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Fracture Toughness of Sugar Palm Fiber Reinforced Epoxy Composites

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Abstract: ***The aim of this study is to determine the fracture toughness, and energy release rates of sugar palm fiber reinforced epoxy composite SPFREC. Randomly chopped short sugar palm fiber with a loading of 20% (by volume) used as reinforcement agents in epoxy composites. The mixing ratio for the epoxy and the hardener was 4:1. Three types of treatments apply during study to be compared with the untreated one. The fiber were left soaked for a period of 30 days in different treatment medium as seawater, pond water and contaminated water before taken out and washed thoroughly with distilled water. Results show that the fracture toughness, and energy release rates registered its highest values of 1.248 MPa√m and 1.19 KJ/m^2 respectively for the seawater. Also, the tests Results shows improving of mechanical properties of sugar palm fiber-reinforced epoxy. The SEM analysis has conducted to provide the analysis on interface adhesion between the surfaces of fiber with the matrix.***

Keywords: Sugar palm fiber reinforced, Composite material, Fracture toughness, Mechanical properties.

1. Introduction

Composites are combinations of two or more than two materials in which one of the materials, is reinforcing phase (fibers, sheets or particles) and the other is matrix phase (polymer, metal or ceramic).Composite materials are usually classified by type of reinforcement such as polymer composites, cement and metal- matrix composites. Polymer matrix composites are mostly commercially produced composites in which resin is used as matrix with different reinforcing materials. Polymer (resin) is classified in two types thermoplastics (polyethylene (PE), polypropylene (PP), polyether ether ketone (PEEK), polyvinyl chloride (PVC), polystyrene (PS), polyolefin etc.) and thermosets (epoxy, polyester, and phenol–formaldehyde resin, etc.) which reinforces different type of fiber like natural (plant, animal, mineral) and man-made-fiber for different application. In metal matrix composites, metal is one of important part of element and other part may be metal, ceramic or organic compounds. Cement matrix composites are made up of cement and with aggregate and basically used in building applications [1].

1.1 Sugar Palm Plant

Sugar palm Figure 1 belongs to the sub-family of Arecoideae and the tribe of Caryoteae. It was earlier given a number of taxonomic names such as Saguerus rumphii and Arenga saccharifera Labill.

Figure 1: Sugar palm tree [2]

However, in 1917 during the International Congress of Botany in Vienna, it was officially renamed as Arenga pinnata [2]. It is one of the most famous plants in Malaysia and Indonesia. Sugar palm is suitable for producing renewable energy in the form of bio-fuels via a fermentation process derived from sugar collected from its bunch [3]. Sugar palm is one of the most versatile palm species because almost all parts of the tree can be used. Although sugar palm has magnificent properties, the work on sugar palm has been restricted to the activity of tapping the palm sap for the production of traditional sugar blocks called gula enau or kabung and neera syrup. There are thousands of farmers in Indonesia and Malaysia (Kuala Pilah and Jempol, Negeri Sembilan; Kuala Lipis, Pahang; Tawau, Sabah; etc.) who earn a living by tapping sugar palm sap [2].

1.2 Sugar Palm Fiber

Figure 2 shows a fiber as another important product of the sugar palm, it has several names such as *Aren*, *gomuti*, and black and locally known as the *Ijuk* fiber.

Figure 2: A bundle of Sugar Palm Fiber [4]

These fibers are known for their high durability and their resistance to sea water. Traditionally, sugar palm fibers were used to make ropes for ship cordages which were proven to have good properties in sea water. Other than that, the preparation for sugar palm fibbers is effortless as the fibbers do not require any secondary processes such as water retting or mechanical decorticating process to yield the fiber. This is due to the fact that the fibbers, originally wrapped around the sugar palm trunk from the bottom to the upper part of the tree as shown in Figure 3, are in the form of natural woven fiber [2].

Figure 3: Sugar Palm Fiber. [5]

To date, the use of sugar palm fiber has moved to another successive level specifically to various engineering applications. For example, it has been used in road constructions for soil stabilization as a substitute for geo-textile fiberglass reinforcement. Apart from that, in certain circumstances, it is also being used for underwater and underground cables [6]. Figure 4 shows the fiber orientations. Fibers in random original orientation mean that they are in their original layered shape straight from the tree trunk.

