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Fracture Surface of OPEFB Fiber Reinforced Polymer Composites-Polymeric Foam Sandwich Panels under Static Loading Conditions

Muftil Badri,[a,*] Dodi Sofyan Arief,[a] Erik Sitio Johanes,[a] Ridho Zarli Rahmat[a]

[a)] *Department of Mechanical Engineering, Universitas Riau, Indonesia*

*Corresponding author: muftil_bm@unri.ac.id

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ABSTRACT

The fracture surface of oil palm empty fruit bunch (OPEFB) reinforced polymer composites sandwich panels depends on different fibers treatment was experimentally investigated under static loading conditions. The static uniaxial tensile and flexural loading for three treatment modes on OPEFB fibers was implemented using servo hydraulic material testing machine. The microstructure was observed using SEM observation in order to better understand damage mechanism during the stress of polyester phase. SEM observation on fracture surface can provide important information for research and development as well as fracture analysis. It was found that fracture modes were considerably different for these composites. OPEFB fibers was soaked with 5% NaOH solution for 2 hours are not removed from the matrix composite. It means the interface bonds of OPEFB fibers can be controlled against the polymer matrix. Damage to polymer matrix interface and OPEFB fiber are boiled with water at temperatures of 50º C to 80º C for 30 minutes due to flexural test.

KEY WORDS: *fibers treatment, SEM, fracture surface, sandwich panels composite.*

1.0 INTRODUCTION

A composite material is a macroscopic combination of two or more distinct materials, having a recognizable interface between them. Composites are used not only for their structural properties, but also for electrical, thermal, and environmental applications. Modern composite materials are usually optimized to achieve a particular balance of properties for a given range of applications. Given the vast range of materials that may be considered as composites and the broad range of uses for which composite materials may be designed, it is difficult to agree upon a single, simple, and useful definition. However, as a common practical definition, composite materials may be restricted to emphasize those materials that contain a continuous matrix constituent that binds together and provides form to an array of a stronger, stiffer reinforcement constituent. The resulting composite material has a balance of structural properties that is superior to either constituent material alone. The improved structural properties generally result from a load-sharing mechanism. Although composites optimized for other functional properties (besides high structural efficiency) could be produced from completely different constituent combinations than fit this structural definition, it has been found that composites developed for structural applications also provide attractive performance in these other functional areas as well [1].

The utilization of palm oil waste for useful technology products is still very limited in number. Some of them have been utilized among others for the manufacture of particle board. Utilization of palm oil waste to become a new commodity is certainly very necessary. In this research, oil palm empty fruit bunch (OPEFB) fiber will be processed as polymeric foam mixture. This material is subsequently used for the sandwich structure of the impact absorption sandwich panels on the motor vehicle supporting components. The impact energy absorbing structures made in this study are not only typical in the selection of materials (OPEFB fiber) but also the design of the construction.

The sandwich composition of foam materials can improve the absorption of the impact energy of the structure. The structure and design of hollow materials have the potential to protect the windshield. Research on the layered board structure has been doing with hollow material [2]. The design of layered board provides a significant influence on the absorption of impact energy [2]. The impact energy of absorbent material has reviewed [3]. The review results show that the design of hollow material structures is very influential to absorb impact energy [3]. A study of polymeric foam responses to impact loading has conducted [4]. The results obtained show that polymeric foam is effectively able to absorb impact energy [4]. Polymeric foam material product design has structural stability when subjected to impact load [5]. The difference in the density of foam material types in layered structures have compared, the results show that foam materials of lower density are able to absorb better energy.

Foam is defined as the spread of gas bubbles that occur in liquid and solid materials. Foam develops into micro cavities that have a diameter of 10 µm. Foams scattered on the polymer can reach $10^8/cm^3$ [6]. At present, the development of research has resulted in the physical and mechanical characteristics of foam materials [7]. Physical characteristics include geometry factors, such as cavity size and cavity wall thickness. In addition to physical characteristics there are also mechanical characteristics.

