Polymer Bulletin (2023) 80:931–957
https://doi.org/10.1007/s00289-021-04049-2

ORIGINAL PAPER

Fabrication and characterization of jute/cotton bio-composites reinforced with eggshell particles

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Received: 8 May 2021 / Revised: 7 December 2021 / Accepted: 21 December 2021 / Published online: 31 January 2022

Abstract
Natural fibers and reinforcing elements are gaining attention from academicians and researchers to be utilized as the reinforcements in composites because of their environment friendly nature and sustainability. The aim of this study is to characterize and analyze the influence of eggshell particles on the mechanical, morphological and thermal properties of jute/cotton fiber reinforced epoxy composites. Composites were analyzed using UTM, SEM, XRD, UV, FTIR, and surface topology (2D and 3D). These experimental results show that addition of more eggshell particles increases the tensile strength but reduces the bending strength. Good thermal stability (300 °C) is obtained for the Jute/cotton/jute/cotton (JCJC) eggshell composites. SEM images confirmed the reinforcement of fibers in resins. FTIR data shows the presence of different active bands in JCJC eggshell composites. EDS analysis reveals the percentage of different compounds present in the composites. Absorption peaks are visualized by UV analysis in composites. The jute/cotton fiber reinforced epoxy composite without eggshell particles are also investigated for better understanding when eggshell particles are available. The findings experimentally prove that the produced composite can be used as an alternative to traditional materials. Beside this, the results of this study would be a noteworthy contribution for designing high performance bio-based composites over synthetic materials in numerous applications such as household products, vessels, and even in the aerospace industry.

Keywords Jute/cotton fibers · Eggshell particles · Mechanical properties · Characterization · Surface morphology · Thermal properties

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Introduction

Rapid growth in industries has led to the need for the advancement of materials in terms of strength, toughness, density, strength, stiffness, and lower cost with sustainability. Composites have appeared as one of the materials possessing such properties serving their potential in diverse applications [1–4]. Composite material is a composition of two or more constituents, one of which is called matrix phase, and another one could be in fiber or particle form also called reinforcing phase. Composite also contains other materials such as fillers, diluents, pigments, additives, hardener, etc. The exploitation of synthetic or natural fibers in the construction of composites has revealed significant applications in a variety of fields such as automobile, aerospace, construction, mechanical, marine, and biomedical applications [5–8].

Many researches show that composites could be an alternative over many monolithic materials as there is a momentous augmentation in the mechanical and tribological properties of fiber-reinforced composite materials [9–11]. Though composite materials pursued in increasing the durability of the material, at present a strong concern for the researcher regarding the collection of plastic waste in the environment has flourished [12]. This suspense has obliged researchers around the world to reveal environment friendly materials [13, 14]. Natural fiber-based composite materials in the polymer matrix could be an eco-friendly, alternative to plastic material. Improved mechanical properties of natural fiber-based composites can minimize the issue regarding environmental concerns [15–17].

At present, researchers are trying to contribute to the fabrication of hybrid composite materials with the combination of synthetic and natural fibers. There are various methods to incorporate these fibers such as the intermingling fibers, stacking layers of fibers, mixing two types of fibers in the same layer fabricating hybrid composites, selective allocation of fibers where it is utilized for better force, and allocating each fiber according to specific orientation [18]. Many researches indicate that hybrid composite material can improve mechanical properties of the composite and reduce the limitations of fibers [19]. Experiments also proved that hybridization not only improves strength-weight ratio and mechanical properties but reduces cost of products [20].

In recent years, the increase of environmental consciousness is reflected in the need of materials which have less or zero environmental impact and damage and need to attempt to replace synthetic materials or polymers [21]. Inevitably, the development of green composites has been receiving a great attention of researchers and seeking a new alternative which is capable to meet mechanical properties as same as or over synthetic polymer matrix materials and low cost with recyclability and renewability. Natural fibers which promote eco-friendly could be durable solutions to resolve this issue and alternative to synthetic fiber reinforced composites in various applications such as automotive, furniture, and household industry. The automotive market immensely increased the use of natural fiber reinforced composites to reduce the manufacturing costs and increase weight reductions which results in energy saving [22].

Chicken eggshell as an agriculture by-product has been identified as one of the worst environmental impacts on earth, especially in countries such as the USA, Bangladesh, and India in where the egg product industry is well established. Eggshell powder has been widely used as soil conditioner and fertilizer [23] with the absorbent of the sorption site of CO_2 [24] and heavy metals [25]. Recently, researchers show a great interest of using spent eggshell powder which is employed as are enforced bio-filler materials in several polymer matrixes including PP [26], low density polyethylene (LDPE) [27], high density polyethylene (HDPE) [28]. Literature showed that eggshell powder can be utilized in metal matrix composites due to the presence of less dense calcium carbonate for improving tri-biological and other properties [29, 30].

Most of the studies investigated the mechanical and other properties of composites using eggshell powder in different natural and man-made fiber. However, to our best knowledge, there are very limited studies on the analysis of jute and cotton fibers composites using eggshell powder which can be an effective alternative to the conventional materials. Moreover, very limited characterization techniques were utilized. Therefore, this investigation is triggered to characterize and analyze the properties such as SEM, XRD, UV, FTIR, surface morphology, tensile strength, compressive strength, bending strength of eggshell particles incorporated jute cotton fibers reinforced epoxy composites to find out mechanical and morphological characteristics of the hybrid composites. The jute/cotton fiber reinforced epoxy without eggshell particles are also analyzed for realizing the presence of eggshell particle in same type of composite.

Experimental details

Materials

Jute cotton fibers were collected locally available in Bangladesh and washed properly by acetone and then dried. Eggshell particles were fabricated in the laboratory.

Eggshell particles

Chicken eggshell is an agriculture byproduct that has been listed worldwide as one of the worst environmental impacts, especially in those countries where the egg product industry is well developed such as the USA, Bangladesh, and India. Eggshell powder has been widely used as soil conditioner and fertilizer [23] with the absorbent of the sorption site of CO_2 [24, 31] and heavy metals [25]. Recently, researchers show a great interest in using eggshell powder which is employed as biofiller materials in several polymer matrices including high density polyethylene (HDPE) [26], low density polyethylene (LDPE) [27], PP [28]. However, the industrial consumption of eggshell persistence is limited. According to the literature, eggshell contributes 11% of the total weight of the egg with its primary component being the calcite form of calcium carbonate crystal (~94%). Other elements of eggshell include $MgCO_3$ (~1%), $Ca_3(PO_4)2$ (~1%), and organic matter (~4%) [32]. This abundance of calcium carbonate ($CaCO_3$) in the waste eggshell introduces a prominent source of bio-mineral $CaCO_3$ with possible opportunities to replace mineral-based and synthetic $CaCO_3$ in polymer composites.

Cotton fibers

Cotton fiber is one of the most versatile textile fibers and consists of about 90–93% cellulose belonging to the genus Gossypium, subtribe Hibisceae family Malvacea. Cellulose is demonstrated in long chains of molecules united to each other by hydrogen bonds, forming a spiral of this fiber. This arrangement provides high tensile strength and dimensional stability to the fiber. Some interesting properties of the cotton fiber are its low density compared to fiberglass high crystallinity and high impact resistance over synthetic fibers [33]. Cotton fiber has extraordinary properties as it has biodegradability, high strength, durability and absorbency [34]. The interfacial adhesion between the composite phases is extremely important and, if not satisfactory, it will not transfer the stresses from the matrix to the fiber, compromising the composite mechanical performance [35]. Green composites such as cotton fibers may resolve this issue because it has the ability of high moisture absorbance.

Jute fibers

Jute is the natural and second most biodegradable fiber [36] and that's why it is an eco-friendly fiber and recyclable. It belongs to *Tiliaceae* family with nearly 30–40 *Capsularis* species of jute. In the present era, composites reinforced with jute fibers are of great interest to the researchers [37, 38]. Generally, jute fiber is used for low end textile's manufacturing industry. Jute is a composition of cellulose (45–70%), ligin (12–26%) and hemicellulose (13.6–21%) [39, 40] shown in Table 3. Ligin is responsible for mechanical support because many aromatic rings inside of the jute fiber. A very few amounts of fats, pectin, and wax is present. The most extensively grown are two varieties of jute: white jute (*Corchoruscapsularis*) and Tossa jute (*Corchorusolitorius*). The Tossa is smooth, soft, and stronger than the white jute. Tossa jute (white jute) is cultivated in India and Bangladesh and Bangladesh is the largest global producer of jute. Chemical composition of jute fiber can be seen in Table 1.

