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Eggshell Particulate Reinforced Polymer Composite – A Review

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ABSTRACT

Due to their low loading bearing, high thermal stability, renewability, and cost-effectiveness, natural filler reinforced polymer composite plays a significant role in the production of biodegradable materials. In spite of the fact that eggshells are discarded as waste, eggs are a highly produced food all over the world. Due to its high calcium carbonate content, eggshell is a potential resource for the polymer industry. This research aims to advance our understanding of eggshell and eggshell particulate reinforced polymer composites. Both fabrication techniques and methods for treating eggshell particles are discussed. Then, the physical and mechanical properties of eggshell-polymer composites are review and presented.

1. Introduction

Particulate reinforced polymer composites are suitable for a variety of applications due to their low cost, favorable physicochemical and mechanical characteristics, simple processing, and positive relationship with the environment. [1]. This role of particulate reinforced polymer composites has paid the attention of researchers to develop biodegradable materials. Natural fillers consist of a series of substances: inorganic or organic, such as eggshell [2], rice husk [3], Fish Bone [4], lignin [5], bagasse [6], and many others. The disposal of inorganic or organic materials has become an environmental problem, causing a risk to public health and pollute the environment [7]. The inorganic or organic materials are reinforced in the form of particles with polymer composites to produce a novel composite having low density, high impact strength, high thermal stability, high specific stiffness, and electric conductivity [8–11]. This property makes natural fillers better suitable for the fabrication of thermoplastic composites rather than glass fiber and talc [12,13].

Natural filler parameters like filler loading [14], existence bio impurities, poor interfacial adhesion between filler-matrix, particle size and shape [15], hydrophilic, and poor dispersion [16] causes drawback in the corresponding composites. The above mention parameters can be reduced by treatments like sodium hydroxide (NaOH), stearic acid, silane, H_2O_2, and $Ca(OH)_2$ [17]; surface

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treatment [18], mechanochemistry treatment (ball milling) [19], and heat treatment [20]. The chemical treatment helps in uniform dispersion of particles, thereby increases mechanical properties [16]. The mechanical properties like tensile, flexural, and impact strength of the corresponding composites have been given more attention by researchers [21–26]. The researchers have utilized natural filler reinforced polymer composite for various applications like automobile [2], aerospace [17], biomedical [27], and leather industries.

An eggshell is a natural porous calcitic bioceramic [28]. The eggshell contains about 95% by weight of calcium carbonate ($CaCO_3$) in the form of calcite (inorganic material) [13] and 5% organic substances including proteins amino acid, type X collagen, and sulphated polysaccharides [7,9,29,30]. The calcium carbonate in the eggshell makes it durable, resists high temperature, and acts as a coupling agent [31,32]. Although the performance of the composites is not far too better, so the hybridization of eggshell particles with other integral materials like jute fiber [33], hemp fiber [20], coir fiber [34], glass fiber [35], fish bone [4], and others too [34,36–38].

Hence, the present review compiles the recent investigations related to the potential usage of eggshell wastes as a low-cost bio-filler for the fabrication of polymer composites. Moreover, this article aims toward the preparation, testing, and factor affecting the performance of composites. Besides that, the comparison between eggshell with other filler composites, application of eggshell-polymer composites, and future prospects was discussed.

2. Eggshell Composition and Characteristics

Eggshells possess a variety of advantageous qualities, including low density, low cost, high sorption capacity, low load-bearing, renewability, and availability [39,40]. For the development of the filler reinforced polymer composites, a better understanding of composition is required. In the following section, discuss the chemical and microstructural properties of eggshells.

2.1 Chemical Composition

An eggshell is a rich source of calcium carbonate [32]. Chemically, eggshells compose mainly calcium carbonate, magnesium, phosphorous, and organic matter as shown in Figure 1. It varies from 94 to 98.2% calcium carbonate, 0.2–1% magnesium, 0.3–1% phosphorous, 2-4% organic matter, and traces of carbon, zinc, manganese, iron, and copper [28,41–47] as shown in Figure 1. The variation in properties may be attributed from one eggshell to another, even within the same species.

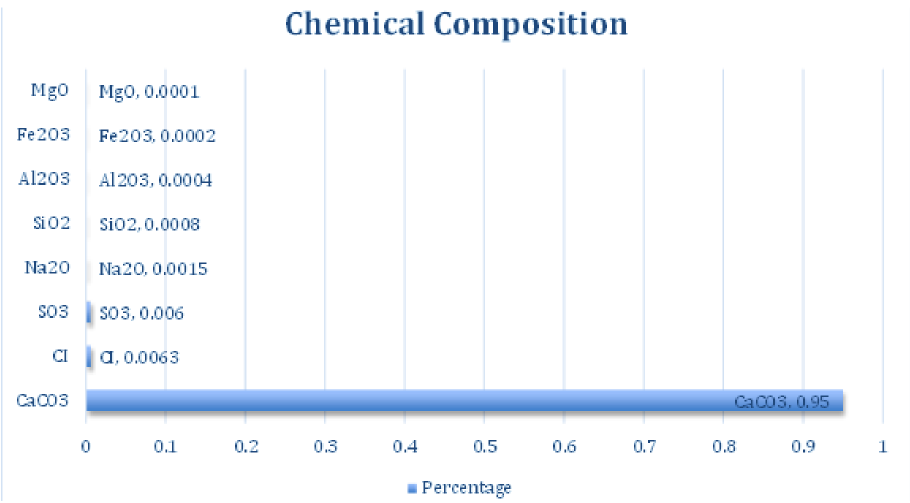

Fig. 1. Chemical Composition of Eggshell Powder

2.2 Microstructural Properties of Eggshell

For studying the microstructural characteristics, a scanning electron microscope (SEM) is employed. The palisade and mammillary knob layers, membranes, surface crystal layer, and cuticle are the layers of the eggshell that A.H. Parsons [48] studies. According to Hincke. M [49], the direction of the crystals has a significant impact on the mechanical characteristics of eggshells. Bio-impurities in an eggshell structure cause a lower adhesive between the filler and the matrix. Different chemical treatments are employed to address drawbacks [50]. An SEM image of the eggshell layers is shown in Figure 2 [48].

