International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.
© 2022 Scholar AI LLC.
Vol. 35 No. 1 October 2022, pp. 150-158

The Effect Of Immersion On The Post-Impact Bending Strength Of A Polyurethane Rigid Foam Sandwich Composite With Bamboo-Fiberglass Woven Reinforcement

Agus Dwi Catur[1], Made Wijana[2]

[1,2]Mechanical Engineering Department, Engineering Faculty, Mataram University
Mataram, Indonesia

[1]e-mail: agus.dc@unram.ac.id, [2]e-mail: wijana.md@unram.ac.id

(cc) BY

Abstract – The development of environmentally friendly composite materials is important because it is a global demand. However, using natural materials does not rule out the possibility of a decrease in quality during use in a wet environment and in conditions of impact defects. This paper analyzes the post-impact bending strength of sandwich composites with woven bamboo reinforcement after being immersed in seawater. Sandwich composites are made by laminated polyurethane rigid foam sheet with polyester resin and bamboo-fiberglass woven hybrid reinforcement. To provide defects in the sandwich composite, dropweight impact was carried out, then it was immersed in seawater and a bending test was carried out. The highest average bending strength of sandwich composites occurs in formations with a higher amount of fiberglass. The performance of maintaining post-impact bending strength is better in composites with more bamboo laminate formations, the decrease in post-impact bending strength is only 2.6%. The post-impact bending strength of sandwich composites in wet conditions has a lower value than in dry conditions. The longer the immersion of the sandwich composite in seawater after impact, the smaller the bending strength

Keywords – immersion; composite; bending; impact; bamboo

I. Introduction

Everything related to environmental friendliness is now a very interesting topic. Even many countries in the world are now make products that are environmentally friendly without forgetting the function of the product. This requires the development of environmentally friendly composite materials. The use of natural fibers in composites is beneficial because natural fibers can produce and are environmentally friendly. Compare this with synthetic fibers such as glass fiber, where all the materials cannot be repaired and the waste cannot be recycled and can harm human health[1]. This is what strengthens the researchers to continue to develop composite materials with natural fibers as constituent.

The development of bamboo fiber composite materials is also based on environmental issues. However, basically any engineering technology that uses natural materials does not rule out the possibility of a decrease in quality during its use for a long time. Boats made of composites, for example, at this time one of the basic composite materials that are trying to be developed are made from natural fibers. Bamboo fiber which has biodegradable properties will weaken when water wets it for a long time, especially in the environment around it there are excess microbes. Microbes break down the bamboo fiber, the fiber then softens and swells due to the absorbed water. Damage to the fiber-matrix interface occurs, weakens the strength of the interface and ultimately reduces the quality of the composite [2]. Matrix crystallization also occurs, resulting in a decrease in the weight and mechanical properties of the composite [3].

The typical sandwich composite structure consists of two thin, rigid and strong skin. The thin skin sheets are separated by a lightweight core which is usually made of a polymer foam, honeycomb, or corrugated core. The core material maintains the skin sheet in position with a slight increase in weight, to increase bending strength, buckling resistance, shear strength, and impact energy absorption capability [4,5,6].

Many studies have investigated the residual strength of sandwich composites after applied impact loads, including those reported on epoxy-fiberglass sandwich composites [7]. The flexural stiffness of the epoxy-fiberglass sandwich composite decreased by about 30.5%; 35.2% and 55.6% for composite cores of balsa, styrene acrylonitrile and polyethylene terephthalate after impacting them. Reductions in flexural forces were also measured as 22.8%, 4.9% and 22.1% for the composite core of balsa, styrene acrylonitrile and polyethylene terephthalate.

Post-impact flexural strength is reported to generally decrease with increasing impact energy. The flexural strength is higher in the case of outward bending than in the case of inward bending, because it reduces the compressive properties of the skin affected by impact [8]. Post-impact compressive strength also decreases in glass fiber-epoxy composites, a decrease in compressive strength occurs with increasing impact energy [9]. The author [10] also previously wrote about the residual bending strength of sandwich composites that have been subjected to impact loads. Defects formed in composites subjected to impact loads are: delamination, hollows and even holes. The more layers of reinforcing fiber in the composite skin, the shallow basin formed. The greater the impact energy, the greater the depth of the basin formed. Sandwich composites still have flexural strength after impact, but decrease with increasing impact energy imposed on the composite.

