Evaluation of Mechanical Properties of Polymer Composites with Hybrid Reinforcements (Glass/Jute/Basalt)

[1*] Rudra K.S, [2] T.N Sreenivasa, [3]Girisha.C

[1,3]AMC Engineering College, [2]Atria Institute of Technology
[1, 2,3]Department of Mechanical Engineering,

Abstract

Composites are heterogeneous in nature, created by combining two or more materials of different phases, continuous and discontinuous phases. The composites could be of metal, ceramic or polymer materials which are reinforced with Fibers, Particulates or Whiskers to enhance the properties. Only a small amount of work has been published using natural reinforcement in polymer matrix composites, which are crucial in applications including weight reduction.Very limited works have been made by the researchers to study the consequence of unidirectional fiber with Nanofillers modified epoxy matrix on the mechanical properties of composites. Present research work is an attempt towards the processing, testing and analyzing the properties of the polymer compound developed with synthetic and natural fibers in various compositions. The materials are being fabricated by the hand layup process and the various mechanical properties are being evaluated to determine the ability of the material under various loading and operating conditions. A combination of Basalt, Jute and Glass fiber. The addition of reinforcement materials has shown increasing trends in the improvement of mechanical properties.

Keywords: Polymers, Glass fibers, Jute fiber, Basalt etc.

1. INTRODUCTION

Manufacturing industries have started to use composites, because of their unique properties[1-2].Composites can be manufactured by methods similar to conventional processing through novel composite processing has been developed[3]. However composite fabrication needs more attention, because of their properties may vary depending on fabrication techniques. Hence, each and every developed composites exhibit unique characteristic like physical, chemical and mechanical properties[4–6]. Natural fibers are utilized in construction materials of building and locomotives because these materials have the capability to replace the synthetic fibers especially for load bearing applications. In order to have the combined property of the natural and synthetic fibers, hybrid composites are developed which provides the benefits of both type of reinforcements[7- 8]. Researchers have studied on the nanofiller composites consist of lower strength in terms of compressive and impact forces. To overcome these deficiencies the natural fibers are alkali treated and the results of the test showed improved flexural strength [9–15].

The major benefits of composites over traditional materials are the incorporation of dissimilar properties which are unable to establish in traditional materials[16]. Further, the requirement of advanced technological applications is for lightweight materials with superior strength and thermal properties as well as wear and corrosion resistance. These factors have propelled the current designers to develop new composite materials for use in large-scale production for requirements that are stringent. There are wide variety of composite materials that can be processed on the application of the materials[17–23].

Polymer composites are the type of composite materials that are most commonly employed in the automotive industry. For the production of door panels, instrument panels, armrests, headrests, seat shells, window frames, moulded panel components, bumper and under-floor protection on passenger cars, especially natural fiber reinforced polymer composites are utilized [24-25]. Additionally, sisal and Roselle fibers have been used to create nameplates, rear view mirror panels, two-wheeler visors, billion seat covers, indicator covers, and cover L-side. To create mirror casings, paper weights, projector covers, voltage stabiliser casings, mobile casings, helmets, and roofs, as well as load-bearing elements like beams, roofs, multifunctional panels, water tanks, and pedestrian bridges, natural fibers with polyester composites are employed[26-27].

Composites made of natural fibers are used for indoor components of housing, temporary outdoor uses including low-cost housing for the military, rehabilitation, and transportation. Due to the insulating properties of jute fibers, the jute fibers composites are also employed in car door/ceiling panels and panels separating the engine and passenger compartments[16-17].

The wide availability of natural fibers has encouraged the researchers to develop natural fiber reinforced polymer matrix composites. Global development depends on effective utilization of resources such as natural materials and its products. However, natural materials possess lower mechanical properties such as strength, flexibility, durability and so on. Hence, the natural fibers are combined with some of artificial materials to produce hybrid composites. Because they are naturally accessible, biodegradable, and have reinforcing qualities, natural fibers including sisal, jute, palm, Roselle and betel nuts are utilized as reinforcement in composite materials. Numerous researchers have analyzed and examined natural fibers and their composites for a variety of applications, including structural, thermal, mechanical, and physical characteristics[30–32].

