Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Evaluation Of Mechanical Properties Of Sustainable And Low Cost Coir Fiber Composite: An Experimental Approach

Surendra Singh Godara, Bharat Goswami

Department of Mechanical Engineering, Rajasthan Technical University Kota, India
Corresponding Author: bharatinku94@gmail.com, (M):8209551184

Now day's upcoming composites are concentrating on natural fiber like: Coir fiber; banana fiber; jute fiber and pineapple fiber etc. Natural fibers are used to make reinforced composites because of its accessibility, durability and adaptability. Simultaneously, these composites should be environment friendly, and its biodegradable. The emergence of green fibers leads to lesser ecological effect because of the biodegradable qualities in its production.
The mechanical behaviors of coir fiber-reinforced composites in terms of tensile, flexural, impact, and hardness were tested, according to ASTM standards, and tested done in well proof lab (MRC lab in MNIT Jaipur). The short treated coir fibers were utilized in reinforcement composite material, with varying ratios of length and made 3 composites (C_1, C_2, C_3) with 30% coir fiber, epoxy resin (LY-556) as matrix material, and hardener (HY-951) both took 70% as the ratio of 10:1 and fly ash as a filler material used last two composites (C_4, C_5), in C_4 fiber-25%, metrix-70% and filler-5%, similar in C_5 fiber-20%, metrix-70% and filler-10%.

Keywords: Coir fibre, Epoxy resin (LY-556), and hardener (HY-951), mechanical properties, Filler materials Fly ash.

1. Introduction

Plastics and ceramics are the main trending composites materials since the 1970s. These composites have proved to be able to the lightweight material, and less cost other compounds material. As a result of trying to be manufacturing inexpensive aesthetic compounds, many innovative manufacturing technologies are presently utilized in the composites manufacturing plants. The improvements are not being sufficient to reduce the price constraint in production techniques mainly for composites components. To be competitive for metals, there should be a unified attempt for drawing, materials, production process, grade guarantee, and system management. The glory of the composites industry is that trading applications of composites offer major business good time compared to the aerospace sector caused by the relatively great dimensions of the conveying industry. In recent years, the transfer of compounds solicitations by the aerospace industry to further trading make use of has begun to be imminent [1]. A composite is a substance that was up of at least two separate materials that are integrated in a way that permits the material to stay prominent and identifiable [2]. The production of brown fiber, which is extracted mechanically from mature brown husk, is increasing dramatically from 335 to 459 thousand tonnes, while the production of white fiber, which is extracted using

traditional backwater retting methods in India, is steadily declining from 95 to 81 thousand tonnes [Mishra & Basu [3]].
The availability of natural fibre, low cost, simple recycling process, light weight, and biodegradability qualities of natural fibre polymer composite goods make them the most popular. Utilizing both treated and untreated fibres, researchers have evaluated the mechanical properties and biodegradability of composite materials formed from coir fibres. Reportedly, treated fibres utilised in the creation of hybrid polymers Natural fibres are sustainable along with acquired from natural assets that confer various benefits, comprising small density, allowable strength to weight ratio attributes, better sound subsiding potentiality, small abrasive, little price, greater environmentally-safe, and the alive of huge assets. Numerous Studies are being carried out to ascertain how best to employ natural fibres as a supporting component composites made of polymer matrix. Owing to its hydrophilic properties and instability in both heat and chemicals, natural fibre poses several obstacles for researchers to overcome in order to make it suited for their needs. Natural fibres can now, however, take the place of synthetic ones to some extent by using surface modification procedures to make them compatible with polymer matrixes.
Obele & Ishidi [4] developed different filler loadings (10, 20, 30, 40, and 50 weight %) of coir fiber/epoxy resin composites for the potential production of helmet shells. The fiber's length was 30 mm, and its epoxy resin to hardener ratio was 1:0.8. Universal testing equipment was used to create and test fifty short beams measuring four millimetres by nineteen millimetres by three hundred millimetres. In addition, tensile and impact tests were conducted. The tensile modulus, impact strength, and tensile strength were then computed. A kind of aromatic polyamide called polyaramid is utilized to reinforce materials because of its high thermal stability. The structure and properties of an epoxy matrix composite reinforced with three different natural fibers (jute, bagasse, and coir fibers) were investigated in relation to the addition of 2 weight percent of nano titanium oxide and 5% polyaramid fibers [Fayaz et al. [5]. Hwang et al. [6] studied and investigated the different composites' for mechanical characteristics, plastic cracking, and impact resistance are how affected when short random coconut fibers are added. Before the fibers were added to the composite mixture, they were pretreated the fibres by washing and boiling. Various volume fractions of random, short coconut fiber were used to create cementitious composite mixes created utilizing the Densified Mixture Design Algorithm (DMDA) approach.

Babu & Vasudevan [7] studied and presented stiffness and strength characteristics of soil reinforced with coir fibers. The strength and stiffness of the soil reaction caused by the fiber inclusion were assessed in tri-axial shear apparatus using cylindrical soil specimens made from soil samples reinforced with coir fibers of varying diameters. The outcomes were compared to those of unreinforced soils. The findings indicate that the clay soil under investigation becomes more robust and stiff when coir is added at a random rate of 1% to 2%. The study on examines how adding coir fibers to black cotton soils improves their strength, swelling, shrinkage, and compressibility behaviour was carried out by Babu & Vasudevan et al. [8].
Maliakal & Thiyyakkandi [9] examined the clay reinforced material's shear strength with coir fibers that are randomly dispersed using a set of consolidated undrained triaxial compression tests. Test findings indicate that as fiber content (Wf) and fiber aspect ratio (Ar) rise, so ensures

the major primary stress at failure for the clay-coir fiber matrix. Anggraini et al. [10] showed that the adding lime, coir fiber, and lengthening the curing period enhanced both the tensile and compressive strengths. The link between the indirect tensile strength and the unconfined compressive strength of the soft soil was predicted based on the test results.
Dutta et al. [11] studied and presented the impact of treated coir fibers, which are 15 mm long, affect clay's unconfined compressive strength. The work used dry coir fibers that had been treated with carbon tetrachloride and sodium hydroxide. The range of the coir fiber content was 0.4% to 1.6%. The findings exppressed that adding sodium hydroxide and carbon tetrachloride to clay and clay containing dried coir fibers can boost their unconfined compressive strength.
Ali [12] presented the coconut fibers versatility and their uses in many engineering fields—particularly as a building material in civil engineering—are discussed in this study. Extracted from the husk of the coconut fruit, coconut fiber is one of the natural fibers found in tropical regions. Not only are the mechanical, chemical, and physical characteristics of coconut fibers displayed, but also those of composite materials (such as mortar, concrete, and/or cement pastes).
Vivek et al [13] examined the impact of chemical treatment on tensile strength. Behaviour of two woven and two nonwoven coir geotextiles were presented that the tensile elongation at failure was greater in the warp direction than in the weft direction. Yan et al. [14] reviewed and addressed the following topics: (1) Features of cellulosic monofilament fibers, such as their chemical composition, microstructure, mechanical properties, and cost; (2) comparison with synthetic fibers; (3) the correlation between the mechanical properties and chemical composition of the fibers; and (4) factors that influence the mechanical properties of the fibers. John et al. [15] analysis was conducted to compare the microstructure of a new and an existing blast-furnace slag cement coir reinforced composite. A 12-year-old house in São Paulo provided the aged samples from both the outside and interior walls. 1:1.5:0.504 (binder: sand: water, by mass) mortar reinforced with 2% of coir fiber by volume was used to create the house's panels. 10% gypsum and 2% lime were added to blast-furnace slag to activate the binder.
Cook et al. [16] discussed the usage of low-cost JBR roofing materials, namely randomly distributed short coir fiber reinforced cement composites. To get the best material, the material parameters were adjusted for fiber length, fiber volume, and compacting or casting pressure. for available, the applicable ASTM standards were followed for conducting tests for bending, impact, permeability, water absorption, combustibility, and dimensional stability. Ali et al. [17] experimentally determined the damping ratio and frequency of fundamental CFRC beams in addition to their mechanical properties. A comparison is made between the dynamic and static moduli. It is examined how cement mass and fiber lengths of 2.5, 5, and 7.5 cm are affected by 1%, 2%, 3%, and 5% fiber concentrations.
Ayrilmis et al. [18] assessed the mechanical, flammability, and physical characteristics of composite polypropylene (PP) panels reinforced with coconut fiber. The PP powder and a coupling agent, 3 weight percent maleic anhydride grafted PP (MAPP) powder, were combined with four different levels of coir fiber content (40, 50, 60, and 70% depending on the composition by weight). Sen & Reddy [19] studied that the composites made of plant fiber are still in the early stages of development. In comparison to other Jute, sisal, bamboo, coir,