Based on the research report above, when the polymer composite works in an aqueous environment, water gets it. Composite materials got a decrease in quality when the composite is exposed to water for a long time. Sandwich composites are hit or hit by falling objects with relatively small energy, the sandwich composites become damaged on the surface or even spread to the composite core. The defect causes a degradation of the strength of the sandwich composite. When the polymer composite has surface defects, water will more easily enter the composite through the reinforcing fiber.

When objects fall or hit the surface of the sandwich composite with relatively small energy, the composite on the skin of the sandwich composite is damaged. In addition to injury, there is also a degradation of the strength of the sandwich composite skin. If the composite is in a wet environment, water can enter the composite. However, as far as the authors know, the effect of water ingress on polymer sandwich composites by immersion in composites that have experienced an impact on their mechanical properties is still very limited. Because of these problems, the idea arose to research and analyze the effect of immersion time on the post-impact bending strength of a polyurethane rigid foam sheet sandwich composite with bamboo-fiberglass woven reinforcement. The number of layers of composite sandwich skin varied. The bending strength of the sandwich composite which was previously deformed from low impact loads after immersion in seawater was analyzed for variations in the number of layers of the sandwich composite skin.

II. MATERIAL & EXPERIMENTAL PROCEDURES

In the research in this paper, the object of research is a sandwich composite with polyurethane rigid foam sheet as the core. The two sandwich composite skins are made of laminated polyester with a hybrid reinforcement of *gigantochloa apus* bamboo woven and fiberglass woven. The making of bamboo strips uses a thin cutter to separate the outermost and innermost skins so as to obtain a strip thickness of 1 mm with a width of 10 mm. The bamboo strips are woven at an angle of 45^0 and -45^0 to form a sheet of bamboo woven for further cutting according to the dimensions of the specimen. The bamboo woven were soaked in 4% NaOH solution for 2 hours. This alkaline treatment aims to remove lignin on the bamboo surface so that the interface bond between the fiber and the polyester matrix is better. After alkaline treatment, the bamboo woven were dried in the sun for 1 day. Bamboo woven weight has an average weight of 576 gr/m^2. Another laminate reinforcement is fiberglass woven with a weight of 200 gr/m^2. The polyurethane rigid foam sheet (PURF) was cut to the size of the sandwich composite specimens (Fig. 1a).

a. 

b 

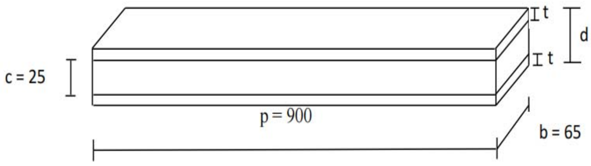
Figure 1 Making sandwich composites: a. cutting polyurethane rigid foam sheet as the core b. sandwich composite core laminate.

The manufacture of sandwich composite skin is done by laminated polyurethane rigid foam sheet (Figure 1b) with polyester resin with a hybrid reinforcement of bamboo woven (B) - fiberglass woven (F). The number and arrangement of reinforcement are varied according to the planned formation. For the formation of the 2F/1B-PURF-1B/2F sandwich composite, the polyurethane rigid foam sheet is sandwiched by a laminated polyester reinforced with 2 sheets of fiberglass woven -1 sheet of bamboo woven for each of the top and bottom skin of the sandwich composites. In the 2F/2B-PURF-2B/2F sandwich composite formation, the laminated polyester reinforced with 2 sheets of fiberglass woven -2 sheets of bamboo woven for each top and bottom skin of the sandwich composites flank a polyurethane rigid foam sheet. While the 3rd formation of sandwich composites is 3F/1B-PURF-1B/3F, namely polyurethane rigid foam sheet flanked by laminated polyester- three fiberglass woven sheet and one sheets of bamboo woven.