Table 1 Chemical composition of jute fiber [41]

Elements	Content (%)
Cellulose	61.0–71.0
Hemicellulose	13.6–20.4
Lignin	12.0–13.0
Pectin	– 0.2
Ash	0.5–2.0
Moisture	12.6
Wax	– 0.5

Epoxy resin

Epoxy is either any of the basic components or the cured end products of epoxy resins, as well as a colloquial name for the epoxide functional group. Epoxy resins, also known as polyepoxides, are a class of reactive prepolymers and polymers which contain epoxide groups. The term epoxy has been widely adapted for many uses beyond fiber reinforced polymer composites. Today, epoxy adhesives are sold in local hardware stores, and epoxy resin is used as the binder in countertops or coatings for floors. The myriad of uses for epoxy continues to expand, and variants of epoxies are constantly being developed to fit the industries and products they are used in. In the realm of fiber reinforced polymers (plastics), epoxy is used as the resin matrix to efficiently hold the fiber in place. It is compatible with all common reinforcing fibers including fiberglass, carbon fiber, aramid, and basalt.

Epoxy hardener

A hardener is a component of certain types of mixtures. In some mixtures, a hardener is used simply to increase the resilience of the mixture once it sets. A hardener can be either a reactant or a catalyst in the chemical reaction that occurs during the mixing process. Mixing the resin and hardener together prompts a chemical reaction, transforming them from a liquid into a solid. Measuring accurately and mixing thoroughly is essential to make sure epoxy resin cures properly. ARALDITE HY951 is an unfilled epoxy casting resin system that is renowned for its excellent electrical properties and the possibility of a high filler addition. ARALDITE HY951 low-viscosity, aliphatic amine hardener for epoxies that offers incredible mechanical strength cures at room temperature.

Experimental setup

The composites have been made in wooden molds prepared in lab. The molds were enclosed from the bottom by polyethylene coated with wax shown in Fig. 1.

Preparation of eggshell particles

Fresh eggshells, collected from waste of the university cafeteria, were washed in distilled water to remove impurities and slag from raw eggshells materials and then dried in an oven at 50 °C for 3 h. The dried eggshell materials were crushed by pulverizer and filtered with a mesh screen of 350. In the end, the filtered eggshell particles again dried in an oven at 50 °C for achieving constant weight.

Preparation of composite materials

The hand lay-up process was utilized and the surface of the polyethylene coated with wax to avoid sticking of the laminates then the fiber mat was placed over the plate. The various volumes of eggshell particles (5 gm, 10 gm, and 15 gm) have

Fig. 1 Experimental setup

been mixed with resin by applying a magnetic stirrer for getting an even distribution. Each laminate consists of 3 layers of jute and cotton fibers. Finally, the fabricated composites are kept under constant loading for 96 to get the uniform cross section. The same process was followed for each volume of composites as shown in Table 2, the fabrication process is shown in Fig. 2 and the fabricated composites are represented in Fig. 3 so that it can be visualized as the end product.

Results and discussion

Analysis of J/C/J/C without eggshell

Mechanical properties analysis

For investigating the impacts of without reinforced natural particles on the mechanical properties; the tensile test, compressive test, and bending test were performed on the specimens containing Tensile test, compression test, and bending test graph are

Table 2 Compositions of JCJC spent eggshell reinforced epoxy composites

Sample no	Sample name	Layer	Eggshell in gram	Epoxy Resin (%)	Hardener (%)
1	S1	J/C/J/C	5	70	30
2	S2	J/C/J/C	10	70	30
3	S3	J/C/J/C	15	70	30

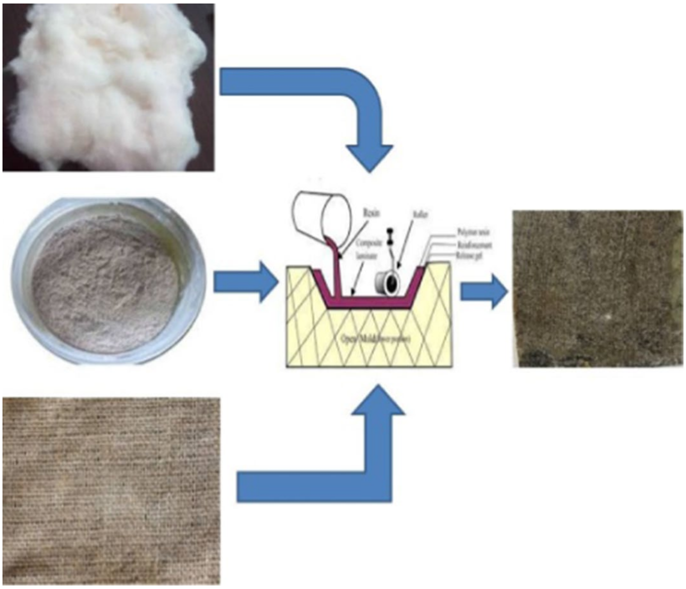


Fig. 2 Composite preparation process

shown in Fig. 4a, b, and c respectively. From the tensile test, maximum stress was found 22.43 N/mm^2. It has been observed that tensile strength JCJC composites are lower as compared to eggshell and spent tea leaf composites which proved that reinforced particles can increase the tensile strength. Compressive strength was found 0.84 MPa and bending strength was found 7.59 MPa as shown in Fig. 4b, and c which signify that reinforced particles influence the mechanical properties. A closer look shows that in the inelastic region the gap between curves for different weight fractions is slightly increasing, indicating that the nonlinearity. The hybrid composite exhibited more percentage elongation than single particles, which indicated that the hybrid composite withstands more strain before failure in tensile testing than single type of natural particle composite.

Characterization of JCJC based composites

SEM analysis was conducted to analyze the epoxy-fiber-spent tea leaves interaction of the composites. From the SEM Fig. 5a, it can be seen, cotton fibers orientation in the matrix is agglomerated. Some void has been identified in SEM and this is caused by lack of fiber/matrix adhesion [42]. No pull out is seen in fiber matrix which signifies that there is strong fiber matrix bond. The X-ray diffraction pattern of JCJC Composites is shown in Fig. 5b. Peak at approximately $2\theta = 30.5°$ corresponds to (1 1 0), and this indicates that crystalline is fixed for this composite. The crystalline grain size was calculated to be 60 nm based on the Scherrer equation. Figure 5c shows three different strong absorption peaks for the JCJC composites. The different peaks were identified such as 345.22 , 553.03,

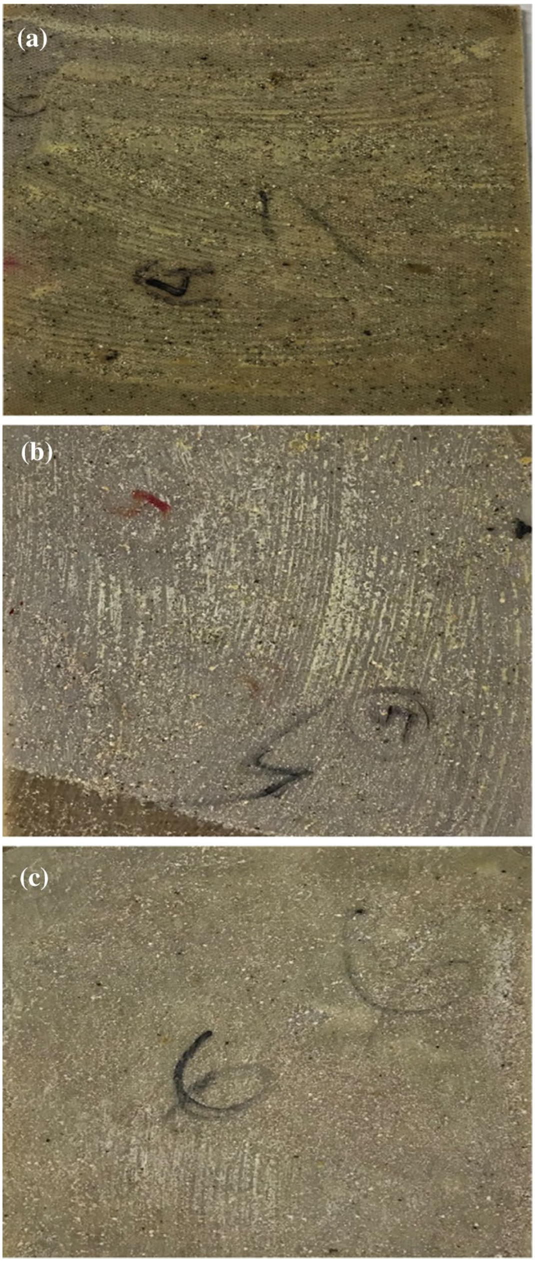


Fig. 3 JCJC eggshell epoxy reinforced composites **a** 5 gm eggshell particles, **b** 10 gm eggshell particles, **c** 15 gm eggshell particles

and 730.75 nm which indicate that spectral is in the visible region and larger spectra than JCJC spent tea leaves and eggshell particle-based composites. The peak 345.22 nm is shifted towards 553.03 nm and the peak 730.75 nm indicates that localized polaron band is converted to delocalized polaron band which is free carrier tail absorption. Figure 5d represents Fourier Transform Infrared

