Journal of Mines, Metals and Fuels, *72(2): 103-109; 2024. DOI: 10.18311/jmmf/2024/42139*

INFORMATICS JOURNALS

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

Fabrication and Mechanical Testing of Glass Fiber Reinforced Epoxy Matrix Composites Modified with Powdered Metallic Fillers

B. Ravikiran Kamath[1,2], M. Sudheer[3], Vidyasagar Shetty[1]*, Deepak Kothari[4] and Thrivikram Prabhu[5]

[1]Department of Mechanical Engineering, Nitte (Deemed to be University), NMAM Institute of Technology (NMAMIT), Nitte, Udupi - 574110, Karnataka, India; vidyasagar.shetty@gmail.com
[2]Visvesvaraya Technological University, Belagavi - 590018, Karnataka, India
[3]Department of Mechanical Engineering, St Joseph Engineering College, Vamanjoor, Mangaluru - 575028, Karnataka, India
[4]Department of Mechanical Engineering, Alva's Institute of Engineering and Technology, Moodbidri, Mangaluru – 574225, Karnataka, India
[5]Department of Mechanical Engineering, Srinivas University Institute of Engineering and Technology, Mangaluru - 575001, Karnataka, India

Abstract

Composite materials made up of polymer matrix reinforced with synthetic fibers have gained popularity of late owing to their enhanced mechanical properties. However, very little work is reported to date on metals being used as filler material. Research gaps were obtained pertaining to the use of metallic fillers in synthetic fiber reinforced polymer composites. This paper demonstrates an attempt to fabricate composites made of Epoxy polymer matrix and E-glass fiber reinforcement with Mild Steel in its powdered form as fillers. Composites are prepared in varying weight percentages of the filler in the order of 2 wt. %, 4 wt. % and 6 wt. %. Hand layup method is employed for fabricating these composites which are later subjected to compression. Further, the samples are machined according to ASTM D3039 standard for tensile test and ASTM D256 standard for Izod impact test. Hardness test is also performed using a Shore D Durometer and these properties are compared with the unfilled samples. The results indicated that the weight percentage of the filler clearly influenced the mechanical properties of the developed composites. This study also revealed that the hardness and tensile strength of these composites improved with the incorporation of fillers up to 2 wt. % whereas, the impact strength improved up to 4 wt. %. Thereafter, there was a decline in their impact and tensile properties. However, hardness marginally increased beyond 4 wt. %. This area is open for research with regard to their usability under tribological, high temperature or magnetic conditions.

Keywords: *Glass Fiber, Hand Lay Up, Mechanical Testing, Metallic Filler, Polymer Composite*

1.0 Introduction

Composite materials, also called as composites, are a class of materials formed when two or more dissimilar materials, each possessing its own characteristics, are combined to form a unique material whose properties are higher than that of the original constituents for a particular application. Development and application of composite

*Author for correspondence

materials for various applications are in practice since the past few decades. In the modern era, researchers have shifted their focus on developing composite materials which possess lighter weight, greater strength, and better electrical, thermal or mechanical properties. The enhanced properties enable these composites to be extensively employed in military, automotive and aerospace industries[1]. The rise in demand of innovative materials in structural applications has generated attention amongst several researchers to develop composite materials that would have greater performance.

Composite materials often consist of a matrix material reinforced with fibers and/or fillers. The mechanical performance of composite materials is primarily influenced by the type, size and quantity of reinforcements embedded in the matrix. There are different kinds of fibers like jute, flax, hemp[2] etc., which are categorized as natural fibers, and carbon, glass, aramid[3] etc. which are categorized as synthetic fibers. On the other hand, metals, ceramics and polymers have been widely used as matrix materials. Synthetic fibers are more preferred owing to the fact that the natural fibers tend to absorb moisture, thereby resulting in reduced mechanical properties[4]. Among the aforementioned matrix materials, polymers have gained popularity because of their low cost, bonding ability and strength. Furthermore, the strength of the composite materials can be enhanced by adding filler materials. Fly ash, graphene, Al_2O_3, SiC particulates[5] etc. have been previously incorporated in the polymer matrix as filler materials.