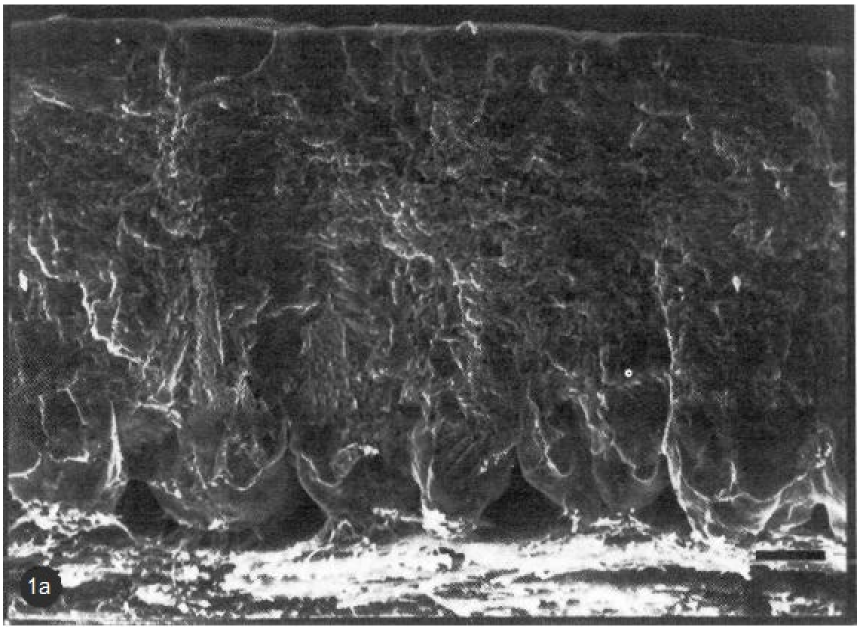

Fig. 2. SEM micrographs of the eggshell layer [118]

2.3 Functional Group Analysis of Eggshell

The functional groups of eggshell and eggshell particulate reinforced composites are examined using attenuated total reflectance-Fourier transform infra-red spectroscopy (ATR-FTIR). The FTIR analysis determines various functional groups of eggshell powder like calcium carbonate (CaCO3), carbonate (CO32-), carbonyls (C=O), hydrocarbon (C-H), water (H2O), and hydroxyl (OH) [41,51–55]. Figure 3 shows the FTIR result for eggshell powder. However, different treatments help in the formation of these functional groups and aids in reduction of hydroxyl [52,56].

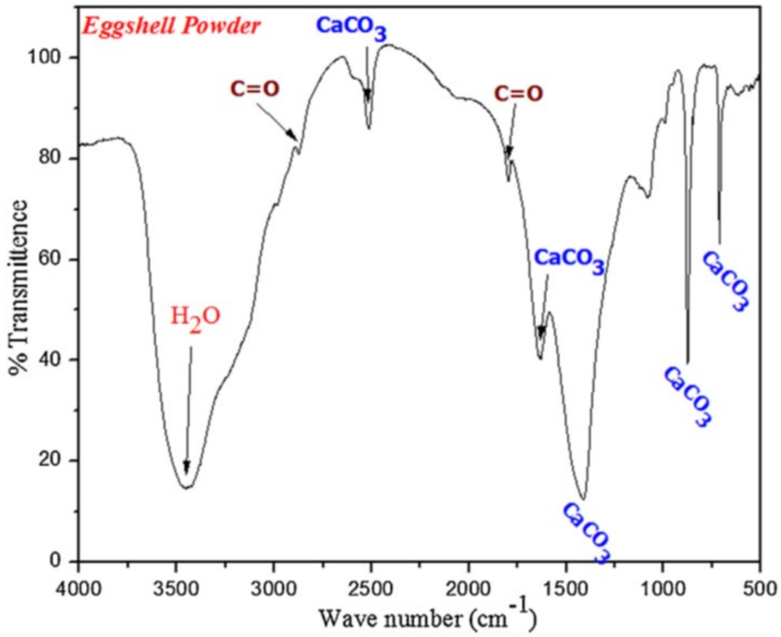

Fig. 3. FTIR spectrum of crushed eggshell powder [55]

Treatments for eggshell filler the raw eggshell particles are non-uniform in size and shape and consist of bio-impurities. This problem can be overcome through various treatments methods like surface treatments (stearic acid treatment), mechanochemistry (ball milling), chemical treatment methods, and coupling agent modification (Silane, Maleic Anhydride grafted copolymers, and Maleated Polypropylene), which helps in decreasing filler polarity and promotes effective filler-matrix bonding [15,33,50]. The following section discusses various treatment methods for modifying eggshell particle properties.

3. Surface Treatment

Stearic acid treatment is the most preferred by researchers for surface treatment of filler which can be noted from Table 1. This treatment shows various effects on fillers like Improving hydrophobic properties, dispersion and adhesion; Removal of bio-impurities; Formation of the small particle; No change in calcite phase; Increase in thermal stability and mechanical properties [41,50]. The following effects are observed using: Scanning Electron Microscope (SEM), Transmission Electron Microscopy (TEM), and Fourier Transform Infrared Spectroscopy (FTIR) [57,58]. Researchers have observed that the use of stearic acid helps in modifying the properties of eggshell particles which leads to better performance of corresponding composites [8,41,50,59–62]. While other researchers have noted that, the stearic acid treatment causes the area of hydroxyl (–OH) to broaden [41,62,63]. Ghabeer [18] studies the mechanical and thermal properties of TES-PP. The result indicates that the stearic acid (6wt.%) treated filler has higher impact resistance; an increase in filler concentration effects composite strength. In a similar experiment, Mohammad [58] treated eggshell powder with stearic acid (8wt.%); shows better properties and filler–polymer interaction at low contents. While Rafah Nasif [64] examines the behavior of three different solutions (7% NaOH, 1% silane, and stearic acid) on the properties of ESP-unsaturated polyester (UP) composites. It was concluded that stearic acid-treated ESP-UP shows a higher value of impact strength than any of the treatments.

