RETRACTION

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This article has been retracted by IOP Publishing in light of admissions from the authors that there are errors in the calculations and figures presented, and as such the results are invalid and cannot be relied upon. As a member of the Committee for Publication Ethics (COPE) this has been investigated in accordance with COPE guidelines and it was agreed the article should be retracted.
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Preparation and evaluation mechanical, chemical and thermal properties of hybrid jute and coir fibers reinforced bio-composites using poly-lactic acid and polycaprolactone blends

Md. Muzammel Hossen ©, Jianyong Feng, Yin Yuxiang and Wenbin Jiang
Department of Textile Science & Engineering, Zhejiang Sci-Tech University, Hangzhou, Zhejiang 310018, People’s Republic of China
E-mail: jyfeng@zstu.edu.cn
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Abstract
Green composites using thermoplastics and thermosets got immense popularity long back when it newly introduced to the industry due to diminishing reliance on oil-based or gasoline materials, which causes numerous environmental problems. In this paper, bio-composites mechanical, chemical, thermal, and degradation properties of hybrid jute and coir fibers reinforced polyactic acid (PLA) investigated. Throughout the fabrication procedure of biocomposites, jute, and coir fibers characterized into three different categories raw, alkali-peroxide, and alkali-silane combined chemical treatments followed a design containing in a total of ten optimized samples. Jute and coir fibers were mixed with a solution of polycaprolactone (PCL) for better fiber-matrix adhesion prior to fabrication. The mechanical properties of alkali-silane treated reinforced fibers biocomposites improved compared to untreated fibers, which exhibited for fiber contents 40% an increase of respectively 32.8% by tensile strength 25.95% by tensile modulus, 24.58% by flexural strength, 23.64% by flexural modulus, and 26.08% by impact strength. Besides, moisture absorption, thickness swelling, thermal stability (TG), and surface chemistry analysis (FTIR) properties investigated, according to fiber-matrix contents ratio, hot-pressing time, temperature, and pressure to identify the effect of biocomposites due to chemical treatments. Moreover, the fiber surface effect of chemical treatments and interfacial adhesion morphologies observed using SEM. Eventually, alkali-silane combined optimized samples demonstrated the most desirable result in every aspect. In addition, a 90 days burial degradation performed to see the degradation flow of the biocomposites.

