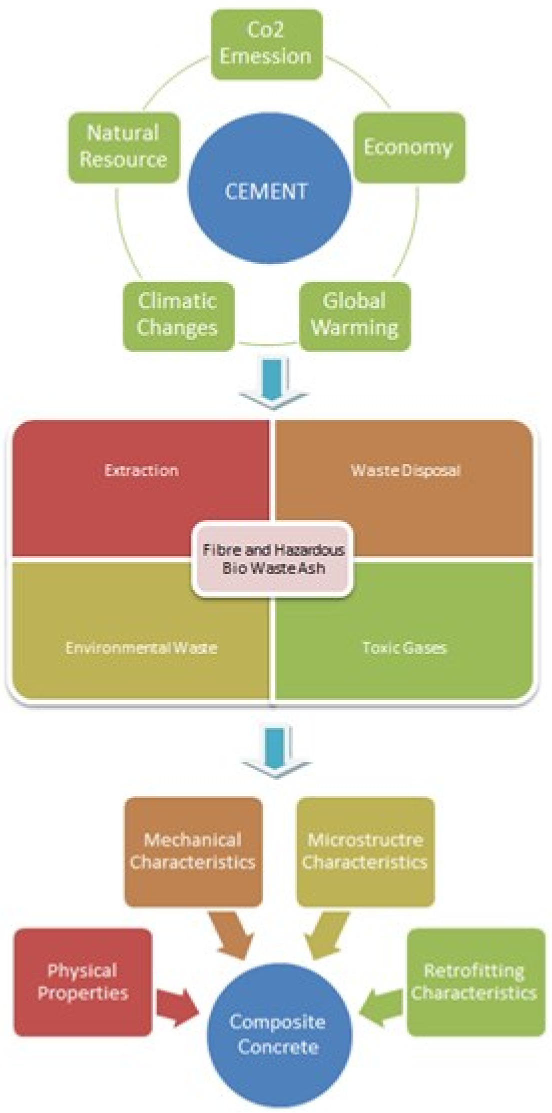
Global NEST Journal, Vol 25, No 4, pp 70-76

Experimental investigation of hybrid composites using biowastes and *Calotropis gigantea* : an eco-friendly approach

Ramshankar.P.[1*], Sashikkumar.M.[1], Ganeshan.P.[2] and Raja.K[4]
[1]Department of Civil Engineering, University College of Engineering, Dindigul, Tamil Nadu, India
[2]Department of Mechanical Engineering, Sri Eshwar College of Engineering, Coimbatore, Tamil Nadu, India
[3]Department of Mechanical Engineering, University College of Engineering, Dindigul, Tamil Nadu, India
Received: 07/12/2022, Accepted: 13/01/2023, Available online: 16/01/2023
*to whom all correspondence should be addressed: e-mail: ramshankar1991@gmail.com
https://doi.org/10.30955/gnj.004620

Graphical abstract



Abstract

The wastes are in many forms consist of organic materials like human, medical, food, plastics, construction waste etc. many researchers are focused on the waste management to gives more importance to the environment. The biodegradable waste was used in this research with naturals fibers. The need for hybrid composites has increased in a variety of industrial applications. A unique and useful substance is created when two or more distinct components join in this kind of composite. Because of its exceptional characteristics, research is being done on the integration of particles bio waste and fiber into polymers. The like a strong weight-to-strength ratio, immunity to rust and temperature changes, and several custom qualities. This research focuses on the property description of *Calotropis gigantea* and Bio waste ashes in form of epoxy matrix and in concrete as retrofitting composite. *Calotropis gigantea* and Bio waste ashes are in composite form. field emission scanning electron microscope (FESEM) The characterisation is used to make sure that the polymer's structural shape and particle dispersion are correct. The mechanical, dynamic mechanical, thermal wear and concrete strength qualities are assessed. When particles are added, the qualities improve. By raising the weight of particle at certain percentage to the matrix and concrete mixture is for to increase the mechanical properties like tension, elongation, impact. To analyze the tribological behaviour, wear analysis is carried out. The results revealed that, the laminates reinforced with *Calotropis gigantea* and Bio waste ashes show maximum strength. This is correlated with the increased interaction between the fiber-matrix, waste ash and homogeneous dispersion particle and also having greater strength compare to conventional concrete. The FESEM micrographs for tensile fracture surface also provided structural morphology. The findings will provide a vivid understanding for the use of composites in various structural retrofitting applications.

