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Study on Mechanical Properties of Polylactic Acid Matrix Added with Fly Ash and Tamarind Kernel Powder Micro Fillers

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Abstract

It may include up to three cited (non-numerical) references. The mechanical characteristics of PLA (Polylactic acid) composites with fly ash and tamarind kernel powder micro fillers were examined in this experimental investigation. Samples were created by changing the amount of tamarind kernel particles from 0 to 4 wt.% when using PLA as the binder (with an increment of 1 wt.% for each sample). Fly ash filler's wt.% was left at 1. Compression moulding was used to create composites. According to the tensile results, the reinforcement using fly ash and tamarind kernel powder greatly increased the PLA matrix's tensile strength. At 1 wt.% fly ash and 2 wt.% tamarind kernel powder composites, respectively, the maximum tensile, flexural, impact, tensile modulus, and flexural modulus of 76.24 MPa, 156.68 MPa, 18.61 kJ/m^2, 2.31 GPa, and 3.86 GPa were attained. The impact and flexural strength of PLA matrices were significantly improved by the particle reinforcements of fly ash (1 wt.%) and tamarind kernel powder (2 wt.%). Additionally, when compared to plain PLA, the composites with fly ash particles showed a 30% increase in microhardness. Additionally, the results showed that an important factor in determining the characteristics of PLA composites is the wt.% of fillers.

Keywords

Fly ash, Tamarind kernel powder, Micro fillers, Composites, Experimentation

Introduction

Hybrid polymer composites, which combine both natural and artificial resources as strengthening materials to enhance the requisite properties of the composites, have developed significantly over the past several years. Modern engineering has replaced many conventional metals and materials with polymers supplemented with synthetic and natural components. This is feasible because reinforced polymers made from natural resources have benefits over traditional materials. The demand for these materials has greatly increased as a result of the development of hybrid bio-composites that utilise various natural resources as reinforcing and filler elements. Modern composite materials, including natural and synthetic fillers, have become more necessary and used in various commercial applications recently [1-3]. Particle reinforced polymer composites are employed in a variety of technical contexts due to their exceptional mechanical and physical qualities while yet being relatively lightweight. To increase mechanical strength, fillers are frequently used as reinforcement. These fillers can be selected as powders like ceramic or as fibres like glass, carbon, or aramid. The typical size of a particle is between one and ten μm, sometimes even more [4]. Fly ash is a type of industrial waste that contains a variety of oxide ceramics and could be used as a filler component in polymer matrix composites. As a result, the composites' mechanical and physical properties are enhanced [5]. The mechanical characteristics of PMC, including as its tensile, impact strength, and hardness, are improved by the addition of smaller-sized filler components [6]. Alumina and silica, which make up the majority of fly ash, are predicted to enhance the composite characteristics. Additionally, some fly ash contains hollow spherical particles that support the composite's ability to retain lesser density values, which is crucial in weight-particular applications [7, 8]. There has been a lot of research on ceramic filled polymer composites during the past 20 years. Reduced costs and increased stiffness are the main reasons why inorganic fillers are added to polymers for commercial applications [9]. Fly ash, which is regarded as an industrial waste product and contaminant, is one of the more recent additions to the family of particle loaded polymer composites [10]. An assortment of PLA/fly ash composites were developed in this investigation, with the ultrafine fly ash reinforced via silane grafting. When fly ash is added to PLA, the resulting composite has a higher tensile strength [11]. For the purpose of determining the tensile strength, impact resistance, and hardness value of two natural fibers, such as tamarind seed particles and palm fiber, hybridized composite samples were created in four different volumetric ratios [12]. Tamarind seed powder was employed as reinforcement along with a specific ratio of Palmyra palm fiber, and epoxy resin was used as the matrix material. The tensile, impact, flexural strength, and moisture absorption properties of the specimens were evaluated using five different sets of test specimens [13]. Researchers conducted an experiment to determine how adding tamarind kernel micro fillers (from 0 to 4 wt.%) and fly ash (from 1 to 4 wt.%) to PLA composites affected their mechanical properties.

