**Tribological Behaviour of Carbon Fiber Reinforced Polymer Composites with Reinforced with Nano-fillers.**

**Shylesh K Siddalingappaa, Bhaskarpalb, Haseebuddinc, K Gopalakrishnad**

*a, b Department of Mechanical Engineering, School of Engineering, Presidency University, Bengaluru-560064, Karnataka State, India.*

*cDepartment of Mechanical Engineering, Dayananda Sagar College of Engineering, Bengaluru-560078, Karnataka State, India.*

*dDepartment of Mechanical Engineering, Centre for Incubation, Innovation, Research and Consultancy (CIIRC), Jyothy Institute of Technology, Bengaluru-560082 Karnataka State, India.*

\*Corresponding author Email: is.shyleshks@gmail.com

------------------------------------------------------------------------------------------------------------------

**Abstract:** Nano-fillers reinforced in to the polymer based composites have found to enhance the tribological properties in polymer composites. Alumina (Al2O3) and Molybdenum-di-Sulphide ((MoS2) were selected as nano-fillers for the present research work. These fillers were added to the epoxy resin in the concentration ranging from (0.1% to 0.7%) of the epoxy resin volume which was chosen as a matrix material and aircraft grade carbon fabric was used as a primary reinforcement. Panels were fabricated using Vacuum Assisted Resin Transfer Molding (VARTM) and test samples were extracted using water jet cut. The extracted samples were subjected to three body wear test and two body wear test as per ASTM standards. The results have demonstrated the significant influence of the nano-fillers in polymer matrix composites and the positive impact of molybdenum-di-sulphide as compared to that of the Alumina for all the concentrations studied.

**Keywords:** Carbon-fibers, Molybdenum-di-Sulphide, Vacuum Assisted Resin Transfer Molding (VARTM), Nano-composites.

1. **Introduction**

Carbon fiber reinforced polymer composites has commanded the major share in the structural polymer composites industry. It is been widely in use for various applications such as aerospace, aeronautical, automobile, locomotive and in recreational applications. The major reason behind gaining such a wider application is its unparalleled material properties which can be tailored as per the end application need, to mention few amongst them is higher strength to weight ratio, higher stiffness, and higher fatigue resistance. Profound research has been carried out by various researchers across the globe in tailoring the carbon fibers as reinforcement for polymer composites for various applications by satisfactorily conducting the array of tests there by determining various mechanical properties and thermal properties [1]. On the other hand advancement in the nanotechnology has lead the materials processed to the nano-size in the form of particles especially have found profound application as a primary as well as the secondary reinforcement. This nano-sized particles in polymeric composites has offered wider scope in developing the material system that uses the existing micro or macro sized fibers along with certain concentration of nano-sized particles with the resin system. These nano-sized particles when added in optimum quantity in to the resin matrix system, it binds the fibers more efficiently and enhances its mechanical properties and thermal properties [2]. In this research work efforts have been made to develop the carbon fiber reinforced epoxy based polymer composite with nano-fillers such as Alumina (Al2O3) and Molybdenum-di-Sulphide (MoS2). Each of the above mentioned nano-filler was separately added and tested for its tribological strength using the modern three body wear testing machine and a traditional pin-on-disc wear testing machine. Subsequent paragraph highlights the literature review carried out, experimental work details, results obtained and the subsequent conclusion drawn based on the results obtained are presented in detail.

1. **Literature Review:**

GuangShi et al had assessed the impact of nano sized alumina fillers on the sliding wear behaviour on the epoxy based polymer composites. The researchers were successful in reducing the reducing the specific wear rate by 97% when the volume of the nano-alumina used was 0.24 vol % than compared to the bare epoxy resin. [3]. B Suresha et al evaluated the tribological properties of Carbon-Epoxy and Glass-Epoxy reinforced polymer composites using Pin on Disc apparatus. It was found that Carbon-Epoxy samples showed lower friction and lower slide wear loss. [4]. A Shafiei-Zarghani et al had developed the Al2O3 nano-composites surface layer on an Al alloy using Friction Stir Welding (FSP). FSP made significant enhancement in the mean micro hardness of the nano-composite layered composite by three times as compared to the bare aluminium substrate [5].

V.P. Gordienko et al studied the significance of adding additives less than one micrometre (<1µm) with polyolefin such as polyethylene and polypropylene by hot pressing under a pressure of 35 MPa for 20 minutes by adding inorganic additive molybdenum-di-sulphide in the range of 0.1 to 10% by volume. It was found that there was increase in the hardness due to the addition of molybdenum in a tracer quantity of 0.3 to 0.5% which enhanced the wear resistance of the composite by 8 to 10% [7]. Zhu Peng et al conducted the study of the tribology performance of molybdenum-di-sulphide reinforced thermoplastic polyamide under dry and wet lubrication conditions. It was found that mechanical performances were superior the thermoplastic filled with molybdenum-di-sulphide [8]. P.H.Sivaraman et al studied the influence of molybdenum-di-sulphide composition on the wear characteristics of the composites fabricated. SEM images were used to study the worn surfaces. It was found that the there was a significant improvements in the composite properties which were doped with molybdenum-di-sulphide than compared with that of the bare composite [9].

