Hindawi
Advances in Polymer Technology
Volume 2022, Article ID 9295407, 7 pages
https://doi.org/10.1155/2022/9295407

Research Article

Effect on Compression Molding Parameters in Mechanical Properties of MWCNT/Glass Fiber/Epoxy Composites

Jayaprakash Venugopal,[1] B. Dhanasakkaravarthi,[2] Raviteja Surakasi,[3] Moti Lal Rinawa,[4] L. H. Manjunatha,[5] Razan A. Alshgari,[6] Saikh Mohammad Wabaidur,[6] Md Ataul Islam,[7] and I. Jenish[8]

[1]School of Mechanical Engineering, Sathyabama Institute of Science and Technology, Semmancheri, Chennai, Tamil Nadu 600119, India
[2]Department of Mechanical Engineering, Panimalar Institute of Technology, Nazarethpettai, Poonamallee, Chennai, Tamil Nadu 600123, India
[3]Department of Mechanical Engineering, Lendi Institute of Engineering and Technology, Denkada, Jonnada, Andhra Pradesh 535005, India
[4]Department of Mechanical Engineering, Government Engineering College Jhalawar, Rajasthan 326023, India
[5]School of Mechanical Engineering, REVA University, Bangalore, 560064 Karnataka, India
[6]Chemistry Department, College of Science, King Saud University, Riyadh 11451, Saudi Arabia
[7]Division of Pharmacy and Optometry, School of Health Sciences, Faculty of Biology, Medicine and Health, University of Manchester, Manchester, UK
[8]Department of Applied Mechanics, Seenu Atoll School, Hulhu-medhoo, Addu City 19060, Maldives

Correspondence should be addressed to I. Jenish; jenish@satollschool.edu.mv

Received 12 January 2022; Accepted 18 June 2022; Published 18 July 2022

Academic Editor: M. Ravichandran

Reinforcing fibers, nanofillers, matrix materials, and manufacturing techniques all have a role in the mechanical characteristics of hybrid composites. MWCNTs-reinforced E-glass/Kevlar/epoxy composites are appropriate fillers for structural applications. The impact of different concentrations of MWCNT fillers (0.4%, 0.8%, and 1.2% wt) on the mechanical characteristics of hybrid composites has been studied. Tensile and bending strength, as well as hardness, were measured in compression-molded composites. The effects of compression pressure, mold temperature, and applied pressure on hybrid (0.8% MWCNT) were investigated. When it came to composite tensile and bending strength, compression pressure was the most important factor, closely succeeded by mold temperature and pressure period. Compression molding were optimized, resulting in a tensile strength of 183 MPa, a bending strength of 158.3 MPa, and a hardness value of 23.8 HV.

1. Introduction

Composites are taking the place of traditional materials due to their low cost and high productivity in manufacturing and processing [1]. Polymeric materials are superior to nonpolymeric materials in a wide range of applications, including structural, automotive, electrical, marine, biomedical, and chemical parts [2, 3]. For the above-mentioned uses, polymer composites made with synthetic or else natural fibers were widely used. Composite structures can benefit from the superior stiffness and strength of synthetic fibers (such as basalt, Kevlar, glass, and carbon) when used for load-bearing purposes [4–6]. Glass-fiber reinforcement has outstanding mechanical and thermal qualities that are ideal for aeronautical use. To make ballistic armor, bulletproof, and other various protective materials, polymer composites are made using matrix material [7, 8]. Using epoxy resin as the matrix material for hybrid composite parts has been shown to increase their tensile, flexural, and impact strength significantly. Epoxy matrix also reduces composite part density by 3.12 percent, allowing for the production of lighter components [9–11]. Sui for aerospace applications, GFEC assessed for adhesive bonding strength exhibits high adhesion. Polymer composites with improved strength and hardness can be made by combining synthetic fibers through epoxy materials and its manufacturing methods [12]. There is an information in Table 1 about the materials and characteristics of polymer matrix composites (PMCs). With significant qualities (physical and mechanical as well as tribological) in epoxy composites, they were best suited for use in many different applications. Polymer matrix composites (PMCs) are made up of fibers that enhance the composite's structural integrity and provide protection from corrosion and heat resistance [13–16].

Figure 1 shows different materials for composite preparations. Epoxy resins have great strength making more useful in aircraft, automobile, and marine applications, despite the large variety of matrix/binding elements utilized [17]. Hydraulic cylinder weight was reduced by 96%, excavator engine hood wear resistance was improved, and engine frame weight was reduced, while stiffness and strength were improved. These techniques include spray-up, resin transfer molding (RTM), and other methods such as vacuum infusion or vacuum-based RTM, compression molding, pultrusion, and filament winding [18, 19]. Compression or hot-pressing procedures require less tool than other processes, but each has advantages and disadvantages. It is possible to produce compound shapes with outstanding dimensional solidity, repeatability, mechanical properties, and spark resistance using the compression molding technique. Compression molding processes for epoxy-based FRPC need to be studied further, according to the aforementioned literature study [20–22].