The two laminates that have been glued flanking the core are then allowed to dry in the room. The sandwich composite has been finished and is ready to be cut using a high speed grinder (Figure 2b) to be made into specimens that are ready to be tested. Referring to the ASTM C 393-00 standard, the dimensions of the composite sandwich test specimen are rectangular in shape (Figure 2a). Where the width must be not less than twice the thickness of the core. The length of the specimen must be equal to the length of the span plus 50 mm (or 2 inches). To ensure that the simple sandwich composite theory applies the rule of thumb for the three-point bending test, the span length divided by the sandwich thickness must be greater than 17.

Falling load impact method using a dropweight impact test tool (Figure 2c). Dropweight impact loading was carried out by applying a shock force to the surface of the composite skin in another study to determine the ability of the skin and core sandwich composite to withstand shock loads. The dropweight impact treatment in this study was intended to provide defects on the surface of the sandwich composite skin so that seawater could enter and further affect the exposed bamboo fibers during immersion. This is to cause defects in the composite by impact, with the analogy of a sandwich composite boat receiving an unexpected impact when using the boat at sea.

After the dropweight impact is carried out, a bending test is performed, so the specimen size is adjusted for the ASTM C 393 sandwich composite bending test specimen size. The dropweight impact loading mechanism in this study is to use a falling load with an energy of 26 joules, the falling load given is 2.6 kg blunt steel (1 inch diameter) at a height of 100 cm, with a span distance of 20 cm and assuming the acceleration of gravity used is 10 m/s^2.



a

b 

c. 

d. 

Figure 2 Specimens and test equipment; a: specimen size (mm),b: cutting specimen,c: dropweight impact test tool,d; three-point bending test

Immersion of sandwich composites using seawater is intended to determine the effect of seawater on test specimens that have been deformed by impact loads. The surface of the composite specimen that has been deformed makes the matrix and fibers that make up the sandwich composite come into direct contact with water. In the background it was reported by previous researchers that moisture can reduce the mechanical strength of composites using fiber. To be able to find out how much influence sea water has on the decrease in bending strength after impact, sandwich composites are treated with seawater immersion at different immersion times, that is 10 days, 20 days and 30 days. Immersion is carried out in a tub filled with sea water originating from sea water from Ampenan beach, Lombok Strait. The sandwich composite is pressed with a rock so that all parts are submerged. After reaching the specified day variation, the specimen was removed from the bath, and allowed to dry in room temperature until no water wetted the specimen surface, then a bending test was carried out.

The type of bending test carried out is three-point bending by applying a bending force slowly in the middle of the specimen supported by roller supports at both ends of the specimen (Figure 2d). The bending test standard is ASTM C 393-00. From this bending test, it is known that the bending force of the composite can withstand the load until the composite breaks or the bending load decreases drastically. Prior to the bending test, the dimensions of the specimen were measured, shifting the bending pedestal so that the distance between the supports is 760 mm and the penetrator is in the middle of the distance between the supports. Bending specimens were placed on a universal testing machine and tested by bending at three points with a deviation speed of 5 mm/min. The magnitude of the addition of bending load and bending deflection that occurs in the specimen is recorded and can be seen on the computer monitor.

When the specimen is tested for bending, the upper part of the specimen is subjected to compressive stress and the lower part is subjected to tensile stress. The maximum bending stress at the bottom surface can be calculated by the equation (ASTM C 393):

$$\sigma_b = \frac{PL}{2t(d+c)b}$$

Where :

σ_b = sandwich composite bending strength (MPa)

P = maximum load applied to the midspan (N)

L = span length (mm)

t = skin thickness (mm)

d = sandwich thickness (mm)

c = core thickness (mm)

b = sandwich width (mm)

