HPDE-GO Nanocomposite with Enhanced Mechanical Properties

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Abstract - *Polymers are now pervasive and are considered to play an important role in reshaping our world. In terms of usage and production scales, High Density Poly Ethylene (HDPE) is one of the most widely used polymers. Looking for ways to improve its performance, dispersion strengthening has been identified as a promising path. Nano-fillers dispersed within the polymer matrix significantly improve the properties and results in Polymer Matrix Nanocomposites (PMN). The goal of this research is to create a graphene oxide (GO) dispersed polymer matrix composite system. In this approach, the Tour's method was used to synthesize Nano Graphene oxide powder. For the composite preparation, ultrasonicated GO particles were used as a precursor. The solvent method of direct mixing and the injection moulding technique were used to process HDPE-GO Nano-Composite. The HDPE and HDPE-GO nanocomposites were characterized for hardness and wear resistance. In comparison to HDPE, the results were found to be in line with expectations, with a multi-fold increase in wear resistance and a slight improvement in hardness.*

Key Words: **High Density Polyethylene, Nanocomposite, Graphene Oxide, Tour's method, Tribology, Hardness**

1.INTRODUCTION

For decades, researchers have been intrigued by polymers matrix composites. Enhancing performance with minimal resources has always been a challenging task. Nanocomposites were created as a result of years of research and are thought to have significantly better properties than traditional composites. Nanocomposites are made up of a variety of solids, at least one of which has a dimension in the nanometer range. The mechanical, chemical, electrical, thermal, and optical properties of nanoscale objects are unusual, distinctive, and exceptional. These anomalies in material behavior are attributed to the size dependent effect of properties.

The advancement of nanotechnologies has accelerated study into the effect of nanoscale fillers on the performance attributes of polymers and their composites. In comparison to micro-scale fillers, nano-scale fillers have several advantages: (a) a less abrasive effect on equivalents; (b) a large specific surface area, and hence a high adhesion to the polymer matrix; and (c) the ability to improve a number of composite properties with a relatively low filler content. Furthermore, by adding nanoparticles to composites based on promising polymers, the tribological properties of the composites can be improved.

Polymer serves as the base material for PMNs polymer matrix nanocomposites, with nanoscale additives or fillers serving as reinforcement. Filler materials are doped into the polymer matrix. The filler material composition and loading proportion must be carefully chosen because they have a significant impact on the composite's properties. Nano-filler materials have become increasingly popular in both research and industry in recent years. Graphene Oxide is a best fit filler material that meets most of the criteria for an idea filler material. It outperforms most used engineered materials in terms of mechanical strength. As a result, researchers began to regard GO as a miraculous material.

This work investigates the relationship between nanofiller loading, dispersion, and matrix binding with the friction vs wear behavior of HDPE nanocomposites. The quality of the filler dispersions was evaluated and tracked back to the nanofiller processing and melt mixing preparation of the nanocomposites. Low filler loadings were chosen because they resulted in considerable changes in micromechanical properties and improved wear properties while having only little effects on polymer crystallization, bulk mechanical properties, or melt viscosity of polymer nanocomposites.

The HDPE-GO composite material was developed in the lab with the intent of enhancing mechanical properties. Tribological properties such as hardness, wear resistance, and frictional force have been studied and reported.

2. Experimental Procedure

2.1 Preparation of Graphene oxide from Tour's Method (Improved Hummers method)

A standard preparation step for synthesis is followed [5]

It involves, Preparing a 9:1 mixture of concentrated H_2SO_4/H_3PO_4 (360:40 ml). Add the acid oxidizing mixture to graphite flakes (3.0 g) and $KMnO_4$ (18.0 g), this is a slightly exothermic reaction which can be sensed by the temperature rise to nearly 40 °C with thermometer. On a hot plate, the reaction temperature is maintained at 50 °C for 12 hours while it is continuously stirred.

