



A Review of Polymer – Particles Composite Materials

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مراجعة لمواد مركبة من البوليمر- الدقائق

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Abstract

In several engineering applications traditional materials are replaced by composite materials. Filled composite materials consist of the continuous matrix and the filling particles. The primary purpose of introducing inorganic solid particles into polymers is to essentially increase mechanical and physical properties. The wear properties of polymer composite can be changed to a greater degree by modifying the process of preparing the filled composite materials. In the present review, a large-scale research has been conducted on the effect of wear on the composites of polymers. The effect of filler on the polymer composites wear behavior has been thoroughly explained.

Keywords: Composites, Polymer, Reinforce, Particles, Wear Properties, Nano-Particles, Micro-Particles.

المستخلص

في العديد من التطبيقات الهندسية، يتم استبدال المواد التقليدية بمواد مركبة. تتكون المواد المتراكبة المعبأة من المادة الأساس المستمرة ودقائق الحشو. الغرض الأساسي من إدخال جسيمات صلبة غير عضوية في البوليمرات هو بشكل أساسي لزيادة الخواص الميكانيكية والفيزيائية. خصائص البلى لمتراكب البوليمر يمكن ان تغيير بدرجة أكبر عن طريق تعديل عملية تحضير المواد المتراكبة المحشوة. في بحث المراجعة هذا ، تم إجراء بحث واسع النطاق حول تأثير البلى على متراكبات البوليمرات. تم شرح تأثير الحشو على سلوك البلى لمتراكبات البوليمر بدقة.

الكلمات المفتاحية: متراكبات، بوليمر، تدعيم، دقائق، خصائص البلى، الدقائق النانوية، الدقائق المايكروية.



Introduction

In various engineering applications traditional materials are replaced by composite materials due to the reasonable cost, their good mechanical resistance and corrosion resistance. It is used in applications of cars, space structures, sports groups, marine equipment, etc. Filled composite materials consist of the continuous matrix and the filling particles (Bazhenov, 2011)-(Mathews & Rawlings, 1999). Composite materials underwent a three-stage development. It started in the late fifties of the last century, were associated with the development of 80% of solid powder particles bound by a flexible rubber matrix. In the seventies of the last century, with the development of complex materials containing polymers filled with rigid inorganic particles. In the late eighties of the last century with the emergence of a type of nanocomposites to which some of the typical principles of compounds filled with microscopic particles could be applied.

The primary purpose of introducing inorganic solid particles into polymers is to mainly increase the elastic modulus of the material or to improve electrical conductivity, thermal resistance and magnetic properties, to reduce flammability and corrosion frictionetc. The significant reduction in fracture strain is due to the main defect which is the fragility of the filled compounds compared to the unfilled polymers (Mathews & Rawlings, 1999)- (Ashby & Jones,2012)- (Bazhenov , et al., 2022)-(Giessen, 2001).

The relative movement between two surfaces leads to the gradual loss of materials from a solid surface and this process is known as wear. The effects of wear are widely studied for the effective use of components (Bazhenov , et al., 2022)-(Giessen, 2001). The wear properties of polymer composite can be changed to a greater degree by modifying the process of preparing the filled composite materials (Giessen, 2001).



For any mechanical process to take place in real life, friction forces must first be overcome, and this requires energy exchange, and this spent energy is wasted in another energy form and may be recovered. These lost energies may be in the intangible forms (such as sound, light, heat, etc.) or concrete (the concrete lost energy form is always related to matter). The ideal practical example of losing energy in shape is the wear. Due to the friction resulting from the relative movement of two surfaces, wear damage arises Ashby & Jones, 2012)-(Giessen, 2001)-(Bazhenov, *et al.*, 1994).

The composites of the Polymers are influenced by friction damage as a result of the extended uses in the applications. In this case, polymer material must have better properties. For example, in many applications of polymer composite, mechanical behavior and friction properties are among the main requirements (Mathews & Rawlings, 1999).

