International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com, Volume 5, Issue 3 (May-June, 2017), PP. 69-74

WEAR ANALYSIS OF ORIENTATION AND APPLIED LOAD ON POLYPROPYLENE: A REVIEW

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***Abstract* — Polypropylene (PP) also known as polypropylene is a thermoplastic polymer used in wide variety of application. The main content of this paper are wear, polypropylene and its application. Wear by abrasion is form of wear caused by contact between a particle and solid material. Abrasive wear is the loss of material by the passage of hard particles over a surface. Abrasion in particular is rapid and severe forms of wear and can result in significant costs if not adequately controlled. These differences extend to the practical consideration of materials selection for wear resistance due to the different microscopic mechanisms of wear occurring in abrasion.This paper also emphasizes on different properties of polypropylene i.e. mechanical, thermal, chemical & optical properties. Wear tests are conducted using pin on disc multi orientation apparatus.**

***Index Terms* — Wear, stages of wear, Polypropylene, properties & applications.**

I. INTRODUCTION

A continuous loss of material from the surface of any metallic & nonmetallic component is called wear. It is a material response to the External impact and can be mechanical or chemical in nature. As advanced Engineering materials, composites , polymers , reinforced materials 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.

Wear may be defined as : “The progressive loss of substance from the operating surface of a component as a result of relative motion of the surface with respect to another component.”[1]. Kloss et al[2] stated that it is a complicated thermal, mechanical and chemical processes and is therefore present in an extremely broad range of situations ; from the rotating components in a motor to the impeller of a pump to the leading edge of a cutting tool. The los s of material has a greater effect on the working & life of a machine, tool or surface that is exposed to a wear process. Tribology is the science and study of interactions between surfaces in relative motion. Friction, wear and lubrication are fundamental concerns that make up this field [3]. Materials that are in contact have, at the interface, two material surfaces will have individual characteristics and therefore a different effect on the tribological relationship. In very simple word we ca said that tribology cons is t of three words , friction, wear & lubrication. Wear models are used to predict the reaction of a material to a wear situation and to forecast the rate of material removal from the s urface of a body. Classical wear theory begins by considering the rate of material removal as a function of the sliding speed, the hardness of the material, the load applied and the probability of a material to produce a wear particle in a given contact situation[7, 8]. There are four main theories that are used as a basis to begin a wear model: a mass balance approach, an energy balance approach, a stress /strain analys is and a contact mechanics approach to determine material behaviour. Wear can occur in a number of different forms and these proces ses differ from each other when you consider the bodies that are in contact, the way in which material is removed and in what amount. The processes do not always occur exclus ively i.e. s everal might be present in a given situation. The primary processes are: abrasion, adhesion, erosion, fretting and cavitations. For example abrasion occurs as a physical gouging effect where the harder of the two surfaces will dig into the softer material and s ubsequently remove material.

II. CLASSIFICATION OF WEAR:

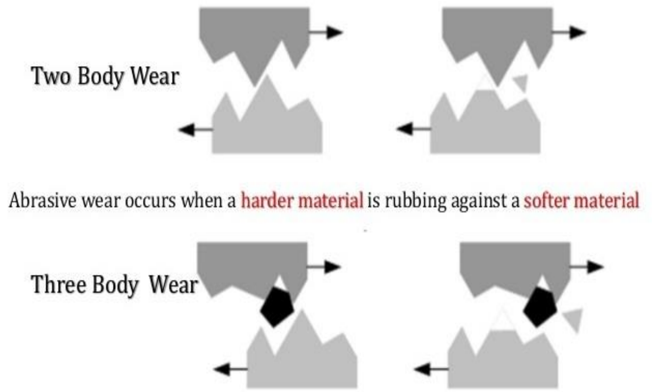
Wear can be classified into following types-
1) Adhesive wear
2) Abrasive wear
3) Surface Fatigue
4) Fretting wear
5) Erosive wear
6) Corrosion and oxidation wear

A. Adhesive Wear:

Adhesive wear can be found between surfaces during frictional contact and generally refers to unwanted displacement and attachment of wear debris and material compounds from one surface to another. Two separate mechanisms operate between the surfaces.