Keywords. Environment, bio waste, *Calotropis gigantea* , composite, fibre, etc.

1. Introduction

1.1. Composite materials

The distinct materials combine together to form a unique composite material. The demands of various operations are achieved by the effective use of engineering materials (Ashok Kumar *et al.*, 2010). The automobile, aeronautical and other industries require characteristic materials with high strength, thermal and corrosion resistant, less weight, etc (Farzi *et al.*, 2019). It is a great challenge to imply all the above necessities in a single material. In order to accomplish this, composite material is the only solution. Since many decades the composite materials are in existence and have enormous demand in sports, automobile, aerospace, boating, structural and many other industries (Vinayagar *et al.*, 2022). Hence composite material is considered to be a significant engineering material. Some gaps found in composite materials are theory and modelling have made a significant impact in understanding the current state of composite concrete and are required to progress further. To further understand the qualities, precise simulations are required. Adoption of materials such as fiber, waste materials, admixture, material combinations, and so on.

1.2. Hybrid composites - significance

Hybrid composites consist of more than two constituents (Ramkumar *et al.*, 2022; Praveena *et al.*, 2020). It is manufactured by combining the macro or nano sized particles with the matrix system. Hybrid composites are developed to introduce more defined quality to the structure. These results in a composite material with the tailor- made properties (Kharwar *et al.*, 2022). The percentage of fiber where decreased or increased by in percentage to the certain limit at concrete can get up to 5 to 50 percentage increased strength of concrete with respect to normal concrete.

There are various uses of composite concrete such as increased sustainability, limitations fracture that develop, enhancement of workability, enhancement of ductile strength etc, and also some application of composite concrete is to have a variety of applications in advanced concrete technology. Blast resistant buildings and precast piles are examples of components that must tolerate severe loads or deformations. Air area overlays, bridge decks, road works, Building floorings works, Canal linings, so on.

2. Design of experiment

Statistical technique design applied to the process of simulating optimization etc. in manufacturing. Optimizing the process parameter improves the product quality. The production of composite laminate includes parameters such as fillers content, stirring speed and stirring duration. Since it is a problem of multi variation, the Taguchi methodology appears ready to a practical and effective way to improve the process parameter.

Polymer composites are advantageous because of its improvement in modulus, impact strength, heat resistance and barrier properties, thermal stability, etc. (Wetzel *et al.*, 2003). Epoxy is a class of thermoset polymer used as matrix *Calotropis gigantea* and Bio waste ashe are taken half of each materials from the total weight (Katare *et al.*, 2022). Epoxy is chosen because of its excellent mechanical and adhesion properties. Various processing techniques are used for preparing composites. Such as mechanical mixing, in situ polymerization, twin screw extrusion, etc. (Koo and Pilato, 2005). The improvement in properties purely depends on the dispersion of particles into the matrix.

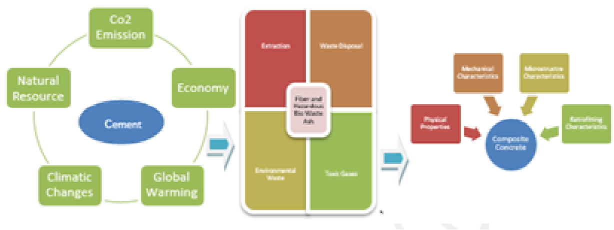


Figure 1. Methodology for the Experimental Setup

Figure 2. A) *Calotropis gigantea* Plant, B) Extraction of *Calotropis gigantea* Fiber, C) Bio-Waste D) Bio-Waste Ash