In engineering and while designing a machine component disposed to slip, wear is a highly significant aspect for being taken under consideration. Nowadays in various engineering designs and due to its potential use more attention has been focused on the polymer composites friction behavior (Ashby & Jones, 2012)- (Bazhenov, *et al.*, 2022)-(Giessen, 2001)-(Bazhenov, *et al.*, 1994)-(Patnaik, *et al.*, 2010). In order to ensure the reliability of the materials, polymeric composite and to know their tolerance to the influence of friction, they are subjected to various severe tests (Bazhenov, *et al.*, 1994)-(Patnaik, *et al.*, 2010)-(Lee, *et al.*, 2002).

In the present review, a large-scale research has been conducted on the effect of wear on the composites of polymers. The effect of filler on the polymer composites wear behavior has been thoroughly explained.



Types of polymer particles reinforcement

Particulate-reinforcement

This class of composite polymeric material is the most widely used because it is cheap and widely available. This type of admirer reinforcement is divided into two main types: particulate- reinforced and dispersion-strengthened composite. Depending on the reinforcement mechanism, a distinction can be made between these two categories (Azem, *et al.*, 2021)-(Taruma, *et al.*, 2012).

In composite that promote dispersion, here the reinforcement occurs at the atomic- molecular level and the particles are relatively small, the size ranges from 0.01 to 0.1 μm (Lim, *et al.*, 2002). That is, the stiffening mechanism is very similar to that of precipitation hardening in metals alloys materials since the major part of the matrix carries the applied load, while function of dispersion particles is for impeding the dislocations movement and the spread of cracks (Arghavanian, *et al.*, 2014).

Another class of supported compounds is Particulate composites. These materials contain large amounts of relatively coarse particles large than 0.1 μm . these composites are designed to produce unusual combinations of properties in addition to improving strength resistance as the major part of the applied load carries the participation of the matrix and particles (Lim, *et al.*, 2002)- (Arghavanian, *et al.*, 2014).

Nano-materials

Wide class of materials, with precision formulations modified on scales less than 100 nanometers. Where the atoms of the materials are arranged in

groups of a nano size, and thus become building blocks or grains that make up the material. To be considered any nanomaterial, it must possess at least one dimension in the range of 1-100 nm (Azem, et al., 2021)-(Subramani, et al., 2017). Nano materials can be divided based on (at least one dimension in the nano-scale meters) to; nano-clays (one-dimensional nano-scale); nano-fibers (two-dimensional nano-scale); nanoparticles (three-dimensional nano-scale). These nanoparticles are added to the polymer materials to produce composite materials with extraordinary properties (Subramani, et al., 2017).

Types of wear in the polymer compound

Coherent wear damage

Abrasion wear: In polymer composite, this is the most widely known wear type that is encountered. Abrasion wear is classified as, 2- and 3-body abrasion wears (Malucelli & Francesco, 2012). The first type (two-body wear abrasion) occurs in the presence of a stiff material that plows weaker material and leads to form a plastic deformation or a breakdown of the weaker material (Malucelli & Francesco, 2012)-(Tanimoto & Nemoto, 2004). In another hand the three-body abrasion wear, it takes place when the wear debris or solid abrasive particles between the sliding bodies: such particles or debris are derived from environmental pollutants or may be formed as a result of scraping with two bodies (Tanimoto & Nemoto, 2004)-(Shimada, et al., 2015). In general, factors on which abrasion wear is reliable, such as applied load, contact material stiffness, abrasive particle geometry and addition to slip distance (Malucelli & Francesco, 2012) -(Tanimoto & Nemoto,



2004)-(Shimada, et al., 2015).

Fatigue wear: occurs as a result of any alternating stress on contacts, and leads to fracture over irreversible change accumulations that determines crack generation, growth and spread. In most cases, this type of the wear occurs (Malucelli & Francesco, 2012) -(Tanimoto & Nemoto, 2004)-(Shimada, et al., 2015).

Delamination wear: occurs as a result of shearing deformation of a smoother surface, through the movement of a stiffer surface, which leads to enhanced cohesion and nucleation of subsurface cracks. As a result, parts of the surface are detached in the form of larger fragments (Malucelli & Francesco, 2012) -(Tanimoto & Nemoto, 2004)-(Shimada, et al., 2015)-(Munoz-Viveros., 1999).

