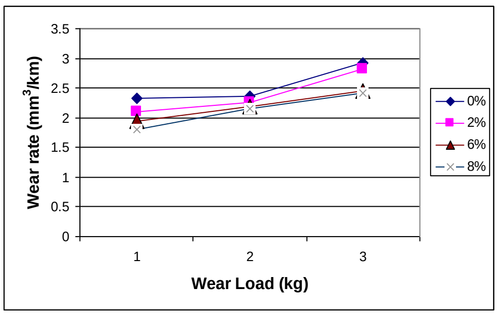


Fig.8 Wear Rate vs. Wear Load at 200 rpm

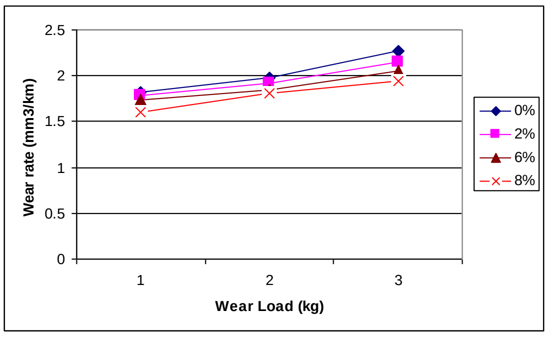


Fig.9 Wear Rate vs. Wear Load at 300 rpm

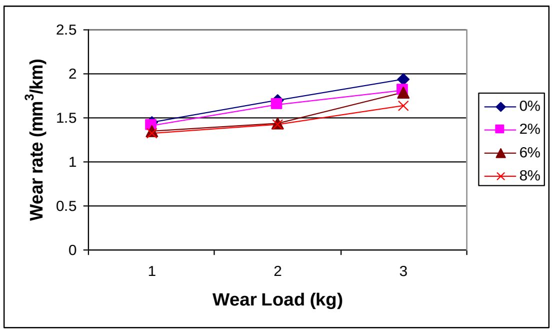


Fig. 10 Wear Rate vs. Wear Load at 400 rpm

3.3 Effect of test speed on wear behavior

The graph of the wear rate against wear test speed for wear loads of 1, 2 and 3 kgf, are shown in Figs. 11 to 13. It can be seen in each graph that the wear rate decreases monotonically with an increase in the sliding velocity. These results may be explained in terms of the smearing process of graphite during sliding. Liu et al.[9] has demonstrated that the smearing process takes time to fully establish a layer of graphite which will cover the entire (or nearly the entire) sliding interface, especially on the side of the composite material.

They found that it would take more than 5 min of sliding at 2 m s-¹, at a wear load of 31 N (very similar to the test conditions used presently), for the embedded graphite particles to come out from the matrix to form the layer, which will provide an effective wear protection. The data presented in Figs. 11 to 13, suggest that when the sliding velocity is increased from 200 to 400 rpm, the time it takes to provide an effective wear protection for the composite material reduces with an increase in the sliding velocity. This implies that the formation of the layer of the smeared graphite is hastened by a higher sliding velocity. It is also interesting to note that the unreinforced alloy also shows the same trend. In this case, it is instructive to make reference to the wear-mechanism map, proposed earlier for aluminum alloys by Liu et al.[9] In this map, the wear behavior (depicted by constant-wear-rate contours) over this range of speed and load suggests that increasing the sliding speed at a constant load will lead to a decrease in the measured wear rates. This has been attributed to the increased extent of oxidation of the aluminum alloy as a result of higher interfacial temperatures; the thicker oxide layer helps to protect the sliding interface, thereby lowering the rate of wear. This can be clearly seen in all the above graphs and at different loads of 1kg, 2kg and 3kg respectively (Figs. 5 to 13) form the above it is clear that the wear rate decreases with increase in graphite percentage, and with increase in test speed, but wear rate increases with increase in wear load, the results are similar to the other researchers [11].