3.1 Mechanochemistry treatment (Ball milling)

Mechanochemistry makes use of mechanical energy to control chemical reactions [65]. Ball milling working is based on mechanochemistry. It is used to mill various materials to nano or micrometers of uniform size. It enhances the potential application of natural materials to a novel level [19]. FTIR analysis of eggshell particles states that the calcite crystalline structure is thermodynamically stable, which is similar to calcium carbonate [66]. While SEM observation stated that eggshell particles are uniformly dispersed along the gain boundaries of the composites [67]. It was reported by Mohan and Kanny [15] that ball milling help in obtaining nearly uniform size and shape of the particles which increases mechanical and water barrier properties. In a similar experiment, Rahman [68] stated that using ball milling and ultra-sonication, there is better dispersion of nano eggshell powder in soy proteins, due to high crystallinity, and surface area. Mohan and Rahman [15,68] have concluded that higher filler content in composite has effects on its properties.

3.2 Chemical Treatment

The hydrophilic feature of eggshell, and hydrophobic characteristics of the polymer matrix, causes the effect on the properties of composites [18,21,23,68,69]. To reduce the hydrophilic feature of eggshell particles, the eggshell particles are chemically treated. The chemical treatment helps in improving the physical properties of a composite simply by improving dispersion and adhesion of the filler and polymer matrix. FITR analysis stated that the chemically treated filler surface forms various reactive groups enable effective grouping with the matrix [41]. The formation of reactive groups reduces free hydroxyl (-OH) of filler which improves the mechanical properties of the composite and removes bio-impurities [50,52]. Table 1 represents the various chemical technics and their effect on eggshell particles.

Table 1
Chemical Treatments Treatment effect

Chemical Treatments	Treatment effect	Reference
Sodium chloride treatment	Remove the layer of membrane on the inner wall.	[106,119]
NaOH treatment	Dissolve the membranes and exposed porous areas. This helps in better interfacial adhesion	[41,68]
Water treatment	The outer layer is clearly removed from the surface of eggshell and surface becomes porous	[120–122]

3.3 Coupling Agents

The coupling agents like Silane [70], titanate [23], polyvinylchloride-maleic anhydride (PVC-MA) [21], 3-aminopropyltriethoxysilane (APTES) [71], Maleic Anhydride grafted copolymers (MAPP) [9], and many others are used to give rise to the insufficient coupling between the inorganic and organic components. The above coupling agents are combined with filler treatments to improve composites parameters. Ahmed Hassen [9] uses MAPP as a coupling agent to enhance mechanical properties (impact strength) and thermal stability. Watcharin [72] investigates the effects of silane coupling agent [titanium (IV) isopropoxide and 3-(trimethoxysilyl) propyl methacrylate] on the mechanical, morphological, and thermal properties of eggshell/Sugarcane bagasse-linear low-density polyethylene (LLDP) composites. The usage of coupling agents considerably affects the physical and thermal properties of the resulting composites [70,73]. It also helps in the formation of various functional groups.

4. Preparation of eggshell particulate-polymer composites

A flow chart (Figure 4) represents information on the preparation of eggshell particulate-polymer composites. There are many methods for the preparation of a composite. The commonly used methods are open moulding (hand lay-up) [74], Compression moulding [75], and Film-casting method [76]. Besides, the above-described methods are conventional too. In the following section, a summary of the above-listed methods is provided as preferred by researchers (Table 2).

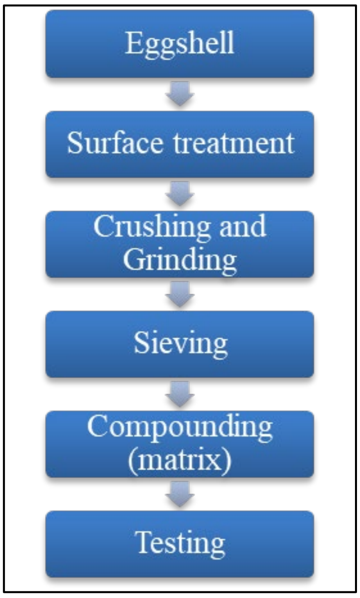

Fig. 4. Flow chart of eggshell composite preparation

Table 1
Treatments and Preparation of eggshell-polymer composites

Filler/matrix	Treatment	Fabrication Process	Reference
Eggshell (ES)/Polypropylene (PP)	Acetone for 2 h and Stearic acid	An intellitorque mixer with roller blades	[123]
Eggshell (ES)/Polypropylene (PP)	Water and ethanol (3:1) for 2 h, stearic acid 6 wt.%, and ball milling	A co-rotational twin screw extruder	[18]
Eggshell (ES)/Epoxy	Water (200ºC)	Hand lay-up technique	[120]
Eggshell (ES)/Propylene carbonate (PPC)	Distilled water and chloroform (10wt.%)	Film-casting method	[89]
Eggshell (ES) /Poly (lactic acid)	Water and chloroform (10wt.%)	Film-casting method	[76]
Nanoeggshell (NES)/Epoxy	Ball milling	Resin casting method	[15]
Eggshell (ES)/bone ash (BA)/Gelatin(G)	Distilled water	Extrusion	[121]
Eggshell (ES)/E-Glass fibre/Epoxy	Sodium chloride (70ºC) and ball milling	Hand lay-up technique	[119]
Eggshell (ES)/Sisal fiber/Epoxy	Heat treatment and ball milling	Hand lay-up technique	[124]
Eggshell (ES)/Glass fibre/Epoxy	Water (60ºC)	Hand lay-up technique	[122]
Eggshell (ES) /Poly (lactic acid)	Deionized water and ball milling	Cold compression moulding	[85]
Eggshell (ES)/BFF fibres/ Isophthalic polyester	Sodium chloride solution (3.5%) for 6 h, heat treatment, and ball milling	Hand-layup and compression moulding	[106]
Eggshell (ES)/E-Glass fibre/Epoxy	-	Hand lay-up technique	[125]

