Materials Physics and Mechanics. 2023;51(7): 99-106
Research article
http://dx.doi.org/10.18149/MPM.5172023_8

Submitted: April 13, 2023
Approved: November 14, 2023
Accepted: December 12, 2023

Evaluation of mechanical properties of ABS-based fiber composite with infill using 3D printing technology

P. Venkataramana [1], S.P. Jani [1], U. Sudhakar [1], M. Adam Khan [2]✉, K. Sravanthi [1]

[1] Marri Laxman Reddy Institute of Technology and Management, Hyderabad, India

[2] Kalasalingam Academy of Research and Education, Tamil Nadu, India

✉ adamkhanm@gmail.com

Abstract. This research explores the utilization of acrylonitrile butadiene styrene (ABS) material for structural applications, addressing the growing demand for polymer composites. Employing fused filament fabrication (FFF) 3D printing with a 2 mm shell thickness, ABS samples were reinforced with basalt, hemp, and glass fibers using epoxy resin to enhance material strength. Mechanical behavior under axial, flexural, and impact loading conditions was investigated, revealing the basalt-reinforced ABS composite's superior performance with a maximum load of 9540 N - three times that of pure ABS (2975 N). The load-bearing capacity of basalt-epoxy reinforced ABS reached 880 N, surpassing glass-epoxy and hemp-epoxy variants. Impact energy was notably higher for reinforced composites (28.9-32.2 KJ/m^2) compared to pure ABS (10.3 KJ/m^2). The SEM analysis also carried out for better understanding of fracture surface of composites. This study recommends the application of these reinforced ABS composites in structural contexts.
Keywords: 3D printing; fibre; epoxy; mechanical load

Citation: Venkataramana P, Jani SP, Sudhakar U, Adam Khan M, Sravanthi K. Evaluation of mechanical properties of ABS-based fiber composite with infill using 3D printing technology. *Materials Physics and Mechanics*. 2023;51(7): 99–106. DOI: 10.18149/MPM.5172023_8.

Introduction

Fused deposition modelling (FDM) is a widely used 3D printing technology that has revolutionized the manufacturing industry. FDM printers use a thermoplastic filament that is melted and extruded layer by layer to create 3D objects [1]. The most commonly used material in FDM printing is acrylonitrile butadiene styrene (ABS). However, ABS has some limitations in terms of strength, stiffness, and thermal stability. To overcome these limitations, researchers have been investigating the use of fiber reinforcements in ABS for FDM printing. The addition of fibers can significantly improve the mechanical properties of the printed parts. In this literature review, we will explore the various types of fibers that can be used as reinforcement in ABS for FDM printing and the impact of fiber reinforcement on the mechanical and thermal properties of the printed parts [2,3].

In recent years, there has been a growing interest in using fiber-reinforced materials for 3D printing. The addition of fibers to a polymer matrix can enhance the mechanical properties of the printed parts, including tensile strength, flexural strength, and impact strength. There are several types of fibers that have been investigated as reinforcement in ABS for FDM printing, including carbon fibers, glass fibers, and natural fibers [4,5].

Carbon fibers are widely used as a reinforcement in composites due to their high strength, stiffness, and low weight. Several studies have investigated the use of carbon fibers as a reinforcement in ABS for FDM printing [6]. Carbon fiber-reinforced ABS (CFR-ABS) can

Publisher: Peter the Great St. Petersburg Polytechnic University

have a tensile strength up to 120 MPa and a modulus of elasticity up to 12 GPa, which is significantly higher than unreinforced ABS [7]. The addition of carbon fibers can also improve the thermal stability of ABS. However, the high cost of carbon fibers and the difficulty in achieving a homogeneous distribution of fibers in the polymer matrix are significant challenges in using CFR-ABS for 3D printing [8].

Glass fibers are another commonly used reinforcement in composites due to their high strength and stiffness. Several studies have investigated the use of glass fibers as a reinforcement in ABS for FDM printing [9]. Glass fiber-reinforced ABS (GFR-ABS) can have a tensile strength up to 80 MPa and a modulus of elasticity up to 7 GPa, which is significantly higher than unreinforced ABS. The addition of glass fibers can also improve the thermal stability of ABS. However, the main challenge in using GFR-ABS for 3D printing is the difficulty in achieving a homogeneous distribution of fibers in the polymer matrix [10].

