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The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites

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The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites

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Abstract:	The high growth of Water Hyacinth/ Eichhornia crassipes (WH) led to several problems such as ecosystem, irrigation, and sedimentation. Meanwhile, cellulose fiber had a potential application in natural fiber composite (NFC). This study aims to investigate the mechanical and physical properties of unidirectional WH and woven fiber reinforced epoxy resin composites. The WH fiber was obtained from a mechanically processed WH plant, in which 15 %, 25 % and 35 % of unidirectional WH and woven fiber were manufactured through the hand lay-up method. The tensile and impact test were carried out based on ASTM D3039 and A370 respectively, while the density of composites was tested based on the Archimedes rule. The results of this study showed that the tested specimens increased in % wt. with a reduction in tensile strength of the WH woven fiber reinforced with epoxy resin composites. The % wt. of WH woven fibers was in direct proportion to the amount of pore or void between the fibers and matrix, which led to a delamination mode fracture. The impact strength of composites was in direct proportion to the % wt. of the WH woven fibers. Tensile and impact strength of unidirectional WH fiber increase by increasing the % wt. of WH fibers
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January 10, 2021
Christian Schulz
Lead Editor
Heliyon

Dear Christian Schulz

Enclosed, please find the manuscript entitled: "*The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites*," submitted for publication in Heliyon. The authors are S. Sulardjaka, N. Iskandar, Sri Nugroho, A. Alamsyah, M. Y. Prasetya.

The essential findings are as follows.

1. This paper proposed development of water hyacinth composites using WH fibers both in unidirectional and woven fibers.
2. Investigate tensile and impact strength of unidirectional and woven fibers epoxy resin composites.
3. Using water hyacinth of fiber form and unidirectional fiber direction produced more effective reinforcement than other previous works (using water hyacinth on stem, stem chopped, sawdust or powder form).

The manuscript is an original work, has not been previously published in whole or in part, and is not being considered for publication elsewhere. All authors have read the final manuscript, have approved the submission to the journal, and have accepted full responsibilities pertaining to the manuscript's delivery and contents. There is no conflict of interests regarding the paper submitted.

Kind regards,

S. Sulardjaka

January 10, 2021

The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites

ABSTRACT

The high growth of Water Hyacinth/*Eichhornia crassipes* (WH) led to several problems such as ecosystem, irrigation, and sedimentation. Meanwhile, cellulose fiber had a potential application in natural fiber composite (NFC). This study aims to investigate the mechanical and physical properties of unidirectional WH and woven fiber reinforced epoxy resin composites. The WH fiber was obtained from a mechanically processed WH plant, in which 15 %, 25 % and 35 % of unidirectional WH and woven fiber were manufactured through the hand lay-up method. The tensile and impact test were carried out based on ASTM D3039 and A370 respectively, while the density of composites was tested based on the Archimedes rule. The results of this study showed that the tested specimens increased in % wt. with a reduction in tensile strength of the WH woven fiber reinforced with epoxy resin composites. The % wt. of WH woven fibers was in direct proportion to the amount of pore or void between the fibers and matrix, which led to a delamination mode fracture. The impact strength of composites was in direct proportion to the % wt. of the WH woven fibers. Tensile and impact strength of unidirectional WH fiber increase by increasing the % wt. of WH fibers.

Keywords: Composite, Epoxy-resin, Water Hyacinth, Woven fiber.

1. INTRODUCTION

Natural fibers are a useful class of materials that are environmentally clean, renewable, and biodegradable resources. They are also used in manufacturing natural fiber composites with advantages which include low impact on the environment, renewability, inexpensive and easily degraded [1-4]. However, the use of natural fibers as a reinforcement of composites is still experiencing several problems such as, low mechanical properties, hydrophilic properties, limited processing temperatures, low matrix and fiber binding forces that are easily degraded [5,6]. Furthermore, studies on the development of natural fiber properties were carried out by pretreating or engineering the manufacturing method [7,8].

Water hyacinth (Eichhornia crassipes) is a type of aquatic plant that floats on the surface of the water. It grows aggressively and was a nuisance on almost all continents for more than 100 years. Furthermore, its high population growth led to several problems related to ecosystem balance, decreased fish production, loss of endemic organisms and sedimentation [9-11]. Numerous studies were carried out to utilize water hyacinth plants as absorbers of heavy metals, absorbing dye waste, biofuel and biogas production, composite catalyst and reinforcing composites [12-19].

Based on previous studies, the problem associated with the utilization of WH materials for composite reinforcement includes, low mechanical strength, ease of water absorption leading to a reduced fiber bond with the matrix and weak compatibility of the WH fiber with the polymer matrix [20-22]. The results of this study show that for these composites, the mechanical properties were relatively low. Although the use of WH fiber as composite reinforcement still requires further studies, it has several advantages which include, increased acoustic, damping ability and good thermal resistance [23].

Furthermore, natural composites, reinforced with WF stem, stem chopped, sawdust, and powder were investigated [22, 24-26]. The WH plant extraction process affected the mechanical properties of the fiber composite. This process aims to separate plant fibers from the wax, pectin, hemicellulose and lignin layers. Also, there were several methods used to extract plant fibers from the parent plant, namely: immersion, chemical methods or mechanical methods [27]. Therefore, this study aims to investigate the mechanical and physical properties of composites reinforced with unidirectional and woven WH fibers.

2. MATERIALS AND METHODS

2.1. Materials

The water hyacinth plants used, were obtained from swamps in Tanggul Village, Mijen District, Demak Regency, Central Java, Indonesia with 50-70 cm length of stems. These plants were mechanically extracted to yield the WF fibers (Figure 1). The fiber extraction was carried out by brushing the WH stems using an iron brush. Furthermore, 10 strands of the sun-dry WH fibers were twisted to produce yarn (Figure 2), which were weaved to produce the WH fiber with dimensions of 30 x 40 cm (Figure 3). The webbing was woven with a fiber direction of 0/90°, using epoxy Bakelite® EPR 174 and resin hardener V-140 used as a matrix and hardener respectively.

2.2. Preparation of Composites

The hand lay-up method was used to fabricate the unidirectional WH fiber and woven fiber reinforced with epoxy-resin composites. This was conducted by applying an epoxy-resin matrix to the WH fibers in the mold specimens with a paintbrush and roller. Furthermore, the composites were compressed and vacuumed to remove voids and obtain a smoothen surface. Waterjet cutting was also used to prepare specimens for testing.

Figure 1. Water Hyacinth Fibers

Figure 2. Water Hyacinth Yarn

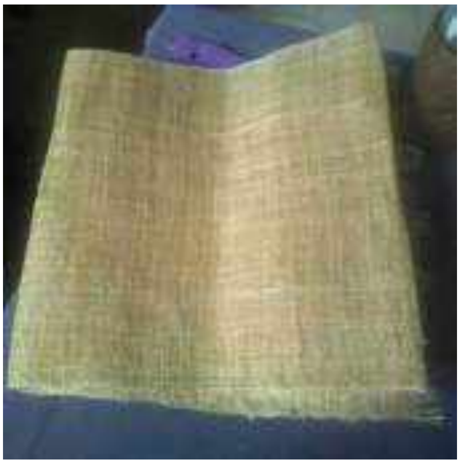
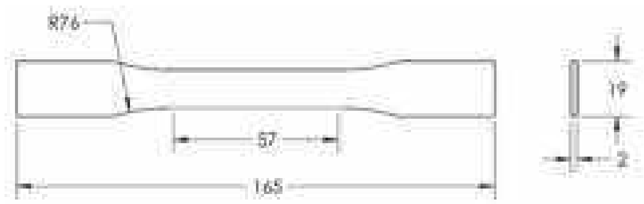


Figure 3. Water Hyacinth Woven Yarn

2.3. Characterization of Composites

The actual density of composites was measured using a densimeter based on Archimedes law according to ASTM B311. The theoretical density was calculated based on rules and mixture, while the porosity of the composites was calculated based on the actual and theoretical densities. Furthermore, the composite tensile and impact test specimens were obtained using variations in the WH fiber reinforcement of 0%, 15 %, 25 % and 35 % wt. Table 1 shows the coding of these specimens, with 6 of them being tested for each parameter. The tensile test for the polymer material (0% reinforcement) was carried out according to the ASTM D638 standard (Figure 4a). Meanwhile, the tensile test of composites was carried out according to the ASTM D3039 standard (Figure 4b). Furthermore, the impact tests were carried out through the Charpy methods according to the ASTM D6110 standard. Figure 5 shows the dimensions and photos of the impact test specimens. Scanning Electron Microscopy (SEM) was used to investigate the tensile test fracture surface of the composite.



a. Dimension of Tensile Test Specimen of Polymer Based on ASTM D638.

b. Dimension of Tensile Test Specimen of Composite Based on ASTM D3039.

Figure 4. Dimension of Tensile Test Specimen

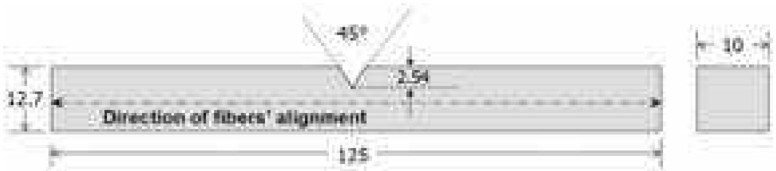


Figure 5. Dimension of Impact Test Specimen of Composite

Table 1. Specimens testing code

Code	Meaning
E(0)	Epoxy – resin, 0 % WH fibers
E(15)	Epoxy – resin, 15 % WH fibers
E(25)	Epoxy – resin, 25 % WH fibers
E(35)	Epoxy – resin, 35 % WH fibers

3. RESULTS AND DISCUSSIONS

The density and porosity test results in Figure 6, shows that both the unidirectional and woven composites increased in mass fraction, while 0, 15, 25 and 35 % wt. increase in the porosity of the composites was observed. Furthermore, figure 6 also shows that for the woven fiber composite, there was an increase in porosity almost linearly from 0.35% to 13.82% with the addition of 35% fiber. The unidirectional WH fiber composite, increased from 15 % to 35 % wt., afterwards, the porosity did not increase significantly. Composites woven fibers also provided more voids than composites UD fibers. For woven fibers, the voids form inside tows, in resin-rich regions or at tow corners, and between plies in composites. Meanwhile, for UD fibers, the voids form within and between the plies [28, 29]. The difference in the direction of the fibers for the composites woven fiber leads to air entrapment and increased porosity. The main source of air entrapment is the inhomogeneous fiber architecture, which leads to a non-uniform fiber permeability carried out with subsequent local variations in resin velocity [30].

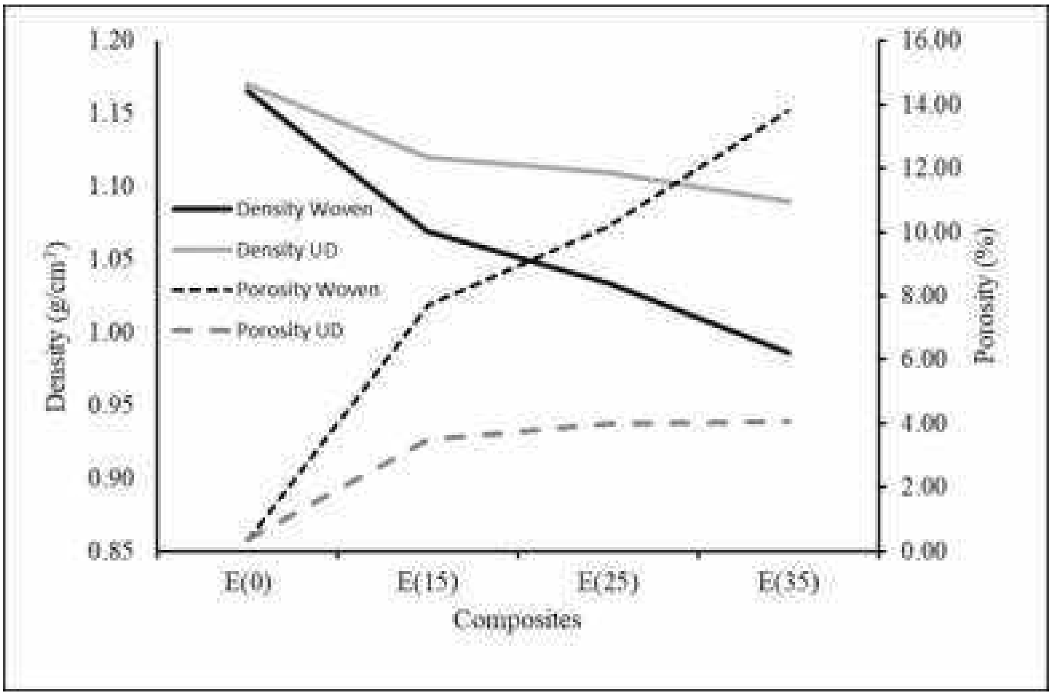


Figure 6. Density and Porosity of WH fibers Composites

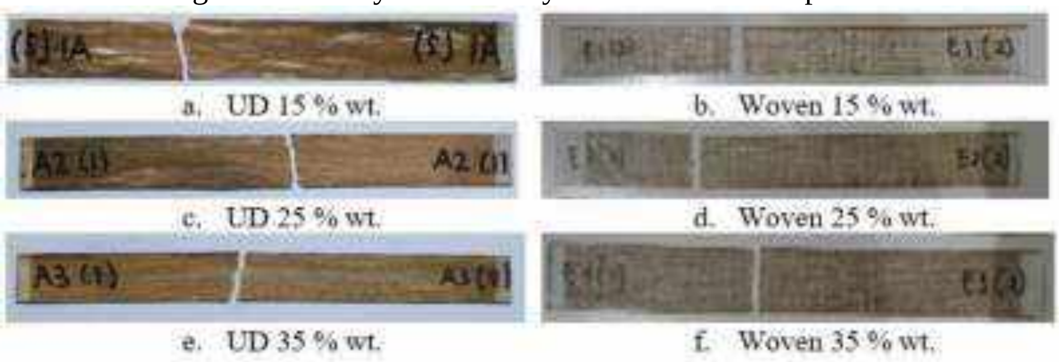


Figure 7. Photo of Tested specimens

Figure 7 shows the specimen after it was tensile tested, with fracture in the gauge length area. Figure 8 shows the tensile test results of the woven and unidirectional WH fiber composites reinforced with epoxy resin. The tensile strength of the woven WH fiber composite was in inverse proportion to the percentage of WH fibers in the composite. An increased fiber mass fraction from 0 to 15%, led to an insignificant decrease in the tensile strength of the composite. Furthermore, with a 35% addition, for every 10% increase in fiber mass fraction, the tensile strength of the composite decreases by about 11-13%. Composite elongation also decreased with the increase in % wt. of WH woven fibers, which also showed that its tensile strength was in direct proportion to the percentage weight of the WH fiber. This tensile strength increased by approximately 10% as the % wt. of WH fibers increased from 15% to 25%. For addition of 35% wt. of WH fiber, the tensile strength of composites increased by about 37%. Compared to the tensile strength of epoxy resin, the composite tensile strength of 35 % wt. for unidirectional WH fiber increased from 41 MPa to 60 MPa or by about 46 %. Furthermore, the lowest composite tensile strength for WH fibers in this study was 30 MPa for woven WH fibers composites containing 35% wt. This result was higher than that of Saputra et al., which discovered that the highest tensile strength was 28.36 MPa [31]. Figure 9 shows the specific tensile strength of composites, which shows that there were no significant differences in the tensile strengths of WH woven fibers composites. Furthermore, reinforcement by WH fibers compensates for the decreasing tensile strength of the composite from porosity. The UD WH fiber composites of 35 % wt., increases in specific tensile strength by about 60 %, which means that, it is in direct proportion with the specific tensile strength of composites.

