CHAPTER 2

REVIEW OF LITERATURE

2.1 WEAR AND FRICTION CHARACTERISTICS OF POLYMER–HYBRID NANOCOMPOSITES (CNTs – Al₂O₃)

Nanotechnologies are new approaches of research and development involving precise control of molecules and atoms to develop novel material with unique deserving properties. The incorporation of nanoparticles in polymer matrix has been impressive as they predominantly improved the properties of polymer materials (Puchy et al. 2013). CNTs may become predominant reinforcing materials for innovating new class of nanostructure composites due to their light weight, attractive mechanical and excellent thermal properties (Wetzel et al. (2003), Dasari et al. (2009)). However, the main challenge is to transmit the significant properties of CNTs and it can only be realized in composites by combining the appropriate processing method and optimal quantity of materials (Zhang et al. (2006), Guadagno et al. (2009)). Alumina (Al₂O₃) is the cost effective ceramics and widely used materials in the group of engineering ceramics. It possesses high hardness, excellent mechanical property, high stiffness and superior thermal properties (Ahmad et al. 2010). Tian & He (2011) reported that homogeneous distribution of MWCNTs/alumina hybrid in a High density polyethylene
matrix achieved the improved young’s modulus and tensile strength. Zakaria et al. (2014) studied the tensile and thermal properties of CNTs-\(\text{Al}_2\text{O}_3\) hybrid epoxy composites. Their results showed that the tensile modulus, strength, thermal conductivity and glass transition temperature value were improved compared to neat epoxy. Zhang et al. (2012) concluded that when arm chair and zigzag architecture form of graphene sheet were subjected to tensile deformation and it still preserved the architecture. It also exhibited the same mechanical strength. Khashaba (2014) in conventional and ultrasonically dispersion of alumina nanoparticles into epoxy matrix, he reported that in the conventional processing method, structural properties were improved. Li et al. (2014) reported that CNTs were synthesized and dispersed with the help of the alumina ‘vehicle’ in mg matrix and improvement in the mechanical properties were achieved. In a study analysed by Pihtili & Tosun (2002) it is defined that load applied on the specimen is more effective on the wear behavior of the specimen than that of the speed. Wear test is performed on ball on disc wear analyzer by Kim et al. (2011) and they have concluded that wear properties of carbon / epoxy composites are improved by the addition and surface modification of CNTs. Liu et al. (2007) investigated MWCNTs/BMI nanocomposites and found that the wear loss rate of all nanocomposites considerably decreased with increasing nanotubes content, until the content reached 2.5 wt.%. Yue et al. (2014) concluded that better dispersion of hybrid filler in the epoxy matrix would improve the mechanical and electrical properties. Wear in polymer materials is closely attributed to the mechanical and thermal properties of polymer. Recently alumina-CNTs has been used as a hybrid component of the polymer matrix to develop high performance multifunctional advanced composites materials. Shen et al. (2011) observed that the tribology performance of carbon nanotube – graphene oxide hybrid epoxy composites will increase the friction coefficient and it would lead to reduction in the specific wear rate. The natural rubber nanocomposites
containing hyper branched polyster modified Al$_2$O$_3$ and carbon blacks gave the best abrasion resistance and thermal stability.

In this study, we have fabricated epoxy matrix composites reinforced by a nano scale hybrid (MWCNTs/Al$_2$O$_3$) in which the MWCNTs are evenly dispersed and strongly bonded with Al$_2$O$_3$ particles. Combining MWCNTs with Al$_2$O$_3$, the following advantages have been recognized during these investigations. Firstly, both MWCNTs and Al$_2$O$_3$ nanoparticles combination in a composite exhibit the improved mechanical properties. Secondly, Al$_2$O$_3$ may be helpful with homogeneous dispersion of MWCNTs in neat epoxy. Where the ceramic acts as ‘vehicles’ for MWCNTs to easier dispersion during ultrasonication. The foremost problem is addressed by the researchers in the CNTs dispersion (or) forms large aggregate in the matrix which may be overcome by means of using surface pretreated MWCNTs. Tian and He (2011) reported that Functionalized MWCNTs surface form a mechanical interlock with Al$_2$O$_3$ to improve matrix properties.

Many investigations are paying attention on further improving polymer materials using nanofillers, and in particular hybrid composites to enhance the tribological properties as well as obtaining multi – functional materials. The last few year’s publications elaborately discussed on the improvement in the mechanical and thermal properties of MWCNTs-Al$_2$O$_3$ hybrid into the polymer matrix and limited investigation has reported on the prediction of tribological performance and optimum weight of hybrid composites. Therefore the potential advantage of the MWCNTs – Al$_2$O$_3$ hybrid particles is employed to improve the tribological properties of the pure epoxy and the optimum weight of MWCNTs- Al$_2$O$_3$ hybrid composites is also discussed.
2.2 MECHANICAL CHARACTERISTICS OF POLYMER – HYBRIDNANOCOMPOSITES (CNTs – Al₂O₃)