Fretting wear: This type of wear occurs if there is a small oscillating relative movement between two contact surfaces. Either the produced wear parts escape from the surfaces, and thus lead to a decrease in the fitting pressure of the two surfaces and a loss of fit between the surfaces that could result in greater vibrational impacts, or wear parts produced stay in sliding surfaces, so that the pressure raises and results in the damage (Malucelli & Francesco, 2012) -(Tanimoto & Nemoto, 2004).

Interfacial wear damage

Transfer wear: includes the transfer film formation (according to the surface temperature this layer is either liquid or solid) in sliding contact forms of polymer-polymer, polymer-ceramic, polymer-metal. It is usually noted that this film always drives from polymer to metal or ceramic, in the case of polymer-polymer slip contact the direction of transfer is not clear



(Malucelli & Francesco, 2012) -(Tanimoto & Nemoto, 2004)-(Shimada, et al., 2015)-(Munoz-Viveros., 1999).

Several factors influence in transfer film formation and its impact in successive processes of the wear which is the film stability and thickness, the adhesion forces between film and the sliding matching part, the cohesion properties between the transport layers (Nunes, et al., 2008)-(Zhang, et al., 2017). The chemical reaction and the presence of dumper and roughness of the sliding interface surface. The polymer structure (elasticity, crystallization, the presence of side chains or hanging sets...) and approved slip conditions (normal load, speed, temperature, air pressure, ..) (Malucelli & Francesco, 2012) -(Tanimoto & Nemoto, 2004)-(Shimada, et al., 2015)-(Munoz-Viveros., 1999)- (Nunes, et al., 2008)-(Zhang, et al., 2017).

Chemical wear: includes a chemical reaction (hydrolysis, degradation, and oxidation that leads to separation of polymer chains with low molecular weight) in the material itself or between sliding bodies or a substance with the surrounding environment (Malucelli & Francesco, 2012) -(Zhang, et al., 2017).

Effect of Particles on Wear Behavior of Polymer Composites

The Polymers exhibit a variety of the tribological characteristics in comparison with the ceramics or the metals. Such difference takes place as a result of viscoelastic properties and polymers low free surface energy. Introducing fillers and fibers improves the polymer composites strength and stiffness (Rakesh, et al., 2019). The polymer composites tribological characteristic differs with the different polymers (i.e. thermoset or thermoplastic), fillers and fibers that are utilized. For the purpose of obtaining the optimal characteristics of the wear and the friction, numerous



researchers have proposed the modification of the polymers with the use of various fillers.

Ibtihal A. Mahmood, *et al.*, (2013) Study The influence of 3 ceramic Fillers, perlite, calcium carbonate, and granite on wear of carbon fabric reinforced composites of the epoxy under the conditions of the dry sliding was studied. It has been noticed that wear resistance increased by increasing the volume fraction of the reinforcement material whereas, the rate of the wear is increased with the increase in the time, sliding distance, and applied load. Results have shown that the filler of granite perlite and CaCO_3 as materials of fillers in the composites of the carbon epoxy result in highly increasing the composites wear resistance compared to the epoxy composite of the carbon fiber fillers only and granite filled CE Composite have shown maximal wear resistance (Mahmood, *et al.*, 2013).

Orhan S. Abdullah *et al.*, have demonstrated the effects of the ceramic fillers and glass fiber contents on wear behavior of (15% fraction of the volume) system of the glass-epoxy composite. The impact of 3 ceramic fillers perlite, CaCO_3 , and granite on wear of glass fiber reinforced epoxy composites have been researched in conditions of the dry sliding. The impact of the variations in the applied load, volume fraction, sliding distance, and time on polymer composites wear behavior has been researched through the application of the pin –on-disc approach. Results have shown that filler of granite, CaCO_3 , and perlite as materials of fillers in the epoxy composites of the glass will result in increasing composites wear resistance by 74%, 72%, and 76% respectively and more than glass fiber fillers epoxy composite only and granite filled GE Composite has shown a maximal wear resistance (Abdalrazaq, *et al.*, 2013).



Majeed *et al.*, (2013), have carried out an experimental work for the demonstration of the effects of the contents of the Nanocarbon black particles types (N-220) on tribological and mechanical behaviors of the unsaturated nano-composite of the polyester. Results have shown that this tribological behavior has been improved in the case where the content of the Nano carbon black particles has been raised to 2.0%wt. at approximately 26% (Majeed, *et al.*, 2013).

