
A REVIEW OF PARTICULATE FILLERS IN UNSATURATED POLYESTER COMPOSITES: PROPERTY ENHANCEMENT AND APPLICATIONS

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ABSTRACT

In this study, a review of mechanical properties of unsaturated polyester reinforced by particle composite material has been investigated. The review study involved the compression, tensile, impact, fatigue properties of polyester reinforced by alumina particles Al_2O_3 . This review presents a comprehensive overview of recent advancements in unsaturated polyester composites reinforced with various particulate materials. The methodology relies on compiling and analyzing the results of several studies that used different proportions of particulate fillers within the polymer matrix. The results showed that the addition of Al_2O_3 particles significantly affects the mechanical properties, improving tensile and fatigue strength at certain filler ratios. However, above a certain concentration, compressive or impact resistance may be reduced due to weak interfacial bonding or particle agglomeration. It was also demonstrated that particle distribution, size, and addition ratio play a key role in determining the mechanical performance of composite materials. It explores the influence of different types of particles (e.g., natural fillers, mineral fillers, synthetic fillers) on the resulting composites' mechanical, thermal, and physical characteristics. Furthermore, the review examines the processing techniques employed for fabricating these composites and highlights the applications of particle-reinforced UPRs across diverse industries, including construction, automotive, and marine sectors. At last, the review identifies current deficiency and future perspectives in developing and use of unsaturated polyester-based particle composite materials.

Keywords: Unsaturated polyester, composite material, polymer matrix composite, particulate fillers.

NOMENCLATURE

Al_2O_3	aluminum oxide	TEM	Transmit electron microscopy
UPRs	unsaturated polyester resins	SiN	Silicon nitride

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PMCS	Polymer matrix composites	MMCS	Metal matrix composites
MRI	Magnetic Resonance Imaging	MgO	Magnesium oxide
CT	Computed Tomography	GRP	Glass fiber reinforced polymer
CMCS	Ceramic matrix composites	σm	Mean stress
SiC	Silicon Carbide	σa	Stress amplitude
AlNPs	Aluminum Nanoparticles	FEM	Finite Element Method

INTRODUCTION

Most materials engineers have the difficult task of developing new composite materials or modifying current composite materials. Polymer matrix alteration is one way to creating a new class of polymer structural materials. This change can be accomplished by combining multiple ceramic powders of varying sizes to get the desired mechanical properties (Daniel and Ishai, 2006). Composite materials were initially developed in the middle of the twentieth century and are currently one of the most important sectors of materials and manufacturing technology (Gay et al., 2014). The incorporation of stiff particles into polymers can create a number of beneficial effects on their characteristics. The different features of particulate-filled resin are a consequence of a complex interplay between the properties of the separate component phases, namely the resin, filler, and interfacial area. Each kind of filler has unique qualities, which affect the properties of polymers. The weight fraction of filler, particle size, filler aspect ratio, filler strength, and adhesion at the resin-filler interface are the most important characteristics that influence the numerous properties of filled polymers. The amount of filler that is inserted inside the matrix is regarded the most critical aspect that can change the performance of the composite system (Anuragi et al., 2024). Composite materials can be described as any multiphase materials exhibiting a considerable amount of the characteristics of both component phases, causing a more desirable combination of features. Thus, they possess two or more physically different and mechanically separated components (Vencl et al., 2020). Because of their outstanding strength-to-weight ratio, they have increasingly been used as engineering materials in numerous applications, including automotive and aerospace parts, construction materials, electrical parts, and other consumer products (Muralidharan, 2016). It may be formed by dispersing one material, the reinforcement, into another material, the matrix, in a regulated manner to obtain optimal characteristics (Hull and Clyne, 1996). Composite materials can be manufactured from lower-cost components and have significantly lower specific weights. Previous items created with pricey monolithic materials are being replaced by composite materials with diverse properties that reveal higher qualities and perform better at a lower cost (Eze et al., 2013). Unsaturated polyester, a thermosetting polymer resin, is one of the most widely used a thermoset in the world (Hassen et al., 2021). Because of the high degree of cross-linking between individual polymer chains, they exhibit a number of desirable properties. Exemplary characteristics include a high glass the transition