B. Abrasive Wear:

Abrasive wear occurs whenever a solid component is loaded to particles of a material that have equal or greater hardness. A common example of this problem is the wear of s hovels on earth-moving machinery. The extent of abrasive wear is far larger than may be observed. Any material, even if the bulk of it is very soft, may cause abrasive wear if hard particles are present. For example, an organic material, such as sugar cane, is associated with abrasive wear of cane cutters and shredders because of the s mall fraction of silica present in the plant fibres. A major obstacle in the prevention and control of abrasive wear is that the term ‘abrasive wear’ does not precisely describe the wear mechanisms involved. There are, in fact, almost always several different mechanisms of wear acting in concert, all of which have different characteristics.



Two and three body abrasive wear

C. Surface Fatigue:

Surface fatigue is a process by which the surface of a material is weakened by cyclic loading, which is one type of general material fatigue. Fatigue wear is produced when the wear particles are detached by cyclic crack growth of microcracks on the surface. These microcracks are either superficial cracks or subsurface cracks.

D. Fretting Wear:

Fretting wear is the repeated cyclical rubbing between two surfaces. Over a period of time fretting, this will remove material from one or both surfaces in contact. It occurs typically in bearings, although most bearings have their surfaces hardened to resist the problem. Another problem occurs when cracks in either surface are created, known as fretting fatigue. It is the more serious of the two phenomena because it can lead to catastrophic failure of the bearing. An associated problem occurs when the small particles removed by wear are oxidised in air. The oxides are usually harder than the underlying metal, so wear accelerates as the harder particles abrade the metal surfaces further. Fretting corrosion acts in the same way, especially when water is present. Unprotected bearings on large structures like bridges can suffer serious degradation in behaviour, especially when salt is used during winter to deice the highways carried by the bridges. The problem of fretting corrosion was involved in the Silver Bridge tragedy and the Mianus River Bridge accident.

E. Erosive Wear:

Erosive wear can be defined as an extremely short sliding motion and is executed within a short time interval. Erosive wear is caused by the impact of particles of solid or liquid against the surface of an object [4]. The impacting particles gradually remove material from the surface through repeated deformations and cutting actions. It is a widely encountered mechanism in industry. Due to the nature of the conveying process, piping systems are prone to wear when abrasive particles have to be transported.

The rate of erosive wear is dependent upon a number of factors. The material characteristics of the particles, such as their shape, hardness, and impact velocity and impingement angle are primary factors along with the properties of the surface being eroded. The impingement angle is one of the most important factors and is widely recognized in literature [5]. For ductile materials the maximum wear rate is found when the impingement angle is approximately 30°, whilst for non ductile materials the maximum wear rate occurs when the impingement angle is normal to the surface.

F. Corrosion and Oxidation Wear:

This kind of wear occurs in a variety of situations both in lubricated and unlubricated contacts. The fundamental cause of these forms of wear is chemical reaction between the worn material and the corroding medium [6]. This kind of wear is a mixture of corrosion, wear and the synergistic term of corrosion-wear which is also called tribocorrosion.

III. STAGES OF WEAR:

Primary stage: Primary stage or early run-in period, where surfaces adapt to each other and the wear-rate might vary between high and low.

Secondary stage: Secondary stage or mid-age process, where a steady rate of ageing is in motion. Most of the components operational life is comprised in this stage.

Tertiary stage: Tertiary stage or old-age period, where the components are subjected to rapid failure due to a high rate of ageing.

IV. POLYPROPYLENE:

Polypropylene (PP), also known as Polypropene, is a thermoplastic polymer used in a wide variety of applications including packaging and labeling, textiles (e.g., ropes, thermal underwear and carpets), stationery, plastic parts and reusable containers of various types, laboratory equipment, loudspeakers, automotive components, transvaginal mesh and polymer banknotes. An addition polymer made from the monomer propylene, it is rugged and unusually resistant to many chemical solvents, bases and acids.

Polypropylene has a relatively slippery "low energy surface" that means that many common glues will not form adequate joints. Joining of polypropylene is often done using welding processes.

In 2013, the global market for polypropylene was about 55 million tonnes.2 Polypropylene is the world's second-most widely produced synthetic plastic, after polyethylene.

Properties of Polypropylene:

V. Mechanical properties

The density of PP is between 0.895 and 0.92 g/cm³. Therefore, PP is the commodity plastic with the lowest density. With lower density, moldings parts with lower weight and more parts of a certain mass of plastic can be produced. Unlike polyethylene, crystalline and amorphous regions differ only slightly in their density. However, the density of polyethylene can significantly change with fillers.

The Young's modulus of PP is between 1300 and 1800 N/mm².