Fig 1: Magnetic Stirring of H_2SO_4, H_3PO_4, $KMNO_4$ and Graphite Flakes

The reaction was cooled to room temperature and poured onto ice (400 ml) with 30% H_2O_2 (3 ml). Later, the reaction mixture was sifted and then filtered through PTFE sieve (45μm). The filtrate was centrifuged (4000 rpm for 4 h), and the supernatant was decanted away. The solid mass was then thoroughly rinsed with 200 ml of water, 200 ml of 30% HCl, and 200 ml of ethanol in the stated order. Repeat the rinsing process for a minimum of 4 times.

The mass is coagulated with 200 ml of ether, and the resultant suspension was filtered over a PTFE micro sieve with a 45 μm pore size. The final filtered product was vacuum dried for 15hrs at room temperature, after drying the product mass was measured to be 5.8 g.

Fig 2: Filtration of Graphene Oxide

2.2 Materials and processing

In this investigation, HDPE pellets were procured, and lab-synthesized Graphene oxide was employed, as well as non-polar solvent Toluene with outstanding solvency.

The sonication method was used to ensure that these ingredients were mixed properly. 0.3 gm graphene oxide was measured and added to toluene during the process. In the second step, the glass container containing the toluene graphene oxide combination was sonicated in an ultrasonic bath for 2 hours and 30 minutes. The sonication mixing is used to break up nanoparticle clusters and ensure that

graphene oxide nanoplatelets are evenly dispersed in the solvent. During sonication, the mixture in the container was exposed to ultrasonic sound at a frequency of 20 KHz. The sound waves propagated into the liquid, causing shear stress and reducing the attractive forces between the individual nanoparticles. The production of nanoparticle agglomerates is avoided with this method.

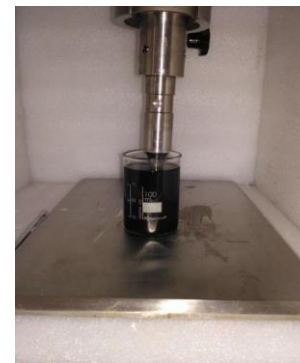**Fig 3:** Sonication of graphene oxide and toluene mixture – Before sonication

Fig 4: Sonication of graphene oxide and toulene mixture – After sonication

Following sonication mixing, the required amount of polymer (HDPE pellets) was added to the graphene oxide and toluene mixture, which was then placed on a heated plate. With the use of a magnetic stirrer, the mixture was heated to 100°C and constantly stirred at 100 rpm. The polymer dissolves slowly and thoroughly in the solvent while simultaneously mixing with the graphene oxide nanoplatelets during the solution mixing process, ensuring uniform dispersion of graphene oxide nanoplatelets in the polymer matrix. The resulting polymer nanocomposite paste was then cut into small pellets and dried for 12 hours at room temperature to evaporate the solvent. The solvent fully evaporated during the solvent evaporation procedure, leaving the HDPE graphene mixture. To justify the complete evaporation of the solvent, the dried polymer nanocomposite pellets are weighed, and the weight of the finally processed polymer nanocomposite is found to be roughly 20gms (weight of graphene oxide + weight of polymer). After reheating the polymer nanocomposite pellets to a semi-solid state, pressure is applied, and the

specimen is moulded into a cylindrical shape. After cooling, the specimen is removed and examined for hardness and wear.

3. Results and Discussion

3.1 Hardness observations

To assess the flexural strength of the composites, the hardness test is performed in a machine in line with ASTM standards. The outcomes are summarized in the table below. A material's hardness is a quality that allows it to resist plastic deformation, most commonly through penetration. Hardness can also refer to resistance to bending, scratching, abrasion, or cutting. The metals industry uses three types of tests to determine hardness: the Rockwell hardness test, the Vickers hardness test, and the Vickers hardness test. Because the definitions of metallurgical ultimate strength and hardness are so similar, a strong metal can be presumed to be a hard metal. The three hardness tests establish a metal's hardness by determining its resistance to the penetration of a non-deformable ball or cone. The tests measure the depth to which a ball or cone will go through metal in a certain amount of time under a given stress.

Using a 1/16" ball indenter and a 60kgf load with a 'B' scale. Due to optimum dispersion and distribution of HDPE and graphene oxide, the optimal rate of hardness will increase.