and lignocellulosic fibers are among the many natural fibers that are of special interest because they form composites with high impact strength and moderate tensile and flexural capabilities. Townsend & Sette [20] approximately estimated the total number of workers in the natural fiber sector, including family labor, hired labor, and employment in industries that provide agricultural services, as well as full-time, year-round employment and part-time or seasonal employment, is approximately 60 million households, or 300 million people, or roughly 4% of the world's population. Mishra & Basu [3] studied and presented the production of brown fiber, which is extracted mechanically from mature husk with brown colour, is increasing dramatically from 335 to 459 thousand tonnes, while the production of white fiber, which is extracted using traditional backwater retting methods in India, is steadily declining from 95 to 81 thousand tonnes.

Paramasivam & Nathant [21] presented that the strength of corrugated slabs with different fiber volume fractions and aspect ratios has been investigated through flexural tests. Additionally, tests and reports have been made on the acoustic and thermal properties of these slabs. Praveen & Kurre [22] studied geo-synthetics with coir fiber in order to improve soil strength for their engineering profession. Coir fiber is incorporated into the soil mass at random to serve as reinforcement. Because fly ash is a plentiful waste material, it has been utilized at a number of construction sites. The project's cost can be decreased by using fly ash effectively, which has an advantage over conserving and protecting natural resources.

Table 1. The work done by various researchers with their year, country, method and outcomes

Author	**country**	**Method of Sample preparation**	**Result**
Yadav & Tiwari (2024) [23]	India	Open moulding process	The combination of treated coir fibres (1%) and cement has the virtue of clay- pond ash mixes up to 20% replacement, can be considered as an efficient method for ground improvement.
Yan et al. (2016) [24]	Germany	Vacuum bagging technique	Alkali treatment improved compressive and flexural strength of coir/cement composite.
Puttaswamygowda et al (2024) [25]	India	Open moulding process	The average mechanical strength increases with an increase in the fiber content.
Asyraf et al - 2024 [26]	Malaysia	Hand-layup method	This experimental investigation showed that 0°/90°/0°-oriented coir fiber in polymer composite could achieve greater impact strength and moisture resistance than stacked fiber in the same direction.

Yazli & Ismail -2024 [27]	Malay sia	Hand-layup method	The specific requirements for an outer car hood application, the coir fibre composite with the 20 wt% coir fibre content is the ideal mixture based on the composite index from the tests done.
Victor & Inyang -2024 [28]	Nigeri a	Hand-layup method	The results showed that the composites produced with fiber size less than 2.36 mm fiber loading have the most optimum tensile and hardness properties but the fewest impact strengths compared to other sizes.
Rajan et al 2020 [29]	India	Hand-layup method	The study showed that CaCo3 can be used to increase mechanical moduli values while reducing the polymer content.
Madyi & Kaymakci (2016) [30]	South Africa	Resin transfer moulding (RTM)	RTM process is recommended due to its favorable geometrical control.
Mishra et al. -2020 [31]	India	hand layup technique	The results of the investigation reveal that the unidirectional fibre reinforced composite has relatively higher magnitudes of the mechanical properties.
Jayabal et al. (2011) [32]	India	hand lay-up process	Comparing with untreated woven coir fiber-reinforced polyester composites, 40 % increase of tensile strength, 42 % increase of flexural strength and 20 % increase of impact strength were achieved by treated woven coir fiber reinforced polyester composites.
Saradava et al. -2013 [33]	India	hand lay-up process	The flexural strength of the coir polyester composites increases by adding the % of the red mud upto a certain limit and then decreases.. Barcol hardness of the coir-polyester composites increases by adding the % of the red mud.
Biswas et al. (2011) [34]	India	hand lay-up process	The fracture surfaces study of coir fiber reinforced epoxy composite after the tensile test, flexural test and impact test has been done. From this study it has been concluded that the poor interfacial bonding is responsible for low mechanical properties.
Dayal et al. -2018 [35]	India	hand lay-up process	The best result of mechanical strength obtained is from specimen 1 (walnut shell powder-50gm, coir fiber- 15gm, jute fiber-25gm,

			epoxy- 120ml) as compared to other specimens.
Faria et al. -2023 [36]	Germany	hand lay-up process	The high mechanical strength, resulted in a decrease in voids and an increase in the mechanical properties of the composites, for the composites produced with fibers treated with NaOH in relation to the resin.
Sadeq et al. (2022) [37]	Baghdad	hand lay-up process	The addition of coir in epoxy resin led to improve the hardness and compression strength. Compressive strength of the composites was increased with the higher grain size of the coir fibres while hardness showed an increment with smaller grain size.
Narayanan-2016 [38]	India	hand lay-up process	Here in this project we fabricated vehicle Brake Disc using Bi-directional 200gsm E -glass fiber with epoxy resin along with coir fiber as reinforcement material. Thereby aiming to reducing the amount of resin used and also improve its mechanical properties.
Lumintangi et al. -2022 [39]	Indonesia	hand lay-up process	The hybrid effect for longitudinal tensile stress and impact strength is positive. The maximum value for both tensile and impact strength.
Gayathri & Singh (2023) [40]	India	Open casting & hand lay up	The surface roughness of natural fibers improved the adhesion between the reinforcements and matrix material.
Marimuthu et al. -2019 [41]	India	hand lay-up process	The hardness of the composite increased. The impact strength increased with addition of coconut fiber in Epoxy Glass fiber composite.
Boopathi et al. -2023 [42]	India	hand lay-up process	The maximum tensile strength has been obtained by mixing flax/coir hybrid composite materials due to the high tensile strength of fiber.
Sathiyamurthy et al. -2011 [43]	India	hand lay-up process	The 2 per cent addition of calcium carbonate improved other mechanical properties. The fibre diameter of 0.18 mm generally gives better tensile and flexural properties.
Verma et al. -2013 [44]	India	hand lay-up process	The objective of the present study is to utilize the advantages offered by renewable resources