Polypropylene is normally tough and flexible, especially when copolymerized with ethylene. This allows polypropylene to be used as an engineering plastic, competing with materials such as acrylonitrile butadiene styrene (ABS). Polypropylene is reasonably economical

Polypropylene has good resistance to fatigue.

VI. Thermal properties

The melting point of polypropylene occurs at a range, so a melting point is determined by finding the highest temperature of a differential scanning calorimetry chart. Perfectly isotactic PP has a melting point of 171 °C (340 °F). Commercial isotactic PP has a melting point that ranges from 160 to 166 °C (320 to 331 °F), depending on atactic material and crystallinity. Syndiotactic PP with a crystallinity of 30% has a melting point of 130 °C (266 °F). Below 0 °C, PP becomes brittle.

The thermal expansion of polypropylene is very large, but somewhat less than that of polyethylene.

VII. Chemical properties

Polypropylene is at room temperature resistant to fats and almost all organic solvents, apart from strong oxidants. Non-oxidizing acids and bases can be stored in containers made of PP. At elevated temperature, PP can be dissolved in non polarity solvents such as xylene, tetralin and decalin.

Most commercial polypropylene is isotactic and has an intermediate level of crystallinity between that of low-density polyethylene (LDPE) and high-density polyethylene (HDPE). Isotactic & atactic polypropylene is soluble in P-xylene at 140 °C. Isotactic precipitates when the solution is cooled to 25 °C and atactic portion remains soluble in P-xylene.

The melt flow rate (MFR) or melt flow index (MFI) is a measure of molecular weight of polypropylene. The measure helps to determine how easily the molten raw material will flow during processing. Polypropylene with higher MFR will fill the plastic mold more easily during the injection or blow-molding production process. As the melt flow increases, however, some physical properties, like impact strength, will decrease.

There are three general types of polypropylene: homopolymer, random copolymer, and block copolymer. The comonomer is typically used with ethylene. Ethylene-propylene rubber or EPDM added to polypropylene homopolymer increases its low temperature impact strength. Randomly polymerized ethylene monomer added to polypropylene homopolymer decreases the polymer crystallinity, lowers the melting point and makes the polymer more transparent.

VIII. Optical properties

PP can be made translucent when uncolored but is not as readily made transparent as polystyrene, acrylic, or certain other plastics. It is often opaque or colored using pigments.

IX. Applications:

As polypropylene is resistant to fatigue, most plastic living hinges, such as those on flip-top bottles, are made from this material. However, it is important to ensure that chain molecules are oriented across the hinge to maximise strength.

Very thin sheets (~2–20 µm) of polypropylene are used as a dielectric within certain high-performance pulse and low-loss RF capacitors.

Polypropylene is used in the manufacturing piping systems; both ones concerned with high-purity and ones designed for strength and rigidity (e.g. those intended for use in potable plumbing, hydronic heating and cooling, and reclaimed water)

Polypropylene, highly colorfast, is widely used in manufacturing carpets, rugs and mats to be used at home.

Polypropylene is widely used in ropes, distinctive because they are light enough to float in water.. For equal mass and construction, polypropylene rope is similar in strength to polyester rope. Polypropylene costs less than most other synthetic fibers.

Polypropylene is also used as an alternative to polyvinyl chloride (PVC) as insulation for electrical cables for LSZH cable in low-ventilation environments, primarily tunnels. This is because it emits less smoke and no toxic halogens, which may lead to production of acid in high-temperature conditions.

Polypropylene is also used in particular roofing membranes as the waterproofing top layer of single-ply systems as opposed to modified-bit systems.

Polypropylene is most commonly used for plastic moldings, wherein it is injected into a mold while molten, forming complex shapes at relatively low cost and high volume; examples include bottle tops, bottles, and fittings.

A. Clothing

Polypropylene is a major polymer used in nonwovens, with over 50% used for diapers or sanitary products where it is treated to absorb water (hydrophilic) rather than naturally repelling water (hydrophobic). Other interesting non-woven uses include filters for air, gas, and liquids in which the fibers can be formed into sheets or webs that can be pleated to form cartridges or layers that filter in various efficiencies in the 0.5 to 30 micrometre range. Such applications occur in houses as water filters or in air-conditioning-type filters. The high surface-area and naturally oleophilic polypropylene nonwovens are ideal absorbers of oil spills with the familiar floating barriers near oil spills on rivers.