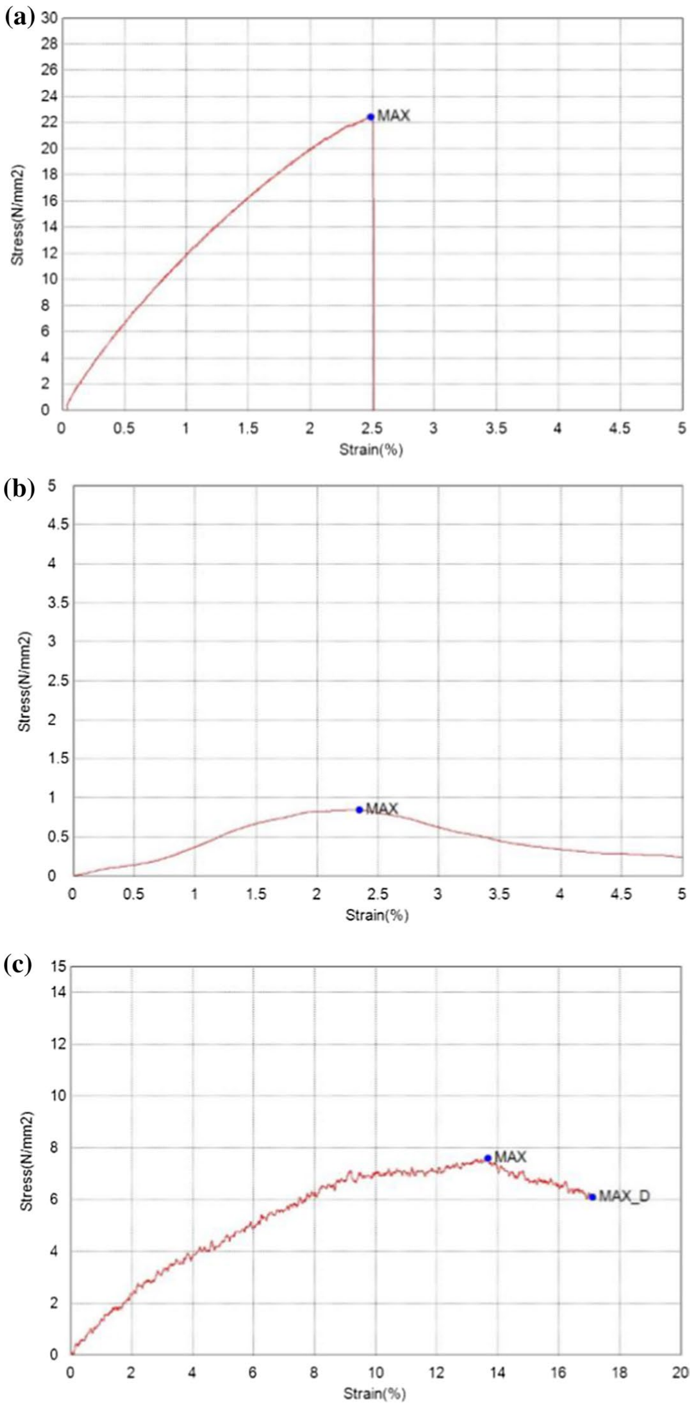


Fig. 4 Mechanical properties of JCJC composites, **a** Tensile test graph, **b** Compression test graph, **c** Bending test

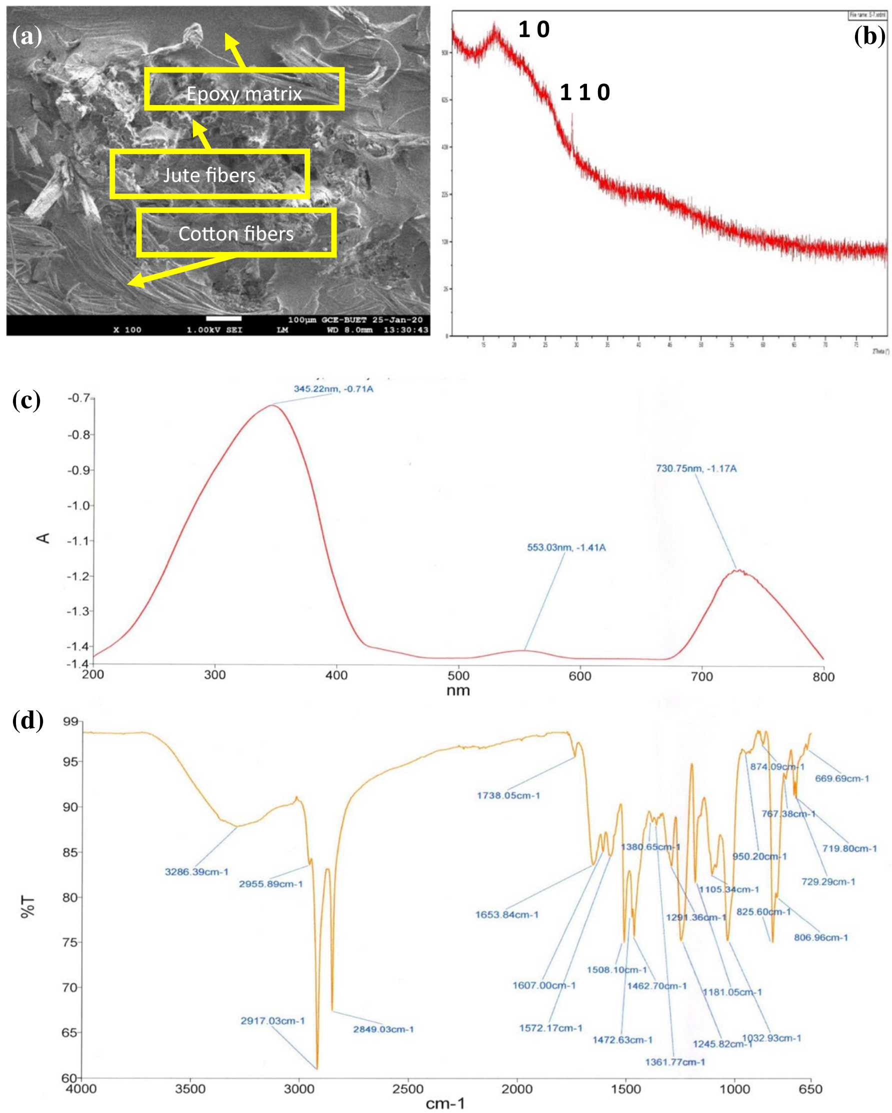


Fig. 5 Characterization of JCJC composites, **a** SEM image, **b** XRD analysis, **c** UV-viz spectra, **d** FTIR graph

Spectroscopy (FTIR) graphs and actual spectra were analyzed in the range of wavenumber 650–4000 cm^{-1}. The chemical structure and polymer chain were observed through the FTIR analysis. The presence of characteristic peaks, chemical functional groups, assignments, vibration types are shown in Table 3. The peak 2966 cm^{-1} is shifted to 2916 and 2646 cm^{-1} which correspond to hydrogen, methylene, and aldehyde groups and vibration types are stretching, asymmetric stretching, stretching, respectively. The peaks 1472 and 1452 cm^{-1} are attributed

Table 3 FTIR analysis data table of JCJC composites

Band (cm^{-1})	Functional class	Assignment	Vibration type
3286.39	Secondary amino	=N–H	Stretching
2955.89	Hydrogen	C–H	Stretching
2916	Methylene	C–H	Asymmetric stretching
2848.69	Methyl ether	$O–CH_3$	Stretching
1654	Alkenyl	C=C	Stretching
1508.54	Aromatic ring	C=C–C	Stretching
1472	Methylene	C–H	Bend
1462.62	Methylene	C–H	Bend
1260.11	Vinylidene	C–H	Bend
1182.03	Aromatic	C–H	In-plane bend
1025.75	Alkyl-substituted ether	C–O	Stretching
873.33	Peroxides	C–O–O–	Stretching
823.93	Alkene	C–H	Bend
803.02	Alkene	C–H	Bend
729.14	Alkene	C–H	Bend
719.45	Aromatic	C–H	Bend