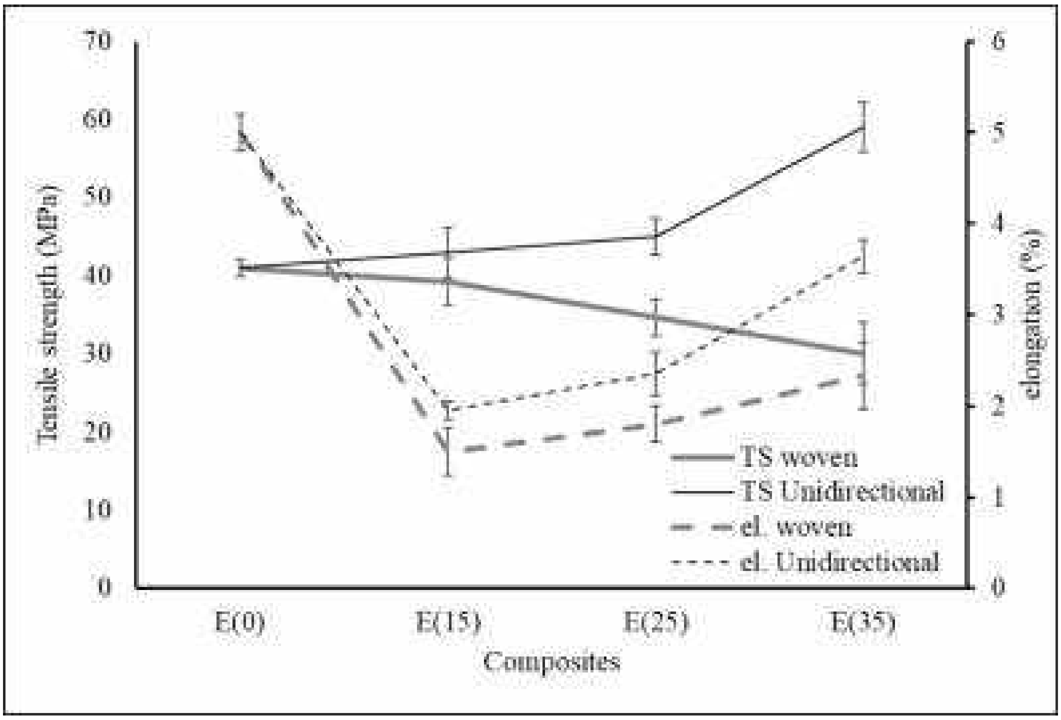


Figure 8. Tensile strength and elongation WH Fibers Reinforced Epoxy-Resin

The single fiber of water hyacinth has a tensile strength of around 105 - 313 MPa [32]. The results of the tensile test show that woven water hyacinth did not provide an effect of increasing strength on uniaxial tensile loads. Furthermore, the increased mass percentage of the WH reinforcing fibers led to increased composite porosity. A larger volume of woven reinforcing fibers leads to an increase in voids [30, 33], due to the pores being trapped causing a void between the matrix and fibers [34]. Voids of composite produce stress concentration on the matrix. For the longitudinal fibers, voids lead to the potential change in stress transfer and redistribution and the cracking of the transverse plies [28]. The voids between fiber and matrix lead to a fiber pull-out fracture as shown in Figure 11a, 11b and 11c.

Composites had an increased tensile strength due to the unidirectional properties of the WH fiber. Additionally, an increase in the percentage weight of these fiber composites also improves tensile strength. This is coherent with the density and porosity test results in Figure 6, which shows that the composites with directional woven fiber exhibited a significant increase in porosity as the fiber percentage weight is increased. The porosity of UD WH fiber composites remained constant as the weight percentage of WH fibers increased. Hence, composites with directional woven fiber increased in % wt. and porosity significantly.

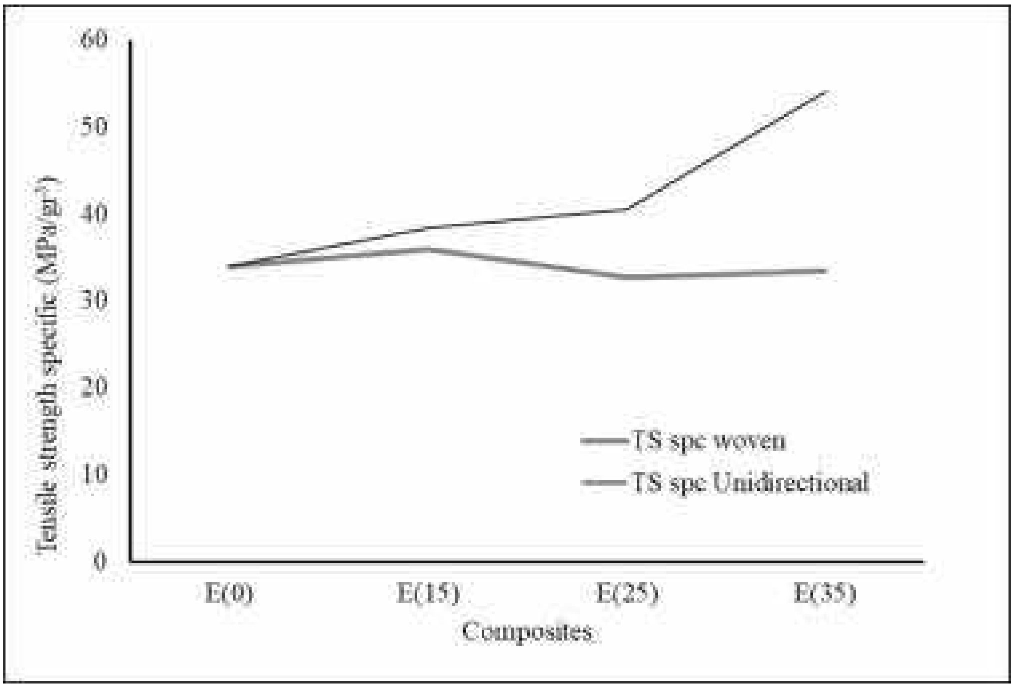


Figure 9. Tensile strength specific of WH Fiber Reinforced with Epoxy-Resin

Figure 10 shows the impact strength of WH fiber reinforced with epoxy-resin. This composite strength was in direct proportion to WH fiber rise of % wt. Furthermore, the interface strength between the woven WH fiber and epoxy - resin matrix contributes to the transfer load from the matrix fiber. This characteristic allows the WH fiber composites to absorb more energy. The fiber flexibility that slides out of the matrix did not break but increased the energy needed to rupture the specimen [35].

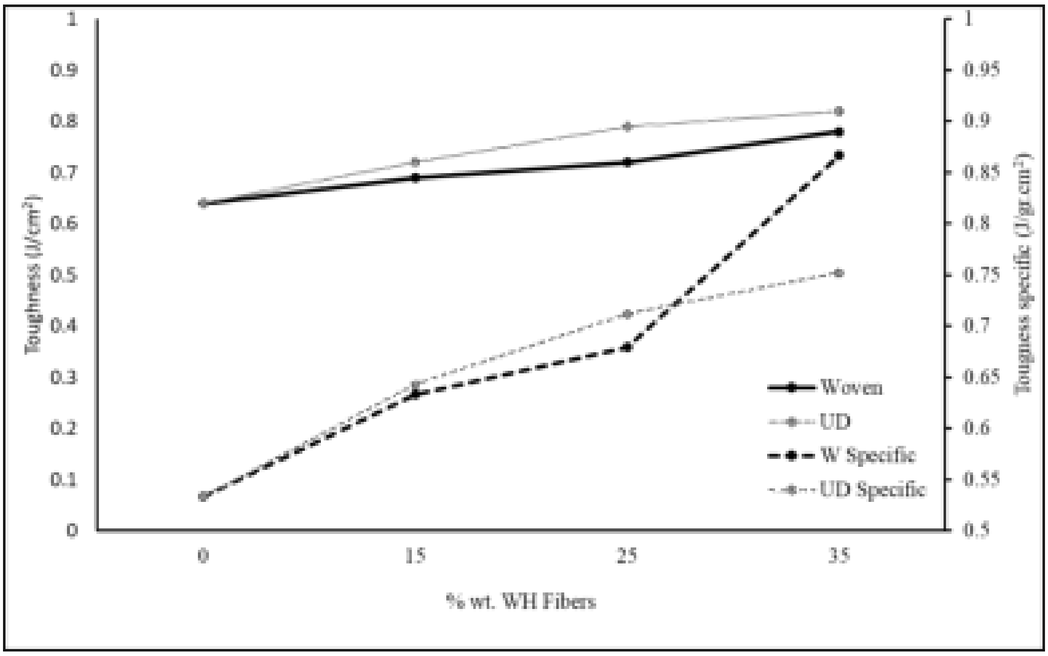
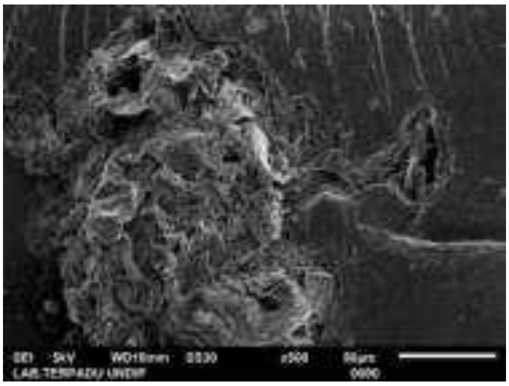
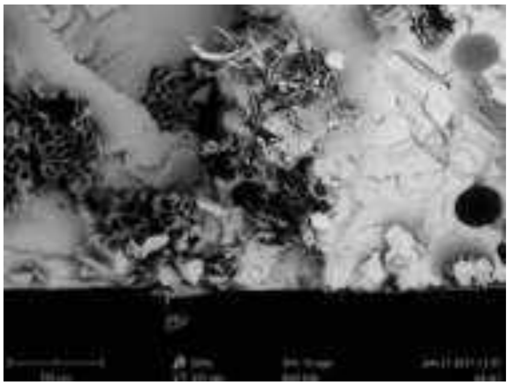


Figure 10. Impact Strength of Composites WH Fibers reinforced Epoxy-Resin



a.



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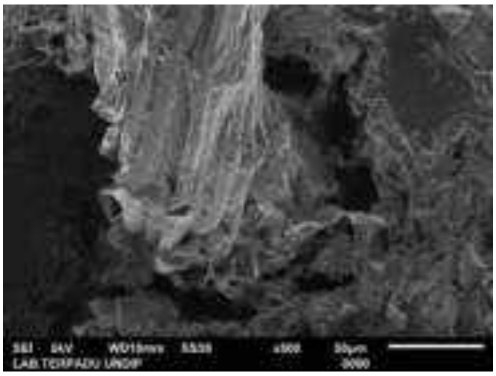
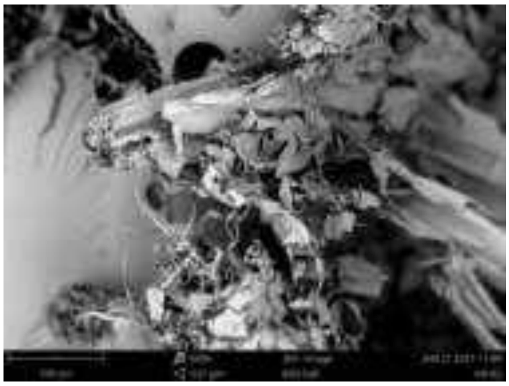


b.



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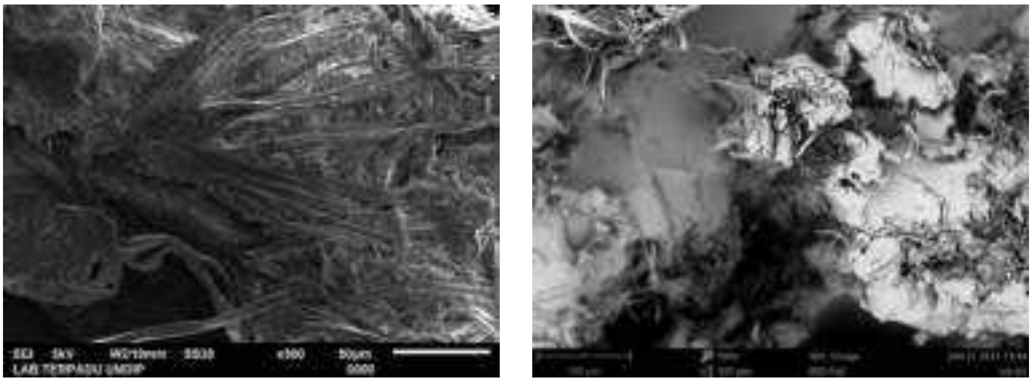

c. f.

Figure 11. SEM Micrograph Surface Fracture of Composites WH Fibers reinforced Epoxy-Resin

Furthermore, the SEM photomicrographs of the fracture surface were used to analyze the WH fiber and matrix adhesion in the composites. The cross-section of these tensile-tested specimens was selected for analysis. Figure 11.a – 11.f shows the fracture surface SEM images of the WH fiber-reinforced epoxy resin composite. Meanwhile, figure 11.a, 11.b and 11.c shows the samples with 15, 25, 35 % of WH woven fiber. Figure 11.d, 11.e and 11.f shows the composite with 15, 25, 35 % of UD WH fiber. From the fractographic examinations by SEM, the fracture behavior of composite was brittle. Some pores, which originated from the fiber pull-out phenomena were found in all cases, while fracture phenomena were also observed in the UD WH fiber. SEM images showed that the WH fiber and epoxy resin were mechanically bound, however, there was no chemical bonding between the WH fiber and epoxy resin. Furthermore, similar natural fiber and polymer adhesion were experimented with and discussed within natural fiber-reinforced plastic composites [36,37]. For this reason, the mechanical properties of UD WH fiber epoxy resin composites had a 60% increase.

CONCLUSION

Increasing the % wt. of the WH woven fibers decreased the tensile strength of the epoxy resin composites. Furthermore, the % wt. of WH woven fibers was in direct proportion to the number of pores or voids between the fibers and matrix which led to a delamination mode fracture. The rise of % wt. of fibers increases the tensile and impact strength of unidirectional WH fibers epoxy resin composite. The utilization of WH fibers obtained an increased effective reinforcement. The impact strength of composites was in direct proportion to the rise of % wt. of WH woven fibers. The mechanical properties of unidirectional WH fiber higher than mechanical properties of woven WH fiber composite.

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Code	Meaning
E(0)	Epoxy – resin, 0 % WH fibers
E(15)	Epoxy – resin, 15 % WH fibers
E(25)	Epoxy – resin, 25 % WH fibers
E(35)	Epoxy – resin, 35 % WH fibers

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Manuscript. Number.: HELIYON-D-22-00395

Title: The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites

Journal: Heliyon

Dear Dr. Sulardjaka,

Thank you for submitting your manuscript to Heliyon. We have completed the review of your manuscript and a summary is appended below. The reviewers recommend major revisions are required before publication can be considered.If you are able to address all reviewer comments in full, I invite you to resubmit your manuscript. We ask that you respond to each reviewer comment by either outlining how the criticism was addressed in the revised manuscript or by providing a rebuttal to the criticism.

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Kind regards,

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Associate Editor - Materials Science

Heliyon

Editor and Reviewer comments:

Reviewer 1: Abstract

1- The results of this study showed that the tested specimens showed an increase in % wt. of fiber content with a reduction in the tensile strength of the WH woven fiber reinforced with epoxy resin composites.
The impact strength of composites was in direct proportion to the %wt. of the WH woven fibers.
- Please describe clearly and straight to point these two results, which loading and what are the optimized results obtained?

2- Please also mention the novelty of this study and the important applications of this study based on the WH use.