temperature, high modulus and specific strength, creep resistance, and superior resistivity to solvents. Superior characteristics, along with ease of processing, have resulted in several uses for these polymers, most notably as matrix materials for fiber-reinforced laminated composites. Unfortunately, this cross-linking also makes these materials intrinsically brittle with low resistance to the start and spread of cracks when compared to comparable engineering plastics (Zhang and Singh, 2004). Over two million tons of this material are employed each year in structural items like tanks and pipes, as well as automotive elements including car bodies, boat hulls, and aircraft panels (Groover, 2012). Unsaturated polyester is strengthened and stiffened by mineral or mineral reinforcement. Organic material reinforcements have we recently acquired plenty of attention due to their low cost and availability. Nanoparticles are frequently generated on a large scale as a dried powder. While synthesizing, particles agglomeration and form powerful aggregates (Nolte et al., 2012). Particulate filler can be made of metal or ceramics, as well as fibers like glass, carbon, and aramid. These particle fiber reinforced composites have a wide range of applications in industrial, structural, and engineering settings (Muslim and Bader, 2021). It is widely assumed that the reinforcing effect of particulate-filled polymer composites is heavily influenced by the filler particles' ability to change the matrix resin to generate the suitable aggregation structure, such as grain size and crystallization degree. In this example, both mechanical strength and Young's modulus increased. That is, the inorganic particles play a heterogeneous nucleation in the matrix resin system (. Baker et al., 2004). Recently, it was shown that the inclusion of nanometer-sized fillers can greatly improve the mechanical properties of thermosetting polymers. It has been shown that the augmentation in fracture toughness of thermosetting polymer composites is directly proportional to the size of nanometer-sized reinforcements, with smaller particle sizes resulting in a higher increase in fracture toughness. This finding contrasts dramatically with standard thermosetting polymer reinforcements using micrometer-sized rubber or glass particles, which result in minor or no increases in fracture toughness. In light of this observation (Zhang and Singh, 2004). Nanocomposites differ from ordinary composite materials in that the reinforcing phase has an extremely high surface area-to-volume ratio and/or aspect ratio. A homogeneous dispersion of nanoparticles results in a relatively large matrix/nanoparticle interfacial area, which modifies the molecular mobility, relaxation behavior, and the consequent thermal and mechanical properties of the material (Kaw, 2005). Nanoparticles exhibit distinct properties as compared to bulk materials; thus, numerous research groups have focused their efforts on creating nanoparticles and employing them in a variety of applications. Metal oxide nanoparticles offer good stability, minimal toxicity, and selectivity for organic compounds. They have demonstrated exceptional uses in catalysis, sensor devices, medication delivery, semiconductor materials, water treatment, and solid oxide fuels. Among these metal oxides, Al₂O₃ nanoparticles are one of the nanostructures that has piqued the interest of materials science researchers due to their wide range of applications, including wear protection, automotive emission control,

hydrogenation, metallurgy, refractories, and catalysis in petroleum refinery. Alumina's fascinating properties, such as high catalytic surface activity, outstanding optical activity, high corrosion resistance, and high surface area, contribute to its many applications (Kandil et al., 2021). Examined Al₂O₃ and/or carbon short fibers exhibit high-temperature wear and friction traits (Li et al., 2004).

Despite extensive studies on the properties of particle-reinforced composites, especially those based on unsaturated polyester resins (UPR) reinforced with oxide aluminum particles (Al₂O₃), there is a clear lack of understanding of the combined effect of multiple factors, such as particle size, weight ratio, distribution within the matrix, and heat treatment conditions. Many studies also fail to connect experimental results with reliable numerical modeling (such as FEM) to better understand material behavior under various loading circumstances (tensile, compressive, and fatigue). Furthermore, the relationship between failure mechanisms (such as microcrack propagation or interfacial separation) and the resulting material properties is still poorly understood, limiting the possibility of designing composite materials with better-than-known performance in advanced engineering applications.

In this study, a review study of different types composite material has been reviewed. As well as, the effect of adding alumina particles to the mechanically characteristics of polyester resin were investigated. The mechanical properties involved the compression, tensile, fatigue properties of composite material reinforced by alumina particles.

COMPOSITE MATERIAL

A composite is a material construction composed minimum two macroscopically distinguishable materials that collaborate to produce a best score. Whenever a composite produce is constructed, both the materials and the structures are frequently produced together. Generally, there's no raw, machined material that is kneaded, distorted, and integrated become a temple, but the temple and the material are manufactured in one go; The term for "material a structure" '. The advantageous features of fibers and matrix are maximized, while the undesirable properties of one component are compensated for by the other component to the greatest extent feasible, resulting in a structure that could not have been created with either component alone (Nijssen, 2015). Composite attributes are determined by the constituent properties, their respective proportions, and the geometry, distribution, and orientation of the dispersion phase. The major factors are the characteristics and the proportion of elements (Balasubramanian, 2013). A variety of theoretical and computational experiments are additionally carried out, with the main aim of predicting the stiffness and strength of the composite based on the mechanical characteristics of the matrix and reinforcing phases (Li and Ramesh, 1998).

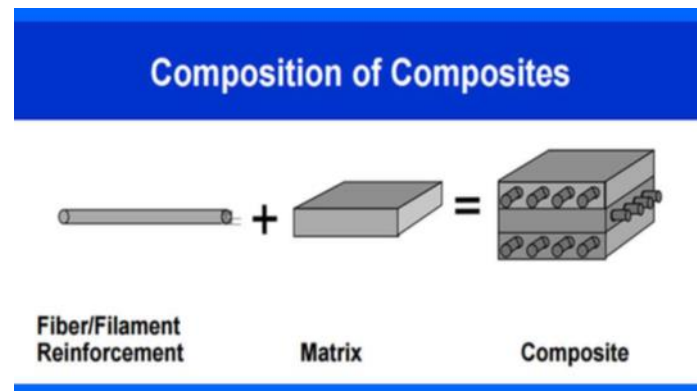


Fig.1. Composite Materials [68].