To make high-strength composite compounds for the automobile and aircraft industries, compression molding is the preferred method. Compression molding was used to create carbon-fiber epoxy composites with improved mechanical properties [23, 24]. Nonwoven mats made of natural fibers and polylactic acid were molded at high temperatures using a compression molding progress. After improving the molding conditions, woven flax/PLA polymer composites made via compression molding had higher impact strength (temperature, pressure, and time). Sheet-molded CFR composites have even more strength and stiffness when exposed to compression molding techniques. Polypropylene materials were examined by [25] for the influence of compression molding temperatures on their viscosity. Viscosity and melt flow velocity of PP are reversed when molding temperature is incorrect. Compression molding factors like as mold temperature, pressure, and duration are critical to the success or failure of thermoset items made using this process [26]. In composite parts, compression molding is an excellent approach for improving qualities that may be found in the preceding literature when the molding parameters are properly adjusted.

Reinforcing epoxy composites with micro- or nanofillers and nanofibers has been a major focus of current research publications, which have improved structural, mechanical, thermal, tribological, and functional qualities [27]. For better performance in engineering materials, fine particles and fillers have a higher aspect ratio and surface area per unit volume than microparticles. A strong interfacial bond between the nanofillers and the fibers is critical to transmitting load from the matrix to the fiber. Epoxy composite filler materials including carbon nanostructures can also improve thermal characteristics. The incorporation of MWCNT to nickel-cobalt materials increases supercapacitor characteristics of electrochemical [28]. MWCNTs are reusable. An increase in compressive strength and reduced shrinkage was achieved by using MWCNTs as nanoreinforcements in hybrid epoxy composites (MWCNT/silica fume cement). The compressive properties of hybrid polymer composites are also improved when MWCNTs are included [29]. Furthermore, it is necessary to do further research into the mechanical and tribological properties of carbon nanotube-based hybrid composite materials.

Despite the fact that the available literature contains a plethora of studies examining the mechanical performance of fiber-reinforced epoxy composites [30, 31], hybrid nanocomposites research, on the other hand, is still mostly underreported to this day. Thus, our aim is to study the influence of factors on mechanical properties of compression-molded polymer composites completely in this work.

2. Materials and Methods

2.1. Materials. Fiber-reinforced plastic has a high level of strength due to the transmission of loads from the matrix to the fibers. Interlaminar bonding between matrix and fiber shear strength are all factors in this phenomena. With over 10 million tons of global yearly output and over 95% of all fiber reinforcement coming from glass fiber, the composite sector relies heavily on this lightweight material with an excellent performance to cost ratio. The primary reinforcing materials in this investigation were 250 gsm (g/m^2) woven E-glass fabrics with a diameter of 12 mm. The following elements are found in E-glass fiber: There are 52-56 percent SiO_2, 12-16 percent Al_2O_3, 16-25 percent CaO, and 8-13 percent B_2O_3 in that mix, for a total of 52-56%. One of the principal reinforcing fibers in composite laminates is Kevlar fiber, which also goes by the name PPTA aramid fiber because of its strong rigid molecular structure. 90% pure MWCNTs (multiwall carbon nanotubes) were employed as a nanofiller in hybrid composites. They have a vast scope of current and emerging uses, including superior structural composites, conductive polymers, battery cathodes, solar arrays, battery packs, nanoelectronics, semiconductors, and power storage. MWCNTs were manufactured by chemical vapor deposition and have the following dimensions: outer diameter of 10-15 nm, interior diameter of 2-6 nm, and length of 1-10 mm.

2.2. Experimental Details and Methodology. Surface contaminants on the MWCNTs were first removed by rinsing them in deionized water. It took three hours to ultrasonically dissolve nanotubes in epoxy resin, which have an average

Table 1: Physical and mechanical characteristics of filler and fibers materials [27].

