Mechanical Behaviour of Cissus Quadrangularis/Basalt Fibre Reinforced Hybrid Biocomposite for Bone Implantations

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ABSTRACT: *Basalt fiber reinforced PLA/CQ hybrid biocomposite is developed by the injection molding technique. Mechanical properties of Basalt fiber reinforced PLA/CQ composites at different weight fractions are investigated. In addition, to analyze the morphological characteristics as well as the fractured and worn-out surface of the raw materials, a Scanning Electron Microscopy (SEM) study is carried out. Poly lactic acid (PLA) is a popular synthetic polymer considered for tissue applications, hence this polymer is proven to support the occurrence of metabolic processes in the human body. PLA parts reinforced with treated basalt fiber seem to be a good selection. Cissus quadrangularis fiber has many medical curing abilities, is first time introduced as a medical filler in short fibers in this hybrid bio-medical composites. The study shows that significant improvement in tensile, flexural, and impact strength of the hybrid composites was observed as the weight percentage of BF and CQ increases. Also, water absorption tests and scanned electron microscopic studies were conducted to further explore the capability of this biocomposite. This composite gives an efficient result as that of bone instead of considering metal as a replacement. This is a novel and innovative finding of new hybrid composites of PLA/BF/CQ biocomposites in the applications of biomedical engineering.*

KEYWORDS: *Basalt Fiber; Cissus Quadrangularis; Flexural Strength; Biocomposite; Water absorption; SEM.*

INTRODUCTION

Huge amounts of plastic waste, evolving from packaging materials to technology products, are buried in huge quantities in landfills and waterfills across the world every year. Electronic - waste is becoming a serious

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1021-9986/2023/7/2160-2174 15/$/6.05

problem because of the increasing rate of deposition of e–waste debris due to the technological growth that millions of devices are becoming obsolete and being replaced by new ones which are faster and more efficient. The nonexistence of appropriate facilities for processing and recycling this hazardous plastic waste and e-wastes have permanently damaged the environment and the health of the people near the waste disposal region. Researchers are working across the world to find alternatives to overcome the challenges faced during the disposal of this e-waste as landfills and waterfills. In recent years, a wide interest has been focused on natural fiber-reinforced composites because of their beneficial characteristics and vast availability. Sustainable biocomposites can be manufactured from a wide range of natural materials. *Czigany et al*. proved that basalt is also considered natural, because it is generated by the solidification of molten lava, and it is also bio inert, having high mechanical properties [1]. *Kogan et al.* proved the increasing application of basalt fiber raised the question whether basalt fiber is harmful to health. They made rats inhale air containing asbestos and basalt fibers for 6 months. According to these results basalt fibers seem to be a good selection to reinforce PLA composites [2]. *Avella et al.* studied the interfacial adhesion of PLA/Kenaf fiber composites with particular attention to the effect of compatibilisation on the composites. Their SEM pictures showed that the Kenaf fibers were not wholly embedded into the PLA matrix in the uncompatibilised samples. The fibers were also strongly damaged and some de-bonding phenomena were observed for the uncompatibilised samples [3]. *Huda et al*. investigated the mechanical and thermo-mechanical properties of wood fiber-reinforced PLA. They reported that there was good adhesion between the wood fiber and the PLA [4]. *Duigou et al.* studied the recyclability of flax/PLLA, prepared through extrusion and injection moulding, and compared them with equivalent Polypropylene composites prepared in the same way. The Young's modulus of the flax/PLLA composites increased, but the stress at break was not enhanced by the reinforcement [5]. *Huda et al.* in their investigation of Recycled Newspaper Cellulose Fiber (RNCF) reinforced PLA biocomposites, found that the presence of RNCF improved the tensile modulus of PLA. This indicated better stress transfer because of good interfacial adhesion between the polymer and the fiber. However, the tensile strength at the break of the PLA was reduced by the incorporation of RNCF [6]. Generally, the glass transition temperatures (Tg) were higher for all fiber-reinforced samples. This showed that the polymer relaxation was delayed due to the chain restriction as a result of increased crystallinity. The cold crystallization was reduced in the presence of fibers due to the nucleating ability of the reinforcement. *Pilla et al*. investigated the effect of adding an epoxy-based chain extender (CE) on the cell morphology and mechanical properties of solid and microcellular PLA [7]. The chain extender clearly separated the PLA melting peaks into two. This double melting peak was attributed to the different crystalline morphologies obtained during the different crystallization processes such as melt-crystallization (from cooling) and cold crystallization. *Huda et al.* revealed the nucleation ability of the RNCF on PLA crystallization. An increase in the crystallization temperature with the introduction of the fibers was observed. The glass transition temperature and crystalline melting point of PLA did not change after reinforcement with RNCF. The crystallization temperature of the RNCF-reinforced PLA composites decreased as compared to neat PLA, which signifies that the cellulose fibers hinder the migration and diffusion of PLA molecular chains to the surface of the nucleus in the composites. The effect of the inclusion of Carbon nanotubes with various polymer matrix inferred that there was significant improvements in the properties and load bearing capacity of the polymers [8-10]. The solar irradiance, stress concentration, and dynamic instability were some of the other properties studied with various biocomposites [11-13]. The biocomposites are also subjected to thermal analysis along with mechanical studies [14 -16].

Kristiina *Oksman et al*. studied that the incorporation of filler in PLA may change its crystallization behavior and consequently its thermal properties. Some filler, such as wood flour or wood fibers, promote the transcrystallization and thus modify crystalline morphology of PLA [17]. *Williams et al*. has presented the wear mechanism maps for various materials. He has concluded that when material is lost from a loaded surface through some form of mechanical interaction, the concentration, size and shape of the debris particle carry important information about the state of the surface [18]. *Briscoe et al*. have constructed wear mechanism maps for polymers in dry sliding conditions to illustrate the behavior of polymeric surfaces

Fig. 1: Poly lactic acid (PLA) pellets

when subjected to scratching, and their dependence on contact conditions [19]. *Cenna et al.* have analyzed the abrasive wear behavior of polymer matrix composites and concluded that the abrasion resistance of reinforced composite materials is a consequence of the micro-mechanics that occur during abrasive wear, which in turn are strongly dependent upon the hardness of the wear media [20].