Polypropylene, or 'polypro', has been used for the fabrication of cold-weather base layers, such as long-sleeve shirts or long underwear. Polypropylene is also used in warm-weather clothing, in which it transports sweat away from the skin. More recently, polyester has replaced polypropylene in these applications in the U.S. military, such as in the ECWCS. Although polypropylene clothes are not easily flammable, they can melt, which may result in severe burns if the wearer is involved in an explosion or fire of any kind. Polypropylene undergarments are known for retaining body odors which are then difficult to remove. The current generation of polyester does not have this disadvantage.

Some fashion designers have adapted polypropylene to construct jewelry and other wearable items.

B. Medical

Its most common medical use is in the synthetic, non absorbable suture Prolene, manufactured by Ethicon Inc.

Polypropylene has been used in hernia and pelvic organ prolapse repair operations to protect the body from new hernias in the same location. A small patch of the material is placed over the spot of the hernia, below the skin, and is painless and rarely, if ever, rejected by the body. However, a polypropylene mesh will erode the tissue surrounding it over the uncertain period from days to years. Therefore, the FDA has issued several warnings on the use of polypropylene mesh medical kits for certain applications in pelvic organ prolapse, specifically when introduced in close proximity to the vaginal wall due to a continued increase in number of mesh-driven tissue erosions reported by patients over the past few years. Most recently, on 3 January 2012, the FDA ordered 35 manufacturers of these mesh products to study the side effects of these devices.

Initially considered inert, polypropylene has been found to degrade while in the body. The degraded material forms a bark-like shell on the mesh fibers and is prone to cracking.

C. EPP model aircraft

Since 2001, expanded polypropylene (EPP) foams have been gaining in popularity and in application as a structural material in hobbyist radio control model aircraft. Unlike expanded polystyrene foam (EPS) which is friable and breaks easily on impact, EPP foam is able to absorb kinetic impacts very well without breaking, retains its original shape, and exhibits memory form characteristics which allow it to return to its original shape in a short amount of time. In consequence, a radio-control model whose wings and fuselage are constructed from EPP foam is extremely resilient, and able to absorb impacts that would result in complete destruction of models made from lighter traditional materials, such as balsa or even EPS foams. EPP models, when covered with inexpensive fibreglass impregnated self-adhesive tapes, often exhibit much increased mechanical strength, in conjunction with a lightness and surface finish that rival those of models of the aforementioned types. EPP is also chemically highly inert, permitting the use of a wide variety of different adhesives. EPP can be heat molded, and surfaces can be easily finished with the use of cutting tools and abrasive papers.The principal areas of model making in which EPP has found great acceptance are the fields of:

- Wind-driven slope soarers
- Indoor electric powered profile electric models
- Hand launched gliders for small children

In the field of slope soaring, EPP has found greatest favour and use, as it permits the construction of radio-controlled model gliders of great strength and maneuverability. In consequence, the disciplines of slope combat (the active process of friendly competitors attempting to knock each other's planes out of the air by direct contact) and slope pylon racing have become commonplace, in direct consequence of the strength characteristics of the material EPP.

EPP has been produced through both solid and melt state processing. Manufacturing of EPP using melt processing with either chemical or physical blowing agents has been successful. Expansion of PP in solid state, due to its highly crystalline structure, has not been successful. In this regard, two novel strategies were developed for expansion of PP. It was observed that PP can be expanded to make EPP through controlling its crystalline structure or through blending with other polymers.,[35][36]

D. Building construction

When the cathedral on Tenerife, La Laguna Cathedral, was repaired in 2002–2014, it turned out that the vaults and domes were in a rather bad condition. Therefore, these parts of the building were demolished, and replaced by constructions in polypropylene. This was reported as the first time this material was used in this scale in buildings.

X. LITERATURE SURVEY:

1. Mani Deep et.al. to study the effect of normal load, weight fraction of graphite and abrading distance on the abrasive wear behaviour of graphite reinforced polymer. Wear studies are carried out using PIN ON DISC APPARATUS. Weight los s 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 us ing pin on disc apparatus under dry contact conditions. Weight los s is determined

for loads of 10N, 20N, 30N with a track diameter of 40 mm, disc rotating s peed of 500 rpm, using 400 grade s silicon carbide emery papers . A series of experiments are conducted to find out the weight los s due to wear and thus estimate the specific wear rate coefficient of each specimen using "ARCHARD'S EQUATION". In this experiment it is shown that 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 .[9]