Methodology
3- The methodology is not clear. The authors should mention the studied wt.% of WH in the abstract and in the preparation of composites, rather than in the characterization of composites (Table 1).

4- I am not sure if this is correct to use different standards to analyse the composites sample. As mentioned by the authors: the pure polymer was analysed using ASTM D 638, while the composites was analysed using ASTM D 3039. Please revise if needed. I think that the authors just need to revise the sentence rather than planning to make a new sample as per revised standard.

5- Different standard would give different interpretation for material itself. It is not comparable.

6- As a researcher in materials, authors must concern on the used standard. ASTMD 638 is for thermoplastic. Is it logic for the authors to cut the brittle epoxy based on that shape ? Unless you have the curved ASTM D 638 mould. Please advise me, if I missed something.

7- Delete Figure 4 (a)

Results
8- Where are the tensile modulus results ?.

9- Authors need to discuss more details and explain the effect of UD and woven fibre composites, rather than just focus on porosity only.

10- The results on UD and woven shows significant differences on tensile and impact properties: instead of using woven reinforcement better use UD, less time and cost to weave the fibre. Please discuss also.

11- The impact energy relates to energy absorption. The authors have mentioned in line 53. I thought that woven would present higher impact energy than UD. But it needs to be discussed further.

Conclusions
12- Please mention the significance or novelty of this study.

Reviewer 2: Paper cannot give new results and information.
It is not reasonable the slightly decreasing in tensile strength at 15wt.% of fiber addition in Fig 8.
Some results from Fig.5 are missing in the paper.
Discussions on the results seem poor and shoud be extended.

*****

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Reviewer 1:

Abstract

1. The results of this study showed that the tested specimens showed an increase in % wt. of fiber content with a reduction in the tensile strength of the WH woven fiber reinforced with epoxy resin composites.
   The impact strength of composites was in direct proportion to the %wt. of the WH woven fibers.
   Please describe clearly and straight to point these two results, which loading and what are the optimized results obtained?
   Answer:
   Thank you very much for your suggestion. We agree with your suggestion. We have improved the abstract. (Write by blue ink)

2. Please also mention the novelty of this study and the important applications of this study based on the WH use.
   Answer:
   Thank you very much for your suggestion. We agree with your suggestion. We have improved the abstract. (Write by blue ink)

Methodology

3. The methodology is not clear. The authors should mention the studied wt.% of WH in the abstract and in the preparation of composites, rather than in the characterization of composites (Table 1).
   Answer:
   Thank you very much for your suggestion. We agree with your suggestion. We have improved the abstract and methodology. (Write by blue ink)

4. I am not sure if this is correct to use different standards to analyse the composites sample. As mentioned by the authors: the pure polymer was analysed using ASTM D 638, while the composites was analysed using ASTM D 3039. Please revise if needed. I think that the authors just need to revise the sentence rather than planning to make a new sample as per revised standard.
   Answer:
   Thank you very much for your suggestion. We agree with your suggestion. We have corrected the methodology. (Write by blue ink)

5. Different standard would give different interpretation for material itself. It is not comparable.
   Answer:
   Thank you very much for your suggestion. We agree with your suggestion. We have corrected the methodology. (Write by blue ink)

6. As a researcher in materials, authors must concern on the used standard. ASTMD 638 is for thermoplastic. Is it logic for the authors to cut the brittle epoxy based on that shape ? Unless you have the curved ASTM D 638 mould. Please advise me, if I missed something.
   Answer:
   Thank you very much for your suggestion. In this research is ASTM D 638 specimens were manufactured used specimen mould. The specimen prepared without cutting the epoxy resin.

7. Delete Figure 4 (a)
   <u>Answer:</u>
   Thank you very much for your suggestion. Figure 4 (a) was deleted.

Results

8. Where are the tensile modulus results ?
   <u>Answer:</u>
   We don't show the tensile modulus results because our extensometer is broken, we didn't measure elastic elongation using extensometer. In my opinion, calculated tensile modulus based on stress and strain curve does not produce accurate tensile modulus values.

9. Authors need to discuss more details and explain the effect of UD and woven fibre composites, rather than just focus on porosity only.
   <u>Answer:</u>
   Thank you very much for your suggestion. We added more details the effect of UD and woven fiber composite in the discussion. (Write in blue ink)

10. The results on UD and woven shows significant differences on tensile and impact properties: instead of using woven reinforcement better use UD, less time and cost to weave the fibre. Please discuss also.
    <u>Answer:</u>
    Thank you very much for your suggestion. In this study, composites with WH woven fiber reinforcement produced high porosity, this resulted in low mechanical properties. Composites with woven fiber reinforcement will provide better mechanical properties, when subjected to a 2-axis load. However, in this study, mechanical characterization has not been carried out when the composite is loaded off the axis.

11. The impact energy relates to energy absorption. The authors have mentioned in line 53. I thought that woven would present higher impact energy than UD. But it needs to be discussed further.
    <u>Answer:</u>
    Thank you very much for your suggestion. We agree with your suggestion. We have corrected the discution of impact test result. (Write in blue ink)

Conclusions

12. Please mention the significance or novelty of this study.
    <u>Answer:</u>
    Thank you very much for your suggestion. We agree with your suggestion. We have improved conclusion to mention the significance or novelty of this study of impact test result. (Write in blue ink)

Reviewer 2:

Paper cannot give new results and information.

It is not reasonable the slightly decreasing in tensile strength at 15wt.% of fiber addition in Fig 8.

Some results from Fig.5 are missing in the paper.

Discussions on the results seem poor and shoud be extended.

Answer:

Thank you very much for your suggestion.

1. The purpose of this research is to investigate at the mechanical (tensille and impact) and physical (density) properties of unidirectional WH and woven fiber reinforced epoxy resin composites in variation of wt. of WH fibers. Previous researches on the use of water hyacinth fiber as reinforcement composite still uses WH in the form of stem, stem chopped, sawdust, and powder. We have not found research has been found that uses water hyacinth in the form of fiber or woven fibers.
2. The tensile strength of water hyacinth fiber about 105 MPa, the presence of porosity causes the tensile strength of the composite reinforced with water hyacinth fiber to decrease. In woven fiber, the mass fraction of the fiber in the direction of the load is less than in UD fiber. Fiber strength is not sufficient to compensate for the decrease in strength due to porosity.
3. Figure. 5 is corrected.
4. We improve the discussions on the results

The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites

ABSTRACT

The high growth of Water Hyacinth/*Eichhornia crassipes* (WH) led to several problems such as ecosystem, irrigation, and sedimentation. The rapid growth of water hyacinth in natural rivers, reservoir, lake and canals causes drainage problems in many nations. As a result, local offices must spend significant annual budgets to dispose of water hyacinth wastes. Meanwhile, cellulose fiber from WH had a potential application in natural fiber composite (NFC). This study investigated the development and use of water hyacinth wastes for the production of unidirectional dan weaved fiber epoxy resin composites. The purpose of this research is to investigate at the mechanical and physical properties of unidirectional WH and woven fiber reinforced epoxy resin composites in variation of 0 % wt., 15 % wt., 25 % wt. and 35 % wt. of WH fibers. The WH fiber was obtained from a mechanically processed WH plants. The composites were manufactured through the hand lay-up method. The tensile and impact tests were carried out based on ASTM D3039 and ASTM D6110 respectively, while the density of composites was tested based on the Archimedes rule. The results of this study showed that increasing of % wt. of the WH woven fiber, the tensile strength of composite decrease. The impact strength of composites increases by the rise of % wt. of the WH woven fibers. The % wt. of WH woven fibers was in direct proportion to the amount of pore or void between the fibers and matrix, which led to a delamination mode fracture. Tensile and impact strength of unidirectional WH fiber increase by increasing the % wt. of WH fibers.

Keywords: Composite, Epoxy-resin, Water Hyacinth, Woven fiber, Unidirectional fiber.

1. INTRODUCTION

Natural fibers are a useful class of materials that are environmentally clean, renewable, and biodegradable resources. They are also used in manufacturing natural fiber composites with advantages which include low impact on the environment, renewability, inexpensive and easily degraded [1-4]. However, the use of natural fibers as a reinforcement of composites is still experiencing several problems such as, low mechanical properties, hydrophilic properties, limited processing temperatures, low matrix and fiber binding forces that are easily degraded [5,6]. Furthermore, studies on the development of natural fiber properties were carried out by pretreating or engineering the manufacturing method [7,8].

Water hyacinth (Eichhornia crassipes) is a type of aquatic plant that floats on the surface of the water. It grows aggressively and was a nuisance on almost all continents for more than 100 years. Furthermore, its high population growth led to several problems related to ecosystem balance, decreased fish production, loss of endemic organisms and sedimentation [9-11]. Numerous studies were carried out to utilize water hyacinth plants as absorbers of heavy metals, absorbing dye waste, biofuel and biogas production, composite catalyst and reinforcing composites [12-19].

Based on previous studies, the problem associated with the utilization of WH materials for composite reinforcement includes, low mechanical strength, ease of water absorption leading to a reduced fiber bond with the matrix and weak compatibility of the WH fiber with the polymer matrix [20-22]. The results of this study show that for these composites, the mechanical properties were relatively low. Although the use of WH fiber as composite reinforcement still requires further studies, it has several advantages which include, increased acoustic, damping ability and good thermal resistance [23].

Previous researches on the use of water hyacinth fiber as reinforcement composite still uses WH in the form of stem, stem chopped, sawdust, and powder [22, 24-26]. No research has been found that uses water hyacinth in the form of fiber or woven fibers. The use of natural fiber as a composite reinforcement, the shape of the reinforcement affects the mechanical properties of composite. This research uses water hyacinth in the form of fibers, either unidirectional or woven fibers. WH fiber can be obtained by extracting WH stem. The WH plant extraction process affected the mechanical properties of the fiber composite. This process aims to separate plant fibers from the wax, pectin, hemicellulose and lignin layers. Also, there were several methods used to extract plant fibers from the parent plant, namely: immersion, chemical methods or mechanical methods [27]. Therefore, this study aims to investigate the mechanical and physical properties of composites reinforced with unidirectional and woven WH fibers.

2. MATERIALS AND METHODS

2.1. Materials

The water hyacinth plants used, were obtained from swamps in Tanggul Village, Mijen District, Demak Regency, Central Java, Indonesia with 50-70 cm length of stems. These plants were mechanically extracted to yield the WF fibers (Figure 1). The fiber extraction was carried out by brushing the WH stems using an iron brush. The fiber is then dried in the sun. After that, 10 strands of the dry WH fibers were twisted to produce yarn (Figure 2), which were weaved with a yarn direction of 0/90° to produce the WH woven with dimensions of 30 x 40 cm (Figure 3). The natural composite was manufactured using epoxy Bakelite® EPR 174 and resin hardener V-140 as a matrix.

2.2. Preparation of Composites

The hand lay-up method was used to fabricate the unidirectional WH fiber composite and woven WH composites. This was conducted by applying an epoxy-resin matrix to the WH fibers in the mold specimens with dimension of 30 x 40 cm using a paintbrush and roller. The composite tensile and impact test specimens were manufactured in variations of the WH fiber reinforcement of 0%, 15 %, 25 % and 35 % wt. The coding of these specimens is shown in Table 1.

Table 1. Specimens testing code

Code	Meaning
E(0)	Epoxy – resin, 0 % WH fibers
E(15)	Epoxy – resin, 15 % WH fibers
E(25)	Epoxy – resin, 25 % WH fibers
E(35)	Epoxy – resin, 35 % WH fibers

Afterward, the composites were compressed and vacuumed to remove voids and obtain a smoothen surface. After removing the produced composite specimen from the mold, specimens of appropriate dimensions were made in accordance with ASTM D3039 requirements. Water jet cutting technique is used for cutting the test specimen as per the required shape. The test specimen having dimension of length 250 mm, width of 25 mm and thickness of 3 mm were prepared for tensile testing.

Figure 1. Water Hyacinth Fibers

Figure 2. Water Hyacinth Yarn

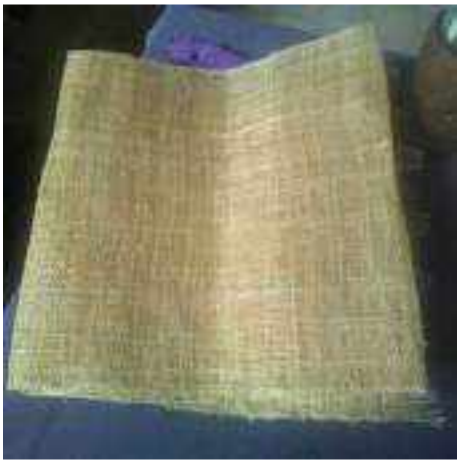


Figure 3. Water Hyacinth Woven Yarn

2.3. Characterization of Composites

The actual density of composites was measured using a densimeter based on Archimedes law according to ASTM B311. The theoretical density was calculated based on rules and mixture, while the porosity of the composites was calculated based on the actual and theoretical densities. The tensile test of composites was carried out according to the ASTM D3039 standard (Figure 4). Furthermore, the impact tests were carried out through the Charpy methods according to the ASTM D6110 standard. Figure 5 shows the dimensions of the impact test specimens. Six identical test specimens were prepared for tensile and impact test to ensure the uniformity of the test. Scanning Electron Microscopy (SEM) was used to investigate the tensile test fracture surface of the composite.

Figure 4. Dimension of Tensile Test Specimen

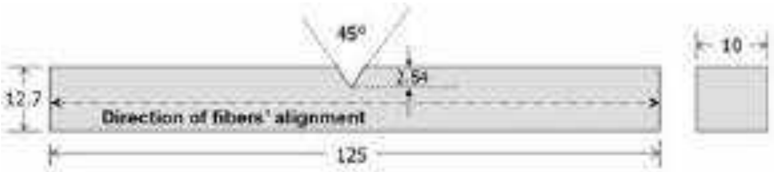


Figure 5. Dimension of Impact Test Specimen of Composite

3. RESULTS AND DISCUSSIONS

The density and porosity test results in Figure 6, shows that both the unidirectional and woven composites increased in mass fraction, while 0, 15, 25 and 35 % wt. increase in the porosity of the composites was observed. Furthermore, figure 6 also shows that for the woven fiber composite, there was an increase in porosity almost linearly from 0.35% to 13.82% with the addition of 35% fiber. The unidirectional WH fiber composite, increased from 15 % to 35 % wt., afterwards, the porosity did not increase significantly. Composites woven fibers also provided more voids than composites UD fibers. For woven fibers, the voids form inside tows, in resin-rich regions or at tow corners, and between plies in composites. Meanwhile, for UD fibers, the voids form within and between the plies [28, 29]. The difference in the direction of the fibers for the composites woven fiber leads to air entrapment and increased porosity. The main source of air entrapment is the inhomogeneous fiber architecture, which leads to a non-uniform fiber permeability carried out with subsequent local variations in resin velocity [30].