Natural fibers such as OPEFB fibers are used almost exclusively in polymer matrix composites. The use of natural fibers with the natural-oil resins described here in promises to give economical, potentially biodegradable or recyclable engineering materials. The advantages of natural fibers include low cost, low density, unlimited and sustainable availability, and low abrasive wear of processing machinery.

Natural plant fibers reinforced polymeric composite, also has some disadvantages such as the incompatibility between the hydrophilic natural fibers and hydrophobic thermoplastic and thermoset matrices requiring appropriate use of physical and chemical treatments to enhance the adhesion between fibers and the matrix [8].

Numerous publications can be found on the SEM observation of natural fibers reinforced polyester composite. A polymer matrix composite contains the various natural fibers as the reinforcement phase was successfully fabricated and the homogeneity of natural fibers-matrix combinations and their bonding structures was characterized through SEM analysis [9]. The effect of the addition of a resin impregnation process on static strength of the injection molded composites was investigated by carrying out tensile and bending tests, followed by SEM observation of fiber surface and fracture surface of composites [10]. The tensile properties, flexural properties and hardness increase with the increase in the weight fraction of natural fibers to certain extent. The morphology of composites is studied by using SEM [11]. SEM observation of a specimen cross section can provide important information for research and development as well as fracture analysis. In many cases, surface observation alone cannot compare to the cross sectional image of granular materials, layered materials, fibrous materials, and metallic coatings, etc [12]

2.0 EXPERIMENTAL METHOD

2.1 Specimen preparation

OPEFB that has been obtained and then grab the fiber by cut and separated from the OPEFB rod. The separated fibers were treated by 3 modes. Mode 1, OPEFB fibers are boiled with water with a temperature of 50º C to 80º C for 30 minutes. Mode 2, the OPEFB fiber was soaked with 5% NaOH solution for 2 hours. Mode 3 OPEFB fiber boiled with 5% NaOH solution for 30 minutes with temperature 50º C to 80º C.

The first fiber using mode 1 is partially taken and then cutting using a blender with a 2-speed variation. The fibers are cut with water to facilitate the enumeration of OPEFB fibers. Cutting using this blender is done for 5 minutes. The fiber that has become the sheet is carried out by using sunlight. Drying of fiber is done until the water content of the fiber has reached 0%. The fiber that has become the sheet is cut with dimensions of 25 mm x 15 mm. Fiber that has not been done by direct enumeration is done by drying until the water content reaches 0%. If the water content test results have not reached 0%, the OPEFB fiber is dried again until the moisture content reaches 0%. The fibers treated with mode 2 and mode 3 are carried out similarly to the fibers treated by mode 1.

The working procedure of the composite technique of making VARI method (Fig. 1) is by operating the pump, after the vacuum pump is operated then adjusting the pressure by closing the inlet channel then arranging the control valve opening to adjust the pressure. The pointer on the manometer is noted until it shows the number of pressure scales to be used.

Figure 1: Vacuum assisted resin infusion (VARI)

Figure 2 shows OPEFB fiber reinforced polymer composites-polymeric foam sandwich panels. This composite material has been made on a highly compact layered structure. The maximum layer thickness of 0.5 mm. the resulting layers are macroscopically bonded together into a composite material.

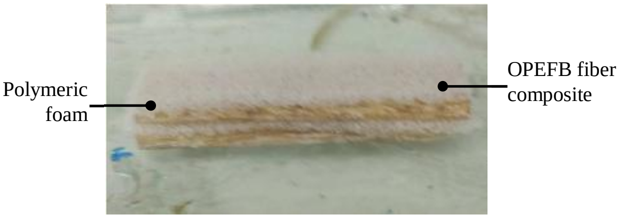

Figure 2: OPEFB fiber reinforced polymer composites-polymeric foam sandwich panels

2.2 Experimental setup

The standard used is ASTM D638- 03 the gauge length and cross head speeds are chosen according to the standard.