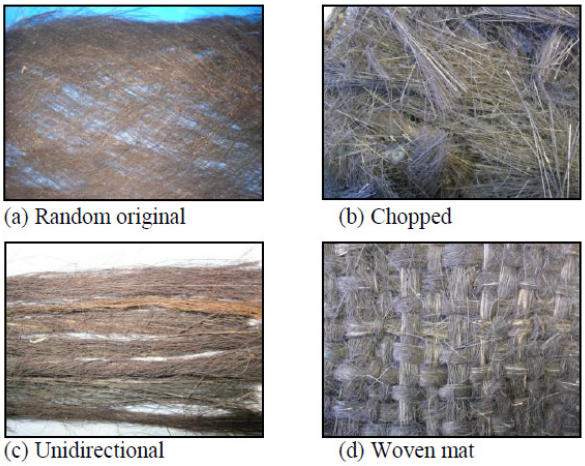

Figure 4: Orientation of the Sugar Palm fibers [7]

1.3 Sugar palm fiber composites

In the field of material engineering, sugar palm fiber is being used as reinforcement in polymer matrix composites. Several studies have shown that sugar palm fibers have great potential to be used in many composite applications, just like other natural fibers such as kenaf, jute, oil palm, sugar cane bagasse, pineapple leaf and banana pseudo stem fiber [6]. [8] Study the effect of fiber content on mechanical properties, water absorption behavior and thermal properties of sugar palm fiber (SPF) reinforced plasticized sugar palm starch (SPF/SPS) bio-composites. The bio-composites were prepared with different amounts of fibers (i.e. 10%, 20% and 30% by weight percent) by using glycerol as plasticizer for the starch. The mechanical properties of plasticized SPS improved with the incorporation of fibers. [9] Study on tensile properties of sugar palm fiber (SPF) reinforced high impact polystyrene (HIPS) composites. Five different fiber loadings of 10, 20, 30, 40 and 50% by weight were mixed with HIPS polymer to form composites fabricated using melt mixer and hot press. Tensile tests of the composites were carried out using Instron machine. The results showed that the increase of short SPF loading in HIPS matrix improved tensile strength and modulus of the composites.

1.4 Mechanical Properties of Sugar palm fiber reinforces epoxy composites

[7] Show that the idea to study the feasibility of using sugar palm fibers as composite material resulted from the observation of the use of the fibers as rope and traditional building material. As rope, the fibers are twisted to a required diameter so to withstand tensile stress. As traditional roofing in rural tropical areas, the fibers are required to withstand wind loads and to provide protection from rain and tropical sun. Therefore, sugar palm fibers are reasonably durable. [10] indicated that previous study on the tensile and flexural properties of sugar palm epoxy composites is concerned with the use of woven roving, long random and chopped random sugar palm epoxy composites and it is found that the woven roving sugar palm epoxy composites gave better properties compared to long random and chopped random fiber composites. However, all the samples showed inferior properties compared with the glass fiber epoxy composites. Hence, the treatment of fiber was needed to improve the materials. So [10] study the effect of

alkaline treatment on tensile properties of sugar palm fiber reinforced epoxy composites. The treatment was carried out using sodium hydroxide (NaOH) solutions at two different concentrations of 0.25M and 0.5M NaOH, at three different soaking times namely 60 minutes, 4 hours and 8 hours. The hydrophilic nature of sugar palm fiber makes it difficult to adhere to hydrophobic epoxy and therefore posed the problem of interfacial bonding between fiber and matrix and such treatment was needed to alleviate such problem. The composite specimens were tested for tensile property determination. Inconsistent results were obtained for tensile strengths Figure 5, which indicate that the treatment is not very effective yet to improve the interfacial bonding. However, for tensile modulus, the results as shown in Figure 6 are much higher than untreated fiber composite specimens, which proved the effectiveness of the treatment.