4.1 Open Moulding

Open moulding is the oldest, most used, and one-sided mould method for the fabrication of composite. In the fabrication process, the resin is poured into a mould or applied to the surface, the fabric is rolled into the resin, then curing is done at room temperature, and finally, normal pressure is applied as shown in Figure 5. It is useful for thermoset composite products and other composite products. It has merits when the product size and shape do not matter and can be fabricated with the help of simple equipment [77]. However, the process has demerits such as high labour intensity, poor working conditions, and low efficiency.

For the fabrication of composites through open moulding, a hand lay-up or spray-up technique is applied. [78]. The hand lay-up is the most preferred process. It is also known as the contact lay-up process. It is a low pressure contacting and forming process performed by hands. The auxiliary work can be complete using equipment and tools. The hand lay-up technique is simple, easy to learn, and relatively inexpensive. Here, the worker's functioning skill creates difficulties in product quality. Although, the product structure is inferior to those products prepared by other processes [79,80].

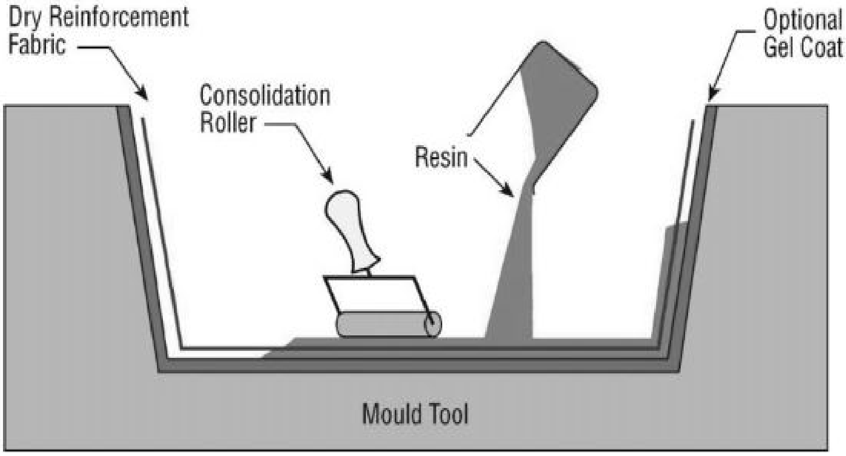

Fig. 5. Open moulding (hand lay-up process) [78]

4.2 Compression Moulding

Compression molding is an old, high pressure, and high-volume method for thermoset materials that employ expensive but very durable metal dies as shown in Figure 6. During the process matrix or resin and reinforced material (powder or fibers) is placed in a metal die at a specified temperature and pressure, making the composite plastic for obtaining die impression. Curing of the composite is carried out either, at room temperature or the specified temperature. It has an advantage such as low cost, high volume, highly accurate product, easy to fabricate complex shapes. It also has disadvantages such as more equipment is needed, a costlier process than hand lay-up molds [81–84]. This process is implemented in the manufacturing of eggshell filled composite by various researchers [85,86].

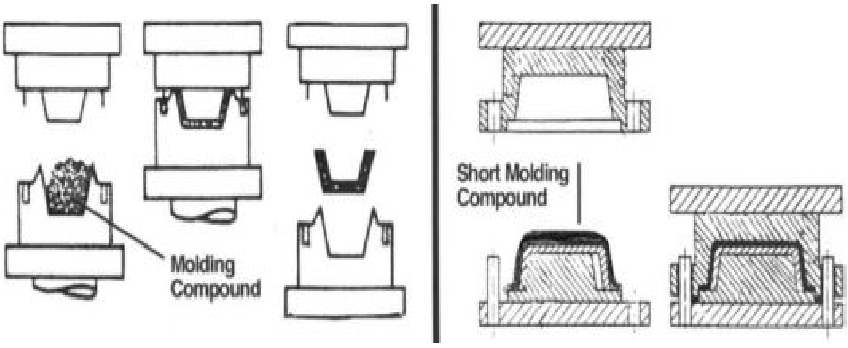

Fig. 6. Compression moulding [82]

4.3 Film-Casting Method

Film casting is very similar to fiber spinning. The film casting process involves extrusion of polymeric material through a rectangle die or slit and, then the film obtain is took up at the chill roll as shown in Figure 7. A film can be cast from a dilute solution, depending on the property of polymer (polyester, polyimide, or fluoropolymer wed) [87]. The film casting process has the merit of permitting composite constructions, and demerits of poor economics, which prevents the extensive use and approval of this manufacturing technique [88]. This technology is preferred by researchers for the fabrication of eggshell filler reinforced polymer composites [76,89–91].