Natural fibers, such as flax, hemp, and jute, have been investigated as a reinforcement in composites due to their low cost, low density, and biodegradability [11]. Several studies have investigated the use of natural fibers as a reinforcement in ABS for FDM printing [12]. Natural fiber-reinforced ABS (NFR-ABS) can have a tensile strength up to 40 MPa and a modulus of elasticity up to 4 GPa. The addition of natural fibers can also improve the thermal stability of ABS. However, the main challenge in using NFR-ABS for 3D printing is the difficulty in achieving a homogeneous distribution of fibers in the polymer matrix [13].

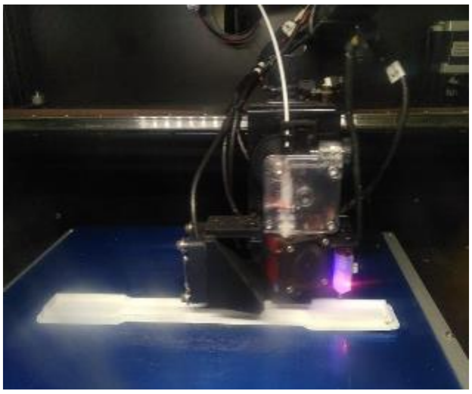
The novelty of this project lies in the investigation of the mechanical behavior of ABS composites reinforced with different types of fibers under different loading conditions. While ABS material is commonly used for soft and low-load applications, the addition of fiber reinforcement can enhance its strength and make it suitable for structural applications. The use of 3D printing technology for fabricating the composite samples provides an efficient and cost-effective way to produce complex geometries. The use of basalt and hemp fibers as reinforcement materials is relatively new and has not been extensively studied in comparison to traditional reinforcement materials like glass fibers. Therefore, this project offers a unique opportunity to explore the mechanical properties of ABS composites reinforced with basalt and hemp fibers in comparison to glass fibers. The study results will contribute to the knowledge of the potential of reinforced ABS composites for structural applications, offering insights into the optimal fiber type and loading conditions for achieving the desired mechanical performance.

Materials and Methods

Sample development. Acrylonitrile butadiene styrene (ABS) is the common thermoplastic polymer material which is highly recommended and used for making the structural device. Most of the toys and play store devices are made using this polymeric material [14,15]. To increase the structural properties in terms of strength, the fiber reinforcement is made inside the 3D printed ABS material. In order to study the strength of 3D printed composite, a common ASTM standard test samples are used. In order to produce the test structure, the ABS wire is used to develop the test sample for tensile test, flexural test and impact test following ASTM standard. Figure 1 shows the photo image of 3D printing of ABS material (Table 1).

The test samples developed through the additive manufacturing are further post processed to fill the structure with different fiber and Epoxy SYSBOND 757 with hardener 757 (10:1) [16]. The fibre and resin in the proportion of 60:40 wt. % is used to fill in the additive – built test coupons. Three different types of fibre namely basalt, glass and hemp fibre are used as a reinforcement material mixed with the epoxy resin; and the same are filled inside the ABS structure. Standard procedure is adopted for resin – catalyst curing with fibre reinforcement. The prepared mixture / blend of fibre and epoxy was refilled as given in the photo image (Fig. 2).

After a proper curing time, the test samples are cleaned and verified to the standard dimensions. The extra projections or overflow in the ASTM standard dimensions are cleared before the mechanical testing (tensile, flexural and impact) of samples. The samples are now designated as i. ABS + Basalt, ii. ABS + Glass and iii. ABS + Hemp combination. The final test samples are given in the following image (Fig. 3). Further, the standard procedure is used to evaluate the mechanical properties of the test samples.