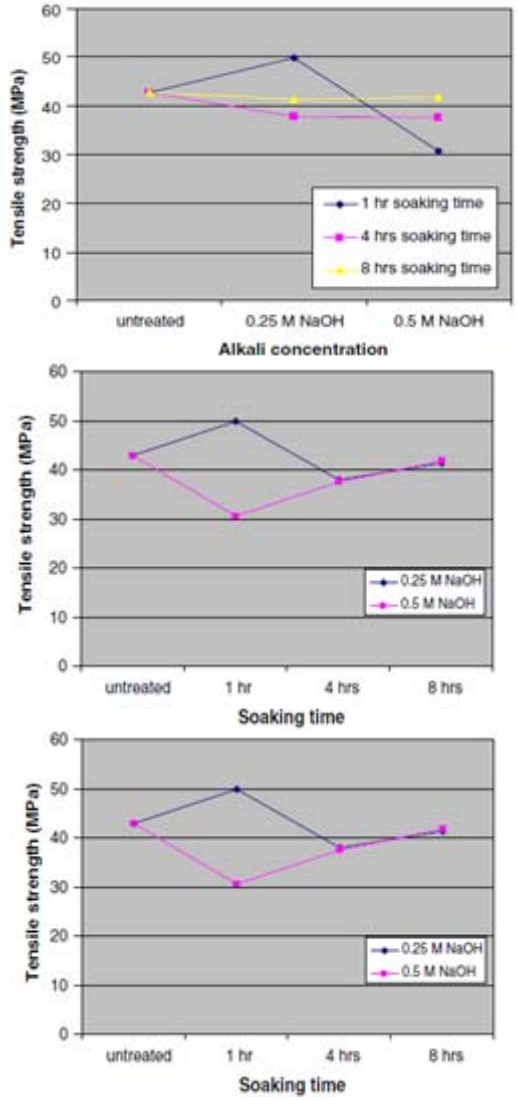

Figure 5: Average tensile strength of SPFREC versus alkaline concentration & soaking time [10]

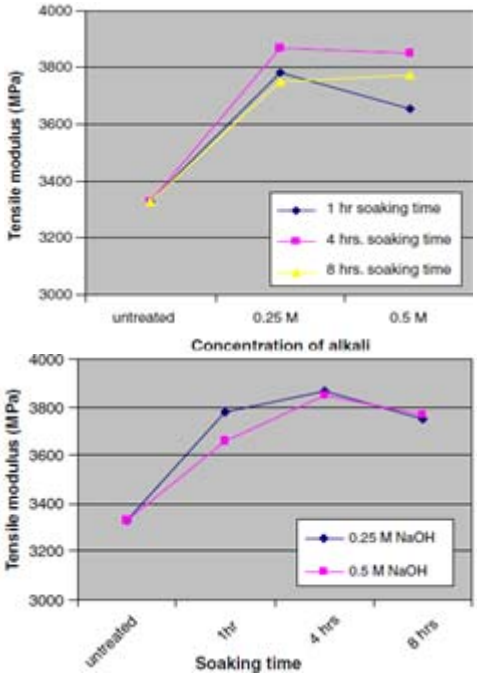

Figure 6: Average tensile modulus of SPFREC versus concentration of alkali &soaking time [10]

2. Materials and Methodology

2.1 Preparation of composite

The fibers were soaked in the different mediums as seawater, pond water and contaminated water at room temperature in the rage of 25 °C with relative humidity range from 66.3%. The fibers were left soaked for a period of 30 days before being taken out and washed thoroughly with purify water. The drying process was carried out for 5 days in room temperature. The fibers were chopped to the average of 1 mm in particle size using a chopper machine so that they could be mixed with the epoxy resin to make the short fiber composite plates. Chopped fibers were sieved so that particles which were longer than 1 mm would be excluded. Randomly chopped short sugar palm fiber with the loading of 20% (by volume) was used as reinforcement agents in epoxy composites. The mixing ratio for the epoxy and the hardener was 4:1. Sugar palm fibers were then mixed with the epoxy and enthused again for 5 minutes. This was to ensure that the fibers were well mixed with the epoxy to produce a good and strong composite plate. The composite mixture was then poured into the open mould and spread evenly before being pressed carefully with a sheet of Mylar. Precaution step must be taken to avoid any unwanted air bubbles as they could reduce the strength of the composite after it has been cured. After 24 hours the composite plates were taken out of the mould carefully as they were still soft before being left again to be fully hardened for 24 hours after which the tensile and fracture test specimens were cut. The composite were fabricated into plates which later were cut into standard sized test specimens. The dimensions of the test specimens followed the ASTM E 1820 for fracture test.

2.2 Fracture toughness test

The fracture toughness of the composite specimens was measured using Fracture Tester (MTS 810 material test system) as shown in Figure 7. The specimens were cut according to dimensions as specified by the ASTM E1820; this test method is for the opening mode (Mode I) of loading. The objective of this test method is to load a fatigue pre-cracked test specimen as shown in Figure 8 to induce either or both of the following responses:

1. Unstable crack extension, including significant pop-in, referred to as "fracture instability" in this test method;
2. Stable crack extension, referred to as "stable tearing" in this test method.

