TRIBO-EFFICIENT MATERIALS – A REVIEW

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***Abstract*— This paper is to highlight the need of tribo-efficient composite materials to design low friction, low wear and self-lubricant materials. The tribo-efficient materials can enhance components life, reduce fuel and power consumption in a machine. In this paper polymer and metal matrix composites were addressed. The influences of different parameters in wear loss of Al/MgO particulate metal matrix composite have been analyzed in detail as a case study. Aluminium metal matrix composites find wide range application in aerospace and automotive industries. A great deal of research work needs to be done to derive maximum tribological potential of CNTs as effective fillers.**

Keywords- Tribo-efficient; SWNT, MWNT; Carbon Onio; MMC; self-lubrication.

I. INTRODUCTION

The multidisciplinary science of interacting surfaces in relative motion is now identified specifically as tribology. It has grown incalculably over the years to an extent that studies on surface related aspects such generation and transmission of force, dissipation of energy (friction), dissipation of mass (wear) and lubrication between two bodies in relative motion have now narrowed down to the fundamental understanding of birth of friction at atomic level. There is an industrial demand to design low friction, low wear materials that are lightweight; corrosion and fatigue resistant; chemically inert, possess high load bearing capacity and can serve in severe operating conditions of speed, pressure, temperature and erosive-corrosive environment. Such so-called ***tribo-efficient materials*** can enhance life of the component, reduce fuel and power consumption in a machine.

Friction is generally defined as the ratio of two forces acting, respectively, perpendicular and parallel to an interface between two bodies under relative motion or impending relative motion and is measured by a dimensionless quantity known as coefficient of friction (μ). Friction between two surfaces in relative motion causes wear and energy dissipation that leads eventually to catastrophic failures in machines that comprise numerous moving parts such as gears, bearing, seals, pistons, valves, cams, clutches, sliders, etc. smooth running of machine means there should be minimum friction and wear between two moving surfaces so as to prevent any dimensional changes even at a micron level [1]. The control of wear and friction has been an indispensable area of research at the moment. Lubrication, the intervening layer between contact surfaces, is an effective means of controlling wear and reducing friction. Since friction, wear and lubrication are tribological phenomena, the subject of tribology has assumed greater significance in the current times.

II. TRIBO-EFFICIENT MATERIALS

Metals, alloys, polymers; composites based on them and carbon-carbon composites, all these materials have been traditionally in tribological applications as anti-friction material (low wear, low friction) such as in gears, bearings, seals, bushes, artificial joints, sliders and friction materials as in brake pads, clutch plates, tyres, etc. tribo-efficient materials are defined as those materials which deliver desired friction and wear performance at high pressure-velocity limits and high operating temperatures. The current demand is for lightweight, wear and corrosion resistant tribo-materials which are expected to increase the life of machine e components despite operating in severe conditions, and at the same time would be easy on fuel and power consumption. These two prime objectives drive the current research across the world.

III. POLYMER COMPOSITES

Engineering polymers appear to be an obvious choice for developing tribo-materials because of their excellent property profile such as lightweight, wear, corrosion and radiation resistance, solvent resistance, self-lubrication, quiet operation and easy mouldability and machining [2]. However, pure polymers are seldom used in tribo-applications because of their inherent weakness such as poor mechanical strength, low thermal stability, low thermal conductivity, low dissipativity and high thermal expansion which limit their tribological performance at high loads, speeds and temperature. Ample opportunities are available to modify polymers by a judicious choice of fibrous/fabric/particulate reinforcement [3 – 11]. The most remarkable feature about polymer based tribo-efficient materials is their self-lubricity. They can be used in tribo-related situations where liquid lubrication is difficult either due to high temperatures or possibility of contamination leading to erosive-corrosive wear and most importantly in situations where hydrodynamic lubrication could not be established due to small oscillatory motion or frequent starts and stops [12]. Thus, heat resistant, high performance self-lubricated or solid-lubricated fiber reinforced polymer composites have been in greater demand. Over the years their tribological performance can be found in the literature [13 – 16].

