Tensile, Shear, and Compressive Strength of Glass, Glass/Carbon, and Kevlar/Carbon Reinforced Vinylester for Marine Application

K. Abdurohman[1, a)] and M. Adhitya[2, b)]

[1]*National Institute of Aeronautics and Space – LAPAN, Jalan Raya LAPAN, Rumpin, Bogor, Indonesia*
[2]*RCAVe (Research Center for Advanced Vehicle Universitas Indonesia), Kampus UI Depok 16424, Indonesia*

[a)]Corresponding author: kosim.abdurohman@lapan.go.id
[b)]madhitya@eng.ui.ac.id

Abstract. Composites are widely used in marine and aerospace applications due to their lightweight, resistance to corrosion and fatigue, and high specific stiffness and strength. This recent study used vinyl ester-based plain e-glass and hybrid composites of e-glass/carbon and kevlar-carbon/carbon fabricated by VARI methods. Tensile, shear, and compressive strength of composites are investigated according to ASTM standards. Comparison of the results to Al 6061-T6 was evaluated. Tensile and compressive strength of kevlar-carbon is superior to e-glass and e-glass carbon. The shear strength of e-glass/carbon hybrid composites is superior to e-glass and kevlar-carbon/carbon composites. Tensile and compressive strength of e-glass/carbon and kevlar-carbon/carbon hybrid composites are higher than Al 6061-T6. However, the shear strength of e-glass, e-glass/carbon, and kevlar-carbon/carbon composites are lower than Al 6061-T6.

INTRODUCTION

Fiber-reinforced polymer composites are widely used in marine, aerospace, and defense applications due to their high specific stiffness and strength.[1] Their lightweight and resistance to corrosion and fatigue make them the choice to substitute metal materials.[2-5] One of the metal materials that have a high strength to weight ratio and excellent corrosion resistance is Al 6061-T6.[6] Its properties make this material the choice for a marine application like the boat and other water vehicles. Another application is the use of Al 6061-T6 as float material of amphibious aircraft. It has tensile, shear, and compressive strength of 310 MPa, 207 MPa, and 234 MPa respectively.[7] Other manufacturers used fiber-reinforced composites as the material of amphibious aircraft float. The common fiber types used are glass, carbon, and aramid or kevlar fibers.

The used of hybrid composites have increased in high tech application such as glass/carbon, kevlar/carbon, and kevlar/glass hybrid composites.[8] The study of Dong and Davis exhibited that the maximum tensile strength of glass/carbon hybrid composites be reached when the hybrid ratio of glass is the lowest.[9] The strength and stiffness of glass/carbon or kevlar/carbon hybrid composites are superior when the carbon layers were placed in the center of the laminate.[10] Another study stated that for the same hybrid composition, compressive properties were affected significantly by stacking sequence than tensile properties.[11] The stacking sequence variation of the laminates of hybrid composites does not significantly influence the tensile strength.[12] The study of Jesthi, *et al*. exhibited that the tensile strength of $[G_2C_2G]$s was higher than $[CG_3C]$s.[13]

This present work, study about the mechanical strength of glass, glass/carbon, and kevlar-carbon/carbon composites. The objective of this study is to evaluate the tensile, shear, and compressive strength of plain glass, hybrid glass/carbon, and hybrid kevlar-carbon/carbon composites and compare them to Al 6061-T6 as an aluminum base material used for marine environment application especially for float material. The material used in this study are vinyl ester resin as matrix; and woven cloth e-glass, woven roving carbon twill, and woven roving hybrid kevlar-carbon twill fabric as reinforcements.

The 8th International Seminar on Aerospace Science and Technology – ISAST 2020
AIP Conf. Proc. 2366, 040001-1–040001-7; https://doi.org/10.1063/5.0060164
Published by AIP Publishing. 978-0-7354-4123-1/$30.00