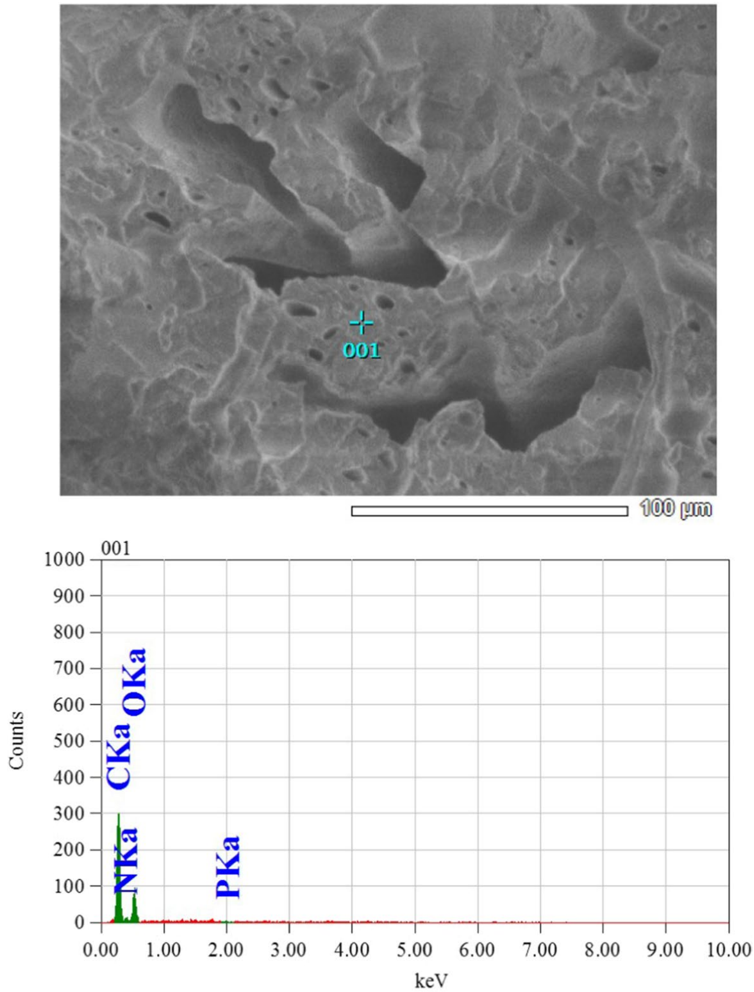
to C–H (methylene) functional class which are bend type vibration. Aromatic rings were found at 1179.93 cm^{-1}, 1068.08 cm^{-1} which attributed to in plane.

The chemical elements were identified as shown using Energy-dispersive spectroscopy (EDS) as shown in Fig. 6. C, O, N, and P elements were attributed in the JCJC Composites. The highest percentage element is Carbon which contains 58.3% which is a smaller amount than the other two composites. Total mass and the second highest element oxygen (O) which contains 27% which signifies that an oxide layer is formed on the composite. Surface morphology was analyzed through surface topology, 3D surface topology shown in Fig. 7. 3D surface topology shows that an almost homogeneous distribution of matrix, fibers and surface topology was found 250 μm.

Thermal analysis (TGA) of JCJC composites

Jute and cotton fibers are biodegradable and non-abrasive. These natural fiber composites have unique properties comparable to those of conventional synthetic fiber composites. However, development of these composites is often hampered by weak compatibility between fibers and polymer matrix and poor thermal resistance, which often reduce their performance.

An effective flame-retardant action is indicated by the high thermal stability of the polymer and composite, i.e., high decomposition temperature and high char residue. The TGA curves were used to determine the thermal behavior such as residual char level, weight loss and to identify the decomposition of material at a certain temperature, respectively. The degradation behavior of cotton fiber and resin as matrix were investigated by TGA in Fig. 8, there is an initial weight loss of 40% in



ZAF Method Standardless Quantitative Analysis
Fitting Coefficient : 0.1304

Element	(keV)	Mass%	Sigma	Atom%	Compound	Mass%	Cation
C K	0.277	58.83	0.14	64.49			
N K	0.392	13.83	0.43	13.00			
O K	0.525	27.34	0.40	22.50			
P K	2.013	0.01	0.05	0.00			
Total		100.00		100.00			

Fig. 6 Energy-dispersive spectroscopy analysis of JCJC composites

cotton fiber below 100 °C that may be attributed to elimination of moisture. Major weight loss took place during a-cellulose decomposition, as a principle component of cotton and jute fiber fibers, at 345 °C. Finally, a residual char level of 19% was obtained. In the TGA curve of the composites without particles shown in Fig. 8c the main weight loss started at 365 °C and reached maximum at 420 °C. The residual char was determined to be 7% at 600 °C.

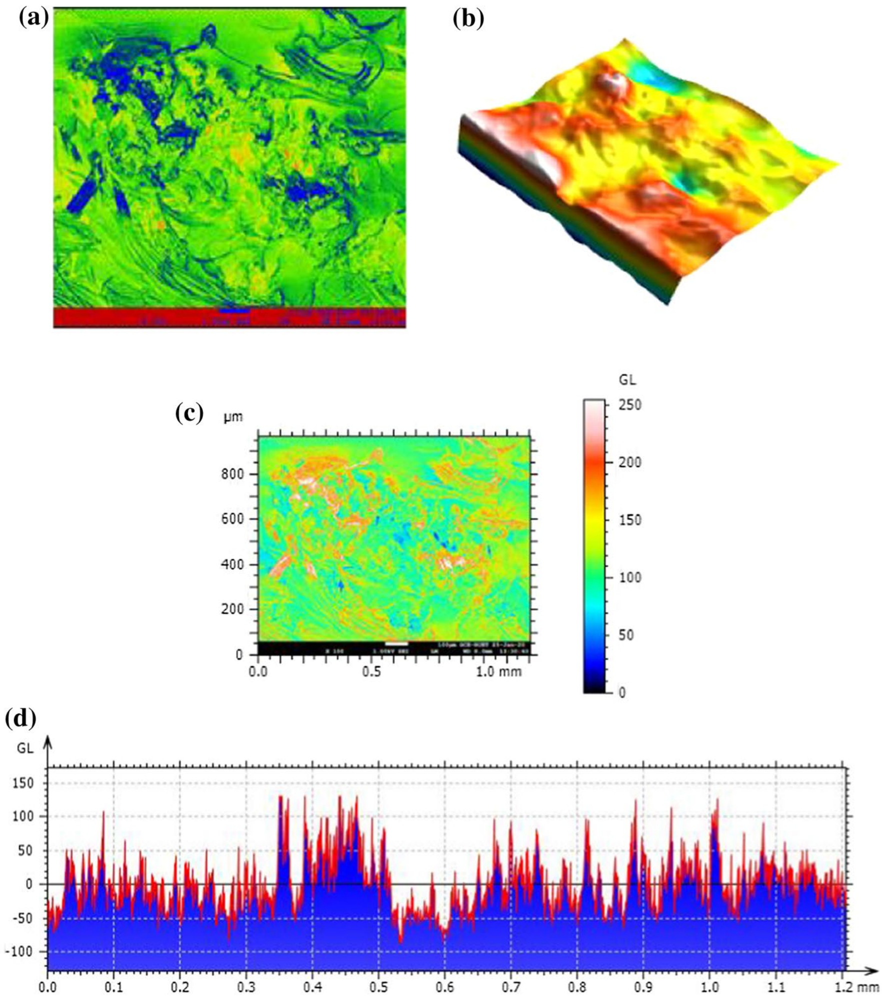


Fig. 7 Surface morphology of JCJC composites, **a** SEM pseudo colored, **b** 3D topology, **c** surface topology

Analysis of J/C/J/C with eggshell

Mechanical properties analysis

To investigate the effects of eggshell particles on the mechanical properties the tensile test, compressive test, and bending test were conducted on the specimens containing various loading of particles. Stress–strain diagram for tensile and compression tests can be seen in Figa. 9, 10. Figure 11 represents tensile strength, compressive strength, and bending strength. From Fig. 11a, it is seen that sample S3 shows highest tensile strength as compared to samples S1, and

