A review on the degradation of properties under the influence of liquid medium of hybrid polymer composites

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Abstract

Hybrid polymer composites are more attractive because of their light in weight, more robust and rigid (in the direction of fiber) than traditional or unreinforced polymers with the added advantage of having their design and form adapted to suit the specifications of a particular application by the combination of the right choice of the materials. Reinforcement in a polymer hybrid composite can be fiber, filler, or fiber& filler together. Integrating reinforcement into polymers can lead to significant growth in the wear characteristics and mechanical properties of the polymer. Nevertheless, in applications wherever interaction by the liquid medium is inevitable, the mechanical properties and wear characteristics of hybrid polymer composites undergo degradation, which is a generally seen phenomenon since liquid medium acts as a plasticizer. This study aims to provide detailed information on the mechanical and tribological effects of hybrid polymer composites. More emphasis is given towards degradation of mechanical properties such as tensile strength, bending strength, and degradation of wear characteristics like erosion wear rate, and respective failure characteristics were analyzed under different environments such as water, kerosene, saline, sub-zero conditions.

Keywords Polymer hybrid composites · Degradation of properties · Fiber · Filler · Mechanical properties · Tribological properties

1 Introduction

Hybrid polymer composites in the developed world, in particular, are common. Its uses vary from the primary components of structural aircraft to tennis racquets, and numerous domestic applications and they use some form of fibers, filler, or fibers& filler as reinforcement [1, 2]. And other applications which also include automotive applications, marine manufacturing industries, bio-medical applications, and even building industries [3–7]. Hybrid polymer composite is defined by reinforcing polymers, for example, epoxy, Polyester, phenolic, polyvinyl ester, polyurethane resins, etc. with reinforcements such as natural fibers/natural fiber, natural fibers/synthetic fibers, synthetic fiber/synthetic fibers, natural fiber/filler, synthetic fiber/

filler, natural fiber/synthetic fiber/filler [8]. Natural fibers may play a vital part in the improvement of green composites to address recent ecological and environmental challenges. Natural fibers are lighter and cheaper, but their mechanical properties are poor when matched with synthetic fibers. The use of synthetic fibers as a reinforcement combined with natural fibers which makes the composite Hybrid will solve this issue. The reinforcement of natural fiber to the synthetic fiber will make the composite hybrid, which is relatively cheaper compared to synthetic fibers alone. [9–11]. Traditionally, fillers were known as extenders that could increase tensile and bending strength (upon addition of filler content to a certain extent) due to their geometric characteristics, surface area or surface chemical composition and their main contribution were to lower

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production costs by replacing the most costly polymer [12]. Fillers can be micro filler and Nano filler, and the concept of combining nanocomposites as a filler material with natural/synthetic reinforcement in a new three-phase composite reinforcement has been shown to have been very successful [13]. So, the properties of the polymers can be boosted by reinforcement of various synthetic and natural fibers and fillers, particularly Nanofillers, since they are replaced by micro fillers [14].

There are many places and applications where composites are in direct contact with the liquid medium. The key downside of polymeric materials is the damage of properties due to contact to the liquid medium, such as marine atmospheres, in which the properties of polymers are profoundly affected by the saltwater with a combination of specific salts. So, immersion or straight interaction with polymer composites in any liquid media can cause degradation of mechanical or wear properties, and it can lead to failure of composites [15, 16]. While numerous review articles on the properties of hybrid polymer composites are available in online, no paper has so far been explained to the greatest of our understanding regarding the association of properties of hybrid polymer composites through liquid media. Thus, in this review, therefore, deliberates in detail in what way polymer hybrid composites perform in the existence of a liquid medium and the justification behind their abnormal behavior.

2 Reinforcing polymer with fibers and particulates

The reinforcement of fiber and particulates to the polymer improves the properties of both mechanical and wear characteristics [17–21]. Comparatively, hybrid polymer composites show better features compared to mono fiber composite [22–24].

2.1 Reinforcing polymer with natural fibers

As a reinforcement of the polymer composites, natural fibers are gaining significant attention due to their high-performance nature, ecological protection, eco-friendly, lighter in weight, and less cost [25–27]. Natural fibers such as jute, sisal, hemp, kenaf, bamboo are abundantly available in nature, but the disadvantages of natural fiber are low strength compared to synthetic fibers. [28]. Table 1. shows the mechanical properties of a few natural and synthetic fibers.