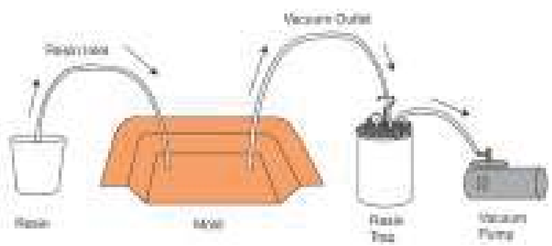
MATERIALS AND METHODS

Materials and Fabrication

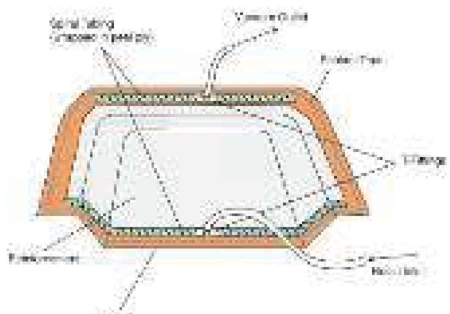
This study used three types of fibers and one type of resin. The fibers used as reinforcement are woven cloth e-glass, woven roving carbon, and woven roving hybrid kevlar-carbon. The matrix material used is vinyl ester resin of bisphenol A, promoter of cobalt naphthenate 0.3%, and hardener of methyl ethyl ketone peroxide 3%. The e-glass and carbon fiber, vinylester, hardener, and promoter were procured from a local distributor of fibers and resins. The hybrid fiber of kevlar-carbon was procured from the commercial online market.

The composites were fabricated using vacuum assisted resin infusion (VARI) methods. There are three types of composites in this study consist of one plain composite and two-hybrid composites. The fabricated composites are e-glass/vinyl ester, e-glass/carbon/vinyl ester, and kevlar-carbon/carbon/vinylester. The e-glass composites consist of 23 plies of woven cloth e-glass fabric of EW-135. The stacking sequence of e-glass/carbon and kevlar-carbon/carbon hybrid composites are symmetrical. The laminate arrangements for e-glass/carbon and kevlar-carbon/carbon hybrid composites are $[GCG_2CG_2C]s$ and $[(KC)_2C_3]s$ respectively. The notation of G is for e-glass fiber, C for carbon fiber, and KC for kevlar-carbon hybrid fiber. There are differences in the number of layers for glass/carbon and KC/carbon composite panels. This is intended to meet the specimen thickness recommendations from the standard used. EW-135 cloth glass fiber has a much thinner thickness than carbon fiber and kevlar-carbon hybrid fiber, which is about 0.13 mm for glass fiber, 0.21 mm for carbon fiber, and 0.3 mm for kevlar-carbon fiber. This causes composites containing glass fiber to have more layers.

The VARI process uses the vacuum power of a pump to flow resin from the resin reservoir to the laminate area. After the resin has flowed and soaked all the fibers, the pump is stopped and allowed to cure resin for 24 hours. The VARI results showed that the resin evenly moistened the fibers and there was no visible bubble visually.



(a)



(b)

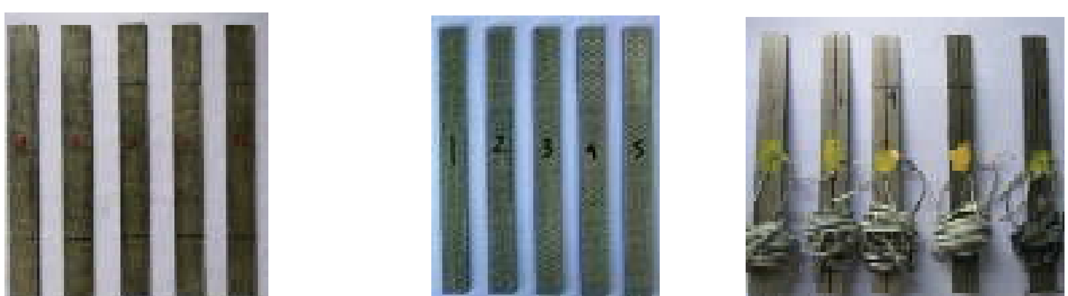
FIGURE 1. Vacuum-assisted resin infusion: (a) process and (b) equipment.

Mechanical Tests

The mechanical tests in this study are the tensile test, shear test, and compressive test. All of the tests were performed using the universal testing machine of Tensilon RTF 2410 with a maximum capacity of 100 kN. The tests were determined according to ASTM D3039, ASTM D3518, and ASTM D6641 for tensile, in-plane shear, and compressive tests respectively. The tensile test and in-plane shear test specimens have a length of 250 mm, a width of

25 mm, and a thickness of 2.5 mm. Different from the tensile test specimen, the fiber orientation of the in-plane shear specimen was arranged in $\pm 45^0$ when the composite panels were fabricated. The tensile and in-plane shear tests were performed using a similar testing jig with tensile loading. The tensile and shear test specimens for hybrid composites are attached with a biaxial strain gauge in the center as can be seen in Fig. 3(c). A biaxial strain gauge was used to record longitudinal and lateral strains. In the tensile test specimen, the strain gauge data is used to determine the Poisson ratio, while in the shear test it is used to determine the shear modulus although both are not discussed in this paper. The specimen size of the compressive test was 140 mm in length, 13 mm in width, and 3 mm in thickness. The compressive test was conducted using the special fixture as per ASTM D6641. The tensile, shear, and compressive properties values were reported.