1. Introduction

Green composites have always placed of interest for researchers and industrial manufacturers for its superior-good mechanical properties such as the higher capacity of strength, stiffness, and zero adverse effects toward the environment. Recent years studies demonstrated that composite of natural fibers reinforced PLA thermoplastic brought a promising prospect for the improvement of bio-based composite in supplanting nonrenewable materials [1–4]. Natural fiber reinforced composites dependent on oil-based thermoplastics, or thermosets have utilized in different industrial segments, mostly in automobiles, furniture, agriculture, flammability, and environmental engineering applications [5–7]. Nowadays, also in the development of the construction industry, as well as unremittingly opening new industrial possibilities, are broadening day by day [8]. All petroleum-based thermoplastic polymer is not well amiable with the environment because of its non-biodegradable property, which causes numerous environmental problems [9]. However, composites fabricated with natural fiber and polymeric matrix procured from starch, cellulose, and other natural resources called ‘green composite’ immensely become popular for their biodegradable properties [10–12]. Thus, researchers, industrially become more reliable in natural fibers reinforced bio-composites using bio-degradable polymers for their friendliness towards nature. Rapidly rising demand in the world market for PLA turns this polymer better choice for...
researchers over the last few decades as a result of alternative synthetic or glass fibers. PLA derived from natural resources such as; corns, sugar, and rice with the advantages of low elongation at break, better stiffness, and strength [13]. This biopolymer also has a significant contribution in the area of tissue engineering [14] and medical surgery [15]. Among other natural fibers, coir fiber (Cocos nucifera) known as versatile lignocellulosic fiber extracted from the tissues surrounding the green coconut, which extensively used in many industrial applications [16]. Coir fiber has a pretty good content of lignin (41%–45%) micro-fibrillar angle of (30°–45°), lower content of cellulose (36%–43%) with hemicellulose of 0.2% [17–19]. Jute (Corchorus capsularis L.) commonly known bast fiber used in excessive amounts after cotton. Jute fiber has an excellent mechanical property of high specific mechanical strength, good enough moisture regain of (13.75%), and 100% degradable. Jute fibers come from renewable resources, ease of access, lower-cost, highly breathable, and lower contamination emission makes it prominent over other vegetable fibers [20, 21]. Besides, these biocomposites have few limitations too, comparatively weak interfacial adhesion between fiber-matrix is a significant problem of natural fiber-based applications. That can overcome by treating the surface of fiber following several pre-treatment processes [22]. Alkali treatment washes out impurities and non-cellulosic substances from the surface of fibers leading to enhanced interfacial adhesion between fiber-matrix by rearranging micro-fibril of cellulosic contents and dissolving lignin of highly hydrophobic contents of fiber [16]. Previous studies exhibited that soaking natural fiber in a silane solution for surface treatment significantly improved fiber-matrix compatibility, which broadly contemplated in Nassiopoulos, E, and Njuguna, J et al [23]. [24] B Surya Rajan et al investigated chemical treatment and fiber loading on the physio-mechanical properties of Prosopis Juliflora fiber reinforced hybrid friction composite. SEM results displayed that due to chemical treatments successfully removed impurities, hemicellulose, and lignin contents from the surface of fibers leading to better interfacial adhesion between fibers and binders. Besides, improved thermal stability of silane treated composite observed during TG analysis with reduced moisture absorption of around 56% and 44% for fiber contents 10 wt% and 5 wt%, respectively. [16] Nam T H et al studied the effect of chemical treatments of coir fiber reinforced PBS biocomposites. Authors also concluded with due to 72 h, hydrogen peroxide treatment of coir fibers at room temperature exhibited the highest interfacial shear strength result, which is 55.6% improved over untreated coir. Also, mechanical properties, respectively 54.6%, 141.9%, 45.7%, and 97.4% of tensile strength (MPa), tensile modulus, flexural strength, and flexural modulus improved after alkali treatment of coir fiber then untreated coir/PBS biocomposite. [25] Kamarudin, Siti Hasnah, et al studied mechanical and morphological properties of PLA based biocomposites prepared with EJO vegetable oil-based plasticizer and kenaf fibers. The result exhibited through alkali treatment of kenaf fibers vastly enhanced tensile strength and stiffness properties over untreated biocomposites which subsequently revealed by observing surface morphology of biocomposites. Besides, author claimed that obtained results after alkali treatment better compared to few synthetic fiber reinforced composites.

The objective of this research, to find out the effect of chemical treatments on bio-composites mechanical, chemical, thermal, and degradation properties. According to the fiber-matrix volume ratio, hot-pressing temperature, pressure, and time. For fabricating optimal possible hybrid jute and coir fibers, reinforced biocomposites using PLA and PCL blends.

2. Experimental details

2.1. Materials and method

Jute fibers collected from six season agro traders (Chittagong, Bangladesh) and cut manually 30–40 mm length. Coir fibers supplied from Jiangxi jiaogocheng import & export trade company Ltd PLA fiber collected from Jiangyin Gao xin chemical fiber company Ltd (China) With an average length of 38 mm. Polycaprolactone (PCL), dichloromethane (DCM), sodium peroxide (H₂O₂), sodium hydroxide (NaOH), and silane coupling acid (3-Glycidoxypropyltrimethoxysilane-KH560) supplied from Hangzhou Mi ke chemical Instrument Co, Ltd (Hangzhou, China). Detail properties of materials mentioned above displaying in Table 1.

2.2. Fiber treatment and biocomposite fabrication

Jute and coir both fibers separately dipped in a solution of 5% NaOH (5 g/1 00 mL water) and dried at 80 °C temperature for 60 min Later, added 3% of H₂O₂ and mixed adequately with the solution using an electric stirrer, then kept in woven for at least 45 min Moreover, during entire pre-treatment process whole solution keeps out several times for manually dipped fibers properly into solution to receive the very best treatment outcome. Subsequently, jute and coir fibers were saturated in (NaOH–5% and KH560%–5% for 100 mL water) combined solution for a maximum of 10 h in room temperature for comparison purposes.