The composite's improved thermomechanical characteristics purely confide in the dispersion particles into the forge. The homogenous dispersion of particles has been viewed as a significant difficulty because of the propensity for particles to agglomerate (Chan *et al.*, 2002). This can be probably achieved by selecting optimal processing parameters. Consequently, the present study's goal is to conduct an experiment to optimize a process parameter in the mechanical mixing of particle into a matrix (Gu *et al.*, 2007). This is achieved by using Taguchi methodology. The tensile strength of the composites is examined using the Taguchi technique in relation to the impacts of process parameter. Factors include: particle content (wt.%), stirring speed and duration (Ma *et al.*, 2010). A suitable processing parameter is estimated. Fiber extracted from the parts of plant there is many process for fiber extraction in this research fiber extracted by manual method. In this process plant parts are soaked in water after that extract by tapping on the soaked plant. The randomly oriented fiber was having higher properties specification. This type of fiber where used in this experiments. and also bio waste ash where from firing of biodegradable waste. The experimental form of current research is explained in Figure 1 and also image form of composites are explained in Figure 2 as 2A) *Calotropis gigantea* Plant, 2B) Extraction of *Calotropis gigantea* Fiber, 2C) Bio –Waste 2D) Bio-Waste Ash.

Concrete cylinders of 30 cm in length and 15 cm in diameter, as well as concrete cube of 150 mm x 150 mm x 150 mm size were produced with composite concrete to compare the test findings. Especially the Composite concrete increase the strength of concrete. The test specimens are made mixing of composites of *Calotropis gigantea* and Bio waste ashes, cement, sand, aggregates with the composition in ratios under certain water cement ratios (Khanzada *et al.*, 2020; Shah *et al.*, 2022). After thorough mixing that results in complete compaction of the concrete without segregation or undue laitance. The mould is filled with layers of concrete that are 5 cm thick and fully compacted. Each scoop of concrete should be filled to the top edge of the mould, which should be checked manually or through vibration. After the top layer has been crushed, a trowel is used to complete levelling the surface with the top of the beam mould. Utilizing a standard tamping rod bar, the beam mould's cross section receives a uniform distribution of bar strokes (Ferreira *et al.*, 2014; Nambiar and Haridharan, 2020). Depending on kind of concrete, different layers require different numbers of strokes to achieve the desired state.

3. Material characterization

3.1. Surface morphology

To look at the structural morphology and metabolism of various ranges of materials. A high resolution analysis of the surface of the manufactured composite laminates is performed using a F E I Quanta FEG 200 – FESEM (Krawiec *et al.*, 2018). Tensile fractured surface is also analysed under FESEM. Sample of dimension less than 1 square centimetre is subjected to FESEM. The FESEM is undertaken in void environment and electrons are used to create images from the Figure 3 SEM Image of composite of *Calotropis gigantea* and Bio waste ashes matrix where shown (Thiagarajan *et al.*, 2015; Saravanan *et al.*, 2021). The sample is coated with gold in the sputtering equipment in order to avoid over charging. It is carried out to increase the conductivity of the material.

4. Mechanical properties

4.1. Tensile strength

The test is calculating the stress on materials and how far it can be extended before breaking. Particle addition enhances the filler-matrix bonding, and a favourable stress distribution area forms (Yooprasertchai *et al.*, 2022). The particles increase the specific surface area, acting as a load resistor. This reduces tension and limits the spread of cracks through the surface (Hameed *et al.*, 2009; Ganeshan *et al.*, 2018). With subsequent increases in the nanoloading, the outcome did, however, somewhat deteriorate. This decrease in strength might be caused by the interaction between the fillers, which produces agglomerates. Agglomerates are large clusters that serve as weak spots and are quickly breakable under stress (Logakis *et al.*, 2011). These develop as a result of poor particle dispersion with increasing loading. Lower values were therefore seen in the composites with larger particle loading. Similar to this, (Yoganandam *et al.*, 2018) showed that adding particle enhanced the tensile strength from the Table 1 the tensile strength of composite is known. Additionally, the FESEM micrographs of the broken sample show that the interfacial adhesiveness is good and that the decreased fiber pull-out may be the cause of the maximum particle loading result (NagarajaGanesh *et al.*, 2022). The number of debonded composites in comparison when the matrix had a larger particle concentration; this could be because agglomerated particles formed (Ashori etal., 2016). The values from the test result of yield strength is 305.23 N/mm2, 316.74 N/mm^2 and 343.05 N/mm^2 for the compositions of 5, 10, and 15 percentage composites.