The use of natural fibers with combinations has also helped in significant improvement in the material's characteristics; hence the utilization of the combined material is of higher interest in the field of the automobile sectors. The processing techniques of these material has been of higher interest and these composite materials can have developed by using various processes, but the selection of exact method is mainly depending on the matrix and reinforcing materials used."Wet-forming" processes are extensively used in the fabrication of composites made of polymers. In this process, resin in liquid state is used to fabricate the composite laminates[33].The curing of the fabricated composite laminates generally accelerated by the surrounding and pressure application. In general, its termed as the Hand layup process[34].

Present research work is an attempt towards the processing, testing and analyzing the properties of the polymer composite (PC) developed with synthetic and natural fibers in various compositions. The materials are being fabricated by the hand layup process and the various mechanical properties are being evaluated to determine the ability of the material under various loading and operating conditions. A combination of Basalt, Jute fibers, Glass fiber and Nano-filler is being embedded with the polymeric materials to prepare the composite material. The details regarding the same are explained in the subsequent chapters.

II. OBJECTIVES

A challenge is made to fabricate and test the performance of the complex material reinforced with different types of natural and synthetic fiber. To fulfill the requirement of the present study the following objectives have been selected based on the literature study and the application of the materials. The following are the objectives of the present study:

- Fabrication of Polymer composites by Hand-lay-up process with varying percentage of natural and synthetic reinforcement by weight percentage.
- Polymer composite fabrication by selecting Basalt fibre and Jute fibres with varying percentages (20%B + 10%J & 10%B + 20J).
- Polymer composite fabrication by selecting Glass fibre and Jute fibres with varying percentages (20%G + 10%J & 10%G + 20J).
- Sample preparation as per the ASTM standard for the mechanical properties (MP) evaluation.
- Evaluation of MP of processed composites subjected to varying load conditions.

III. EXPERIMENTAL WORK

Having defined with the objective of the present research work, the experimental work to be carried out to fulfill the above objectives is being discussed in this section.

3.1 Materials and preparation

The strength and other properties of developed composites is dependent on its materials (matrix &reinforcement) especially its physical, chemical and mechanical properties. The selected materials should be amenable for easily fabrication and must exhibit good machinability characteristics. The following materials (Fig.1) have been selected to prepare the hybrid composites in the present work: Epoxy material, LY-556, Hardner HY-951, Basalt fiber, Jute Fiber. Basalt is bio-inert material, environmentally ecofriendly and also can use at very high or low temperature range from -269ºC to ± 650ºC, Improved the shear strength, compression strength, oxidation resistance, and radiation resistance.

a).Basalt fibre b).Jute fibre

c).Glass fibre

Fig.1 Reinforcement Materials

Jute fiber is one of the most commonly used normal fibers. It's a fine, soft and Vegetable fiber with shine that may be spun into strong, coarse threads. Jute is used for the production of bags; sacks etc. and widely used to manufacture matting twine ropes, clothes like cotton and wool. Jute fibers are easily blends with other fibers, both natural and synthetic. In industry, glass fibers are well known and readily available materials. It derived from compositions containing silica.

3.2 Specimen preparation

After the fabrication, the specimens of composites laminates are prepared for the mechanical properties evaluation. The trials are prepared as per different ASTM standards.

3.3 Hardness Test

The hardness is the ability of the materials to resist indentation. Hardness of both reinforced and non-reinforced rigid plastics were measured using Vickers's micro hardness tests. All the tests measure the resistance of fiber reinforced plastic composites by the application of uniform pressure. In the present study, Matsuzawa Make-MMT-X7A Vickers's micro hardness tester is used for the test specimens as per ASTM D 2583 standard.