A critical review of literature suggests that glass fiber reinforcements provide good stiffness and high tensile strength[6]. Few studies also reported that Epoxy polymer matrix provides good stiffness, high strength and good corrosion resistance[7,8]. The filler material, weight ratio of resin to fiber and the particle size of the fillers influence the mechanical performance of the polymer composites[9-11]. The performance of a material under the conditions of wear and friction between the mating parts also play a pivotal role in selecting them for tribological applications. Some of the examples include machine elements such as gears, bearings or cams. Few researchers have attempted to use natural or metallic fillers to improve the tribological performance of polymer composites. Rout[12] employed rice husk as the filler material and witnessed that the incorporation of rice husk enhanced the wear performance of the Glass-Epoxy composites under erosion. Another study conducted by Sudheer M[13] revealed that the addition of cast iron powders as a micro level filler enhanced the wear performance of the Epoxy polymer. Several researchers[14-19], have attempted incorporating different metallic fillers into the polymer resin and reported an increase in the mechanical properties like impact strength, hardness and tensile strength. Limited amount of work is reported in literatures where a metallic filler is used together with a synthetic fiber reinforcement and a polymer matrix. Hence, this combination is expected to be a potential material for tribological applications. However, this article mainly focuses on the mechanical performance of the fabricated samples.

In this study, Glass-Epoxy composites are fabricated by Hand layup method, which is then followed by compression. Powdered mild steel is used as the filler material and is varied in weight percentage in the order of 2 %, 4 % and 6 % and the samples thus fabricated are subjected to mechanical testing in accordance with ASTM (American Society for Testing and Materials) standards. The mechanical properties of the filled composites are then compared with the unfilled composites.

2.0 Materials and Methods

In the present work, saline treated E-glass fiber of 220 GSM is used as the reinforcement material, which is supplied by M/S Arun Fabrics, Bengaluru. The matrix material used is Epoxy resin (LY556) also known as bisphenol-A-diglycidyl-ether. The hardener used is HY951. They are supplied by M/S Herenba Instruments, Chennai. Mild Steel provides high tensile strength, impact strength and good ductility. The powders obtained during power hacksawing of Mild Steel blocks are accumulated from workshop and sieved to 75 μm size and is employed as a micro-filler in the study.

Hand layup method is employed to fabricate the Glass-Epoxy composites, followed by subjecting the sample to compression under a UTM (Universal Testing Machine). From the sample calculations, it is observed that, in order to achieve a thickness range of 2.8-3.2 mm as per ASTM standards, around 12-14 layers are necessary. Hence, 14 layers of dimensions 200*200 mm of E-glass fibers were used for the study. Two Steel plates of size