Figure 3: Tensile testing machine

The test is carried out in Universal Testing Machine (UTM) at room temperature as shown in Figure 3. The test involves application of tension in the work piece until it fracture. The tensile stress recorded according to strain. The test conducted for the following combinations and corresponding graph is plotted.

The three points bending flexural test of composite sample is carried out in ASTM D 790 test standard. In flexural test, a uniaxial load was applied through both the end as shown in Figure 4.

Figure 4: Flexural testing machine

The microstructure was observed using SEM observation in order to better understand damage mechanism during the stress of polyester phase. SEM observation on fracture surface can provide important information for research and development as well as fracture analysis.

Samples for SEM have to be prepared to withstand the vacuum conditions and high energy beam of electrons, and have to be of a size that will fit on the specimen stage. Samples are generally mounted rigidly to a specimen holder or stub using a conductive adhesive.

The morphological characterization of the composite surface is observed in scanning electron microscope of TESCAN VEGA3 as shown in Figure 5. TESCAN offers the LaB6 – lanthanum hexaboride – electron source as an option, which can be classified as somewhere in-between the Schottky emitter and a tungsten heated filament.

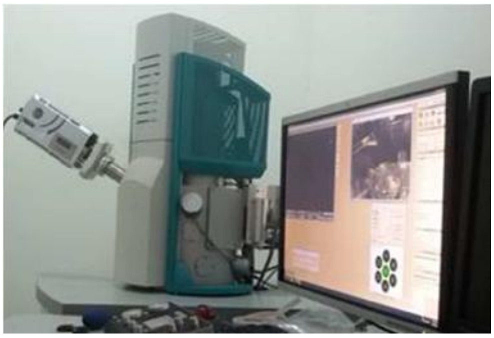

Figure 5: TESCAN VEGA3

3.0 RESULTS AND DISCUSSION

Three different fiber treatment of OPEFB fiber reinforced polymer composites-polymeric foam sandwich panels were subjected under static uniaxial tensile and flexural loading. The influence of coconut fibers orientation on static uniaxial tensile and flexural properties were studied [10]. The longitudinal orientation of coconut fibers resulted in a maximum tensile and flexural strength [10].

The fracture surface of OPEFB fiber reinforced polymer composites-polymeric foam sandwich panels by SEM. From SEM observation, it is found that different fibers treatment may be due to the changed microstructure which is influence for the fracture behavior and damage mechanism of OPEFB fiber reinforced polymer composites-polymeric foam sandwich panels. It shows that the morphology of the fracture OPEFB fiber reinforced polymer composites-polymeric foam sandwich panels revealed the tensile and flexural behavior.

Figure 6 shows the micrograph of OPEFB fibers/matrix debonding were treated with mode 1 subjected to uniaxial tensile loading.

Figure 6: SEM of OPEFB fibers/matrix debonding were treated with mode 1 subjected to uniaxial tensile loading

The OPEFB fiber aligned parallel to tensile load. Tensile load, once carried out by the matrix, is transferred by shear to the fiber which are still intact. This shear force eventually become so large that the bond between fiber and matrix fails. A cylindrical crack at the interface propagates from the polymer matrix crack surface along the OPEFB fiber as the tensile load applied.

Figure 7 shows the micrograph of OPEFB fibers/matrix pullout were treated with mode 1 subjected to uniaxial tensile loading.