2. Srinivas Lakshmi et al. In this experiment the composites with varying weight fractions of graphite have been prepared by melt mixing technique. Wear tests were conducted us ing a pin on disc apparatus under dry contact conditions . Mass los s was determined as a function of sliding velocity corresponding to the loads of 5N, 10N and 15N with an abrading distance of 314.2 m. The wear tests showed that graphite fillers improved the wear resistance and reduced the coefficient of friction of the PA6. The best properties achieved with the composite filler content of 25%. [10]

3. Suresha B. et al. investigated the influence of graphite filler additions on two -body abrasive wear behaviour of compress ion moulded carbon –epoxy (C– E) composites have been evaluated using reciprocating wear unit and pin -on-disc wear unit under s ingle pas s and multi-pass conditions respectively. The carbon fabric used in the present study is a plain one; each warp fibre pas s alternately under and over each weft fiber. The fabric is symmetrical, with good stability and reasonable porosity. Abrasive wear studies were carried out under different loads /abrading distance using different grades of SiC abrasive paper (150 and 320 grit size). Graphite filler in C– E reduced the specific wear rate. Further, the wear volume loss drops significantly with increase in graphite content. Comparative wear performance of all the composites showed higher specific wear rate in two-body wear (single-pass conditions) compared to multi-pass conditions. Further, the tribo-performance of C–E indicated that the graphite filler inclusion resulted in enhancement of wear behaviour significantly. Wear mechanisms were suggested and strongly supported by worn surface morphology using scanning electron micros copy. [11]

4. Mohd Shahdab Khan et al. were carried out "Statistical analysis for the Abrasive wear behaviour of Al6061". The experiment has been conducted using central composite design in the design of the experiment (DOE) on pin-on-disc type wear testing machine, against abrasive media. A second order polynomial model has been developed for the prediction of wear loss. The model was developed by response surface method (RSM). Analysis of variance technique at the 95% confidence level was applied to check the validity of the model. The effect of volume percentage of reinforcement, applied load and sliding velocity on abrasive wear behaviour was analysed in detail. To judge the efficiency and ability of the model, the comparison of predicted and experimental response values outside the design was carried out. The result shows, good correspondence, implying that, empirical models derived from response surface approach can be used to describe the tribological behaviour of the Al composites. [12]

5. Sandeep Badlani, Prof.Roopesh Tiwari et al The objective is to calculate the coefficient of friction and total wear with respect to the variable (time, load and velocity) by the help of pin on Disc method to evaluate the property of the materials for the comparative study of them. To select the best material from the materials going to use in this test or enhance the properties of them to increase the life of clutch.[13]

6. K.Kanny, P.Jawahar et al the wear rates and quasistatic mechanical properties of polypropylene (PP) infused with layered organo-modified montmorillonite nanoclays. Test results show that PP infused with 2 wt.% of organomodified montmorillonite gives improved mechanical strength, higher fracture toughness, and lower wear rates. Transmission electron microscopy shows that the structure of the modified nanocomposite changes from an exfoliated structure at 1 wt.% nanoclay loading to an intercalated structures at 5 wt.% nanoclay loading. The general improvement in properties, which includes but not limited to the thermal barrier properties, may be attributed to the change in structure. [14]

7. Sbbaya K.M et.al investigated an experiment on three body abrasive wear of C-E with addition of graphite. The three-body abrasive wear behaviour of carbon fabric reinforced epoxy (C-E) composites has been evaluated by the addition of graphite (G) particles as a secondary reinforcement. Three -body abrasive wear test were conducted using dry s and rubber wheel abrasion tester as per ASTM G-65 with three process parameters load, abrading distance and filler content. To assess the abrasive wear behaviour of particulate filled C-E composites satisfying multiple performance measure, grey -based Taguchi approach has been adopted.[15]

8. Lagiewka M et al. work deals with the influence of the addition of soft graphite particles on the abrasive wear of composite reinforced with hard SiC particles . The discussed hybrid composites were produced by stirring the liquid alloy and simultaneous adding the mixture of particles.[16]

CONCLUSION

The mechanism of abrasive wear is extremely interesting for interpreting the wear because abrasive wear is very common type of wear in mining, agriculture, cement industry, civil engineering and metallurgy. And the polypropylene composites are tested for wear analysis. Abrasive wear test of various engineering material with addition of polypropylene are tested by various testing machine but no work is reported yet on pure polypropylene or say more than 90% polypropylene in an engineering material, therefore my objective of work is to find out abrasive wear analysis of orientation and applied load on polypropylene with the help of specified specimen.

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