2.2 Reinforcing polymer with synthetic fiber

In the most recent 20 years, ' usage of synthetic fibers like glass fibers, carbon, and boron fibers has become increasingly common. Synthetic fiber-reinforced polymers are high-performance and rigidity materials widely recognized as aircraft and automobile products [31]. Synthetic fibers such as Kevlar®, S-Glass, Carbon are commonly used. Compared to natural fibers, synthetic fibers give high strength and are hydrophobic (where the moisture absorption content is low). Yet the downside is that they are not biodegradable [32, 33]. From Table 1. It can be seen that synthetic fiber has high strength compared to natural fiber. A modern hybrid composite composed of natural and synthetic fiber, which increases the mechanical strength of polymer composites, is mostly used to compensate for the drawbacks of natural fibers and synthetic fiber. Figure 1 shows the classification of fiber.

2.3 Reinforcing polymer with particulates

Particulates are another type of reinforcements that can be used in composite materials. They are mostly used for cost reduction of polymer and fiber if used, and improvement in thermal conductivity mechanical properties and wear characteristics can be observed. Improvement depends

Table 1 Mechanical properties of a few natural and synthetic fibers [28–30]

Fiber type	Density (kg m ⁻³)	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break %
Jute	1300–1400	393–773	13.0–26.5	1.2–1.5
Sisal	1400	468–640	9.4–22.0	3.0–7.0
Hemp	–	690	30–60	1.6
Kenaf	–	930	53.0	1.6
Bamboo	600–1100	140–230	11–17	–
E-glass	2500	2000–3500	70.0	2.5
S-glass	2500	4570	4570	4570
Kevlar®	70.5 × 10 ³ –112.4 × 10 ³	993	2757	1430
Carbon	125 × 10 ³ –181 × 10 ³	1013	4127	1600

Fig. 1 Classification of fiber

on the type of filler material which is being used and size, shape, surface chemistry, and content of filler content. Filler loading is one of the vital factors for the improvement of properties in the polymer [34]. Raghavendra et al. [35] observed the mechanical properties such as tensile and flexural properties of both micro and nano fly ash filled hybrid composites and determined that the addition of fly ash in composites managed to increase both tensile and flexural strength in the hybrid composites and inclusion of nanofiller content further enhanced the properties. Figure 2. It can be seen that the polyester/glass fiber composites showed a smooth fracture surface,

mainly on the polyester matrix compared to the polyester/glass fiber composite, the fracture surface of the polyester/glass fiber/nanoclay composites showed a much rougher fracture surface [36].

3 Degradation of properties of hybrid polymer composites in liquid media

For hybrid polymer composites few factors can be responsible for influencing the degradation of properties based on the literature (i) Aging in the type of liquid (ii) Aging

Fig. 2 **a** SEM of S-glass/polyester composite, **b** SEM of S-glass/polyester/nano clay [36]

time (iii) Curing rate of resin (iv) Type of polymer (v) Type of Reinforcement (vi) Treatment of fiber (vii) Filler content loading and (viii) diffusion coefficients etc. [37–39].

3.1 Degradation of Mechanical properties of hybrid polymer composites

The mechanical properties of the composite materials remain very much significant in deciding the application of these materials. And the degradation of mechanical properties is very much evident if they are exposed to liquid media since liquid media acts as plasticizer [14]. Natural and aramid fibers are hydrophilic, while polyalkenes are hydrophobic, and other polymers may be polar with hydrophilic properties [40–42]. Table 2. Shows saturation moisture content for various polymers and fibers where M% depends on Fiber/Resin chemistry. In natural fiber reinforcement, moisture absorption is very high compared to synthetic fiber reinforcement [43]. The hybridization of composites shows better resistance to the degradation of properties compared to normal composites [44]. Mohd Shahneel Saharudin et al. [45] studied the deprivation of mechanical properties where halloysite Nano clay is reinforcing in Polyester. They found that upon the increase of the nano clay content in Polyester, seawater absorption has been increased. It is because seawater enters into the voids of the polymer. Compared to monolithic Polyester, microhardness reduced from 107 to 42 HV (61% decrease). Young's modulus showed a 33% decrease, and the flexural modulus showed a 43% decrease. Microhardness, tensile properties, flexural properties, and impact toughness were adversely impacted after 168 h by seawater immersion. Table 3. shows the degradation of the mechanical properties of hybrid polymer composites.