Afterward, treated jute and coir fibers rinsed with regular water using few drop acetic acids till surplus alkali (NaOH), hydrogen peroxide (H₂O₂), and silane coupling acid (KH560) removed away with a maintained
Table 1. Demonstration of mechanical and chemical properties of jute fiber, coir fibers, PLA, and PCL.

| Physical properties       | Jute  | Coir  | PLA   | PCL   |
|---------------------------|-------|-------|-------|-------|
| Strength (MPa)            | 479   | 152.3 | 75    |       |
| Young’s Modulus (GPa)     | 19500 | 3101.2| 3600  | 0.280 |
| MFI (g/10 min⁻¹)          | 10    | 20.9  |       |       |
| Glass transition temp. (°C)| 60–64 | −60   |       |       |
| Melting temp. (°C)        | 160–170| 64    |       |       |
| Molecular weight (g/mol)  | 2 × 10⁴| 38000 |       |       |
| Density (g/cm³)           | 1.30 ± 0.1| 1.2 ± 0.1| 1.1  |       |
| Diameter (μm)             | 115 ± 5| 202 ± 10|     |       |
| Lumen width (μm)          | 6 ± 2  | 13 ± 4 |       |       |
| Cellulose content (%)     | 64.7 ± 1| 36.25 ± 1.21|     |       |
| Hemicelluloses content (%)| 17 ± 22| 12.65 ± 1.43|     |       |
| Lignin content (%)        | 12 ± 2 | 45.35 ± 0.8|    |       |
| Elongation at break (%)   | 1.17 ± 0.2| 35.5 ± 0.2| 2.4  |       |
| Microfibrillar angle (°)  | 8     | 39 ± 5 |       |       |

pH level of 6. Subsequently, treated jute and coir fibers keep in room temperature for 5 days then dried in an oven at 80 °C (Shanghai hasuc tools fabricate co. Ltd, Model: DHG-90538) for almost 20 h. Moreover, jute, coir, and PLA fiber mixed with a solution of PCL and DCM (1 gm PCL for 3 mL DCM) before going through fabrication of biocomposites for better interfacial adhesion. A design containing a total of ten samples followed closely. The hot-pressing process was selected and intended to detect a suitable condition for preparing biocomposites according to fiber mass volume ratio, hot pressing temperature, pressure, and time. By assembling parameters presented in Table 2 fabricated jute and coir fibers reinforced PLA biocomposites with a size of 25 cm × 25 cm × 3 mm using (Daylight hydraulic automatic press machine, Model: XLB-D350, China). Besides, a schematic representation of fabricating biocomposites demonstrated in Figure 1.

2.3. Characterizations
2.3.1. Mechanical properties testing of biocomposites
For mechanical tests, every specimen tested at least five times, and averaged values were reported. Tensile and flexural bending strength, modulus test of jute, and coir fiber-reinforced PLA biocomposites performed and documented data at room temperature of 20 ± 2 °C and 65% relative humidity employing a computer-controlled Instron tester (Model: 5943, Instron shanghai Ltd, China). The entire testing carried out following the Chinese standard of GBT – 1447–2005 and GBT – 1449–2005 with a loading speed rate of 5 mm min⁻¹ [26, 27]. Likewise, the impact strength of biocomposites accomplished with a specimen size of 64 × 13 × 3 mm according to Chinese standard GB/T 1451–2005 [28], using an impact tester (Dongguan xin bao Instrument Co., Ltd Model; XB-OTS-C500, China). Moreover, specimens for the following tests prepared using a diamond band cutting saw machine (Shenyang kejing auto-instrument Co., Ltd, Model; SYJ-D2000, China).

2.3.2. Thickness swelling (TS)
Thickness swelling (TS) conducted according to American standard ASTM, D570, and outcomes listed according to Equation (1) [29]. Prepared specimen’s dimensional stability measured carefully before immersion.
in distilled water. After taking out, specimens were wiped using a piece of cotton fabric and recorded changes using a thickness tester (Wenzhou Fang yuan Instrument Co. Ltd, Model: FY144, China). In total, five times tested every optimized sample, and averaged values reported to get accurate data.

\[
TS (%) = \frac{T_1 - T_0}{T_0} \times 100
\]

Where \(T_1\) and \(T_0\) stand for the thickness of biocomposites after and before soaking.