Figure 7: Fracture Tester (MTS 810 material test system)

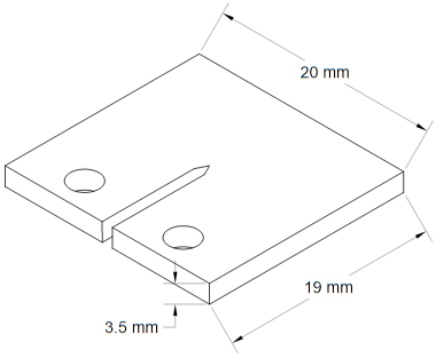

Figure 8: Fracture test specimen

Fracture instability results in a single point-value of fracture toughness determined at the point of instability. Stable tearing results in continuous fracture toughness versus crack-extension relationship (R-curve) from which significant point-values may be determined. Stable tearing interrupted by fracture instability results in an R-curve up to the point of instability [11]. This investigation split into two major computation scopes to estimate the fracture toughness and energy release rate: it include the experiment data for sugar palm fiber reinforcement epoxy composites (SUPFREC) specimens. Meanwhile, the compact tension (CT) specimen was instructed according to the ASTM E 1820 standard for the fracture toughness measurement. The thickness was 3.5 mm for all the specimens, while the initial notch length to specimen was between 10 mm and the notch tip was sharpened with a razor blade to simulate a sharp crack. The tensile test for 20 specimens was conducted to estimate the fracture toughness and J-integral for this particular composite. At load $P_{(i)}$ the calculation of $K_{(i)}$ was computed instantaneous at all the recorded points in the load-displacements curve. Thus, the instantaneous fracture can be mathematically expressed using the following expression:

$$K_{(i)} = \frac{P_i}{(BB_N W)^{1/2}} f(a_i/W) \quad (1)$$

Where:

$$f(a_i/W) = \frac{\left[\begin{array}{l}(a_i/W)(0.886+4.64(a_i/W))- \\ 13.32(a_i/W)^2+14.72(a_i/W)^3-5.6(a_i/W)^4\end{array}\right]}{(1-a_i/W)^{3/2}} \quad (2)$$

Meanwhile, J for the compact specimen was calculated, as follows:

$$J = J_{el} + J_{pl} \quad (3)$$

The J calculations for the basic test method for the compact specimen are related to the Poisson's ratio and young modulus.

$$J = \frac{K^2(1-\nu^2)}{E} + J_{pl} \quad (4)$$

The plastic component of J was calculated, as follows:

$$J_{pl} = \frac{\eta A_{pl}}{B_N b_o} \quad (5)$$

Where:
$K_{(i)}$ = stress intensity factor with $a = a_{(i)}$,
P_i = load
B_N = net specimen thickness (B_N = B if no side grooves are present),
W = width,
$a_{(i)}$ = current crack length,
J = J-integral
J_{el} = elastic component of J,
J_{pl} = *plastic component of J.*
K = stress intensity factor with $a = a_o$,
ν = Poisson's ratio,
E = elastic modulus at the test temperature,
A_{pl} = area under the load and displacement curve,
$b_o = W - a_o$.
a_o = original crack length, and
$\eta = 2 + 0.522 b_o/W$.

In addition, the crack length is given as follows:

$$a_i/W = \left[\begin{array}{l}1.000196 - 4.06311u + 11.242u^2 \\ -106.043u^3 + 464.335u^4 - 650.677u^5\end{array}\right] \quad (6)$$

Where:

$$u = \frac{1}{(BEEC_{(i)})^{1/2}+1} \quad (7)$$

To account for crack opening displacement in C(T) specimens, the crack length estimation shall be corrected for rotation. Compliance is corrected as follows:

$$C_{(i)} = \frac{C_i}{\left[\frac{V_i}{P_i}\sin\theta_i - \cos\theta_i\right]\left[\frac{V_i}{P_i}\sin\theta_i - \cos\theta_i\right]} \quad (8)$$

$$B_e = B - (B - B_N)^2/B \quad (9)$$

$$\theta = \sin^{-1}\left[\frac{\left(\frac{V_m}{2}+D\right)}{(D^2+A^2)^{1/2}}\right] - \tan^{-1}\left(\frac{A}{D}\right) \quad (10)$$

Where:

$C_{c(i)}$ = specimen load-line crack opening elastic compliance $(\Delta v/\Delta p)$ on an unloading/reloading equence corrected for rotation

C_i = measured specimen elastic compliance (at the loadline),

H^* = initial half-span of the load points (center of the pin holes),

R = radius of rotation of the crack centerline, $(W + a)/2$, where a is the updated crack length,

D = one half of the initial distance between the displacement measurement points,

u = angle of rotation of a rigid body element about the unbroken midsection line, or

d_m = total measured load-line displacement

The calculation was programmed in an Excel sheet so that the reading of K_{IC} and J_{IC} can be found for any load P_i.