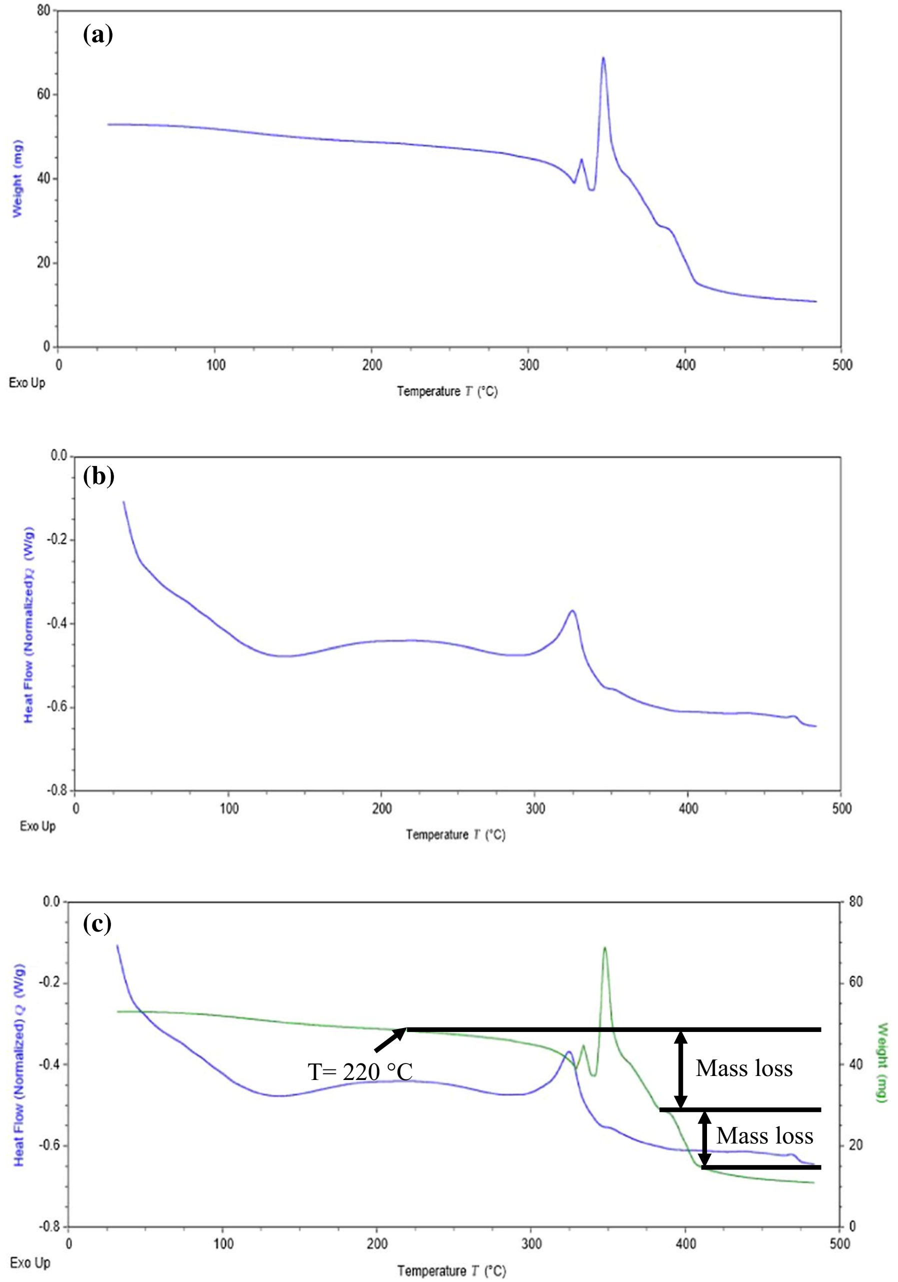


Fig. 8 Thermal analysis of JCJC spent tea leaves and eggshell particle-based composites **a** TGA graph, **b** DSC graph, **c** TGA and DSC graph

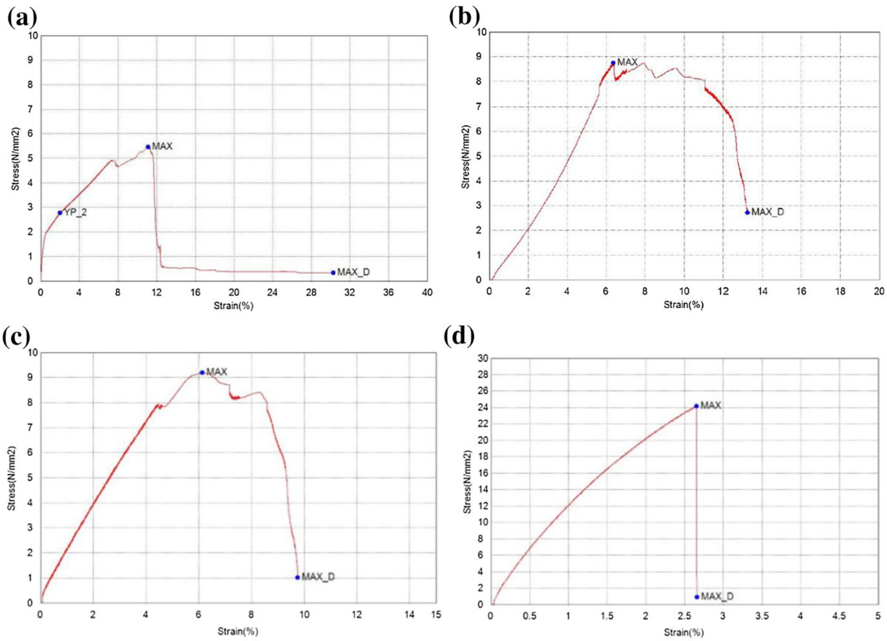


Fig. 9 Stress vs strain diagram of tensile test **a** 0 gm ESP, **b** 5 gm ESP, **c** 10 gm ESP, **d** 15 gm ESP

S2. Similarly, compressive strength as shown in Fig. 11b of the S3 is maximum; this behavior indicates that the mechanical behaviors such as tensile and compressive strength are increasing with increasing eggshell particles. The maximum tensile strength and compression strength are 24.17 and 10.40 MPa at 15% of eggshell particles. Uniform particle shapes and sizes of S-shell may be another reason for an increase in the tensile strength [43, 44]. Better dispersive mixing may contribute to the higher tensile strength [45]. Similar results are also found in the literature [46–48]. In addition, highest bending strength is 74 MPa at 10% of eggshell particles which is maximum compared to sample 1 and sample 3. From the bending strength results as shown in Fig. 11c, it can be seen that bending strength is highest at minimum percentage of eggshell particles; this is due to increasing elastic properties with decreasing percentage of eggshell particles. The addition of reinforcing particles to the composites increases the hardness. The presence of the hard phase of the composites facilitated the load transfer from the matrix to the reinforcement through the interface. This increases the resistance to plastic deformation during the application of an external load [49–51]. Compared to the compressive properties [42], it can be seen that tensile yield strength is much higher than compression strength. It may be due to fracture failure in compressive modulus. Aggregation and bubbles in the matrix may lead to stress concentration.