			for the development of composite materials based on coir fibers.
Rout et al. (2001) [45]	India	hand lay-up process	Surface modified coir fibres and polyester matrix can be molded into a cost effective but value added composite material.
Romli et al. -2012 [2446]	Malay sia	factorial experiment al data	Based on the ANOVA result, the coir fiber volume fraction appears to be the most dominant factor in influencing the tensile strength of the resultant composite.
Nam et al. (2011) [47]	Japan	hot press used to fabricate composite plates.	Alkali treatment of coir fibers increased the interfacial bonding strength and the wettability of the fibers by PBS resin leading to the enhancement in mechanical properties of the composites.
Darshan et al. -2021 [48]	India	Hand lay-up and compressio n moulding	Fiber treated with 8% NaOH mainly resulted in an increase in the tensile and bending strengths along with strain rate of hybrid composites.
Naveen & Yasaswi -2013 [49]	India	hand lay-up process	The composite having a coir fibers volume of 5% showed a significant result compared to high fiber loading composites due to the effect of material stiffness.
Harish et al. -2008 [50]	Usa & India	hand lay-up process	Coir/epoxy composites exhibit average values for the tensile strength, flexural strength and impact strength of 17.86 MPa, 31.08 MPa and 11.49 kJ/m2 , respectively.
Gopalan et al. -2022 [51]	India	Taguchi's L9 array & DOE technique	Length of reinforcing fibres is found to vary for upper bound properties. Small size coir fibre (0.001 mm) yields improved tensile behaviors and flexural modulus. However, long coir fibres are for higher flexural stress.
Bavan et al. (2021) [52]	Thaila nd & India	Fabrication of epoxy hybrid composites	The collected outcomes signify that reinforced fly ash and TiC nanoparticles enhanced the flexural modulus and strength of the produced composites, particularly in the condition of fly ash and TiC nanoparticles in the epoxy polymer.

Table 1 presented the sample casting methods by various researchers [23-52] from various countries and outcomes of their research. It is observed that the simplest method of sample casting is hand lay-up method, so the sample casting has been done by this method in this research/dissertation work.

In this regards, Yadav et al. [23] studied and characterized the materials, it was used a variety of standard Proctor tests, unconfined compressive strength, and split tensile strength tests to examine the behaviour of clay combined with pond ash, cement, and treated coir fibers. Yan et al. [24] studied the both untreated and alkali-treated (i.e., 5wt.%NaOH solution at 20 C for 30 min) coir fibers were utilized in work as reinforcement for cementitious (CFRC) and epoxy (CFRE) composites. The microstructures of untreated and treated coir fibers, fiber/epoxy, and fiber/cement interfaces were investigated using scanning electron microscopy (SEM). Vibration, tensile, and flexure tests were used to establish the mechanical characteristics of CFRE, whereas compression and four-point bending tests were used to determine the mechanical properties of CFRC. Puttaswamygowda et al. [25] studied the composite materials and emphasized for how crucial it is to comprehend and how natural fibers, nano clay, and epoxy resin interact in order to maximize the composite's performance in practical applications. By cleaning the fiber's surface of debris and lignin, the alkaline treatment improves the fiber's mechanical qualities and ability to connect with the matrix.

Asyraf et al. [26] **e**valuated the coir fiber reinforced composite's mechanical (flexural and impact) and moisture-resistant qualities. Three distinct fiber orientations were used to stack the fiber were: 0°/0°/0°, 0°/90°/0°, and 0°/+45°/0°. The hand lay-up approach was utilized to produce the composite. The results showed that the composite specimens with the orientation of 0°/0°/0° have the best water penetration resistance and flexural qualities. The optimal stacking order for impact properties was 0°/+45°/0°. Nonetheless, it provided the least amount of water resistance at this angle out of all the configurations that were examined. Yazli & Ismail [27] examined the potential of coir fiber composites for use in automotive applications, particularly for an automobile's exterior hood. It was used variable weight percentages of coir fiber (10%, 15%, and 20%) in combination with epoxy resin and hardener. Accordingly, the coir fiber composite with 20 weight % coir fiber content is the best mixture based on the composite index from the tests conducted. Victor & Inyang [28] advised for the production of low density polyethylene composites and it can also be used as an additive for the production of lightweight polymer materials for applications of packing tools, table top furniture designs, windows, door frames, cloth pegs, and stool tops, while reducing pollution by using nylon and waste sachets. According to the results, composites made with fiber loading less than 2.36 mm have the best tensile and hardness characteristics but the lowest impact strengths when compared to other sizes.

Rajan & Shanmugam [29] studied and presented the substantial improvement in the mechanical moduli and a slight rise in mechanical strengths by surface morphology, SEM pictures of the tensile test. The inclusion of $CaCO_3$ resulted in a 4.25% increase in impact strength, while the tensile and flexural moduli increased by 14.3% and 21.4%, respectively. Effective stress transfer occurred through the reinforcing coir fiber, according to SEM measurements. The $CaCO_3$ can be employed to lower the polymer content and raise mechanical moduli values. Madyira & Kaymakci [30] examined the resin transfer rate affects the product's performance. RTM is used to generate coir fiber/epoxy resin composites with varying resin transfer rates and fiber fractions for treated and untreated fibers. It was reported that stiffness and strength improved as the volume fraction increased, which was consistent with previous research. Nevertheless, the data showed that performance declined over a 30% fiber volume portion.

Mishra et al. [31] developed a natural fiber reinforced composite (NFRC) of three distinct fiber configurations—unidirectional, woven at an orientation of ±45°, and chopped fiber—are used to evaluate the composite. Jayabal et al. [10] investigated the average tensile, flexural, and impact strength values and observed 19.9 MPa, 31.3 MPa and 49.9kJ/m^2 respectively of the woven coir-polyester composites. The impact of NaOH treatment on the enhancement of mechanical characteristics of woven coir-polyester composites was examined. The treated woven coir fiber-reinforced polyester composites increased the tensile strength by 40%, the flexural strength by 42%, and the impact strength by 20%.
The combination of fibers and particles in a polymer may work in concert to produce better qualities. In this work, red mud-filled coir fiber reinforced polymer composites are processed and their mechanical properties are evaluated. Mechanical qualities are determined at different percentages of the red mud used as filler material by methodical experimentation [**32-47]**.
Darshan et al. [48] studied and described the process of creating a hybrid composite and testing the samples for a variety of mechanical and tribological tests, including slurry erosion, flexural, and tensile tests, for coir/sisal hybrid fibers with fly ash as filler in unsaturated polyester resin. In building technology, this material has been utilized for roofing in buildings and as a packaging material in automotive industry. The work on new class of polyester composites based on natural fibers, reinforced with coir and epoxy resin have been carried out to developed and characterized by [49-52]. The mechanical stresses can be assessed by using the trapezoidal plate theory analysis for linear or non-linear bending [53]. The sustainability is increasing due to enhancing the application of waste and degradable materials for various applications either in direct or indirect utilization of human beings [54-55]. The similar composite can be used in other applications in buildings for sustainable enhancement or to achieve sustainable development goals [56].
The strength of natural fibre composites is less than that of manufactured composite materials, nevertheless. So much study has been done to improve natural fibre composites. The drilling characteristics and mechanical attributes of coir-fibre-based hybrid epoxy composites are examined in this work in relation to the impacts of blending various natural fibres. The research gap has been specifically identified by the following coir-fibre-based composite research initiatives.