(a)

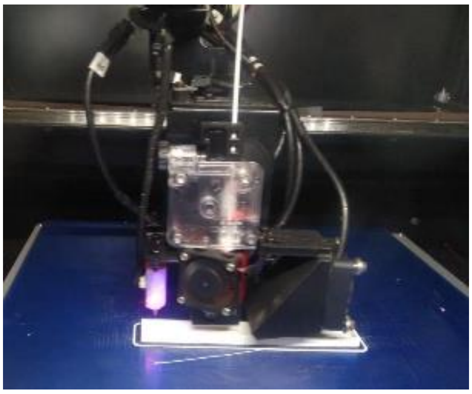

(b)

Fig. 1. 3D printing of hollow structure using ABS wire for mechanical test specimen following ASTM standard dimensions: (a) tensile test sample; (b) flexural test sample

Table 1. Printing specification

Initial layer height, mm	0.2
Top/bottom thickness, mm	0.68
Infill density, %	100
Infill pattern	Lines
Infill line direction, °	90
Bed plate temp., °C	100
Travel speed, mm/s	100
Fan speed, %	100
Adhesion Type	Skirt
Speed, mm/s	80
Thickness, mm	0.16
Temp., °C	270

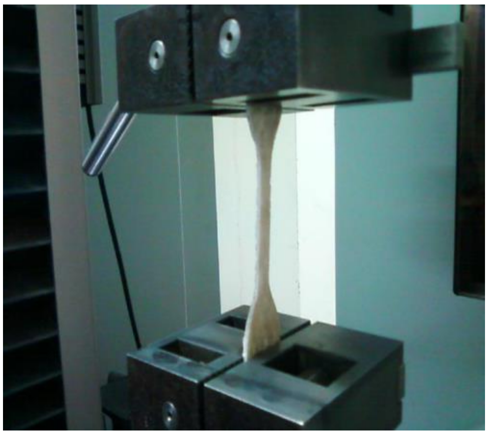
Fig. 2. The filling of fibre – epoxy mixture in the ABS structure

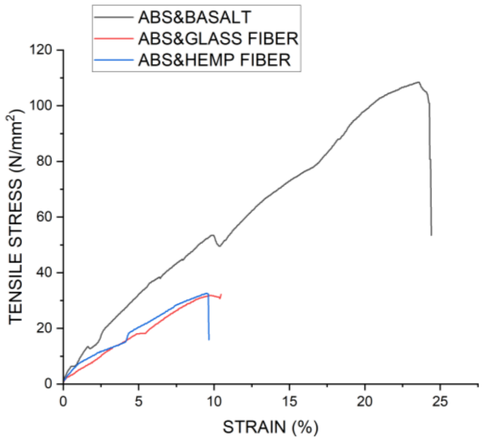
Fig. 3. Test samples after curing of fibre – epoxy resin in the ABS structure

Results and Discussion

Tensile testing. The mechanical testing of the ABS build structure with fiber – epoxy filling is compared with pure ABS 3D printed sample. The test samples are investigated to report the material behaviour under axial loading condition. The tensile testing is followed with an ASTM

Standard number ASTM D638-14 for evaluation. The test samples are designated in three different groups of combination for better comparison and illustration; and the samples are as:
1. ABS with basalt fibre and epoxy resin (ABS + basalt);
2. ABS with glass fibre and epoxy resin (ABS + glass);
3. ABS with hemp fibre and epoxy resin (ABS + hemp).





(a) (b)

Fig. 4. Universal testing machine (a) and stress-strain graphs (b)

Figure 4 shows the mechanical testing facility for the test sample (UTM 2010 Model) and the result of test samples in the form of graph. The stress – strain curves recorded for the ABS with different fiber and epoxy resin indicate the appreciable result. The difference in yield point and fracture point are wide in range for the samples based on the reinforcement material. While comparing the individual results, the performance of the ABS material with basalt fiber maximum [17]. The maximum load for the ABS material with basalt fiber is, 9540 N as the basalt natural material has high strength compared to the other fiber material. It is three times stronger than the pure ABS 3D printed material (2975 N load) as indicated in the Fig. 5 as tensile load factor. The ABS with glass fiber (3360 N load) and hemp fiber (3240 N load) are less compared to basalt fiber material. The brittleness nature of glass fiber has induced the composite to fracture in the early stage rather than the basalt.