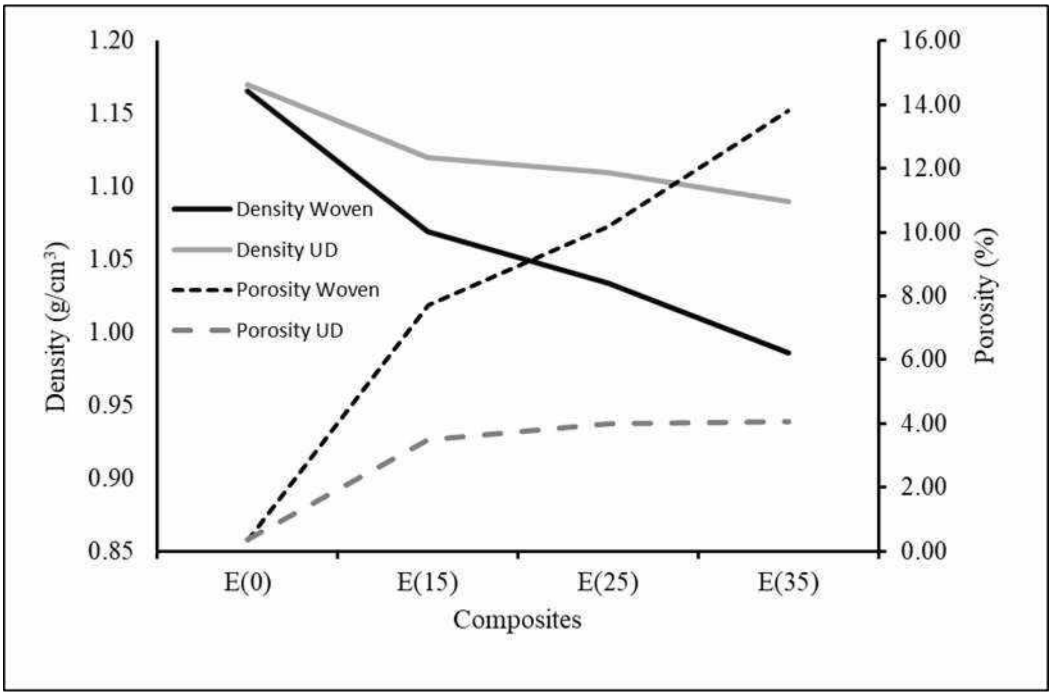


Figure 6. Density and Porosity of WH fibers Composites

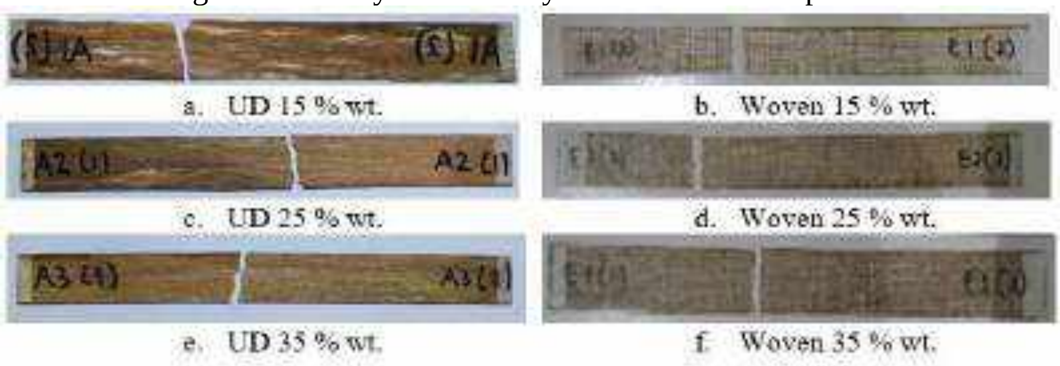


Figure 7. Photo of Tested specimens

Figure 7 shows the specimen after it was tensile tested, with fracture in the gauge length area. Figure 8 shows the tensile test results of the woven and unidirectional WH fiber composites reinforced with epoxy resin. The tensile strength of the woven WH fiber composite was in inverse proportion to the percentage of WH fibers in the composite. An increased fiber mass fraction from 0 to 15%, led to an insignificant decrease in the tensile strength of the composite. Furthermore, with a 35% addition, for every 10% increase in fiber mass fraction, the tensile strength of the composite decreases by about 11-13%. Composite elongation also decreased with the increase in % wt. of WH woven fibers, which also showed that its tensile strength was in direct proportion to the percentage weight of the WH fiber. This tensile strength increased by approximately 10% as the % wt. of WH fibers increased from 15% to 25%. For addition of 35% wt. of WH fiber, the tensile strength of composites increased by about 37%. Compared to the tensile strength of epoxy resin, the composite tensile strength of 35 % wt. for unidirectional WH fiber increased from 41 MPa to 60 MPa or by about 46 %. Furthermore, the lowest composite tensile strength for WH fibers in this study was 30 MPa for woven WH fibers composites containing 35% wt. This result was higher than that of Saputra et al., which discovered that the highest tensile strength was 28.36 MPa [31]. Figure 9 shows the specific tensile strength of composites, which shows that there were no significant differences in the tensile strengths of WH woven fibers composites. Furthermore, reinforcement by WH fibers compensates for the decreasing tensile strength of the composite from porosity. The UD WH fiber composites of 35 % wt., increases in specific tensile strength by about 60 %, which means that, it is in direct proportion with the specific tensile strength of composites.

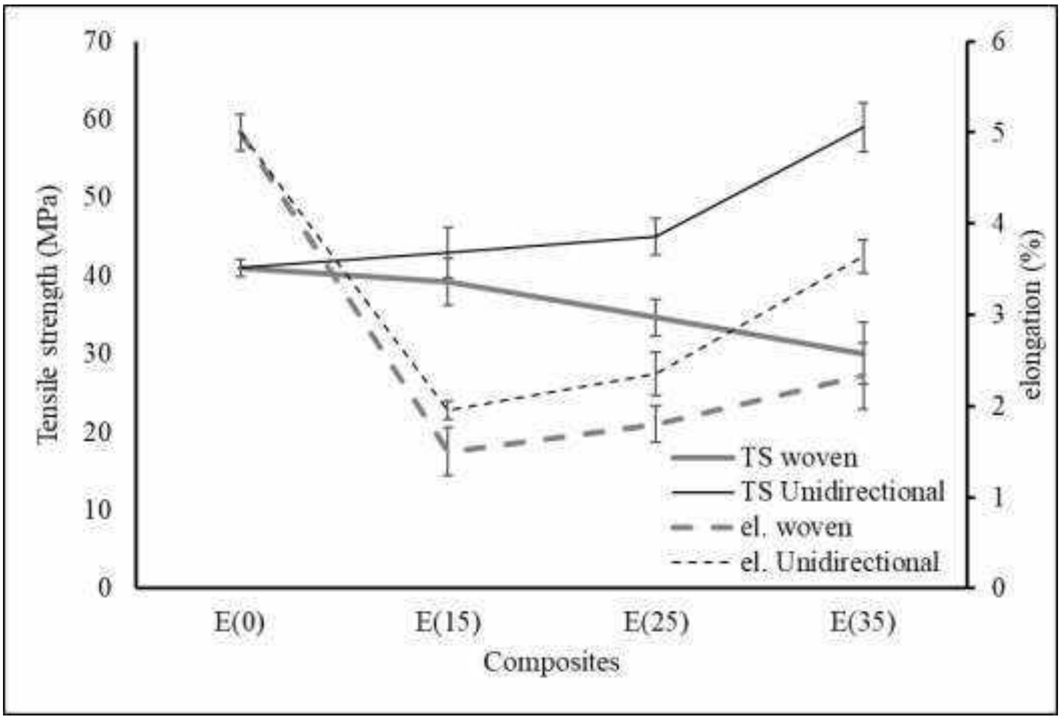


Figure 8. Tensile strength and elongation WH Fibers Reinforced Epoxy-Resin

The single fiber of water hyacinth has a tensile strength of around 105 - 313 MPa [32]. The results of the tensile test show that woven water hyacinth did not provide an effect of increasing strength on uniaxial tensile loads. Furthermore, the increased mass percentage of the WH reinforcing fibers led to increased composite porosity. A larger volume of woven reinforcing fibers leads to an increase in voids [30, 33], due to the pores being trapped causing a void between the matrix and fibers

[34]. Voids of composite produce stress concentration on the matrix. For the longitudinal fibers, voids lead to the potential change in stress transfer and redistribution and the cracking of the transverse plies [28]. The voids between fiber and matrix lead to a fiber pull-out fracture as shown in Figure 11a, 11b and 11c.

Composites had an increased tensile strength due to the unidirectional properties of the WH fiber. The unidirectional fiber has a higher percentage of fiber in the direction of tensile load than woven fiber. Based rule of mixture theory, higher % wt. of fiber on axis direction of load yields higher values of tensile strength than the combination of axial and transversal fiber direction in woven fiber. Additionally, an increase in the percentage weight of these fiber composites also improves tensile strength. This is coherent with the density and porosity test results in Figure 6, which shows that the composites with directional woven fiber exhibited a significant increase in porosity as the fiber percentage weight is increased. The porosity of UD WH fiber composites remained constant as the weight percentage of WH fibers increased. Hence, composites with directional woven fiber increased in % wt. and porosity significantly.

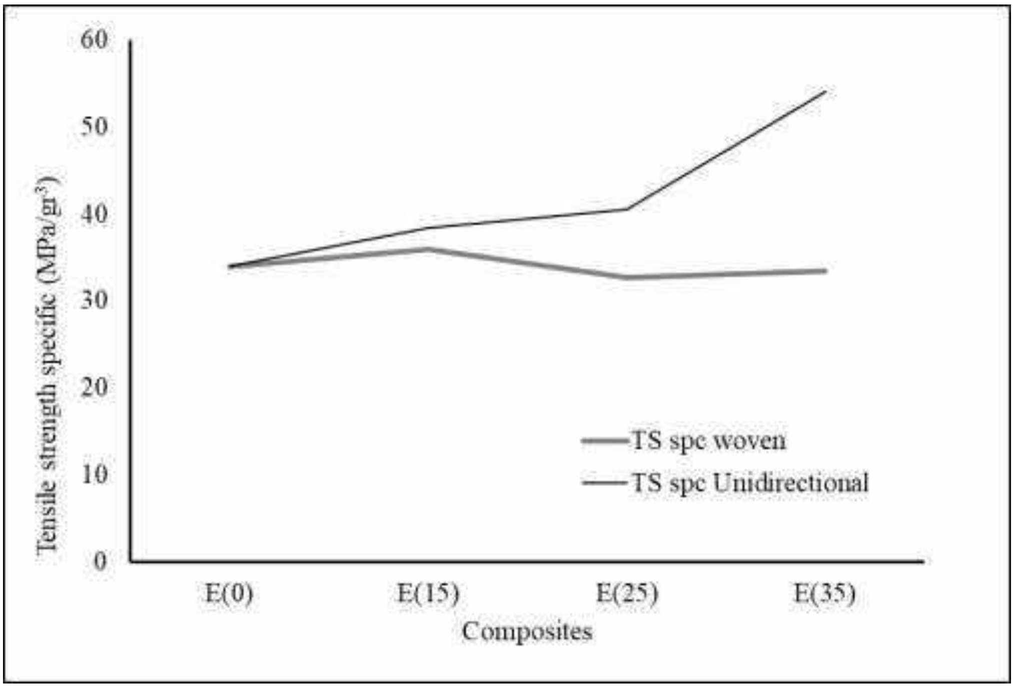


Figure 9. Tensile strength specific of WH Fiber Reinforced with Epoxy-Resin

Figure 10 shows the impact strength of WH fiber reinforced with epoxy-resin. This composite strength was in direct proportion to WH fiber rise of % wt. Increasing of % wt. of UD fiber from 0 % to 35 % wt., increase the impact strength of composite about 28 %. The impact strength of woven fiber composite increases about 22 % when the % wt. of fiber increase from 0 % to 35 % wt. The highest impact strength is about 0.82 kJ/cm^2 at the UD fiber composite with 35 % wt. of fiber. Figure 10 also shows specifics impact strength of composite. Graph in Figure 10 shown that specific impact strength of composite with 35 % wt. woven WH fiber higher than specific impact strength of 35 % wt. of UD composite. The porosity on woven composite produced lighter composite than UD composite. Woven WH fibers increase the impact strength of the composite and produce a tougher composite. Woven WH fibers have good ability to absorb large share kinetic energy so fibers role should be crack stopper [35]. The UD composite fibers break at the impact axis and the failure of the woven specimen is caused by shear stress [36]. The increase in composite impact strength is due to the interface strength between the woven WH fiber and epoxy - resin matrix contributes to the transfer load from the matrix fiber. This characteristic allows the WH fiber composites to absorb more energy. The fiber flexibility that slides out of the matrix did not break but increased the energy needed to rupture the specimen [37].

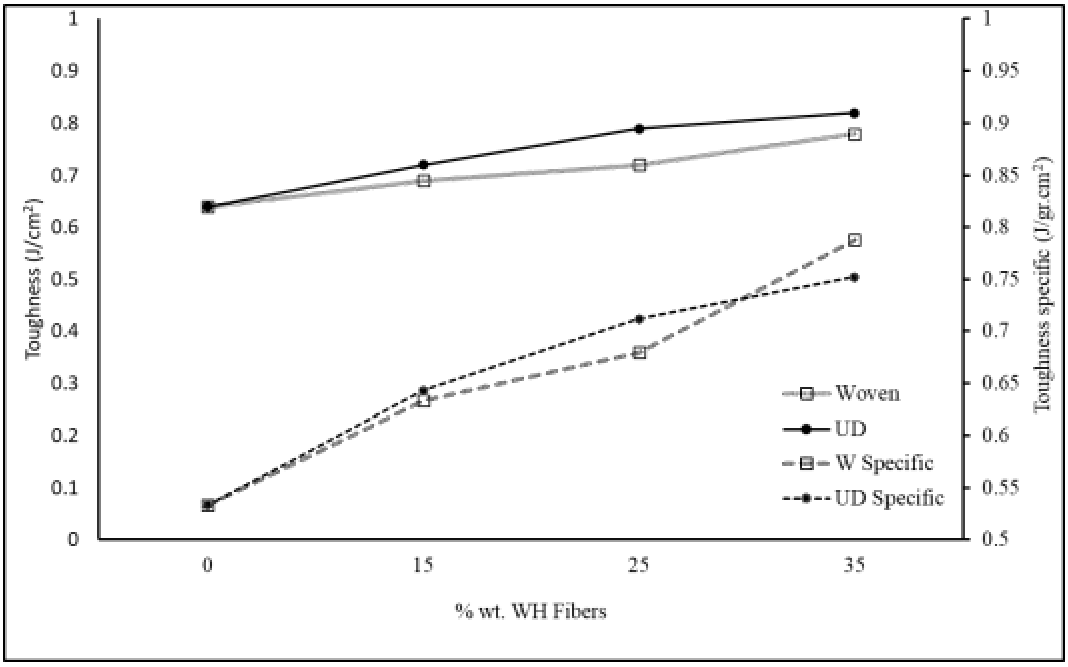
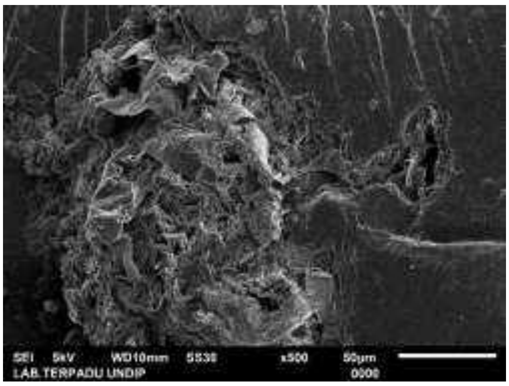


Figure 10. Impact Strength of Composites WH Fibers reinforced Epoxy-Resin



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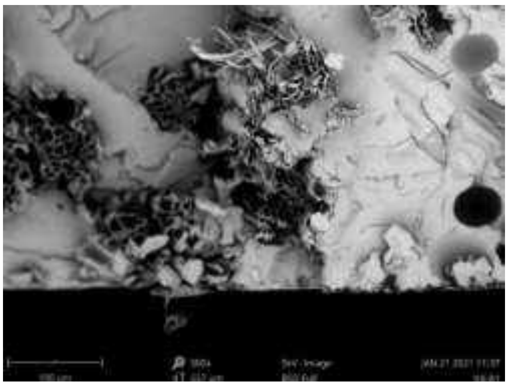