Om Prakash et al. [50] studied the tensile strength of the Arhar (pigeon pea) fiber (extracted from stalks and branches) reinforced epoxy composites under the influence of different environments such as Kerosene, Sub-zero, Mineral Water, and saline. Figure 3 Shows the tensile strength of epoxy and arhar fiber with different wt% in different environments. It shows that composites under

the influence of saline medium degradation of mechanical properties are more compared to other liquid mediums and immersion in kerosene, which is non-polar liquid media showed the least degradation of tensile properties compared to normal composites. It is due to Hydrocarbons contained in kerosene that can affect the interface bonding energy, and not losing the power of Composite. The properties are almost the same compared to the sub-zero condition, and the optimum fiber loading of the composites is 10 wt% of arhar fiber.

Raghavendra et al. [55] reported that composite samples with three layers have maximum mechanical properties compared to others. Figure 4 shows the Tensile strength obtained for different environments and three distinct layers, and the Sub-zero environment has the ultimate tensile strength compared to other environments, i.e., Normal, Saline, and Mineral water. In contrast, mineral water exposed samples have a maximum flexural strength compared to different environments. And saline environment exhibited the least properties compared to other environments in both the properties.

3.2 Degradation of wear properties of hybrid polymer composites

Wear is unnecessary damage to the surface of a solid due to its relative motion, which entails the partial loss of material from the contacting surfaces. It is a natural reaction of a substance that may either be mechanical or chemical [56]. One of the principal causes of material failure and damage to equipment is identified as friction and wear [57–59]. Manoj Panchal et al. [60] reported tribological properties of boiled and unboiled eggshell particulates epoxy composites that are exposed to saline, mineral, sub-zero, and kerosene environments. The maximum erosion rate is observed at 60° for all the composites, but for sub-zero condition samples, it is 90° for particle impingement. When the maximum erosion rate occurs at a normal occurrence (90°), it is categorized as brittle behavior. In contrast, ductile behavior is indexed by the highest erosion wear rate at lower angles, i.e., between 15° and 30° angles of

Table 2 A Table of saturation moisture content can be seen below for various polymers and fibers

Saturation moisture content	Characteristics	Polymers/fibers
M% max < 0.5%	Only apolar groups	Polyolefins, PTFE, Polystyrene, Polydimethylsiloxane [42]
M% max < 3.0%	Non-hydrogen donors	Polyethers, Polyesters [42]
M% max < 3.0%	–	Cured Epoxy [42]
M% max < 10%	H-donors in hydrogen bonding	Polyvinylalcohol, Polyacrylic acid, Polyacrylamide [42]
M% max: 10.5–12.3%	Natural fibers	flax, hemp, jute, sisal [46]

Table 3 A summary of the degradation of mechanical properties on hybrid polymer composites

Author	Year	Matrix	Reinforcement (fiber/filler)	Reinforcement wt%	Liquid media	Immersion time	Results
Huang et al. [47]	2006	Polyester	Glass (Three layers)	–	Water	7, 14, 21 days	Upon immersion Deterioration in Tensile stress and breaking strength upon increasing immersion time. The 21-day immersion period showed the most degraded properties. This is due to enlargement and hydrolysis of matrix
Alamri et al. [48]	2012	Epoxy	Nano Clay HNT Nano silica carbide	1, 3, 5 wt%	Water	180 days at room temperature	Degradation of flexural strength and modulus, whereas fracture toughness and impact strength were seeming to be increased when exposed to water, n Sic showed better properties when compared with clay and HNT. Water uptake is least for 5 wt% Nano clay.
Alhuthali et al. [49]	2012	Vinyl ester resin	Recycled cellulose fiber sheets/Nano Clay	RCFs:40 wt% Nano clay: 1, 3, 5 wt. %	Water	120 days	Reinforcement with Nano clay enhanced the mechanical properties compared to RCFs. An increase in RCFs/Nano clay reduced the water absorption compared to other filler loadings. 5 wt% is the optimum Nano clay for water uptake content.
Mohd Shahneel Saharudin [15]	2016	Polyester	Nano Clay	0.1, 0.3, 0.7, 1 wt%	Diluted methanol	1 day at room temperature	After immersion into diluted methanol 1 wt% showed the maximum mechanical properties. Increase of 45% micro-hardness, 70% Young's modulus, 17. 4% tensile strength, 113% flexural strength, 184% impact toughness compared to Polyester.