600*400*10 mm are used as the upper and lower mold plates, which are tightly wrapped by means of PVC (Poly Vinyl Chloride) sheets with no air gap, upon which the fiber layers will be laid. A duct tape is applied across the boundaries where the sample will be fabricated in order to maintain the resin inside when the load is applied. A thin coat of separator wax is applied on the sheets using cotton, which helps in easier release of composite samples from the mold plates. The required number of fiber layers are weighed, and the fiber and resin are maintained in the proportion 50:50 by weight. To remove any moisture content from the collected Mild Steel powders, a known quantity of this micro-filler is preheated to 80°C for 2 hours in a closed compartment of an air oven. This would permit the heat to reach uniformly to all metal particles. Otherwise, the particles which are in contact with the heating surface would dry, but not those which are far away from the heating surface. These filler particles are then allowed to cool to ambient temperature. The filler is then mixed with Epoxy resin and gently stirred for 15 minutes. After a clear solution is achieved, the hardener is added to the filler-resin mixture in the ratio 10:1 as provided by the supplier. Stirring is continued and a coating of this mixture is applied on the PVC sheets of the bottom mold plate to the size of the sample with the help of a brush. This is followed by laying the first layer of E-Glass fiber and applying a thin coating of the mixture. A roller is used to get rid of any excess resin and air so that the mixture is uniformly distributed. This procedure is repeated for all the remaining fiber layers. After the final layer is laid, it is allowed to settle for 20 minutes, and the top mold plate is placed. This is followed by placing the mold plates below the UTM and subjecting it to a compressive load of 150KN for 20 minutes. The mold plates are removed from the UTM, and dead loads are placed on it for a duration of 24 hours and allowed to settle. The thus fabricated composite sample is finally removed from the mold plates. The thickness was measured at distinct localities of the sample and the average thickness was found to be 3 mm. It is machined to the required dimensions according to ASTM standards. For tensile specimen, a rectangular cross section specimen is used as per ASTM D3039 machined to dimensions 150 x 12.5 x 3 mm, while ASTM D256 is adopted for Izod Impact test and the sample dimensions are 60 x 12.5 x 3 mm. Shore D Hardness value was determined as per ASTM D2240. Table 1 presents the material properties of E-glass, Epoxy and Mild Steel[20]. Figure 1 illustrates the flow diagram of the fabrication process of the composites.

2.1 Mechanical Tests

Tensile test was performed on a Computerized UTM for Polymers and its Composites with 1000 kg load capacity, resolution 0.1 kg, cross travel of 1000 mm and speed of 500 mm/min. Figure 2 shows the various machined specimen for conducting the tensile test. Tensile strength was measured as the average value obtained from 9 specimens taken from 3 samples for a given weight percent of the filler.

The impact test was performed on a Computerized Impact Testing Machine for Polymers and its composites, having a capacity of up to 25 J, release angle of pendulum of 150°, and a minimum resolution of 0.02 J. Impact strength was measured as the average value obtained from 9 specimens taken from 3 samples for a given weight percent of the filler.

A Shore D Durometer, with a resolution of 0.5 HD, measuring range of 0–100 Shore D units, and having an indentor of 30° cone was used to measure the hardness.

Table 1. Material properties

Property	Units	E-Glass Fiber	Epoxy Resin	Mild Steel
Tensile strength	MPa	2050	6.9	550
Density	kg/m^3	2600	1400	7850
Impact strength	J/m	300	68	600
Tensile modulus	GPa	85	3.35	200