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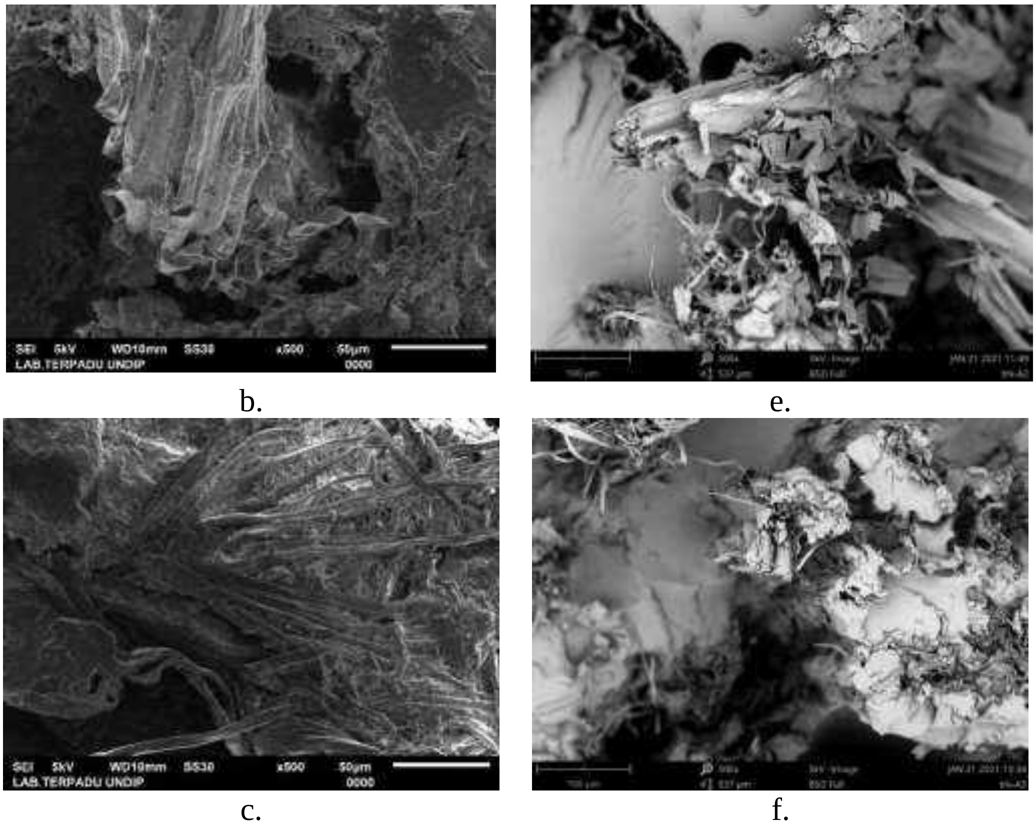

Figure 11. SEM Micrograph Surface Fracture of Composites WH Fibers reinforced Epoxy-Resin

Furthermore, the SEM photomicrographs of the fracture surface were used to analyze the WH fiber and matrix adhesion in the composites. The cross-section of these tensile-tested specimens was selected for analysis. Figure 11.a – 11.f shows the fracture surface SEM images of the WH fiber-reinforced epoxy resin composite. Meanwhile, figure 11.a, 11.b and 11.c shows the samples with 15, 25, 35 % of WH woven fiber. Figure 11.d, 11.e and 11.f shows the composite with 15, 25, 35 % of UD WH fiber. From the fractographic examinations by SEM, the fracture behavior of composite was brittle. Some pores, which originated from the fiber pull-out phenomena were found in all cases, while fracture phenomena were also observed in the UD WH fiber. SEM images showed that the WH fiber and epoxy resin were mechanically bound, however, there was no chemical bonding between the WH fiber and epoxy resin. Furthermore, similar natural fiber and polymer adhesion were experimented with and discussed within natural fiber-reinforced plastic composites [38,39]. For this reason, the mechanical properties of UD WH fiber epoxy resin composites had a 60% increase.

CONCLUSION

Previous researches that used water hyacinth fiber as a composite reinforcement in the form of stem, stem chopped, sawdust, and powder produced mechanical properties under the tensile strength of the matrix material. The use of UD WH fiber as reinforcement results in an increasing of strength of composite. The lowest tensile strength produced in this research is also higher than the highest tensile strength produced by previous researchers. Increasing the % wt. of the WH woven fibers decreased the tensile strength of the epoxy resin composites. Furthermore, the % wt. of WH woven fibers was in direct proportion to the number of pores or voids between the fibers and matrix which led to a delamination mode fracture. The rise of % wt. of fibers increases the tensile and impact strength of unidirectional WH fibers epoxy resin composite. The utilization of WH fibers obtained an increased effective reinforcement. The impact strength of composites was in direct proportion to the rise of % wt. of WH woven fibers. The mechanical properties of unidirectional WH fiber higher than mechanical properties of woven WH fiber composite.

ACKNOWLEDGMENT
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The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites

Dear Dr. Sulardjaka,

We have received the above referenced manuscript you submitted to the Materials Science section of Heliyon. To track the status of your manuscript, please log in as an author at https://www.editorialmanager.com/heliyon/, and navigate to the "Revisions Being Processed" folder.

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Title: The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites
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Dear Dr. Sulardjaka,

We have now received all of the reviewers' comments on your recent submission to Heliyon.

The reviewers have advised that your manuscript should become suitable for publication in our journal after appropriate revisions.

If you are able to address the reviewers' comments, which you can find below, I would like to invite you to revise and resubmit your manuscript. We ask that you respond to each reviewer comment by either outlining how the criticism was addressed in the revised manuscript or by providing a rebuttal to the criticism. This should be carried out in a point-by-point fashion as illustrated here: https://www.cell.com/heliyon/guide-for-authors#Revisions

To allow the editors and reviewers to easily assess your revised manuscript, we also ask that you upload a version of your manuscript highlighting any revisions made. You may wish to use Microsoft Word's Track Changes tool or, for LaTeX files, the latexdiff Perl script (https://ctan.org/pkg/latexdiff).

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We understand that the COVID-19 pandemic may well be causing disruption for you and your colleagues. If that is the case for you and it has an impact on your ability to make revisions to address the concerns that came up in the review process, please reach out to us.

I look forward to receiving your revised manuscript.

Kind regards,

Kevin Yu
Editorial Section Manager
Heliyon

Editor and Reviewer comments:

The authors should complete their manuscript by answering the remarks of reviewer 3. In principle, this can be easily done.

Reviewer 1: Authors have improved the manuscript accordingly to my comments and suggestions. Satisfied.

Reviewer 3: Methods:
1. The water hyacinth fibers were twisted to yarn and weaved to bidirectional mat. Were those made by hand in laboratory? Was there any associated machine or tool used? If it was, please describe it.
2. What was the method to identify the porosity in the composites?

Results:
1. The "tensile strength specific" used might be "specific tensile strength"?
2. The woven fiber composites resulted in lower strength. This was addressed to be caused by the high porosity. Will that be due to the incomplete infiltration of resin in the hand lay-up process?

*****

Heliyon

The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites

--Manuscript Draft--

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Abstract:	The high growth of Water Hyacinth/ Eichhornia crassipes (WH) led to several problems such as ecosystem, irrigation, and sedimentation. The rapid growth of water hyacinth in natural rivers, reservoir, lake and canals causes drainage problems in many nations. As a result, local offices must spend significant annual budgets to dispose of water hyacinth wastes. Meanwhile, cellulose fiber from WH had a potential application in natural fiber composite (NFC). This study investigated the development and use of water hyacinth wastes for the production of unidirectional dan weaved fiber epoxy resin composites. The purpose of this research is to investigate at the mechanical and physical properties of unidirectional WH and woven fiber reinforced epoxy resin composites in variation of 0 % wt., 15 % wt., 25 % wt. and 35 % wt. of WH fibers. The WH fiber was obtained from a mechanically processed WH plants. The composites were manufactured through the hand lay-up method. The tensile and impact tests were carried out based on ASTM D3039 and ASTM D6110 respectively, while the density of composites was tested based on the Archimedes rule. The results of this study showed that increasing of % wt. of the WH woven fiber, the tensile strength of composite decrease. The impact strength of composites increases by the rise of % wt. of the WH woven fibers. The % wt. of WH woven fibers was in direct proportion to the amount of pore or void between the fibers and matrix, which led to a delamination mode fracture. Tensile and impact strength of unidirectional WH fiber increase by increasing the % wt. of WH fibers.
Opposed Reviewers:	

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August 3rd, 2022
Kevin Yu
Editorial Section Manager
Heliyon

Dear Kevin Yu

Enclosed, please find the 2nd revised manuscript of manucript entitled: "*The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites*," submitted for publication in Heliyon. The authors are S. Sulardjaka, N. Iskandar, Sri Nugroho, A. Alamsyah, M. Y. Prasetya.

Kind regards,

S. Sulardjaka

Reviewer 3:

Methods:

1. The water hyacinth fibers were twisted to yarn and weaved to bidirectional mat. Were those made by hand in laboratory? Was there any associated machine or tool used? If it was, please describe it.

   Answer:

   Thank you very much. The water hyacinth yarns were made using traditional yarn spinner tool by yarn craftsman. The water hyacinth yarns mat was made using loom. The weaving process is carried out by traditional cloth craftsmen.

   We have added this description inside the methods (written in blue ink)

2. What was the method to identify the porosity in the composites?

   Answer:

   According to ASTM D2734 the porosity can be obtained by the relative difference between theoretical density of composite (ρ_{th}) and measured density of composite (ρ_m). The density of composite (ρ_m) can be measured through water buoyancy by Archimedes Principle (ASTM D792). This leads to the following equation for calculation of the porosity content:

   $$porosity = 100 - \rho_m \left(\frac{W_r}{\rho_r} + \frac{W_f}{\rho_f} \right)$$

   where W and ρ represent the weight percentage and the density, and subscripts *r* and *f* stand for resin and fiber, respectively.

   We have added the description into the methods (written in blue ink).

Results:

1. The "tensile strength specific" used might be "specific tensile strength"?

   Answer:

   Thank you very much for your suggestion. We agree with your suggestion. We have corrected the "tensile strength specific" with "specific tensile strength"

2. The woven fiber composites resulted in lower strength. This was addressed to be caused by the high porosity. Will that be due to the incomplete infiltration of resin in the hand lay-up process?

   Answer:

   Thank you very much for your suggestion. We agree with your suggestion. We have added that analysis to our discussion (written in blue ink).

The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites

ABSTRACT

The high growth of Water Hyacinth/*Eichhornia crassipes* (WH) led to several problems such as ecosystem, irrigation, and sedimentation. The rapid growth of water hyacinth in natural rivers, reservoir, lake and canals causes drainage problems in many nations. As a result, local offices must spend significant annual budgets to dispose of water hyacinth wastes. Meanwhile, cellulose fiber from WH had a potential application in natural fiber composite (NFC). This study investigated the development and use of water hyacinth wastes for the production of unidirectional dan weaved fiber epoxy resin composites. The purpose of this research is to investigate at the mechanical and physical properties of unidirectional WH and woven fiber reinforced epoxy resin composites in variation of 0 % wt., 15 % wt., 25 % wt. and 35 % wt. of WH fibers. The WH fiber was obtained from a mechanically processed WH plants. The composites were manufactured through the hand lay-up method. The tensile and impact tests were carried out based on ASTM D3039 and ASTM D6110 respectively, while the density of composites was tested based on the Archimedes rule. The results of this study showed that increasing of % wt. of the WH woven fiber, the tensile strength of composite decrease. The impact strength of composites increases by the rise of % wt. of the WH woven fibers. The % wt. of WH woven fibers was in direct proportion to the amount of pore or void between the fibers and matrix, which led to a delamination mode fracture. Tensile and impact strength of unidirectional WH fiber increase by increasing the % wt. of WH fibers.

Keywords: Composite, Epoxy-resin, Water Hyacinth, Woven fiber, Unidirectional fiber.

1. INTRODUCTION

Natural fibers are a useful class of materials that are environmentally clean, renewable, and biodegradable resources. They are also used in manufacturing natural fiber composites with advantages which include low impact on the environment, renewability, inexpensive and easily degraded [1-4]. However, the use of natural fibers as a reinforcement of composites is still experiencing several problems such as, low mechanical properties, hydrophilic properties, limited processing temperatures, low matrix and fiber binding forces that are easily degraded [5,6]. Furthermore, studies on the development of natural fiber properties were carried out by pretreating or engineering the manufacturing method [7,8].

Water hyacinth (Eichhornia crassipes) is a type of aquatic plant that floats on the surface of the water. It grows aggressively and was a nuisance on almost all continents for more than 100 years. Furthermore, its high population growth led to several problems related to ecosystem balance, decreased fish production, loss of endemic organisms and sedimentation [9-11]. Numerous studies were carried out to utilize water hyacinth plants as absorbers of heavy metals, absorbing dye waste, biofuel and biogas production, composite catalyst and reinforcing composites [12-19].

Based on previous studies, the problem associated with the utilization of WH materials for composite reinforcement includes, low mechanical strength, ease of water absorption leading to a reduced fiber bond with the matrix and weak compatibility of the WH fiber with the polymer matrix [20-22]. The results of this study show that for these composites, the mechanical properties were relatively low. Although the use of WH fiber as composite reinforcement still requires further studies, it has several advantages which include, increased acoustic, damping ability and good thermal resistance [23].

Previous researchers on the use of water hyacinth fiber as reinforcement composite still uses WH in the form of stem, stem chopped, sawdust, and powder [22, 24-26]. No research has been found that uses water hyacinth in the form of fiber or woven fibers. The use of natural fiber as a composite reinforcement, the shape of the reinforcement affects the mechanical properties of composite. This research uses water hyacinth in the form of fibers, either unidirectional or woven fibers. WH fiber can be obtained by extracting WH stem. The WH plant extraction process affected the mechanical properties of the fiber composite. This process aims to separate plant fibers from the wax, pectin, hemicellulose and lignin layers. Also, there were several methods used to extract plant fibers from the parent plant, namely: immersion, chemical methods or mechanical methods [27]. Therefore, this study aims to investigate the mechanical and physical properties of composites reinforced with unidirectional and woven WH fibers.

2. MATERIALS AND METHODS

2.1. Materials

The water hyacinth plants used, were obtained from swamps in Tanggul Village, Mijen District, Demak Regency, Central Java, Indonesia with 50-70 cm length of stems. These plants were mechanically extracted to yield the WF fibers (Figure 1). The fiber extraction was carried out by brushing the WH stems using an iron brush. The fiber is then dried in the sun. After that, 10 strands of the dry WH fibers were twisted to produce yarn (Figure 2). The water hyacinth yarns were prepared by yarn craftsmen using a traditional yarn spinner. The WH yarns were then woven using a loom. The weaving process was carried out by traditional cloth craftsmen. This process produced WH mat with dimensions of 30 x 40 cm with direction of yarn 0°/90° (Figure 3). The natural composite was manufactured using epoxy Bakelite® EPR 174 and resin hardener V-140 as a matrix.

2.2. Preparation of Composites

The hand lay-up method was used to fabricate the unidirectional WH fiber composite and woven WH composites. This was conducted by applying an epoxy-resin matrix to the WH fibers in the mold specimens with dimension of 30 x 40 cm using a paintbrush and roller. The composite tensile and impact test specimens were manufactured in variations of the WH fiber reinforcement of 0%, 15 %, 25 % and 35 % wt. The coding of these specimens is shown in Table 1.

Table 1. Specimens testing code

Code	**Meaning**
E(0)	Epoxy – resin, 0 % WH fibers
E(15)	Epoxy – resin, 15 % WH fibers
E(25)	Epoxy – resin, 25 % WH fibers
E(35)	Epoxy – resin, 35 % WH fibers

Afterward, the composites were compressed and vacuumed to remove voids and obtain a smoothen surface. After removing the produced composite specimen from the mold, specimens of appropriate dimensions were made in accordance with ASTM D3039 requirements. Water jet cutting technique is used for cutting the test specimen as per the required shape. The test specimen having dimension of length 250 mm, width of 25 mm and thickness of 3 mm were prepared for tensile testing.