In the past one decade, advanced bone implant materials have been deployed based on their biocompatibility and biotolerant. Biotolerant materials such as polymethyl methacrylate (PMMA), and bioinert materials such as aluminum oxide and titanium were widely used in bone implantations. These materials are characterized by fibrous thin tissue surfaces and high integrity in the bone system. Calcium phosphate, ceramics, and glass have also shown remarkable chemical integrity in bone implants. The problems faced with these materials are the cell proliferation resistance to corrosion and comparatively low biocompatibility [21-23].

For the last few decades, wide attention has been given to the development of polymer bio-composites due to the increasing environmental concerns and the decreasing fossil resources. Plastic waste disposal is a great problem for the effective functioning of the eco-system globally. However, it is a reality that if industries take change over from the usage of pure plastic products to polymer composites with mineral-reinforced fibers and fillers synthesized using agro resources, the threat to the eco-system can be faced effectively with the usage of polymer biocomposites obtained from natural resources. Nowadays, cissus quadrangular bio fiber has started to attract many researchers due to its unique properties. Various studies are being conducted to explore this bio-fiber compatibility. The efficacy of cissus quadrangularies in pharmaceutical mechanisms proved that the cissus quadrangularies exhibits excellent Antimicrobial activity, Anti-diabetic activity, Anti-inflammatory activity, Anti-oxidant activity, Bone Turnover activity, and also it was proved that the cissus quadrangularies helps in retaining the microarchitecture of long bones [24-26]. Hence, in this investigation, Basalt fiber reinforced PLA/CQ hybrid biocomposite is developed by the injection molding technique and then studied for Mechanical properties. The main aim of this work is to study the effect of Cissus quadrangularis on the mechanical properties of PLA/ basalt fiber/. Cissus quadrangularis is added with composites at different weight fractions so that the fabricated polymer bio-composite can be deployed for further medical applications such as bone transplantations.

EXPERIMENTAL SECTION

Materials

In the present research, the polymer matrix used for compounding hybrid composites is poly lactic acid (PLA). Poly lactic acid (PLA) Biopolymer 3052 D designed for injection molding application was obtained from Nature-Tec India Pvt Ltd., Chennai, Tamilnadu, India. It was dried at 120°C for 6 hours prior to extrusion to improve the adhesion between the fibers and the matrix material. The schematic view of PLA pellets is shown in Fig. 1.

Besides natural fibers, a promising alternative may be the usage of basalt fibers, which is a novel reinforcement for composites. Although basalt fibers are not biodegradable but still considered as natural, because they can be produced by using basalt (volcanic) rocks, which can be found in nature and virtually in every country around the globe. Moreover, basalt is biologically inert, and the weathering of basalt rocks increase the mineral content of soil which further strengthens its natural character. Basalt fibers are typically produced by two different technologies: Junkers method and spinneret technology. The shorter basalt fibers are prepared by the Junkers method and the continuous fibers are prepared by the spinneret technology. Basalt base composites can replace steel (1 kg of basalt reinforces equals 9.6 kg of steel) as lightweight material can be obtained from basalt fiber. The basalt has low density like 2.8 g/cc to 2.9 g/cc, which is much lower than metal (steel) and closer to carbon and glass fibers. The basalt fiber used in this work

Fig. 2. Short basalt fibers

Fig. 3: Cissus quadrangularis

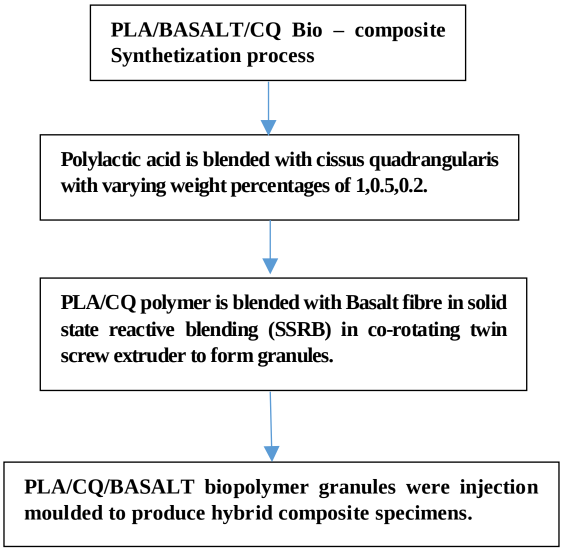


Fig. 4. Synthetization procedure of test samples

was supplied from Muktagiri Industrial Corporation, Borivali West, Mumbai, India, and it was supplied as silane treated, developed specially for strong adhesion with Poly lactic acid (PLA). The average diameter of the fibers was 13 μm and length about 4-6 mm. Schematic view of Short basalt fiber are shown in Fig. 2.

It is cultivated in plains coastal areas, jungles and wastelands up to 500m elevation. It influences the rate of fracture healing by influencing the early regeneration of all connective tissues involved in the healing and quicker mineralization of callus. The pictorial representation of Cissus quadrangularis is shown in Fig. 3.

Synthetization of biocomposites

Fabrication of basalt fiber reinforced PLA/CQ hybrid biocomposite consists of two stages. In the first stage PLA and CQ polymers are blended with basalt fibers by Solid-State Reactive Blending (SSRB) in co-rotating twin screw extruder into granules. And in the second stage extruded granules were injection molded to produce hybrid composite specimens. The systemization procedure involved in the fabrication of the test specimen is presented in Fig..4.

