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RESEARCH ARTICLE

INVESTIGATION OF ABRASIVE WEAR PROPERTIES OF GRAPHITE REINFORCED PA66 POLYMER COMPOSITES

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ABSTRACT

An experimental investigation is carried out to study the effect of normal load, weight fraction of graphite and abrading distance on the abrasive wear behavior of graphite reinforced polymer. Wear studies are carried out using PIN ON DISC APPARATUS. Weight loss of composites during abrasion has been examined as a function of sliding distance, normal load and weight fraction of graphite. Specimens with varying weight fraction of 10, 15, 20, 25, 30 of graphite have been taken and wear test is conducted using pin on disc apparatus under dry contact conditions. Weight loss is determined for loads of 10N, 20N, 30N with a track diameter of 40 mm, disc rotating speed of 500 rpm, using 400 grade silicon carbide emery papers. A series of experiments are conducted to find out the weight loss due to wear and thus estimate the specific wear rate coefficient of each specimen using **"ARCHARD'S EQUATION".** Graphs are plotted to show the variation of weight loss with abrading distance, with increase in graphite percentage at various loading conditions and variation of specific wear rate against applied load with increase in graphite percentage at various abrading distances

INTRODUCTION

Polymer matrix composites are emerging as promising materials in many structural and tribological applications. Because of the high strength to weight and stiffness to weight ratios, easy processibality and chemical resistance, the composites are finding a wide variety of structural applications in aerospace, automobile and chemical industries.

Polymer matrix composites are being used increasingly in applications where friction and wear are important parameters like gears, seals, bearings, brakes etc. Polymer materials have been replacing metallic materials in friction and wear applications for many years. It is often found that however the unmodified homo polymer could not satisfy the demands arising from the situations where combinations of good mechanical and tribological properties are required.

Polymer blending is a fascinating method for polymer modification because it has simple processing and unfolds unlimited possibilities of producing materials with variable properties. Studies by some researchers about tribological properties of polymer blends have shown that the frictional wear properties varied continuously with compositions for most polymer blends and the optimal properties were obtained at a certain compositions although some data reported were conflicting.

Wear

A Progressive loss of material from the surface of any component is called wear. It is a material response to the External stimulus and can be mechanical or chemical in nature. As advanced Engineering materials, composites are used in many applications where high wear resistance is required; these include electric contact brushes, cylinder liners, artificial joints and helicopter blades. In order to obtain optimal wear properties without compromising the beneficial properties of the matrix material, an accurate prediction of the wear of composites is essential.

Abrasive wear

Abrasive wear occurs when a hard rough surface slides across a softer surface. ASTM (American Society for Testing and Materials International) defined it as the loss of material due to hard particles or hard protuberances that are forced against and move along a solid surface.

Importance of graphite reinforcement

Graphite fiber is one of the most useful reinforcement materials in composites, its major use being the manufacture of components in the aerospace, automotive and leisure industries. The unique features of carbon fiber are low density, high strength, high modulus and high stiffness leading to the

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development of new Industrial applications. Graphite has extremely good machining and forming capabilities and has a very low coefficient of expansion.

PA66

Polyamide66 (PA66) is a semi crystalline thermoplastic polymer used for numerous engineering applications due to its combination of high thermal and mechanical properties with easy processing techniques. PA 66: [NH−$(CH_2)_6$−NH−CO− $(CH_2)_4$−CO] $_n$ made from hexamethylene-diamine and adipic acid.

Properties of PA66

PA66 is a semi crystalline material with one of the highest melting point among commercially available polyamides. PA66 does not absorb moisture after molding, but retention is not as high as PA6. Moisture absorption depends on the composition of material, wall thickness and environmental conditions. Dimensional stability and properties are all affected by the amount of moisture absorption, which must be taken in to account for product design. Viscosity of PA66 is low so it flows easily, which enables the molding of thin components. Viscosity is very sensitive to temperature. Shrinkage is of the order of 0.01-0.02 mm/mm (1-2%). The reinforcement of glass fibers reduces the shrinkage to 0.2-1% .Differential shrinkage in the flow and cross-flow directions are quite high. PA66 is resistant to most solvents, but not to strong acids or oxidizing agents. Minimum operating temperature of PA66 is -40°c and has maximum operating temperature of 85°c and has a tensile strength of 12000 PSI.