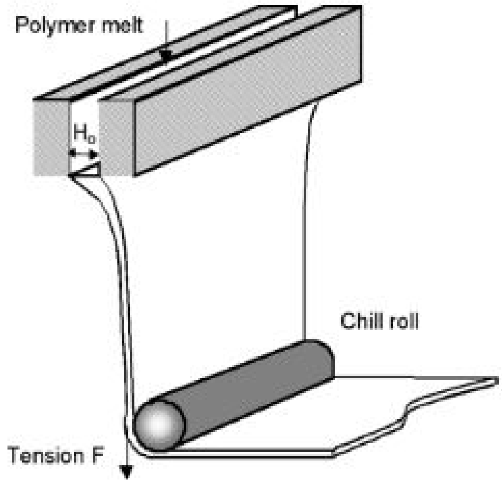

Fig. 7. Film-casting process [88]

5. Characteristics of Eggshell Filler-Composites

The mechanical properties test is conducted base on American Standard Testing Methods (ASTM) such as ASTM D638 (tensile strength test), ASTM D790 (flexural strength test), and ASTM D265-88 (impact strength test) [9,18]. The tabulation of the mechanical properties of eggshell particulate-polymer composites is represented in Table 3. The table represents that the filler parameters like particle size and shape, filler loading, bulk volume, density, and surface impurities; the matrix parameters like viscosity, density, and temperature; affects the mechanical properties of eggshell particulate reinforced polymer composites [4,25,92]. The above mention effects in the eggshell particles can be reduced by various treatments elucidated in section 3.0 [9,15,19,23,51,68,71].

Table 3

Composite	Filler loading (wt %)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at break (%)	Flexural Strength (MPa)	Impact Strength (kj/m^2)	Ref.
ES-coir-Polyster	70	16.76	0.016	0.688	53.25	9.59	[24]
PE-ES-Sil	20	16.9 ± 0.3	0.402 ± 0.0215	17.4 ± 0.1	24.8 ± 1.2	0.16 ± 0.3	[23]
NES-Epoxy	2	53.79 ± 3	3.61 ± 0.31	1.49±0.07	-	0.75 ± 0.06	[15]
SS-ES-epoxy	10	70	6.9	-	-	2.25	[25]
PLA-NR-ES	3	21.5	0.75	0.05	-	2.1	[126]
ESP-RPS-PS	20	24.5	2.94	1.2	-	31.5	[127]
ES-BFF-Polyster	2	45.75	-	-	52.76	16.89	[106]
CES-Epoxy	10	17	-	-	40	6.3	[128]
LDPE–ESP-PEMAH	10	11.7	0.23	110	-	-	[129]
ES-Epoxy	16	47	-	4.9	96	167	[108]
ES-PP	30	28	-	10	1816	112.82	[130]
ES-Rice husk-coir-Polyester	15	31.5	-	-	33	43.5	[131]
ES-Epoxy	20	52	8.16	-	-	1.74	[25]

5.2 Structural Properties

Structural analysis of composites is commonly carried out using a Scanning Electron Microscope (SEM) and Field Emission Scanning Electron Microscopy (FESEM) [93,94]. The structural analysis reported that treated filler show better interfacial adhesion with matrix due to homogeneous dispersion, results in superior mechanical properties [8,19]. While untreated filler tends to agglomerate (voids) due to non-uniform particles size and shape, causing stress concentration, and reduces tensile strength [95]. Ahmer Hussain Shah [41] observed that the stearic acid (SA) treated eggshell particles shows uniform size and shape, reduces agglomeration in composites; removal of bio-impurities and gummy surface; and modify the surface roughness of composite. Figure 8 is the image of Eggshell particles dispersed in the PP matrix while Figure 9 is the image of treated eggshell particles. Krishnan [96] reports that the use of micro-size particles helps in achieving uniform stress transfer between filler and matrix. Moreover, chemical modification aids in uniform dispersion as well as the effective size reduction of eggshell particles within polymers. However, Mohan [15] concluded that nanoparticles possess a higher surface area in comparison to micro fillers and the inter-particle adhesion was much stronger.

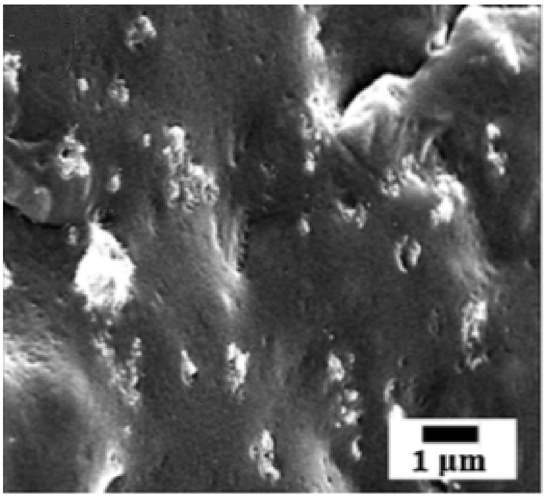

Fig. 8. FE-SEM image of ES particles dispersed in the PP matrix [96]

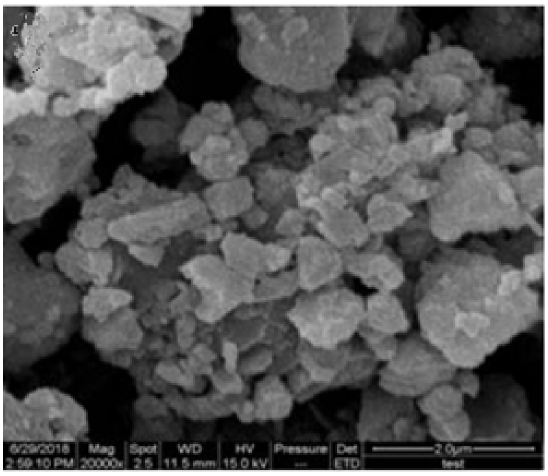

Fig. 9 Morphological images of treated eggshell particles [41]

5.3 Thermal Properties

Thermal properties of bio-filler composites are determined using two major tools such as Thermo-gravimetric analysis (TGA) and Differential Scanning Calorimetry (DSC) [18,97]. Wajid Hamid [98] studies the thermal stability of epoxy/4wt.% ES and neat epoxy composite. It is noted that at the higher temperature (400–600 °C) epoxy/ES losses thermal stability due to the decomposition of eggshell powder. Epoxy/4% ES holds good thermal stability up to 3500C. Ahmer Shah [41] makes use of Thermo-gravimetric analysis (TGA) to study the effect of stearic acid-treated eggshell particles in the epoxy composite. The analyzer report concluded that as the loading of TES particles increases, the initial degradation temperature of the composite gets to improve.