Solid state reaction blending by twin screw extruder

There are some challenges to overcome when using small-sized CQ in the extrusion process. The main challenges are the difficult feeding of the material into the extruder and the tendency of tiny materials to agglomerate when dry. To overcome this problem Cissus quadrangularis and PLA were blended with basalt fiber in a co-rotating twin screw extruder (CIPET, KOCHI, INDIA), specially designed for solid-state reactive blending (SSRB). The final process of extrusion of hybrid composites involves blending of premixed PLA/ CQ with basalt fiber in three different ratios such as PBC1, PBC2, and PBC3 with the ratio of PLA/BF/CQ as Shown in Table 1. It was inferred from the previous research works that 0, 25, 35, and 45 weight percentages of CQ added to polymers showed remarkable improvements in mechanical properties. With an intention of still exploring the compatibility and properties of Cissus quadrangular, the weight percentage is reduced in this research work. It is expected that the low content of CQ will produce remarkable impact in polymer matrix due its comparatively unique properties [27, 28]. 5 samples were fabricated in each composition of PLA/BASALT/CQ for testing purpose. The twin extruder is represented in Fig. 5. The twin screw speed is maintained at 150 rpm and extruded through 1mm gauge strand die at a speed of 10 mm per second. The strands were cooled in a water bath and then fed into pelletizer to make compound pellets. The strands extreuded from the

Table 1: Weight percentage of hybrid composites

Samples	Weight Percentage (%)		
	PLA	BF	CQ
PBC1	99	0	1
PBC2	87.5	12	0.5
PBC3	91.8	8	0.2

Fig. 5: Twin extruder

Fig. 6: Extruded composite from twin extruder

Fig. 7: (a). Cutting machine, (b). sample formulations I, II, III

Fig. 8: Injection moulding machine

twin extruder are shown in Fig. 6.The compounded pellets were dried at 60°C in a vacuum for 8 hrs.

Specimen Preparation by Injection moulding

PLA is processed in injection moulding machine. The cutting machine used for processesing and the final formulations of biocomposites are shown in Fig. 7. (a) and (b).The PLA/BF/CQ compounded pellets were processed by injection molding at a melt temperature of 170°C, back pressure of 7 bar, screw speed of 60 mm/ sec, and mold temperature of 30°C. A screw diameter 30 mm with Length to diameter ratio of 20 is used to obtain a hybrid composite specimen in the Injectiomoldingng machine as shown in Fig. 8. Specimens fothe r mechanical tests, such as flexural test, impact test, and tensile test were produced as per ASTM standards namely ASTM D638, ASTM D790 and ASTM D256 respectively. The test specimens for thermal behavior such as Differential Scanning Calorimetry (DSC), Thermo Gravimetric analysis (TGA), and Dynamic Mechanical analysis (DMA) were also fabricated according to ASTM E794, ASTM E 1131, and ASTM D4065 standards respectively. The composite specimens are shown in Fig. 9.

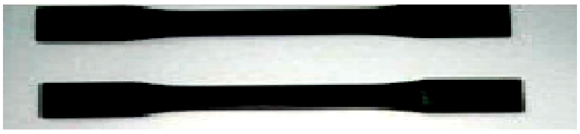
Mechanical properties testing

Tensile testing

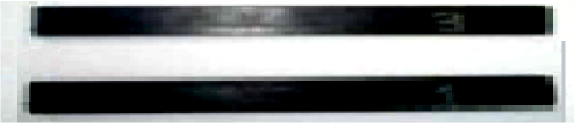
A universal mechanical testing machine Ziwck 1455, with a 20 kN loading capacity was used to measure the tensile properties of the PLA/BF/CQ composites. A series of tensile experiments of different PLA/BF/CQ composites were performed at room temperature to investigate the mechanical properties under tension. A load cell of 10 kN and constant crosshead speed of 1mm/min and 10 mm/min for the tensile modulus and the tensile ultimate stress was applied respectively. The speed

(a) Formulation 1 **(b) Formulation 2** **(c) Formulation 3**

Fig. 9: Testing specimens



(a) : Tensile Strength Specimen



(b) : Flexural Strength Specimen

Fig. 10: Tensile and flexural specimens

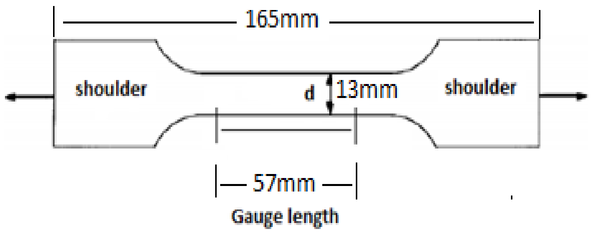


Fig. 11: Dimensions of tensile test specimen

and load are selected depending upon the flexural and impact strength of the biocomposite. As per the ASTM D 638 standard, for the polymer biocomposite, the nominal speed and load are selected.The testing specimens are shown in Fig. 10. The tensile test is carried in the normal size specimen and the dimensions of specimen is presented in the Fig. 11.

Three-point bending flexural testing

Static three-point test of the manufactured polymer composites were performed on rectangular specimens of 12.8 × 2.8 mm^2 using an Instron 4301 universal testing machine with a 5 kN load capacity. The applied crosshead speed was 1 $mm \cdot min^{-1}$and the gauge length was 63 mm. The test was performed at room temperature. and the average of at least three statically relevant flexural data has been reported.