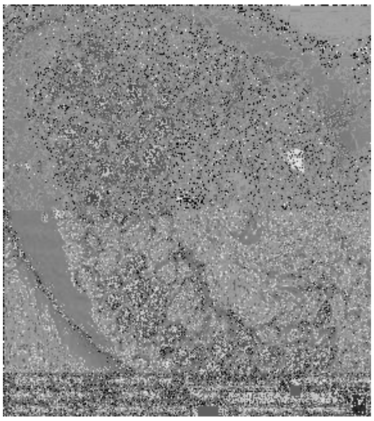

Figure 7: SEM of OPEFB fibers pullout were treated with mode 1 subjected to uniaxial tensile loading

The friction produces a non-uniform stress along the debonded OPEFB fiber. Because of the variable strength of OPEFB fiber along its length the fiber is able to break some distance from the polymer matrix crack-plane where the tensile stress is highest. The average tensile strength of the multi-stage polymeric foam sandwich panels of OPEFB fiber boiled with water at a temperature of 50º C to 80º C for 30 minutes (mode 1) was obtained 14.08 N/mm^2 [13].

Figure 8 shows the micrograph of OPEFB fibers/matrix debonding were treated with mode 2 subjected to uniaxial tensile loading.

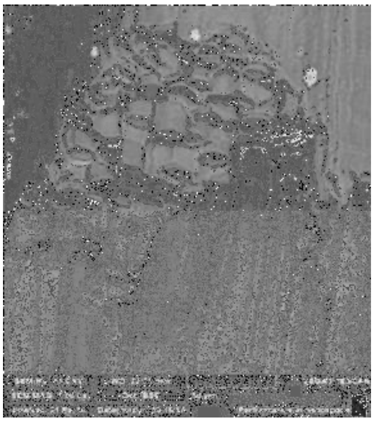

Figure 8: SEM of OPEFB fibers/matrix debonding were treated with mode 2 subjected to uniaxial tensile loading

The frictional transfer between OPEFB matrix and polymeric fiber is due to compressive radial stress produced both by the shrinkage of the polymer during cure and thermal mismatch effects during cooling. Figure 9 shows the micrograph of OPEFB fibers/matrix pullout were treated with mode 2 subjected to uniaxial tensile loading. The fundamental of pullout is the variable strength of the OPEFB fiber. In the absence of strength-reducing flaws a OPEFB fiber would break in the region of maximum stress, between the face of a polymer matrix crack, an pullout would not result. The average tensile strength of the composite by method 2 was 18.12 N/mm^2. The standard deviation of the tensile strength of the test results is known to be 4.11 N/mm^2 [13].

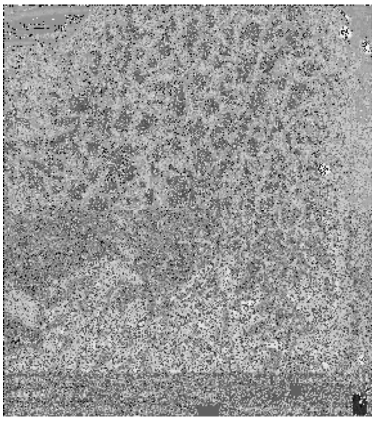

Figure 9: SEM of OPEFB fibers pullout were treated with mode 2 subjected to uniaxial tensile loading

Figure 10 shows evidence of matrix cracking and debonding of OPEFB fibers/matrix were treated with mode 3 subjected to uniaxial tensile loading, often first occurring around the OPEFB fibers oriented 90° to the loading direction.

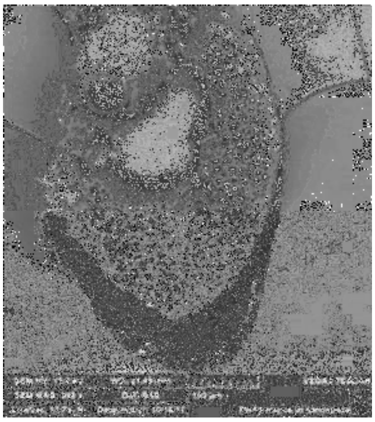

Figure 10: SEM of OPEFB fibers/matrix debonding were treated with mode 3 subjected to uniaxial tensile loading

The debonded OPEFB fiber and matrix accompanied by surface matrix cracking. As well as OPEFB fiber structures that are also damaged so that OPEFB pull-out fibers occur as debonded between OPEFB fiber. The failure of OPEFB fiber and debonded fiber and matrix result micro-cracking which occurs on polymer matrix wall. Micro-cracking in polymer fibers propagated and affects the interface bonds of other OPEFB fibers.