III. RESULT AND DISCUSSION

Table 1 shows the average maximum bending force of the bending test results on all sandwich composite specimens: without treatment, with drop weight impact and immersion treatments. The average maximum bending force of sandwich composites that have been treated with drop weight impact and immersion is smaller than that of composites without any treatment. There is a decrease in the bending force of the sandwich composite in all composite formations. The average maximum bending force on the sandwich composite 2F/2B-PURF-2B/2F without treatment obtained a force of 773 newtons. The bending force on sandwich composites with impact treatment without immersion resulted in a decrease in the force to 605 newtons. After impact treatment and immersion using seawater, the composite bending force decreased with increasing immersion time, i.e. soaking 10 days to 467 N, 20 days to 487 N and immersion for 30 days obtained a decrease in the average maximum bending force value to 402 N. The same thing happened to decrease the average maximum bending force in sandwich composites with the 2F/1B-PURF-1B/2F formation and the 3F/1B-PURF-1B/3F formation.

The decrease in the value of the maximum bending force of this composite indicates the weakening of the strength of the matrix in binding the fiber due to damage to the skin when it gets impact and the effect of seawater immersion on the specimen after being given an impact. From table 1 there is a relationship that the longer the immersion in seawater, the greater the reduction in the maximum bending force of the sandwich composite.

Table 1 Average maximum bending force of sandwich composite

sandwich composite formation	average bending force (N)				
	no dropweight impact, no immersion	with dropweight impact			
		no immersion	10 days immersion	20 days immersion	30 day immersion
2F/2B-PURF-2B/2F	773	605	467	487	402
3F/1B-PURF-1B/3F	642	427	357	357	338
2F/1B-PURF-1B/2F	535	380	312	337	335

To calculate the bending strength of sandwich composites, the composite dimension measurement data and the maximum composite bending force in table 1 are applied to equation 1. The composite bending strength values obtained from the three sandwich composite formations, before and after being treated by impact and immersion in seawater are shown in the figure. 3. From figure 3 it can be seen that there are several factors that affect the value of the bending strength of sandwich composites i.e. the effect of variations in the composite skin constituent layers, the effect of impact treatment and the effect of variations in immersion time.

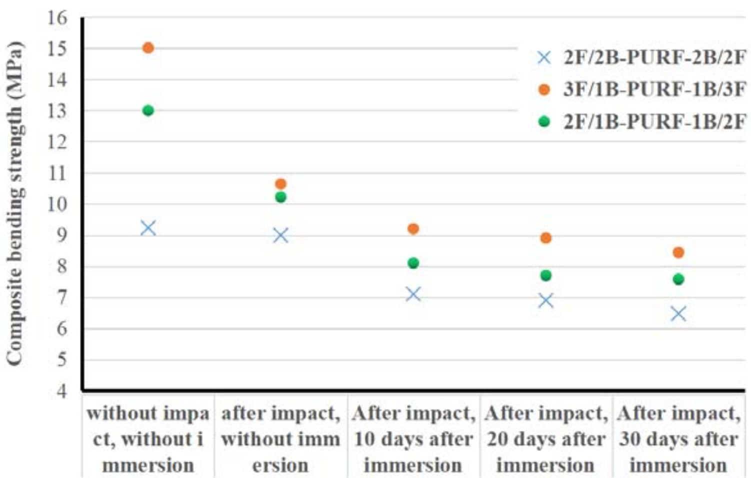


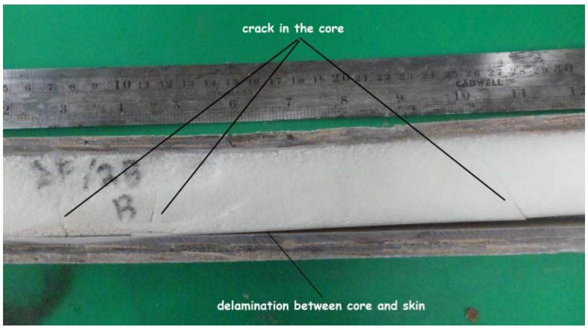
Figure 3 Graph of sandwich composite bending strength before and after impact and after immersion

The bending strength is influenced by the sandwich composite formation. The highest average bending strength is in the 3F/1B-PURF-1B/3F formation, which is a sandwich composite with the top and bottom skins each laminated 3 sheets of fiberglass-1 sheet of bamboo fiber. The intermediate bending strength is the 2F/1B-PURF-1B/2F composite, and is followed by the 2F/2B-PURF-2B/2F composite formation. If there has not been a failure in the skin and core, the upper sandwich composite skin is still able to transmit the bending force to the core with a greater magnitude, then it is forwarded to the bottom skin. The presence of fiberglass reinforcement in the sandwich composite,so skin is stronger than the reinforcement of woven bamboo strips. Bamboo strip woven has a thickness dimension that is greater than fiberglass woven, the bamboo strip woven cavity is filled by a matrix causing the strength of this laminate to be smaller besides that the fiberglass strength is better.