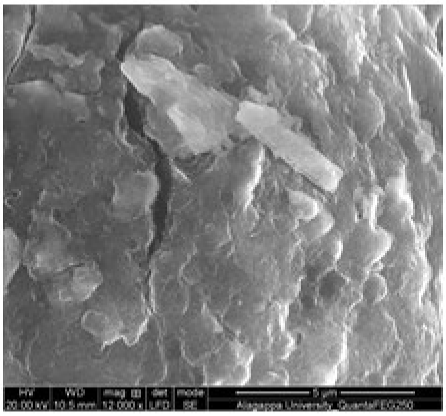


Figure 3. SEM Image of composite of *Calotropis gigantea* and Bio waste ashes matrix

Table 1. Tensile strength of Composites at different weight composition

S.No.	Composition (Wt%)	Tensile Strength (N/mm^2)
1	5	305.23
2	10	316.74
3	15	343.05

4.2. Flexural strength

Strength is to measure the potential and hold against the braking when the load is applied to the materials. The buckling stability increased comparison to straightforward epoxy composite (Ravi *et al.*, 2022). Greater value acting as an outcome of the particle's homogeneous distribution, which limits their capacity for plastic deformation (Sulym *et al.*, 2016; Rahmanian *et al.*, 2014). Additionally, it functions as a network-like structure that reduces cavitation and avoids breakage. The outcome is equivalent to composite materials without any particle addition in terms of flexural strength (Ganeshan *et al.*, 2018; Yoganandam *et al.*, 2019). The Table 2 refers to the flexure strength of composites. From the results composition weight of 5, 10, 15 percentage composites having strength as 315.68 N/mm^2, 316.47 N/mm^2, 328.31 N/mm^2 respectively from these values composite 15% having more values compared to other composition.

Table 2. Flexural strength of Composites at different weight composition

S.No.	Composition (Wt%)	Flexure Strength (N/mm^2)
1	5	315.68
2	10	316.47
3	15	328.31

4.3. Impact strength

The test regulates how much energy a material absorbs during rupture. The sample with no notches is upright when the pendulum applies a rapid weight (Ng *et al.*, 1999; Ahmed *et al.*, 2012). The three main contributing aspects were thought to be deformability, fracture, and composites pull-out from matrix (Bozkurt *et al.*, 2007). As can be observed, adding particles increases the impact strength. The values of impact strength are noted and described in Table 3. During impact, composites contributes to this in part, but the reinforcing action of the nanoscale filler may also be to blame. From the results composition weight of 5, 10, 15 percentage composites having strength as 206.37 N/mm^2, 214.81 N/mm^2, 218.64 N/mm^2 respectively from these values composite 15% having more values compared to other composition (Figure 4).

Table 3. Impact strength of Composites at different weight composition.

S.No.	Composition (Wt%)	Impact Strength (N/mm^2)
1	5	206.37
2	10	214.81
3	15	218.64

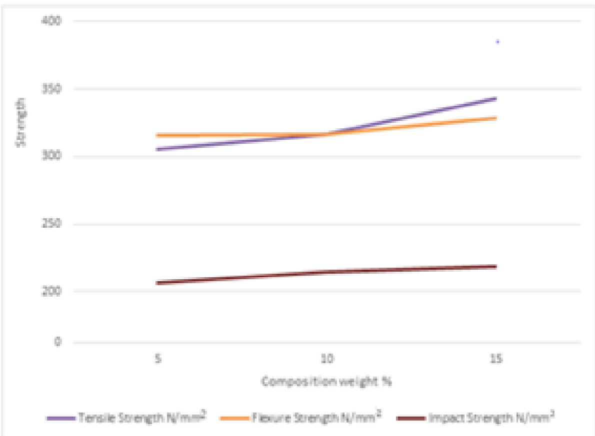


Figure 4. Mechanical properties of Composites

5. Test on composite concrete

5.1. Concrete composite's compressive strength

Among the most important and practical characteristics of concrete is its compressive strength, which is seen in the Figure 5. The compressive strength of different mix elements is typically used to gauge their ability to produce concrete (Veigas *et al.*, 2021; Ardanuy *et al.*, 2015). Other qualities of hardened concrete are also qualitatively measured using compressive strength, using different composition of composites are added and test values were noted and described in Table 4–6. The results of compression test for the composite concrete for compositions weight of 5, 15 percentage composites having average strength as 31.7 N/mm^2, 10 percentage composites having average strength of 34.7 N/mm^2 and also having more values compared to other composition.