TYPE OF COMPOSITE MATERIAL

Polymer matrix composites (PMCS)

Polymer matrix composite materials are those that use organic polymers as a matrix and fibers as support. Fibers often have substantially higher strength and modulus than matrix materials (Wang et al., 2011). A result of this, there are various aspects to consider while developing Polymer matrix composites. Several factors are taken into account, including matrix and reinforcement types, relative ratios, enhancing geometry, and interphase structure. Medical appliances integrating polymer matrix composites comprise MRI machines and X-ray sofas, CT machines, mammograms plates, operative target gadgets, prosthesis, the tables and wheelchairs. Polymer matrix composites are employed in microelectronic applications such as boards for printed circuits, connectors, encapsulations, substrates, electrical wiring contacts, the interlayer a dielectric, heat sinks, and connections (Dhanasekar et al., 2022). PMCs are made up of various organic polymers that incorporate continuous or short fibers with varying reinforcing agents. This improves the stiffness, strength, and fracture toughness of composite materials (Sajan and Selvaraj, 2021). PMCs are lightweight materials that have excellent stiffness and strength in the direction of the reinforcing fiber (Kar, 2017). The major reasons for the growing use of polymer matrix are lower weight, the ability to coordinate parts with one another, low tooling costs, prolonged protection from corrosion and damage, and enhanced internal damping (Rice and Sparks, 2018).

Ceramic matrix composites (CMCS):

Due Most ceramics is renowned for their high melting points and heat its stability, as well as their non-brittle mechanical behavior, Ceramic matrix composites (CMCS), which consist of a ceramic matrix strengthened for ceramic fibers, are promising Material for outstanding performance structural uses (Naslain, 2016). Advanced ceramics possess a distinct assortment Properties such as higher tensile strength at high temperatures, superior

wear resistance, high hardness, low density, powerful elastic modulus, and lower coefficients of rubbing make them substitutes to pure metals for a wide range of structural application. Advanced ceramics are currently in use in a number of uses, such coatings, wear components, heat exchangers, and cutting tools. However, ceramics need to be made more reliable and less brittle in order to be used in new applications like motors and turbines. CMCS was useful for aero planes whose mission performance is dependent on both lightweight design and environmental durability. These materials can drive spacecraft more than ten times faster with the same quantity of fuel, thus increasing travel distance while reducing vehicle size. Silicon nitride (Si_3N_4) and silicon carbide are the most ideal lightweight ceramic materials for space uses since they can resist high heat. Their stiffness, these variables will be influenced by thermal stability, high temperature stiffness, thermal shock resistance, and oxidative conditions (Dhanasekar et al., 2022).

According to nanostructure control, CMC is roughly divided into two categories: particle dispersion and fiber reinforcement, which includes continuous fibers and whiskers (Okamura, 1995).

Metal matrix composites (MMCS).

Metal-matrix composites (MMCs) are designed to combine two or even more materials, including the one which are a metal, in which various ingredients are systematically combined to provide specific features (Rohatgi, 1993). Due to their high mechanical attributes and resistance to wear, metal-matrix composites, or MMCs, are utilized extensively in several industries (Sevik and Kurnaz, 2006). Commercial applications for MMCs include fiber-reinforced pistons, aluminum crankcases with enhanced a cylinder surfaces, and particle-strengthened braking discs (Kainer, 2006). Most commonly used in the cars for aerospace sectors, reinforcement compounds like as SiC and Al_2O_3 can be readily and efficiently blended with molten aluminum to provide desired qualities such as enhanced strength, improved stiffness, lower density, controlled the expansion of heat, and improved wear resistance (Rajak et al., 2019). Thus, MMCs provide high melting temperatures, improved physical qualities, and superior mechanical properties throughout a wide temperature range (Singh et al., 2020). Metals and alloys are often created and molded in bulk, but they can also be intimately mixed with other materials to increase their performance: The final material is a metal matrix composite (MMC) (Mortensen and Llorca, 2011). Metal matrix composites (MMCs) have a variety of intriguing features that make them ideal for structural aerospace applications (Kuşay, 2004). Its low weight and thermal insulation requirements make it ideal for usage in aero plane fuselages (Degraff, 1982).

APPLICATION FILLER COMPOSITE.

Fillers are essential components in the manufacture of composite materials, used to improve the mechanical, thermal, and functional properties of polymeric or ceramic materials. Fillers vary in type, including metallic, ceramic, nano, or organic fillers, and are

selected based on the desired properties of the final product. Fillers in various composite systems are widely used in the packaging, biomedical, cosmetic, pharmaceutical, paper, food, paint, and glue sectors. This is because it has been shown to increase the materials' specific qualities such as stiffness, strength, clarity, creep resistance, and physical appearance (Loos, 2001). The use of fillers for the enhancement of polymer properties has been well documented. Initially, fillers were used to reduce the cost of the polymeric products. However, with time, fillers became an integral part in many applications, particularly for reinforcing the mechanical properties of the polymer. "Reinforced" polymers consist of a polymeric matrix and a relatively stiff inorganic filler that undergoes dramatic change in modulus or stress at given strain over the pure polymer. Improving wear and friction resistance. The inclusion of hard fillers such as SiC or Al_2O_3 increases wear and scratch resistance, making the composite material suitable for use in applications subject to constant friction, such as brake pads, gears, and pumps (Jawaid and Thariq, 2019).