### 2.3.3. Water absorption (WA)

Water absorption (WA) behavior of biocomposites performed following American standard ASTM D570 and each of the calculations & outcomes carried out according to Equation (2) [29]. Before immersion in distilled water, all prepared specimens dried at 60 °C for 5 h afterward, WA test was sustained till 180 h. Each of the outcomes listed carefully within the specified time interval using Yueping automatic electrical balance (Capacity of Min: 10 mg, Max: 100 gm, Model: FA1004B, Shanghai Yueping scientific tool Co., Ltd China) respectively at 20 °C room temperature and 65% relative humidity.

\[
WA (%) = \frac{W_a - W_b}{W_b} \times 100
\]

Where \(W_a\) representing biocomposite weight after soaking and \(W_b\) is initial dry biocomposite weight.

### 2.3.4. Morphology analysis of optimized composites

The SEM specimens received from fracture occurred during tensile strength test. The fractured surface of tensile-tested biocomposites examined under a scanning electron microscope (SEM). In order to reduce extent of sample arcing, fractured surfaces of the composite specimens coated with a thin film (25 nm) of gold employing a plasma sputtering apparatus before examining sem using (Scanning Electron Microscopes JSM-5610LV from JEOL, Japan) and (JFC-1600 fine auto coater from JEOL, Japan).

### 2.3.5. Fourier Transform Infrared (FTIR)

Fourier transform infrared (FTIR) performed to observe and detect new absorption bands of treated fiber due to chemical modifications into jute and coir fibers. Dried 2 mg powder of jute fiber mixed with KBr further compounded into a fine powder using mortar and pestle then compressed in 10 MPa using a manual compressor. Both treated and untreated fibers surface chemistry analyzed using (Nicolet, Model: iS50 FT-IR) within a range of 500–4000 cm⁻¹.
2.3.6. Thermogravimetric analysis of optimized composites
Thermogravimetric or thermal decomposition analysis (TGA) of jute and coir fibers reinforced PLA biocomposites performed to observe the effect in thermal decomposition behavior of both treated and untreated fibers. Whereas, the weight range of the prepared specimens was 3–8 mg, a temperature range of 30–600 °C, with a decomposition rate of 20 °C/min, respectively using (NETZSCH Model: TG209 F1 Libra; Germany).

2.3.7. Burial degradation analysis
For burial degradation of biocomposites, specimens were prepared into 20 × 20 mm² size and buried under 25 cm depth for 90 days. Specimens were buried inside Zhejiang Sci-Tech University, Hangzhou, China, and full process accomplished under daily observations. From each group, five specimens tested and recorded the averaged value using Equation (3) [30]. Besides, before compositing specimens dried in woven at 70 °C for 1 h to remove absorbed moisture. After keeping out buried specimens washed with distilled water and dried again in the woven for 5 h at 80 °C before recording obtained outcomes. Moreover, additional lukewarm water used to maintain an effective degradation process along with microscopic images captured to see the degradation flow of biocomposites using (Jenoptic ProgRes® CT3 microscope machine, Model: Stemi-200C, USA).

\[ W_{loss} (%) = \frac{W_o - W_t}{W_o} \times 100 \]  

Where \( W_o \) representing specimens weight before composting and \( W_t \) is the weight of after composting.

3. Results and discussion

3.1. Tensile strength and modulus
Figure 2 representing tensile strength and modulus (MPa) of jute and coir fibers reinforced PLA biocomposites for various preparing conditions (preparing conditions 1, 2, 3, 4, ..., 9), as displayed in table 2.

Appropriate working parameters are very fundamental to deliver extraordinary outcomes with essential physical and chemical characteristics needed. As demonstrated in Figure 2, combined treated optimized sample B-2 indicating a significantly maximum result compared to other biocomposites of the experimental group. The fiber volume ratio plays an essential part in carrying and transfer heat to matrix for adequately moist all over fiber throughout the fabrication of biocomposites [31]. Moreover, insufficient fiber ratio with short fiber length can affect the reinforcement of jute and coir fibers to inappropriate stress transfer between fibers and matrix resulted in lower mechanical strength [1, 32]. Optimized sample B-2 (40:60 fibers, PLA ratio, 7 MPa hot-pressing pressure, 170 °C temperature, and 8 min of hot-pressing with 5 min curing) can be considered suitable parameters for this experimental category. Similarly, optimized sample C-2 has also displayed comparable better tensile strength and modulus in contrast to optimized sample B-2, which is 19.67% higher than optimized sample A-2. That can be evident of wash out all impurities from fibers surface, leading better interfacial adhesion among treated fibers with PLA [16]. Hot pressing at a lower temperature with insufficient pressure requires a long time for PLA to permeate the exterior of jute and coir fibers to get the desired wettability. Due to this, outcomes of optimized samples A-1, B-1, and C-1 exhibited comparatively lower tensile strength and modulus that may also be attributed to weak interfacial adhesion between fibers and PLA [33]. Similarly, optimized samples B-3 and C-3 exhibiting moderate tensile strength and modulus due to removing non-cellulosic
amorphous materials during the treatment of fibers [1]. Besides, tensile modulus of biocomposites displaying a similar result accompanied with tensile strength of biocomposites, which is around 26% higher for sample B-2 compared to optimized sample A-2. This attributed to alkali-silane treatments better interfacial adhesion between fibers and PLA formed, resulting in enhancing the load transfer from matrix to fiber [34, 35].