Figure 11 shows the micrograph of OPEFB fibers/matrix pullout were treated with mode 3 subjected to uniaxial tensile loading. The nature of fracture surface appearance of OPEFB fibers can also be related to OPEFB fiber composite strength, fiber fracture resistance and fiber degradation and surface defects. OPEFB fibers show individual fiber pullout with little polymer matrix between the OPEFB fibers. The OPEFB fiber boiled with 5% NaOH solution for 30 minutes with temperature 50º C to 80º C reinforced polymer matrix shows a solid bundle which has fractured and pulled-out with intact polymer matrix binding the OPEFB fibers.

Figure 11: SEM of OPEFB fibers pullout were treated with mode 3 subjected to uniaxial tensile loading

Figure 12 shows the micrograph of OPEFB fibers/matrix debonding were treated with mode 1 subjected to flexural loading. It was observed that the fiber and matrix OPEFB bonds are affected by tensile and compressive stresses that occur during flexural loading. The flexural stress also affects the debonding of OPEFB fiber and polymer matrix.

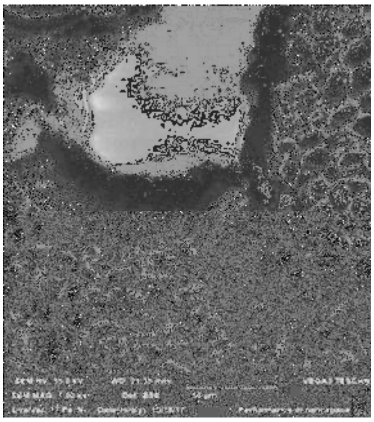

Figure 12: SEM of OPEFB fibers/matrix debonding were treated with mode 1 subjected to flexural loading

The debonding failure due to flexural load causes damage to the bonding of OPEFB fibers. The debonding of OPEFB fiber occurs on OPEFB-polymeric foam laminate composite. It is important to note that the flexural behavior occurs because of debonding of the fiber/matrix interface and subsequent fiber pullout due to fracture of the interphase and fibers.

Figure 13 shows the micrograph of OPEFB fibers/matrix pullout were treated with mode 1 subjected to flexural loading. The OPEFB fiber pullout is almost invisible on the surface of OPEFB fiber composite-polymeric foam. This failure mechanism is also followed by debonding between OPEFB fiber and polymer matrix.

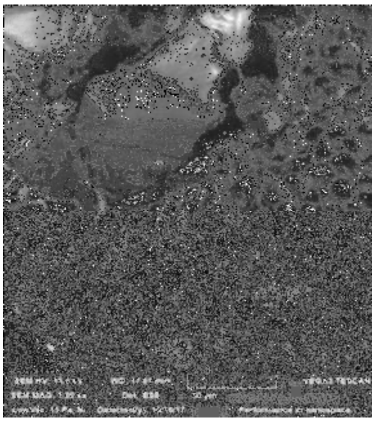

Figure 13: SEM of OPEFB fibers pullout were treated with mode 1 subjected to flexural loading

The debonding of OPEFB fibers/matrix were treated with mode 2 subjected to flexural loading is shown in Fig. 14. The debonding of OPEFB fibers and the polymer matrix occurs in the initial cracking that propagates on the surface of the polymer matrix. This brittle failure due to increased shear stress on OPEFB fiber and matrix surface.