3. Results and Discussion

3.1 Fracture test results

A test was carried out to determine the maximum fracture toughness of the SPFREC, which was fabricated using the treated fibers. The fracture testing machine was used in the measurement of loads and the associated test specimen deformation. The specimens used for the test were fabricated according to the ASTM E 1820 standard for the fracture toughness measurement as shown in figure 9.

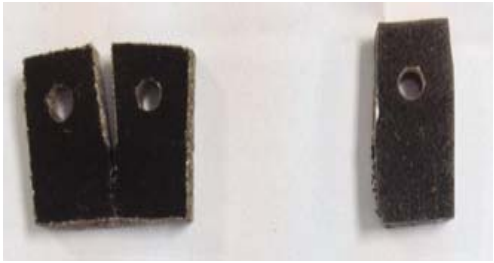

Figure 9: illustrate a specimen sample of 20 wt% SPFREC after test.

For the study, the fracture strength and the energy release rate (J-integral values) were focused. Figure 10 and 11, presents the results of fracture toughness and energy release rate for average five specimens tested of the 20 wt% composite SPFREC.

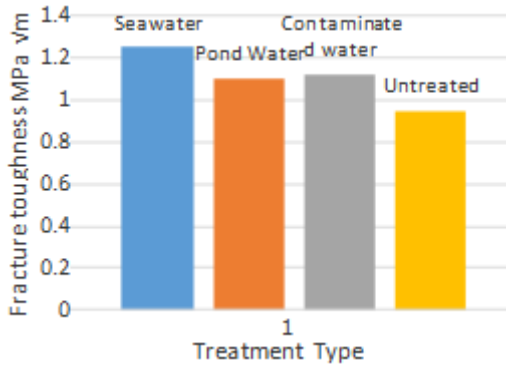

Figure 10: Effects of Different Treatment Methods (30 Days) on the Average fracture toughness for 20wt. % of SPFREC

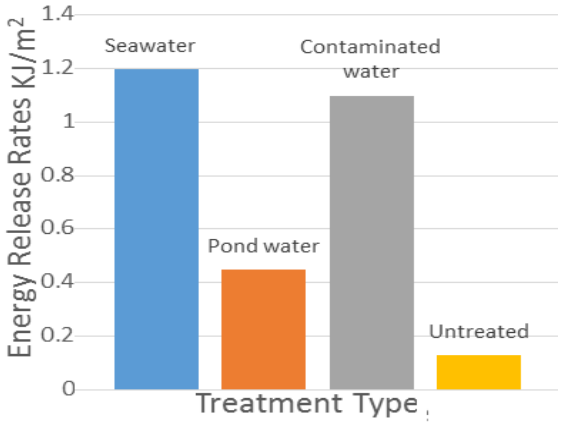

Figure 11: Effects of Different Treatment Methods (30 Days) on the Average Energy Release Rates for 20wt. % of SPFREC

From Figure 10, it can be seen that the highest fracture toughness found for the seawater treated fibers compared to untreated fibers due to the removal of surface impurities after the treatment. The increased surface uniformity of the fibers increased the toughness as points of unconformity were removed during the treatment and this changed the deformation behavior of the fibers.

The J-integral values and the corresponding crack extension values must be plotted, as shown in Figure 12. Hence, the J-R curve is defined as the data in a bounded region by the coordinate axes, J_{max} and Δa_{max}.