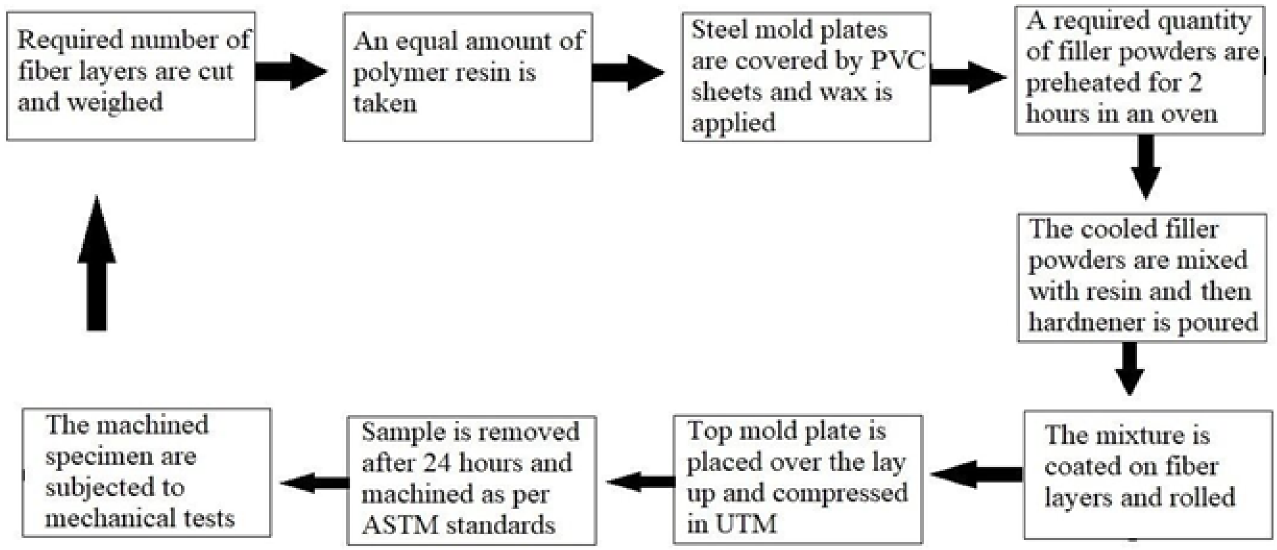

Figure 1. Flow Diagram of the fabrication process.

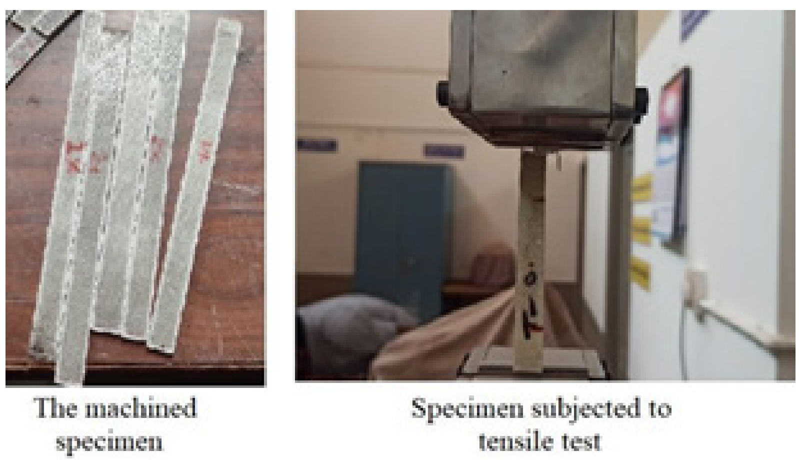

Figure 2. Tensile test specimen.

Hardness was measured at various locations of the sample and was averaged.

3.0 Results and Discussions

Following are the results obtained from the various mechanical tests performed on the composites.

The tensile strength of Glass-Epoxy composites with Mild Steel powders as fillers are depicted in Figure 3. The unfilled composite had a tensile strength of 215.29 MPa, while the tensile strengths of 2 wt. %, 4 wt. % and 6 wt. % samples were respectively 233.6 MPa, 231.6 MPa and 209.36 MPa. It is observed that, as the filler content increased to 2 wt. %, the tensile strength increased by 8.504% when compared to unfilled composite, then decreased by 0.856% for 4 wt. % and thereafter it significantly reduced. On the other hand, the tensile modulus was found to be 1.257 GPa for the unfilled composite, and it reduced by 29.27% to 0.889 GPa for 2 wt. %, decreased further by 8.661% to 0.812 GPa for 4 wt. % and increased by 8 % to 0.877 GPa for 6 wt. %. The percentage elongation ranged from 6.636 % for the unfilled samples to 8.067 % for 2 wt. %, 7.903 % for 4 wt. % and 6.843 % for 6 wt. %. E-glass and Epoxy generally possess higher tensile strengths compared to Mild Steel. As the proportion of Mild Steel filler increases, the mechanical

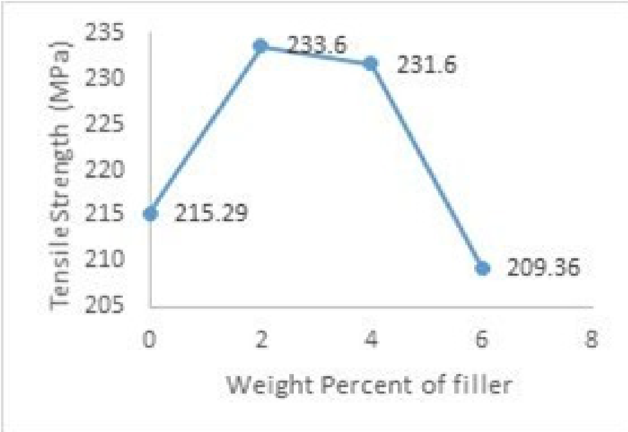

Figure 3. Tensile test results.