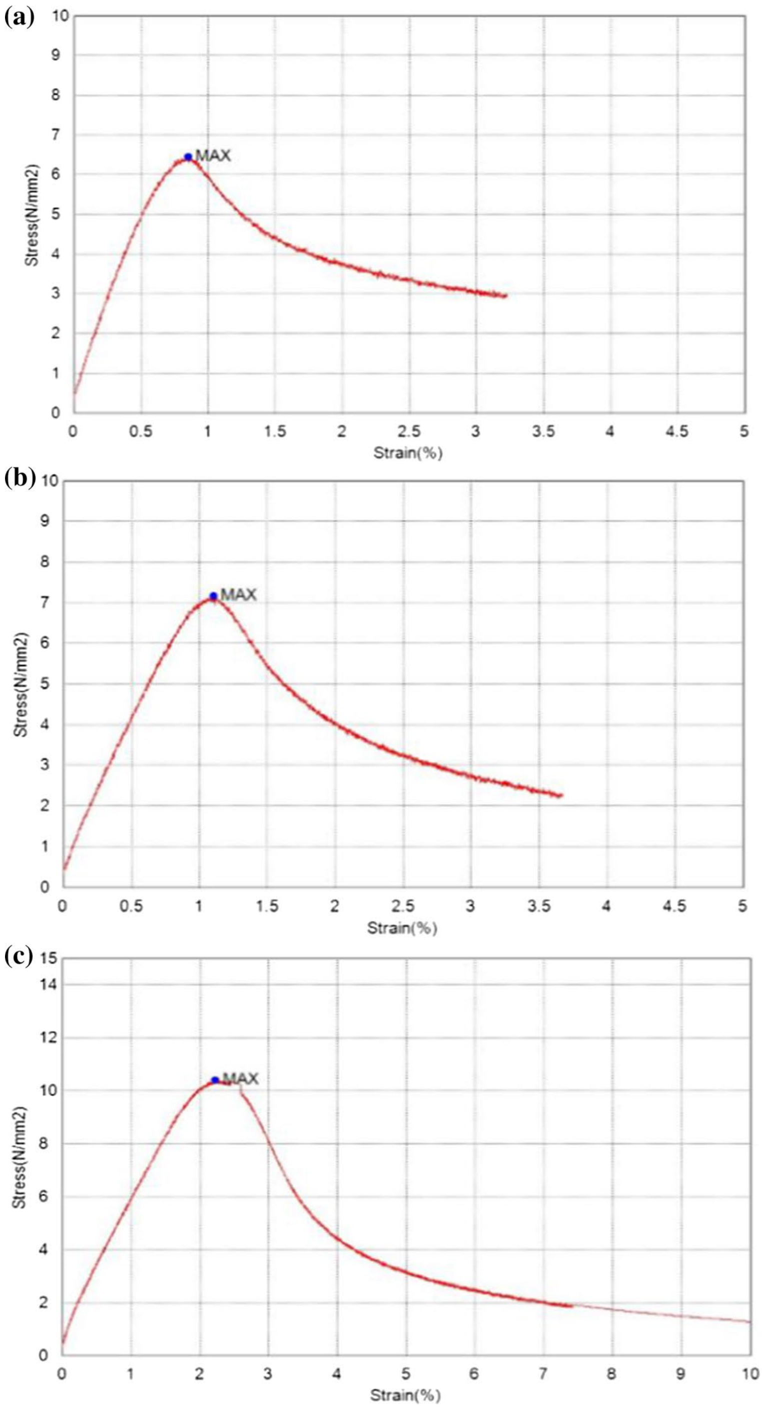


Fig. 10 Stress vs strain diagram of compression test **a** 5 gm ESP, **b** 10 gm ESP, **c** 15 gm ESP

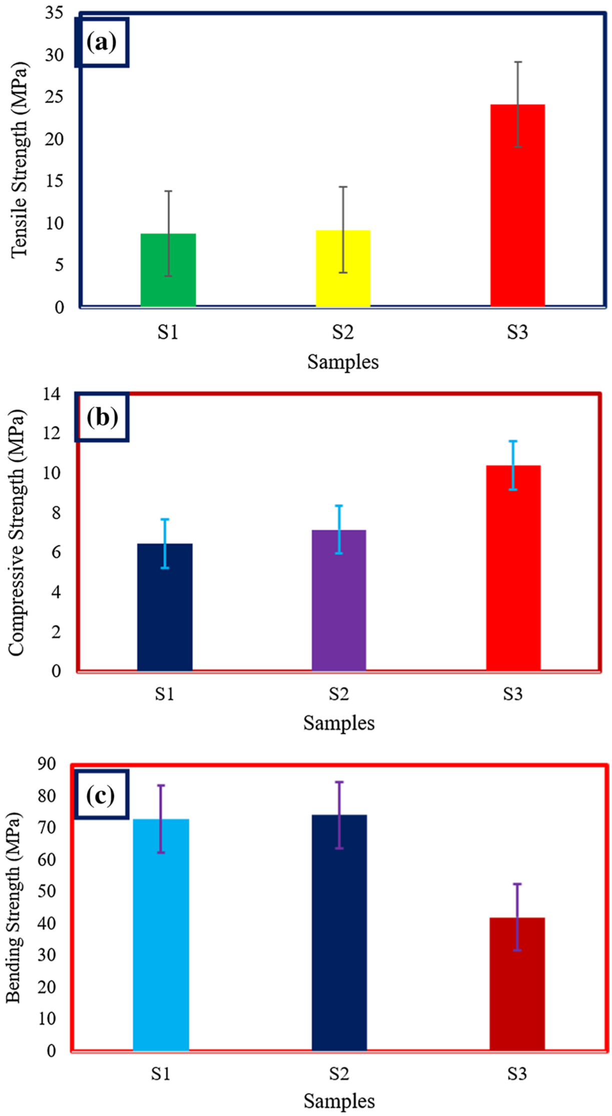


Fig. 11 Mechanical properties **a** tensile strength of sample 1 (5 gm ESP), **b** compressive strength of sample 2 (10 gm ESP), **c** bending strength of sample 3 (15 gm ESP)

Characterization of JCJC eggshell composites

SEM analysis was conducted to analyze the epoxy-fiber-eggshell particles interaction of the composites. From the SEM Fig. 12, it can be seen, jute and cotton fibers in the composites with eggshell compounds showed smooth surfaces that were fully covered with the adhesive. Cotton fibers and jute fibers orientation in matrix is agglomerated. Some void, and crack have been identified; these are

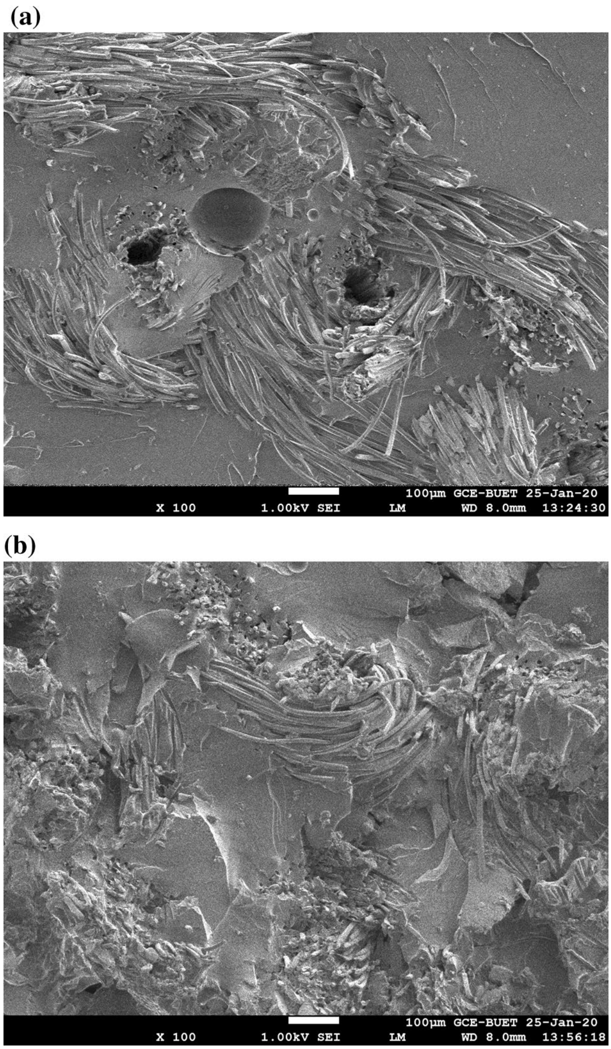


Fig. 12 SEM micrographs of the fabricated composites; **a** 5 gm eggshell particles; **b** 10 gm eggshell particles, **c** 15 gm eggshell particles

caused by lack of fiber/matrix adhesion [52]. Figure 12a shows that no pull out is seen in the fiber matrix which signifies that there is strong fiber matrix bond and the polarity of the particles supports the composite bonding. The agglomeration of the eggshell particles is attached to the surface which is attributed to reduce the contact area between the jute, cotton fibers and epoxy resin. Improper adhesion is observed for 10 gm eggshell particles as seen in Fig. 12a. Good adhesion between fibers and reinforcement is confirmed from the SEM micrograph presented in Fig. 12c. Surface morphology was analyzed through surface topology, 3D surface topology shown in Fig. 13. 3D surface topology as represented