5.2. Rebound hammer (RH)

A rapid and simple evaluation of compression strength of concrete is provided by test, which is a non-destructive concrete testing process. The RH is frequently known as a Schmidt hammer(SH), Its made up of a substance that is steered by a spring and within a tubular shell, travels along a plunger. A spring-controlled mass with consistent energy caused to impact the concrete's surface when is produced by RH's plunger is driven into concrete. Surface hardness is determined by measuring the amount of rebound on a scale with grades. This numerical value, which is measured, as well as know the rebound number (rebound index). test values and results were described in Table 4–6. Less stiff and powerful concrete will absorb more energy, decreasing the rebound value. From the results for RH composition weight of 5, 10, 15 percentage composites having strength as 32.33 N/mm^2, 36.33 N/mm^2, 35 N/mm^2 respectively from these values composite 10% having more values compared to other composition in concrete

5.3. Ultrasonic pulse velocity (UPV)

Durability, quality of concrete etc examine by UPV test. By measuring the speed at which an UPV passes through one concrete structure. The UPV is used to test the concrete, the pulse is to send into the concrete structure and recorded the time taken of travelling pulse (Goyat *et al.*, 2011). As the result determined through velocities that lower and higher velocity may indicate concrete having numerous breaks or cavities, and excellent quality and uniformity of the substance. A pulse production circuit, and an electrical circuit for producing pulses, is part of ultrasonic testing equipment. A pulse receiving circuit that picks up the signal from the board, and a transducer for converting mechanical pulse from electronic pulse into with an oscillation frequency between 40 kHz and 50 kHz. The oscillation circuit, oscillator, clock, power source, transducer are equipped for usage. Positioned the transducer on the material's different sides after validation to a sample of a substance with established characteristics. A simple formula may be used to calculate pulse velocity and velocities results are explained in Table 4–6 and also explained as graphical Figure in Figure 6–8. The breadth of the structure multiplied by the pulse's transit time yields the pulse's velocity. The results obtained from the test UPV for the different composition weight of 5, 10, 15 percentage composites having strength as 5.11 m/s, 5.85 m/s, 5.35 N/mm^2 respectively from these values composite 10% having more values compared to other composition.

Table 4. Results of concrete strength in 5 % of Composites content

Specimen No.	Compressive Strength (N/mm2)	Rebound Hammer (N/mm2)	Ultrasonic Pulse Velocity (m/s)b
1	30	35	5.15 (Excellent)
2	34	30	5.11 (Excellent)
3	31	32	5.09 (Excellent)

Table 5. Results of concrete strength in 10% of Composites content

Specimen No.	Compressive Strength (N/mm2)	Rebound Hammer (N/mm2)	Ultrasonic Pulse Velocity (m/s)
1	32	38	6.12 (Excellent)
2	35	35	5.73 (Excellent)
3	37	36	5.72 (Excellent)

Table 6. Results of concrete strength in 15% of Composites content

Specimen No.	Compressive Strength (N/mm2)	Rebound Hammer (N/mm2)	Ultrasonic Pulse Velocity (m/s)
1	30	35	5.32 (Excellent)
2	34	37	5.38 (Excellent)
3	31	33	5.36 (Excellent)