5.4 Water Absorption Property

Water absorption is the capacity of a composite to absorb water under specific conditions [77]. ASTM D570-98 standards are used for performing water absorption tests [99]. The water absorption of a composite depends on particle size, lumens, fine pores, the matrix used, hydrogen bonding sites, surface area, and length of exposure [100,101]. Hydrophilic property of nanoparticles and uniform distribution of particles lead towards high water absorption of a composite [21,102]. To reduce such causes eggshell particles are chemically treated results in the reduction of free hydroxyl (-OH) [52].

A water absorption test was conducted by Abdullah [16] to observe the behavior of ES-polyethylene composites (up to 25 wt.% filler loading) when exposing to water. It was concluded that, because of difficulty in achieving uniform dispersion of filler with matrix or resin, there’s an increased formation of agglomerations with an increase in filler content. While S. M. Mousavi [52] concluded that the presence of eggshell nanoparticles in Polypropylene can increase water adsorption. Farahani *et al.,* [21] studies water absorption characteristics of rHDPE/EVA/ESP and rHDPE/EVA/ESPPVC-MA composites at room temperature. The study revealed that TES has fewer hydroxyl group which helps in the lower water absorption rate. While for UES the rate of water absorption increased with an increase in filler loading. A very familiar study by Siti and Supri [103] discusses the water intake properties of LDPE-ESP composites. The author reports that the treatment of ES reduces the number of free hydroxyl groups and better interfacial strength, result in a low rate of the water absorption of the composite. The TES composites show lower water intake capacity than UES composites.

6. Factor Affecting Properties of Eggshell-Polymer Composite

The parameters like properties of matrix or resin, filler loading, chemical treatments, processing methods, homogeneous dispersion of the filler, and interfacial adhesion between filler and matrix govern the properties of composites [104]. These parameters are varied by researchers to study their influence on the physical, morphological, mechanical, and thermal properties of eggshell-polymer composites. A fishbone diagram is shown below (Figure 10) studies the factors like matrix properties, surface treatment, filler loading, and particle size. An enhancement of these parameters mostly results in an optimum effect on the characteristics of the composites.

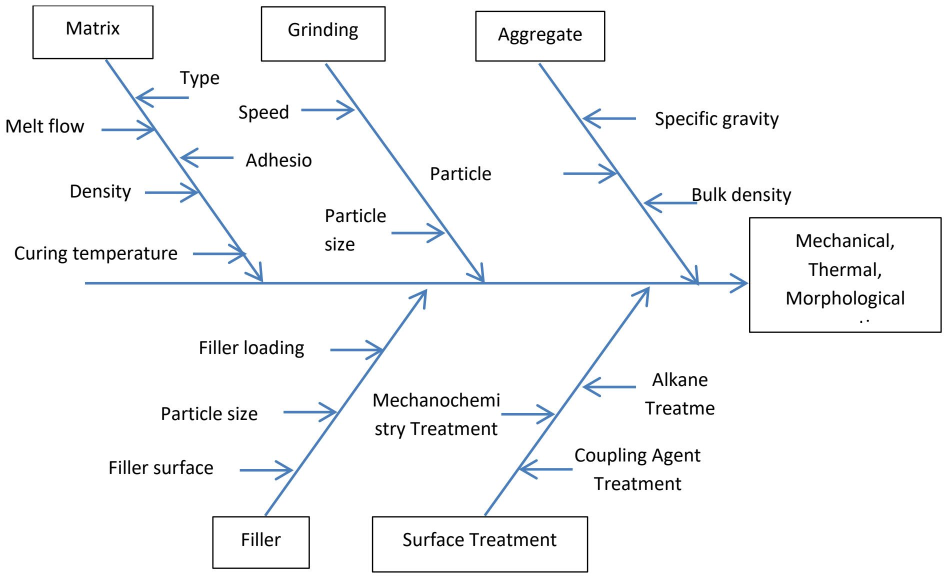

Fig. 10. Fishbone Diagram of eggshell reinforced polymer composites

The eggshell particle size and shape cause' effect on the mechanical properties of eggshell filler reinforced polymer composite. For that purpose, Hassan [105] noted that the low density of carbonized (heat-treated) eggshell filler helps in achieving better mechanical properties of the composite. Filler density also has a proportional effect on the particle size as well as on the interfacial adhesion of composites. Hence, filler density also plays an important role in mechanical properties. Anil, Suhas [106] observed that sodium chloride treated and carbonized eggshell fillers with low filler loading resulted in the high interfacial adhesive which tends towards the increase in composite properties.

7. Natural Filler Epoxy Composites

The following section provides a comparison of mechanical properties (tensile, flexural, and impact strength) between eggshell filler and other natural fillers reinforced epoxy composites. Epoxy resin-based composites were selected because of their popularity in this review with regards to eggshell filler and others to [15,24–26,107–111]. The mechanical properties of eggshell filler epoxy composites are equated with epoxy reinforced with cocoa-pod [26], snail shell [25], rice husk [111], goat bone [110], hazelnut shell, sunflower husk, and walnut shell [109] filler. For better comparison of the properties, untreated or unmodified filler reinforced epoxy composites were selected.