The recent development and advances in nano-scale science and engineering have provided new prospects to develop the composite materials with superior performances. The multi-scale hybridization of Carbon Nanotubes (CNTs) with micro-particles in polymers offers new opportunity to develop high performance multifunctional composites. Hybrid composites are used as structural materials due to their high strength, low weight ratio and specific modulus (Li et al. 2014). The CNTs play an important role in the load carrying due to their excellent mechanical properties, exceptionally high stiffness, strength, resilience, as well as superior electrical and thermal properties and moreover attractive candidates for the reinforcement materials (Ebbesen et al. 1996), (Hussain et al. 2006), (Qian et al. 2002). The Young’s modulus and the yield strength have been doubled and quadrupled for composites with respective 1 and 4 wt. % nanotubes, compared to the pure resin matrix (Allaoui et al. 2002). Alumina exhibiting high specific stiffness, superior high temperature, mechanical properties and excellent oxidation resistance is widely used in structural applications (Brown&Ellyin 2011), (Wetzelet al. 2002). Rahmanian et al. (2014) states that the multiscale composites revealed significant improvement in elastic and storage modulus, strength as well as impact resistance in comparison to CNT–epoxy composites. McGrath et al. (2008) reveals that the epoxy-alumina composites are a robust materials system and fairly large changes in particle shape and size distribution can be tolerated without causing a substantial change in the thermal and mechanical properties or fracture toughness of the system. This is happened due to a weak epoxy-alumina interaction and traditional wisdom is supported. When this data are compared with existing literature, it is clear that the incorporation of filler into an epoxy matrix is more effective in improving
the relative fracture toughness in composites with resins that exhibit a lower initial unfilled matrix toughness.

Li et al. (2013) reported that the embedding of CNT–GNP hybrids into pristine epoxy endows optimum dispersion of CNTs and GNPs as well as better interfacial adhesion between the carbon fillers and matrix, which results in a significant improvement in load transfer effectiveness and the resulting the tensile strength is enhanced by significantly with respect to the neat epoxy. The chemical hybrid filler of CNT–Al₂O₃ produced via CVD performs better than the physically mixed hybrid filler of CNT–Al₂O₃ in terms of tensile and thermal properties in the given filler loading. The increase in tensile performance of the chemical hybrid CNT–Al₂O₃ is associated with improved stress transfer between filler and matrix with the presence of the CNTs on the surface of Al₂O₃ particle (Zakaria et al. 2014). Khashaba (2014) described that the well dispersion of hard alumina-nanoparticles in epoxy resin has played a key role in improving the alumina/matrix interfacial bond strength. Therefore, the applied stress is effectively transferred to the particles from the matrix and accordingly, the flexural strength, modulus, and fracture toughness of alumina nanocomposites are enhanced considerably. Lee et al. (2011) concluded that the improved tensile properties of the silanized carbon/CNT/epoxy three-phase composite are due to the increased dispersibility and interfacial interactions between the silane-functionalized CNTs and epoxy in the carbon/epoxy composite. The well dispersed alumina-nanoparticles in epoxy resin significantly improve the mechanical properties of alumina-nanocomposites. Tian and He (2011) concluded that Fracture surface showed homogenous dispersion of nanotubes and Al₂O₃ in the HDPE matrix and presence of interlocking like phenomena between hybrid and HDPE matrix may contribute to the effective reinforcement of the HDPE composites. Zhang and Jiang (2011) reported that chemically functionalized MWCNTs and chemically interconnected MWCNTs improve the fracture
strain and therefore the toughness of the composites significantly improve. Mishnaevsky (2014) concluded that Glass/carbon fibers hybrid UD composites clearly demonstrated higher stiffness and lower weight with increasing the carbon content; however, they can show lower strength and elongation to failure compared with usual glass fiber polymer composites. The strength (critical stress) of hybrid composites can be lower than that of both pure glass and pure carbon composites, especially under uniform displacement loading. The critical elongation of the hybrid composites decreases with increasing fraction of carbon fibers in the hybrid.

Considering the above discussion of existing techniques and various new findings, the present study aims to develop and observe the influence of MWCNTs–Al$_2$O$_3$ addition on the mechanical properties such as tensile strength, micro hardness and impact energy of traditional epoxy reinforced composites. As a major ceramic material, it is commonly used for structural applications due to its high specific stiffness, Al$_2$O$_3$ is selected as the binder for CNTs. MWCNTs–Al$_2$O$_3$ hybrids comprised of well-aligned MWCNTs are synthesized by chemical vapour deposition process (CVD). Hybridizing Al$_2$O$_3$ with MWCNTs may be helpful with the dispersion of CNTs in the host matrix.