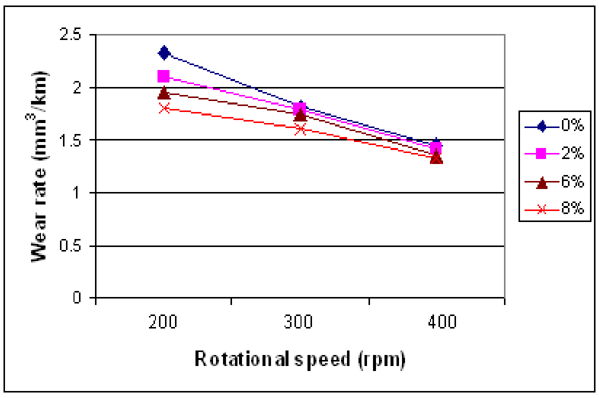


Fig.11 Wear Rate vs. Test Speed for 1 kg

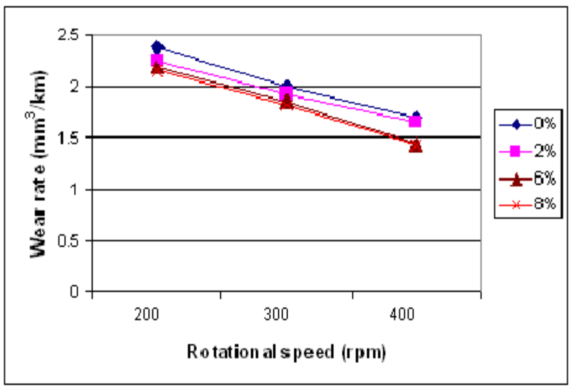


Fig.12 Wear Rate vs. Test Speed for 2 kg

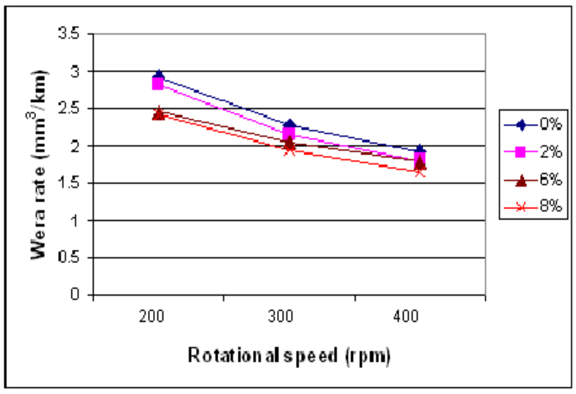
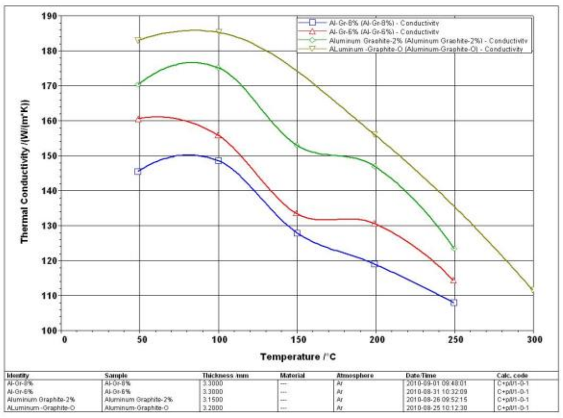


Fig.13 Wear Rate vs. Test Speed for 3 kg

3.4 Thermal conductivity & Thermal diffusivity

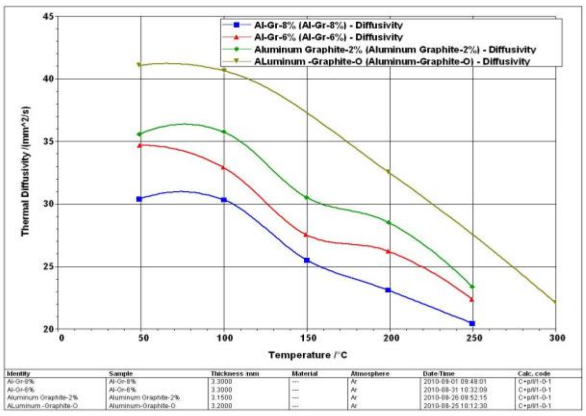
Thermal conductivity (k) is the property of a material that indicates its ability to conduct heat,thermal conductivity tests were conducted using Thermal analyzer results (Figs. 14-15) shows that thermal conductivity decreases with increase in temperature for all values of graphite reinforcement i.e. thermal conductivity value of 182 $W \cdot K^{-1} \cdot m^{-1}$ at 48^0C to 110 $W \cdot K^{-1} \cdot m^{-1}$ at 300^0 C for ZA-27 and further with the addition graphite particles Thermal conductivity decreases with the increase of reinforcement percentage showing value of 145 $W \cdot K^{-1} \cdot m^{-1}$ at 48^0C for 8% graphite particle reinforcement.