Notched izod impact test

The standard ASTM D256 test method is used to test the impact properties of PLA/BF/CQ composite specimens. The specimens are prepared to the dimensions of 64 x 12 x 4 mm with a V- V-notch. The specimen is clamped into the pendulum impact test fixture with the notched side facing the striking edge of the pendulum. The pendulum is released and allowed to strike through the specimen. If breakage does not occur, a heavier hammer is used until failure occurs. Since many materials (especially thermoplastics) exhibit lower impact strength at reduced temperatures, it is appropriate to test materials at temperatures that simulate the intended end-use environment. Toughness measurement of PLA/BF/CQ composites through impact testing is measured using the following equation.

Impact Strength = [Impact Energy / Area of the specimen] Joules /mm^2

Water absorption test at ASTM D570

Water absorption is used to determine the amount of water absorbed under specified conditions. Factors affecting water absorption include the type of plastic, additives used, temperature, and length of exposure. The performance of the materials in water or humid environments can be unfolded using the water absorption test and the test confirms whether the composite material is hydrophobic

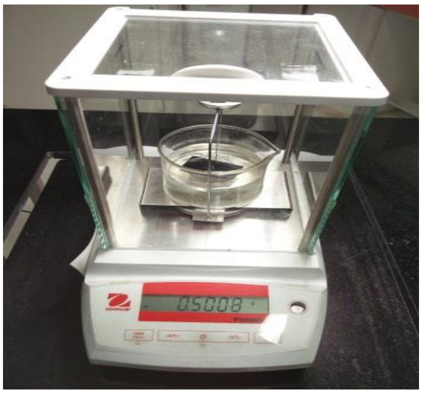


Fig. 12: Water absorption tester

Fig. 13: shore D hardness tester

Fig. 14: Loading arrangements for tensile test

or hydrophilic in nature. This test method covers the determination of the relative rate of absorption of water by plastics when immersed. This test method is used for testing all types of plastics, including cast, hot-molded, and cold-molded resinous products, and both homogeneous and laminated plastics in rod and tube form and in sheets of 0.13 mm. For the water absorption test, the specimens are dried in an oven for a specified time and temperature and then placed in a desiccator to cool. Immediately upon cooling the specimens are weighed. Water Absorption Tester is shown in Fig. 12.

Shore D hardness test (ASTM D-2240)

The Shore “D” Durometer is utilized to measure the hardness of harder materials such as rigid epoxy based materials. Shore D Hardness tester is shown in Fig. 13.

Morphological Characterization

Scanning electron microscopy (SEM)

The morphological characteristics as well as the fractured and worn-out surface of the raw materials and the manufactured polymeric matrix bio composites were observed via Scanning Electron Microscopy (SEM) using a SEM JEOL JSM 6060.

RESULTS AND DISCUSSION

Tensile strength of PLA/BF/CQ composites

Tensile tests were performed with Universal Testing Machine Instron according to ASTM D638 standards. Crosshead speeds for injection molded samples were 6.5 cm/min, respectively. Dog bone-shaped molded samples were used and measurements were done at 24°C and 5 kN load cell was used in the measurements. The loading setupp is shown in Fig. 14.

The highest initial tensile strength is seen for the 80/20 wt% ratio of PLA/BF, at 61.06 MPa. Ratio of 90/10 wt % of PLA/BF is the second strongest at 60.99 MPa, after which the tensile strengths drop considerably for the 70/30 wt % of PLA/BF (51.83 MPa) and virgin PLA (48.47 MPa) composite. Tensile strength for the PLA/BF composite increased regularly with fiber loading. For PLA/BF/CQ composite the tensile strength showed maximum value at 20% fiber loading. This composite showed higher tensile strength values at all fiber loadings indicating enhanced adhesion in the composite. The optimum fiber loading is increased from 10 to 20%, which is again an indication of enhancement in fiber/matrix adhesion in the composite. The variation of the tensile strength of PLA/BF composites with different fiber loading is shown in Fig. 15. It is clearly observed that the tensile strength is improving with an increase in fiber reinforcement. This shows an effective stress transfer within the composite after the incorporation of fibers into the matrix. It has been reported in their study that the tensile modulus depends mainly on the fiber volume

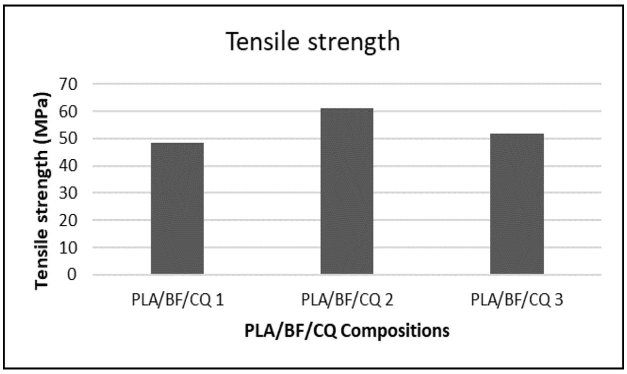
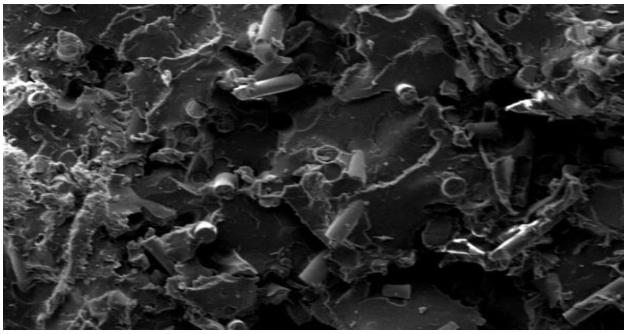
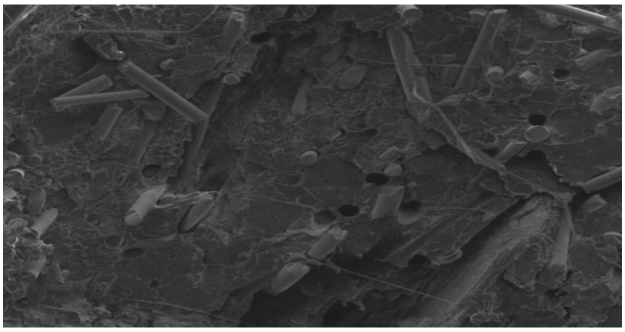