Therefore, natural fiber with resin matrix is used as reinforcement materials in presented work. Owing to its high specific strength will dominate a number of applications likes house's paneling, roofing materials, wall panels, coconut fibre boards, motorcycle helmets etc. For these applications natural fibers can be used as reinforcement composites. In addition to being durable, accessibility and lightweight, natural fibres are also comparatively quite affordable. Hand lay- up method had been done for the fabrication of composites materials. The study was carried out to understand the behaviour of fly ash on mechanical characteristics of coir epoxy composites. This work shows the mechanical properties of natural fiber-based reinforced composite made of epoxy resin as the matrix material and coir as the fiber and fly ash as a filler material.

2. Material and Methods:

The following work assertion has been rephrased as design and development of sustainable and low cost coir fiber composite which rooted on a thorough examination of the written word.

The primary target for the extant effort is to create and obtain composite by cellulose, hemicellulose, and lignin agricultural waste, and examine the developed composite's mechanical properties. In this segment provides information on the experimental materials methods in order that was taken into consideration for production of composites, the testing methods used in order to characterise composites, step by step, the raw materials:- Coconut coir fibre, Epoxy resin(LY556), Hardener(HY-951), Fly ash, Mold release wax

2.1 Materials used

This coconut coir fibre assembled in order to creation by compounded is sourced to regional materials. The coir fibres are first finely separated, and then they are chopped into pieces that are about 12 mm long. The matrix binder chosen is the epoxy resin (LY-556) Herenba Instruments & Engineers, distributes. Epoxy resin typically has subpar mechanical and thermal properties. The resin must go through a curing reaction in order to improve its qualities, during which the structure of the liner epoxy resin transforms into a three-dimensional cross-linked thermoset structure. Epoxy resin is mixed in a 10:1 ratio with hardener, a curing agent, to initiate the curing reaction. The homo-polymerization of resin occurs in the next step, which is exothermic in nature. The hardener or curing agent (HY-951) is also provided by Herenba Instruments & Engineers.

(a) (b)

Figure 1: (a) Epoxy (LY-556) and Hardner (HY-951), (b) Treated Coir Fibre.

2.2 Alkali treatment

Coir fibre is put through an therapy of alkali process to be able to improve the composites' physical and mechanical characteristics. Fibres are first prewashed with a significant volume that is distilled water before being seared at a stable thermal treatment of 50°C in an alkali treatment. The alkalization procedure involved submerging coir fibres of a specific weight in an aqueous solution of 5% (w/v) Sodium hydroxide (NaOH) in order to 3 hours at 70°C. Fibre is then taken out of the alkali solution and neutralised by dipping it in a 5% acetic acid solution. After that, it is thoroughly dried after being rinsing with distilled water for two hours during electric oven at 1100^0C [37].

2.3 Composite fabrication

The traditional approach known as using a hand lay-up is utilized in manufacturing composites. A 210 x 210 x 40 mm3 mold is employed. A 10:1 ratio of epoxy resin and the matching hardener is fully blended. Once the mold-releasing sheet has been sprayed with silicon, the chopped fibre and resin mixture are then carefully poured over the sheet while it is still inside the mold. The release agent's main function is to make it simpler to remove the composite from the mold when it has dried. Under a pressure of 20 kg over the cast, the combination is permitted to solidify within the mold in order to duration by 24 time hours. The specimen is then trimmed to the proper size for the mechanical testing. In this manufacturing process, fly ash is added to composites in weight percentages of 5% and 10% to improve their mechanical qualities. There are three types of composites manufactured by various creations, as exhibition in table no. 2.

Figure.2: Aluminium mold and Mold release wax.

Table 2: Labeling of reinforced composites material

Composites	Resin Epoxy (Weight %)	Coconut coir fibre –treated (Weight %)	Fly ash (weight %)
Composite 1	70	30(fibre length 5mm)	0
Composite 2	70	30(fibre length 20mm)	0
Composite 3	70	30(fibre length 30mm)	0
Composite 4	70	25	5
Composite 5	70	20	10

2.4 Tests of Mechanical Properties

2.4.1 Tensile strength

The composites underwent a tensile strength in accordance with ASTM D3039 standards. A common assessment device was used for test. The sample must be 100 x 15 x 6 mm3 in size. The composite cast had a dimension removed from it. The test was run at a constant strain rate of 2 mm/min. was run. Figure 3(a) depicts the configuration for the tensile test.

(a)

(b)

(c)

(d)

Figure 3: (a) Loading configuration for the tensile test (b) Arrangement for loading the three-point bending test (c) Vickers hardness testing (d) Impact testing [MRC lab]

2.4.2 Flexural strength

It greatest strength of tensile so that a composite is able to bear before breaking when bending is known as its flexural strength. The composites underwent a flexural test in accordance with ASTM D790-03 test specifications. The triangular the composites were put through a bend test on the identical global testing device with 1mm/min speed of cross head. Figure 3(b) depicts the loading setup for the flexural test. For each composite type, the test was run three times, and the mean score was calculated.

2.2.3 Hardness

The harnesses of composite specimens were measured using a Vicker-hardness test. The experimental setup for the hardness test is shown in Figure 3(c) under a force of 2.94 N, a 136° apical angle diamond intender was planned over the specimen's level. This indentation's two diagonals, D1 and D2, were measured after the load was removed. The hardness test was carried out in a Vickers hardness testing machine. The load applied to the composite specimen was 0.3 kg and the holding time was 10 seconds. In the Vickers hardness test, a square base pyramid-shaped diamond was used for testing.

2.4.4 Impact Test

Testing of impact was drive and determines impact strength of the materials. Until the examination, samples were put under intense strain for a brief period of time. Any material's higher impact strength demonstrates its capacity to withstand shocks.

The toughness and flexibility of the material both increase with the amount of impact energy. Figure 3(d) depicts the impact tester in visual form. As to strike the specimen, the pendulum was released from a height; the specimen was clamped inside the tester. In relation to impact energy measurements for several specimens were obtained straight from the dial indicator. According to ASTM D256 standard, the Izod impact test specimen of 64 mm × 12.7 mm × 3.2 mm size is prepared from the developed coconut coir fibre composite.

3. Result and Discussions

The mechanical characteristics of coir epoxy reinforced composites observed different based on the amount of fibre and fibre length and epoxy as a matrix and how much fly ash powder is added as an filler material. Thus, five composites C_1, C_2, C_3, C_4, and C_5 have prepared and tested for mechanical characteristics like tensile, flexural, hardness, and impact.

3.1 Composites' mechanical properties

The mechanical properties of composites are significantly affected by fiber length, amount of fiber, the amount of matrix and fly ash as a filler material, of composites. These mechanical properties are shown in Table 3, composites with various amount of fiber and fiber lengths, matrix amounts, and filler materials also undergoing thesis are shown.

Table 3: The composite mechanical characteristics

Name of Composite materials	Tensile strength(MPa)	Flexural strength (MPa)	Impact strength(kJ/m^2)	Hardness (Hv)
C_1	9.05	28.05	18.05	17.0
C_2	11.57	35.43	20.50	15.8
C_3	15.29	40.01	22.40	20.50
C_4	20.41	41.25	23.38	25.30
C_5	25.96	42.45	25.12	28.41

The table shows that the treated fibre with differ the amount of fibre with differ fiber length and the amount of matrix and filler material composites are stronger and improved the mechanical characteristics than the composites without filler material. The greatest composites out of all are C5 made using 10% fly ash and 20% coir treated fiber with 20mm fiber length gives great results. The simple explanation is that the way in which the due to the elimination of some coir fibre from the coconut fibre. Additionally, the Na in the NaOH solution causes the hydrogen being released from this hydroxide bond and to occupy the hydrogen position. This explains why the chemically treated fibre composites give great results.