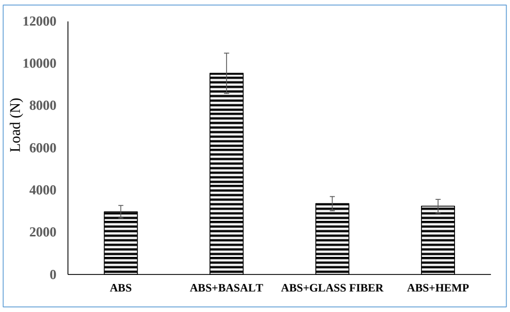


Fig. 5. Tensile load recorded for the ABS with different fibre – epoxy resin

Further, the material quality in terms of strength is evaluated for comparison. As recorded, the maximum yield load in the axial condition has increased tensile strength of different material combination. Figure 6 shows tensile strength recorded for different fiber material in the ABS material. As the load increase, the intensity of the subjected area will subsequently support to increase the strength. Therefore, the tensile strength of the material will be maximum [18,19]. On the other hand, the material behaviour in terms of young's modulus is one of the predominant factor. The result of stress and the strain induced in the material during the axial load is used to find the modulus of the material. Figure 7 is the calculated value of modulus based on stress and strain of the material behaviour. The difference in modulus is very less compared to each material combination. For example, the hemp and glass fiber (3.2 and 3.1 KPa) is close to the basalt fiber (4.3 KPa), indicating the difference in deformation. As the elongation increases, the modulus of the material will be reduced. By the for pure ABS material the modulus recoded is 1.8 KPa where the elongation is maximum compared to the fiber reinforcement. Therefore, the load bearing capacity of the ABS material with basalt – epoxy resin reinforcement has developed a better result compared to other materials.

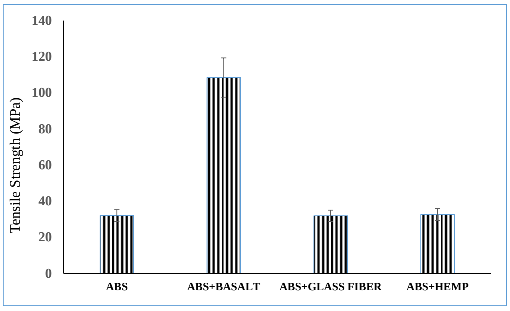


Fig. 6. Tensile strength of ABS with different fibre – epoxy resin

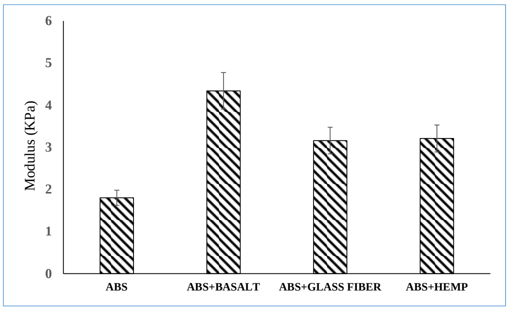


Fig. 7. Youngs modulus of ABS with different fibre – epoxy resin

Flexural test. The flexural testing of the material is made through the three point bending method following the simply supported loaded structure. The ASTM standard was followed for the flexural loading (ASTMD790-30) with a defined set of geometrical dimensions and experimental procedure. Like the tensile testing, the samples are designated as:
1. ABS with basalt fibre and epoxy resin (ABS + Basalt);
2. ABS with glass fibre and epoxy resin (ABS + glass);
3. ABS with hemp fibre and epoxy resin (ABS + hemp).

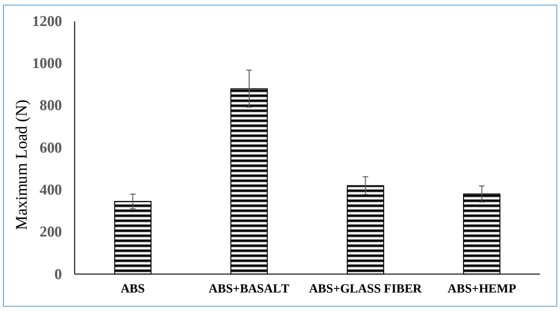


Fig. 8. Flexural load recorded for the ABS material reinforced with different types of fibre – epoxy resin