3.2. Flexural strength and modulus
Flexural properties provide an indirect idea regarding interfacial and stiffness properties of composites [36]. Due to providing reduced pressure resulting in fracture or significant crack in composites leading to failure for less interfacial adhesion among fiber and reinforcement polymer [37]. Effect of flexural bending strength and modulus (MPa) of treated and untreated fibers mass contents of 30%, 40%, and 50% reinforced PLA biocomposites displayed in Figure 3.

Following tensile strength and modulus graph optimized samples, B-2, and C-2 have revealed maximum results in the experimental group. As demonstrated, optimized samples B-3 and C-3 exhibited comparatively lower flexural strength after increasing fiber mass content up to 30%, and modulus that attributed to the shortage of PLA matrix failed to wet out jute and coir fibers thoroughly. Alkali treated optimized samples representing higher flexural properties due to the contribution of sodium hydroxide by improving fibers surface properties with improved fiber–matrix adhesion [38]. Besides, optimized samples B-2, B-3, C-2 and C-3 exhibited respectively 24.57%, 16%, 21.14% and 12% flexural strength and 23.64%, 16.08%, 19.37%, and 12.40% of higher flexural modulus compared to untreated optimized sample A-2.

On the other hand, optimized sample A-1, B-1, and C-1 were showing comparatively lower scores due to reduced hot-pressing temperatures and weak interfacial bonding with PLA, according to Nam T, H et al [31]. This attributed to PLA matrix melts gradually and wetting jute, and coir fibers were not successful as optimized sample B-2. Furthermore, flexural bending modulus of optimized samples exhibited more improved results than the tensile modulus results, but flexural strength was exhibiting different results. The reason behind this during failure of jute and coir fibers reinforced PLA biocomposite specimens in flexural property generally shows no fiber pull out or very little due to applying the forces in a 90-degree angle into the specimen [10, 16].

3.3. Impact strength
The result of jute and coir fibers reinforced PLA biocomposites impact strength displayed in Figure 4. The jute and coir fibers reinforced PLA biocomposites revealed considerable improvements from the impact strength compared to pure PLA, which gradually increase with fiber loading according to previous investigations [39, 40]. Alkali and silane treatment washes out impurities by activating the surface and leaves the roughness with several pits onto the fiber surface, which leads better interfacial adhesion within the reinforced matrix and fibers consequence improved impact strength of biocomposites [16, 41]. For this reason, optimized sample B-2 showing more significant results in impact strength due to supplied essential heating for PLA to moist jute and coir fibers along with optimized sample B-3 and C-2. The improved interfacial adhesion between fiber–matrix detrimentally affected the impact strength, as energy retention from jute-coir reinforced PLA biocomposites resulting in reduced fiber pull out. However, the energy retaining limit of the fibers recognized as a significant parameter in deciding the degree of harm can bring from impact energy into the composite surface [42, 43]. Similarly, optimized samples B-1, and C-1 demonstrating the lowest impact strength due to the failure of moist fibers thoroughly while other optimized samples were exhibiting moderate results in the experimental group.
Besides, pure PLA exhibited the lowest result over other optimized samples attributed to blending PLA with other substances improves the impact toughness, although proper melting turns PLA into more brittle material [44]. As a result, an optimized sample of fiber content 40% B-2 demonstrating 26.08% from optimized sample B-2 and 15.52% from C-2 reduced impact strength within the experimental group. Moreover, a suitable condition (fiber-matrix ratio, hot-pressing temperature, pressure, and time) is the essential element in embellishing jute and coir fiber reinforced PLA combination into a competitive biocomposite.