Friction behaviour of polymer composites is different from that of other materials because they do not obey Coulomb's basic laws of friction. Friction coefficient (μ) is a function of load and sliding speed. With increasing load, μ necessarily decreases because polymers are viscoelastic plastic with low moduli and low melting points. With increase in temperature or speed, μ does not show a fixed pattern for all the polymers and it is unpredictable too. It may show a peak at typical speed followed by a decrease which is mainly due the dependence of their viscoelastic nature on temperature. Counterface material and its roughness also influence μ significantly. Generally μ is the lowest in the range of 0.1 – 0.2 for most of the polymers. Similarly wear behaviour of polymer composites depends on the type of fibre and matrix concentration, dispersion, aspect ratio (length/radius of fibre), alignment and fibre-matrix adhesion. The higher the aspect ratio (A0 more load will be transferred from the matrix to the fiber and more is the wear resistance following the equation [17]:

$$\sigma_f = \tau A + \sigma_m \tag{1}$$

where σ_f is the contact stress, σ_m is the compressive stress of the matrix in the composite loaded against counterface under a load w, τ is the tangential stress produced because of the difference in the moduli of matrix and fibre.

The friction and wear behaviour of carbon filled PTFE composites for bearing applications have been found to be excellent even at elevated temperature tests. A low friction and wear factor were measured for carbon/graphite filled PTFE at 2600C. Tribology of PEEK composites shows that 30% short carbon fibre reinforced PEEK composites with a heat deflection temperature of 3150C were most suitable for use at selected temperatures [18]. Sun et al. [19] treated surface of CFs by means of oxygen plasma and observed that higher reactivity between fiber surface and matrix as a result of an increase of COOH, --C--OH and =C=O groups on the fiber surface. The surface constitution was changed by the plasma treatment and improved the wetting properties of fiber surface. In another work, carbon nanofiber (CNF) was treated with HNO3 and a coupling agent. This surface modification was reported to decrease the friction coefficient as well as wear loss pf CNF/PTFE composites slightly [20]. Tiwari et al. [21] oxidized CFs by boiling in nitric acid (HNO3, 65-68%) at 110°C. The duration of the acid treatment varied from 15 to 180 minutes and observed that with increasing treatment time, roughness of fiber surface increased (Figure 1) and for treated fibers, ether, carboxyl and carbonyl groups were observed on spectra corresponding to wave number range of 950-1200 cm-1 and 1650-1710 cm-1 respectively.

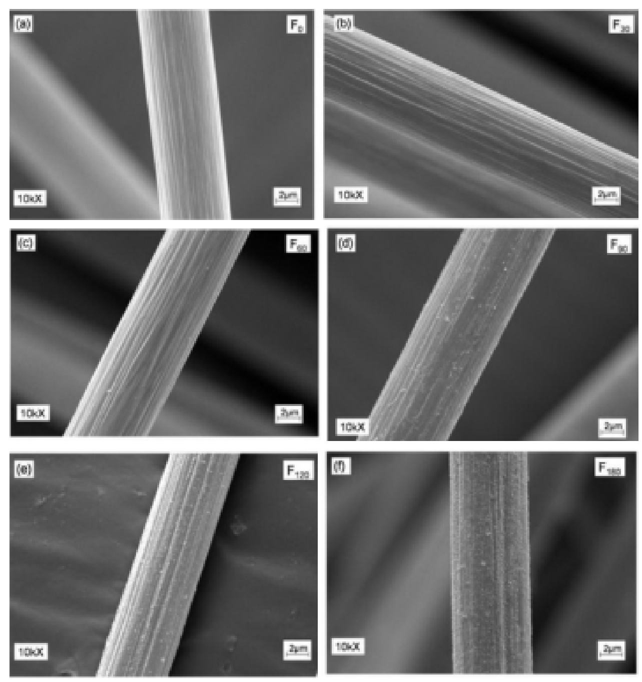

Figure 1. SEM micrograph of untreated and HNO_3 treated CF; (a) untreated (b) 30 (c) 60 (d) 90 (e) 120 (f) 180 mints treated CF's.