From the above discussion it was brought to conclusion that there is documented research work carried out in fabricating polymer based nano-composites using nano sized alumina and nano sized molybdenum-di-sulphide. Most of the work involved fabricating the samples from hand layup, compression molding, but no evident found about using VARTM method of fabrication and testing the composites in the range discussed using three body abrasive wear test and traditional pin-on-disc apparatus. Hence the present research work of developing the VARTM fabricated nano-composites reinforced with nano sized in different proportions and conducting three body abrasive wear and two body abrasive wear studies is believed to have the wider scope.

1. **Materials and Method of Fabrication:** Structural grade carbon fabric was used as a primary fiber and epoxy resin HTR 212 was mixed with hardener HTR-386-99 these materials were procured from Aircraft Spruce, USA were used in preparing the polymer composites without any nano-fillers. Alumina (Al2O3) particles sized about 18 nm and Molybdenum-di-Sulphide (MoS2) in the particle size range of 80nm-100nm with 99.9% purity was used as nano-fillers in the volume of 0.1%, 0.2%, 0.4%, and 0.7% to develop the nano-fillers reinforced polymer composites. Vacuum Assisted Resin Transfer Molding (VARTM) method was used for fabricating the composite panels. The resin was mixed with the nano-fillers using ultrasound powered ultrasonicator for uniformly distributing the nano-fillers with the pure epoxy resin. The whole setup is as shown in the figure 1. Panels were fabricated resembling the size of the VARTM mold and samples were extracted by water jet cutting as per the ASTM standards. The photographs of the extracted samples are as shown in figure 2.

|  |  |
| --- | --- |
| **Fig. 1.** Vacuum assisted resin transfer molding. | **Fig. 2.** Composite panels extracted from water jet cutting. |

1. **Experimental Testing**
   1. **Three Body Abrasive Wear Test:** Three body abrasive wear tests were conducted in accordance with ASTM G-65. The equipment used is shown in the figure 3. The initial weight of specimen was recorded. The velocity and test time was set. Abrasive particles from the hopper were introduced between the test specimen and rotating cholorobutyl rubber tyre abrasive wheel (hardness; Durometer-A 58-62). At the end of the set duration, specimen was removed and cleaned thoroughly. The final weight of the tested specimen was recorded. Thus measuring the wear loss. The above procedure was repeated for varying abrading radius for different concentrations of the nano-fillers used at two different weights of 24N and 48N [9].

|  |  |
| --- | --- |
| **Fig. 3.** Three body abrasive wear test setup | **Fig. 4.** Two body abrasive wear test setup  1. Pin holder with screw, 2**.** Specimen with holder, **3.** Rotating disc. |

**4.2 Two Body Wear Test:** Two Body Abrasive wear tests were conducted in accordance with ASTM G-99. The rotating disc of the apparatus was cleaned using the acetone so as to remove any dirt, grease or any material debris attached from the previous test. Initial weight of the sample was measured and recorded and the specimen was fixed to the sleeve based upon the preselected abrading radius. The specimen was loaded by the predefined magnitude of weight and brought in contact with the rotating disc. As the machine was switched on, the specimen in contact with the rotating disc abraded gradually. The test was performed for a fixed duration of time as per the standard mentioned above and finally the weight of the specimen after the test was denoted. Thus measuring the wear loss. The above procedure was repeated for varying abrading radius for different concentrations of the nano-fillers used at two different weights of 24N and 48N [10].

**5. Results and Discussions**

**5.1 Three Body Wear Test:** The plots shown in figure 5.1 and figure 5.2 shows the variation of wear rate against the abrading distance. The wear test was carried out at various concentrations varied in the steps of 0.0%, 0.1%, 0.2%, 0.4% and 0.7% at 24N and 48N respectively. In all the plots shown figure 5.1 and figure 5.2 it was observed that the wear rate has gradually increased when the load was varied during the test from 24N to 48N for a particular concentration of the sample tested. However the wear rate observed between Al2O3 and MoS2 for any concentration studied at 24 and 48N conveyed that the wear rate of MoS2 was lesser compared as that of Al2O3. This could be for the fact that, the MoS2 being a soft reinforcement acts as a solid lubricant and aids in smooth removal of the material and hence the wear rate is less as compared to that of Al2O3. For instance at 0.4% concentration Al2O3 sample wear rate was 0.2 units whereas that of the MoS2 was 0.135, i.e. the former wear rate was more by 0.065 units as compared to the latter one as observed for the abrading distance of 1000m at 24N. Similar trend can be observed at 48N.