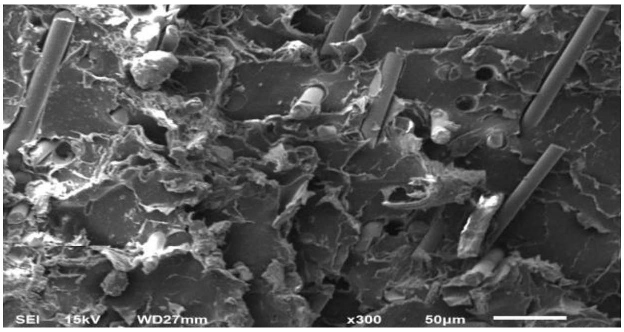
Fig. 15: Tensile strength of PLA/BF/CQ graphical representation



(a) PLA/BF/CQ tensile specimen 1



(b) PLA/BF/CQ tensile specimen 2



(c) PLA/BF/CQ tensile specimen 3

Fig. 16: SEM image of PLA/BF/CQ specimen

fraction and not on the physical structure of the fibers. It is also observed that the composite with 20 wt% fiber loading exhibits better tensile strength and modulus as compared to other composites.

Fig. 17: Loading arrangements for flexural test

The interfacial bonding between basalt fiber and Cissus quadrangularis with PLA matrix observed in SEM photographs are shown in Figs. 16 which reveals that the high interface adhesion resulted in better tensile strength. The reduction of strength at low basalt/ Cissus quadrangularis content may be attributed to the increasing probability of fiber agglomeration. It is essential that adhesive bonding forces between fiber and matrix be high to minimize fiber pull-out. The adequate bonding is essential to maximize the stress transmittance from the weak matrix to the strong fibers and thereby improve the mechanical properties of the material [29-34].

For the tensile tested composite specimens, the debonding at the interface of the PLA matrix and basalt fiber with Cissus quadrangularis dispersed shows a pullout of the basalt fibers exhibiting voids clearly in SEM photographs. This mainly happens due to a lack of proper interfacial adhesion. The micrographs clearly show that the basalt fiber is randomly oriented and a large number of particles are subjected to tensile stresses acting on the planes perpendicular to them where crack propagation takes place. As the basalt fiber has low splitting energy it undergoes delamination. Occurrences of high levels of particles pulling out are due to low strength and low elongation at break.

Flexural strength of PLA/BF/CQ composite

Figs. 17 & 18 illustrate the effect of fiber loading on the flexural behavior of composites. It is observed from Fig. that the flexural strength of the composite decreased at 30 wt.% fiber loading but further at 20% wt of fiber in the PLA matrix increases the flexural properties. The initial reduction in flexural properties may be due to the weak interfacial bonding. At 10%wt of basalt fiber a noticeable

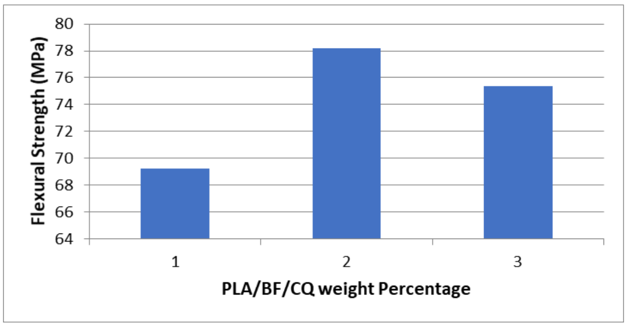
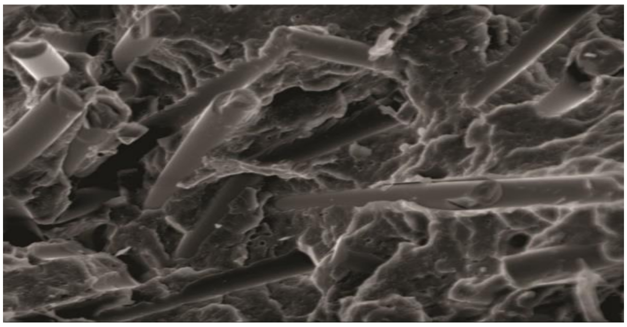
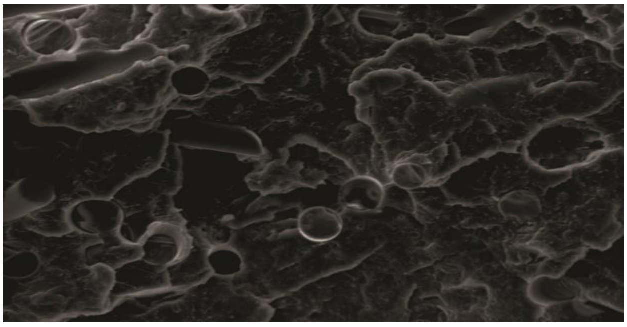


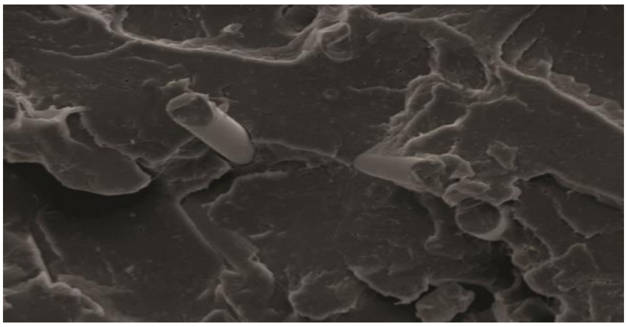
Fig. 18: Flexural strength of PLA/BF/CQ graphical representation



(a) PLA/BF/CQ flexural specimen 1



(b) PLA/BF/CQ flexural specimen 2



(c) PLA/BF/CQ flexural specimen 3

Fig. 19: SEM image of bio - composite specimens

improvement in tensile strength is observed, the further addition of fiber improves the flexural strength of composite.