The carbon nanotubes are still in the early stages of tribological investigation and it has been found single-wall carbon nanotubes (SWNTs), multiwall carbon nanotubes (MWNTs), fluorinated SWNTs, Graphitized MWNT, carbon nano-onions and carbon nitride sphere (figure 2) have superior friction properties and endurance lives in air or ultrahigh vacuum indication their potential use as lubricant in aerospace applications in microelectromechanical systems (MEMS) and micromachines. All nanocarbons can improve stiction and friction between contacting surfaces under dry cinditions, a major issue for MEMS and micromachines. The coefficient of friction for graphitized MWNTs is one fifth that of MoS_2 in ultrahigh vacuum. It has been reported that CNTs filled PTFE composites exhibit friction coefficient that decreases with increasing CNT content probably due to self-lubricating nature of CNT [22]. When reinforced with MWNTs, an increase in hardness as well as wear resistance was observed [23].

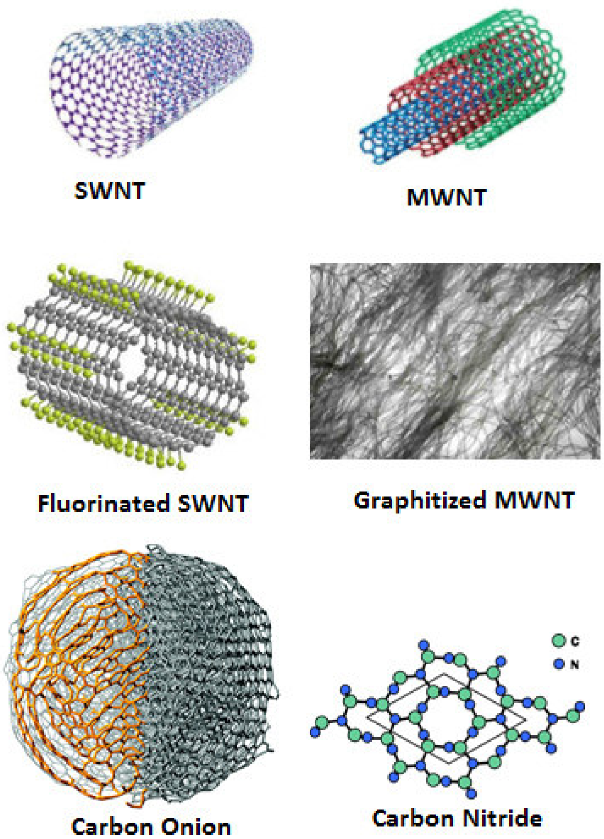

Figure 2 SWNT, MWNT, Carbon Onion, fluorinated SWNT, graphitized MWNT, Carbon Nitride.

IV. Metal Matrix Composites

Metal matrix composites (MMC) are attractive materials because of their high specific strength, stiffness and wear resistance [24-26]. Among modern composite materials, particulate reinforced MMCs are finding increased applications due to their favourable mechanical properties. Due to their tribological as well as mechanical properties, aluminium matrix composites find exhaustive applications in aerospace and automotive industries and also it is considered to be the most important material when reinforced with particulates [27]. Many parameters influence the wear characteristics of a metal matrix material but important parameters on which researchers concentrate are speed and load [28-31]. When Al is reinforced with SiC [32-34], TiC [35-38], B_4C [39-42], ZrC [43-45], TiB_2 [46-49], BN [50, 51], TiN [52, 53], Si_3N_4 [54, 55], Fe_2O_3 [56], SiO_2 [57-59], TiO_2 [60-62], MgO [63-65], ZrO_2 [66, 67], C [68-70], Graphite [71-73] nanoparticles an improved wear resistance was evidenced on comparing an unreinforced matrix material during dry sliding.