Fiber	Density (g/cm^3)	Tensile strength (MPa)	Elongation on break (%)	Tensile modulus (GPa)
Kevlar	1.51	3100	2.6-3.8	65
E-glass	2.6	2100-3600	0.6	75
Multiwall carbon nanotube	2.0	100,000		1300

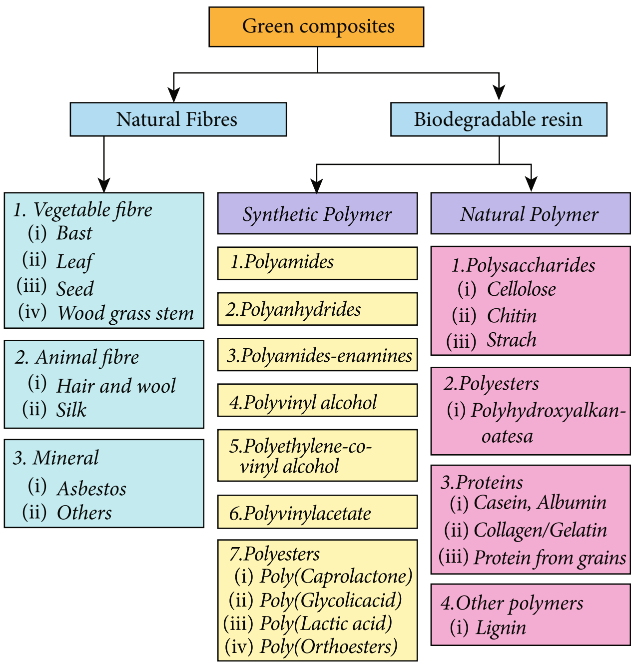

Figure 1: Different materials for composites.

Table 2: Epoxy matrix properties [31].

Property	Corresponding value
Density (g/cm^3)	1.28
Youngs modulus (Mpa)	3300
Tensile strength (Mpa)	87.2
Poisson ratio	0.38

diameter of 10 to 15 nm and an average length of 1-10 mm. A magnetic stirrer was used to mix the epoxy and MCWNTs with K-6 Hardener, ensuring that the nanoparticles were dispersed. All three MWCNT weight-percentage hybrid composites are created with the following: glass, Kevlar, and epoxy. Table 1 shows the physical and mechanical characteristics of filler and fibers materials. Table 2 shows epoxy matrix properties. Agglomerations which impair mechanical characteristics occur when carbon nanotubes make up more than one weight percent of a composite matrix. However, the properties of MWCNTs with varying weight proportions were found to vary after showing lab tests and consulting literature. It is therefore being attempted to establish the ideal percentage of MWCNT in hybrid composites to achieve bending, tensile, and hardness.

Layers of composites are assembled. It was covered with a nanofiller-reinforced matrix on every layer of bi-directional fabric. For automotive and industrial applications, compression molding can produce high-strength sheet molding parts. Figure 2 shows a schematic representation of the compression molding process experimental set-up. As a result of the introduction of heat to the vice, compression molding is sometimes known as a "hot press." Compression molding's experimental set-up appears to be small, with the supporting structure resting on a firm base. Hydraulics can move up and down the press thanks to the press's four slide pillars. Electricity is used to heat the bottom or lower platen to a predetermined temperature of 120°C. Figure 3 depicts the key phases in compression molding method for producing composite products. In order to gain a deeper understanding of composite properties, existing literature led us to select the most important factors. Table 3 shows the production of composites with various compositions.

2.3. Testing of Composite Samples. The ASTM D790 standards were used to prepare and test tensile composite specimens for tensile and flexural strengths. An AG-X Plus machine was used for the tests. Each tensile and flexural test was performed five times, and the average results were recorded. For testing, 5 samples of size 300 × 300 × 3 mm are taken from composites at random. A microhardness tester was used to quantify the hardness of the composite specimens in accordance with the ASTM E 384. The examinations were performed with a 100 g load and a dwell period of 15 seconds. The mechanical characteristics of the produced composites were tested. Two distinct thicknesses of composites, 3 mm and 5 mm, are created and post-cured at room temperature for 10 hours to meet the pre-determined dimensions. ASTM standards were used to characterize the mechanical of the prototypes.

3. Results and Discussion

Experiments conducted in this part demonstrated how MWCNTs, compression molding parameters, and other variables affect hardness, tensile, and bending strength. Compression molding operating parameters, as well as the degree to which each of these process factors affected mechanical performance, were identified using single-factor studies on compression temperature, pressure holding time and pressure.