FIGURE 2. Universal testing machine tensilon RTF 2410.



(a) (b) (c)

FIGURE 3. Sample test specimens for (a) tensile test, (b) compressive test, and (c) in-plane shear test.

RESULTS AND DISCUSSION

Figure 4 exhibits the ultimate tensile strength of plain e-glass, e-glass/carbon, and kevlar-carbon/carbon hybrid composites. The tensile strengths are 175 MPa, 464 MPa, and 515 MPa for e-glass, hybrid e-glass/carbon, and hybrid kevlar-carbon/carbon composites respectively. The values show that the tensile strength of e-glass/carbon 2.7 times of e-glass composites due to additional carbon fiber in the laminate. It corresponds to other studies that indicate an increase of tensile strength as a result of the existence of carbon layers in the laminate.[10,11,12,14] The tensile strength of kevlar-carbon/carbon composites is 3 times of e-glass composites and higher than e-glass/carbon composites up to

11%. It exhibits that the tensile strength of kevlar-carbon/carbon composites is superior due to hybrid fiber layers of kevlar-carbon on the outer of laminate and carbon fiber layers on the center of the laminate.

Figure 4 represent the tensile strength comparison of the composites to Al-6061-T6 as one of the base aluminum used for marine application especially for float device of amphibious aircraft. The results exhibit that the tensile strength of plain e-glass composite is much lower than Al-6061-T6. The tensile strength of e-glass/carbon and kevlar-carbon/carbon hybrid composites are higher than Al -6061-T6 up to 50% and 66%, respectively.

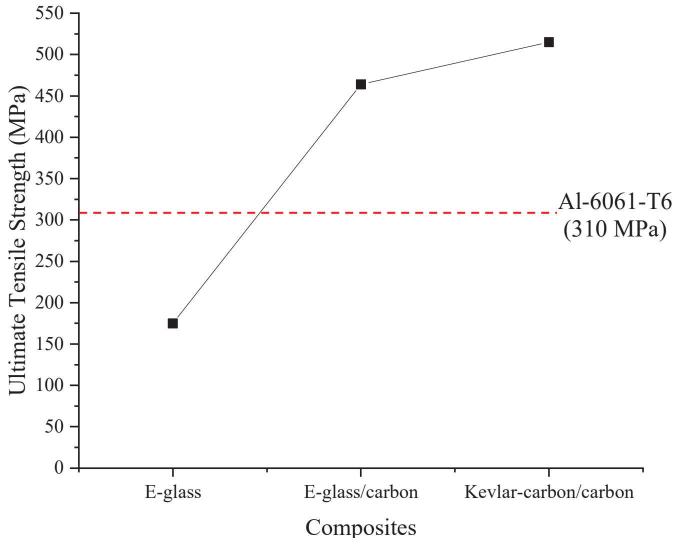


FIGURE 4. Ultimate tensile strength of e-glass and hybrid composites.

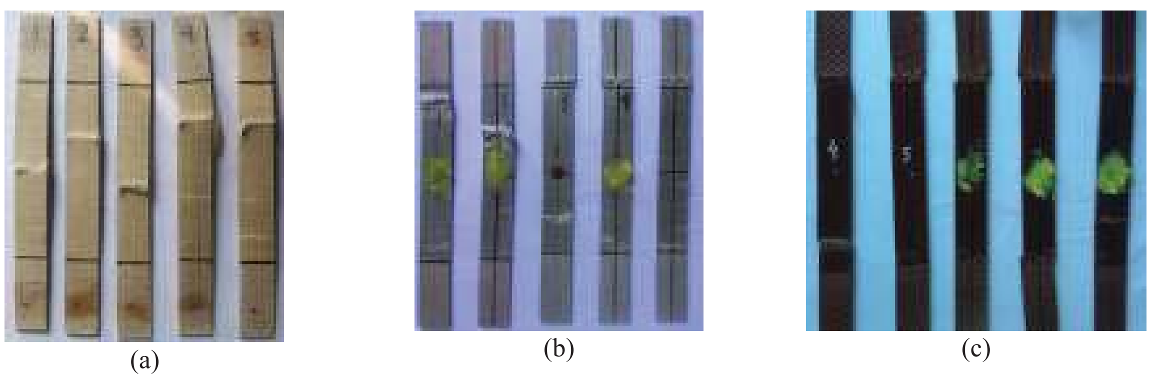


FIGURE 5. Specimens after tensile tests for (a) glass/vinylester, (b) glass/carbon/vinylester, and (c) kevlar-carbon/carbon/vinylester.