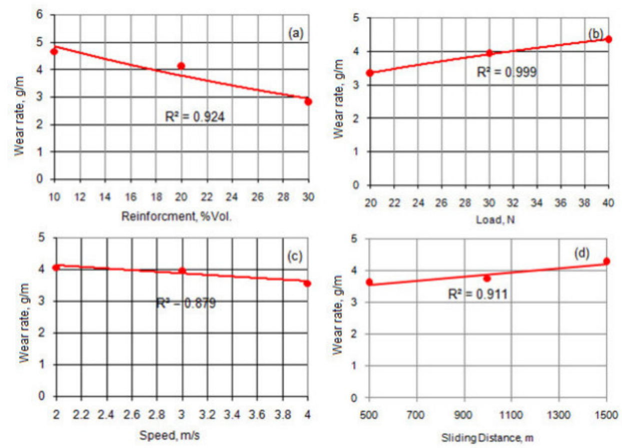

Figure 3. Influence of tribology parameters on wear rate.

A case study of tribological behaviour on AA7020/MgO metal matrix composites is preented. It can be seen from figure 3a that the wear rate was decreased with increase in volume fraction of MgO in AA7020 alloy matrix. This is owing to high hardness of MgO as compared to soft AA7020 alloy matrix. Composites produced by low volume fraction of MgO, wear out faster than those produced by high volume fraction of MgO. The wear rate was increased with load as shown in figure 3b. This can be attributed to increase of friction with normal load applied on the wear specimen. The wear rate was decreased with increase of speed (figure 3c). From figure 3d it is observed that the wear rate was proportional to the sliding distance. The R-squared values, which are attributable to volume fraction of reinforcement, normal load, sliding speed and sliding distance, respectively, are 0.924, 0.999, 0.879 and 0.911. These values indicate the best fit of the trend. The change in hardness of the worn specimens is shown in figure 4. It can be seen that the hardness values increase after wear test. The increase in hardness in the worn specimens may be attributed to the work hardening mainly due to influence of volume fraction of MgO and normal load applied on the test specimens. When the reinforcement was increased to 30 %, a decrease in wear rate was detected. The removal of particles (A) from the matrix and scratches in the matrix regions (B) were observed. The particle removal was higher in the composites having 30% MgO than in the composites having 10% MgO.

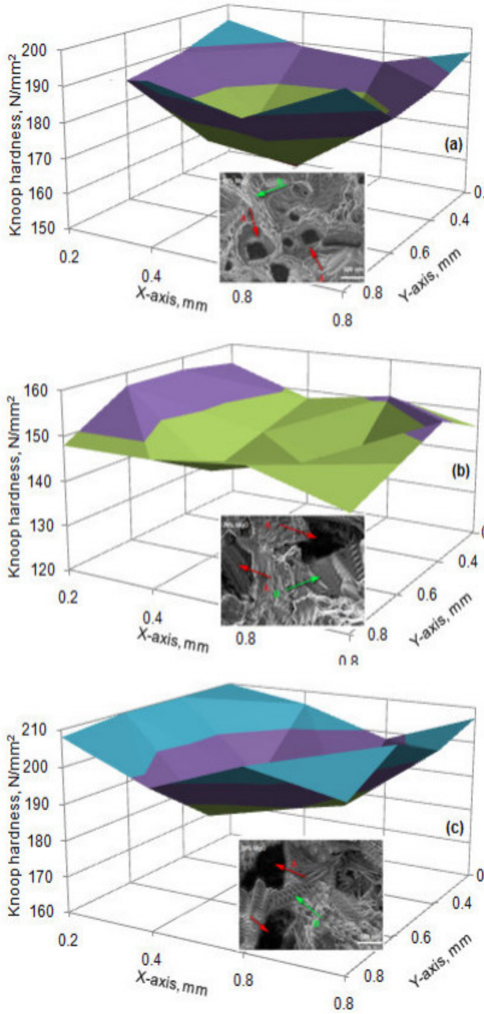

Figure 4. Hardness of AA7020/MgO composites after wear test: (a) 10 vol.%MgO (b) 20 vol.%MgO and (c) 30 vol.%MgO..

IV. CONCLUSION

This paper could present tribo-efficient materials like polymer composites, metal matrix composites, and polymer composites reinforced with nanotubes. Frictional interactions in micro and nanocomponents are being increasingly important for the development of new products in several industries.