3.1. Effect of Multiwall Carbon Nanotubes on the Composite Samples. With the use of compression molding, composite samples (neat and hybrid) can be created. Table 4 shows the mean TS of five samples under each testing condition when MWCNT amounts were changed. The tensile characteristics of MWCNT-reinforced composites were found to

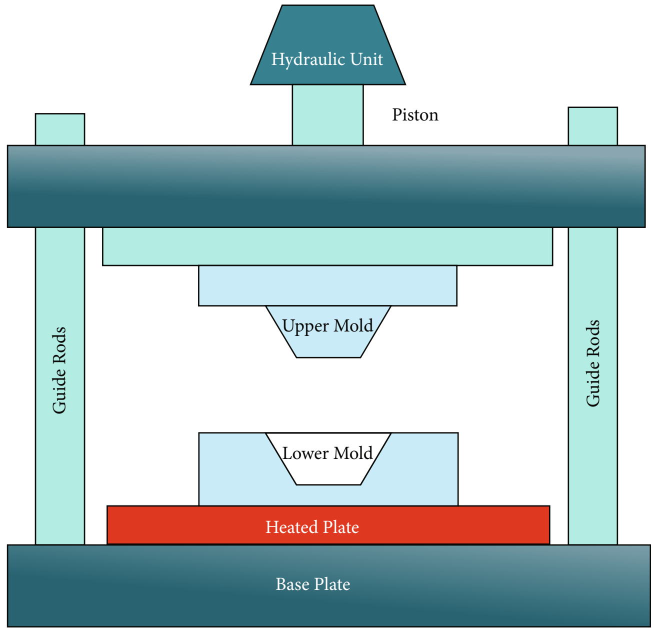

FIGURE 2: Schematic view of compression molding machine.

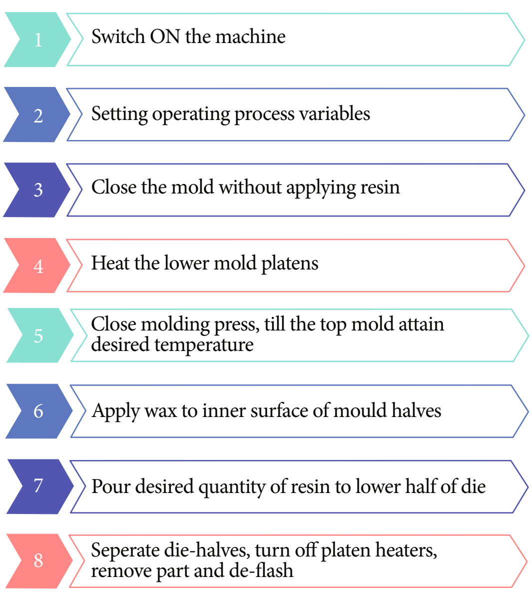

FIGURE 3: Steps involving the compression molding process for producing hybrid composites.

TABLE 3: Fabrication of composites.

Type of composites	Sample designation	Weight %		
		MWCNTs	Epoxy	Glass + Kevlar
Neat	NGKEC	0	50	50
	MWCNTKEC	0.4	50	49.60
Hybrid	MWCNTKEC	0.8	50	49.2
	MWCNTKEC	1.2	50	48.8

be superior to those of the unreinforced composites. Adding MWCNTs (nanofillers) prevents crack formation and propagation, allowing the composite to absorb the maximum amount of load until it cracks. There was a drop in tensile strength after adding 0.8 weight percent of MWCNTs to the clean composite, which may be the result of nanofiller agglomeration in the matrix.

Composite samples with 0.8 percent weight of MWCNTs had the highest tensile strengths. This may be because of consistent distribution of MWCNTs between the epoxy matrix and the fiber surface. The gaps in composites increase when MWCNTs nanoparticles exceed the critical weight limit (i.e., 1.2 wt. percent). As a result of the epoxy resin having a higher viscosity, trapped gases or bubbles and volatile impurities may be held back from dissolving and contaminating the finished product. Since the MWCNTs in the epoxy matrix are spread evenly, the fiber and epoxy have better interfacial interaction and interlocking. When comparing a neat composite to a hybrid composite, the hybrid composite has a greater surface area enclosed in stress versus strain area curves, and it is shown in Figure 4. In the MWCNT composites, the MWCNTs serve as crack arresters and bridge the cracks, resulting in a toughening effect.

The hardness variations in composite samples are shown in Table 5. At 1.2 wt. percent of MWCNT, agglomeration causes nanocomposites to be more prone to porosity. Nanotubes in nanocomposites experience axial compression, bending, and buckling as the indenter slides. The following features of MWCNTs contribute to their improved interfacial bonding: One-dimensional nanostructure with a high aspect ratio and a C-C covalent bond directed on axis of CNT improved strength of the material. In nanocomposite, a material's robust network structure provides higher hardness and strength. In contrast, inadequate dispersion can lead to agglomeration and void formation in composites

Table 4: Reinforcement of NGKEC with NEAT and multiwalled carbon nanotubes.