Figure 6 shows the shear strength of plain e-glass, e-glass/carbon, and kevlar-carbon/carbon hybrid composites. The shear strengths are 73 MPa, 85 MPa, and 80 MPa for e-glass, hybrid e-glass/carbon, and hybrid kevlar-carbon/carbon composites respectively. The values show that the shear strength of e-glass/carbon and kevlar-carbon/carbon composites higher than e-glass composite up to 16% and 10% respectively. The shear strength of the e-glass/carbon composite is slightly higher than the kevlar-carbon/carbon composite up to 6%. The results exhibit that the shear strength of e-glass/carbon hybrid composite is superior to e-glass and kevlar-carbon/carbon composites.

Figure 6 shows the shear strength comparison of the composites to Al-6061-T6 as one of the base aluminum used for marine application especially for float devices of amphibious aircraft. The results show that the shear strength of plain e-glass, e-glass/carbon, and kevlar-carbon/carbon composites is much lower than Al-6061-T6.

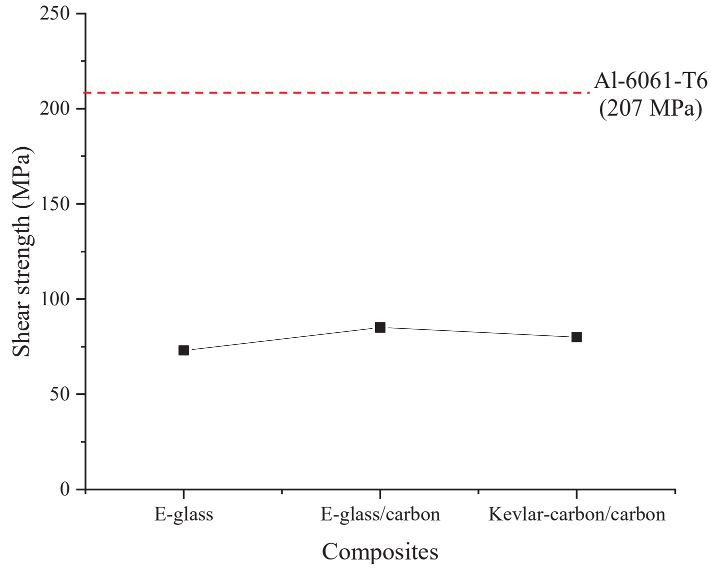
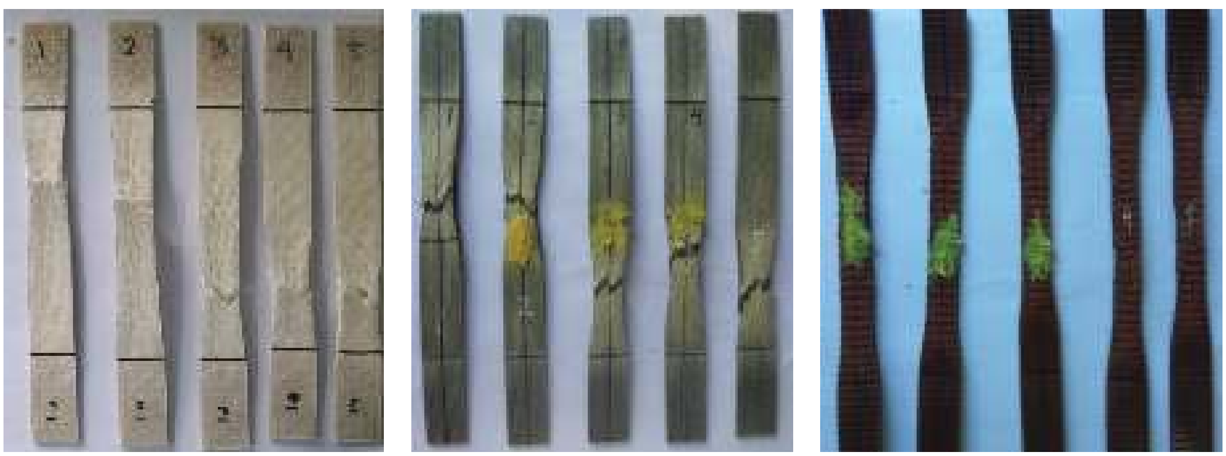


FIGURE 6. The shear strength of e-glass and hybrid composites.