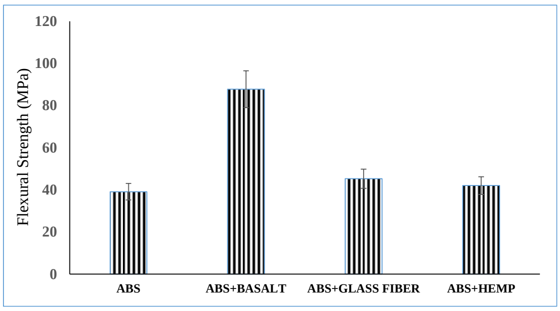


Fig. 9. Flexural strength recorded for the ABS material reinforced with different types of fibre – epoxy resin

The samples are tested and evaluated to report the flexural strength and the bending load of the material. From the experimentation, the flexural load and the strength of the material. Figure 8 indicates the maximum load for ABS with different reinforcement material. The load bearing capacity of the basalt – epoxy reinforced ABS material recorded with a maximum load of 880 N. The basalt fiber possess high strength, and it has high flexural properties just like the carbon material. The nature made basalt material (derived from the rock) has high damping energy, and it can withstand maximum load. For the glass and hemp reinforced ABS material possess two times less load compared to the basalt material. When comparing the pure ABS with fiber reinforced material; the quality of pure ABS found discouraging to select in terms of load. As the pure ABS material developed through the additive manufacturing does not have enough bonding to bear the load.

In general, the additive build materials are anisotropic in nature, and they are in need of secondary process or support to bear the load. In this case, the ABS structure with different types of fiber – epoxy resin is filled and investigated. The reinforcement has a reasonable strength compared to the ABS built material structure. From the graph (Fig. 9) the flexural strength of the material is recorded. The basalt fiber – epoxy has a maximum flexural strength of 87.7 MPa indicating the strength as in the axial loading. For the glass fiber and hemp fiber – epoxy reinforced ABS structure has less strength in the two-fold of basalt material. When the load is applied on the hatch layers, the structure is subjected to sliding of the material and it fails. At the same, the hatch layers do not have good bonding with maximum loading and make the material fracture. To increase the strength, the reinforcement in the ABS structure has supported the layer to withstand the applied load.

Impact strength. The impact strength of the above designed materials is studied to record the impact energy observed in the material. The ASTM standard was followed for the Impact (ASTM D256) with a defined set of geometrical dimensions and experimental procedure. The impact energy of the ABS structure reinforced with the basalt – epoxy resin has a maximum impact energy of 53.9 KJ/m^2. As mentioned in the previous section, the data recorded for the ABS with basalt – epoxy resin has two time high strength compared to the other two fibers. The glass – epoxy and hemp – epoxy has an average of 28.9 and 32.2 KJ/m^2 impact energy. At the same, the pure ABS structure has 10.3 KJ/m^2 energy. The ABS is the pure soft material which is vulnerable towards the impact load and do not have strength to face the load. However, on reinforcement of hard fiber in the ABS structure have absorbed the impact energy. From the Fig. 10 analysis, the mechanical behaviour of the material with fiber – epoxy reinforced structure results indicate that the basalt fiber has high strength in terms of tensile loading, flexural load and impact load.