Applications of PA66

It has found wide range of applications in transportation, electronics and electrical, consumer goods, building and construction and packing industries. In automotive industries it is used as an alternative to metals like hood parts and where design flexibility, temperature as well as chemical resistance are critical.PA66 is an excellent material when complex designs are needed and it is a cost efficient solution.

Specimen Preparation

The varying amounts of Graphite powder via 10, 15, 20, 25 and 30% by weight with PA66 were first mixed in a high speed grinder followed by melt mixing in a co rotating intermesh twin screw extruder. The extrudate is then quenched in cold water and pelletized. The resulting PA66 / G composite mixtures were subsequently compression molded in injection molding machine in order to obtain samples of size 6mm x 7mm cross section and 90mm long. These samples were then cut, ground and polished to the specimen size of 4mm x 4mm x32mm. Here we must know about the “Twin screw extrusion” and “Injection molding”.

Twin screw extrusion

Twin screw extrusion is used extensively for mixing, compounding, or reacting polymeric materials. The flexibility of twin screw extrusion equipment allows this operation to be designed specifically for the formulation being processed. The active part of the machine consists of 2 identical co-rotating and intermeshing screws, hence the name "twin screw extruder". The screws are mounted on shafts, supported by bearings and rotate inside a fixed closed housing called "barrel". To adapt this equipment to different industrial applications, the screws, which perform most of the work of transporting, conveying, mixing, compressing, kneading or shearing of raw materials, have been designed to be totally modular. The screw segments are stacked one beside another on a splined shaft. Their composition can be rapidly modified depending on the products to be processed and the final product desired. Twin screw technology offers the advantages of a continuous process that is both flexible and easy to automate. The multi functionality of this technology results in a compact design of the equipment, reduces the investment costs, often uses far less water and allows the use of greater diversity of raw materials. This continuous processing machine has multiple functions such as conveying, melting, shearing, mixing, cooking, cooling, washing, bleaching, shaping etc., depending on the industrial application.

In addition, the configurations of the screws themselves may be varied using forward conveying elements, reverse conveying elements, kneading blocks, and other designs in order to achieve particular mixing characteristics. Polymer extrusion is one of the most important polymer processing methods. It is a very complex and involves the following:

1. Preparation and feeding of the polymer powder to the extruder.
2. Initially complex mixing, melting and forced flow of the melt with moving solid boundaries of extruder screw(s) is done. Then the melt is heated and cooled to the desired conditions. The final extruder profile dimensions, its consistency and accuracy depend on overall material properties. Extruder mechanical design and overall process control, including mechanical, material flow, pressure, temperature, and environmental conditions. This is further complicated in polymer processing due to the fact that its critical visco- elastic properties are highly nonlinear and dependent on stress-strain, temperature. Thus they are highly dependent on overall velocity and temperature profile which in turn are dependent on extruder dimensions, and process parameters and control.

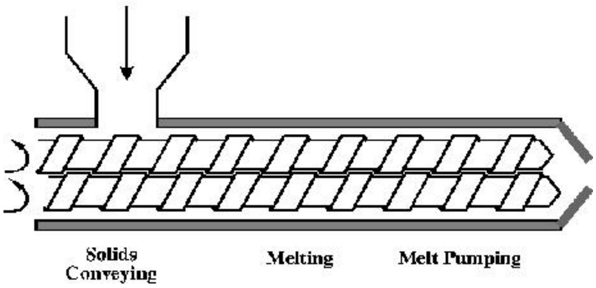


Fig Injection Molding

Co-rotating twin-screw extruder has features such as homogeneity, plasticization, solidification and granulation .The newly designed torque distribution system, high-precision grinding of hardened gear teeth, and the interlocking of lubrication system are among the reasons for the good reliability of products. Both screws and barrels are designed using the building block principle. The screw configuration, barrel setup, its L/D ratio, the number and protocol of feeding and venting, screen change, way of granulating, and the electric control mode are optimally adjusted according to different material properties and process requirements in consideration to the machine's versatility in other general applications.