3.2 Tensile strength:

On a gauge-length Universal Testing Machine (UTM) of 50 millimetre, tensile testing is done. This ASTM D3039 Standard specifies that the tensile test's specimen size is100 x 15 x 6 mm3. The mechanical attributes, such as break load, the table below lists the five specimen coir fibre composites' maximum ultimate tensile strengths. Figure 4 shows the impact of the differ amount of fiber with differ fiber length and the impact of filler loading on the tensile properties of the composite samples. It was observed from the test results that the value of tensile strength slightly improved due to the addition of differ the amount of fiber with differ fiber length and particulate filler. The maximum tensile strength was obtained for the specimen C_5 which consist of the filler loading of 10%, further incorporation of the filler in the matrix resulted in a reduction in the tensile properties. The maximum value of tensile strength was obtained at 25.96 MPa. Since the fibers are in general carry the load and the stress is transferred from the matrix, the addition of filler had an insignificant change in the tensile properties.

Table 4: Results from Experimental and Reference Paper Comparison

Experimentation Findings results		**Results of Reference Papers [12]**	
Composites	**Tensile strength (MPa)**	**Composites**	**Tensile strength (MPa)**
C_1	9.05	C_1	3.208
C_2	11.57	C_2	9.15
C_3	15.29	C_3	13.05
C_4	20.41	C_4	NIL
C_5	25.96	C_5	NIL

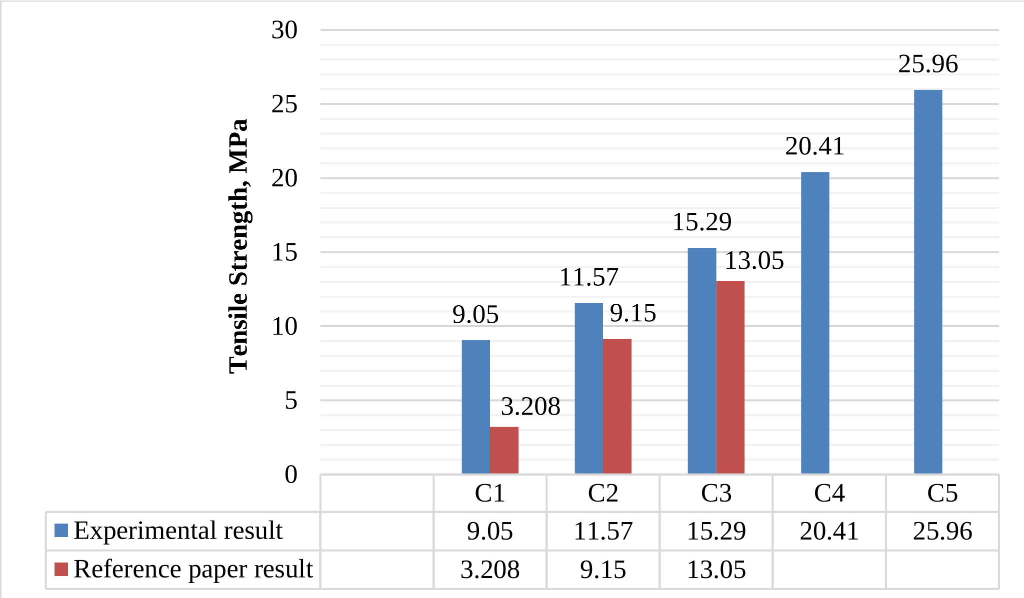


Fig. 4: Tensile strength of the composites is compared.

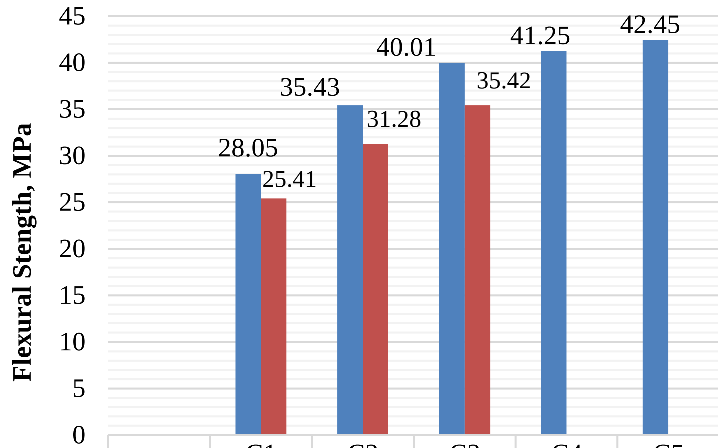
3.3 Flexural strength

Flexural test according to ASTM D790 standard is conducted using 3-point setup of flexural strength. The outcomes are displayed in the figure 5 as below, where specimen size is 120mm length, 15mm width and 3mm thickness. The properties such as flexural load and flexural strength were determined and the results were presented in the table 5 as below lists the five specimen coir fibre composites' maximum flexural strengths. The flexural strength also showed a similar trend as that of the tensile strength. The maximum flexural strength was observed for the specimen C5 which consists of 10% fly ash filler loading. The maximum flexural strength was obtained as 42.45 MPa. The fibres can take the load directly from the matrix hence they play a vital role in composite strength, whereas the particulate fillers generally occupy the voids and they increase the matrix surface adhesion by improving the surface area of interaction. Particulates generally assist in transferring the load from the matrix and thereby increase the strength.

Table 5: Results from Experimental and Reference Paper Comparison

Experimentation Findings results		Results of Reference Papers [12]	
Composites	Flexural strength (MPa)	Composites	Flexural strength (MPa)
C1	28.05	C1	25.41
C2	35.43	C2	31.28
C3	40.01	C3	35.42
C4	41.25	C4	NIL

C5	42.45	C5	NIL



	C1	C2	C3	C4	C5
Experimental result	28.05	35.43	40.01	41.25	42.45
Reference paper result	25.41	31.28	35.42		

Fig. 5: Flexural strength of the composites is compared

3.4 Impact test

The patterns of the reinforcement materials were created test of this impact stability in accordance with this ASTM D256 criteria. The composite specimens had the following measurements: length of 64 mm, width of 12.7 mm, and thickness of 3.2 mm as shown in table 6. Impact testing equipment was employed in this test. To ascertain the composites' resilience to impact, a testing of izod impact was performed. Release of an arm held at a particular height throughout this test. This sample was finally broken when the arm hit it. It shows its impact energy of the specimen has received. The specimens are clamped in a square support and are struck at their central point by a hemispherical bolt of diameter 5 mm. The respective values of impact energy of different specimens are recorded directly from the dial indicator. The maximum impact energy was observed for the specimen C_5 which consists of 10% fly ash filler loading. The maximum impact energy was obtained as 28.43 MPa as shown in figure 6.