3.4 Impact Test

Impact test helps to evaluate the toughness of the material behavior at higher deformation speed. Impact tests are two types, pendulum type and drop weight type, Izod and Charpy are normally used as impact test for examination. For this research work charpy impact test is used to observe the impact strength of the complex material as per ASTM D256 with the measurement of 68 x 12.5 x 3 mm specimens are prepared and average value is taken for study.

3.5 Tensile Test

The tensile test is used to assess the performance and behaviour of material that has been stretched under load. It is sometimes referred to as tension testing, and it is a basic technique for engineering and material testing. Tensile test provides the information like ultimate tensile strength (UTS), breaking strength and maximum elongation strength of the material to be tested. The specimen material prepared is with the ASTM standard D638-04 the dimension of 216 x 19 x 3 mm. Specimens is tested and typical values are taken to measure the tensile strength of the material.

IV.RESULTS & DISCUSSIONS

The processed materials are being testing to evaluate the various properties ranging from microstructure, mechanical properties. The processed hybrid composite with Glass and Jute fibers are being tested as per the ASTM standard specimens in various equipment's and the obtained results are explained in detail in this section.

4.1 Density Test

Theoretical density is found by the rule of mixture technique and the real density of the material are measured by experimentation where in the difference between the sample weights in air and water medium is used to measure the densities.

Table 1 Percentage composition of materials

SI. No	Laminates	Hybrid	basalt(B)wt %	Jute(J)wt %	Glass(G)wt %	Epoxy with wt%
1	L_1	B+J	10	20		70
2	L_2	B+J	20	10		70
3	L_3	B+G	10		20	70
4	L_4	B+G	20		10	70

Table-1shows the percentage composition of the materials used. Table-2 shows the conversion of weight percentage to volume percentage. Table-3 shows the theoretical and actual densities.

Densities of the materials used: Epoxy - 1.8, Basalt fibre-2.8, Jute -1.5, GF -2.5.

Conversion of weight percentage to volume percentage

For Laminate L_1= (70/1.8) + (10/2.8) + (20/1.5) =38.88 + 3.57 +13.33 = 55.78

Volume of Matrix = ((38.88(100/100))/55.78 = 69.70%

Volume of Basalt Reinforcement. = ((3.57(100/100))/55.78 = 6.40%

Volume of Jute Reinforcement. = ((13.33(100/100))/55.78 = 23.90%.

Similarly, other percentages are calculated and the theoretical densities of each of the composites are derived by the rule of mixture method.

Table-2 Converting weight percentage to volume percentage

Laminates	Material	Percentage by weight	Percentage by volume
L_1	Epoxy	70	69.70
	Basalt	10	6.40
	Jute	20	23.90
L_2	Epoxy	70	73.80
	Basalt	20	13.55
	Jute	10	12.65
L_3	Epoxy	70	77.06
	Basalt	10	7.07
	Glass	20	15.85
L_4	Epoxy	70	77.06
	Basalt	20	7.07
	Glass	10	15.85

4.2 Theoretical Density

L_1 - Composite with, by rule of mixture method

$$\rho_{th} = (V_m \times \rho_m) + (V_r \times \rho_r) + (V_r \times \rho_r)$$
$$\rho_{th} = (0.697 * 1.8) + (0.064 * 2.8) + (0.239 * 1.5)$$
$$\rho_{th} = 1.7923 \text{ g/cm}^3$$

From the results (Fig.2) obtained from the investigational work, it can be well-known that the density of the composite material is found to be increased with rise in the reinforcement percentage, and the theoretical and actual density align in the same manner. The difference between the values of the theoretical and actual densities varies marginally due to the processing constraints while fabricating the composites, hence there is presence of the porous elements.