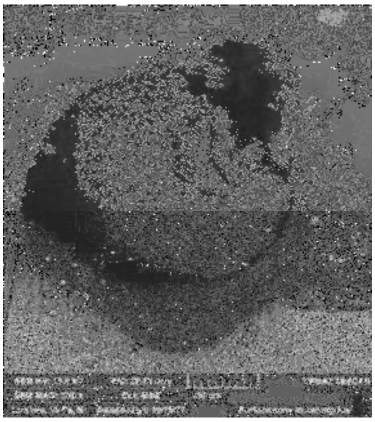

Figure 14: SEM of OPEFB fibers/matrix debonding were treated with mode 2 subjected to flexural loading

The fracture of OPEFB fiber pull out in the polymer matrix composite is shown in Figure 15. OPEFB fiber that pulls out occurs due to debonding on the surface of a polymer matrix fracture. The fiber OPEFB strength decreases due to debugging OPEFB fiber so the ability of polymer matrix to bind fibers is reduced.

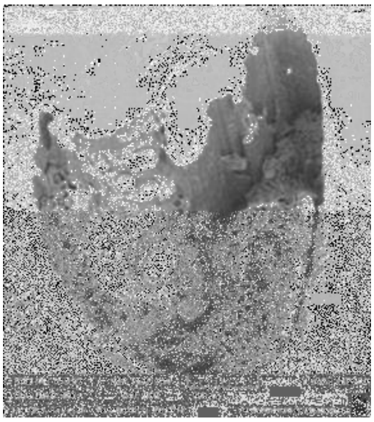

Figure 15: SEM of OPEFB fibers pullout were treated with mode 2 subjected to flexural loading

Figure 16 shows micrograph of OPEFB fibers/matrix debonding were treated with mode 3 subjected to flexural loading. In mode 3, the strength of OPEFB fiber occurs due to failure of polymer matrix and OPEFB fiber pullout. The tensile strength obtained depends on the OPEFB fiber and polymer matrix. However, the interface binding of OPEFB fiber and polymer matrix which have occurred initial crack condition result the continuous crack propagation.

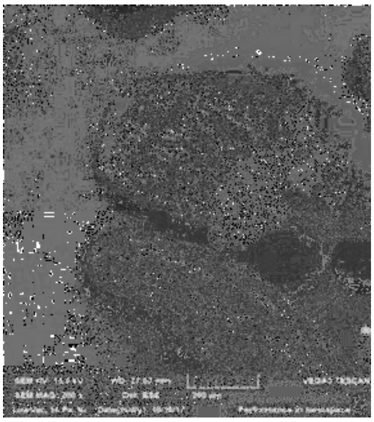

Figure 16: SEM of OPEFB fibers/matrix debonding were treated with mode 3 subjected to flexural loading

The micrograph of OPEFB fibers pullout were treated with mode 3 subjected to flexural loading is shown in Fig. 17. OPEFB fiber and polymer matrix are debonding tend to show fracture due to shear stress. OPEFB fiber boiled with 5% NaOH solution for 30 minutes with temperatures 50º C to 80º C effect on shear strength OPEFB fiber and polymer matrix.

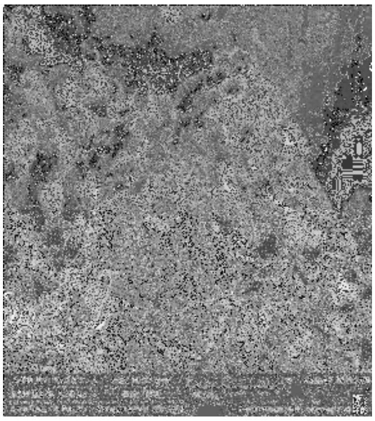

Figure 17: SEM of OPEFB fibers pullout were treated with mode 3 subjected to flexural loading

Differences in OPEFB fiber treatment affect the fracture mode of OPEFB fiber reinforced polymer composite-polymeric foam sandwich panels. In addition to fracture surface, mechanical properties such as tensile strength and flexural strength are also influenced. From the tensile test results of multi-stage polymeric foam sandwich panels of OPEFB fiber obtained high tensile strength on composites with OPEFB fibers soaked with 5% NaOH solution for 2 hours. From the results of batch testing of polymeric foam sandwich panels of fiber OPEFB fiber obtained high flexural strength on composites with OPEFB fibers boiled with water with a temperature of 50º C to 80º C for 30 minutes [13].