Injection molding

Injection molding is a manufacturing process for producing parts from both thermo-plastic and thermo-setting materials. Material is fed into a heated barrel, mixed, and forced into a mold cavity where it cools and hardens to the configuration of the cavity. After a product is designed, usually by an industrial designer or an engineer, molds are made by a mold maker from metal, usually either steel or aluminum, and precision-machined to form the features of the desired part. Injection molding is widely used for manufacturing a variety of parts, from the smallest component to entire body panels of cars.

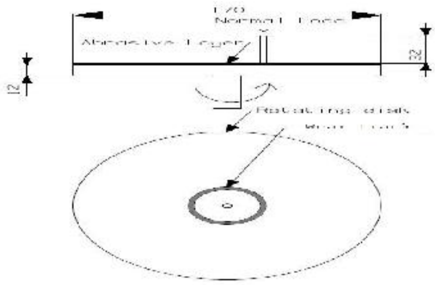
Process Characteristics

- Utilizes a ram or screw-type plunger to force molten plastic material into a mold cavity.
- Produces a solid or open-ended shape that has conformed to the contour of the mold.
- Uses thermoplastic or thermoset materials.
- Produces a parting line, sprue, and gate marks.
- Ejector pin marks are usually present.

Applications: Injection molding is used to create many things such as wire spools, packaging, bottle caps, automotive dashboards, pocket combs, some musical instruments, one-piece chairs and small tables, storage containers, mechanical parts (including gears), and most other plastic products available today. Injection molding is the most common method of part manufacturing. It is ideal for producing high volumes of the same object. Some advantages of injection molding are high production rates, repeatable high tolerances, the ability to use a wide range of materials, low labor cost, minimal scrap losses, and little need to finish parts after molding. Some disadvantages of this process are expensive equipment investment, potentially high running costs, and the need to design moldable parts.

Equipments: Digital Electronic Balance

It is capable of making precise measurements of weight up to milligrams. The measuring pan of balance is inside a transparent enclosure with doors so that dust does not collect and any air currents in the room do not affect the balance's operation. This enclosure is often called a draft shield. Electronic analytical scales measure the force needed to counter the mass being measured rather than using actual masses. As such they must have calibration adjustments made to compensate for gravitational differences. It uses an electromagnet to generate a force to counter the sample being measured and outputs the results by measuring the force needed to achieve balance. Such a measurement device is called electromagnetic force restoration sensor. Digital electron balance is easy to read and use which are fully automatic and with built in weight for accurate results.



Schematic View

Pin on disc apparatus

The apparatus used for this experimentation is win ducom TR-20LE, which is a wear testing machine represents a substantial advance in terms of simplicity and convenience of operation. The machine is designed to apply loads up to 200N and is intended doth for dry and lubricated test conditions, additionally specimen pin can be heated to 1000°c and temperature measured is displayed.

It also facilitates study of friction and wear characteristics in sliding contacts under desired conditions. Sliding occurs between the stationary pin and a rotating disc. Normal load, rotational speed and wear track diameter can be varied to suit the test conditions. Tangential frictional force and wear are monitored with electronic sensors and recorded on PC. These parameters are available as functions of load and speed. The temperature raise during the test is measured, recorded and displayed.

The pin on disc wear testing machine consists of

1. Machine
2. Controller
3. Data acquisition system
4. Sensor
5. Cables

Pin On Disk Set Up

Machine

It is made of mechanical assemblies of the following

- Structure
- Spindle assembly

- Loading lever assembly
- Sliding plate assembly
- Lubrication unit
- Environmental chamber

Structure

MS tubes are welded to form homogeneous structure, which form the base of the machine, on top of its base plate is fixed firmly. Structure houses AC motor fitted to the bottom of the base plate and sides are covered with panels. A lubrication unit is also fixed on the side of the structure and on remaining empty portion a side panel is fixed.