The tensile strength of natural filler-epoxy composites can be noted from the Figure 11 with snail shell (SS)-epoxy composite having higher tensile strength because of the large volume of carbon in SS. Figure 12 shows the flexural properties of eggshell-epoxy composites that were seen to be intermediate. Although, Figure 13 indicates the impact property of eggshell-epoxy composites which were relatively lower when compared with sunflower husk, hazelnut shell, and walnut shell. However, eggshell fillers show's better mechanical properties than other fillers taken into account. Composite with 5% Egg Shell and 5% Rice Husk powder had higher tensile strength and flexural strength. The results also showed that composite with 5% Egg Shell and 5% Rice Husk powder has a better surface–property relationship than other composites. [132]. The addition of 9% Powder Eggshell bio-filler increased tensile characteristics, flexural strength, and Shore D hardness. The inclusion of PES above 9% in Jute Fiber epoxy composite was not impressive and hence, it is recommended to use 9% Egg Shell Powder in Jute fibre /Egg Shell Powder Epoxy hybrid composites. [133].

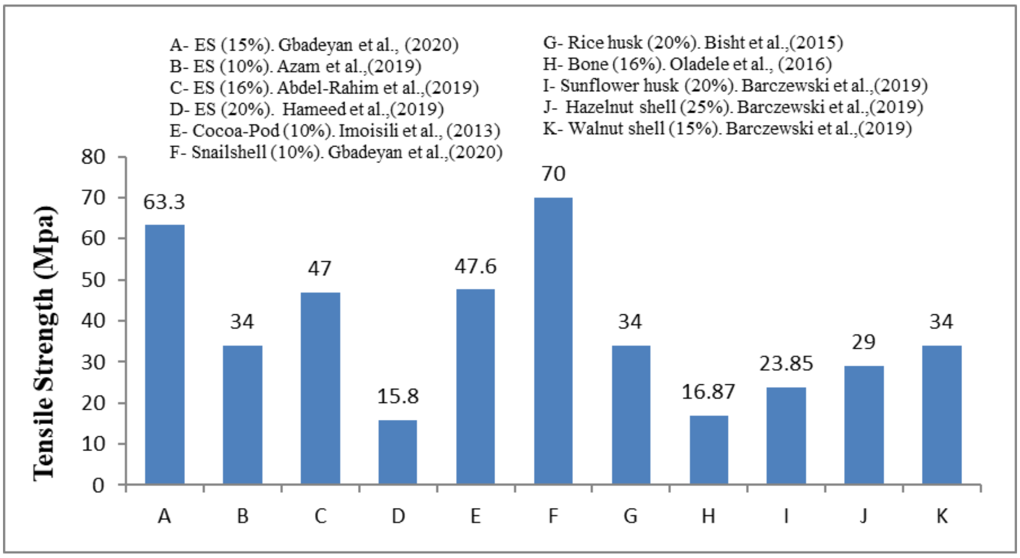

Fig. 11. Tensile Strength of different filler reinforced Epoxy Composites

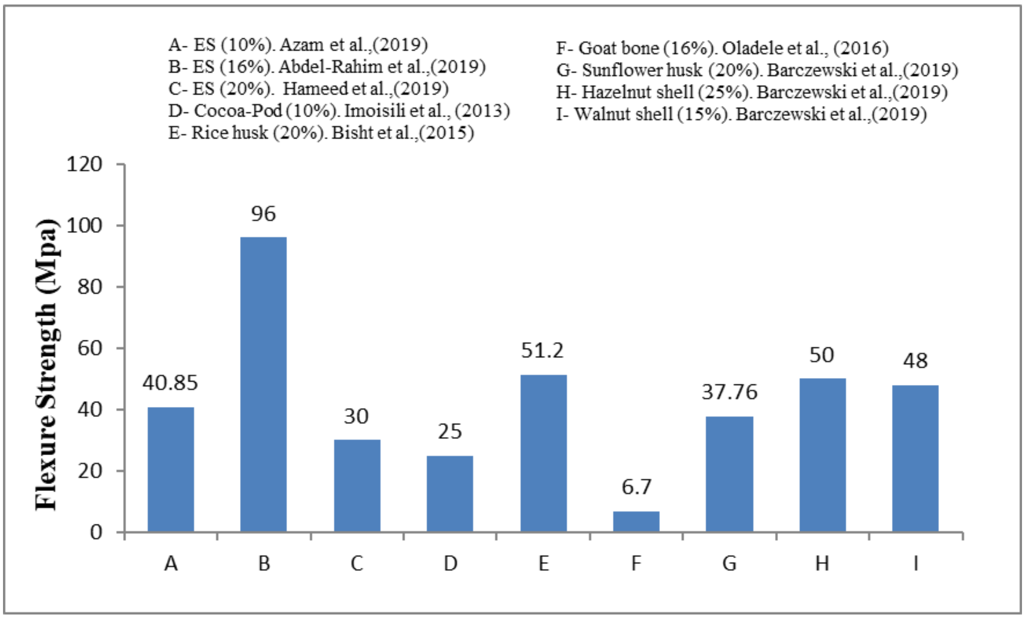

Fig. 12. Flexure Strength of different filler reinforced Epoxy Composites

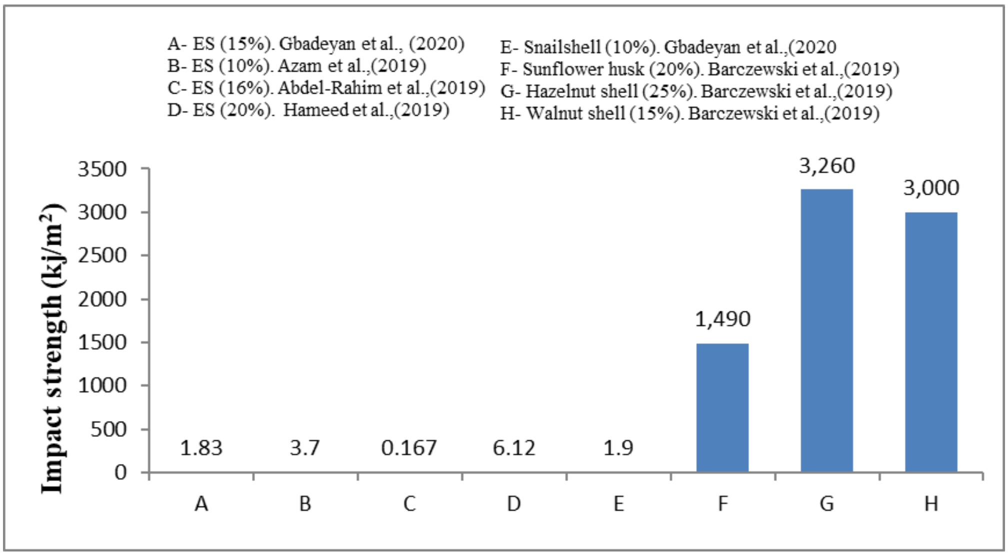

Fig. 13. Impact Strength of different filler reinforced Epoxy Composites

8. Applications of Hybrid Bio-Derived Composite Materials

Natural Filler Composites can be applied in various industries like decoration, packaging, and furnishings [112]. The natural filler-polymer composites were also used extensively in the defense industry, furniture industry, automotive industry, space industry, aerospace industry, building, leather industry, and sports material [57]. Eggshell filler composites have been used by researchers in the preparation of artificial rock [113], drone frame [6], Shield against beta radiation and gamma [114], guayule rubber [73], and concrete [115]. The use of eggshell-polymer composites also focuses on the application like thermal insulation and film for packaging purpose [91,98]. Pedro [116] develops composite from bio-hydroxyapatite derived from eggshells as filler and PLA as the matrix for the biomedical application. Dinesh [117] studies the behavior of Eggshell-Kevlar-Coir-Epoxy composites for marine application. For the water absorption test, three samples of the composite were soaked in water for 80 days. The result shows that Eggshell-Kevlar-Coir-Epoxy composite has higher mechanical properties and can be used as a pump for marine application. While eggshell filler loading affects water absorption property but it can be lower by adding more percentage of coir fibers. Based on the results of LOI, cone calorimeter, smoke density test, and TG analysis of ES reinforced epoxy and polyamide composite [53] suggested that a mixture of 5 wt.% ES, 40wt.% epoxy, 20wt.% polyamide, and 35wt.% intumescent flame retardant (IFR) gives an optimal composite coating for smoke suppression application. Advancements in natural fibers reinforced polylactic acid (PLA) composites, emphasizing PLA's biodegradability and environmental benefits. PLA, derived from renewable sources, degrades easily, mitigating pollution from petrochemical plastics, making it a promising material for various applications [134]. Emphasis is placed on transitioning to green chemistry and production methods, utilizing biopolymers derived from natural sources to mitigate environmental impact. Utilizing biopolymers as binders in