Impact treatment reduces the bending strength of sandwich composites, this can be seen from Figure 3. The bending strength of sandwich composites with the 3F/1B-PURF-1B/3F formation without impact treatment and without immersion is 15.01 MPa, this is down 29% due to impact treatment to 10.64 MPa. The bending strength of the sandwich composite with the 2F/1B-PURF-1B/2F formation without impact treatment and without immersion was 13 MPa, this decreased by 21% due to impact treatment to 10.22 MPa. Impact also reduced the strength of the 2F/2B-PURF-2B/2F sandwich composite from 9.23 MPa to 8.99 MPa or down 2.6%. The bending strength of the 3F/1B-PURF-1B/3F post-impact sandwich composite is better than the other two formations, this cannot be separated from the role of fiberglass which dominates the reinforcement in the sandwich composite skin. However, the performance of maintaining the original bending strength is better in the composite with the 2F/2B-PURF-2B/2F formation, the dominance of thickness by the bamboo laminate makes the impact only damage a limited area on the surface so that the decrease in post-impact bending strength is only 2.6%.

Composites are very sensitive to loads in the thickness direction, especially low velocity impact [11]. The energy of the impact penetrator imposed on the sandwich composite results in the failure/damage of the composite. In the presence of impact energy at a certain collision contact time and the resistance to the impactor causes fluctuations in the impact force, causing damage to the composite. Through the experiment, it was found that the low velocity impact caused damage to the laminated sandwich composite skin. The polymer sandwich composite that received the impact load experienced defects on the surface which continued to the core. Some of the damage modes that occur are: delamination, fiber breaking, matrix cracking, concave surface, even holes or through. Sandwich composite damage due to impact depends on the impact parameters such as the shape and mass of the impactor, impact energy, and the material and size of the composite [10]. An example of a defect that occurs after impact is shown in Figure 4a.

a.



b.

Figure 4. Failure modes on a sandwich composite specimen; a: post-impact defects of the 2F/1B-PURF-1B/2F sandwich formation, b: bending specimen damage after impact of the 2F/2B-PURF-2B/2F sandwich formation

Sandwich composites that have been impacted result in a decrease in bending strength due to the initial defects due to the impact given before the bending test. Impact treatment causes a decrease in bending strength in all variations of composite skins. Impact damage on the three sandwich composite formations caused a significant decrease of up to 29% in the residual bending strength of the material. This is the same as the research of Genghan et al [11], Zhang et al [12] on fiber-reinforced composites, which concluded that the residual strength of fiber-reinforced composites after impact was studied to be reduced. The failure of the after impact bending specimen in the form of delamination between the skin and the bottom sandwich composite core and the occurrence of cracks in the core (figure 4b). This failure occurs because the strength difference and the deformation limit are relatively too far between the skin material and the sandwich composite core. Core to the limit of deformation is not able to transmit the force to the sandwich composite skin. It can be seen in Figure 4b that the crack starts from the bottom of the core where in this section the tensile stress is more dominant.