Spindle Assembly

Spindle is driven by AC motor & AC drives through timer pulley arrangement. Spindle housed inside taper roller bearings is mounted firmly on bottom of base plate through housing, on top of a spindle a wear disc holder is fixed and over it a wear disc is clamped by screws, at bottom of the spindle an driven pulley is fitted and to it an proximity sensor disc is fixed. A proximity sensor is fixed perpendicular to sensor disc to measure spindle speed.

Loading Lever Assembly

The loading lever is made of a single bar with specimen holder fixed at one end to get 1:1 loading lever ratio. The LVDT plunger rests on loading lever projection to measure wear, a ball fixed on lever side pushes the load cell to measure frictional force. A safety bracket is provided to prevent over travel for LVDT.

Sliding Plate Assembly

The loading lever assembly ,pulley for loading pan, wear & frictional force load cell are mounted on sliding plate assembly, this assembly moves over base plate to set wear track diameter using a graduated scale. The assembly movement is guided by two guiding rails fixed on base plate and locked in position by 6 screws. The minimum wear track diameter possible is100 mm.

An adjusting block fixed on sliding plate helps to set specimen height properly. A wire rope from loading lever passes over pulley and at the end a loading pan is hung. Normal load is applied by placing dead weights on loading pan, for this a set of weights are provided along with m/c, the maximum load applied is 200N.

Lubricating Unit

It consists of a lube tank with motor and pump, inlet pipe supplies oil to near specimen through polyurethane tube and outlet carries used oil to tank for recirculation. Wire gauge provided at entry port to tank collects debris and allows oil to flow through.

A flow valve adjusts oil flow and it can regulate up to 20 drops/min. A chamber with top lid is provided around wear disc, it ensure no spillage of oil during testing and allows oil to flow back to metallic tank.

Environmental Chamber

It is made of two parts, the top part is a leak proof chamber with acrylic top to view test progress. The bottom part is a cylindrical wall container which is also a lubrication chamber when test is conducted under lubrication. It has ports for inlet & outlet for gases, port for lubrication pipe, port to pass steel wire for frictional force calibration and port for entry for loading lever. Sufficient inclination is provided at bottom chamber for outlet of oil into drain port. A rubber is provided on loading lever to prevent oil flow into bellow during spindle rotation. A bellow is connected between environmental chamber and loading lever top close entry port at loading lever end.

Controller

The front panel of controller has four displays wear frictional force, speed and time. A toggle switch for power on and off, 2 zero push buttons for initializing the display of normal load and frictional force to zero are present. An rpm potentiometer knob is used for setting rpm. A toggle switch for selecting mode of test duration either time or rev mode, set and enter push button for entering test duration in timer display are also there. A PID is also present at middle to measure temperature of the specimen and display it on the front screen. Soft keys of PID allow the setting of temperature required for pin heating.

Back panel

It has two D type sockets for signal input and data acquisition from controller, when power is switched on by the MCB. It is fixed on the machine supply which goes to drive and controller through control cables. Now switching on the power of controller, 230 V supply from m/c is sent to transformer inside controller through control cable. This supply is sent down to 0-15V and 0-5V. Both these voltages are sent to power supply card, rectified and regulated to +/-15v, +/-5v and 5V.

The +/-15V and +/-5V is sent to instrumentation card and 5V is sent to display and timer RPM card .In addition +/-5V&5v is also sent to data acquisition card. The signals from wear and friction sensors are sent to instrumentation card. The output from instrumentation card is sent to display on controller and to pc. The output from timer card is sent to the timer display and when set value on timer display is reached, the output value becomes zero and op to coupler switches off ac drive through signal. From rpm card 5V signal is sent to proximity sensor, the signal from potentiometer sensor is sent to the ac drive to regulate speed, the output from proximity sensor is sent to display on RPM card.