**5.2** **Two Body Wear Test:** With reference to the above discussion, the results obtained in the two body wear test are as shown in the plots given in figure 6.1 and figure 6.2. The results obtained shows the similar trends as that in case of three body wear test. However the wear rate obtained were far more less as compared to that of the three body wear results. The abnormalities in the last plot shown in figure 6.2 can be attributed for the reason of loose gripping of sample in the pin-on-disc machine.

|  |  |  |
| --- | --- | --- |
|  | |  |
| **Fig. 5.1.** Three body abrasive wear test results showing the variation of wear rate against the abrading distance for different concentrations of Al2O3 and MoS2 at 24N. | | |
|  |  | |
| **Fig. 5.2.** Three body abrasive wear test results showing the variation of wear rate against the abrading distance for different concentrations of Al2O3 and MoS2 at 48N. | | |

|  |  |
| --- | --- |
|  |  |
| **Fig.6.1.** Two body abrasive wear test results showing the variation of wear rate against the abrading distance for different concentrations of Al2O3 and MoS2 at 24N. | |

1. **Conclusions:**
2. Composite panels with Al2O3 and MoS2 nano-fillers were fabricated using Vacuum Assisted Resin Transfer Moulding (VARTM) in the varying concentrations (0.0%, 0.1%, 0.2%, 0.4% and 0.7%) of the nano-fillers. The samples were subjected to three body and two body abrasive wear tests as per the ASTM standard ASTM G-65ASTM G-99 respectively.
3. The results obtained clearly depicted that composites reinforced with MoS2 showed better wear resistance at all the concentrations studied as compared to that of the composites reinforced with Al2O3 nano-filler.
4. MoS2 at 0.4% concentration showed the better wear resistance at all the instances than the other concentrations of the reinforcement studied.

|  |  |
| --- | --- |
|  |  |
| **Figure 6.2.** Two body abrasive wear test results showing the variation of wear rate against the abrading distance for different concentrations of Al2O3 and MoS2 at 48N. | |

**7.0 References**

1. P K Mallick (2007) Fiber reinforced Polymer Composites, Materials, Manufacturing and Design. CRC Press, New York.
2. C Soutis (2005) “Fiber reinforced composites in aircraft construction”. Program Aero Science, 41 (2) (2005), pp. 143-151.
3. GuangShi, Ming QiuZhang, [Min ZhiRong](http://sci-hub.tw/https:/www.sciencedirect.com/science/article/abs/pii/S0043164803005337/" \l "!), BerndWetzel, KlausFriedrich (2004) “Sliding wear behavior of epoxy containing nano-Al2O3particles with different pretreatments” Wear Volume 256, Pages 1072-1081.
4. B. Suresha, G. Chandramohan, P. Samapthkumaran, S. Seetharamu, S. Vynatheya, (2006) “Friction and Wear Characteristics of Carbon-epoxy and Glass-epoxy Woven Roving Fiber Composites“. The Journal of Reinforced Plastics and Composites, Volume: 25 issue: 7, page(s): 771-782.
5. A.Shafiei-Zarghani S.F.Kashani-BozorgA. Zarei-Hanzaki (2011). “Wear assessment of Al/Al2O3 nano-composite surface layer produced using friction stir processing”. Wear, Volume 270, Issues 5–6, 10 February 2011, Pages 403-412.
6. V.P. Gordienko, V.G. Sal’nikov, R.V. Podlesnyi, A.V. Kasperskii (2009). “Hardness and wear resistance of certain polyolefins with additions of molybdenum-di-sulphide”. Plasticheskie Massy (Plastic Weight), Volume 10, pages. 13–15.
7. Zhu Peng, Wang Xiao, Wang Xiao‐dong, Huang Pei, Shi Jun (2013). “Tribology performances of molybdenum disulfide reinforced thermoplastic polyimide under dry and water lubrication conditions”. Industrial Lubrication and Tribology, Vol. 58 Issue: 4, pp.195-201.
8. P.H.Sivaraman, R.Vimal, S.Badrinarayanan, R.Vignesh Kumar (2017). “Study of Wear Properties of Jute/Banana Fibers Reinforced Molybdenum-di-sulphide Modified Epoxy Composites” Materials Today Proceedings”. Volume 4, Issue 2, Part A, 2017, Pages 2910-2919.
9. ASTM G65-04, Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus, Annual Book of ASTM Standards, Vol. 03.02, 2004.
10. ASTM G99-17, Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus, ASTM International, West Conshohocken, PA, 2017.