Materials and Methods

Covai Seenu and Company in Coimbatore, India, a nearby merchant, supplied the virgin PLA pellets. According to the provider, the PLA has a melt flow index of 15 - 35 g/min and a density of 1.232 g/cm^3, respectively. The melting point is 185 ˚C, the glass transition temperature is 70 ˚C, and the crystallization temperature is 130 ˚C. To avoid any hydrolytic scission during processing, the PLA pellets were held at 70 ˚C in a dry air oven. At 235 ˚C in a muffle furnace, PLA was melted to create resin. The local resources are used to collect fly ash and the abandoned tamarind seed kernels. To naturally evaporate the water content in the tamarind kernels, they were dried in the sunlight. The tamarind kernels were then processed through the nearby flour mill for 1.5 hours at 650 rpm. The fillers have demonstrated improved absorption behavior as their size has decreased. In order to acquire the size between 65 and 95 m, the tamarind kernel powders were sieved. At 235 ˚C, the fly ash and tamarind kernel micro fillers were applied separately to the molten PLA resin. The fillers and resin were thoroughly mixed by hand to ensure that the fillers were evenly distributed throughout the matrix. With great care, PLA resin with filler was poured into the mould and then kept under pressure of at least 6 bars for 1.5 hours, or until room temperature was reached. When compared to other resins, the PLA resin tends to cure quickly, which drastically cuts the manufacturing time for creating composites (Figure 1). The composite plate was removed from the mould after curing, and samples were cut using a water jet cutter. At room temperature, the Archimedes method was used to determine the samples' densities. The measurement was performed using a scale with great accuracy. Each sample was weighed three times, and the mean of those measurements served as the actual density value for that particular sample. Tensile tests on the samples (Figure 2) with dimensions of 150 x 25 x 3 mm were performed in accordance with ASTM D 3039 standards. A 400 kN load cell capacity Universal testing equipment was used for the tests. Researchers conducted all of our experiments with a gauge length of 75 mm and a crosshead speed of 2 mm/min. The crosshead displacement was measured by a potentiometer. Each material type had four samples tested, and the average result was reported as the material's tensile property. Flexural characteristics were evaluated via a three-point bending test. The test employed 150 x 20 x 3 mm samples (Figure 3) that met the requirements of ASTM D 790. Test conditions included a crosshead speed of 1 mm/min and a support span of 80 mm. The analysis of four samples yielded the average flexural value. The 300 J Charpy impact testing apparatus was used to conduct the impact test. According to ASTM D 256, the notched samples of size 75 x 10 x 10 mm

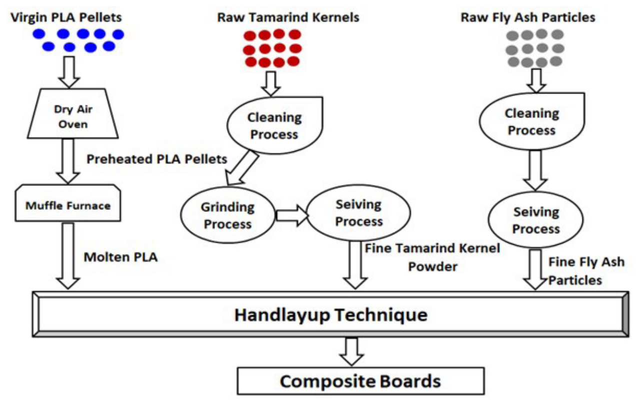

Figure 1: Schematic of composite preparation process.

Figure 2: Tensile test specimens.

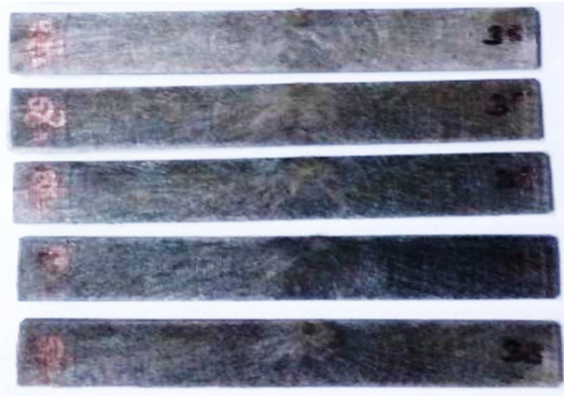

Figure 3: Flexural test specimens.

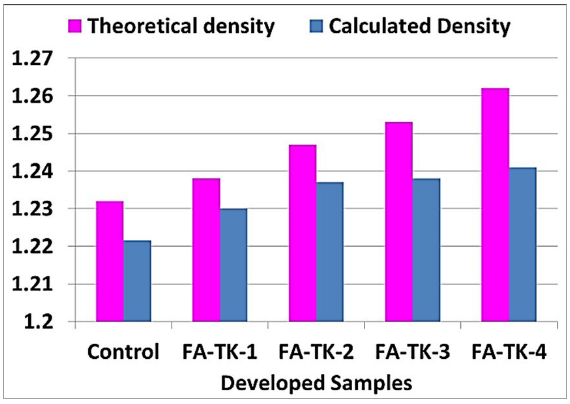

Figure 4: Density test results comparison of the composites.

were put to the test. The hardness attribute was evaluated by taking the mean value of four separate samples at the point of yield. The hardness was measured using a micro hardness tester and compared to the ASTM D 2240 specification. It is an indentation test in which the test material is indented on by a conical diamond. The specimen's surface resistance was then measured using the Vickers scale. After indenting at least four different sites on several specimens, the material's mean hardness value was calculated.