Table 3 (continued)

Author	Year	Matrix	Reinforcement (fiber/filler)	Reinforcement wt%	Liquid media	Immersion time	Results
Om Prakash et al. [50]	2017	Epoxy	Arhar	5, 10, 15 wt%	Mineral Water, Saline Water, Kerosene, Sub-zero	8 days	As Fiber content is increasing moisture absorption content is increasing, Saline water is more prone to degradation compared to other liquid media with a 43% reduction in tensile strength
Saxena et al. [51]	2018	Epoxy	Mango wood Sal Wood	33 wt% (Mango wood: 0–100 wt%) (Sal wood: 0–100 wt%)	Water	1 day	Hybrid Composite showed significant mechanical properties and these are composites with least water absorption compared other hybrid composites
Chaudhary et al. [52]	2018	Epoxy	Jute Hemp Flax	25 wt%	Water	Up to 6 days	Water absorption is linear with time up to 5 days upon it became saturated. Tensile strength reduced up to 47% and flexural strength up to 45%. SEM analysis showed that fiber debonding, fracture and dislocation are the reasons for the reduction of properties
Mohammad Hazim Mohamad Hamdan et al. [53]	2019	Polyester	Woven Jute Woven ramie Woven roselle	0–26 wt%	Water	30 days	Immersion of 0–7 days greatly influenced the water uptake content. Hybrid jute ramie composite showed better mechanical properties. The stacking sequence has an influence only on flexural properties. Deprivation of mechanical properties is seen in all hybrid composites

Table 3 (continued)

Author	Year	Matrix	Reinforcement (fiber/filler)	Reinforcement wt%	Liquid media	Immersion time	Results
Dinesh et al. [54]	2019	Epoxy	Jute Fiber Rosewood dust filler Padauk wood dust filler	50 wt% Jute RDF: 0–10 wt% PDF: 0–10 wt%	Water	50 days	Moisture absorption became constant after 15 days of immersion. PDF/Jute composite showed the least water absorption since the PDF filler is hygroscopic caused improper wetting of Composite.

impingement. The material is said to exhibit semi-brittle behavior for maximum erosion at 60° ranges. The maximum erosion rate is for 12 wt% boiled eggshells of loading. This may occur due to the agglomeration of egg particles. Wear resistance is less for boiled eggshells compared to un-boiled. Optimum filler loading is at 4 wt% Un-boiled eggshells. Figure 5 shows the erosion wear rate of 4 wt% of boiled and un-boiled eggshells for the sub-zero condition. An overview of the degradation of tribological properties has been reported in Table 4. From the literature, it can be observed that hybrid composites showed better improvement of wear characteristics, and maximum degradation of properties to moisture content can be observed for saline water immersion and least for kerosene. This is due to Hydrocarbons contained in kerosene that can affect the interface bonding energy, and not losing the power of Composite. So. When designing tanks to store kerosene, hybrid polymer composites can be used.

4 Conclusions

A literature review is provided for the degradation of properties for hybrid polymer composites, which have been reported. Reinforcement with fiber/filler to particular loading greatly enhances its mechanical properties and wear characteristics for hybrid polymer composites. But immersion of samples in liquid media can lead to degradation of properties. From the literature, Hybrid composites showed better resistance to degradation of properties compared to normal composites. As per the literature, degradation of properties depends on (i) Aging in the type of liquid (ii) Aging time (iii) Curing rate of resin (iv) Type of polymer (v) Type of Reinforcement (vi) Treatment of fiber (vii) Filler content loading, etc. These effects are studied in the literature, and various conclusions can draw from the study, which is discussed below.

1. Mechanical properties and wear characteristics of hybrid polymer matrix composites under any liquid media undergo degradation, and the reason for degradation is liquid media acts as a plasticizer.
2. The maximum degradation of mechanical properties and erosion wear rate is for the immersion of samples in saline water because the absorption of sodium and chlorine ions occurs in saline water settings leading to any chemical reaction with the subsequent degradation of the material.
3. Compared to other liquid media, immersion in kerosene has the least degradation of the mechanical properties. As water absorption content is less reduction in mechanical strength is also less, this is due to Hydrocarbons contained in kerosene that can affect

Fig. 3 Tensile strength of arhar fiber reinforced epoxy composites in different environments [50]

the interface bonding energy, and not losing the power of Composite. So. When designing tanks to store kerosene, hybrid polymer composites can be used. The Coefficient of friction is reduced with the immersion of water.