Data acquisition system

This system includes data acquisition cable and a cd containing the winducom software. The wear, frictional force, and temperature data are processed in the controller and serially transmitted to the PC through data acquisition cable.

Sensors

LVDT (Linear Voltage Differential Transducer)

The plunger movement as an indication of wear rate is sensed by LVDT as the plunger lifts up. This movement is displayed as wear on controller. The least count of LVDT is 1 micrometer. The initial position of plunger measurement is kept in mid point to have both positive and negative wear readings .In addition to the wear as indicated by LVDT, the wear on specimens may also be measured using digital vernier calliper or micrometer. The LVDT is mounted on flexure fixed on base plate and it can measure wear between +_2m.

Frictional Force

A beam type load cell with maximum capacity of 20 kg is provided to measure frictional force up to 200N. It is fixed on sliding plate with bracket and moves along with sliding plate. The construction of load cell is explained below. This is a strain gauge type of load cell. It is primarily a column of corrosion resistant super alloy of high tensile strength steel that deforms very minutely under load.

This deformation is sensed by foil type strain gauges bounded on to the column and connected to form balanced Wheatstone bridge. The electrical output from wheat stone bridge is proportional to the load acting on the column. The extremely rugged and hermetically sealed construction makes them ideal choice for this application.

Sensors

Proximity Sensors

This sensor is used to measure the RPM of spindle. An rpm sensor disc with slots on circumference is fixed to bottom of spindle and rotates along with it. Proximity sensor is mounted perpendicular to it on bracket signal is generated when sensor disc approaches the active surface with in the specified switching distance. The sensors function in contact less fashion and do not require any sensing mechanisms.

An inductive proximity sensor is selected as it has excellent means of detecting the presence of a wide range of metallic targets. The detection is accomplished without contacting target and is mechanically wear free. It is comprised of a high frequency oscillator circuit followed by level detector, a post amplification signal circuit and drives a buffer solid state output.

When the sensor disc is brought into effective range of the field of oscillator, a damping action is resulted. This reduces the amplitude of the oscillator. This amplitude shift is converted to digital signal by the level detector which drives a buffer stage. When the object is removed, the oscillator and the digital output are turned to its former state.

Experimental procedure

Connect the power input cable to 230V, 50 Hz, and 5 Amps supply. Thoroughly clean specimen, remove burs from the circumference using emery paper. 400 grit size silicon carbide papers are attached to the rotating disc such that it should stick firmly to the rotating disc even under heavy loading conditions and high speeds. The weight of each test specimen is calculated by using a 0.0001 gm. accuracy weighing machine**.**

Then insert specimen pin and collet inside specimen holder and adjust the pin with respect to the wear disc using height adjustment block after ensuring that the loading arm is parallel to the plane of the wear disc. Tighten the clamping screws on the top to retain specimen position. Swivel the height adjustment block away from loading arm.

Set required track radius by moving the sliding plate over graduated scale on base plate. Tighten the slider plate over graduated scale on base plate. Tighten the slider clamping screws and ensure assembly is clamped firmly.

Then set the time of running the machine to get the desired abrading distance using controller. Then press ON button on controller and gradually increase the speed of disc to desired r.p.m. The rotating disc automatically stops rotating after reaching the set time covering the desired abrading distance and produces wear in the specimen. Now remove the specimen from the collet and weigh the abraded specimen up to an accuracy of 0.0001gms.

Set Test Duration on Controller

Procedure to set test duration*:* Enter the required data of Timer or Counter of the test using SET, and ENTER push buttons. Data entry takes place from the last digits i.e. seconds, minutes and hours (two digits each separated by a decimal point) or counts up to eight digits. Enter push button is used to shift flashing display on time window on controller from last digit to 2nd last digit,3rd,4th digit and so on. SET button is used to increase display value by pressing once.