REFERENCES

1. A. C. Reddy, B. Kotiveerchari, P. Rami Reddy, Saving of Thermal Energy in Air-Gap Insulated Pistons Using Different Composite Materials for Crowns, International Journal of Scientific & Engineering Research, vol.6, no.3, pp.71-74, 2015.
2. K. Zum Gahr, Microstrucutre and wear of materials, tribology Series 10, Elseveir Science Publishers, 1987.
3. A. C. Reddy, Evaluation of Curing Process for Carbon-Epoxy Composites by Mechanical Characterization for Re-entry Vehicle Structure, International Journal of Scientific & Engineering Research, vol.6, no.3, pp.65-70, 2015.
4. A. C. Reddy, Evaluation of Curing Process for Bi-directional S-Glass (5HS)/Epoxy (780E +782H) Composites Fabricated by Vacuum Infusion Process for Wind Energy Blades, International Journal of Advanced Research, vol.3, no.4, pp.667-675, 2015.
5. K. Agarwal, N. Akhil, R. Srinivas, A. C. Reddy, Enhancement in Mechanical Behavior of Nylon/Teflon Composites by Addition of Nano Iron Oxide (γ-Fe2O3), International Journal of Science and Research, vol.4, no.5, pp.927-932, 2015.
6. A. C. Reddy, Characterization of Mechanical Behavior of Nylon/Teflon Nano Particulate Composites, International Journal of Advanced Research, vol.3, no.5, pp.1241-1246, 2015.
7. A. C. Reddy, Design and Finite Element Analysis of E-glass Fiber Reinforced Epoxy Composite Air Bottle used in Missile System: Experimental Validation, International Journal of Scientific & Engineering Research, vol.6, no.8, pp.157-165, 2015.
8. A. C. Reddy, Shock Analysis of E-Glass/Epoxy Composite Submersible Hull Subjected to Pressure Loads of Underwater Explosion using Finite Element Method - Experimental Validation, International Journal of Scientific & Engineering Research, vol.6, no.9, pp.1461-1468, 2015.
9. S. Pitchi Reddy, A. C. Reddy, Tensile and Flexural Strength of OKRA Fiber Reinforced Polymer Composites, International Journal of Engineering and Management Research, vol. 6, no.1, pp.491-495, 2016.
10. A. C. Reddy, Finite element analysis of elastic-plastic and tensile damage response in carbon-carbon composites under vechicular crush conditions, National Conference on Emerging Trends in Mechanical Engineering, Nagapur, 05-06th February 2004, TIME/109/e-06.
11. A. C. Reddy, Strength and fracture mechanisms in carbon-carbon composites, International symposium on Advanced Materials and Processing, Bagalkot, 29-30th October 2007, pp.138-144.
12. F.J. Clauss, Solid lubricants and self-lubricant solids, chapter 3, Academic press, New York, 1972.
13. A. C. Reddy, Characterization of Mechanical and Tribological Behavior of (Nylon 6 + Graphite + Teflon) Nano Particulate Composite: Application Perspective, International Journal of Scientific & Engineering Research, vol.6, no.4, pp.378-386, 2015.
14. A. C. Reddy, M. Vidya Sagar, Two-dimensional theoretical modeling of anisotropic wear in carbon/epoxy FRP composites: comparison with experimental data, International Journal of Theoretical and Applied Mechanics, **vol.**6, no.1, pp.47-57, 2010.
15. A. C. Reddy, Evaluation of Curing Process for Kevlar 49-Epoxy Composites by Mechanical Characterization Designed for Brake Liners, International Journal of Science and Research, vol.4, no.4, pp.2365-2371, 2015.
16. K. Friedrich, Friction and wear of polymer composites, Composites Materials Series, vol.1, Elseveir, 1986.
17. J.K. Lancaster, In: Friction and wear of polymer composites, Composites Materials Series, vol.1, Elseveir, 1986.
18. M.P. Wolverton, J.E. Theberge and M.L. McCadden, Machine Design, vol.3, pp.55, 1983.
19. M. Sun, B. Hu, Y. Wu, Y. Tang, W. Huang, and Y. Da, Surface of CFs continuously treated by cold plasma, Comp Sci Tech, vol. 34, pp.353-64, 1989.
20. N.L. McCook, MA. Hamilaton, D.L. Burris and W.G. Sawyer, Wear, vol.262, p.1511, 2007.
21. Tiwari S, Bijwe J, Panier S. Tribological studies on Polyetherimide composites based on carbon fabric with optimized oxidation treatment.Wear 2011; 271: 2252-60.