POLYESTER

Polyesters are among the more versatile synthetic copolymer. Polyester is made in large quantities, with global production topping 30 billion pounds per year. They are widely employed economically as fibers, polymers, composites, and in coating applications. They are hetero chain macromolecules containing carboxylate ester groups as an integral element of the polymer backbones (Dholakiya, 2012). As shown in figure.2 (Nijssen, 2015). Polyester resins it frequently applied in open-mold lamination and casting, and after curing, they frequently acquire a sticky surface feel. Because the free radical polymerization process is oxygen-sensitive, it interrupts the surface connecting mechanism and causes the cure more difficult. Fiber reinforcements such as glass greatly increase the strength of all polyester resins. Glass-fiber mats are typically used to create laminates (Nava, 2015). It is used to assess the concentration of aberrant red blood cells in human blood by creating microprobe membranes for blood filtration. These are valuable moulding compounds since they are resistant to cover and hacking it. The sheet casting compound is made from unsaturated polyester resin the syrup has excellent tensile strength. It is utilized to manufacture offering trays, shades for lamps, flat sheets that and corrugated boards for the building industry, ammo cases, throwaway glass tanks, and other cases (Dhanasekar et al., 2022).

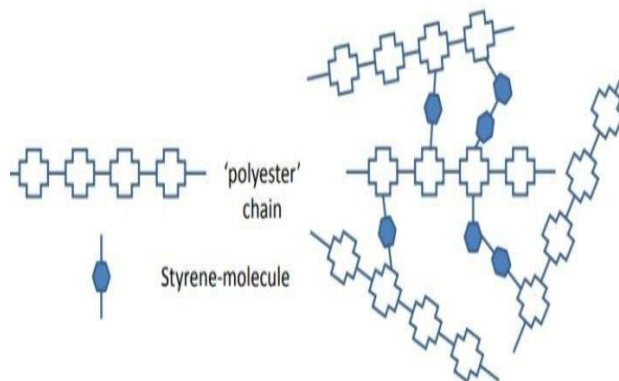


Fig. 2. Schematic representation of cured polyester (Nijssen, 2015).

ALUMINUM OXIDE (Al_2O_3) NANOPARTICLES

Aluminum oxide nanoparticles (AlNPs), a kind a porous nanomaterial. These metal oxide nanomaterials' have a corundum-like its structure with six atoms of oxygen surrounding one aluminum atom (Hassanpour et al., 2018). These are Nano sized particles derived from an alumina bulk. Alumina nanoparticles can be created using a variety of processes, which includes pyrolysis, sputtering, sol gel, and the most widely utilized technique, laser ablation (Yatsui et al., 2000). Laser ablation is convenient since it can be performed in gas, liquid, or via vacuum conditions (Drah et al., 2019). Since 1970, alumina has been utilized to make prosthetics and surgical device components. It is an inert component that resists rusting in vivo. It produces only a small reaction in the tissue and remains stable for many years (Al-Timimi and Tammemi, 2021). Aluminum oxide is also extensively employed in many fields of industry for preparing various types of ceramic and refractory components, catalytic the carriers, absorbents, fillers for the rubber engineering, and plastic things (Fathy et al., 2016). Aluminum oxide is non-toxic, easy to use, a chemically stable and comprises numerous hydroxide groups, making it an excellent adsorbent. Since 1923, aluminum oxide has been used as an adsorbent to eliminate pigments, antibiotics, heavy metals, dissolved organics, etc (Hami et al., 2020).

PREPARATION OF ALUMINA NANOPARTICLES

Alumina Nanoparticles is generated using Various ways, Includes arc plasma, the hydrothermal, sol-gel, laser ablation (Saravanakumar et al., 2018). Laser ablation is a popular approach for the production of nanoparticles since it can be done in gas, vacuum, or liquid. This technology has various benefits over other methods, includes a faster and higher purity process (Mutlag et al., 2020). moreover, nanoparticles made by Laser ablation of materials in fluid makes it more effortless collect than those produced in a gas atmosphere (Moustafa et al., 2002). Prepared alumina nanoparticles in a direct current the

arc plasma a reactor uses isochronal flow of oxygen conditions. Transmit electron microscopy or TEM. The infrared and absorption spectra revealed a collision ally quenched structure with very tiny particles condensing from the plasma (Madhu et al., 2011).

ALUMINA FIBERS

Alumina fiber is a high-performing inorganic fiber, consisting primarily of aluminum oxide (Al_2O_3), with trace amounts of SiO_2 and MgO . Alumina fiber is well known for its incredible heat resistance, exceedingly low heat conductivity, and high chemical stability, making it widely employed in the aerospace, extreme temperature insulation, and catalytic carrier fields (Mortensen and Llorca, 2011). The demand for increased modulus of elasticity, melting point, and extraordinary resilience to corrosive conditions led to the development of pure or almost pure Al_2O_3 fibers. As the temperature rises, alumina crystallizes and undergoes phase transitions until it reaches the stable α phase. As temperature decreases, the Al_2O_3 phase transitions from η to γ , δ , β , and eventually α . The α phase of Al_2O_3 is ideal for fibers utilized in composites with extreme temperatures because to their excellent temperature resistance and modulus worth. Table.1 compares the characteristics of alumina and other fiber materials (Tjong, 2013).

Table 1. Properties of Fiber Materials, (Tjong, 2013).