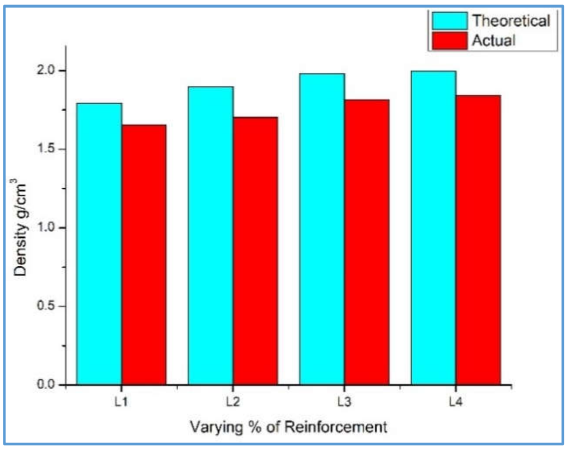

Table .4 Theoretical and Actual Density

Sl. no	Laminates	Theoretical Density g/cm^3	Actual Density g/cm^3	Porosity
1	L_1	1.792	1.654	7.70
2	L_2	1.897	1.702	10.28
3	L_3	1.981	1.813	8.48
4	L_4	1.998	1.844	7.71

Fig.2 Density v/s Varying % of Reinforcement

4.3 Micro hardness Test

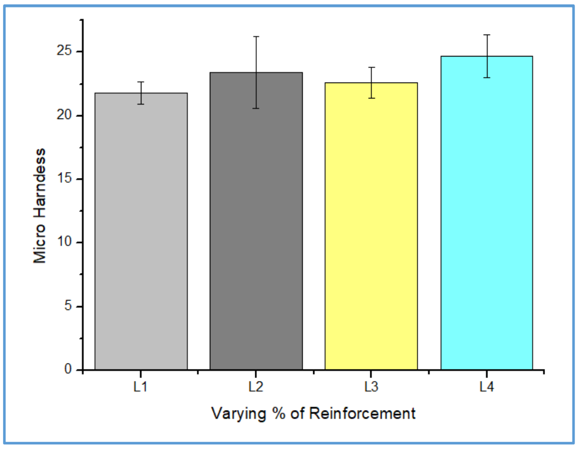

Table.5 Micro Hardness v/s reinforcement

Sl. no	Laminates	Micro Hardness	Standard Deviation
1	L_1	21.82	0.87
2	L_2	23.39	2.82
3	L_3	22.62	1.21
4	L_4	24.67	1.69

Fig.3 Micro Hardness v/s Varying % of Reinforcement

One of a material's characteristics is hardness. Indentation resistance is the definition of hardness. Usually, the permanent depth of the depression is used to determine hardness. The durometer conducts the test. It is one of the tools used to gauge the toughness of materials like rubber, polymers, and elastomers. The volume fractions and fiber arrangement are often the key elements that influence the composite's characteristics. The relationship between volume fraction and hardness is straightforward. High hardness and high volume fraction are related, and vice versa. Table 5 indicates the corresponding hardness values obtained for the identical percentage of epoxy and reinforcement materials.

The hardness profile of different composites is shown in the Fig 3. It can be seen that, as the percentage of reinforcement content increases, the hardness of the composites also enhances. The distribution of the test load over the fibers, which reduces the test indenter's penetration through the surface of the manufactured composite material and as a result raises the composite material's hardness, increases the strength of the material when glass and jute fibers are added. Since the as epoxy material has low hardness, the strength of the composite material will be less hence glass fibers are added to enhance the indentation resistance properties to the composite materials. On the other hand, the jute fibers also serve the same purpose as the glass fibers but the density of the material is less for the jute fibers hence there is a lower level of hardness in the material.