The effect of immersion with seawater after impact treatment causes a decrease in the bending strength of all sandwich composite formations with the length of immersion time, this can be seen in the trend of the bending strength graph in Figure 3. The after impact bending strength of 2F/1B-PURF-1B/2F is 10.22 MPa. Immersion of this sandwich composite with post-impact seawater for 10 days, 20 days and 30 days caused a decrease in bending strength to 8.1 MPa, 7.7 MPa and 7.58 MPa. On the open surface, the reinforcing fiber and the surface between the fiber - matrix in the sandwich composite skin cause water to easily enter the composite, this is due to the capillarity of water in a narrow gap. Water can have an adverse effect on polymer composites both chemically and physically. Chemically, water affects the chemical structure of the resin matrix and water can lower the glass transition temperature [13]. Physically, water can swell the matrix and cause fiber-matrix separation due to the internal tension between them [14]. This causes cracks in the matrix and the separation of the matrix-fiber interface so that the strength of the composite decreases.

The post-impact bending strength of the 2F/2B-PURF-2B/2F sandwich composite was 8.99 MPa, decreased to 7.1 MPa, 6.9 MPa, and 6.47 MPa after being immersed in seawater for 10 days, 20 days and 30 days. The surface of the sandwich composite that has been deformed and exposed allows seawater to enter and freely wet the natural fibers which are the reinforcement of the composite. Seawater can reduce the mechanical strength of natural fibers, as a result, it can reduce the bending strength of the bamboo fiber-reinforced composite which is used as a composite reinforcement in this study. The effect of water absorption on the mechanical properties of plant fiber composites was also studied by Sanjeevi et al. [15], namely composites with areca fine fibers and calotropic gigantea fiber reinforcements. The water absorption behavior of the composite follows the non-fickan law, the penetration of water in the fiber disrupts the interfacial bond which causes poor strength in the composite.

The degradation of the fiber-matrix interface caused by exposure to moisture resulted in a significant decrease in the mechanical properties of the composite [16], even a decrease in mechanical properties not only occurred in polymer composites with animal natural fiber reinforcement, but also with plant natural fiber reinforcement caused by hydration in the fiber matrix composites [17]. In wet and dry conditions, the hybrid sandwich composite with 2 layers of fiberglass skin reinforcement - 1 layer of woven bamboo strips showed better strength than the other two composite formations. However, the bending strength is greatly reduced when the material is wet. The bending strength of the 3F/1B-PURF-1B/3F sandwich composite post-impact without seawater immersion is 10.64 MPa, with 10 days of immersion the bending strength value becomes 9.82 MPa, while at 20 days of immersion the bending strength value decreases to 8.9 MPa and if immersed in 30 days the bending strength decreased to 8.44 MPa. The banding properties of post-impact sandwich composites in wet conditions have a lower value than post-impact sandwich composites in dry conditions.

IV. CONCLUSION

From the results of experiments and analysis, several findings have been obtained:

1. The strength of the composite sandwich depends on the skin formation, the highest average bending strength is in the formation with a higher amount of fiberglass 3F/1B-PURF-1B/3F, which is a composite sandwich with the top and bottom skins of each laminate 3 fiberglass sheet - 1 sheet of woven bamboo.
2. The performance of post-impact bending strength is better in composites with the 2F/2B-PURF-2B/2F formation, the dominance of thickness by bamboo laminate makes the impact only damage a limited area on the surface so that the decrease in post-impact bending strength is only 2.6% .
3. The comparative properties of post-impact composite sandwiches under wet conditions have lower values than those of post-impact composite sandwiches under dry conditions.
4. The longer the immersion of the sandwich composite in seawater after impact, the lower the bending strength.
5. Longer immersion in seawater on the after-impact sadnwich composite causes the lower bending strength.

ACKNOWLEDGEMENTS

The author takes this opportunity to thank all those who have helped so that this research and paper can be completed, especially

head of the mechanical engineering materials laboratory of the University of Mataram.

REFERENCES

[1] Asif uz Zaman Saud A Gutub, Mohamed F Soliman,Mahmoud A Wafa, Sustainability and human health issues pertinent to fibre reinforced polymer composites usage: A review, Journal of Reinforced Plastics and Composites, June 2014, 33(11):p.1069-1084.

[2] Abdul Moudood , Anisur Rahman1 , Andreas Ochsner, Mainul Islam3 and Gaston Francucci; Flax fiber and its composites: An overview of water and moisture absorption impact on their performance; Journal of Reinforced Plastics and Composites, 2019, Vol. 38(7), p. 323–339.