Results and Discussion

Examining the volume void content of composite materials allows one to gauge the degree of adhesion among the filler and matrix. Table 1 contains the results for neat matrix's volume void content, measured density, and theoretical and measured densities. All of the composite samples had void volume contents that were less than 4 wt.%. Less porosity is the consequence since it shows that the matrix and filler have high adhesive qualities. The inclusion of filler material raised the void content. The PLA composites with the largest void content were found to contain tamarind kernel filler at a 4% by weight concentration. In a composite made of 95 wt.% PLA, 1 wt.% fly ash, and 4 wt.% tamarind kernels, the maximum void content was 1.822% (Figure 4). The fillers may have clumped together and pulled out of the matrix as a bunch, which would explain the large increase in void content at higher filler content. It might have produced micro cavities and voids. As seen in figure 5 and figure 6, it has been discovered that adding fillers to the matrix improves its tensile qualities. Incorporating fly ash filler and tamarind kernel filler into the pristine PLA matrix boosted its tensile strength by 36%. The highest tensile property was attained at fly ash and tamarind kernel filler concentrations of 1 and 2 wt.%. In most

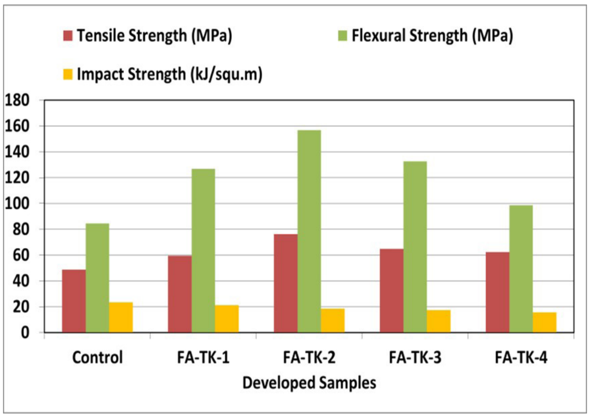

Figure 5: Comparison of tensile, flexural, and impact strength of the developed composites.

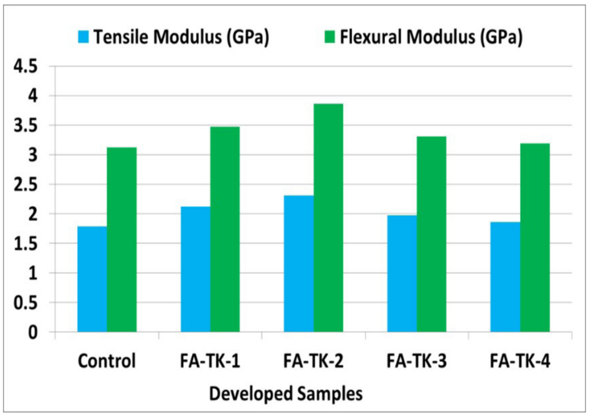

Figure 6: Comparison of tensile and flexural modulus of the developed composites.

Table 1: Density test results of developed composites.

Sample	Matrix (wt.%)	Fly ash (wt.%)	Tamarind kernel (wt.%)	Density (g/cm^3)		Void (%)
				Theoretical	Calculated	
Control	100	0	0	1.232	1.228	0.324675
FA-TK-1	98	1	1	1.238	1.230	0.646204
FA-TK-2	97	1	2	1.247	1.238	0.721732
FA-TK-3	96	1	3	1.253	1.236	1.356744
FA-TK-4	95	1	4	1.262	1.239	1.822504