Materials designation	Tensile strength	E_t	Bending strength	E_f
NGKEC	138	3419	105.6	3012
0.4 MWCNTKEC	155	3521	125.1	2009
0.8 MWCNTKEC	183	3942	158.3	8064
1.2 MWCNTKEC	178	3321	114.6	5091

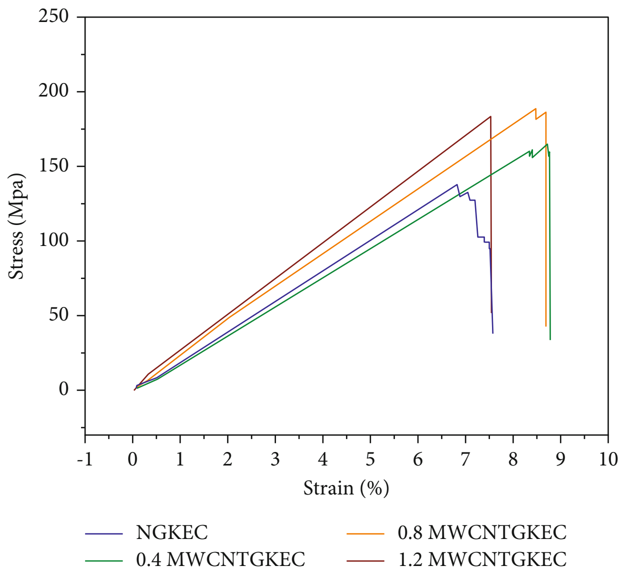

Figure 4: Plot of stress-strain data comparing neat and hybrid composites for tensile strength.

Table 5: Glass/Kevlar/epoxy composites enhanced with NEAT and MWCNT at high hardness.

Material designation	Hardness (HV)
NGKEC	21
0.4 MWCNTKEC	22.1
0.8 MWCNTKEC	23.8
1.2 MWCNTKEC	21.6

when MWCNTs are used in concentrations greater than 0.8%. Consequently, the microhardness of these composites is greater than the microhardness of their neat counterparts.

3.2. Influence of Compression Molding Parameters. The mechanical performance of the compression-molded hybrid composite (0.8MWCNTGKEC) is assessed at a pressure time of 10 minutes and a compression pressure of 20 MPa. Optimized molding temperature settings of 80°C yield the best mechanical qualities, and it is shown in Figure 5. Fiber impregnation is reduced when the epoxy matrix does not fully melt or flow at low mold temperatures. There will be excessive flow viscosity and inadequate saturation if the heating temperature is too low during the molding process because the resin cannot fully melt or flow; if heating temperature is too high, the resin will be degraded and its mechanical performance will be reduced. When a thermoset matrix material has hardened, it can never come back to its original state. This may be due to the formation of cross-links, which are three-dimensional molecule chains. In order for the matrix to be so strong and thermally robust, the curing temperature must be increased. Fibers begin to disorder and epoxy matrix starts to destroy above the critical set mold temperature (>80°C), resulting in brittleness and decreased strength. The findings are in line with previous studies. Using experimental input-output data, the impact of mold temperature was evaluated. The tensile and bending strengths of composites are determined to be 139.87 and 169.88 MPa, respectively, when compression temperatures changed among their corresponding ranges. In hybrid composites, tensile and bending strength increase by 21.46% and 21.26%.

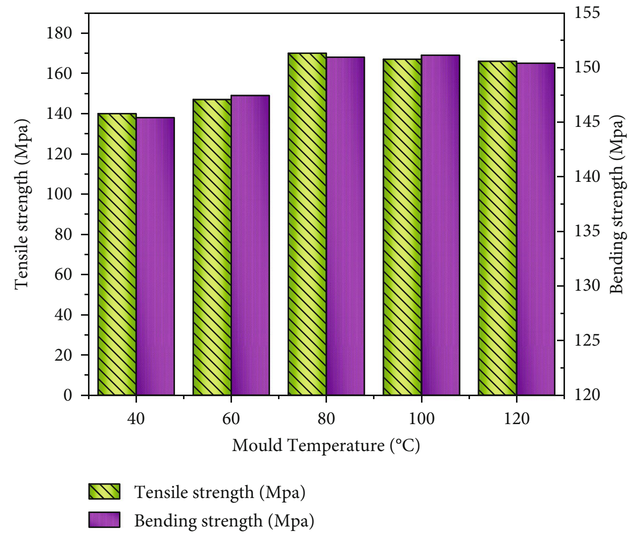

Figure 5: Tensile and bending strength changes with the temperature of the mold.

3.3. Compression Pressure Has an Effect on Tensile and Bending Strength. Hybrid composites are manufactured using pre-set compression molding conditions (0.8MWCNTGKEC) and the effect of compression pressure on mechanical properties.