Setting of Test Time: Initially last digit timer display will be flashing.

Press once ENTER button to shift flashing display to next digit.
Press once SET button to increase the displayed value.
Now display value shows

To set values: 99 59 59

Initially all display values are zero and last digit on display will be flashing.

Press SET button ill display shows 00 00 09

Press ENTER button, flash from last digit displays shifts to 2nd last digit. **00 00 59**

Press SET button till display shows
Similarly repeat till values. **99 59 59**

Formulae and Calculations

Time required to cover the required abrading distance (t) = V*60*1000/ (π*D*N).

V= sliding velocity.
D= track diameter in mm
N= speed of rotating disc in rpm
Where abrading is distance in meters.

Specific wear rate coefficient is calculated by using Archards equation which is given by

$$\text{Specific wear rate coefficient} = \frac{\text{Weight loss}}{\text{Abrading distance} \times \text{density of Specimen}}$$

W = Wi - Wf . (Weight loss = initial weight of virgin specimen - final weight of specimen after wear)

Graph showing the weight loss due to wear for an abrading distance of 2000 m

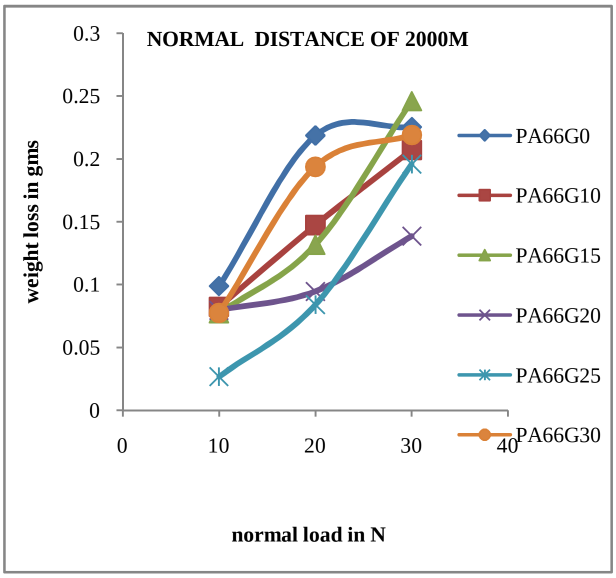


Table showing the weight loss due to wear for an abrading distance of 3000 m

LOAD	PA66 G0	PA66 G10	PA66 G15	PA66 G20	PA66 G25	PA66 G30
10	0.138	0.113	0.092	0.094	0.033	0.094
20	0.242	0.188	0.192	0.13	0.198	0.213
30	0.212	0.211	0.269	0.154	0.201	0.223

Table Showing The Weight Loss Due To Wear For An Abrading Distance Of 1000m

LOAD	PA66 G0	PA66 G10	PA66 G15	PA66 G20	PA66 G25	PA66 G30
10	0.0826	0.06	0.059	0.0188	0.0132	0.0485
20	0.1692	0.126	0.0863	0.081	0.053	0.0103
30	0.1837	0.1825	0.2056	0.1182	0.0706	0.2133