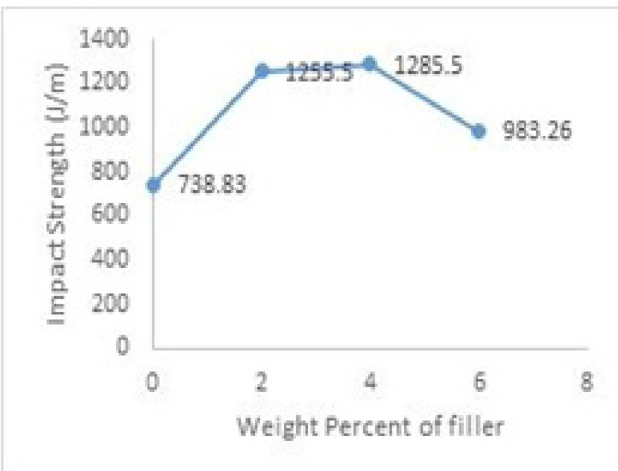

Figure 4. Impact test results.

performance of these composites is more influenced by the weaker Mild Steel component. This could have been attributed to the inability of uniformly distributing the stresses and resulted in the decline of the tensile strength.

The Izod Impact strength of Mild Steel filled Glass–Epoxy composites are shown in Figure 4. The unfilled Glass-Epoxy composites had an impact strength of 738.83 J/m, while the impact strength increased by 69.93% to 1255.5 J/m for 2 wt. %, further increased by 2.389% to 1285.5 J/m for 4 wt. % and reduced by 23.51% to 983.26 J/m for 6 wt. %. This reduction in the impact strength could be attributed to the decrease in ductility, as indicated by the percentage elongation, thereby resulting in brittle behavior of the composite during impact loading.

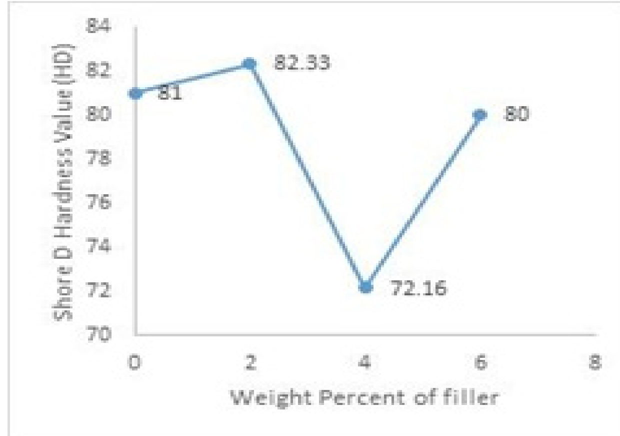

Figure 5. Shore D hardness test results.

The Shore D hardness of Glass-Epoxy composites with Mild Steel fillers are presented in Figure 5. The hardness value of the unfilled Glass-Epoxy composite was 81HD, while the hardness values of 2 wt. %, 4 wt. % and 6 wt. % samples were found to be respectively 82.33HD, 72.16HD and 80HD. Table 2 presents the mechanical properties of the developed composites.