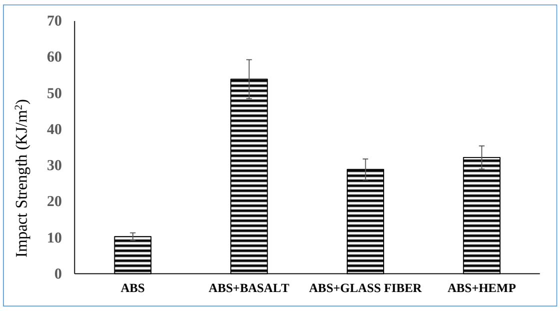
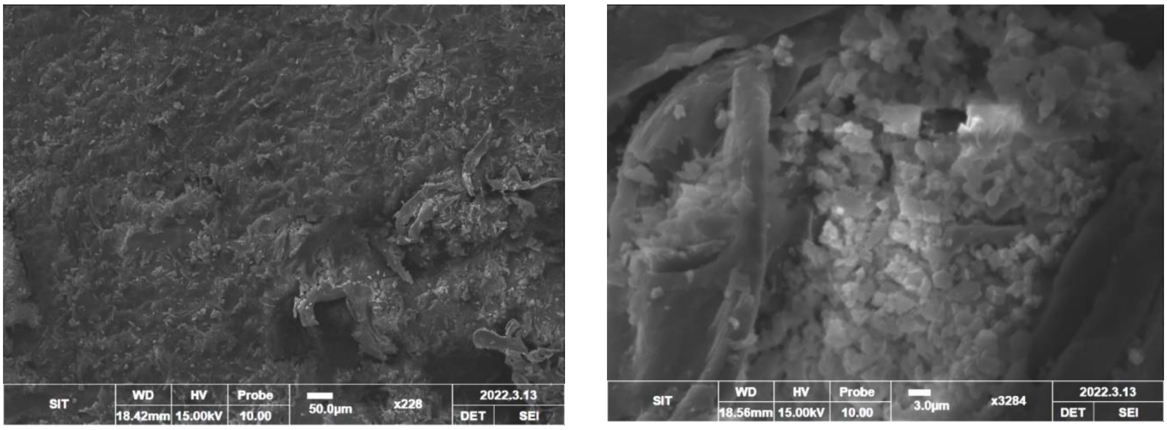


Fig. 10. Impact strength recorded for the ABS material reinforced with different types of fibre – epoxy resin

Scanning electron microscopy (SEM) analysis (Fig. 11) was conducted on fractured samples from the tensile and flexural testing of hemp-reinforced ABS composites. The examination aimed to elucidate the microstructural features and fracture surfaces, providing insights into the material's failure mechanisms. The SEM images revealed the dispersion and alignment of hemp fibers within the ABS matrix, contributing to the enhanced mechanical properties observed in the tensile and flexural tests. Fracture surfaces exhibited characteristic patterns indicative of fiber-matrix interactions, offering valuable information on the composite's structural integrity. This analysis further supports the comprehensive understanding of the mechanical behavior and performance of hemp-reinforced ABS composites in structural applications.



(a) (b)

Fig. 11. Fracture image of hemp ABS fibre: (a) tensile tested sample; (b) flexural tested sample

Conclusions

The study utilized ABS material to construct a test structure, extending its application by developing three distinct fiber-epoxy reinforced ABS composites for comparative analysis. Findings indicate that fiber reinforcement significantly enhances axial load strength, with the basalt-epoxy composite demonstrating notable yielding strength. Deformation resistance, particularly towards elongation and strain rate, was improved through fiber-epoxy reinforcement, with the basalt fiber-epoxy composite displaying high resistance. In flexural strength, the basalt fiber-epoxy reinforced ABS material exhibited commendable bending strength and resistance against maximum bending load, making it suitable for structural applications. Contrarily, the soft ABS material demonstrated lower strength than its fiber-epoxy reinforced counterparts. Scanning electron microscopy (SEM) analysis confirmed the uniform distribution of fibers within the ABS matrix. The study recommends a shift in the application of soft ABS material towards mechanical loading and structural applications when reinforced with fibers and epoxy. For future work, optimizing fiber content, exploring additional composite materials, conducting durability studies, and assessing scalability for industrial applications are proposed avenues to refine and expand the application scope of fiber-reinforced ABS composites.

Reference

1. Jani SP, Kumar AS, Anushraj B, Mashinini PM, Uppalapati S. Development and Optimization Study of Poly-Lactic Acid Blended Carbon Particles by Fused Deposition Modelling Method. In: *Innovations in Additive Manufacturing.* Cham: Springer; 2022. p.121-138.

2. Mazzanti V, Malagutti L, Mollica F. FDM 3D printing of polymers containing natural fillers: A review of their mechanical properties. *Polymers.* 2019;11(7): 1094.

3. Morales MA, Atencio Martinez CL, Maranon A, Hernandez C, Michaud V, Porras A. Development and characterization of rice husk and recycled polypropylene composite filaments for 3D printing. *Polymers*. 2021;13(7): 1067.

4. Sanei SHR, Popescu D. 3D-printed carbon fiber reinforced polymer composites: a systematic review. *J Composites Sci*. 2020;4(3): 98.