Figure 6 demonstrates that the tensile and bending strength increases about to 22 MPa at pressure and then stabilizes. To maximize the strength of hybrid composites, compression pressure of 20 MPa should be applied. As the resin impregnation increases, porosity decreases, as does the resin flow and spreading across the fiber surfaces. Fiber structure may be damaged if compression is applied beyond 20 MPa, resulting in lower mechanical strength. With regard to part removal, a high level of compression pressure makes it difficult to separate solidified parts from their mold cavities, notwithstanding shrinkage as a result of cooling and an adequate die design for ease of removal. Compression pressure is examined by altering the pressure within and between the two ranges they occupy. When it comes to composite materials, the low and high tensile strengths are 140

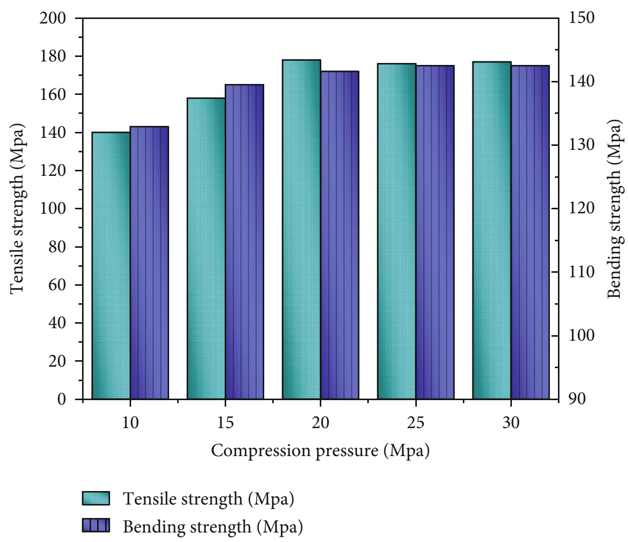

Figure 6: Tensile and bending strength as a result of compression pressure.

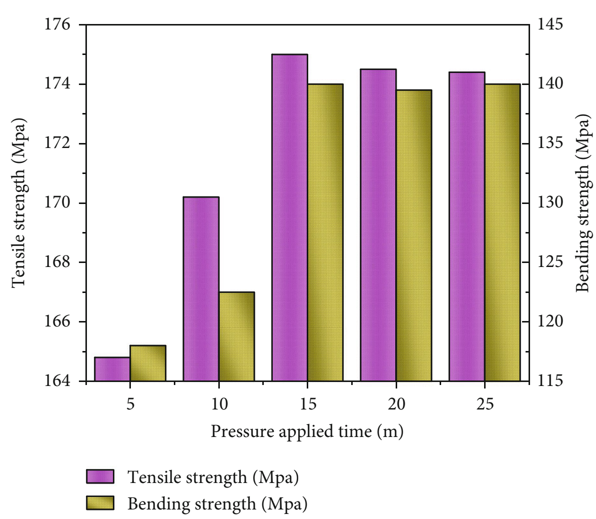

Figure 7: Tensile and bending strength as a function of time applied pressure.

and 178.23 MPa, respectively, while the bending strengths range from 99.23 to 142.32 MPa. In terms of tensile and bending strengths, the hybrid composite caused in a 27.3 percent and 43.42 percent increase in compression pressure, respectively.

3.4. The Tensile and Bending Strength of a Material as a Function of the Amount of Pressure Applied over Time. The mechanical properties of composites are shown in Figure 7 as a function of the amount of pressure applied over time. In order to maintain a consistent compression pressure and mold temperature of 80°C, the experiments must be performed under constant conditions. When pressure is applied for a longer period of time, mechanical strength increases substantially for the first 15 minutes, but after that point, there are no discernible improvements. The fabricated composites may have some voids or porosity if a low compression pressure holding time is used.

Hybrid composites were subjected to a variety of pressure applied times between 5 and 25 minutes. The tensile strength ranges from 165 MPa to 175 MPa, while the bending strength ranges from 120.12 MPa to 136.69 MPa. The localized heat is a mix of the two. When MWCNTs are included in the composite, they enable strong interaction among matrix fibers, resulting in enhanced load transfer as an outcome of the larger aspect ratio and surface area of nanofiller.