(a) (b) (c)

FIGURE 7. Specimens after in-plane shear tests for (a) glass/vinylester, (b) glass/carbon/vinylester, and (c) kevlar-carbon/carbon/ vinylester.

Figure 8 exhibits the compressive strength of plain e-glass, e-glass/carbon, and kevlar-carbon/carbon hybrid composites. The compressive strengths are 214 MPa, 244 MPa, and 266 MPa for e-glass, hybrid e-glass/carbon, and hybrid kevlar-carbon/carbon composites respectively. The results show that the tensile strength of e-glass/carbon higher than plain e-glass composite up to 14%. The compressive strength of kevlar-carbon/carbon composites is higher than e-glass and e-glass/carbon composites up to 24% and 9% respectively. It exhibits that the tensile strength of kevlar-carbon/carbon composites is superior to e-glass and e-glass/carbon composites.

Figure 8 exhibits the compressive strength comparison of the composites to Al-6061-T6 as one of the base aluminum used for marine application especially for float devices of amphibious aircraft. The results exhibit that the tensile strength of plain e-glass composite is lower than Al-6061-T6. The tensile strength of e-glass/carbon composite is slightly higher than Al-6061-T6 up to 4%. However, the tensile strength of kevlar-carbon/carbon hybrid composites is higher than Al -6061-T6 up to 14%.

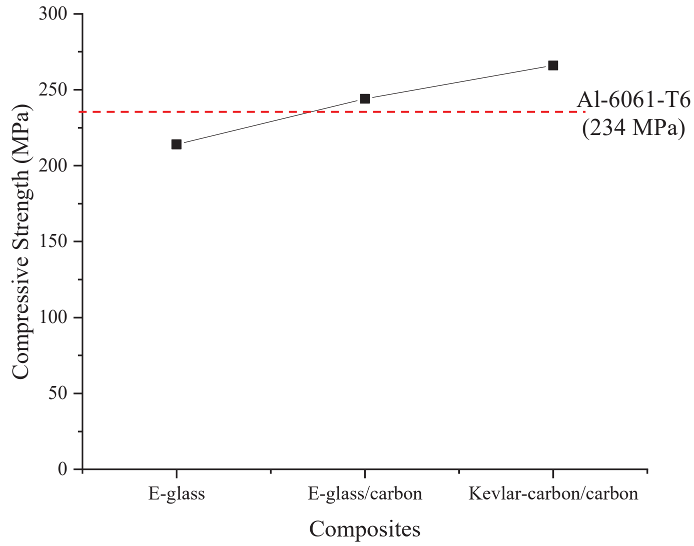


FIGURE 8. The compressive strength of e-glass and hybrid composites.

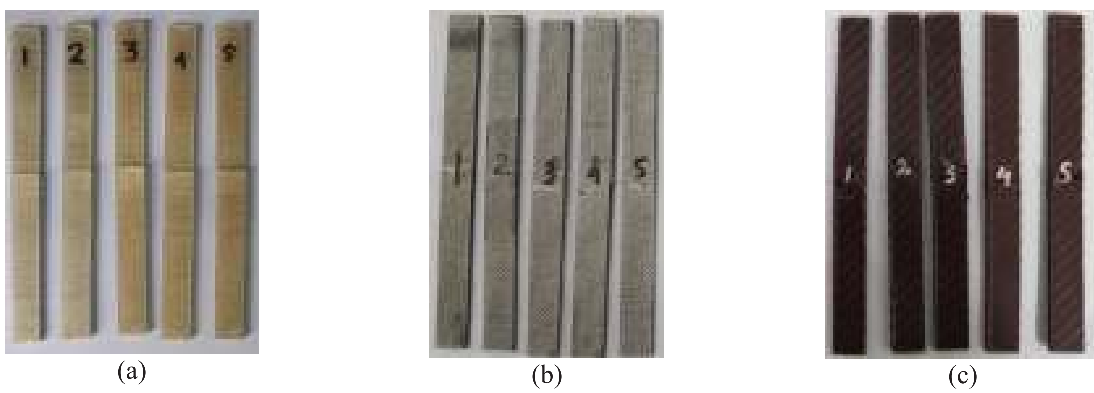


FIGURE 9. Specimens after compressive tests for (a) glass/vinylester, (b) glass/carbon/vinylester, and (c) kevlar-carbon/carbon/ vinylester.