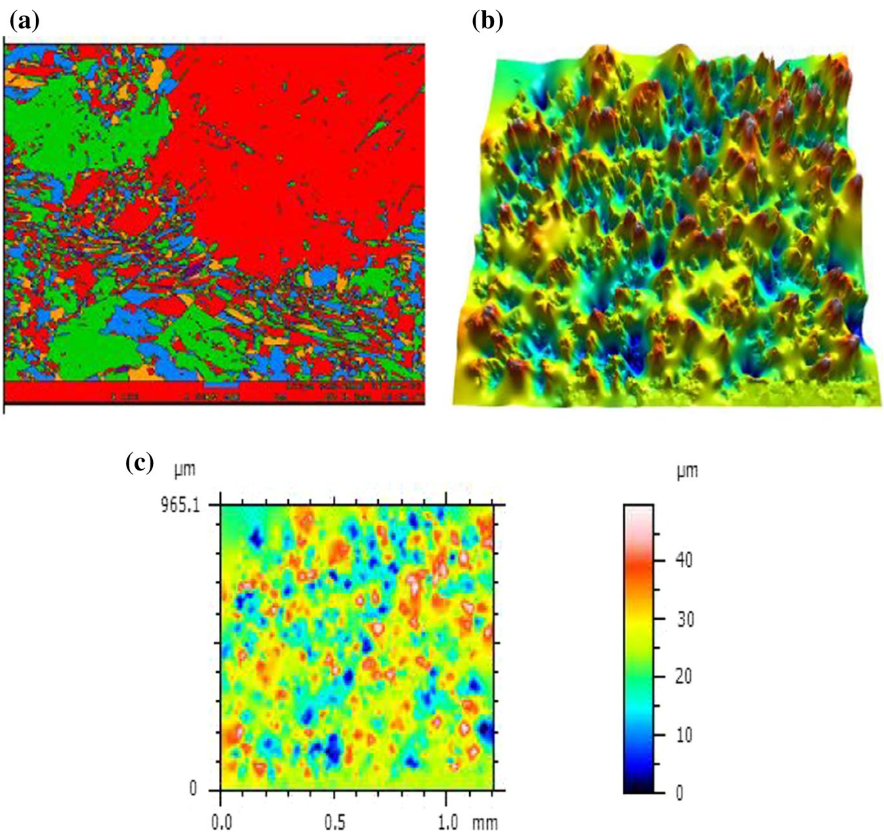


Fig. 13 Surface morphology analysis of JCJC eggshell composites **a** Pseudo colored, **b** 3D topology, **c** surface topography

in Fig. 13b shows that an almost homogeneous distribution of matrix, fibers and particles and surface topology was found 50 µm.

The X-ray diffraction pattern of JCJC eggshell Composites is shown in Fig. 14a. Peak at approximately $2\theta = 28°$ corresponds to (2 0 0), and this indicates that crystalline is fixed for this composite. The crystalline grain size was calculated to be 30 nm based on the Scherrer equation. Figure 14b shows three different strong absorption peaks for the Composites. The different peaks were identified such as 349.82, 553.02, and 730.82 nm which indicate that spectra are transferred from ultraviolet region to visible region. Figure 14c represents Fourier Transform Infrared Spectroscopy (FTIR) graphs and actual spectra were analyzed in the range of wavenumber 650–4000 cm^{-1}. The chemical structure and polymer chain were observed through the FTIR analysis. The presence of characteristic peaks, chemical functional groups, assignments, vibration types are shown in Table 4. The peak 3297 cm^{-1} hydrogen functional group is shifted to 2916 and 2646 cm^{-1} which correspond to methylene, and aldehyde group and vibration types

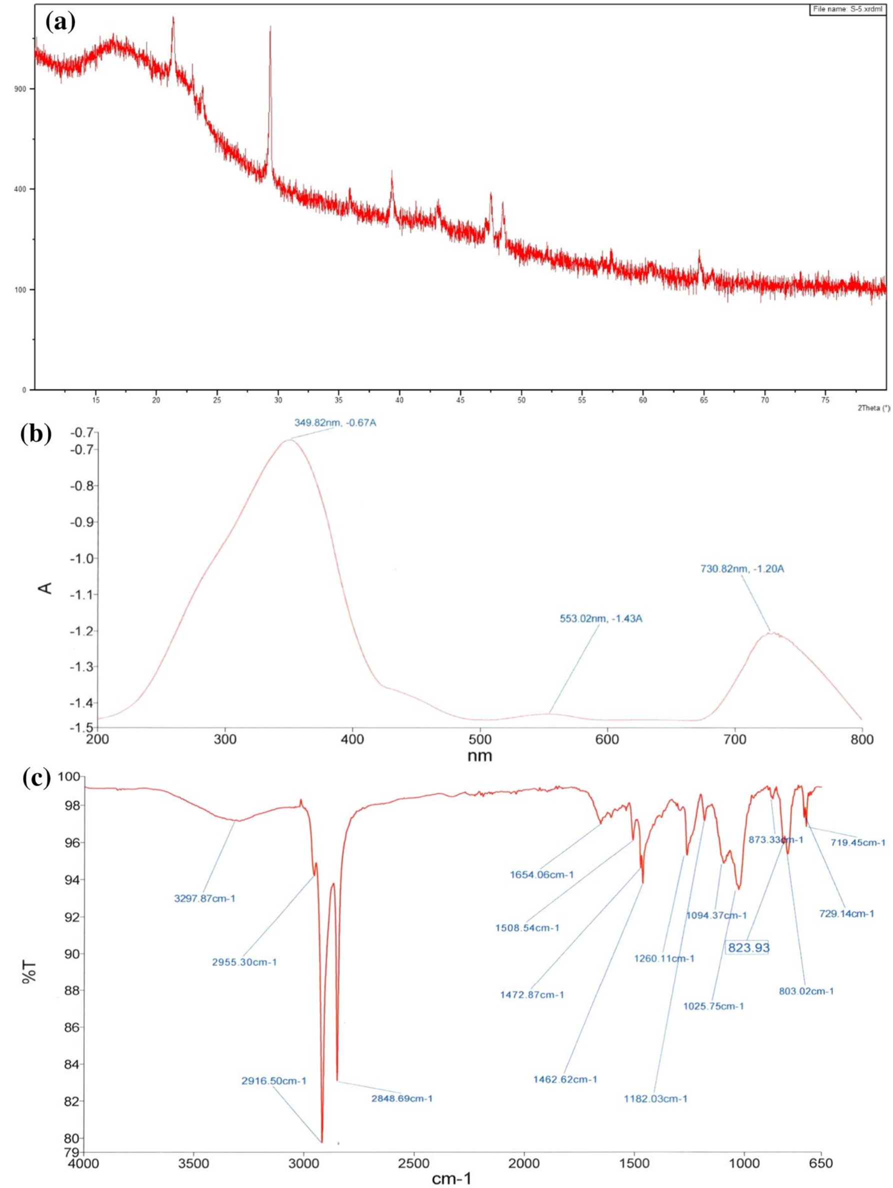


Fig. 14 Characterization of JCJC Eggshell particles composites, **a** XRD analysis, **b** UV-viz spectra, **c** FTIR graph

are stretching, asymmetric stretching, stretching, respectively [53]. The peaks 1472 and 1452 cm^{-1} are attributed to C–H (methylene) functional class which are bend type vibration [54]. Aromatic rings were found at 1182.03 cm^{-1},

1025.75 cm^{-1} which attributed C–O to in-plane stretching. The characteristic peaks for calcium carbonate, a major constituent of eggshell. This finding indicated

Table 4 Characteristics chemical functional group and vibration type of JCJC EggShell Composites

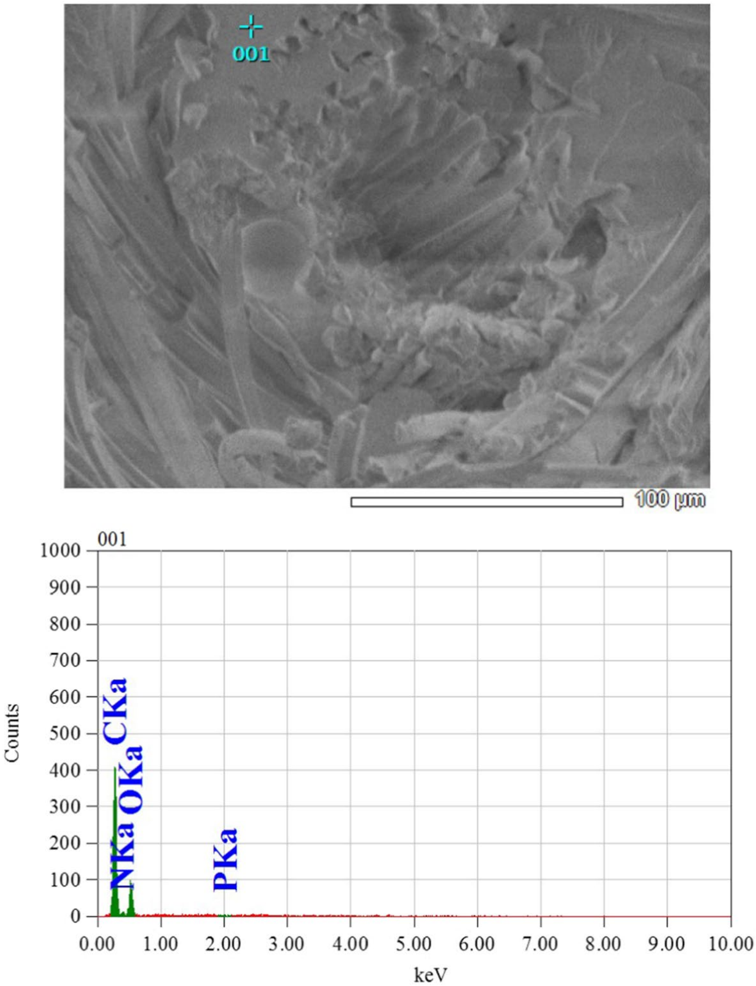
Band (cm^{-1})	Functional class	Assignment	Vibration type
3297.87	Hydrogen	NH_2	Stretching
2955	Hydrogen	C–H	Stretching
2916	Methylene	C–H	Asymmetric Stretching
2848.69	Methyl ether	O–CH_3	Stretching
1654	Alkenyl	C=C	Stretching
1508.54	Aromatic ring	C=C–C	Stretching
1472	Methylene	C–H	Bend
1462.62	Methylene	C–H	Bend
1260.11	Vinylidene	C–H	Bend
1182.03	Aromatic	C–H	In-plane bend
1025.75	Alkyl-substituted ether	C–O	Stretching
873.33	Peroxides	C–O–O–	Stretching
823.93	Alkene	C–H	Bend
803.02	Alkene	C–H	Bend
729.14	Alkene	C–H	Bend
719.45	Aromatic	C–H	Bend

no covalent bonds between jute and the eggshell matrix, and hence, physical phenomenon such as adsorption might be responsible for a non-covalent interaction between the eggshell and matrix. This is also verified by other research work [55].