Figure 5. Compressive strength of Composite concrete by UTM

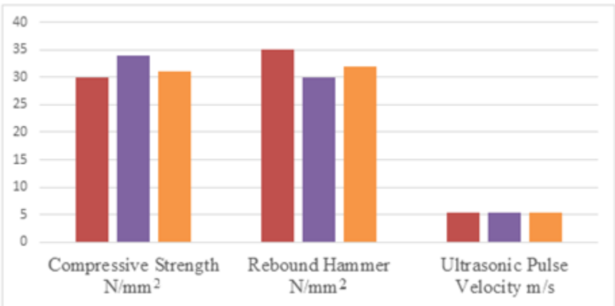


Figure 6. Properties of Composite concrete in 5% of Composites content

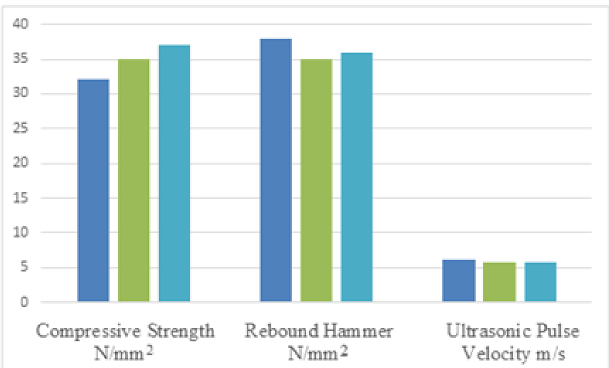


Figure 7. Properties of Composite concrete in 10% of Composites content

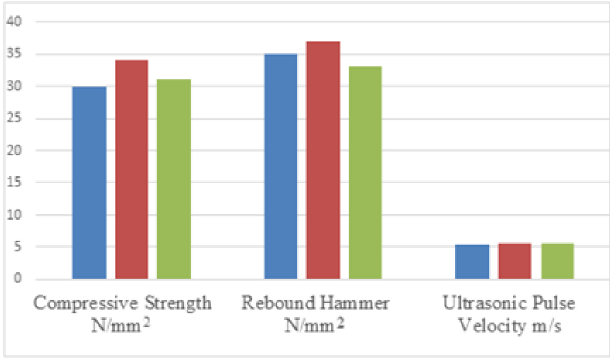


Figure 8. Properties of Composite concrete in 15% of Composites content

6. Future scope of work

The composite fiber deployed for the hybrid concrete has more than M50 grades. Addition of other fibers and other waste materials to concrete for improvement of mechanical, chemical, and durability properties. The use of fibers and biowaste as retrofit components in buildings improves mechanical properties and decreasing environmental degradation.

7. Conclusions

It can be concluded natural fiber and bio waste ashes with epoxy matrix having more adhesion, forming higher connection between fiber, ash and epoxy. The mechanical properties of *Calotropis gigantea* and Bio waste ashes composites with different composition, configuration were evaluated. This paper evaluvated that the composites configuration plays vital role to getting a high mechanical strength and concrete strength compared to conventional concrete. Mechanical properties in form of flexural, impact, tensile strength, concrete durability in form of destructive type by compressive strength and non-destructive types by RH and UPV methods were recorded for composites *Calotropis gigantea* and Bio waste ashes. It was found that 15% wt composition having higher tensile, flexural and impact strength and in concrete composition same 10% wt composition, having good results in compression strength found through RH and UPV methods. Fiber concrete results are around 30 percentage increased where compared with normal concrete. The other combination produced mixed results. These compositions used for the structural elements like retrofitting of structural members, buildings, industrial buildings, concrete roads. Thus these composites are mostly used materials in all applications and intensify quality of fiber used products.

References

Ahmed K.S., Khalid S.S., Mallinatha V. and Amith Kumar S.J. (2012). Dry sliding wear behaviour of SiC/Al2O3 filled jute/epoxy composite. Materials and Design, 36, 306–315.

Ardanuy M., Claramunt J. and Filho R.D.T. (2015). Cellulosic fiber reinforced cement-based composites: A review of recent research. J. Construction and building materials, 79, 115–128.

Ashok Kumar M., Hemachandra Reddy K., Mohana Reddy Y.V, Ramachandra Reddy G. and Venkata Naidu S. (2010). Improvement of tensile and flexural properties in epoxy-clay nanocomposites reinforced with weave glass fiber reel, Inter. Journal of Polymer Materials, 59, 854–862.

Ashori A., Menbari S. and Bahrami R. (2016). Mechanical and thermo-mechanical properties of short carbon fiber reinforced polypropylene composites using exfoliated graphene nanoplatelets coating. Journal of Industrial and Engineering Chemistry, 38, 37–42.

Bozkurt E., Kaya E. and Tanoglu M. (2007). Mechanical and thermal behavior of non-crimp glass fiber reinforced layered clay/epoxy nanocomposites. Composites Science and Technology, 67, 3394–3403.