4.4 Impact Testing (Toughness Test)

Impact is a crucial element for a structure's lifespan. In order to examine material toughness, impact tests were utilised. Toughness is a measure of a material's capacity to absorb energy, when plastic deformation occurs.Izod impact tester underwent an impact strength test. The samples were prepared for testing using the ASTM standard size. Using a water jet cutter and emery paper, samples were first cut from composite panels and then completed to size. The specimens were fractured by a single pendulum swing after being clamped vertically. To get an average value from the four samples examined, the impact that happened on the specimen's notched side was recorded, and the trail was repeated.

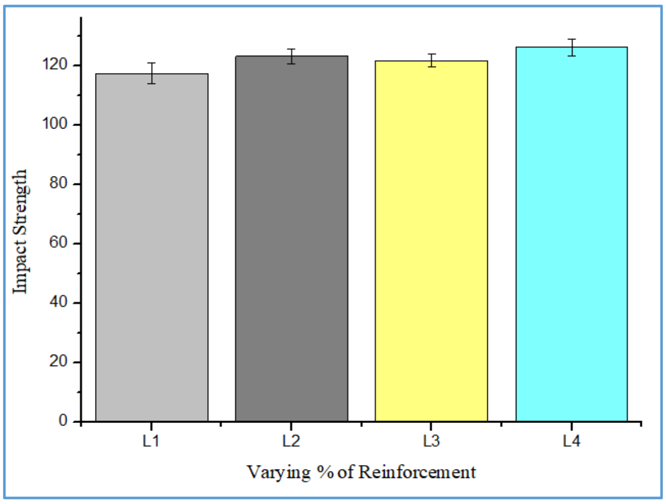

Table- 6 Impact Strength v//s Reinforcement

Sl. no	Laminates	Impact Strength (J)	Standard Deviation
1	L_1	117.50	3.41
2	L_2	123.25	2.5
3	L_3	121.75	2.21
4	L_4	126.25	2.75

Fig .4 Impact Strength V/s Varying % of Reinforcement

An important phenomenon in the control of a structure's life is impact. In order to examine material toughness, impact tests were utilized. Toughness is a measure of a material's capacity to absorb energy during plastic deformation. The impact strength values of the jute fiber, glass fiber composites are presented in Fig.4.and listed in the Table 6. The base material with Basalt and Jute fibers has impact strength rate which is lesser than that of the other Basalt and Glass fibers. The reason is that the Basalt and the Glass fiber’s strength and stiffness is higher, subsequent in a increased ability to absorb impact energy. Impact strength has been increased as a result of the hybrid composites' use of glass fiber together with basalt fiber. It should be noted that the placement of the glass fibers on the surface has improved the bending stiffness and increased the impact strength of the composite.

4.5 Tensile Test

Tensile strength of composites materials is mainly decided by the fiber strength as well as fiber contents. So variation in composites strength with different fiber loading is obvious. The results of tensile test indicate that there is an increase in tensile strength of the composite material with increase in the content of fibers. The effect of fiber loading on the tensile strength and modulus are shown in Table 7.

Table .7 Tensile strength values with Standard deviation

Sl. no	Laminates	Avg. Tensile Strength (Mpa)	Standard Deviation
1	L_1	332.85	5.80
2	L_2	350.29	11.08
3	L_3	357.95	6.71
4	L_4	365.85	7.78