Fibers	Density(g/cm^3)	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Thermal Expansion ($10^{-6}/^\circ\text{K}$)
E-glass	2.55	3440	72.3	
S-glass	2.50	4480	86.8	
Alumina	3.15	2070	172.1	7.0
Graphite (high Strength)	1.50	2760	275.4	
Graphite (high Modulus)	1.50	1860	530.2	

FUNCTIONS OF THE MATRIX

The matrix links the fibers together and keeps them aligned in the strained directions. Loads imparted the matrix then transfers the loads to the fibers, the primary load-bearing

component of the composite, allowing it to withstand compression, bending, shear, and tensile forces. The capability of short fiber reinforced composites to bear various loads relies on the matrix serving as the load-transfer medium, with the effectiveness of this transfer being directly correlated to the integrity of the fiber/matrix bond. up a large number of reinforcing fibers. Not only are fibers stiffer than the monolithic form of the exact same substance. When such materials are utilized as fine fibers, but there is also the added advantage that the fiber aggregation will not fail catastrophically bearing ability. However, these fiber aggregate benefits can be obtained only if the matrix separates the fibers from one another, preventing cracks from passing unhindered through series of fibers in contact, resulting in totally brittle composites. The matrix should shield the reinforcing filaments from environmental threats and mechanical harm like abrasion. Since many of the resins used as matrix for glass fibers allow water to diffuse, many GRP materials frequently fail to fulfil this purpose, and stress exacerbates the resulting environmental degradation. The alkaline nature of the matrix in cement is harmful to ordinary glass fibers, hence alkali-resistant glasses containing zirconium have been designed to combat this. For composites like MMCs or CMCs that operate at high temperatures, the matrix must shield the fibers from oxidative damage. A ductile matrix will slow or stop cracks that may have developed at broken fibers, but a brittle matrix may rely on the fibers for serving as matrix crack stoppers (Gopalakrishnan et al., 2021).

MECHANICAL TESTS

Compression Test

It is the maximum compressive force applied to the unit area of the specimen, and it depends on the type of material, form factor, flexibility, and degree of deformation of the material, Figure 3. The test aims to determine the material's elasticity and the ability to return to its original thickness after being under pressure. The difference in the degree of deformation of the material is due to the type of composite material (brittle, flexible, sticky, etc.) (Purohit et al., 2013) (Sahin et al., 2003). The quantifiable strength for compression of a lamination is frequently lower than the tensile strength, although stiffness is about equivalent. Although a compression test can be performed using the clamping jaws of a typical test equipment, there are many dedicated attachments that can amended the quality of a compression test (Nijssen, 2015). Compression strength is determined by the materials, reinforcing materials, and strength matrix qualities of linking across surfaces, as well as the reinforcement material fraction volume. It is evident that adding alumina to polyester resins lessens the ultimate compressive strength of the composites. This could be attributed

to an increase in alumina content, which causes limited adhesion between alumina powder and matrix, reducing the strength of unsaturated polyester composites, as shown in the figure 4 (Karakuzu et al., 2016). A composite's compressive strength is essentially determined by significant grain refinement, the existence of appropriately dispersed hard particles, and load transfer from the matrix to the reinforcing phase. The impact of Al_2O_3 composition on compressive strength is significant. Though the porosity increases as the Al_2O_3 content increases, the compressive strength also increases. This affirms the clear effect of Al_2O_3 particles on composites' strengthening mechanisms, as shown in the figure 5 (Mahdi et al., 2015).

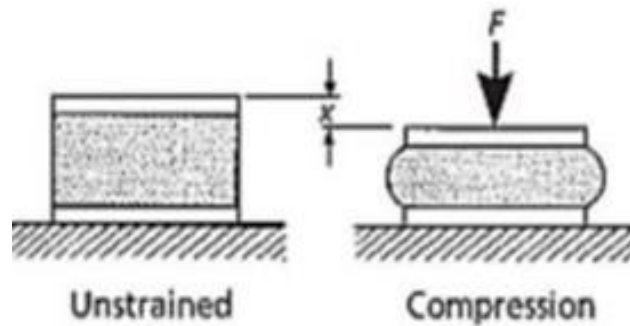


Fig.3. Compression test sketch (Purohit et al., 2013).

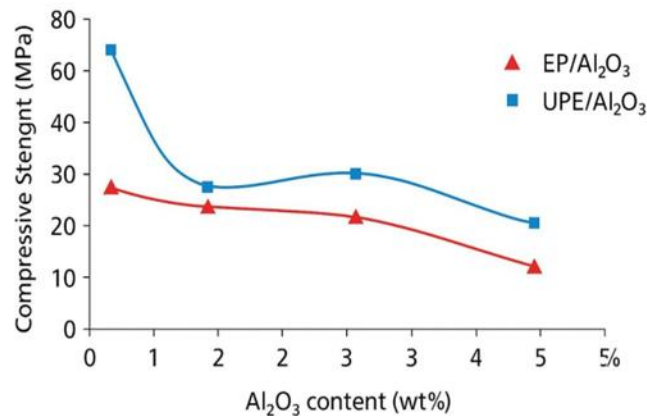


Fig.4. Ultimate Compressive Strength variation with Al_2O_3 powder content in EP, UPE resins composites containing (Karakuzu et al., 2016).