Table 6: Results from Experimental and Reference Paper Comparison

Experimentation Findings results		**Results of Reference Papers [12]**	
Composites	**Impact Energy (kJ/m^2)**	**Composites**	**Impact energy (kJ/m^2)**
C_1	18.05	C_1	16
C_2	20.50	C_2	16.5

C_3	22.40	C_3	17.5
C_4	25.35	C_4	NIL
C_5	28.43	C_5	NIL

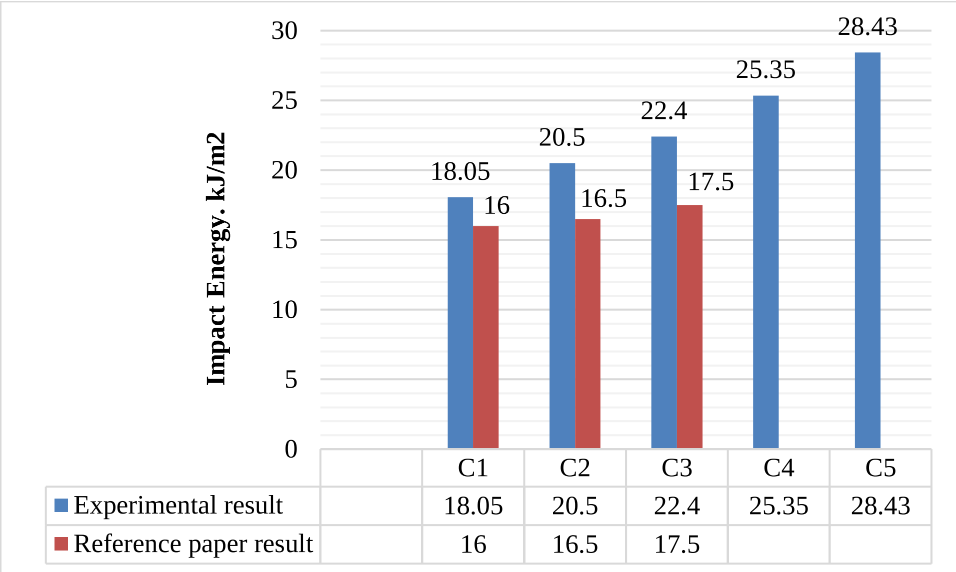


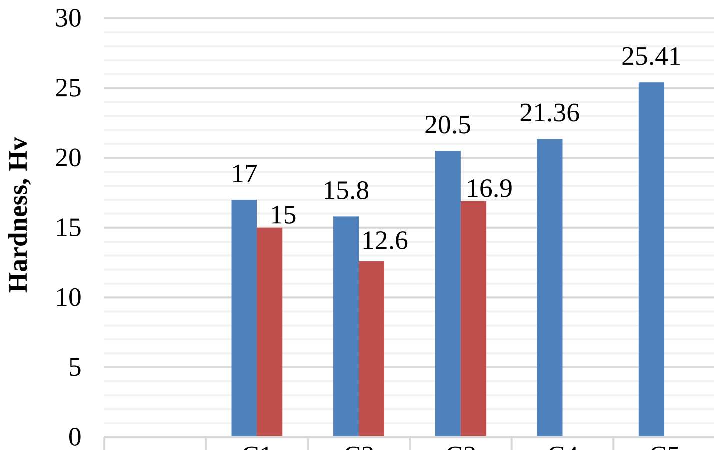
Fig. 6: Comparison of the Impact Energy of the composite

3.5 Hardness Test:

On the Vickers hardness machine, the hardness test is running. The L scale's hardness measurement. According to ASTM D785, the composite specimens with coir fibre reinforcement are prepared. The specimen size and dimensions must meet the ASTM standard, which is 25mm x 25mm x 6mm. Take four readings for each specimen. Additionally, determine each specimen's average value. The maximum hardness was observed for the specimen C_5 which consists of 10% fly ash filler loading as shown in table 7. The maximum hardness was obtained as 25.41 MPa s shown in figure 7.

Table 7: Results from Experimental and Reference Paper Comparison

Experimentation Findings results		Results of Reference Papers [12]	
Composites	Hardness (Hv)	Composites	Hardness (Hv)
C1	17.00	C1	15.00
C2	15.80	C2	12.60
C3	20.50	C3	16.90
C4	21.36	C4	NIL
C5	25.41	C5	NIL



	C1	C2	C3	C4	C5
Experimental result	17	15.8	20.5	21.36	25.41
Reference paper result	15	12.6	16.9		

Fig. 7: Comparison of the Impact Energy of the composite

4. Conclusions:

In this reinforced composite, on the mechanical characteristics of the effects of varying ratios of length of short treated coir fibres and filler material as a fly ash were tested. The following results have been obtained through various experiments.

- The reinforced composite was fabricated for applying the hand lay-up technique. The methods were create three composites (C_1, C_2, C_3) made of coir fiber, epoxy and two composites (C_4, C_5) made of coir fiber, epoxy, fly ash as a filler material.
- In testing of tensile, the strength of tensile of the reinforcement rise as the fibre concentration does. Additionally, it has been discovered utilizing this treated coir fiber weighted reinforcement have superior compares tensile strength to reference paper. Like consequence, reinforced composites C_5 with 10 weight percent of fly ash exhibit the maximum tensile strength.
- Similar results were also achieved in flexural testing. Flexural toughness rises as fiber meditation does, and the highest value here is at 20% fiber and 10% fly ash concentration.
- Hardness also shows characteristics that are similar to those of flexural and tensile strength. By fiber packing and surface preparation, it rises. The reinforced composite with 20% fiber and 10% fly ash had the highest hardness.
- It was expressed that the quantity of fiber loading, impact strength increased as well. Treatment increases the coir-epoxy composite's impact strength. The impact strength was significantly improved when fly ash powder was added to the treated version. and the highest value here is at 20% fiber and 10% fly ash concentration.

Future Scope:

Future scholars have a lot of scope to study recently areas of study. This project is able to expanded upon to examine further composites-related topics such as,

- Utilization of various natural fibers and their behavior based on the same criteria as those employed here.
- Alternative than the hand lay-up approach, other production techniques like as spraying, compression molding, filament winding, etc., can be used to study composite qualities.
- Analysis of experimental results and evaluation and optimization of tribological, electrical, thermal and other properties.

Conflict of Interest:

There is no conflict of interest.

Acknowledgement:

The authors are acknowledging the Department of Mechanical engineering, Rajasthan Technical University Kota for providing an opportunity to do this work in my master's degree program.

References:

1. Vivek, Dutta, R. K., & Parti, R. (2020). Effect of chemical treatment on the tensile strength behavior of coir geotextiles. Journal of Natural Fibers, 17(4), 542-556. https://doi.org/10.1080/15440478.2018.1503132
2. Yan, L., Kasal, B., & Huang, L. (2016). A review of recent research on the use of cellulosic fibres, their fibre fabric reinforced cementitious, geo-polymer and polymer composites in civil engineering. Composites Part B: Engineering, 92, 94-132. doi:10.1016/j.compositesb.2016.02.002.
3. Mishra, L., & Basu, G. (2020). Coconut fibre: its structure, properties and applications. In Handbook of natural fibres (pp. 231-255). Woodhead Publishing. ; https://doi.org/10.1016/B978-0-12-818398-4.00010-4.
4. Obele, C., & Ishidi, E. (2015). Mechanical properties of coir fiber reinforced Epoxy resin composites for helmet shell. Industrial Engineering Letters, 5(7):67-74.
5. Fayaz, H., Karthik, K., Christiyan, K. J., Kumar, M. A., Sivakumar, A., Kaliappan, S., ... & Yishak, S. (2022). An Investigation on the Activation Energy and Thermal Degradation of Biocomposites of Jute/Bagasse/Coir/Nano TiO2/Epoxy-Reinforced Polyaramid Fibers. Journal of Nanomaterials, 2022(1), 3758212. https://doi.org/10.1155/2022/3758212.
6. Hwang, C. L., Tran, V. A., Hong, J. W., & Hsieh, Y. C. (2016). Effects of short coconut fiber on the mechanical properties, plastic cracking behavior, and impact resistance of cementitious composites. Construction and Building Materials, 127, 984-992. https://doi.org/10.1016/j.conbuildmat.2016.09.118.
7. G.L. S. Babu, A. K. Vasudevan, Strength and Stiffness Response of Coir Fibre-Reinforced Tropical Soil, J. Mater. Civ. Eng, 20 (2008) 571–577. doi:10.1061/(ASCE)0899-1561(2008)20:9(571).
8. G.L. Sivakumar Babu, a. K. Vasudevan, M.K. Sayida, Use of Coir Fibres for Improving the Engineering Properties of Expansive Soils, J. Nat. Fibres, 5 (2008): 61–75. doi:10.1080/15440470801901522.
9. T. Maliakal, S. Thiyyakkandi, Influence of Randomly Distributed Coir Fibres on Shear Strength

of Clay, Geotech. Geol. Eng, 31 (2013) 425–433. doi:10.1007/s10706-012-9595-1.

10. V. Anggraini, A. Asadi, B.B.K. Huat, H. Nahazanan, Effects of coir fibres on tensile and compressive strength of lime treated soft soil, Meas. J. Int. Meas. Confed, 59 (2015) 372–381. doi:10.1016/j.measurement.2014.09.059.
11. Dutta, R. K., Khatri, V. N., & Gayathri, V. (2012). Effect of addition of treated coir fibres on the compression behaviour of clay. Jordan journal of civil engineering, 6(4), 476-488.
12. Ali, M. (2011). Coconut fibre: A versatile material and its applications in engineering. Journal of Civil engineering and construction Technology, 2(9), 189-197.
13. Vivek, Rakesh Kumar Dutta & Raman Parti (2018): Effect of Chemical Treatment on the Tensile Strength Behavior of Coir Geotextiles, Journal of Natural Fibers, DOI: 10.1080/15440478.2018.1503132
14. Yan, L., Kasal, B., & Huang, L. (2016). A review of recent research on the use of cellulosic fibres, their fibre fabric reinforced cementitious, geo-polymer and polymer composites in civil engineering. Composites Part B: Engineering, 92, 94-132. doi:10.1016/j.compositesb.2016.02.002.
15. John VM, Cincotto MA, Sjostrom C, Agopyan V, Oliveira C (2005). Durability of slag mortar reinforced with coconut fibre. Cement Conc. Comp, 27(5): 565-574; https://doi.org/10.1016/j.cemconcomp.2004.09.007.
16. Cook DJ, Pama RP, Weerasingle HLSD (1978). Coir fibre reinforced cement as a low cost roofing material. Building Environ. ltd 2000, 13(3): 193- 198; https://doi.org/10.1016/0360-1323(78)90043-4
17. Ali, M., Liu, A., Sou, H., & Chouw, N. (2012). Mechanical and dynamic properties of coconut fibre reinforced concrete. Construction and Building Materials, 30, 814-825; https://doi.org/10.1016/j.conbuildmat.2011.12.068.
18. Ayrilmis, N., Jarusombuti, S., Fueangvivat, V., Bauchongkol, P., & White, R. H. (2011). Coir fiber reinforced polypropylene composite panel for automotive interior applications. Fibers and polymers, 12, 919-926; https://doi.org/10.1007/s12221-011-0919-1.
19. Sen, T., & Reddy, H. J. (2011). Application of sisal, bamboo, coir and jute natural composites in structural upgradation. International journal of innovation, management and technology, 2(3), 186; http://www.ijimt.org/papers/129-M533.pdf.
20. Townsend, T., & Sette, J. (2016). Natural fibres and the world economy. In Natural fibres: advances in science and technology towards industrial applications: from science to market (pp. 381-390). Springer Netherlands. doi:10.1007/978-94-017-7515-1_30.
21. Paramasivam, P., Nathan, G. K., & Gupta, N. D. (1984). Coconut fibre reinforced corrugated slabs. International Journal of Cement Composites and Lightweight Concrete, 6(1), 19-27; https://doi.org/10.1016/0262-5075(84)90056-3.
22. G.V. Praveen, Pandu Kurre (2021). Influence of coir fibre reinforcement on shear strength parameters of cement modified marginal soil mixed with fly ash, Materials today proceedings, 39(Part1): 504-507 https://doi.org/10.1016/j.matpr.2020.08.238.
23. Jitendra Singh Yadav, Suresh Kumar Tiwari Behaviour of cement stabilized treated coir fibre-reinforced clay-pond ash mixtures Manuscript_de46b9d017472f1380801cd96480b5eb doi.org/10.1016/j.jobe.2016.10.006.
24. L. Yan, N. Chouw, L. Huang, B. Kasal, Effect of alkali treatment on microstructure and mechanical properties of coir fibres, coir fibre reinforced-polymer composites and reinforced-cementitious composites, Construction and Building Materials, 112 (2016) 168–182. doi:10.1016/j.conbuildmat.2016.02.182
25. Puttaswamygowda, P. H., Sharma, S., Ullal, A. K., & Shettar, M. (2024). Synergistic Enhancement of the Mechanical Properties of Epoxy-Based Coir Fiber Composites through