Pure HDPE	HDPE -Graphene Oxide Nanocomposite
65.8	69.6

Table 1: Hardness observations of HDPE and HDPE-Graphene Nanocomposite in HRB

3.2 Wear test Observations (Pin-on-disc)

The test sample is loaded with a precisely known force via a flat or sphere-shaped indenter (various materials are conceivable). As a frictionless force transducer, the indenter (a pin or a ball) is mounted on a stiff lever. The resulting frictional forces acting between the ball or pin and the plate are monitored by extremely slight deflections of the arm using a strain gauge sensor as the plate rotates. The volume of material lost during a specific friction run can also be used to calculate wear rates for both the pin and the sample. With altering time, contact pressure, velocity, temperature, humidity, lubrication, and other variables, this simple method permits the determination and study of friction & wear behavior of practically any solid-state material combination. Throughout the wear test, the following limitations were maintained: load applied =4.00 kgf, disk speed =1000 rpm, samples per minute =60, and rack diameter =100 mm.

a) Pure HDPE sample

The applied load is 4 kgf, and the speed of the pin-on disk is 1000 rpm. The rotating disk collects approximately 60 samples from the surface of the component. The sample track diameter is 100 mm. The experiment time is maintained at 120 seconds. We discovered that for pure HDPE samples, the wear rate of 2000 μm occurred in 22 seconds and the wear rate of 3800 μm occurred in 48 seconds.

b) Graphene oxide dispersed HDPE

Graphene Oxide Dispersed HDPE we observe that 2069 μm wear occurs in 106 seconds. This is the maximum wear rate peak observed during the study.

3.3 Comparison between HDPE and GO dispersed HDPE

a) For Wear:

There is clear enhancement in wear resistance of the Graphene Oxide dispersed HDPE composite.

b) For frictional force:

From the values between frictional force and time for both HDPE and Graphene Oxide dispersed HDPE composite, we observed that there is significant decrease in Frictional force of Graphene oxide dispersed HDPE composites. This may be due to lubrication effect of the Graphene oxide layer in the HDPE polymer composite matrix.

3.4 Fracture Imaging

Figure 5 shows scanning electron microscopic image of a fractured cross section of the HDPE-GO nanocomposite. At higher magnification, the rough fractured surface may be seen clearly. The wrinkled layers are visible, indicating that the composites contain GO. Additionally, the border between the GO and HDPE matrix is obscured by the fact that the GO is twisted or covered by the polymer matrix, implying a strong interfacial adhesion and favorable - interactions between the HDPE matrix and GO sheets.
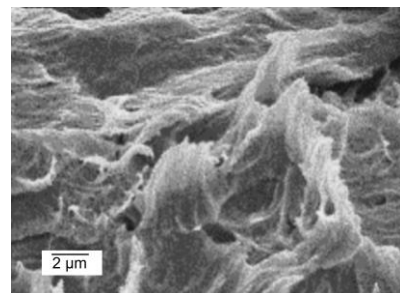

Fig 5: Cross section SEM image of fractured surface of HDPE-GO

4. CONCLUSIONS

The fundamentals of nanotechnology, as well as various types of polymer nanocomposite preparation methods, are discussed in this report. Graphene oxide nanoplatelets are of particular interest among nanomaterials because of their excellent surface-dependent material properties. When separated down to 1 nm, graphene oxide sheets have a high aspect ratio, surface area, and surface energy, and when added to a polymer matrix, they have been shown to improve material properties more than any other nano reinforcement material. The addition of 1.5 wt% graphene oxide to HDPE polymer improves its properties.

HDPE graphene oxide nanocomposite samples are made using the least expensive solvent method, which is assisted by ultrasonication, and then injected into molds. For the improvement of mechanical properties such as hardness and wear resistance, a sample of PMNs with 1.5 wt% graphene oxide inclusions was prepared, tested, and evaluated. There is a significant improvement in mechanical properties of PMNs with only a small amount of graphene oxide added. The improved molecular interaction between the molecules of HDPE and graphene oxide is responsible for the composites' increased hardness and wear resistance. This is due to the fact that at room temperature, a single graphene sheet separated down to 1nm has a very high mechanical strength and young's modulus. We are pleased to report that the synergetic properties of HDPE and Graphene oxide have been achieved.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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