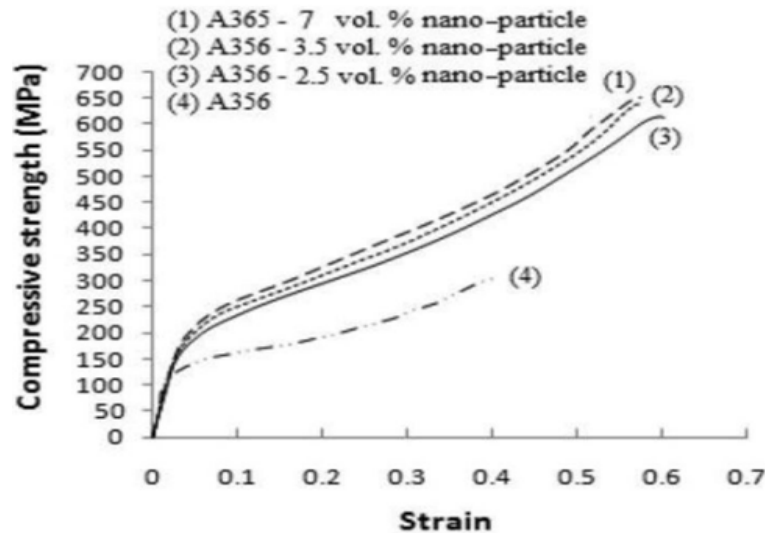


Fig.5. The tensile flow curves of the Al_2O_3 nanoparticles, cast at 750,800 and 900°C (Mahdi et al., 2015).

Fatigue test

Researchers investigated the strength and durability of polymeric nanocomposites under fatigue conditions. Composite fatigue cases include Tension-Tension (T-T), Compression-Compression (C-C), Tension-Compression (T-C), bending, thermal, and a few combined loading modes. The various loading modes result in distinct damage mechanisms. Recently, the fatigue degradation behavior of structural composites under various loading conditions has been investigated. Some studies also look at the fatigue behavior of composite materials. However, further research is needed to better understand their fatigue-failure resistance behavior and damage mechanisms. Unidirectional transverse specimens fail instantly with the formation of the first transverse crack, but multidirectional laminates have a negative impact on fatigue performance (Farid et al., 2018). Fatigue tests can be used to determine the fatigue properties of materials structural by Bending and torsional loads can be applied to the sample until it fractures (the range of low- or high-cycle fatigue), or the test can be completed even if no failure happens as long as a large the number of cycling are performed (Omrani et al., 2015). The number of fatigue cycle is calculated after the failure of the specimen utilizing a stopping the sensor. that causes the testing equipment to shut down (Prasad and Krishna, 2007). Material qualities and testing conditions have a significant influence on these parameters, Main components of fatigue that trigger the damage mechanism in any engineering structure are the mean stress (σ_m), stress amplitude

(σ_a) and sufficient number of cycles (N) to cause failure. The stress ratio ($R = \sigma_{min} / \sigma_{max}$) is the ratio between the minimum and maximum applied stress during a loading cycle. It describes different fatigue loading scenarios, which can be read as tension-tension (t-t) fatigue when $0 \leq R < 1$, tension-compression (t-c) fatigue when $-\infty < R < 0$, and compression-compression (c-c) fatigue for $1 < R < \infty$. (Ghaffarian et al., 2013). Secondary stresses induced specimen non-recti linearity or misaligned in the testing device jaws might also be difficult to avoid (Arif et al., 2013). During the fatigue test, temperature fluctuations and fatigue damage cause the test specimen's stiffness to fluctuate, which causes the natural frequency to shift moment by moment. Nevertheless, throughout the fatigue test, this control logic keeps the specimen in its resonant state despite variations in stiffness (Thirumalai et al., 2021). Actually, Fatigue failure in composites is frequently caused by serious harm, which is exacerbated by specimen volume, rather of a prominent single break, as seen in most isotropic brittle materials (Singla et a., 2010). The fracture surface is made up of smooth parts with beach marks, a ring with the center representing the crack's commencement, and rough parts represent fracture area, as shown in figure.6 (Lee et al., 2010).

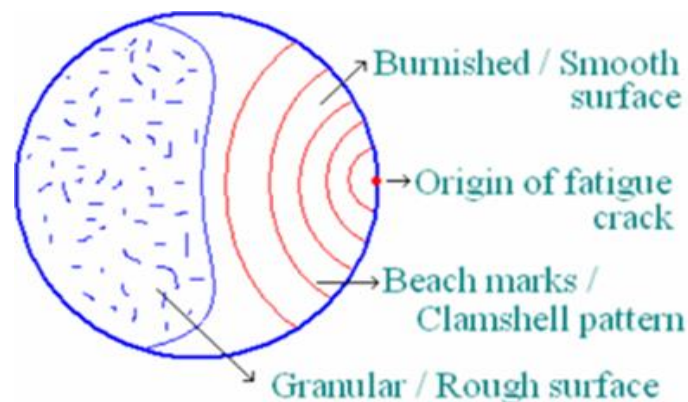


Fig. 6. Fatigue fracture surface (Lee et al., 2010).

Tensile Test

Stress is the load per unit area acting on material (tension, compression), while strain is the increase and decrease in the length per unit of the original length of the material. Plastic materials in a stress-strain curve depend on the rate of strain, unlike metal materials. It is known that polymers are strongly influenced in their physical properties by temperature, which leads to a change in some properties such as stress. Increasing the temperature leads to a decreasing the strength of the material as the elastic modulus (Zainab, 2022). Every tensile test involves applying a tensile force throughout the length of a lengthy specimen.