Chan C.M., Wu J., Li J.X. and Cheung Y.K. (2002). Polypropylene/calcium carbonate nanocomposites. Polymer, 43, 298120–2992.

Farzi G., Lezgy-Nazargah M., Imani A., Eidi M. and Darabi M. (2019). Mechanical, thermal and microstructural properties of epoxy-OAT, Composites Construction and Building Materials, 97, 12–20.

Ferreira S.R., Lima P.R.L., Silva F.A. and Filho R.D.T. (2014). Effect of sisal fiber hornification on the fiber-matrix bonding characteristics and bending behavior of cement based composites. Key Engineering Materials. J. 600, 421–432.

Ganeshan P., NagarajaGanesh B., Ramshankar P. and Raja K. (2018). Calotrpis Gigantea Fibers – A Potential Reinforcement for Polymer Matrices. International Journal of Polymer Analysis and Characterization, Taylor & Francis, 23(3), 271–277.

Ganeshan P., Senthil Kumuran S., Raja K. and Venkateswarlu D. (2018). An investigation of mechanical properties of madar fiber reinforced polyester composites for various fiber length and fiber content. Materials Express Research, IOP Publishing Ltd, UK, Accepted for Publication DOI: 10.1088/2053-1591/aae5bd.

Goyat M.S., Ray S. and Ghosh P.K. (2011). Innovative application of ultrasonic mixing to produce homogenously mixed nano particulate-epoxy composite of improved physical properties. Applied Science and Manufacturing, 42, 1421–1431.

Gu J.W., Zhang Q.Y., Li H.C., Tang Y.S., Kong J. and Dang J. (2007). Study on preparation of SiO2-epoxy resin hybrid materials by means of sol-gel. Polymer-Plastics Technology, 46, 1129–1134.

Hameed N., Sreekumar P.A., Valsaraj V.S. and Thomas S. (2009). High-Performance composite from epoxy and glass fibers: morphology, mechanical, dynamic mechanical, thermal analysis. Polymer composites, 30, 982–992.

Katare K.N., Samaiya N.K. and Murthy Y.I. (2022). Strength and durability properties of concrete using incinerated biomedical waste ash. Environmental Engineering Research, 28(2), 21–30.

Khanzada G.M., Memon B.A., Oad M., Aijaz Khanzada M.A. and Lashari A.M. (2020). Effect of Bio-Medical Waste on Compressive Strength of Concrete Cylinders. Quest Research Journal, 18(1), 29–35.

Kharwar K.L., Maurya K.K. and Rawat A. (2022). Retrofitting techniques of damaged concrete structure for environment concern: A review. Materials Today: Proceedings, 65, 1161–1168.

Koo J.H. and Pilato L.A. (2005). Polymer nanostructured materials for high temperature applications. SAMPE Journal, 41(2), 7–19.

Krawiec H., Vignal V., Krystianiak A., Gaillard Y. and Zimowski S (2018). Mechanical properties and corrosion behaviour after scratch and tribological tests of electrodeposited Co-Mo/TiO2 nano-composite coatings. Applied Surface Science, doi: https://doi.org/10.1016/j.apsusc.2018.12.099.

Logakis E., Pandis C.H. and Pissis.P. (2011). Highly conducting poly (methyl ethacrylate)/carbon nano tubes composites: investigation on their thermal, dynamic mechanical, electrical and dielectric properties. Composites Science and Technology, 71, 854–862.

Ma A.J., Chen W.X., Hou Y.G., Zhang G. (2010). Dispersion, mechanical and thermal properties of epoxy resin composites filled with the nanometer carbon black. Polymer-Plastics Technology, 49, 916–920.

NagarajaGanesh B., Rekha B., Mohanavel V. and Ganeshan P. (2022). Exploring the Possibilities of Producing Pulp and Paper from Discarded Lignocellulosic Fibers. Journal of Natural Fibers, DOI: 10.1080/15440478.2022.2137618

Nambiar R.A., Haridharan M.K. (2020). Mechanical and durability study of high performance concrete with addition of natural fiber (jute). Materials Today: Proceedings, 46, 4941–4947

Ng C.B, Sckadler L.S. and Siegel R.W. (1999). Synthesis and mechanical properties of TiO2-epoxy nanocomposites. Nanostructured mater, 12, 507–510.