22. W. X. Chen, F. Li, G. Han, J.B. Xia, L.Y. Wang, J.P. Tu, Z.D. Xu, Tribological Behavior of Carbon-Nanotube-Filled PTFE Composites, Tribology Letters, vol. 15, no. 3, pp.275-278, 2003.

23. J.Y. Zoo, D. L. An and D. S. Lim, Tribology Letters, vol.16, 2004, 3055.

24. A. C. Reddy, Prediction of CTE of Al/TiB2 Metal Matrix Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12th May 2001, pp.270-275

25. A. C. Reddy, Effect of Clustering Induced Porosity on Micromechanical Properties of AA6061/Titanium Oxide Particulate Metal Matrix Composites, 6th International Conference on Composite Materials and Characterization, Hyderabad, 8-9th June 2007, pp.149-154.

26. A. C. Reddy, Evaluation of Thermal Expansion of Al/B_4C Metal Matrix Composites, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25th February 2002, pp.196-200

27. C. R. Alavala, Influence of Debris on Wear Rate of Metal Matrix Composites, Journal of Materials Science & Surface Engineering, vol.4, no.6, pp.458-462, 2016.

28. A. C. Reddy, Wear Resistant Titanium Boride Metal Matrix Composites, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25th February 2002, pp.201-205

29. C.R. Alavala, Synthesis and Tribological Characterization of Cast AA1100-B_4C Composites, International Journal of Science and Research, vol.5, no.6, pp.2404-2407, 2016.

30. A. C. Reddy, Significance of Testing Parameters on the Wear Behavior of AA1100/B_4C Metal Matrix Composites based on the Taguchi Method, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May, 2001, 276-280

31. A. C. Reddy, Correlation of Surface Profiles and Worn Surfaces of AA6061/Graphite Metal Matrix Composites, 2nd International Conference on Modern Materials and Manufacturing, Pune, 10-11th December 2010, pp.307-311.

32. A. C. Reddy, B. Kotiveerachari, Influence of microstructural changes caused by ageing on wear behaviour of Al6061/SiC composites, Journal of Metallurgy & Materials Science, vol.53, no.1, pp.31-39, 2011.

33. A. C. Reddy, Reduction of Vibrations and Noise using AA7020/SiC Nanocomposite Gear Box in Lathe, International Journal of Scientific & Engineering Research, vol.6, no.9, pp.678-684, 2015.

34. T. K. K. Reddy, A. C. Reddy, Tribological Behavior of AA8090/SiC Composites, 2nd International Conference on Thermal and Tribological Behavior of Composites, New Delhi, 27-28th Decembe, 2013, pp.149-154.

35. A. C. Reddy, Wear Characteristics of AA5050/TiC Metal Matrix Composites, National Conference on Advanced Materials and Manufacturing Techniques, Hyderabad, 08-09th March 2004, pp. 356-360.

36. G. V. R. Kumar, A. C. Reddy, Surface Profiles of Dry Worn Surfaces of AA2024 Alloy/TiC Metal Matrix Composites, 2nd International Conference on Modern Materials and Manufacturing, Pune, 10-11th Decembe, 2010, pp.302-306.

37. M. Mastanaih, A. C. Reddy, Influence of Reinforcing Particle Size on Tribological Properties of AA6061-Titanium Carbide Microcomposites, 5th International Conference on Modern Materials and Manufacturing, Bangalore, 6-7th December 2013, pp.389-393.