4. Conclusions

The mechanical and tribological characteristics of MWCNT reinforced with different fibers and epoxy composites were investigated in this work under the impact of compression molding parameters. The current study discovered that MWCNT reinforced with glass/Kevlar/epoxy composites resulted in composites that were stronger and tougher. 0.8 percent MWCNTGKEC outperformed 0.4% and 1.2% nanofiller additions to a pure composite, respectively. All compression molding factors were shown to have a considerable impact on composite mechanical strengths and hardness. Compression pressure has the biggest influence on composite tensile and bending strength, followed by mold temperature and pressure application duration. In 0.8% CNTGKEC, the hybrid composite had higher tensile strengths of 183 MPa, bending strengths of 158.3 MPa, and hardness of 23.8 HV.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The authors appreciate the supports from Seenu Atoll School, Maldives, for providing help during the research and preparation of the manuscript. The authors thank to Sathyabama Institute of Science and Technology, Lendi Institute of Engineering and Technology, King Saud University, University of Manchester, and REVA University for providing assistance in completing work. This work was funded by the Researchers Supporting Project number (RSP-2021/265) King Saud University, Riyadh, Saudi Arabia.

References

[1] V. Mohanavel, S. Suresh Kumar, J. Vairamuthu, P. Ganeshan, and B. NagarajaGanesh, "Influence of stacking sequence and fiber content on the mechanical properties of natural and synthetic fibers reinforced penta-layered hybrid composites," *Journal of Natural Fibers*, pp. 1–13, 2021.

[2] S. Islam, A. Kovalcik, M. Hasan, and V. K. Thakur, "Natural fiber reinforced polymer composites," *International Journal of Polymer Science*, vol. 2015, Article ID 813568, 2 pages, 2015.

[3] R. Hsissou, R. Seghiri, Z. Benzekri, M. Hilali, M. Rafik, and A. Elharfi, "Polymer composite materials: a comprehensive review," *Composite Structures*, vol. 262, article 113640, 2021.

[4] R. Velumayil and A. Palanivel, "Hybridization effect on mechanical properties of basalt/Kevlar/epoxy composite laminates," *Polymers*, vol. 14, no. 7, p. 1382, 2022.

[5] M. A. Rahuman, S. S. Kumar, R. Prithivirajan, and S. Gowri Shankar, "Dry sliding wear behavior of glass and jute fiber hybrid reinforced epoxy composites," *International Journal of Engineering Research and Development*, vol. 10, no. 11, pp. 46–50, 2014.

[6] H. Abdellaoui, M. Raji, H. Essabir, and R. Bouhfid, *Mechanical behavior of carbon/natural fiber-based hybrid composites in Mechanical and Physical Testing of Biocomposites*, Mechanical and Physical Testing of Biocomposites, Fibre-Reinforced Composites and Hybrid Composites, 2019.

[7] N. Barton and F. d'Errico, "North African origins of symbolically mediated behaviour and the Aterian," *Developments in Quaternary Sciences*, vol. 16, pp. 23–34, 2012.

[8] N. M. Nurazzi, M. R. M. Asyraf, A. Khalina et al., "A review on natural fiber reinforced polymer composite for bullet proof and ballistic applications," *Polymers (Basel)*, vol. 13, no. 4, p. 646, 2021.

[9] R. Hanumantharaya, I. Sogalad, S. Basavarajappa, and G. C. M. Patel, "Modelling and optimisation of adhesive bonded joint strength of composites for aerospace applications," *International Journal of Computational Materials Science and Surface Engineering*, vol. 8, no. 3/4, pp. 167–184, 2019.

[10] W. Ferdous, A. Manalo, P. Yu et al., "Tensile fatigue behavior of polyester and vinyl ester based GFRP laminates—a comparative evaluation," *Polymers (Basel)*, vol. 13, no. 3, p. 386, 2021.

[11] S. Syaqira, N. Shamsudin, Z. Leman, S. M. Sapuan, T. T. Dele-Afolabi, and A. Hanim, "Tensile strength and moisture absorption of sugar palm-polyvinyl butyral laminated composites," *Polymers (Basel)*, vol. 12, no. 9, p. 1923, 2020.

[12] M. N. F. Norrrahim, H. Ariffin, T. A. T. Yasim-Anuar et al., "Performance evaluation of cellulose nanofiber with residual hemicellulose as a nanofiller in polypropylene-based nanocomposite," *Polymers (Basel).*, vol. 13, no. 7, p. 1064, 2021.

[13] M. Villani, R. Consonni, M. Canetti et al., "Polyurethane-based composites: effects of antibacterial fillers on the physical-mechanical behavior of thermoplastic polyurethanes," *Polymers (Basel).*, vol. 12, no. 2, p. 362, 2020.

[14] A. Verma, P. Negi, and V. K. Singh, "Experimental analysis on carbon residuum transformed epoxy resin: chicken feather fiber hybrid composite," *Polymer Composites*, vol. 40, no. 7, pp. 2690–2699, 2019.