The material experiences some deformation as an outcome of the applied force. Typically, the specimens' cross sections are spherical or flat, as shown in the figure7. A sample's end is fastened to a result of the applied force. A sample's end is tied to a stationary component of the device, while the other end is fastened to the crosshead, which moves steadily. As the specimen extends, the force that is applied is calculated using a load cell connected in series with it. It is critical to understand that not all of the crosshead's displacement is transferred the length of the gauge segment of the specimen (Bayraktar, 1997). A simple tensile test involves tugging a sample to its breaking point in order to determine the material's maximum tensile strength, as shown in the figure.8 (Ackermann, 1997). As the weight % of Al₂O₃ particles increases, so does the composites' tensile strength. Because the Al₂O₃ particles prevent dislocations from moving, the composites' strength is boosted (Atluri, 2004). Tensile strength increases because of alumina dispersal and stronger bonding of the interface between the filler and matrix in composites, as shown in the figure.9 (Abdullah et al., 2005). This test is crucial for determining the specimens' strain-to-failure, tensile strength, and tensile modulus (Chawla, 2012). A tensile test can reveal the tensile strength, stiffness, Poisson contraction, and strain at fracture, as shown in the figure. 10. A tensile test on a $\pm 45^\circ$ laminate can determine its shear characteristics (Nijssen, 2015).

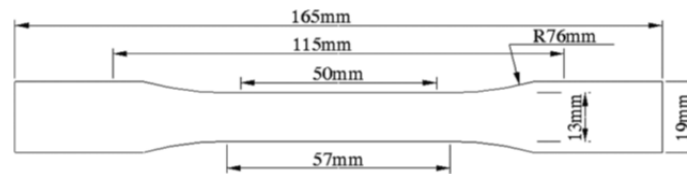


Fig.7. The tensile test spacemen dimension.

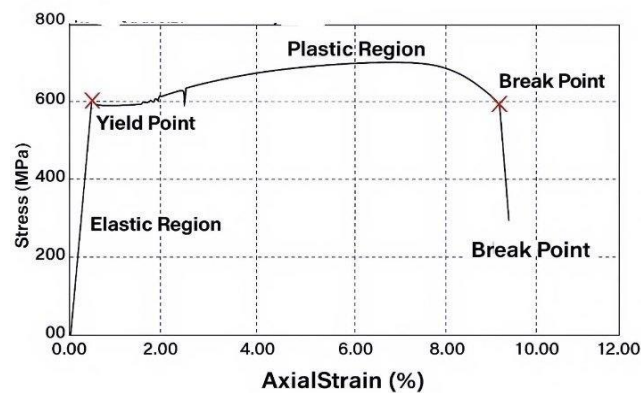


Fig. 8. Tensile test ASTM- A14 (Ackermann, 1997).

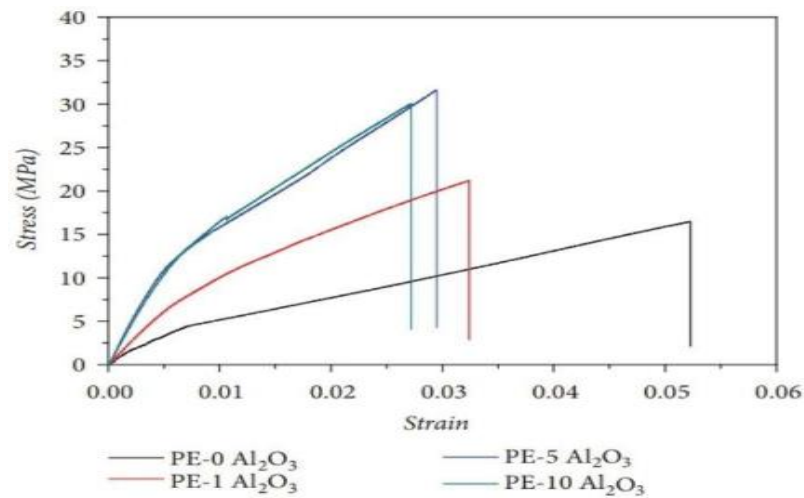


Fig. 9. Stress-strain curves of polyester/alumina Composite at strain rate $\times 10^{-4}$ /s (Abdullah et al., 2005).

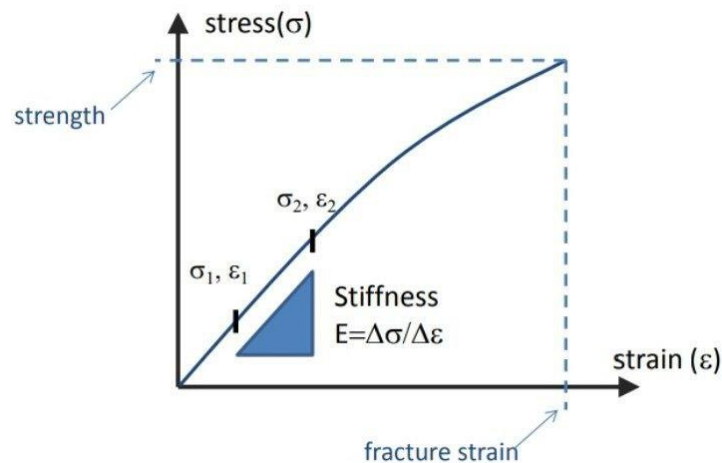


Fig. 10. Properties from the Stress-strain diagram of a tensile test (Nijssen, 2015).