38. A. C. Reddy, Tribological Behavior of Nano Titanium Carbide Particles Embedded in 8090 AL alloy Metal Matrix Composites, 2nd International Conference on Thermal and Tribological Behavior of Composites, New Delhi, 27-28th December 2013, pp.155-160.

39. C.R. Alavala, Synthesis and Tribological Characterization of Cast AA1100-B_4C Composites, International Journal of Science and Research, vol.5, no.6, pp.2404-2407, 2016.

40. M. S. Ramgir, A. C. Reddy, Control of B4C Reinforced Particulates on Dry Wear Resistance of AA2024/B4C Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10th Decembe, 2011, pp.336-340.

41. R. G. Math, A. C. Reddy, Tribological Performance of AA3003/B4C Metal Matrix Composites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8th Decembe, 2012, pp.314-318.

42. V. K. Reddy, A. C. Reddy, Wear performance of AA4015/Boron Carbide Metal Matrix Composites, 5th International Conference on Modern Materials and Manufacturing, Bangalore, 6-7th December 2013, pp.384-388.

43. M. Mastanaiah, A. C. Reddy, Abrasive Wear of AA3003/ZrC Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10th December 2011, pp.347-351.

44. M. Mastanaih, A. C. Reddy, Three-Body Wear Behavior of AA1100/ZrC Metal Matrix Composites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8th December 2012, pp.319-323.

45. V. B. Reddy, A. C. Reddy, Sliding Wear by Hard and Micro-Particles of AA2024-Zirconium Carbide Metal Matrix Composites, 5th International Conference on Modern Materials and Manufacturing, Bangalore, 6-7th December 2013, pp.399-403.

46. G. V. R. Kumar, A. C. Reddy, Tribological Analogy of Cast AA2024/TiB2 Composites, 2nd International Conference on Modern Materials and Manufacturing, Pune, 10-11th December 2010, pp.287-291.

47. V. K. Reddy, A. C. Reddy, Mathematical Models for Dry Wear of H18 Heat Treated AA1100/TiB2 Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10th December 2011, pp.341-346.

48. V. K. Reddy, A. C. Reddy, Unlubricated Sliding of AA4015/TiB2 Metal Matrix Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10th Decembe, 2011, pp.352-356.

49. A. C. Reddy, Estimation of Wear and Thermoelastic Behavior of AA2024/Titanium Diboride Nanoparticle Metal Matrix Composites, 5th International Conference on Materials Processing and Characterization (ICMPC-2016), Hyderabad, March, 2016, pp.2806–2812.

50. C.R. Alavala, Weight Loss Functions for Tolerable Wear Rate of AA1100/BN Metal Matrix Composites, International Journal of Mechanical Engineering and Technology, vol.7, no. 5, pp.9-17, 2016.

51. A. C. Reddy, Study of Factors Influencing Sliding Wear Behavior of Hexagonal Boron Nitride Reinforced AA6061 Metal Matrix Composites, 5th International Conference on Modern Materials and Manufacturing, Bangalore, 6-7th December 2013, pp.409-413.

52. A. C. Reddy, Impact of Particle Size on Dry Wear Formulation of AA2024/Titanium Nitride Macro-particle Metal Matrix Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10th December 2011, pp.362-366.

53. V. K. Reddy, A. C. Reddy, Role of Reinforcing Particle Size in the Wear Behavior of AA6061-Titanium Nitride Composites, 5th International Conference on Modern Materials and Manufacturing, Bangalore, 6-7th December 2013, pp.394-398.

54. V. K. Reddy, A. C. Reddy, Influence of Matrix Alloy and Si3N4 Nanoparticle on Wear Characteristics of Aluminum Alloy Composites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8th December 2012, pp.324-328.

55. M. Mastanaih, A. C. Reddy, Exploitation of Reinforcement in Revision of Wear Behavior of AA1100/Si3N4 Metal Matrix Composites, 5th International Conference on Modern Materials and Manufacturing, Bangalore, 6-7th December 2013, pp.379-383.

56. A. C. Reddy, Reduction of Vibrations and Noise using AA7020/Fe2O3 Nanocomposite Gear Box in Lathe, International Journal of Scientific & Engineering Research, vol.6, no.9, pp.685-691, 2015.