[3] Feiwen Yang,Haibo Long,Baojun Xie,Wuyi Zhou,Ying Luo,Chaoqun Zhang,Xianming Dong, Mechanical and biodegradation properties of bamboo fiber-reinforced starch/polypropylene biodegradable composites, Journal of applied polymer science, vol.137, issue 20, 2019.

[4] Zenkert D, Nordisk I. The handbook of sandwich construction. Cradley Heath, West Midlands: Engineering Materials Advisory Services Ltd. (EMAS), 1997.

[5] Gibson LJ, Ashby MF. Cellular solids: structure and properties: Cambridge university press, 1999.

[6] Allen HG. Analysis and Design of Structural Sandwich Panels: The Commonwealth and International Library: Structures and Solid Body Mechanics Division: Elsevier, 2013.

[7] Ismet Baran, Wouter Weijermars, Residual bending behaviour of sandwich composites after impact, Journal of Sandwich Structures & Materials, 0(0), p.1–21, 2018.

[8] M.H. Khan 1 , Bing Li 2 and K.T. Tan, Impact Performance and Bending Behavior of Carbon-Fiber Foam-Core Sandwich Composite Structures in Cold Arctic Temperature, Journal of Composite Science, 2020, vol 4, p. 133.

[9] Mehmet Aktas, H. Ersen Balcıog˘lu, Alaattin Aktas, Erkan Turker, M. Emin Deniz,2012,Impact and post impact behavior of layer fabric composites, Composite Structures, 94, p.2809–2818.

[10] Catur, A.D., Sinarep, Paryanto D.S., Zainuri,A., Supriyadi, *Bending After Impact Komposit Sandwich Berpenguat Serat Bambu-Fiberglass Dengan Core polyurethane Rigid Foam*, Dinamika Teknik Mesin, Volume 5 No.1, 2015, p.32- 41.

[11] Geng Han, Zhidong Guan, Xing li, Shanyi Du, Failure analysis of carbon fiber reinforced composite subjected to low velocity impact and compression after impact Journal of Reinforced Plastics and Composites, January 2016, 35(9).

[12] Zhang Hongji,Ge Yuanyuan,Tang Hong,Shi Yaoyao, Miao Yinggang,Hu Yuan, Examination of low-velocity impact and mechanical properties after impact of fiber-reinforced prepreg composites, Polymer Composites, Volume 40, Issue6, June 2019.

[13] Delasi, R., and Whiteside, J.B., 1987, Effects Moisture on Epoxy Resins and Composite, in J.R. Vinson (ed.) Advanced Composite MaterialsEnvironmental Effects, ASTM STP 658, pp. 2-20, American Society for Materials Testing, Philadelphia.

[14] Gibson, R.F., 1994, Principles of Composite Material Mechanics, Mc Graw-Hill. New York.

[15] Sekar Sanjeevi, Vigneshwaran Shanmugam, Suresh Kumar, Velmurugan Ganesan, Gabriel Sas, Deepak Joel Johnson, Manojkumar Shanmugam, Athijayamani Ayyanar,Kakur Naresh, Rasoul Esmaeely Neisiany,Oisik Das, Effects of water absorption on the mechanical properties of hybrid natural fibre/phenol formaldehyde composites, Scientific report, 2021, 11, 13385.

[16] T.Ramakrishnan, S. Senthil Kumar, Samson Jerold Samuel Chelladurai, S. Gnanasekaran, N. K. Geetha, Ramesh Arthanari, and Baru Debtera, Effect of Moisture Content on Mechanical Properties of AAM Natural Fiber-Reinforced Isophthalic Polyester Composites, Hindawi Advances in Materials Science and Engineering Volume 2022, Article ID 3533143, 10 pages

[17] Wenhan Tian, Kang Yang, Sujun Wu, Jiping Yang, Hongyun Luo, Juan Guan, Robert O.Ritchie, Impact of hydration on the mechanical properties and damage mechanisms of natural silk fibre reinforced composites, Composites Part A: Applied Science and Manufacturing, Volume 147, August 2021, 106458.