This may be due to the favorable entanglement of the polymer chain with reinforcement which has overcome the weak fiber matrix adhesion with an increase in fiber loading. Composite with 48 wt.% fiber loading shows maximum of composites under the present study. The three-point bend test is carried out to obtain the flexural properties of flexural strength and modulus as compared to all other sets of composite samples using the same universal testing machine Instron 1195. The tests were performed as per the ASTM D 790 standards with a cross-head speed of 10 mm/min. The flexural strength (*FS*) of the composite specimen is determined using Equation (1).

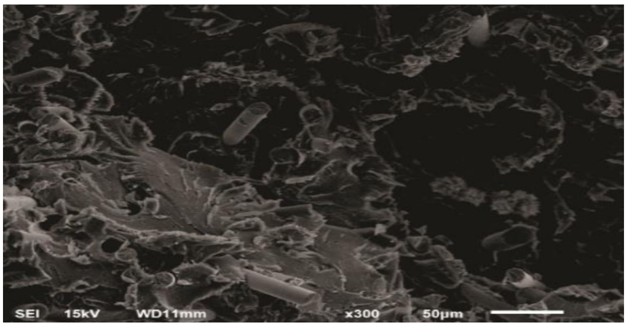
$$F_s = \frac{3PL}{2bt^2} \qquad (1)$$

Where, P is the load applied. L is the span length of the sample; b and t are the width and thickness of the sample, respectively.

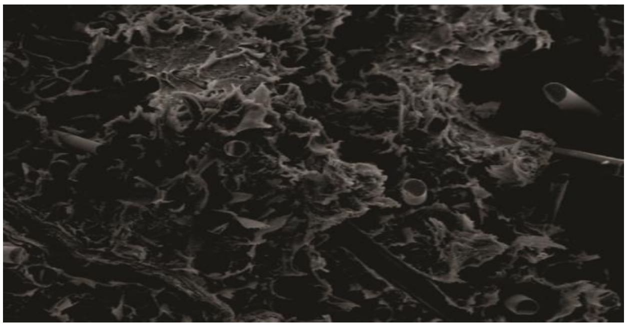
The highest bending strength is seen for the 80/20 wt% ratio of PLA/BF/CQ at 75.75 MPa. Ratio of 90/10 wt % of PLA/BF/CQ is the second strongest at 70.20 MPa, after which the flexural strength drops considerably for the 70/30 wt % of PLA/BF/CQ (69.04 MPa) and virgin PLA (64.65 MPa) composite. For PLA/BF composite the Flexural strength showed maximum value at 20% fiber loading. The fiber composites showed higher flexural strength values at all fiber loadings indicating enhanced adhesion in the composite. The optimum fiber loading is increased from 10 to 20%, which is again an indication of enhancement in fiber/matrix adhesion in the composite. At higher fiber loadings of 30%, the flexural strength values showed a gradual decrease. Figs. 19 (a), (b) and (c) show the SEM photographs of flexural fracture surface of PBC1, PBC2 and PBC3. The SEM shows the breakage of fiber material and damage of the matrix material. It also shows the fiber are totally misaligned and the formation of voids in between the matrix.

Impact strength of hybrid composites

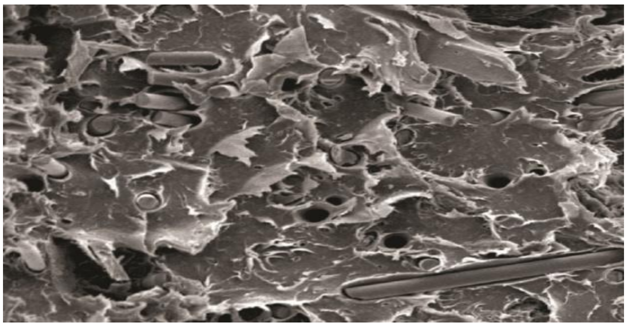
The impact strength of the short basalt fiber composites was measured with varying fiber content and fiber lengths. The gradual increase in impact strength is due to the increases in fiber content and also due to compression pressure which eliminates void contents in the composites. And the length of the fiber also contributed to increasing the impact strength. Particularly 13wt% of fiber and fillers shows better property than others. Due to the incorporation of fiber contents in the composite, voids in the composite are significantly reduced. Fiber plays an importance



(a) PLA/BF/CQ impact specimen 1



(b) PLA/BF/CQ impact specimen 2



(c) PLA/BF/CQ impact specimen 3

Fig. 20: SEM image of PLA/CQ bio composites

role in impact strength; they should resist the crack propagation and act as a load transfer medium. Improvement in impact strength of the composites is due to increment in fiber content. The applied stress is transferred effectively due to effective interfacial bonding strength. Weight percentage of fiber has significantly affect the impact strength to withstand sudden load, when the impact energy exceeds the fiber strength fiber fracture occurs, and the fracture transfers through the composites.