Figure 1. Water Hyacinth Fibers

Figure 2. Water Hyacinth Yarn

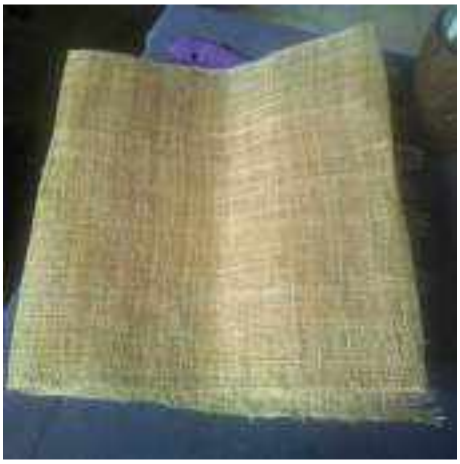

Figure 3. Water Hyacinth Woven Yarn

2.3. Characterization of Composites

The actual density of composites was measured using a densimeter based on Archimedes law according to ASTM B311. According to ASTM D2734 the porosity can be obtained by the relative difference between theoretical density of composite and measured density of composite (ρm). The density of composite (ρm) can be measured through water buoyancy by Archimedes Principle (ASTM D792). This leads to the following equation for calculation of the porosity (eq. 1).

$$\text{Porosity} = 100 - \rho m\{(Wr/\rho r) + (Wf/\rho f)\} \qquad (1)$$

where W and ρ represent the weight percentage and the density, and r and f stand for resin and fiber, respectively.

The tensile test of composites was carried out according to the ASTM D3039 standard (Figure 4). Furthermore, the impact tests were carried out through the Charpy methods according to the ASTM D6110 standard. Figure 5 shows the dimensions of the impact test specimens. Six identical test specimens were prepared for tensile and impact test to ensure the uniformity of the test. Scanning Electron Microscopy (SEM) was used to investigate the tensile test fracture surface of the composite.

Figure 4. Dimension of Tensile Test Specimen

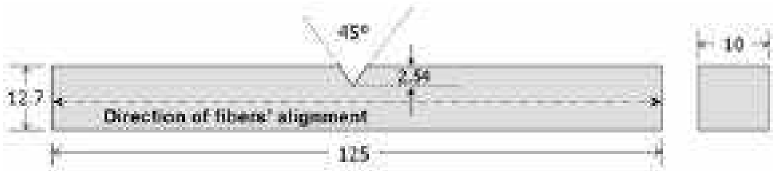

Figure 5. Dimension of Impact Test Specimen of Composite

3. RESULTS AND DISCUSSIONS

The density and porosity test results in Figure 6, shows that both the unidirectional and woven composites increased in mass fraction, while 0, 15, 25 and 35 % wt. increase in the porosity of the composites was observed. Furthermore, figure 6 also shows that for the woven fiber composite, there was an increase in porosity almost linearly from 0.35% to 13.82% with the addition of 35% fiber. The unidirectional WH fiber composite, increased from 15 % to 35 % wt., afterwards, the porosity did not increase significantly. Composites woven fibers also provided more voids than composites UD fibers. For woven fibers, the voids form inside tows, in resin-rich regions or at tow corners, and between plies in composites. Meanwhile, for UD fibers, the voids form within and between the plies [28, 29]. The difference in the direction of the fibers for the composites woven fiber leads to air entrapment and increased porosity. The main source of air entrapment is the inhomogeneous fiber architecture, which leads to a non-uniform fiber permeability carried out with subsequent local variations in resin velocity [30].

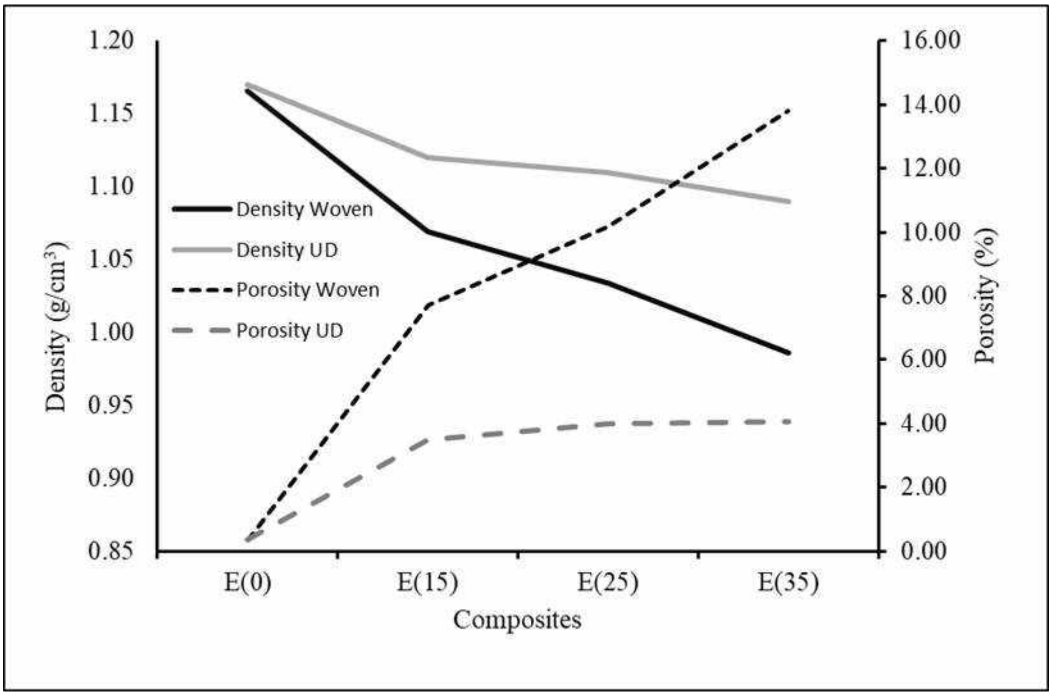

Figure 6. Density and Porosity of WH fibers Composites

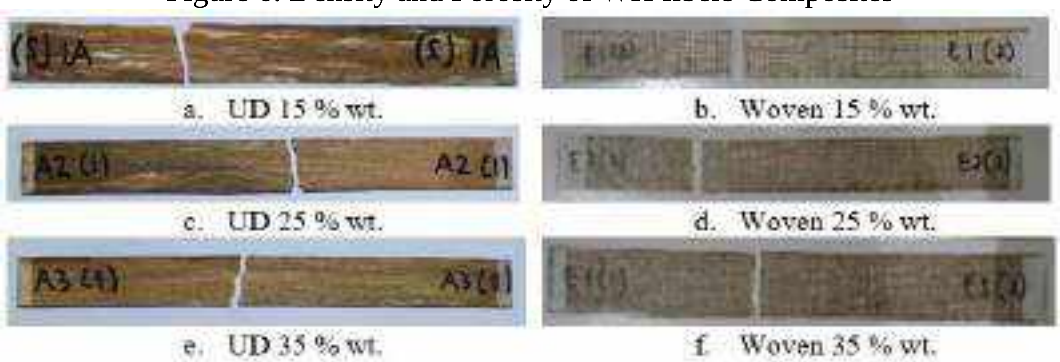

Figure 7. Photo of Tested specimens

Figure 7 shows the specimen after it was tensile tested, with fracture in the gauge length area. Figure 8 shows the tensile test results of the woven and unidirectional WH fiber composites reinforced with epoxy resin. The tensile strength of the woven WH fiber composite was in inverse proportion to the percentage of WH fibers in the composite. An increased fiber mass fraction from 0 to 15%, led to an insignificant decrease in the tensile strength of the composite. Furthermore, with a 35% addition, for every 10% increase in fiber mass fraction, the tensile strength of the composite decreases by about 11-13%. Composite elongation also decreased with the increase in % wt. of WH woven fibers, which also showed that its tensile strength was in direct proportion to the percentage weight of the WH fiber. This tensile strength increased by approximately 10% as the % wt. of WH fibers increased from 15% to 25%. For addition of 35% wt. of WH fiber, the tensile strength of composites increased by about 37%. Compared to the tensile strength of epoxy resin, the composite tensile strength of 35 % wt. for unidirectional WH fiber increased from 41 MPa to 60 MPa or by about 46 %. Furthermore, the lowest composite tensile strength for WH fibers in this study was 30 MPa for woven WH fibers composites containing 35% wt. This result was higher than that of Saputra et al., which discovered that the highest tensile strength was 28.36 MPa [31]. Figure 9 shows the specific tensile strength of composites, which shows that there were no significant differences in the tensile strengths of WH woven fibers composites. Furthermore, reinforcement by WH fibers compensates for the decreasing tensile strength of the composite from porosity. The UD WH fiber composites of 35 % wt., increases in specific tensile strength by about 60 %, which means that, it is in direct proportion with the specific tensile strength of composites.

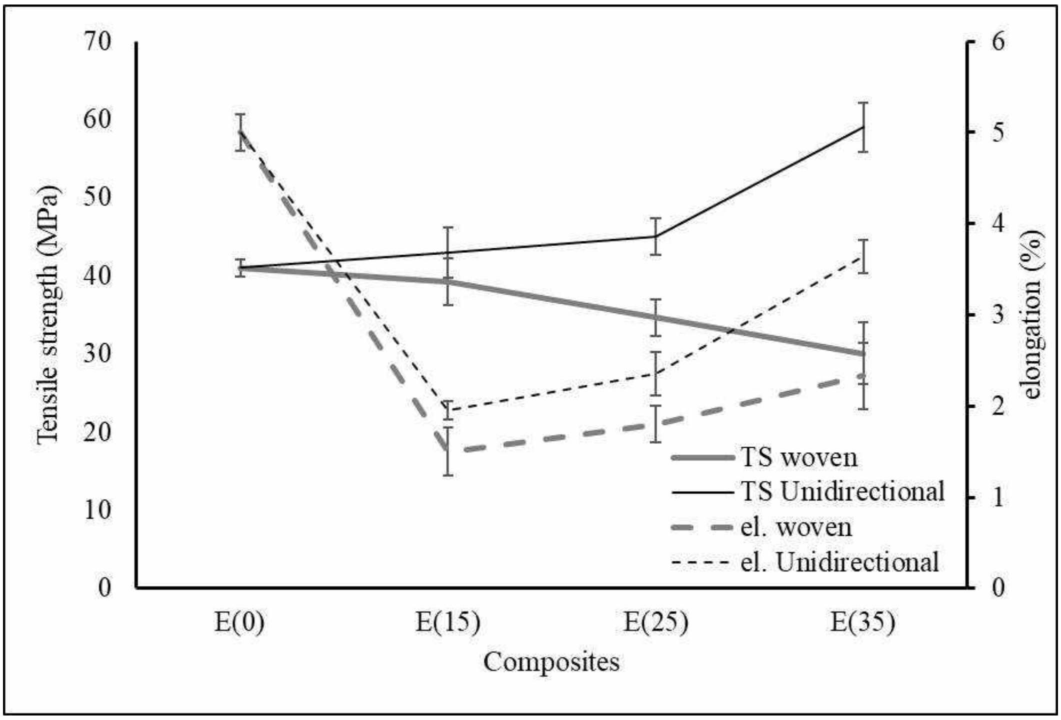

Figure 8. Tensile strength and elongation WH Fibers Reinforced Epoxy-Resin

The single fiber of water hyacinth has a tensile strength of around 105 - 313 MPa [32]. The results of the tensile test show that woven water hyacinth did not provide an effect of increasing strength on uniaxial tensile loads. Furthermore, the increased mass percentage of the WH reinforcing fibers led to increased composite porosity. A larger volume of woven reinforcing fibers leads to an increase in voids [30, 33], due to the pores being trapped causing a void between the matrix and fibers [34]. The increasing porosity also caused by the incomplete infiltration of resin in the hand lay-up process. Voids of composite produce stress concentration on the matrix. For the longitudinal fibers, voids lead to the potential change in stress transfer and redistribution and the cracking of the transverse plies [28]. The voids between fiber and matrix lead to a fiber pull-out fracture as shown in Figure 11a, 11b and 11c.

Composites had an increased tensile strength due to the unidirectional properties of the WH fiber. The unidirectional fiber has a higher percentage of fiber in the direction of tensile load than woven fiber. Based rule of mixture theory, higher % wt. of fiber on axis direction of load yields higher values of tensile strength than the combination of axial and transversal fiber direction in woven fiber. Additionally, an increase in the percentage weight of these fiber composites also improves tensile strength. This is coherent with the density and porosity test results in Figure 6, which shows that the composites with directional woven fiber exhibited a significant increase in porosity as the fiber percentage weight is increased. The porosity of UD WH fiber composites remained constant as the weight percentage of WH fibers increased. Hence, composites with directional woven fiber increased in % wt. and porosity significantly.

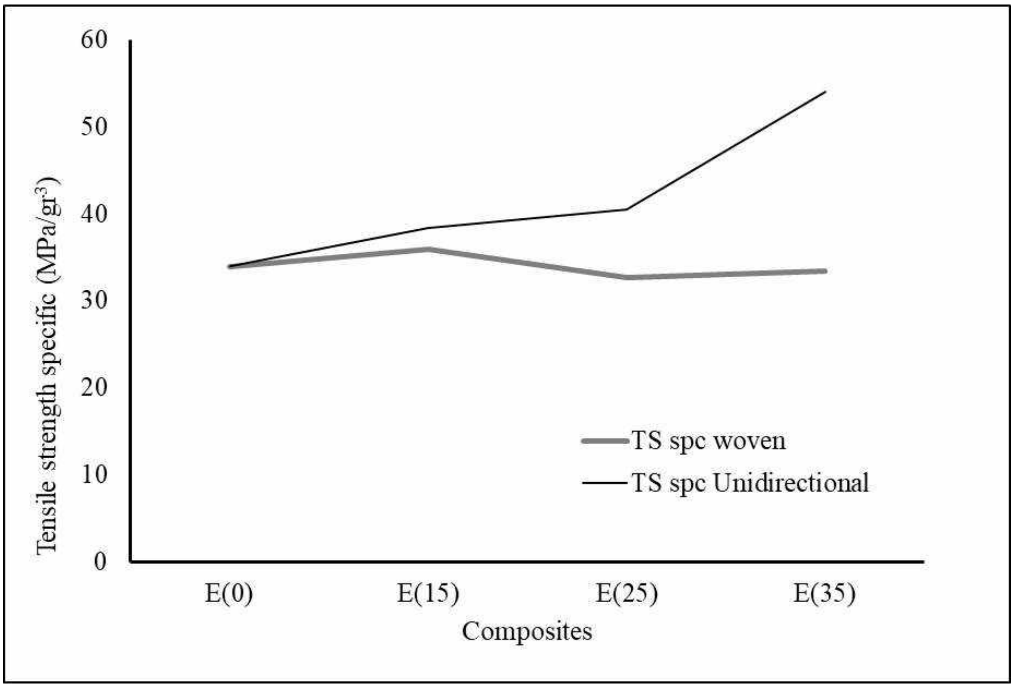

Figure 9. The specific tensile strength of WH Fiber Reinforced with Epoxy-Resin

Figure 10 shows the impact strength of WH fiber reinforced with epoxy-resin. This composite strength was in direct proportion to WH fiber rise of % wt. Increasing of % wt. of UD fiber from 0 % to 35 % wt., increase the impact strength of composite about 28 %. The impact strength of woven fiber composite increases about 22 % when the % wt. of fiber increase from 0 % to 35 % wt. The highest impact strength is about 0.82 kJ/cm^2 at the UD fiber composite with 35 % wt. of fiber. Figure 10 also shows specifics impact strength of composite. Graph in Figure 10 shown that specific impact strength of composite with 35 % wt. woven WH fiber higher than specific impact strength of 35 % wt. of UD composite. The porosity on woven composite produced lighter composite than UD composite. Woven WH fibers increase the impact strength of the composite and produce a tougher composite. Woven WH fibers have good ability to absorb large share kinetic energy so fibers role should be crack stopper [35]. The UD composite fibers break at the impact axis and the failure of the woven specimen is caused by shear stress [36]. The increase in composite impact strength is due to the interface strength between the woven WH fiber and epoxy - resin matrix contributes to the transfer load from the matrix fiber. This characteristic allows the WH fiber composites to absorb more energy. The fiber flexibility that slides out of the matrix did not break but increased the energy needed to rupture the specimen [37].