Graph showing the weight loss due to wear for an abrading distance of 1000m

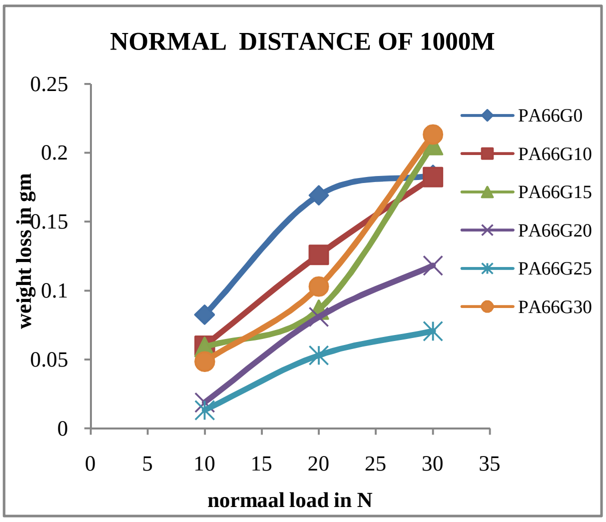


Table showing the weight loss due to wear for an abrading distance of 2000 m

LOAD	PA66 G0	PA66 G10	PA66 G15	PA66 G20	PA66 G25	PA66 G30
10	0.0989	0.0823	0.0773	0.0796	0.0268	0.0774
20	0.2187	0.1473	0.1318	0.0946	0.084	0.1937
30	0.2254	0.207	0.246	0.1386	0.1958	0.219

Graph showing the weight loss due to wear for an abrading distance of 3000 m

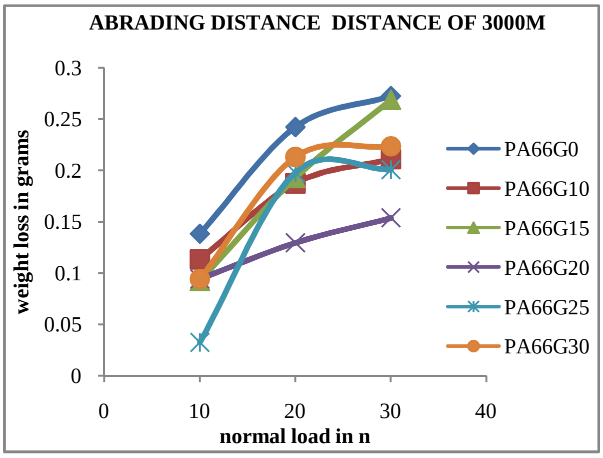


Table showing the weight loss due to wear for a normal load of 10n

Abrading Distance	PA66 G0	PA66 G10	PA66 G15	PA66 G20	PA66 G25	PA66 G30
1000	0.083	0.06	0.59	0.0189	0.013	0.049
2000	0.099	0.082	0.077	0.0796	0.027	0.077
3000	0.138	0.113	0.092	0.0942	0.033	0.094

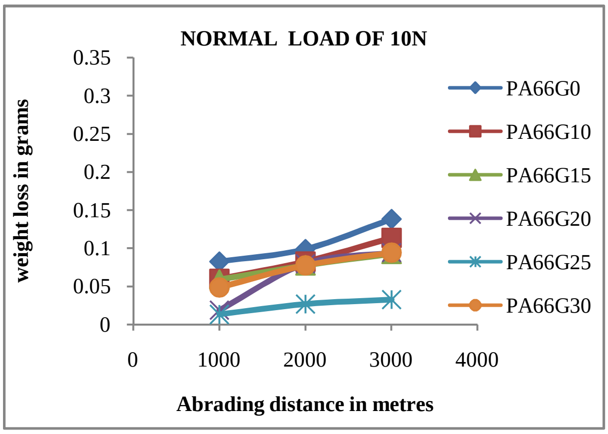


Table showing the weight loss due to wear for a normal load of 20n

Abrading Distance	PA66 G0	PA66 G10	PA66 G15	PA66 G20	PA66 G25	PA66 G30
1000	0.1692	0.126	0.0863	0.081	0.053	0.103
2000	0.2187	0.1473	0.1318	0.0946	0.084	0.1937
3000	0.2421	0.1876	0.1928	0.1295	0.1979	0.213