CONCLUSIONS

The mechanical properties study of plain e-glass, hybrid e-glass/carbon, and hybrid kevlar-carbon/carbon composites has been performed experimentally. The composites were fabricated using vacuum assisted resin infusion (VARI) method. The vinylester resin was used as a matrix and reinforcement used are woven cloth e-glass, woven roving carbon, and woven roving kevlar-carbon hybrid fibers. The tensile, shear, and compressive strength of the composites are evaluated. The tensile and compressive strength of kevlar-carbon/carbon hybrid composite is superior to plain e-glass and e-glass/carbon composites, and the tensile and compressive strength of e-glass/carbon and kevlar-carbon/carbon hybrid composites are higher than Al-6061-T6. Meanwhile, the shear strength of e-glass/carbon hybrid composite is superior to e-glass and kevlar-carbon/carbon composites, and the shear strength of plain e-glass, hybrid e-glass/carbon, and hybrid kevlar-carbon/carbon composites is lower than Al-6061-T6.

ACKNOWLEDGMENTS

Many thanks go to the composites workshop and material testing laboratory of the Aeronautics Technology Center, LAPAN for the technical support of composites manufacturing and testing facilities used in this study.

REFERENCES

1. J. Naveen, M. Jawaid, E. S. Zainudin, M. T. H. Sultan, and R. Yahaya, J. Mater. Res. Technology **8**, 1308–1318 (2019).
2. K. V Arun, S. Basavarajappa, and B. S. Sherigara, Materials & Design **31**, 930–939 (2010).
3. M. Assarar, D. Scida, A. El Mahi, C. Poilâne, and R. Ayad, Materials & Design **32**, 788–795 (2011).
4. M. E. Deniz and R. Karakuzu, Composites Part B: Engineering **43**, 1130–1138 (2012).
5. A. M. Visco, N. Campo, and P. Cianciafara, Composites Part A: Applied Science and Manufacturing **42**, 123–130 (2011).
6. M. Chacko and J. Nayak, "Corrosion inhibition using 2-mercaptobenzimidazole on T6 treated 6061 Al-SiCp composite in acetic acid," in *The 4th Intl. Conf. Mater. Processing and Characterization*, Materials Today Proc. 2 edited by S. K. Singh (Elsevier B.V., Amsterdam, The Netherlands, 2015), pp. 2728–2736.
7. "Aluminum 6061-T6; 6061-T651," see at asm.matweb.com/search/SpecificMaterial.asp?bassnum=MA6061T6 (MatWeb, LLC, Blacksburg, VA, 2012).
8. K. S. Pandya, J. R. Pothnis, G. Ravikumar, and N. K. Naik, Materials & Design **44**, 128–135 (2013).
9. C. Dong and I. J. Davies, Materials and Design **54**, 955–966 (2014).
10. J. H. Song, Composites Part B: Engineering **79**, 61–66 (2015).
11. J. Zhang, K. Chaisombat, S. He, and C. H. Wang, Materials and Design **36**, 75–80 (2012).
12. D. K. Jesthi and R. K. Nayak, Composites Part B: Engineering **168**, 467–475 (2019).
13. D. K. Jesthi, P. Mandal, A. K. Rout, and R. K. Nayak, "Effect of carbon/glass fiber symmetric inter-ply sequence on mechanical properties of polymer matrix composites," in *The 2nd Intl. Conf. Mater., Manufacturing and Design Eng.,* Procedia Manuf. 20, edited by N. G. Patil, *et al.* (Elsevier B.V., Amsterdam, The Netherlands 2018), pp. 530–535.
14. D. K. Jesthi, P. Mandal, A. K. Rout, and R. K. Nayak, "Enhancement of mechanical and specific wear properties of glass/carbon fiber reinforced polymer hybrid composite," in *The 2nd Intl. Conf. Mater., Manufacturing and Design Eng.,* Procedia Manuf. 20, edited by N. G. Patil, *et al.* (Elsevier B.V., Amsterdam, The Netherlands 2018), pp. 536–541.