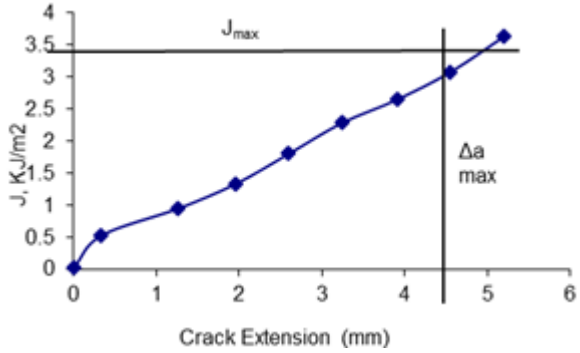

Figure 12: Crack extension and energy release rate (J-R curve) of seawater treated for 20 wt. % of SPFREC

3.2 Fiber Surface Morphology

Scanning electron microscopy (SEM) analysis was used for direct observation the failure of composite surface. Micrographs were taken of the surface of the fracture test samples. Figure 13 shows the SEM micrograph for seawater sugar palm fiber reinforced epoxy composite after fracture test at three places, namely, cutting area, fracture area and the area between cutting and fracture area. The figure shows a significantly good bonding between fiber and matrix. The surface of fiber is seen rougher than untreated fiber composite samples as shown in Figure 14 and it may be attributed to the enhancement of the bonding strength between fiber and matrix. In general, it was seen that the interfacial bonding between fiber and matrix shows good performance. The surface of fiber also rougher than the untreated fiber and it created interlocking mechanism with

the surface of matrix which can indicate the increment in the tensile strength value.

Figure 14 shows the SEM micrographs for untreated sugar palm fiber epoxy composite fracture after fracture test at three places, namely, cutting area, fracture area and the area between cutting and fracture area. From the figure it is shown that the fracture area was rough which indicate the strength adhesive between fiber and epoxy, however, it can be observed a small gap has occurred between a fiber and matrix, which may due to the effect of the processing condition, Although there is the presence of a small gap, generally that composite specimen shows good interfacial adhesion.

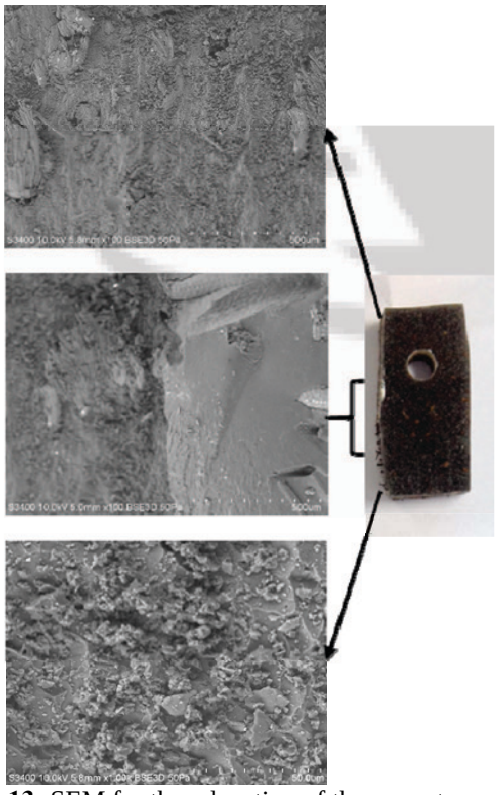

Figure 13: SEM for three location of the seawater specimen

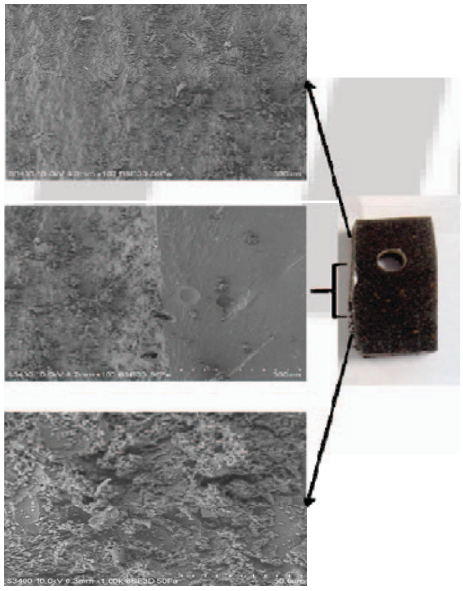

Figure 14: SEM for three location of the untreated specimen

4. Conclusion

The conclusions that can be derived from this research are as follows:

1. The fracture toughness of seawater immerses specimen register better fracture toughness than other type of treatments.
2. The seawater absorption and the swelling rate are deeply influenced by the dispersion rate of high fracture toughness.
3. The SEM results images revealed more cursive structure of seawater treated in the structure of the composite to become more fragile and brittle for higher bonding forces subject to the fibers.

Therefore, the knowledge gained through this study will help us to prepare better composites for the near future applications.

5. Acknowledgement

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