The izod impact strength of basalt fiber reinforced PLA/CQ composites When PLA/CQ matrix was reinforced with 12% wt of basalt and 0.5% wt of Cissus quadrangularis, the impact strength is 8.4 further reduction of basalt fiber to the polymer composite decreases the impact strength. This is due to the addition of basalt and

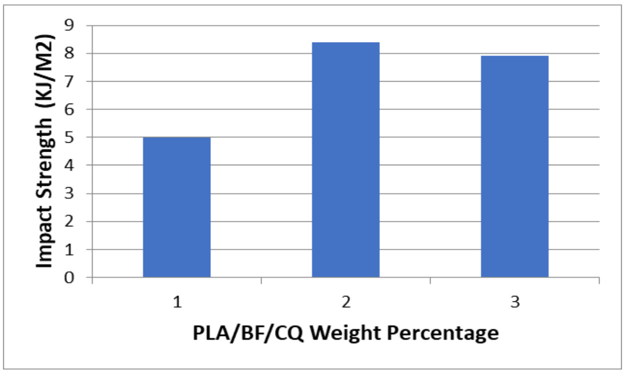


Fig. 21: Impact strength of PLA/BF/CQ graphical representation

Cissus quadrangularis to PLA matrix increases the toughness. Figs. 20 (a), (b), and (c) show SEM photographs of the impact fracture surface of a different combination of basalt fiber reinforced PLA/CQ composites.

The SEM shows the breaking of fiber, submerged micro cutting, and deep straining of matrix that is responsible for the least impact strength in the case of PBC2, PBC3. Matrix cracking is the first type of failure, usually caused by low-velocity impact, and occurs parallel to the fibers due to tension, compression, and shearing. Shear cracking (inclination of 45º) and bending cracking (vertical inclination) are examples of matrix cracking. It is the first damage that affects the structure but cannot be seen by the naked eye. The impact response of the structure is not affected by matrix cracking. It can decrease the interlaminar shear and compression strength properties on the resin or the fiber/resin interface. The impact strength exhibited by all three compositions is represented in Fig. 21. The highest impact strength is witnessed in PLA/BF/CQ 2 composition. The interfacial bonding between PLA/BASALT/CQ was confirmed from the scanned electron microscopic studies conducted. The uniform distribution of basalt fibers and cissus quandragularies is evident from the microscopic images.

Water absorption 24-hour/equilibrium ASTM D570

A water absorption test is used to determine the amount of water absorbed under specified conditions. Factors affecting water absorption include the type of plastic, additives used, temperature, and length of exposure. The results reflect the performance of the materials in water or humid environments. This test method covers the determination of the relative rate of absorption of water by plastics when immersed. This test method is intended

Table 2: Water absorption test results

PROPERTY	STANDARD	PBC 1	PBC 2	PBC 3
Water Absorption	ASTM D570	0.11	0.15	0.12

Table 3: Shore D hardness test results

PROPERTY	STANDARD	PBC 1	PBC 2	PBC 3
SHORE D HARDNESS TEST	(ASTM D-2240)	32.0	40.0	38.0

to apply to the testing of all types of plastics, including cast, hot-molded, and cold-molded resinous products, and both homogeneous and laminated plastics in rod and tube form and in sheets 0.13 mm. Water Absorption Test results are given in Table 2. It was inferred from the experimental work that the higher water absorption rate resulted in the extraction of water soluble components and resulted in adverse effects in mechanical properties such as tensile strength, hardness and impact strength, the load bearing capacity of the biopolymer is found to get reduced.

Shore D hardness test (ASTM D-2240)

Shore Hardness (ASTM D-2240) Shore hardness is a relative measure of load-bearing capacity of the material. The Shore "D" Durometer is utilized to measure the hardness of the fabricated biocomposites. Shore D Hardness Test Results are given in Table 3. The test methods employed vary greatly from a field-applied test to a very controlled laboratory test. The Shore "A" Durometer is utilized to measure elastomeric materials that are relatively soft in nature such as a silicone or polyurethane sealant, while the Shore "D" Durometer is utilized to measure the hardness of harder materials such as rigid epoxy-based materials. Both scales are from 0 to 100; hence a unit-to-unit correlation is not always possible dependent upon the particular hardness of the material being measured. Hardness is highly influenced by the distribution of Cissus quadrangularies and basalt fibers in polylactic acid. Uniform distribution and excellent interfacial bonding will always produce remarkable improvements in the load-bearing capacity of the Biopolymer. The results observed show that the PBC 2 composition exhibits significant hardness when compared to the other two compositions. This is attributed to the uniform distribution of basalt fibers and Cissus, which act as load-bearing components and resist deformation on the fabricated components.

Outcomes of the Pla/Basalt/Cq Bio-composite for bone Implantation

The experimental investigations with the various compositions of PLA/BASALT/CQ proved that the composition PLA/BASALT/CQ 2 exhibits better properties when compared with the other compositions synthesized. This composition of biocomposite is used for further comparative study with the outcomes of the various materials used previously for bone implantations. The outcomes of the present research work on PLA/BASALT/CQ is compared with the outcomes of similar works carried out with other materials such as Polyether ether ketone (PEEK), titanium, and Magnesium for bone implantation applications. The tensile strength and flexural strength of various compositions of PEEK with polymethyl methacrylate (PMMA) and carbon fiber produced by the electrospinning method is compared with the tensile and flexural strength of PLA/BASALT/CQ 2 composition biocomposites [35]. The PEEK is reinforced with PMMA and carbon fiber with different compositions ([60 PEEK : 60 wt% of PEEK, 35 wt% of PMMA, 5 wt% of carbon fiber], [55 PEEK : 55 wt% of PEEK, 35 wt% of PMMA, 10 wt% of carbon fiber], [45 PEEK : 45 wt% of PEEK, 35 wt% of PMMA, 20 wt% of carbon fiber], [35 PEEK : 35 wt% of PEEK, 35 wt% of PMMA, 30 wt% of carbon fiber] . It is inferred from the comparative study that the 45 PEEK & 35 PEEK is comparatively high and the tensile strength of PLA/BASALT/CQ is comparatively low. But the biocompatibility of PLA/BASALT/CQ is higher when compared to the polymer composites. A typical trend is observed in flexural strength where the PLA/BASALT/CQ bio composite exhibited low flexural strength when compared to other compositions of Polyether ether ketone. The comparison of mechanical properties of different weight proportions of PEEK with PLA/BASALT/CQ is represented in Table 4. The tensile strength and flexural strength of various compositions of PEEK is compared with PLA/BASALT/CQ and is represented in Fig. 22 and Fig. 23.