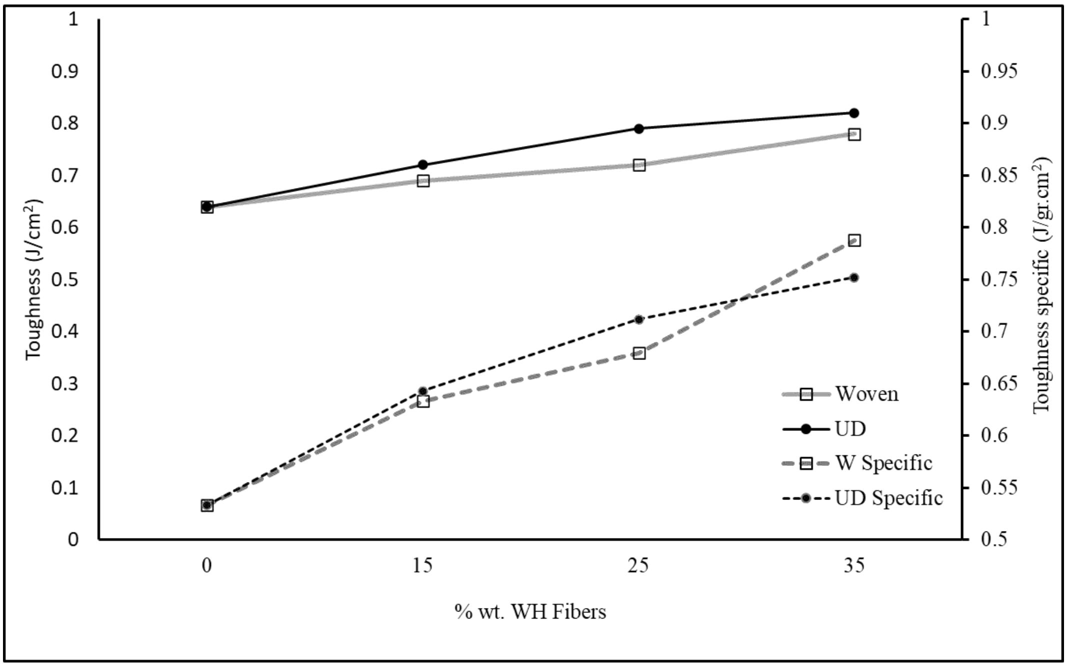

Figure 10. Impact Strength of Composites WH Fibers reinforced Epoxy-Resin

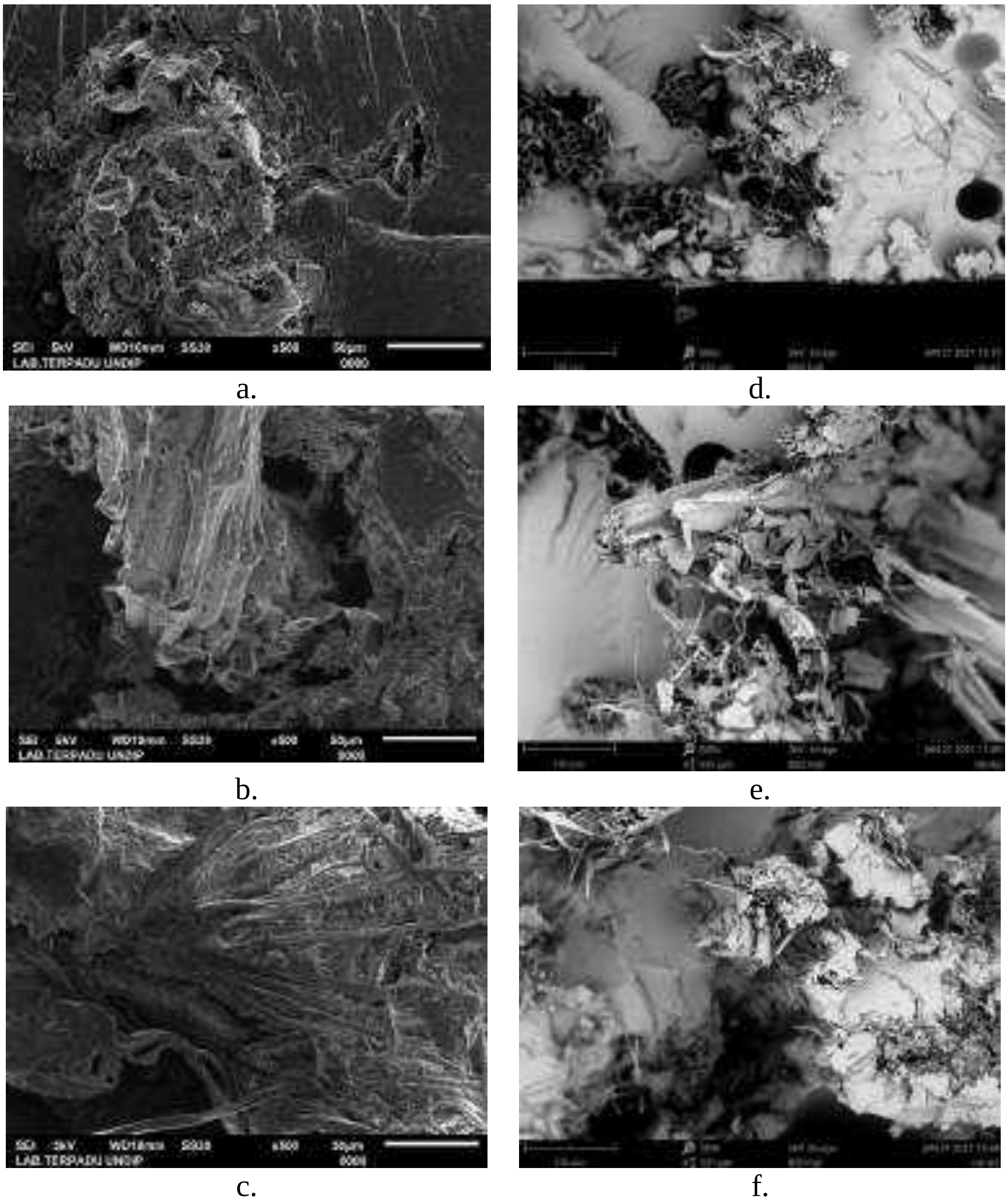

Figure 11. SEM Micrograph Surface Fracture of Composites WH Fibers reinforced Epoxy-Resin

Furthermore, the SEM photomicrographs of the fracture surface were used to analyze the WH fiber and matrix adhesion in the composites. The cross-section of these tensile-tested specimens was selected for analysis. Figure 11.a – 11.f shows the fracture surface SEM images of the WH fiber-reinforced epoxy resin composite. Meanwhile, figure 11.a, 11.b and 11.c shows the samples with 15, 25, 35 % of WH woven fiber. Figure 11.d, 11.e and 11.f shows the composite with 15, 25, 35 % of UD WH fiber. From the fractographic examinations by SEM, the fracture behavior of composite was brittle. Some pores, which originated from the fiber pull-out phenomena were found in all cases, while fracture phenomena were also observed in the UD WH fiber. SEM images showed that the WH fiber and epoxy resin were mechanically bound, however, there was no chemical bonding between the WH fiber and epoxy resin. Furthermore, similar natural fiber and polymer adhesion were experimented with and discussed within natural fiber-reinforced plastic composites [38,39]. For this reason, the mechanical properties of UD WH fiber epoxy resin composites had a 60% increase.

CONCLUSION

Previous researchers that used water hyacinth fiber as a composite reinforcement in the form of stem, stem chopped, sawdust, and powder produced mechanical properties under the tensile strength of the matrix material. The use of UD WH fiber as reinforcement results in an increasing of strength of composite. The lowest tensile strength produced in this research is also higher than the highest tensile strength produced by previous researchers. Increasing the % wt. of the WH woven fibers decreased the tensile strength of the epoxy resin composites. Furthermore, the % wt. of WH woven fibers was in direct proportion to the number of pores or voids between the fibers and matrix which led to a delamination mode fracture. The rise of % wt. of fibers increases the tensile and impact strength of unidirectional WH fibers epoxy resin composite. The utilization of WH fibers obtained an increased effective reinforcement. The impact strength of composites was in direct proportion to the rise of % wt. of WH woven fibers. The mechanical properties of unidirectional WH fiber higher than mechanical properties of woven WH fiber composite.

ACKNOWLEDGMENT

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E(15)	Epoxy – resin, 15 % WH fibers
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The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites

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Abstract:	The high growth of Water Hyacinth/ Eichhornia crassipes (WH) led to several problems such as ecosystem, irrigation, and sedimentation. The rapid growth of water hyacinth in natural rivers, reservoir, lake and canals causes drainage problems in many nations. As a result, local offices must spend significant annual budgets to dispose of water hyacinth wastes. Meanwhile, cellulose fiber from WH had a potential application in natural fiber composite (NFC). This study investigated the development and use of water hyacinth wastes for the production of unidirectional dan weaved fiber epoxy resin composites. The purpose of this research is to investigate at the mechanical and physical properties of unidirectional WH and woven fiber reinforced epoxy resin composites in variation of 0 % wt., 15 % wt., 25 % wt. and 35 % wt. of WH fibers. The WH fiber was obtained from a mechanically processed WH plants. The composites were manufactured through the hand lay-up method. The tensile and impact tests were carried out based on ASTM D3039 and ASTM D6110 respectively, while the density of composites was tested based on the Archimedes rule. The results of this study showed that increasing of % wt. of the WH woven fiber, the tensile strength of composite decrease. The impact strength of composites increases by the rise of % wt. of the WH woven fibers. The % wt. of WH woven fibers was in direct proportion to the amount of pore or void between the fibers and matrix, which led to a delamination mode fracture. Tensile and impact strength of unidirectional WH fiber increase by increasing the % wt. of WH fibers.
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The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites

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ABSTRACT

The high growth of Water Hyacinth/*Eichhornia crassipes* (WH) led to several problems such as ecosystem, irrigation, and sedimentation. The rapid growth of water hyacinth in natural rivers, reservoir, lake and canals causes drainage problems in many nations. As a result, local offices must spend significant annual budgets to dispose of water hyacinth wastes. Meanwhile, cellulose fiber from WH had a potential application in natural fiber composite (NFC). This study investigated the development and use of water hyacinth wastes for the production of unidirectional dan weaved fiber epoxy resin composites. The purpose of this research is to investigate at the mechanical and physical properties of unidirectional WH and woven fiber reinforced epoxy resin composites in variation of 0 % wt., 15 % wt., 25 % wt. and 35 % wt. of WH fibers. The WH fiber was obtained from a mechanically processed WH plants. The composites were manufactured through the hand lay-up method. The tensile and impact tests were carried out based on ASTM D3039 and ASTM D6110 respectively, while the density of composites was tested based on the Archimedes rule. The results of this study showed that increasing of % wt. of the WH woven fiber, the tensile strength of composite decrease. The impact strength of composites increases by the rise of % wt. of the WH woven fibers. The % wt. of WH woven fibers was in direct proportion to the amount of pore or void between the fibers and matrix, which led to a delamination mode fracture. Tensile and impact strength of unidirectional WH fiber increase by increasing the % wt. of WH fibers.

Keywords: Composite, Epoxy-resin, Water Hyacinth, Woven fiber, Unidirectional fiber.

1. INTRODUCTION

Natural fibers are a useful class of materials that are environmentally clean, renewable, and biodegradable resources. They are also used in manufacturing natural fiber composites with advantages which include low impact on the environment, renewability, inexpensive and easily degraded [1-4]. However, the use of natural fibers as a reinforcement of composites is still experiencing several

problems such as, low mechanical properties, hydrophilic properties, limited processing temperatures, low matrix and fiber binding forces that are easily degraded [5,6]. Furthermore, studies on the development of natural fiber properties were carried out by pretreating or engineering the manufacturing method [7,8].

Water hyacinth (Eichhornia crassipes) is a type of aquatic plant that floats on the surface of the water. It grows aggressively and was a nuisance on almost all continents for more than 100 years. Furthermore, its high population growth led to several problems related to ecosystem balance, decreased fish production, loss of endemic organisms and sedimentation [9-11]. Numerous studies were carried out to utilize water hyacinth plants as absorbers of heavy metals, absorbing dye waste, biofuel and biogas production, composite catalyst and reinforcing composites [12-19].

Based on previous studies, the problem associated with the utilization of WH materials for composite reinforcement includes, low mechanical strength, ease of water absorption leading to a reduced fiber bond with the matrix and weak compatibility of the WH fiber with the polymer matrix [20-22]. The results of this study show that for these composites, the mechanical properties were relatively low. Although the use of WH fiber as composite reinforcement still requires further studies, it has several advantages which include, increased acoustic, damping ability and good thermal resistance [23].

Previous researchers on the use of water hyacinth fiber as reinforcement composite still uses WH in the form of stem, stem chopped, sawdust, and powder [22, 24-26]. No research has been found that uses water hyacinth in the form of fiber or woven fibers. The use of natural fiber as a composite reinforcement, the shape of the reinforcement affects the mechanical properties of composite. This research uses water hyacinth in the form of fibers, either unidirectional or woven fibers. WH fiber can be obtained by extracting WH stem. The WH plant extraction process affected the mechanical properties of the fiber composite. This process aims to separate plant fibers from the wax, pectin, hemicellulose and lignin layers. Also, there were several methods used to extract plant fibers from the parent plant, namely: immersion, chemical methods or mechanical methods [27]. Therefore, this study aims to investigate the mechanical and physical properties of composites reinforced with unidirectional and woven WH fibers.

2. MATERIALS AND METHODS

2.1. Materials

The water hyacinth plants used, were obtained from swamps in Tanggul Village, Mijen District, Demak Regency, Central Java, Indonesia with 50-70 cm length of stems. These plants were mechanically extracted to yield the WF fibers (Figure 1). The fiber extraction was carried out by brushing the WH stems using an iron brush. The fiber is then dried in the sun. After that, 10 strands of the dry WH fibers were twisted to produce yarn (Figure 2). The water hyacinth yarns were prepared by yarn craftsmen using a traditional yarn spinner. The WH yarns were then woven using a loom. The weaving process was carried out by traditional cloth craftsmen. This process produced WH mat with dimensions of 30 x 40 cm with

direction of yarn 0°/90° (Figure 3). The natural composite was manufactured using epoxy Bakelite® EPR 174 and resin hardener V-140 as a matrix.

2.2. Preparation of Composites

The hand lay-up method was used to fabricate the unidirectional WH fiber composite and woven WH composites. This was conducted by applying an epoxy-resin matrix to the WH fibers in the mold specimens with dimension of 30 x 40 cm using a paintbrush and roller. The composite tensile and impact test specimens were manufactured in variations of the WH fiber reinforcement of 0%, 15 %, 25 % and 35 % wt. The coding of these specimens is shown in Table 1.