Graph Showing The Weight Loss Due To Wear For A Normal Load Of 20n

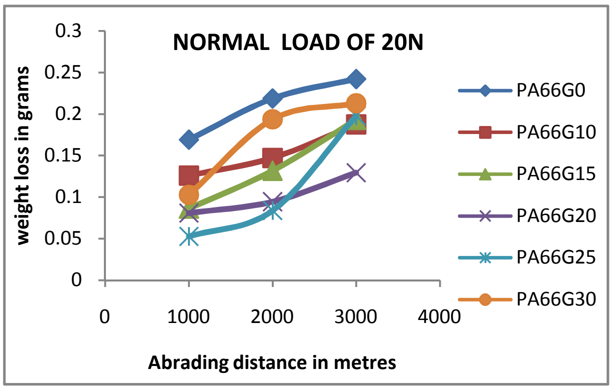
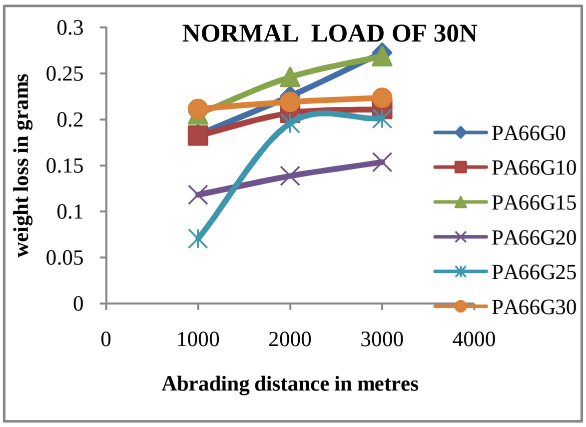


Table showing the weight loss due to wear for a normal load of 30n

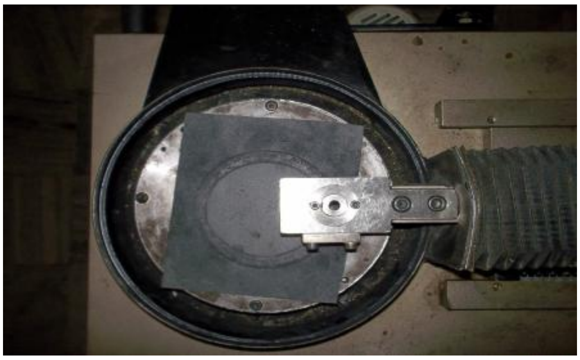
Abrading Distance	PA66 G0	PA66 G10	PA66 G15	PA66 G20	PA66 G25	PA66 G30
1000	0.184	0.183	0.206	0.118	0.071	0.211
2000	0.225	0.207	0.246	0.139	0.196	0.219
3000	0.272	0.211	0.269	0.154	0.201	0.223

Graph Showing The Weight Loss Due To Wear For A Normal Load Of 30n



Emery Papers Showing Wear Track

Pin On Disk



RESULTS AND DISCUSSION

Influence of load

The applied load is transferred to the pin-on-disc set up from load end to disc end by lever action. Due to increase in pressure more wear occurs. Also the contact between specimen and emery paper increases, so more grains will come in contact with the w/p. Thus it is expected that with increase in load for a particular abrading distance and graphite composition weight loss due to wear also increases.

Effect Of Transfer Film

Transfer film is formed when the grains on the track get worn out and the worn polymer powder gets clogged along the circumference of the track. This prevents the work piece to wear by obstructing the contact between work piece and grains. Probability of formation of transfer film early is enhanced with increase of load. But it is inevitable after particular time.

Percentage Of Graphite

With increase of graphite decrease in wear is expected. Here transfer film formation occurs due to wear of grains on abrasive paper majorly and clogging is minor case here.

Inluence Of Abrading Distance

The abrading distance is varied by changing the time of disc rotation. It can also be varied by altering track diameter but for our convenience and anticipated accuracy without disturbing the set up for the consecutive readings the above method is preferred. As abrading distance increases the total wear increases as the specimen will come in to contact with emery paper for a longer duration of time. But after a specified time a transfer film will start forming on the abrading paper.

CONCLUSIONS

The graphs plotted for normal load vs weight loss and abrading distance vs weight loss for various percentages of graphite in the polymer specimens demonstrate the trends followed by them.

The wear characteristics of PA66 graphite reinforced polymer was studied in terms of weight loss and specific wear rate by varying percentage of graphite, abrading distance, normal load and we have observed that the best results are obtained for PA66G10 and PA66G20.

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