eco-friendly composites, highlighting their potential to address environmental concerns in material manufacturing [135]. Gypsum and Kapok fiber composite as an effective material for fire-resistant doors in areas like entrances and staircases, demonstrating its ability to withstand fire for 30 to 60 minutes. Furthermore, the analysis underscores the importance of door thickness in determining the fire resistance rating, providing valuable insights for designing and manufacturing fire-resistant doors [136]. Notched flax fiber composites exhibit lower flexural strength compared to un-notched ones, suggesting that the presence of notches weakens the material. Additionally, the study reveals that smaller notched diameters result in higher flexural strength compared to larger ones, implying a correlation between notch size and material performance. Overall, the research underscores the significant impact of notch size on the flexural strength of flax fiber composites, providing valuable insights for designing and optimizing such materials for various applications [137]. Natural fiber-based epoxy composites, specifically focusing on integrating kenaf fiber reinforcement with epoxy matrix using a high-speed mechanical stirrer apparatus from the early stages of production [138].

9. Future Prospective

Tables 2-3, stated that the researchers prefer epoxy resin and polypropylene (PP) matrix for fabricating eggshell-polymer composites. Though, matrix/resin like Polylactic acid (PLA), polyester, polyethylene, and natural rubber were also used. Besides, the utilization of matrix/resin like gelatin, polystyrene (PS), ethylene vinyl acetate, and vinyl esters are not satisfactorily studied. The dynamic characteristics of the eggshell particulate reinforced polymer composites needed attention. This characteristic makes eggshell- polymer composites suitable for shock absorption application. There's no registration on the effect of concentration of coupling agent for eggshell particles (within the author's scope).

10. Concluded Remarks

This work makes an effort to discuss the use of eggshells as a reinforced material for polymer composites. Eggshell properties like chemical and microstructural, besides those of composites: mechanical, thermal, structural, and water absorption properties were also discussed. These properties can be modified by various filler treatment methods. The widely used treatment method was ball milling, stearic acid treatment, and water treatment. Researchers prefer using the matrix: epoxy and polypropylene; the preparation method: hand lay-up (contact lay-up) technique for fabricating eggshell particulate reinforced polymer composites. The particle size and shape, filler loading, and matrix density show an effect on the mechanical characteristics of eggshell composites. SEM analyses stated that the usage of treatment reduced the size of eggshell particles to a greater extent resulting in good dispersion of eggshell particles in polymer composite. The presence of crystalline calcite in ES results in attaining higher thermal stability of eggshell-polymer composite with the increase in filler content. Based on the experimental analysis, the treated eggshell-polymer composites are less subject to high water absorption than the untreated ones because of the reduction in free hydroxyl (-OH) through treatment. The eggshell-polymer composites are applicable for various applications like a shield against beta and gamma radiation, thermal insulation, smoke suppression, and artificial rock. Prospects like dynamic properties and chemical treatments need more insights.

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