Praveena B.A., Santhosh N., Archana D.P., Buradi A., Fantin Irudaya Raj. E., Chanakyan C., Elfasakhany A. and Basheer D. (2022). Influence of Nanoclay Filler Material on the Tensile, Flexural, Impact, and Morphological Characteristics of Jute/E-Glass Fiber Reinforced Polyester-Based Hybrid Composites: Experimental, Modeling, and Optimization Study. Journal of Nanomaterials, 1653449, 1–17.

Rahmanian S., Suraya A., Shazed M., Zahari R. and Zainuddin E.S. (2014). Mechanical characterization of epoxy composite with multiscale reinforcements: Carbon nanotubes and short carbon fibers. Materials and Design, 60, 34.

Ramkumar R., Saranya K., Saravanan P., Srinivasa Perumal K.P., Ramshankar P., Yamunadevi V. and Ganeshan P. (2022). Dynamic mechanical properties and thermal properties of madar fiber reinforced composites. Materials Today: Proceedings, 51, 1096–1098.

Saravanan N., Ganeshan P., Prabu B., Yamunadevi V., NagarajaGanesh B. and Raja K. (2021). Physical, Chemical, Thermal and Surface Characterization of Cellulose Fibers Derived from Vachellia Nilotica Ssp. Indica Tree Barks. Journal of Natural Fibers, DOI - 10.1080/15440478.2021.194148

Shah I., Li J., Yang S., Zhang Y. and Anwar A. (2022). Experimental Investigation on the Mechanical Properties of Natural Fiber Reinforced Concrete. Journal of Renewable Materials, 10(5), 1308–1320.

Sulym I., Sternik D., Oleksenko L. and Lutsenko L. (2016). Highly dispersed silica-supported ceria-zirconia nanocomposites: Preparation and characterization. Surfaces and Interfaces, 5, 8–14.

Theja M.R., Ramshankar P., Sashikkumar M.C., Muthu Kumaran A., Mohamed Ibrahim A., Vairamuthu J. and Suresh Kumar S. (2022). Investigation into mechanical properties of

EPDM/SBR-nanoclay nanocomposites. Materials Today: Proceedings, Accepted for Publications, https://doi.org/10.1016/j.matpr.2022.01.395.

Thiagarajan A., Palaniradja K. and Velmurugan K. (2015). Effect of Interfacial bonding on impact properties of chopped glass fiber polymer nanocomposites. Composite Interfaces, 22, 265–280.

Veigas M.G., Najimi M. and Shafei B. (2021). Cementitious composites made with natural fibers: Investigation of uncoated and coated sisal fibers. Case Studies in Construction Materials, 16, 1–13.

Vinayagar K., Ganeshan P., Nelson Raja P., Zakir Hussain M.S., Vengala Kumar P., Ramshankar P., Mohanavel V., Mathankumar N., Raja K. and Bezabih T.T. (2022). Optimization of Crashworthiness Parameters of Thin-Walled Conoidal Structures. Advances in Materials Science and Engineering, 4475605, 6, https://doi.org/10.1155/2022/4475605.

Wetzel B., Haupert F. and Zhang M.Q. (2003). Epoxy nanocomposites with high mechanical and tribological performance. Composites Science and Technology, 63, 2055–2067.

Yoganandam K., Ganeshan P., NagarajaGanesh B. and Raja K. (2019). Characterization studies on Calotropis procera fibers and their performance as reinforcements in epoxy matrix. Journal of Natural Fibers, DOI: 10.1080/15440478.2019.1588831.

Yoganandam K., Ramshankar P., Ganeshan P. and Raja K. (2018). Mechanical Properties of Alkali Treated MadarAnd Gongura Fiber Reinforced Polymer Composites. International Journal of Ambient Energy, Taylor & Francis, Accepted for Publication DOI: 10.1080/01430750.2018.1477066.

Yooprasertchai E., Wiwatrojanagul P. and Pimanmas A. (2022). A use of natural sisal and jute fiber composites for seismic retrofitting of nonductile rectangular reinforced concrete columns. Journal of Building Engineering, 52, 104521.