Table 4: Comparison of mechanical properties of peek with PLA/BASALT/CQ

Materials	Tensile Strength (MPa)	Flexural Strength (MPa)
60 PEEK	70	140
55 PEEK	110	145
45 PEEK	140	164
35 PEEK	130	150
PLA/BASALT/CQ	60	78

Table 5: Comparison of mechanical properties of natural bone, Mg alloys, Ti alloys, With PLA/BASALT/CQ bio-composites

Materials	Tensile strength (MPa)	Impact Strength (MPa)
Natural Bone	130 – 180	3 – 6
Magnesium Alloys	100 – 120	15 – 35
Titanium Alloys	750 – 1110	55 - 115
Polyether ether Ketone	95	-
PLA/BASALT/CQ	60	8

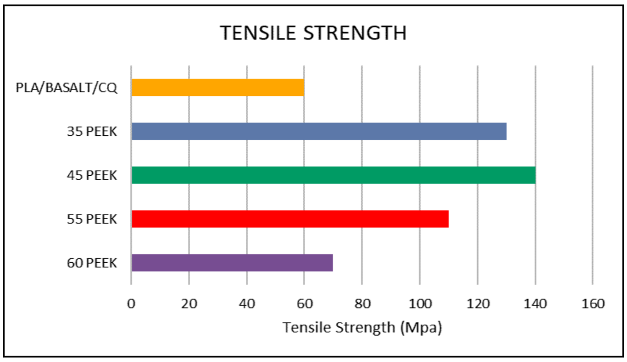


Fig. 22: Comparison of tensile strength of various compositions of PEEK/PMMA/CF with PLA/BASALT/CQ

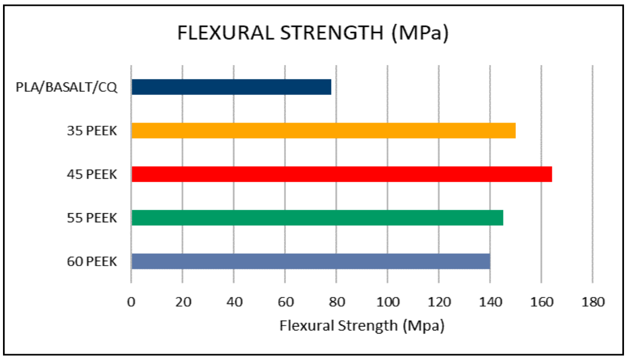


Fig. 23: Comparison of Flexural strength of various compositions of PEEK/PMMA/CF with PLA/BASALT/CQ

The mechanical properties of PLA/BASALT/CQ is compared with the mechanical properties of natural bone, Magnesium alloys, titanium alloys and polyether ether ketone as observed by *Yo Guo et.al* (2022) and represented in Table 5. The comparative study proved that the impact strength of PLA/BASALT/CQ is comparatively higher when compared to natural bone but the tensile strength of natural bone is 30% higher than the PLA/BASALT/CQ biocomposite. Magnesium and titanium alloys exhibited higher tensile strength and impact strength when compared to PLA/BASALT/CQ [36-38]. In spite of having low tensile strength, flexural strength and impact strength when compared to magnesium alloys, titanium alloys and PEEK composites, the PLA/BASALT/CQ has the convincing point of exhibiting lightweight and biocompatible which is very important when human comfort is considered. Corrosion resistance, biodegradability and biocompatibility are some of the promising properties of biocomposites that makes these materials a tough competent for magnesium and titanium alloys. Considering the human physiological system, it is further decided to conduct study on osteopromotive, bioactive and biological properties to further explore the compatibility of this PLA/BASALT/CQ biocomposite for deploying in clinical applications.

CONCLUSIONS

The mechanical and morphological properties of PLA mixed BASALT/CISSUS have been investigated. There are three varieties of proportions of materials used for the investigation to find the proportion giving the promising result. The “Twin Screw Extruder” process is selected for making pellets of composites. The “Injection Moulding Machine” is used for making the composites using the pellets. Some additional tests were also conducted on composites like the “water absorption test” to test their other properties for functional purposes [39,40]. The highest initial tensile strength is seen for the 80/20 wt% ratio of PLA/BF, at 61.06 MPa. The ratio of 90/10 wt % of PLA/BF is the second strongest at 60.99 MPa, after which the tensile strengths drop considerably for the 70/30 wt % of PLA/BF (51.83 MPa) and virgin PLA (48.47 MPa) composite. The results observed in hardness test showed that the PBC 2 composition exhibits significant hardness when compared to other two compositions. This composite can be used for bone replacement, because these composites fulfill the function of bone. It also has some additional properties like bio-degradation after its lifetime so it is eco-friendly and it will eliminate the problems faced by using metal plates instead of bone. These composites also have medicinal functions because of Cissus quadrangularis. This composite gives an efficient result as that of bone instead of considering metal as a replacement. The study shows that significant improvement in tensile, flexural, and impact strength of the hybrid composites was observed as the weight percentage of BF and CQ increases. The optimum weight percentage of basalt fiber and Cissus quadrangularis were found to be 12% and 0.5% respectively which augmented the mechanical properties of the composites. This is a novel and innovative finding of new hybrid composites of PLA/BF*/CQ* composites in the applications of bio-medical engineering [41-43].

Received : Aug. 11 , 2022; Accepted : Nov. 21 , 2022

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