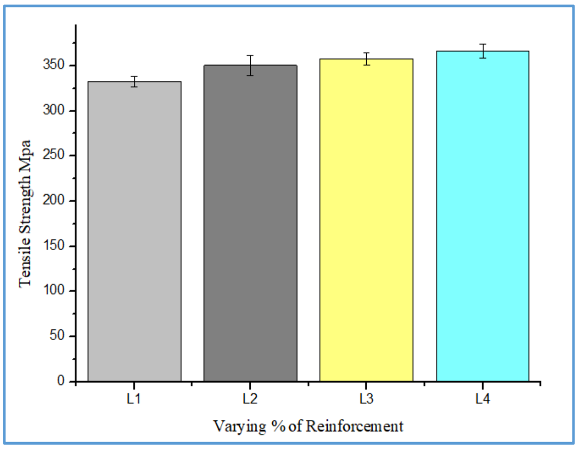

Fig .5Tensile Strength v/s Varying % of Reinforcement

The ultimate tensile strength (UTS) of basalt, jute and glass fiber reinforced epoxy hybrid composites are shown in the Fig.5. As the fiber content increases, the tensile strength also increases correspondingly. The composite material with Basalt and Glass fiber exhibited higher tensile strength compared to other composites. It is noted that the addition of fibers helps to increase the tensile strength of the basalt/glass hybrid composites because density of basalt as well as glass fiber is much higher than the basalt and jute fibers. Proper adhesion between the both types of fiber and the matrix gives continuous increment in tensile strength of composite as increases fiber wt%. The hybridization of the fibers has provided considerable improvement of tensile strength when compared to individual reinforcement; this is mainly due to transfer of loads and shearing of loads among the fibers.

SEM study of the tensile samples is been carried out and the results obtained are indicated in the Fig.6 and Fig.7 before and after the tensile test. It can be noted that the reinforcement materials are inbound with the matrix material and the alignment of the fibers is in line along the direction of the loading. The presence of the hard fibrous material in the matrix has helped in improving the tensile strength of the composite with Basalt and Glass fibers. This proves that the presence of the more amounts of fibers along the direction of the load resist the deformation of the material and in turn provides strength to overcome the load before failure.

Fig.6 SEM of Tensile Sample with Basalt and Glass Fibers before Failure

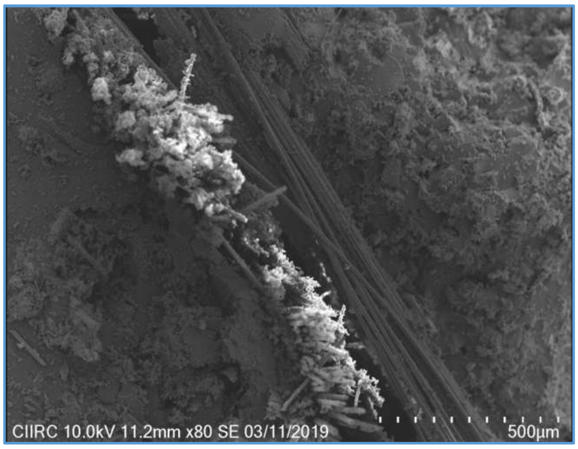

Fig. 7 SEM of Broken Out Tensile Sample with Basalt and Glass Fibers

V. CONCLUSIONS

Increased usage of polymeric composites for various applications has necessitated investigations to study the behavior of these materials under various operating conditions. Present investigation has been carried out to study the importance of the natural and the glass fibers reinforced epoxy hybrid composites. The following conclusion has been drawn based on the results obtained from the investigation. Polymer composite with varying percentage of reinforcements has been fabricated successfully by the hand layup process.

- Density of the materials is also found to be increased for the glass fiber reinforced composite when compared to other hybrid reinforcement
- With the addition of glass fibers and basalt and glass fibers, the strength is increased because the test load is distributed over the fibers, which reduces the penetration of the test indenter to the surface of the fabricated composite material and, as a result, raises the composite material's hardness.

- Similar to the Hardness, Tensile strength of the materials is also being found to be enhanced due to the reinforcement addition. Presence of the more amounts of fibers along the direction of the load resist the deformation of the material and in-turn provides strength to overcome the load before failure.
- The reason behind increase in tensile strength is strong interfacial bonding between fibers and epoxy which act as mechanical interlocking between basalt/jute/glass fiber and epoxy and no porous in between fiber and matrix. This creates a high friction coefficient and increases the strength.