3.4. Thickness swelling (TS)

The thickness swelling behavior of jute and coir fibers reinforced PLA biocomposites after immersed with distilled water exhibited in Figure 5.

The TS of composite has been arising predominantly due to the vulnerability of this lignocellulosic fiber around the surface of composite because the amount of lingo cellulosic fiber varies with distinct moisture material. The hydrophilic properties of lingo cellulosic substances with medium called capillary action get the consumption of water once the samples were saturated in water boost the fiber resulting in changing the dimensional measurements of the composite [45]. Figure 5 demonstrated that the raw biocomposites are showing exceeding results among the optimized experimental group. Because of low interfacial adhesion, micro air-filled void space and pores appear in the composite, which uptake the water inside those micro-voids, and

![Figure 4. Impact strength of jute and coir fibers reinforced PLA biocomposites.](image1)

![Figure 5. Thickness swelling effect of jute and coir fibers reinforced PLA biocomposites.](image2)
pores take part in changing dimensional stability of composites [46], as exhibited in Figure 5. Interestingly, as we expected, the lowest TS result is showing the combined treated bio-composites compared to raw biocomposites, which is 5.1 mm lower after 180 h of immersion, due to reducing the hydroxyl (OH) group of fibers that is responsible for water uptake after chemical treatments. At the beginning of immersion, raw biocomposites dramatically uptakes more water and showing exceeding TS change than the treated reinforced composites [47].

It summarized from figure 5, optimized sample B-2 showing moderate result in contrast pure PLA recorded the lowest score in the optimized experimental group.

3.5. Water absorption (WA)

WA performed to observe the amount of water uptake by biocomposites optimized samples after immersion in distilled water for a 160 h time interval, and obtained results displayed in Figure 6.

According to Figures 5, 6 demonstrates that due to consuming water in air-filled void and pores leads to consuming more water and increase the weight of biocomposites. WA behavior of biocomposites determined by the capability of their fiber to consume water or moisture due to existence of hydroxyl groups, which mainly responsible for WA throughout the creation of (H) bonding. The higher the moisture content in any organic fiber, the higher shift in mechanical and physical characteristics of the composite, resulting in lower adhesion between reinforced matrix with fiber [48]. Due to this, raw jute-coir and PLA reinforced biocomposites showing maximum WA result (20.2%). Similarly, raw jute and coir fibers reinforced PLA bio-composites consumed more water at the beginning of immersion than the treated jute-coir biocomposites. Due to chemical treatment, fiber will restrict absorption of moisture within the fiber, and reinforced matrix since the air-filled voids and pore are filled up throughout the fabrication of bio-composites [47]. This may reason behind exhibiting optimized samples of biocomposites B-2 and C-2 moderate results in WA, which is respectively 12.1% and 14.9%. Besides, pure PLA absorbed the lowest amount of water, which is less than 1.5% because of PLA thermoplastic polymer insoluble in water [49]. After conducting TS and WA, we observed a common tendency of biocomposites exhibiting significant changes with increasing immersion time until achieved a stable condition.

3.6. Biocomposites morphology analysis

Figure 7. displaying the surface morphologies of jute and coir fibers reinforced PLA biocomposites of fiber mass contents 30%, 40%, and 50%. The SEM specimen received from the fracture during tensile strength and modulus test.

SEM undoubtedly an excellent way to observe the surface of fibers and interfacial adhesion between fiber-matrix. Figure 7(a) demonstrated untreated jute fiber, and Figure 7(b) demonstrated alkali-peroxide treated jute fiber. From the figures mentioned above, it could be observed that surface treatment done without occurring any damage in the surface of fibers. After alkali treatment, impurities and other non-cellulosic substances wash from the surface of jute fiber and put roughness into the surface of fiber that responsible for developing a strong bonding directly between fibers and PLA [50]. Figure 7(c) demonstrates that PLA coated adequately into the surface of coir fibers after alkali-peroxide treatment.
On the other hand, figure 7(d) displaying irregular, rough structure and micro-cracks in raw biocomposite surface due to the brittleness nature of PLA, which can help to spread the crack quickly during mechanical tests [25]. The effect of micro-cracks can be observed in Figure 7(f). A strong possible covalent bond formed due to combined chemical treatments of jute and coir fibers with the alkali-silane solution and hydroxyl groups of cellulose. Besides, the combined treatment develops an active bridge between fibers and matrix, which can absorb more energy during mechanical tests when forces try to fracture the reinforced structure [51, 52]. Moreover, having OH and Amine (Primary NH2 and Secondary NH4) groups, the silane coupling agent can help to set up a bond between the fibers and matrix, leading to better stiffness and interfacial adhesion within PLA and reinforced fibers. Figure 7(f) exhibiting fiber pull out of tensile fracture with crack, which attributes to weak interfacial adhesion of PLA with reinforced jute and coir fibers. Interestingly the cracks are comparatively minor in alkali-silane combined treatment [53]. Therefore, the above outcomes suggest that alkali-silane combined treatments are essential to improve interfacial fibers-PLA adhesion preceding biocomposites fabrication.