4.0 Conclusions

Fabrication of composites made up of Glass and Epoxy using powdered Mild Steel as fillers was achieved by a simple hand lay-up method with a subsequent compression. The tensile strength, impact strength and hardness of these new class of composites improved with the incorporation of the filler up to a definite weight percent, thereafter there was a drop in the properties. Tensile strength increased with the filler content from 215.29 MPa to 233.6 MPa by a margin of 8.504% for 2 wt. %, followed by 0.856% reduction in the value to 231.6 MPa for 4 wt. % and 9.602% reduction to 209.36 MPa for 6 wt. %. The tensile modulus decreased as the filler content increased up to 4 wt. % from 1.257 GPa to 0.812 GPa and there was an increase in the trend up to 0.877 GPa by 8% for 6 wt. %. Percentage elongation, which is a measure of ductility, increased with the filler content till 2 wt. % from 6.6% to 8.0% and thereafter it reduced up to 6.8%. However, when compared to the unfilled composite, the percentage elongation of 6 wt. % sample was slightly higher. The Izod impact strength also increased as the

Table 2. Mechanical properties of the fabricated composites

Mechanical Properties	0 wt. %	2 wt. %	4 wt. %	6 wt. %
Tensile strength (ASTM D3039) MPa	215.29 ± 5.488	233.6 ± 3.333	231.6 ± 14.503	209.36 ± 8.386
Tensile modulus (ASTM D3039) GPa	1.257 ± 0.400	0.889 ± 0.0535	0.812 ± 0.0266	0.877 ± 0.0446
Percentage elongation (ASTM D3039)	6.636 ± 0.3125	8.067 ± 0.3057	7.903 ± 0.3981	6.843 ± 0.4945
Impact strength (ASTM D256) J/m	738.83 ± 95.57	1255.5 ± 123.47	1285.5 ± 252.20	983.26 ± 237.26
Shore D hardness (ASTM D2240) HD	81	82.33	72.16	80

filler content increased up to 4 wt. % from 738.83 J/m to 1285.5 J/m and reduced thereafter to 983.26 J/m, while the Shore D hardness value increased up to 2 wt. % from 81 HD to 82.33 HD and decreased to 72.16 HD for 4 wt. %. As a future scope, this research work can be carried forward for testing their thermal, tribological or magnetic properties.

5.0 Acknowledgments

The authors wish to express their gratitude to N.M.A.M. Institute of Technology, Nitte and St Joseph Engineering college, Mangaluru for providing the essential amenities to accomplish the research work. The authors thank all those who directly or indirectly helped in executing the work.

6.0 References

1. Gebrehiwet L, Abate E, Negussie Y, Teklehaymanot T, Abeselom E. Application of composite materials in aerospace and automotive industry:review. International Journal of Advances in Engineering and Management (IJAEM). 2023; 5(3):697-723. https://doi.org/10.35629/5252-0503697723
2. Murali B, Yogesh P, Karthickeyan NK, Chandramohan D. Multi-potency of bast fibers (flax, hemp and jute) as composite materials and their mechanical properties: A review. Materials Today: Proceedings. 2022; 62(4):1839-43. https://doi.org/10.1016/j.matpr.2022.01.001
3. Dong T, Wu G, Peng H, Ma P. Mechanical performance of aramid/glass fiber hybrid weft-knitting-reinforced composites under low-velocity impact. Journal of Industrial Textiles. 2023; 53:1-33. https://doi.org/10.1177/15280837231190105
4. Bachchan AA, Das PP, Chaudhary V. Effect of moisture absorption on the properties of natural fiber reinforced polymer composites: A review. Materials Today: Proceedings. 2022; 49(8):3403-8. https://doi.org/10.1016/j.matpr.2021.02.812
5. Nabhan A, Taha M, Ghazaly NM. Filler loading effect of Al_2O_3/TiO_2 nanoparticles on physical and mechanical characteristics of dental base composite (PMMA). Polymer Testing. 2023; 117. https://doi.org/10.1016/j.polymertesting.2022.107848
6. Bednarowski D, Bazan P, Kuciel S. Enhancing strength and sustainability: evaluating glass and basalt fiber-reinforced biopolyamide as alternatives for petroleum-based polyamide composite. Polymers. 2023; 15. https://doi.org/10.3390/polym15163400
7. Bharadwaja K, Rao SS, Rao TB, Pydi HP. Evaluation of Mechanical Properties for epoxy resin in nano composite diffusion. Advances in Materials Science and Engineering. 2023. https://doi.org/10.1155/2023/8598585
8. Parbin S, Waghmare NK, Singh SK, Khan S. Mechanical properties of natural fiber reinforced epoxy composites: A review. Procedia Computer Science. 2019; 152:375–9. https://doi.org/10.1016/j.procs.2019.05.003
9. Yadav R, Singh M, Shekhawat D, Lee SY, Park SJ. The role of fillers to enhance the mechanical, thermal, and wear characteristics of polymer composite materials: A review. Composites Part A: Applied Science and Manufacturing. 2023; 175. https://doi.org/10.1016/j.compositesa.2023.107775