57. A. C. Reddy, On the Wear of AA4015 – Fused Silica Metal Matrix Composites, 4th International Conference on Composite Materials and Characterization, Hyderabad, India, 7-8th March 2003, pp.226-230.

58. R. G. Math, A. C. Reddy, Hardness Patterns on Worn Surfaces of AA7020 Alloy/SiO_2 Particulate Metal Matrix Composites, 2nd International Conference on Modern Materials and Manufacturing, Pune, 10-11th December 2010, pp.297-301.

59. M. Mastanaih, A. C. Reddy, Implication of Macro-sized Silicon Oxide Particles on Wear Rate of AA2024Alloy Metal Matrix Composites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8th December 2012, pp.334-338.

60. A. C. Reddy, Sliding Wear and Micromechanical Behavior of AA1100/Titanium Oxide Metal Matrix Composites Cast by Bottom-Up Pouring, 7th International Conference on Composite Materials and Characterization, Bangalore, 11-12th December 2009, pp.205-210.

61. A. C. Reddy, Hardness Contours and Worn Surfaces of AA1100 Alloy/TiO2 Metal Matrix Composites, 2nd International Conference on Modern Materials and Manufacturing, Pune, 10-11th December 2010, pp.292-296.

62. R. G. Math, A. C. Reddy, Inference of Macro-particles on Wear Rate of AA2024/TiO_2 Metal Matrix Composites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8th December 2012, pp.329-333.

63. A. C. Reddy, Tribological Behavior of AA8090/MgO Composites, 5th National Conference on Materials and Manufacturing Processes, Hyderabad, 9-10th June 2006, pp.169-173.

64. R. G. Math, A. C. Reddy, Sliding Wear of AA7020/MgO Composites against En32 Steel Disc, 2nd International Conference on Modern Materials and Manufacturing, Pune, 10-11th December 2010, pp.281-286.

65. T. K. K. Reddy, A. C. Reddy, Wear Performance of Magnesia as Reinforcement of AA2024 Metal Matrix Composites, 5th International Conference on Modern Materials and Manufacturing, Bangalore, 6-7th December 2013, pp.404-408.

66. A. C. Reddy, Experimental Validation of Dry Wear Formulation of AA7020/Zirconia Nanoparticle Metal Matrix Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10th December 2011, pp.357-361.

67. V. K. Reddy, A. C. Reddy, Tribological Investigation of Particle Size Effect on Wear Rate of Zirconium Oxide Microcomposites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8th December 2012, pp.339-343.

68. T. Prasad, A. C. Reddy, Sliding Wear of AA6061/Carbon Black Metal Matrix Composites, International Journal of Mechanical Engineering and Technology, vol.8, no.2, pp.203–209, 2017.

69. T. Prasad, A. C. Reddy, Effects of Carbon Black Nanoparticles on Wear Resistance of AA6063/CB Metal Matrix Composites, International Journal of Materials Science, vol.12, no.1, pp.87-95, 2017.

70. T. Prasad, A. C. Reddy, Effects of Carbon Black Nanoparticles on Wear Resistance of A7020/Carbon Black Metal Matrix Composites, American Journal of Materials Science, vol.7, no.3, pp.47-52, 2017.

71. A. C. Reddy, Wear and Mechanical Behavior of Bottom-Up Poured AA4015/Graphite Particle-Reinforced Metal Matrix Composites, 6th National Conference on Materials and Manufacturing Processes, Hyderabad, 8-9th August 2008, pp.120-126.

72. A. C. Reddy, Influence of Agglomeration of Nanoparticles on Tensile Strength and Wear Rate of AA6061/Graphite Metal Matrix Composites, 1st International Conference on Thermal and Tribological Behavior of Composites, Bangalore, 26-27th December 2008, pp.144-155.

73. A. C. Reddy, Application of Factorial Techniques to Validate Wear Model of AA2024-Graphite Microcomposites, 4th International Conference on Modern Materials and Manufacturing, Chennai, 7-8th December, 2012, pp.344-348.