3.7. Chemical effects analysis of biocomposites
The consequences of chemical treatment on Jute-coir reinforced PLA biocomposite observed in respectively Figures 2, 3, and 4. As stated in Figure 8, biocomposites mechanical property vastly enhanced after alkali-silane combined chemical treatment compared to raw jute, coir fibers, and pure PLA.

The untreated biocomposites revealed a broad and powerful vibration range of 3481 cm$^{-1}$ suggesting OH bond. Meanwhile, after the chemical treatment of the biocomposites, the peaks were transferred to 3437 cm$^{-1}$ and 3442 cm$^{-1}$ due to lignin and cellulose content of fibers, which is more or less similar with [46]—
Furthermore, the spectrum corresponding at 2945 cm\(^{-1}\) and 2997 cm\(^{-1}\) indicating vibration of CH linkage. The peak is showing at 1756 cm\(^{-1}\) corresponding vibration stretching from the Carbonyl (C=O) bond (due to attributing lignin group) having hemicellulose content in jute and coir fiber, which significantly minimized after the chemical treatment of the composites. Besides, absorption spectra detected at 1460 cm\(^{-1}\) represents CH\(_3\) bond, respectively. Moreover, peak presenting in 1385 cm\(^{-1}\) has detected due to deforming jute and coir into the CH bond. Hence, alkali-silane (NaOH + KH560) combined treatment exhibiting vibration peak at around 1100 cm\(^{-1}\) depicts C–O stretching of a secondary alcohol. Also, Peaks presenting at 1058 cm\(^{-1}\) attributed to cellulose. Also, vibration spectra detected at 871 cm\(^{-1}\) representing CH scissoring and C–C bending. This may due to the silane treatment forming alcohol and silanol through reacting with water \[54\]. KH560 holds OH and NH\(_2\) group, which creates a connection involving treated fibers with PLA matrix as well as occupying polar and non-polar groups supplied maximum pressure and heat to treated fiber throughout biocomposites fabrication \[53, 55\].

3.8. Thermal decomposition analysis (TGA)

Even the (TGA) outcomes affirmed that the accession of jute and coir fiber into the PLA matrix raised the operation of degradation resistance for this biocomposite. PLA decomposes at an insignificant temperature compared to other corresponding optimized samples, as demonstrated in figure 9, both WL % and DWL% graph. PLA initiated decomposing at approximately 288.5 °C and proceeded to accomplish decomposition in 394.9 °C. Due to an increase and decrease of PLA, reinforced molecular mass adversely affects entire thermal degradation process of biocomposites \[40, 56\]. Similarly, the thermal decomposition starts for combined treated jute–coir fibers reinforced PLA biocomposites from 307.2 °C following reached to ultimate stage almost at 451.8 °C, which is 9.21% higher compared to pure PLA.

In contrast, optimized sample B–2 were showing a significantly maximum result in thermal decomposition, which starts from 295.1 °C and completely decomposed at 431.8 °C, respectively. After decomposing char left
for pure PLA, raw, alkali-peroxide, and alkali-silane combined treated biocomposites 0.05, 0.09, 0.41, and 0.32, respectively. Which, also indicating the effect of the treatments in decomposition [53]. Optimized sample A-2 demonstrating a two-stage thermal degradation among experimental group. Moreover, thermal decomposition of raw jute and coir fibers reinforced PLA biocomposite can distinguish into three particular peaks. That attributed to heat range between 25 °C–150 °C bio-composites weight loss indicated due to water volatilization. The second peak was allocating between 190 °C–300 °C, indicating the degradation of hemi-cellulose contents.