References

1. Suriani MJ, Rapi HZ, Ilyas RA, et al (2021) **Delamination and manufacturing defects in natural fiber-reinforced hybrid composite:** A review. Polymers (Basel). 13
2. Dalla Libera Junior V, Leão RM, Franco Steier V, da Luz SM (2020) **Influence of cure agent, treatment and fibre content on the thermal behaviour of a curaua/epoxy prepreg. Plast Rubber Compos** 49:. https://doi.org/10.1080/14658011.2020.1729658.
3. Ramesh Kumar SC, Kaviti RVP, Mahesh L, Mohan Babu BM (2022) **Water absorption behavior of hybrid natural fiber reinforced composites**. Mater Today Proc 54:. https://doi.org/10.1016/j.matpr.2021.08.281.
4. Suresh Kumar S, Thirumalai Kumaran S, Velmurugan G, et al (2021) **Physical and mechanical properties of various metal matrix composites**: A review. In: Materials Today: Proceedings.
5. Kaczmar JW, Pietrzak K, Wlosiński W (2000) **Production and application of metal matrix composite materials**. J Mater Process Technol 106:. https://doi.org/10.1016/S0924-0136(00)00639-7.
6. Guler O, Bagci N (2020) **A short review on mechanical properties of graphene reinforced metal matrix composites.** J. Mater. Res. Technol. 9.
7. Neto J, Queiroz H, Aguiar R, et al (2022) **A review of recent advances in hybrid natural fiber reinforced polymer composites.** J. Renew. Mater. 10.
8. Selver E, Dalfi H, Yousaf Z (2022) **Investigation of the impact and post-impact behaviour of glass and glass/natural fibre hybrid composites made with various stacking sequences: Experimental and theoretical analysis.** J Ind Text 51:. https://doi.org/10.1177/1528083719900670.
9. Kumar MP, Raga S, Chetana S, Rangappa D (2022) **Realization of Anomalous Microwave Absorption Characteristics of PVB-PEDOT:PSS with Electromagnetic**

Data-Driven Discovery. IEEE Trans Dielectr Electr Insul 29:. https://doi.org/10.1109/TDEI.2022.3148440.

10. Mudike R, Sabbanahalli C, Sriramoju JB, et al (2022) **Copper zinc tin sulfide and multi-walled carbon nanotubes nanocomposite for visible-light-driven photocatalytic applications.** Mater Res Bull 146:. https://doi.org/10.1016/j.materresbull.2021.111606.
11. Kumar M, Kumara Swamy BE, Reddy S, et al (2019) **ZnO/functionalized MWCNT and Ag/functionalized MWCNT modified carbon paste electrodes for the determination of dopamine, paracetamol and folic acid.** J Electroanal Chem 835:. https://doi.org/10.1016/j.jelechem.2019.01.019.
12. Sriramoju JB, Muniyappa M, Marilingaiah NR, et al (2021) **Carbon-based TiO_2-x heterostructure nanocomposites for enhanced photocatalytic degradation of dye molecules.** Ceram Int 47:. https://doi.org/10.1016/j.ceramint.2020.12.014.
13. Shetty M, Schüßler C, Shastri M, et al (2021) O**ne-pot supercritical water synthesis of Bi2MoO6-RGO 2D heterostructure as anodes for Li-ion batteries.** Ceram Int 47:. https://doi.org/10.1016/j.ceramint.2020.12.061.
14. Shastri M, Shetty M, Rani M N, et al (2021) **Reduced graphene oxide wrapped sulfur nanocomposite as cathode material for lithium sulfur battery**. Ceram Int 47:14790–14797. https://doi.org/10.1016/J.CERAMINT.2020.10.215.
15. Casati R, Vedani M (2014) **Metal matrix composites reinforced by Nano-Particles-**A review. Metals (Basel). 4.
16. Mehra N, Mu L, Ji T, et al (2018) **Thermal transport in polymeric materials and across composite interfaces.** Appl. Mater. Today 12.
17. Chetana S, Shetty M, Roy K, et al **Study on the DC supply and charging effect on the growth of carbon nanotubes and their electrochemical properties**. J Mater Sci Mater Electron. https://doi.org/10.1007/s10854-022-08813-6.
18. S C, Roy K, Kumar MP, et al (2022) **Supercritical fluid synthesized Cu2ZnSnS4-Polyaniline nanocomposites for supercapacitor application.** Ceram Int. https://doi.org/10.1016/J.CERAMINT.2022.08.104.
19. Jhilmil Swapnalin, Prasun Banerjee, Chetana Sabbanahalli, et al (2022) **Computational Techniques on Optical Properties of Metal-Oxide Semiconductors.** In: Optical Properties and Applications of Semiconductors. pp 155–166.
20. Choudhary P, Pathak A, Kumar P, et al **Commercial production of bioplastic from organic waste-derived biopolymers viz-a-viz waste treatment: A minireview.** 1:3. https://doi.org/10.1007/s13399-022-03145-1.