5. Mazzanti V, Malagutti L, Mollica F. FDM 3D printing of polymers containing natural fillers: A review of their mechanical properties. *Polymers*. 2019;11(7): 1094.

6. Billah KMM, Lorenzana FA, Martinez NL, Wicker RB, Espalin D. Thermomechanical characterization of short carbon fiber and short glass fiber-reinforced ABS used in large format additive manufacturing. *Additive Manufacturing*. 2020;35: 101299.

7. Ahmed SW, Hussain G, Altaf K, Ali S, Alkahtani M, Abidi MH, Alzabidi A. On the effects of process parameters and optimization of interlaminate bond strength in 3D printed ABS/CF-PLA composite. *Polymers*. 2020;12(9): 2155.
8. Adeniran O, Cong W, Oluwabunmi K. Thermoplastic matrix material influences on the mechanical performance of additively manufactured carbon-fiber-reinforced plastic composites. *J Composite Materials*. 2022;56(9): 1391-1405.
9. Badogu K, Kumar R, Kumar R. 3D Printing of Glass Fiber-Reinforced Polymeric Composites: A Review. *J Institution of Engineers (India): Series C*. 2022;103(5):1285-1301.
10. Chabaud G, Castro M, Denoual C, Le Duigou A. Hygromechanical properties of 3D printed continuous carbon and glass fibre reinforced polyamide composite for outdoor structural applications. *Additive Manufacturing*. 2019;26: 94-105.
11. Mazzanti V, Malagutti L, Mollica F. FDM 3D printing of polymers containing natural fillers: A review of their mechanical properties. *Polymers*. 2019;11(7): 1094.
12. Parpala RC, Popescu D, Pupaza C. Infill parameters influence over the natural frequencies of ABS specimens obtained by extrusion-based 3D printing. *Rapid Prototyping J.* 2021;27(6): 1273-1285.
13. Ismail KI, Yap TC, Ahmed R. 3D-Printed Fiber-Reinforced Polymer Composites by Fused Deposition Modelling (FDM): Fiber Length and Fiber Implementation Techniques. *Polymers*. 2022;14(21): 4659.
14. Le Duigou A, Correa D, Ueda M, Matsuzaki R, Castro M. A review of 3D and 4D printing of natural fibre biocomposites. *Materials & Design*. 2020;194: 108911.
15. Antony S, Cherouat A, Montay G. Fabrication and characterization of hemp fibre based 3D printed honeycomb sandwich structure by FDM process. A. *Composite Materials*. 2020;27: 935-953.
16. Asokan R, Rathanasamy R, Paramasivam P, Chinnasamy M, Pal SK, Palaniappan SK. Hemp composite. In: *Green Sustainable Process for Chemical and Environmental Engineering and Science*. Elsevier; 2023. p.89-112.
17. Chinnasamy V, Subramani SP, Palaniappan SK, Mylsamy B, Aruchamy K. Characterization on thermal properties of glass fiber and kevlar fiber with modified epoxy hybrid composites. *J Mater Res Technol*. 2020;9(3): 3158-3167.
18. Jayanth D, Kumar PS, Nayak GC, Kumar JS, Pal SK, Rajasekar R. A review on biodegradable polymeric materials striving towards the attainment of green environment. *J Polymers Environ*. 2018;26: 838-865.
19. Kaliyannan GV, Rathanasamy R, Kumar HKM, Raj MKA, Chinnasamy M, Pal SK, Palaniappan SK. Natural fiber-based bio-degradable polymer composite. In: *Green Sustainable Process for Chemical and Environmental Engineering and Science*. Elsevier; 2023. p.145-165.
20. ASTM D256. *Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics*.
21. ASTM D790. *Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials*.
22. ASTM D638. *Standard Test Method for Tensile Properties of Plastics*.

THE AUTHORS

Venkataramana P.
e-mail: nagakiransai123@gmail.com

Jani S.P.
e-mail: spjani10@gmail.com

Sudhakar U.
e-mail: sudhakar_uppalapati@yahoo.com

Adam Khan M.
e-mail: adamkhanm@gmail.com

Sravanthi K.
e-mail: kundhurusravanthi@gmail.com