[15] O. Laban and E. Mahdi, "Energy absorption capability of cotton fiber/epoxy composite square and rectangular tubes," *Journal of Natural Fibers*, vol. 13, no. 6, pp. 726–736, 2016.

[16] H. B. Bisen, C. K. Hirwani, R. K. Satankar, S. K. Panda, K. Mehar, and B. Patel, "Numerical study of frequency and deflection responses of natural fiber (Luffa) reinforced polymer composite and experimental validation," *Journal of Natural Fibers*, vol. 17, no. 4, pp. 505–519, 2020.

[17] T. Yu, Z. Zhang, S. Song, Y. Bai, and D. Wu, "Tensile and flexural behaviors of additively manufactured continuous carbon fiber-reinforced polymer composites," *Composite Structures*, vol. 225, article 111147, 2019.

[18] S. Ekşı and K. Genel, "Comparison of mechanical properties of unidirectional and woven carbon, glass and aramid fiber reinforced epoxy composites," *Composites*, vol. 132, pp. 879–882, 2017.

[19] Z. Jia, T. Li, F. Chiang, and L. Wang, "An experimental investigation of the temperature effect on the mechanics of carbon fiber reinforced polymer composites," *Composites Science and Technology*, vol. 154, pp. 53–63, 2018.

[20] C. Barba, S. Scott, A. Roddick-Lanzilotta et al., "Restoring important hair properties with wool keratin proteins and peptides," *Fibers and Polymers*, vol. 11, no. 7, pp. 1055–1061, 2010.

[21] K. Karthik, D. Rajamani, A. Manimaran, and J. Udayaprakash, "Evaluation of tensile properties on glass/carbon/Kevlar fiber reinforced hybrid composites," *Materials Today: Proceedings*, vol. 39, pp. 1655–1660, 2021.

[22] S. Hussian Siyal, S. Ali Jogi, S. Muhammadi et al., "Mechanical characteristics and adhesion of glass-Kevlar hybrid composites by applying different ratios of epoxy in lamination," *Coatings*, vol. 11, no. 1, p. 94, 2021.

[23] A. I. Selmy, A. R. Elsesi, N. A. Azab, and M. A. Abd El-baky, "In-plane shear properties of unidirectional glass fiber (U)/random glass fiber (R)/epoxy hybrid and non-hybrid composites," *Composites. Part B, Engineering*, vol. 43, no. 2, pp. 431–438, 2012.

[24] M. Sayer, N. B. Bektaş, E. Demir, and H. Çallioğlu, "The effect of temperatures on hybrid composite laminates under impact loading," *Composites. Part B, Engineering*, vol. 43, no. 5, pp. 2152–2160, 2012.

[25] F. M. Monticeli, J. H. S. Almeida Jr., R. M. Neves, F. G. Ornaghi, and H. L. Ornaghi, "On the 3D void formation of hybrid carbon/glass fiber composite laminates: a statistical approach," *Composites. Part A, Applied Science and Manufacturing*, vol. 137, article 106036, 2020.

[26] V. Fiore, C. Sanfilippo, and L. Calabrese, "Dynamic mechanical behavior analysis of flax/jute fiber-reinforced composites under salt-fog spray environment," *Polymers (Basel)*, vol. 12, no. 3, p. 716, 2020.

[27] M. Shunmugasundaram, P. Anand, M. A. A. Baig, and Y. Kasu, "Experimental investigation on tensile property of vacuum infused Kenaf-based polymer composite with the presence of nanofillers," in Springer, Singapore, 2020.

[28] A. S. Perna, A. Viscusi, A. Astarita et al., "Manufacturing of a metal matrix composite coating on a polymer matrix composite through cold gas dynamic spray technique," *Journal of Materials Engineering and Performance*, vol. 28, no. 6, pp. 3211–3219, 2019.

[29] Y. Mujahid, N. Sallih, M. Z. Abdullah, and M. Mustapha, "Effects of processing parameters for vacuum bag only method on void content and mechanical properties of laminated composites," *Polymer Composites*, vol. 42, no. 2, pp. 567–582, 2021.

[30] L. X. Zhong, S. Y. Fu, X. S. Zhou, and H. Y. Zhan, "Effect of surface microfibrillation of sisal fibre on the mechanical properties of sisal/aramid fibre hybrid composites," *Composites. Part A, Applied Science and Manufacturing*, vol. 42, no. 3, pp. 244–252, 2011.

[31] K. P. Matabola, A. R. De Vries, F. S. Moolman, and A. S. Luyt, "Single polymer composites: a review," *Journal of Materials Science*, vol. 44, no. 23, pp. 6213–6222, 2009.