4. Water Uptake content increases with exposure time, but at one point in time, it becomes saturated. As the

Fig. 5 Erosion wear rate of 4 wt% of boiled and un-boiled eggshell composites for the sub-zero condition [60]

amount of fiber/filler content is increased in hybrid composites, moisture uptake content is increased but has superior mechanical and tribological properties compared to normal composites. Particular treatment of fiber with different solutions such as NaOH and alkaline solutions can reduce the water absorption content.

Fig. 4 Tensile and flexural strength under different environments of jute reinforced epoxy composite [55]

Table 4 An summary of degradation tribological properties on polymer hybrid composites

Author	Year	Matrix	Reinforcement (fiber/filler)	Reinforcement wt%	Liquid media	Immersion time	Results
Srinath et al. [61]	2007	Polyamide	Nano clay	1, 3, 5 wt%	Water	1 day	Under wet conditions, the average wear rate of Polyamide nanocomposite and pure Polyamide with load and upturns with load and is higher than under dry conditions.
Chauhan et al. [62]	2010	Vinyl Ester	Glass fiber SiC	Glass fiber:50 wt% SiC:10, 20 wt%	Water	1 day	Reinforcement of glass fiber and SiC filler improved wear characteristics under both dry and water-lubricated conditions
Chand et al. [63]	2008	Polyester	Sisal Fiber	4–42 wt%	Saline	1 day	The Coefficient of friction improved with the addition of sisal fiber but decreased with the increase of applied load. Saline treatment played a significant role in reducing the wear of sisal reinforced polyester composites.
Abdul Samad Moham-med et al. [64]	2016	Polyethylene	Organoclay	0.5, 1.5, 3 wt%	Water	2 days	Specific wear rate and Coefficient of friction rate increased with a surge in clay content up to a certain extent, and the optimum clay loading is obtained at 1.5 wt%.
Om Prakash et al. [65]	2017	Epoxy	Arhar	5, 10, 15 wt%	Kerosene, mineral water, saline, sub-zero	9 days	The optimum fiber loading is for 10 wt% Arhar fiber, as the least erosion rate is observed among other fiber loadings. And the maximum erosion rate is observed at saline water as in saline absorption of sodium and chlorine ions occurs, leading to some chemical reaction with the fiber results in degradation.

Table 4 (continued)

Author	Year	Matrix	Reinforcement (fiber/filler)	Reinforcement wt%	Liquid media	Immersion time	Results
Wang et al. [66]	2017	Polyethylene	Glass fiber Carbon fiber	10 wt% 10 wt%	Water	1 day–28 days	The Coefficient of friction decreased with additional fibers, while water absorption properties increased. Coefficient of friction under water lubrication is lower than dry conditions.
L. Jiang et al. [67]	2018	PVC	Alkali treated sorghum straw fiber	0–6.5% NaOH concentrations of alkali treatment fiber	Seawater, acid rain	2 days in seawater. 2 days in acid rain as a 12-day cycle	Exposure to salt water and acid rain resulted in reduced wear resistance properties. After 12 days resulted in abrasive wear, which led to the formation of fiber pullout.
Shiva Murthy et al. [68]	2018	Epoxy	Banana short fiber $\text{Al}(\text{OH})_3$	Banana Short Fiber: 5–10 vol% $\text{Al}(\text{OH})_3$: 0–7.5 vol%	Water	5 days	Upon the addition of $\text{Al}(\text{OH})_3$, there is a reduction in water absorption. An increase in filler showed consistently in a specific wear rate in both 5 and 10% of fiber volume.
Suresh et al. [69]	2019	Vinyl ester resins	Banana hemp	Banana: 5–25 wt% Hemp: 5–25 wt%	Water	5 days	The sliding distances and sliding velocities were tested for all loads applied. At all sliding conditions, the produced 20 wt% the hybrid composite showed low wear loss and low friction coefficient.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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