The chemical elements were identified using Energy-dispersive spectroscopy (EDS) as shown in Fig. 15. C, O, N, and P elements were attributed in the JCJC eggshell Composites. The highest percentage element is Carbon which contains 64.46% of total mass composites and the second highest element Oxygen (O) which contains 24.89%.

Thermo-gravimetric analysis

The effective retardant action was identified by the high thermal stability of the composite, i.e., high decomposition temperature and high char residue. The TGA curves were used to determine the thermal behavior such as residual char level, weight loss and to identify the decomposition of material at a certain temperature, respectively. The degradation behavior of cotton fiber and resin as matrix and reinforcement eggshell particles were investigated by TGA and DSC in Fig. 16, there is a very small amount initial weight loss may be of 1% in cotton fiber and jute fiber below 100 °C that may be attributed to elimination of moisture that were very less amount moisture in the forms of free water, bound water, and water vapor. Major weight loss took place during a-cellulose decomposition, as a principal component of cotton and jute fiber fibers, at 300 °C. The second stage at which occurred at temperatures between 300–400 °C, is the stage with the weight loss observed is 36.3%. Maximum weight loss 45.4% is observed at



ZAF Method Standardless Quantitative Analysis
Fitting Coefficient : 0.1174

Element	(keV)	Mass%	Sigma	Atom%	Compound	Mass%	Cation
C K	0.277	64.46	0.66	69.86			
N K	0.392	10.62	0.94	9.87			
O K	0.525	24.89	0.98	20.25			
P K	2.013	0.02	0.06	0.01			
Total		100.00		100.00			

Fig. 15 Energy-dispersive spectroscopy analysis of JCJC Eggshell composites

400 °C. Finally, at the last stage a residual char level of 18% was obtained. In the TGA curve of the composites, Fig. 16a the main weight loss started at 300 °C and reached maximum at 474 °C. The residual char was determined to be 5% at 460 °C and was impacted to the reduction of the remaining elements.

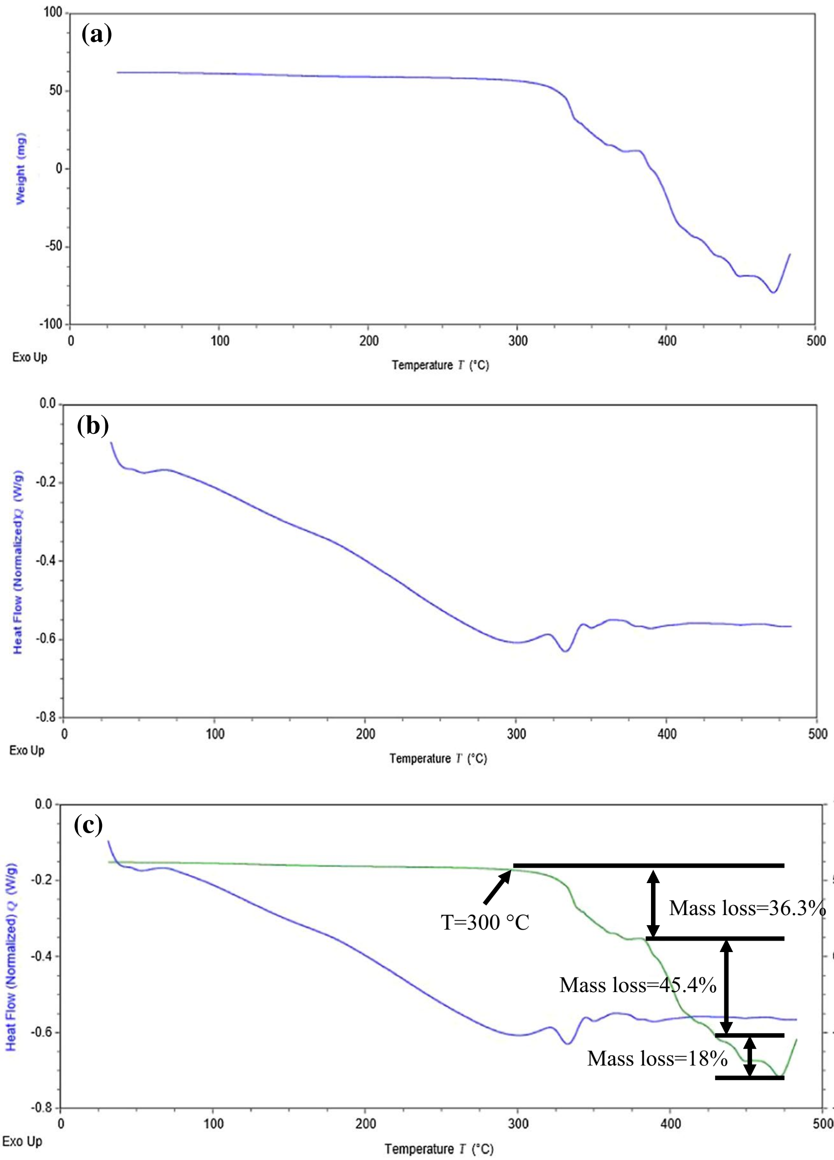


Fig. 16 Thermal analysis JCJC eggshell composites **a** TGA graph, **b** DSC graph, **c** TGA and DSC graph

Conclusion

Bio-composites are a reasonably recent addition to the advanced composites class, with desirable properties in various engineering applications. It is now clear that this success of natural fibers and reinforced with eggshell particles composites relies comprehensively on the compatibility of the materials and the formed interactions.

Various characterization techniques were utilized to structure, character and thermal behaviors of the JCPC eggshell particles and without particles JCPC composites so that its usability can be proven as an alternative of traditional materials. From the results and discussion, the following conclusions are made.

- Jute/cotton reinforced fiber with eggshell shows better performance, characterization and properties in comparison of same composite without eggshell particles.
- This study shows that the tensile and compressive strengths of the composites are increased with the increasing of eggshell particles weight in the composites. However, it is noticed that bending strength is minimum at higher weight of eggshell particles this is due to increasing plastic properties with increasing percentage of eggshell particle
- Surface micrograph shows that both jute and cotton fibers orientation in matrix is agglomerated. Some void, and crack have been identified, this is caused by lack of fiber/matrix adhesion. Very few pull out is seen in fiber matrix which signifies that there is strong fiber matrix bond.
- The X-ray diffraction pattern analysis of the composites shows that crystalline grain sizes was 30 nm for eggshell composites
- From the UV analysis strong absorption peaks were found in the visible range 349.82 nm, 553.02 nm, and 730.82 and there is less variation which could be ignorable. These UV results show that within the visible range all composites' properties would be durable.
- FTIR analysis shows that the reinforcing particles have shown similar chemical functional groups such C-H, $NH_{2,}$ –OH, C–O, C–O–O- and so on and these groups are stretching, bend and plane vibrations.
- Chemical elements were identified using Energy-dispersive spectroscopy (EDS) are C, O, N, and P with various percentages. Maximum C percentage (64.4%) were found in the eggshell composites.
- Good thermal stability is found of the eggshell composites and the results show major weight loss took place during a-cellulose decomposition, as a principal component of cotton and jute fiber fibers, at 300 °C. The stage at which occurred at temperatures between 300–400 °C, is the stage with the maximum weight loss observed. Finally, a residual char level of 10% was obtained. The main weight loss started at 300 °C and reached maximum at 474 °C.

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