2.3 EROSION CHARACTERISTICS OF POLYMER – HYBRID NANOCOMPOSITES (CNTs – Al$_2$O$_3$)

Solid particle erosion is the phenomenon where the progressive material removes itself from a solid surface due to the high velocity stream of solid particle travelling over the surface. Polymer composites are extensively used as bulk structural materials in aerospace, marine, automobile and refining industry due to its excellent specific properties. In the past few decades, polymer composites materials in erosive environment have been increasing...
with wide range of engineering applications like aircraft engine blade, aircraft operating in desert environments, helicopter rotor blades and pipe line carrying sand slurries in petroleum refining. Srivastava and Pawar (2006) reported that addition of GFRP composites with fly ash fillers in epoxy resin improves the erosive resistance as fillers restrict the fiber – matrix debonding. Further, Fouad et al. (2011) reported that the erosion behavior of epoxy/GFRP has changed from ductile to brittle at 60° impingement angles with high erosion losses. Zhang et al. (2013) investigated research on solid particles erosion behavior of carbon fiber (CF) woven fabric and carbon nanofiber paper coated epoxy composites. The CNF is able to provide a much stronger erosion resistance compared to the CF reinforced epoxy composites, which is attributed to the high strength of CNFs and their nanoscale structure. Tilly and Sage (1970) reported that the erosion resistance depends upon the type of fiber used resulting in the improvement or worsen of epoxy and nylon 66 composites. Tewari et al. (2003) investigated that the erosion wear of the unidirectional carbon and glass fiber reinforced epoxy composites exhibit semi-ductile erosion behavior, with maximum erosion rate at 60° impingement angle and the fiber orientations has significant influence on erosion. Extensive research was carried by Patnaik et al. (2008) on the solid particle erosion characteristics of various filler such as SiC, flyash and alumina on polymer composites. The investigation revealed that addition of fillers in the considerable weight fraction in the matrix would yield good results. It is well known that the erosion rate of polymer composites is usually higher than that of neat polymers. During the last decade, many investigations have been reported on epoxy (Barkoula & Karger-Kocsis 2000), Polypropylene (Walley & Field 1984), nylon (Tilly 1969), polyethylene (Walley & Field 1987), ultra high molecular weight polyethylene (Wang et al. 1998),polyetheretherketone (Walley et al. 1987), rubber (Penkin 1982), (Bartenev & Penkin 1980) and hybrid composites (Rout &Satapathy 2012). In general, fiber/filler content in the composites control the mechanical and tribological properties. In order to
obtain the desired material properties for a particular application, it is significant to know how the material performance changes with the fiber content under given loading conditions (Harsha et al. 2003). The behavior of fiber content polymer composites have been studied to a limited extend (Barkoula & Karger-Kocsis 2000), (Tewari et al. 2003).

The aim of this present experimental investigation is to study the influence of solid particles on MWCNTs – alumina hybrid nanocomposites of erosion behavior with pure epoxy composites. The influences of hybrid nanofillers weight fraction and impingement angle on the solid erosion of composites is studied.

2.4 NUMERICAL APPROACHES OF POLYMER – HYBRID NANOCOMPOSITES (CNTs – Al₂O₃) USING ANN

Recently, Artificial Neural Networks (ANNs) have been emerged as good candidates to mathematical models, due to their learning capabilities from experimental data to generalization of nonlinear behavior. Wear of composites, especially in the polymers–originates, has numerous sets of complex interactions on bonding structure on macro and microscopic levels. These interactions depend on the materials, geometrical and tribological characteristics of the surfaces and sliding conditions, e.g. load, temperature, lubricating conditions and type of contact.

Artificial Neural Network (ANN) has been recently used in modeling the mechanical, physical, manufacturing and properties of engineering materials. It is a promising field of research in predicting results of nonlinear and a more complex one among all engineering problems. It has the ability to learn from the small experiments datasets compared to other computational numerical approach.
Pujari et al. (2017) described that ANN network model is suitable for predicting the absorption coefficient with a very high degree of accuracy in natural fibers matrix and the prediction accuracy of ANN models is much better than that of other network models. Soorya prakash et al. (2017) demonstrated that better predictability is achieved from feed forward back propagation ANN model with topology 3-7-1 and they predict the wear loss Cu–MWCNTs composite based on MWCNTs as reinforcement, applied load and sliding distance. Abdelbaryet al. (2012) concluded that the performance of the network is governed by the ANN configuration and size of input parameters. Successful introduction of ANNs in tribological applications could be a beneficial one to reduce the number of tribo-experiments as well as estimating the actual life time of bearing components. Study was carried out by Gencel et al. (2011) on wear loss in concrete, he indicated that the ANN model is the best predictor for estimation of wear loss in concrete based on the value of RMSE, RAE and R² statistics. Gyurova & Friedrich (2011) explained that conventional regression analysis constructs a solution without the need of relationships between variables. These techniques are very helpful for modeling the network and solutions are not easily formulated in a short time. Hanief & Wani (2015) developed a mathematical model to characterize the surface roughness during running – in wear process, resulting ANN can be used to predict the required results with high accuracy.

Gyurova et al. (2010) exploded that the tribological properties of new material combinations are gained from utilizing ANN networks. Furthermore, when comparing the predicted and real test values, the quality of prediction is good. Xu et al. (2014) explained the feed-forward network with 8 hidden layers and twelve neurons to predict the corrosion behavior of Ni – SiC composites coatings. Lingaraju et al. (2011) investigated that ANN is highly suitable for predicting mechanical and tribological properties of synthetic materials while compared to regression model.