Briscoe *et al.*, (1974) have stated that high density polyethylene (HDPE) wear rate has been decreased by adding inorganic fillers, like the Pb3O4 and CuO. Tanaka (1986) has reached a conclusion that poly-tetrofluoroethylene (PTFE) wear rate has been decreased in the case where they were filled by TiO2 and ZrO2. Bahadur *et al.* (Bahadur, *et al.*, 1985)- (Bahadur, *et al.*, 1992) -(Bahadur, *et al.*, 2000) have discovered that copper compounds like the CuS and CuO have been highly effective to reduce PTFE, PEEK, HDPE, and Nylon wear rates. Kishore *et al.* (2000) have researched the sliding velocity and load impacts on GE composites friction and wear behavior, which is filled by the particles of either oxide or rubber, and have stated that there has been an increase in the wear loss by increasing the load/speed. The solid lubricants like the MoS2 and graphite (Kishore, *et al.*, 2005)- (Wang, *et al.*, 2003) in the case of being added to the polymers have proven their effectiveness in the reduction of the composites coefficient of friction and wear rate.

The polyester composites which have been reinforced by fly ash-filled glass fiber have been analyzed by Satapathy and Patnaik (2010) for the evaluation of their erosion wear responses. The fly ash inclusion on the polyester resin has shown enhanced erosive resistance, while the mechanical characteristics have not been significant.



Fillers such as silicon carbide (SiC), aluminum oxide (Al₂O₃), calcium carbonate (CaCO₃), and boron carbide (B₄C), in the case of being added to PVC, remarkably improved the neat PVC wear characteristics (Yang & Hlavacek, 1999)-(Baptista & do Carmo Vaz, 1993).

Numerous PTFE composites were produced then tested for the wear and friction analyses. Most often utilized fillers/fibers with the PTFE are carbon, graphite, molybdenum disulfide (MoS₂), glass. The fiber volume percentage has a considerable impact on PTFE wear properties. An optimal of 7% graphite+18% carbon, 5% MoS₂ +20% glass fibers. Throughout the PTFE composites wear testing (Khedkar, *et al.*, 2002)-(Tomescu, *et al.*, 2002).

Copper sulfides (CuS) and oxides (CuO), in the case of being added into PEEK and PA polymers result in greatly reducing the wear. In addition to that, the fillers like zinc sulfides (ZnS), zinc fluoride (ZnF₂), silver sulfides (Ag₂S), and lead sulfides (PbS) are the additives which are helpful to reduce polymers wear rate like the PPS and PA (Yu, *et al.*, 2000)-(Xing, *et al.*, 2004)

It can be observed as well that fillers of TiO₂ affect epoxy composite wear rate as nano-fillers <100nm, in general, provide more sufficient wear characteristic compared to the microfillers. Those fillers provide an additional enhancement to wear property in the case of being utilized in combinations with the fibers like the carbon and glass fibers (Zhang, *et al.*, 2004).



Conclusion

1. Fillers can be described as solid additives, added for improving the considerable composite characteristics. The particulate materials like the organic, metallic, and inorganic substances have been utilized as filler materials to strengthen polymer composites.
2. Wear resistance can be considered one of the main concerns concerning the composite resins. Generally, it has been proposed for composite resins that have smaller particles wear less and the components of the filler specify the patterns of the wear particularly in occlusal contact area.
3. The filler sizes and shapes have an impact on the wear particles polymer composite performance as well.
4. Heat curing composites abrasion resistance is regulated as well by the size of the filler and its content.
5. The composite resins wear resistance is improved as a result of the existence of higher volume of the filler and functional silane treated microfiller particles.
6. The increase in the content of the filler presents properties such as the bulk curing with lower shrinkage of polymerization, decrease in wear and packability to composite resin.
7. Filler content impact on the wear resistance could differ based on the variety of the resin matrices.
8. Fillers size has an impact on composite wear rate as the nano-fillers, in general, provide more sufficient wear characteristic compared to the micro-fillers.



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