Thermal diffusivity (α) is the thermal conductivity divided by the volumetric heat capacity. Test results (Figs. 14-15) shows that thermal diffusivity decreases with increase in temperature for all values of graphite reinforcement i.e. thermal diffusivity value of 43 mm²/s at 48^0C to 22 mm²/s at 300^0 C for ZA-27 and further with the addition graphite particles Thermal diffusivity decreases with the increase of reinforcement percentage showing value of 30mm²/s at 48^0C for 8% graphite particle reinforcement.



Identity	Sample	Thickness /mm	Material	Atmosphere	Date/Time	Calc. code
Al-Gr-8%	Al-Gr-8%	3.3000	---	Ar	2010-09-01 09:48:01	C+p/l/1-0-1
Al-Gr-6%	Al-Gr-6%	3.3000	---	Ar	2010-08-31 10:32:09	C+p/l/1-0-1
Aluminum Graphite-2%	Aluminum Graphite-2%	3.1500	---	Ar	2010-08-26 09:52:15	C+p/l/1-0-1
ALuminum -Graphite-O	Aluminum-Graphite-O	3.2000	---	Ar	2010-08-25 10:12:30	C+p/l/1-0-1

Fig. 14 Thermal Conductivity for Various Graphite Percentage & Temperature



Identity	Sample	Thickness /mm	Material	Atmosphere	Date/Time	Calc. code
Al-Gr-8%	Al-Gr-8%	3.3000	---	Ar	2010-09-01 09:48:01	C+p/l/1-0-1
Al-Gr-6%	Al-Gr-6%	3.3000	---	Ar	2010-08-31 10:32:09	C+p/l/1-0-1
Aluminum Graphite-2%	Aluminum Graphite-2%	3.1500	---	Ar	2010-08-26 09:52:15	C+p/l/1-0-1
ALuminum -Graphite-O	Aluminum-Graphite-O	3.2000	---	Ar	2010-08-25 10:12:30	C+p/l/1-0-1

Fig. 15 Thermal Diffusivity for Various Graphite Percentage & Temperature

4. Conclusion

Aerospace and other structural applications demand high strength to weight ratio which insists use of low density material such as graphite as reinforcement. Experimental results indicate that the addition of graphite particles to ZA-27 zinc alloy matrix improves the wear resistance of the composite, benefit of reinforcement is found more at 2 to 4 % compared to higher values. This is a good indication that the graphite reinforcement will certainly help the designers to develop a suitable bearing material which gives better performance at elevated temperatures, also Thermal properties of composite indicate decrease of thermal conductivity and diffusivity these indicating the need to optimize as per designers requirement.

References

1. *Bragg W L (1928), "Introduction to Crystal Analysis". Bell and son, London, 64-70.*
2. *Schaller R (2003), "Metal Matrix Composites A Smart Choice for High Damping Materials", J. Alloys Compd., Vol. 355,131-135.*
3. *Smith W (1993), "Structures and Properties of Engineering Alloys", McGraw Hill, New York, 2nd edition, 561-566.*
4. *Alan Wolfenden and Vikram Kinra K (1997), "M3D III: Mechanics and Mechanisms of Material Damping", ASTM Publications, 130,148,156.*
5. *Zhang J M, Perez R J, Wong C R and Lavernia E J(1994)' "Effects of Secondary Phases on the Damping Behavior of Metals, Alloys and Metal-Matrix Composites", Mater. Sci. Eng. Vol. 13, 325-389.*
6. *James D W (1969), "High Damping Metals for Engineering Applications", Mater. Sci. Eng., Vol. 4, 1-8*
7. *Zhang J, Perez R J, Lavernia E J(1993), "Documentation of Damping Capacity of Metallic, Ceramic and Metal-Matrix Composite-Materials". J. Mater. Sci. Vol. 28, 2395-2404.*
8. *Lavernia E J, Perez R J, Zhang J (1995), "Damping Behavior of Discontinuously Reinforced Al-Alloy Metal-Matrix Composites", Metall. Mater. Trans. A, Vol.26, 2803-2818.*
9. *Liu Y B, Lim S C, Ray S and Rohatgi P K (1992), "Friction and Wear of Aluminium-Graphite Composites", Wear, Vol.159, 201-205.*
10. *Pai B C, Rohatgi P K and Venkatesh S V (1974), "Wear Resistance of Cast Graphite Aluminium Alloys, Wear,Vol. 30,117-122.*
11. *Seah K H W, Sharma S C, Garish B M and Lima S C (1995), "Wear Characteristics of as-cast ZA-27/Graphite Particulate Composites". Materials and Design Vol.16, 337-341*