Alkaline Treatment and Nanoclay Reinforcement. Journal of Composites Science, 8(2), 66. doi.org/10.3390/jcs8020066.
26. Asyraf, M. R. M., Syamsir, A., Supian, A. B. M., Zaki, M. A. F. M., Hazrati, K. Z., Ashraf, W. & Aksoylu, C. (2024). Investigating the influence of stacking sequences on the physical and mechanical characteristics of coconut coir fiber-reinforced unsaturated polyester composites. Fibers and Polymers, 25(2), 661-672. DOI: 10.1007/s12221-023-00465-5.
27. Yazli, D. I. M., & Ismail, N. (2024). Study on the Characteristics of Natural Fibre Composite Using Coir Fibre Composite for Car Outer Hood. Progress in Engineering Application and Technology, 5(1), 296-302. doi.org/10.30880/peat.2024.05.01.031.
28. Victor, A. A., & Inyang, U. E. (2024). Development and Properties Characterization of Polyethylene Based Composite Using Coconut Fiber. JJMIE, DOI:10.59038/jjmle/180203.
29. Rajan, V. V., Shanmugam, M., Santhanam, V., & Ramkumar, S. (2020, December). Effect of CaCo3 particulate filler on the mechanical properties of surface modified coir fibre/epoxy composite. In IOP Conference Series: Materials Science and Engineering (Vol. 988, No. 1, p. 012046). IOP Publishing. doi:10.1088/1757-899X/988/1/012046.
30. Madyira, D., & Kaymakci, A. (2016). Mechanical characterization of coir epoxy composites and effect of processing methods on mechanical properties. In COMA international conference on competitive manufacturing (pp. 187-192).
31. Mishra, S., Nayak, C., Sharma, M. K., & Dwivedi, U. K. (2021). Influence of coir fiber geometry on mechanical properties of SiC filled epoxy composites. Silicon, 13(2), 301-307.doi: 10.1007/s12633-020-00425-1.
32. Jayabal, S., Velumani, S., Navaneethakrishnan, P., & Palanikumar, K. (2013). Mechanical and machinability behaviors of woven coir fiber-reinforced polyester composite. Fibers and Polymers, 14, 1505-1514.doi: 10.1007/s12221-013-1505-5.
33. Saradava, B. J., Rachchh, N. V., Misra, R. K., & Roychowdhary, D. G. (2013). Mechanical characterization of coir fiber reinforced polymer composite using red mud as filler. J Inf Knowl Res Mech Eng, 2, 472-476.
34. Biswas, S., Kindo, S., & Patnaik, A. (2011). Effect of fiber length on mechanical behavior of coir fiber reinforced epoxy composites. Fibers and Polymers, 12, 73-78. doi: 10.1007/s12221-011-0073-9
35. Dayal, A. R., Gaikwad, A. B. H. I. S. H. E. K., & Pawar, A. S. (2018). Development of a new bio composite material by utilizing walnut shell powder, coir and jute fiber and evaluation of its mechanical properties. Int. J. Mech. Prod. Eng. Res. Dev, 8, 819-826.
36. Faria, D. L., Mendes, L. M., & Junior, J. B. G. (2023). Effect of surface treatment on the technological properties of coconut fiber–reinforced plant polyurethane composites. Environmental Science and Pollution Research, 30(18), 52124-52140. doi.org/10.1007/s11356-023-25946-1.
37. Sadeq, N. S., Mohammadsalih, Z. G., & Mohammed, R. H. (2022). The influence of particle size on the mechanical performance of epoxy coir composites. Journal of the College Of Basic Education. 22(SI), 1-11, https://doi.org/10.35950/cbej.v22iSI.5911
38. Narayanan, M. R. (2016). Experimental Analysis and Fabrication of Coir Fiber Disk Brake Rotor. Journal of Applied Science and Engineering Methodologies, 2(2), 255-259.
39. Lumintang, R. C., Umboh, M., Mende, J., & Poeng, R. (2022). Hybrid Effect of Polyester Composite Reinforced Palm Powder and Coconut Coir Fiber. IRE Journals, 6(5):54-67
40. Gayathri, G., & Singh, J. Materials Prepared from Thermosetting Resins and Natural Fibers: Bio-Composites. International Journal of Advances in Engineering and Management (IJAEM), 6(1): : 61-63, DOI: 10.35629/5252-05016163
41. Marimuthu, K. P., Kumar, S. M., Kumar, V. R., & Govindaraju, H. K. (2019). Characterization

of mechanical properties of epoxy reinforced with glass fiber and coconut fiber. Materials Today: Proceedings, 16, 661-667. doi.org/10.1016/j.matpr.2019.05.143.
42. Boopathi, S., Balasubramani, V., & Kumar, R. S. (2023). Influences of various natural fibers on the mechanical and drilling characteristics of coir-fiber-based hybrid epoxy composites. Engineering Research Express, 5(1), 015002. DOI: 10.1088/2631-8695/acb132.
43. Sathiyamurthy, S., Thaheer, A. S. A., & Jayabal, S. (2012). Mechanical behaviours of calcium carbonate-impregnated short coir fibre-reinforced polyester composites. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 226(1), 52-60. DOI: 10.1177/1464420711422794.
44. Verma, D., Gope, P. C., Shandilya, A., Gupta, A., & Maheshwari, M. K. (2013). Coir fibre reinforcement and application in polymer composites. J. Mater. Environ. Sci, 4(2), 263-276.
45. Rout, J., Misra, M., Tripathy, S. S., Nayak, S. K., & Mohanty, A. K. (2001). The influence of fibre treatment on the performance of coir-polyester composites. Composites Science and Technology, 61(9), 1303-1310. https://doi.org/10.1016/S0266-3538(01)00021-5.
46. Romli, F. I., Alias, A. N., Rafie, A. S. M., & Majid, D. L. A. A. (2012). Factorial study on the tensile strength of a coir fiber-reinforced epoxy composite. AASRI Procedia, 3, 242-247. https://doi.org/10.1016/j.aasri.2012.11.040.
47. Nam, T. H., Ogihara, S., Tung, N. H., & Kobayashi, S. (2011). Effect of alkali treatment on interfacial and mechanical properties of coir fiber reinforced poly (butylene succinate) biodegradable composites. Composites Part B: Engineering, 42(6), 1648-1656. https://doi.org/10.1016/j.compositesb.2011.04.001..
48. Darshan, M. L., Biradar, S., & Ravishankar, K. S. (2021). Investigation on Hybrid Polyester Composite Comprising of Sisal and Coir as a Reinforcement and Fly Ash as Filler. In Intelligent Manufacturing and Energy Sustainability: Proceedings of ICIMES 2020 (pp. 251-260). Springer Singapore. https://doi.org/10.1007/978-981-33-4443-3_24.
49. Naveen, P. N. E., & Yasaswi, M. (2013). Experimental analysis of coir-fiber reinforced polymer composite materials. Int. J. Mech. Eng. & Rob. Res, 2(1), 2278-0149.
50. Harish, S., Michael, D. P., Bensely, A., Lal, D. M., & Rajadurai, A. (2009). Mechanical property evaluation of natural fiber coir composite. Materials characterization, 60(1), 44-49. https://doi.org/10.1016/j.matchar.2008.07.001.
51. Gopalan, V., Sampantham, A., Govindaraman, L. T., Pragasam, V., & Chinnaiyan, P. (2022). Investigations on tensile and flexural behaviours of fly ash/coir reinforced polymer matrix composites. Brazilian Archives of Biology and Technology, 65, e22210473. https://doi.org/10.1590/1678-4324-2022210473.
52. HM, K., Bavan, S., MR, S., Siengchin, S., & Gorbatyuk, S. (2021). Effect of coir fiber and inorganic filler on physical and mechanical properties of epoxy based hybrid composites. Polymer Composites, 42(8), 3911-3921. https://doi.org/10.1002/pc.26103.
53. Kumari E., S. lal. 2022. Nonlinear Bending Analysis of Trapezoidal Panels under Thermo-Mechanical Load. Forces in Mechanics (Elsevier) 8 (2022) 100097, PP. 1-11, ISSN: 2666-3597, DOI: https://doi.org/10.1016/j.finmec.2022.100097
54. Kaushik S.C., T. Garg, S. Lal. 2014. Thermal Performance Prediction and Energy Conservation Potential Studies on Earth Air Tunnel Heat Exchanger for Thermal Comfort in building. Journal of renewable and sustainable energy (JRSE-AIP), vol. 6, issue 1, pp. 1-12 (013107), 2014, DOI: 10.1063/1.4861782.
55. S. Lal, Balam N B, Jain H K. 2014. Performance evaluation, energy conservation potential, and parametric study of borehole heat exchanger for space cooling in building. Journal of renewable and sustainable energy (JRSE-AIP), vol. 6, 1-12 (023123), DOI: 10.1063/1.4872362.
56. S. Lal. 2022. Green Building Design Concept: A Sustainable Approach. Journal of Mechanical

and Construction Engineering, ISSN-2583-0619, Vol 2, Issue 1, pp. 1-10, DOI: 10.54060/jmce/002.01.003