5.0 CONCLUSION

This work has reported the fracture surface of OPEFB reinforced polymer composites sandwich panels. It was found that fracture modes were considerably different for these composites. OPEFB fibers are boiled with water with a temperature of 50º C to 80º C for 30 minutes tends to show the surface fracture debonding interfaces OPEFB fiber and polymer matrix. While OPEFB fiber was soaked with 5% NaOH solution for 2 hours result pull out of matrix. However, OPEFB fiber boiled with 5% NaOH solution for 30 minutes with temperatures 50º C to 80º C effect on shear strength OPEFB fiber and polymer matrix.

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REFERENCE

1. ASM International Handbook Committee. (2001). *Composites*. Vol. 21.
2. Vaziri A, Xue Z, Hutchinson J W. 2006. Metal Sandwich Plates with Polymer Foam-Filled Cores. Journal of Mechanics of Materials and Structure. Vol. 1 No. 1:95-125.
3. Qiao P, Yang M, Bobaru F. 2008. "Impact Mechanics and High-Enegy Impact Absorbing Materials: Review. *Journal of Aerospace Engineering* 21(4): 235-248.
4. Badri M, Syam B, Rizal S, dan Bhuana K. 2010. Respons *Polymeric Foam* Diperkuat Serat Tandan Kosong Kelapa Sawit akibat Beban Tekan Statik dan Impak (Simulasi Numerik). *Jurnal Spektrum*. Volume 9 Nomor 2: 275-288.
5. Badri M. 2010. Pengaruh Serat Tandan Kosong Kelapa Sawit (TKKS) terhadap Perilaku Mekanik *Polymeric Foam* akibat Beban Tekan Statik. Jurnal Spektrum. Vol.9 No.1.
6. Kumar, V. ”Phenomenology of Bubble Nucleation in the Solid State Nitrogen-Polystyrene Microcellular Foams”. *International Journal of Colloids and Surface A: Physicochem. Eng. Aspects* 263 (2005): 336-340.
7. Klempner, D dan Sendijarevic, V. 2004. “Polymeric Foams and Foam Technology”. *Journal of Carl Hanser Verlag* : 584.
8. Neher, B., Bhuiyan, M.M.R., Kabir, H., Qadir, M.R., Gafur, M.A. and Ahmed, F. (2014). *Study of Mechanical and Physical Properties of Palm Fiber Reinforced Acrylonitrile Butadiene Composite*. Materials Sciences and Applications, 5, 39-45.
9. Senthiil Dr P V, Sirsshti A. (2014). *Studies on material and mechanical properties of natural fiber reinforced composite*. International Journal of Engineering and Science : 18-24.
10. Nam G, Wu N, Okubo K, Fujii T. *Effect of natural fiber reinforced polypropylene composite using resin impregnation*. Journal of Scientific Research 5 (2014): 1338-1343.
11. Sivakumar M, Kumar R M, Sasikumar S, Prabhu D, Sabarish C, Sengottaiyan P. (2016). *Mechanical properties and SEM analysis of glass/nylon/jute reinforced epoxy hybrid composites*. International Journal of Mechanical Engineering and Technology (IJMET). Volume 7 : 196-207.
12. Erdman N, Rodriguez S A. *New cross-section sample preparation method applied to microstructural and chemical investigation of steel coating using FE-SEM*.
13. Badri M, Arief D.A., Johanes E.S., Rahmat R.Z. (2017). Mechanical Behavior of OPEFB Fiber Reinforced Polymer Composites - Polymeric Foam Sandwich Panels under Static Loading Conditions. *Proceeding of Ocean, Mechanical, and Aerospace-science and engineering* (POMAse) 2017.