21. Joshi NC, Rawat BS, Bisht H, et al (2022) **Synthesis and supercapacitive behaviour of SnO_2/r-GOnanocomposite.**SynthMet289:117132. https://doi.org/10.1016/J.SYNTHMET.2022.117132.
22. Halligudra G, Paramesh CC, Gururaj R, et al (2022) **Magnetic Fe_3O_4 supported MoS_2 nanoflowers as catalyst for the reduction of p-nitrophenol and organic dyes and as an electrochemical sensor for the detection of pharmaceutical samples.** Ceram Int. https://doi.org/10.1016/J.CERAMINT.2022.06.188.
23. Mackenzie JD, Bescher EP (2018) **Mechanical properties of organic-inorganic hybrids.** In: Handbook of Sol-Gel Science and Technology: Processing, Characterization and Applications.
24. Huda MS, Drzal LT, Ray D, et al (2008) **Natural-fiber composites in the automotive sector. In: Properties and Performance of Natural-Fibre Composites.**
25. Huda MK, Widiastuti I (2021) **Natural Fiber Reinforced Polymer in Automotive Application:** A Systematic Literature Review. In: IOP Conference Series: Earth and Environmental Science.
26. De Souza MC, Moroz I, Cesarino I, et al (2022) **A Review of Natural Fibers Reinforced Composites for Railroad Applications**. Appl. Sci. Eng. Prog. 15.
27. Mayilswamy N, Kandasubramanian B (2022) **Green composites prepared from soy protein, polylactic acid (PLA), starch, cellulose,** chitin: a review. Emergent Mater.
28. .Faruk O, Bledzki AK, Fink HP, Sain M (2014) **Progress report on natural fiber reinforced composites**. Macromol. Mater. Eng. 299.
29. Sreenivas HT, Krishnamurthy N, Arpitha GR (2020) **A comprehensive review on light weight kenaf fiber for automobiles.** Int. J. Light. Mater. Manuf. 3.
30. Kumar S, Prasad L, Patel VK, et al (2021) **Physical and mechanical properties of natural leaf fiber-reinforced epoxy polyester composites.** Polymers (Basel). 13.
31. Asim M, Abdan K, Jawaid M, et al (2015) **A review on pineapple leaves fibre and its composites**. Int. J. Polym. Sci. 2015.
32. Rafiqah SA, Khalina A, Harmaen AS, et al (2021) **A review on properties and application of bio-based poly(Butylene succinate).** Polymers (Basel). 13.
33. Hjelt T, Ketoja JA, Kiiskinen H, et al (2020) **Foam forming of fiber products: a review**. J Dispers Sci Technol. https://doi.org/10.1080/01932691.2020.1869035.
34. Du Y, Wu T, Yan N, et al (2014) **Fabrication and characterization of fully biodegradable natural fiber-reinforced poly(lactic acid) composites.** Compos Part B Eng 56:. https://doi.org/10.1016/j.compositesb.2013.09.012.