10. Boukhoulda A, Bendine K, Boukhoulda F, Bellali M. Effects of fibre weight fraction on the mechanical properties of bio-Composite reinforced with Alfa fibres: Experimental and numerical investigation. Journal of Composite Materials. 2024; 58(1):133-42. https://doi.org/10.1177/00219983231217076
11. Nagrale A, Nevrekar S, Kawle S, Gawande H, Gupte J, Gaikwad S. Influence of filler particle sizes on the physical properties of bulk-fill composites compared to conventional composites. Cureus. 2023; 15(3). https://doi.org/10.7759/cureus.36032
12. Rout AK, Satapathy A. Development and characterization of rice husk-filled Glass fiber-reinforced Epoxy biocomposites. Composites: Mechanics, Computations, Applications. 2012; 3:95-106. https://doi.org/10.1615/CompMechComputApplIntJ.v3.i2.10
13. Mudradi S. Dry sliding wear behavior of cast iron powder filled epoxy composites. AIP Conference Proceedings. 2019; 020020-1–020020-6. https://doi.org/10.1063/1.5092903
14. Bhavith K, Pai P, Sudheer M, Ramachandra CG, Prashanth BHM, Kumar BK. The effect of metal filler on the mechanical performance of epoxy resin composites. Engineering Proceedings. 2023; 59(1). https://doi.org/10.3390/engproc2023059200
15. Abdulkareem SA, Amosa MK, Adeniyi AG, Magaji MM, Ajibola RA. Effect of metallic fillers on the hardness of polystyrene composites: An experimental investigation. IOP Conference Series: Materials Science and Engineering. 2019. https://doi.org/10.1088/1757-899X/640/1/012058
16. Divya G, Suresha B. Role of Metallic Nanofillers on Mechanical and Tribological Behaviour of Carbon Fabric Reinforced Epoxy Composites. Materials Sciences and Applications. 2018; 9:740-750. https://doi.org/10.4236/msa.2018.99054
17. Ye TP, Liao SF, Zhang Y, Chen MJ, Xiao Y, Liu XY, Liu ZG, Wang DY. Cu(0) and Cu(II) decorated graphene hybrid on improving fireproof efficiency of intumescent flame-retardant epoxy resins. Composites Part B: Engineering. 2019; 175. https://doi.org/10.1016/j.compositesb.2019.107189
18. Suriani MJ, Sapuan SM, Ruzaidi CM, Nair DS, Ilyas RA. Flammability, morphological and mechanical properties of sugar palm fiber/polyester yarn-reinforced epoxy hybrid biocomposites with magnesium hydroxide flame retardant filler. Textile Research Journal. 2021; 91(21):2600-11. https://doi.org/10.1177/00405175211008615
19. Ishak MR, Rafidah M, Razman MR. Polymer Composites Filled with Metal Derivatives: A Review of Flame Retardants. Polymers. 2021; 13(11):1701-21. https://doi.org/10.3390/polym13111701
20. Chopra R, Gupta RK, Kumar M, Akhtar N. Experimental study on mechanical properties of E-Glass fiber reinforced with epoxy resin composite and compare its properties with hybrid composite. Materials Today: Proceedings. 2022; 63:417-21. https://doi.org/10.1016/j.matpr.2022.03.435

Abbreviations

UTM = Universal Testing Machine
ASTM = American Society for Testing and Materials
PVC = Poly Vinyl Chloride