Similarly, the third peak is showing between 300 °C–360 °C attributed to decomposing of cellulose contents of jute and coir fibers. Besides, the lignin degradation of fibers takes place between 280 °C–500 °C. The reason behind showing better thermal resistance of alkali-treated optimized samples could be described by during treatment removing a substantial amount of hemicellulose as well as natural hydrolyzed elements that decompose before that lignin and cellulose [57, 58].

3.9. Burial degradation in soil

Composting of a natural fiber-reinforced matrix into soil trend to decomposing is an ordinary manner of biocomposites with the presence of water and carbon dioxide [59].

Figure 10(a) demonstrates that with an increasing number of degradation days, mass loss also increasing at a subsequent rate. The degradation of the first three-stage insignificant compared to the last three-stage (60–90 days). Degradation of weight loss PLA scored very less among the group, which is approximately 24.7% because it takes a bit longer time to hydrolyze with soil [60, 61]. Similarly, raw jute-coir and PLA biocomposites demonstrating the highest result of 66.9% in the group. Due to weak bonding between untreated fiber with PLA matrix resulting in comparatively faster degradation of biocomposites than treated fibers during the burial period [54, 62, 63].

On the other hand, high cellulose content of jute fiber aptitude to absorb more water within a couple of time consequences quicker degradation [64]. Alkali-peroxide treated jute-coir and PLA biocomposites exhibit a moderate result of 39.5%, and alkali-silane combined treated optimized sample scored 37.2%, respectively.

After hydrogen peroxide, alkali or silane coupling treatment hydrophobic characteristics in the surface of fiber leads to a significantly limit the amount of moisture uptake as well as comparatively better interfacial bonding between treated fiber and reinforced matrix resulting in slower degradation then untreated fiber [31, 65]. Furthermore, the surface of biocomposite eroded with few cracks observed for starting moderate hydrolyzing the PLA with soil due to buried for a long time proved the degradation process working as displaying in Figure 10(b).

4. Conclusion

In this experiment, a design containing a total of ten optimized samples characterized as pure PLA, raw, alkali-peroxide, and alkali-silane combined treatments prepared using hot-pressing process following fiber mass contents 30%, 40%, and 50%. According to fabrication parameters such as fiber-matrix volume ratio, temperature (160 °C, 170 °C, and 180 °C), pressure (7 MPa) with 8-min of heating and 5-min of curing time. Besides, fiber treatments performed before the fabrication of bio-composites to identify the effect of chemical treatments in mechanical, chemical, thermal, and degradation properties. As expected, in tensile, flexural bending, and impact test alkali & silane combined optimized samples exhibited competitively enhanced results compared to raw biocomposites. Similarly, alkali-peroxide treated biocomposite exhibited moderate results in the experimental group. By observing the surface morphologies of tensile fractures significant notable cracks, and void evident that raw jute and coir fibers were responsible for comparatively lower fiber-matrix adhesion. The alkali-peroxide, alkali-silane combined treated fibers exhibited roughness into the surface of treated fibers resulting in better fiber-matrix adhesion.

Moreover, significantly improved thermal stability achieved due to alkali-peroxide and alkali-silane combined treatments over untreated jute and coir fibers. A 90 days burial degradation performed to observe consequences due to chemical treatments for different time intervals. The obtained investigation result demonstrated cellulose and lignin content of untreated fibers absorb additional moisture and enhanced degradation flow of biocomposites. Although, pure PLA takes more time for hydrolyzing leading to slower decomposition over other optimized samples. Subsequently, the entire degradation process accelerated with proceeding time as well, exhibited a bit darker shade throughout the last burial degradation stage. Consequently, alkali-silane combined treatment demonstrated maximum outcome over other characterized samples with (40:60) fiber-matrix ratio, 170 °C of temperature, and 7 MPa of pressure considered best parameters for fabricating these biocomposites.
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Figure 10. (a) Burial degradation behavior of jute and coir fibers reinforced PLA biocomposites. (b) Microscopic view of buried jute and coir fibers reinforced PLA biocomposite optimized samples degradation in various magnification ranges throughout different time intervals.
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Conflicts of interest

The authors declared no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

ORCID iDs

Md. Muzammel Hossen  https://orcid.org/0000-0001-8471-0680

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