cases, the inter-laminar region is responsible for determining the ultimate strength of composites containing fillers. High tensile characteristics can be attained because the use of fillers reinforces the matrix material in this area, which inhibits the onset of cracks [1]. Fly ash and tamarind kernel filler PLA composites had an elastic modulus that was up to 22.51% higher than that of clean polymer. The minor improvement in cellulose and hemicellulose content of tamarind kernel filler may have contributed to its higher elastic modulus value. Beyond that, the aggregation of fillers may have caused the tensile quality to degrade. Overall, the strong interfacial bonding has made it possible for stresses to go from the matrix to the fibre, increasing strength and stiffness. Figure 5 and figure 6 demonstrate how the neat matrix's increased flexural capabilities as a result of the inclusion of micro fillers. The neat polymer has a flexural strength of 84.52 MPa. The flexural strength of the fly ash and tamarind kernel filled PLA composite is almost two times more than that of plain PLA. The flexural strength of PLA has been improved by a factor of 1.5, thanks to the use of fly ash and tamarind kernel fillers. As a result of its large size, tamarind kernel filler efficiently fills the voids in the composites and increases their force resistance, allowing composites with 2% tamarind kernel filler to display the highest flexural property of all the filler composites tested. A concentration of 1 wt.% fly ash and 2 wt.% filler was used to attain the desired characteristic. The increase in flexural strength is evidence of the fillers' superior matrix absorption [14]. With the addition of fillers, the flexural modulus of plain PLA significantly increased as shown in figure 6. When PLA was filled with 2 wt.% of tamarind kernel fillers and 1 wt.% of fly ash, its flexural modulus improved by 19.17%. When compared to composite that also contained particle seed powder fillers, the PLA was shown to have higher impact strength (Figure 5). This might be because PLA is fragile at normal temperature. On the other hand, it was claimed that the reduced impact strength was caused by greater voids and worse interfacial adhesion among the filler and matrix, which led to specimens shattering earlier than they should have [15]. In this investigation, the composites with 1 wt.% fly ash and 4 wt.% tamarind kernel fillers displayed an impact strength that was approximately 26.65% lower than the plain PLA. Figure 7 depicts the microhardness trend of the PLA, fly ash, and tamarind kernel filler-based composites that were created. The neat polymer has a micro hardness of 17.51 HV. According to earlier investigations, filler loading and smaller filler particle size result in an increase in hardness [16]. According to earlier studies, adding fillers at a smaller size of 65 - 95 microns cause the PLA polymer's hardness to rise. The composite with 1 wt.% fly ash and 4 wt.% tamarind kernel fillers had a maximum micro hardness of 25.17 HV. But as fillers were added, the micro hardness of the PLA/fly ash/tamarind kernel composite kept rising.

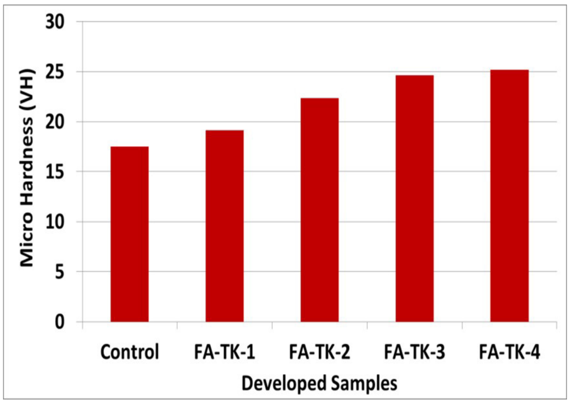

Figure 7: Variation on microhardness of the developed composites.

Conclusion

Compression molding was used to create composites made of PLA, fly ash, and tamarind kernels. Investigations into the mechanical behaviour of the composites in relation to various tamarind kernel filler concentrations were conducted. The particle composites had a filler concentration of no more than 4% when they were created and tested. The results of the experiment led to the following conclusions: The tensile test findings demonstrated that the PLA matrix's tensile strength was greatly improved due to the seed filler reinforcement. The composite made from PLA, fly ash, and tamarind kernel has a maximum tensile strength of 76.24 MPa. The flexural strength of PLA matrix was virtually doubled by the particle reinforcements of fly ash and tamarind kernel. The highest flexural strength of 156.68 MPa was achieved with a concentration of 1 wt.% fly ash and 2 wt.% tamarind kernel filler. In contrast to PLA's brittleness at room temperature, the impact strength of composites followed a distinct trend. When compared to neat particle reinforced PLA composite, the microhardness of the PLA/fly ash/tamarind kernel composite increased by 30.43%, whilst the pure PLA composite showed just minimal micro hardness. PLA/fly ash/tamarind kernel composite has inconsistently better mechanical properties than pure PLA. It might have been as a result of the PLA matrix's proper addition of fly ash and tamarind kernel particles. Because of the fillers' extraordinary ability to absorb matrix material, bio-composites made of PLA, fly ash, and tamarind kernel exhibit better mechanical performance. For applications involving mild and medium loads, the composite may be recommended. The composite composition can be further studied for usage in 3D printing applications because the used seed fillers were less than 95 m and the PLA matrix itself was the most widely used material in filament printing.

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None.

Conflict of Interest

The authors declare no conflict of interests that are relevant to the content of this article.

Credit Author Statement

Thangavel Palaniappan: Resources, Validation; Vignesh S: Investigation; Sureshkumar R: Funding acquisition; Gowrishankar A: Conceptualization; Girimurugan R: Writing - original draft preparation; Nanthakumar S: Methodology. All the authors read and approved the manuscript.

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