Impact tests

In the early phases of the design process, impact tests are typically conducted to ascertain the material's integrity under impact loading. Finding the highest the maximum load from impact that a material can endure at a given temperature is typically accomplished through impact testing. Addition alumina nanoparticles into the polymer matrix produces considerable variations in impact strength, such that the impact strength first increases and then falls as shown in the figure.11 (Callister and Rethwisch, 2014). The impact test was

used to determine the impact energy absorbs by specimens subjected to a swing impact force (Mallick, 2007). Impact resistance is considered as a key material property. Materials ability for with standing knocks of accidental able to determine its failure or success in special application (Karakuzu et al., 2016). The improvement in impact strength is attributed to the best dispersal of nanoparticles in the sample, which contains alumina nanoparticles in the polymer matrix as shown in the figure.12 (Mallick, 2007). Furthermore, when it comes to impact improvement, the usage of boosting chemicals works well by altering weight ratios based on individual application needs (Tjong, 2013).

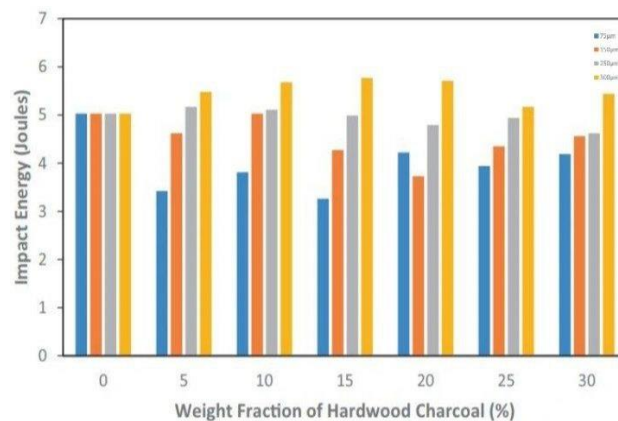


Fig.11. plot of the average values of impact energy versus particulate different alumina weight fraction (%) of Hardwood-polyester resin matrix composites (Callister et al., 2014).

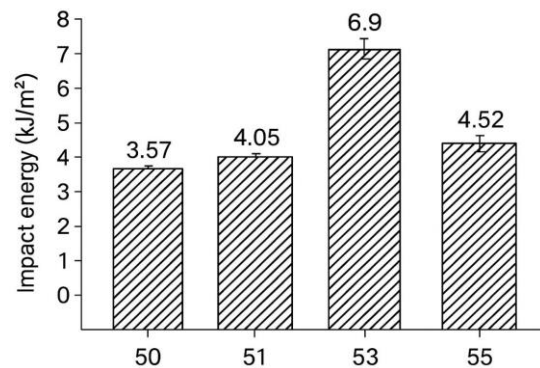


Fig.12. Impact energy changes nanoparticles content 0, 1, 3, and 5 wt.% (Mallick, 2007).

Numerical Method

To solve many engineering problems, and with the advancement of technology, many engineering programs have been designed that can find engineering solutions through

analytical methods (Jones, 1998). (FEM) Finite Element Method is a popular computational technique for numerically solving various parametric issues. The meshing procedure has been completed by selecting the number of components and volume in the body (Hull and Clyne, 1996), (Agarwal et al., 2006). Unfortunately, it is still difficult to develop a stable and dependable technique for using FEM is to precisely model failure in bonded joints (Strong, 2008). After the content has been examined and comprehended, analytical testing can be carried out with simulation programs that apply theories, equations, and algorithms related to the phenomena under study. These algorithms allow the behavior and performance of the material to be evaluated using the mathematical models that have been created (Gibson, 2011). illustrates the model and its behavior under boundary conditions, as well as the maximum stresses that are created within the model (Muslim, A. H. and Bader, 2021).

Conclusions

This review has provided an overview of composite materials, with a specific focus on unsaturated polyester resins reinforced with particulate fillers, particularly alumina. The effect of using aluminum oxide (Al_2O_3) particles was investigated. The results showed that the incorporation of these particles directly affects the mechanical properties of the composite material. Increasing the particle filler ratio was shown to improve tensile strength and stiffness by enhancing the cohesion between the polymer matrix and the particles, fine particles also inhibit sliding and deformation within the matrix, enhancing its stiffness and resistance. However, the maximum effectiveness of the filler depends on several factors, such as the homogeneous distribution of particles, the volume-to-area ratio, and the interfacial adhesion between the particles and the matrix. Some results have shown that increasing the filler content to a certain extent may lead to a decrease in impact or compression resistance due to agglomeration or poor adhesion between components. Based on the above, the use of aluminum oxide particles as a particulate filler can improve the mechanical performance of polyester composite materials, but this improvement is dependent on careful control of the filler content, its physical properties, and processing techniques. The inherent advantages of composite materials, stemming from the synergistic combination of matrix and reinforcement, make them attractive alternatives to traditional monolithic materials. Further research employing numerical methods like FEM, alongside experimental studies, is essential to fully understand and predict the behavior of these composite systems under various loading conditions, ultimately guiding the development of high-performance and reliable materials for diverse engineering applications.

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