Table 1. Specimens testing code

Code	Meaning
E(0)	Epoxy – resin, 0 % WH fibers
E(15)	Epoxy – resin, 15 % WH fibers
E(25)	Epoxy – resin, 25 % WH fibers
E(35)	Epoxy – resin, 35 % WH fibers

Afterward, the composites were compressed and vacuumed to remove voids and obtain a smoothen surface. After removing the produced composite specimen from the mold, specimens of appropriate dimensions were made in accordance with ASTM D3039 requirements. Water jet cutting technique is used for cutting the test specimen as per the required shape. The test specimen having dimension of length 250 mm, width of 25 mm and thickness of 3 mm were prepared for tensile testing.

Figure 1. Water Hyacinth Fibers

Figure 2. Water Hyacinth Yarn

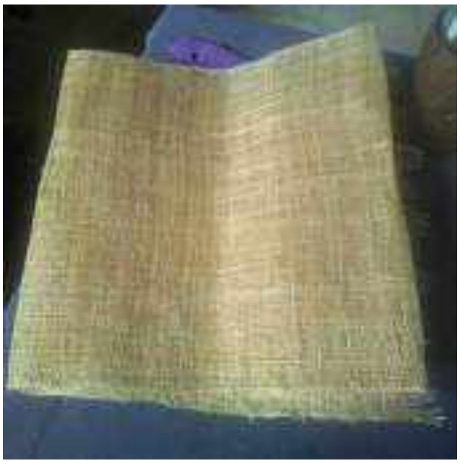


Figure 3. Water Hyacinth Woven Yarn

2.3. Characterization of Composites

The actual density of composites was measured using a densimeter based on Archimedes law according to ASTM D792. According to ASTM D2734 the porosity can be obtained by the relative difference between theoretical density of composite and measured density of composite (ρm). The density of composite (ρm) can be measured through water buoyancy by Archimedes Principle (ASTM D792). This leads to the following equation for calculation of the porosity (eq. 1).

$$\text{Porosity} = 100 - \rho m\{(Wr/\rho r) + (Wf/\rho f)\} \quad (1)$$

where W and ρ represent the weight percentage and the density, and r and f stand for resin and fiber, respectively.

The tensile test of composites was carried out according to the ASTM D3039 standard (Figure 4). Furthermore, the impact tests were carried out through the Charpy methods according to the ASTM D6110 standard. Figure 5 shows the

dimensions of the impact test specimens. Six identical test specimens were prepared for tensile and impact test to ensure the uniformity of the test. Scanning Electron Microscopy (SEM) was used to investigate the tensile test fracture surface of the composite.

Figure 4. Dimension of Tensile Test Specimen

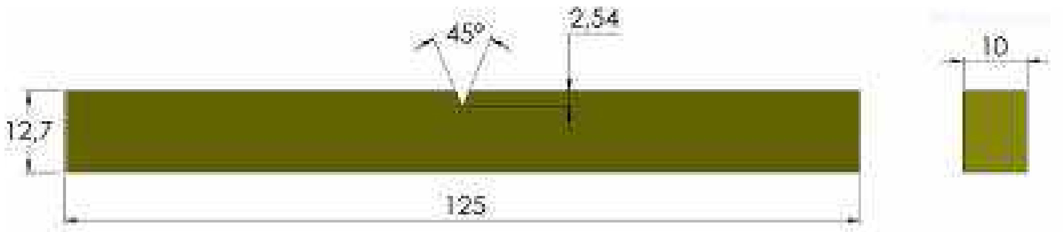


Figure 5. Dimension of Impact Test Specimen of Composite

3. RESULTS AND DISCUSSIONS

The density and porosity test results in Figure 6, shows that both the unidirectional and woven composites increased in mass fraction, while 0, 15, 25 and 35 % wt. increase in the porosity of the composites was observed. Furthermore, figure 6 also shows that for the woven fiber composite, there was an increase in porosity almost linearly from 0.35% to 13.82% with the addition of 35% fiber. The unidirectional WH fiber composite, increased from 15 % to 35 % wt., afterwards, the porosity did not increase significantly. Composites woven fibers also provided more voids than composites UD fibers. For woven fibers, the voids form inside tows, in resin-rich regions or at tow corners, and between plies in composites. Meanwhile, for UD fibers, the voids form within and between the plies [28, 29]. The difference in the direction of the fibers for the composites woven fiber leads to air entrapment and increased porosity. The main source of air entrapment is the inhomogeneous fiber architecture, which leads to a non-uniform fiber permeability carried out with subsequent local variations in resin velocity [30].

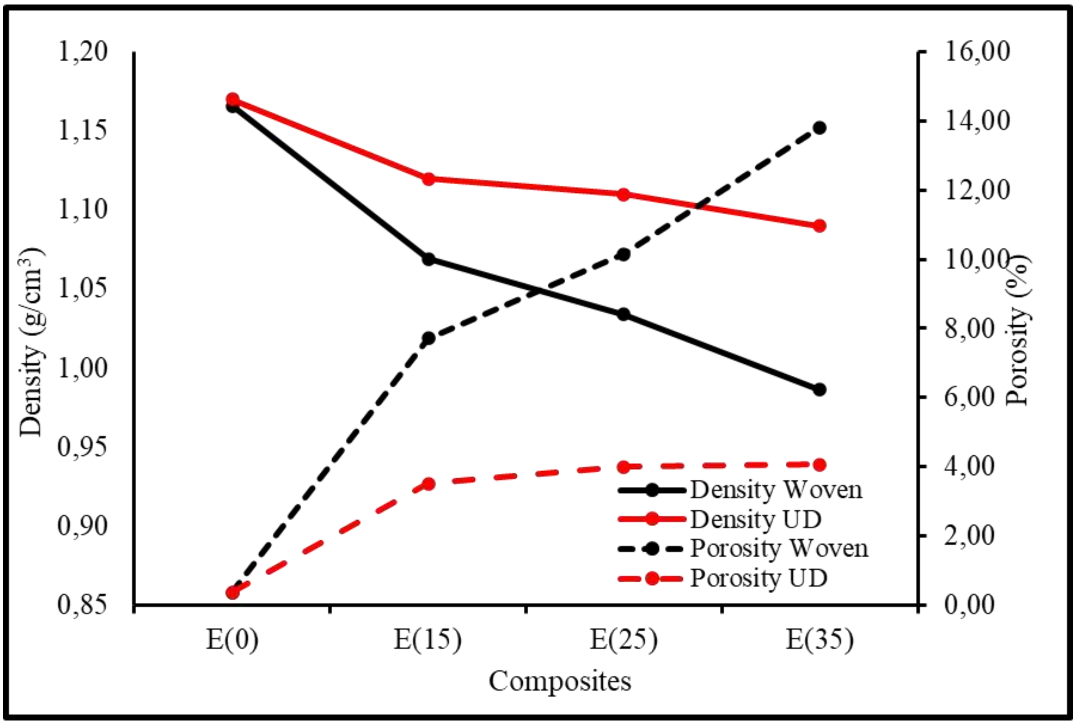


Figure 6. Density and Porosity of WH fibers Composites

a. Fracture specimen of 15 % unidirectional WH fiber composite.

b. Fracture specimen of 15 % WH woven fiber composite

c. Fracture specimen of 25 % unidirectional WH fiber composite

d. Fracture specimen of 25 % WH woven fiber composite

e. Fracture specimen of 35 % unidirectional WH fiber composite

f. Fracture specimen of 35 % WH woven fiber composite

Figure 7. Photo of Tested specimens

Figure 7 shows the specimen after it was tensile tested, with fracture in the gauge length area. Figure 8 shows the tensile test results of the woven and unidirectional WH fiber composites reinforced with epoxy resin. The tensile strength of the woven WH fiber composite was in inverse proportion to the percentage of WH fibers in the composite. An increased fiber mass fraction from 0 to 15%, led to an insignificant decrease in the tensile strength of the composite. Furthermore, with a 35% addition, for every 10% increase in fiber mass fraction, the tensile strength of the composite decreases by about 11-13%. Composite elongation also decreased with the increase in % wt. of WH woven fibers, which also showed that its tensile strength was in direct proportion to the percentage weight of the WH fiber. This tensile strength increased by approximately 10% as the % wt. of WH fibers increased from 15% to 25%. For addition of 35% wt. of WH fiber, the tensile strength of composites increased by about 37%. Compared to the tensile strength of epoxy resin, the composite tensile strength of 35 % wt. for unidirectional WH fiber increased from 41 MPa to 60 MPa or by about 46 %. Furthermore, the lowest composite tensile strength for WH fibers in this study was 30 MPa for woven WH fibers composites containing 35% wt. This result was higher than that of Saputra et al., which discovered that the highest tensile strength was 28.36 MPa [31]. Figure 9 shows the specific tensile strength of composites, which shows that there were no significant differences in the tensile strengths of WH woven fibers composites. Furthermore, reinforcement by WH fibers compensates for the decreasing tensile strength of the composite from porosity. The UD WH fiber composites of 35 % wt., increases in specific tensile strength by about 60 %, which means that, it is in direct proportion with the specific tensile strength of composites.

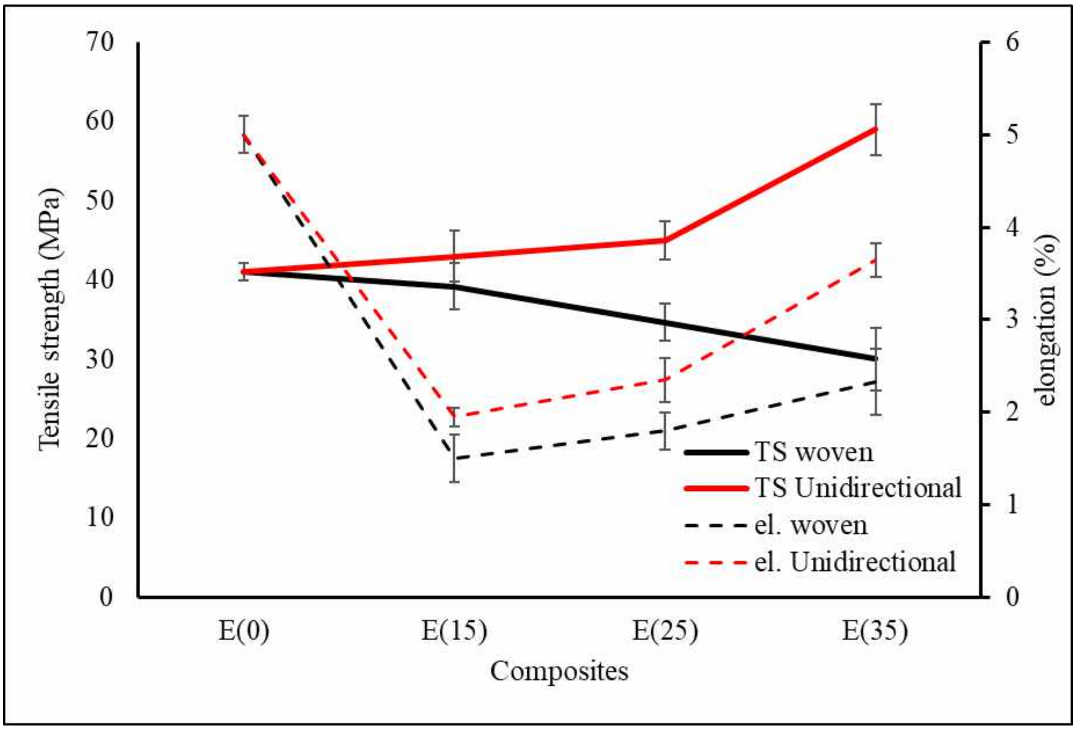


Figure 8. Tensile strength and elongation WH Fibers Reinforced Epoxy-Resin

The single fiber of water hyacinth has a tensile strength of around 105 - 313 MPa [32]. The results of the tensile test show that woven water hyacinth did not provide an effect of increasing strength on uniaxial tensile loads. Furthermore, the increased mass percentage of the WH reinforcing fibers led to increased composite porosity. A larger volume of woven reinforcing fibers leads to an increase in voids [30, 33], due to the pores being trapped causing a void between the matrix and fibers [34]. The increasing porosity also caused by the incomplete infiltration of resin in the hand lay-up process. Voids of composite produce stress concentration on the matrix. For the longitudinal fibers, voids lead to the potential change in stress transfer and redistribution and the cracking of the transverse plies [28]. The voids between fiber and matrix lead to a fiber pull-out fracture as shown in Figure 11a, 11b and 11c.

Composites had an increased tensile strength due to the unidirectional properties of the WH fiber. The unidirectional fiber has a higher percentage of fiber in the direction of tensile load than woven fiber. Based rule of mixture theory, higher % wt. of fiber on axis direction of load yields higher values of tensile strength than the combination of axial and transversal fiber direction in woven fiber. Additionally, an increase in the percentage weight of these fiber composites also improves tensile strength. This is coherent with the density and porosity test results in Figure 6, which shows that the composites with directional woven fiber exhibited a significant increase in porosity as the fiber percentage weight is increased. The porosity of UD WH fiber composites remained constant as the weight percentage of WH fibers increased. Hence, composites with directional woven fiber increased in % wt. and porosity significantly.

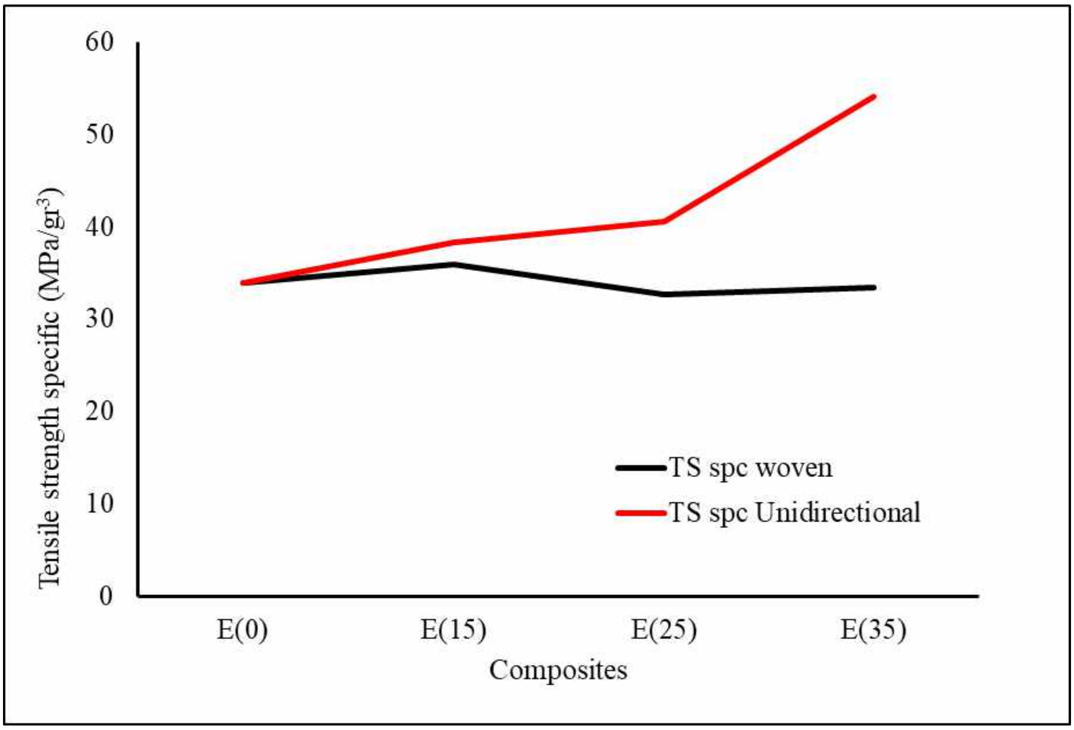


Figure 9. The specific tensile strength of WH Fiber Reinforced with Epoxy-Resin

Figure 10 shows the impact strength of WH fiber reinforced with epoxy-resin. This composite strength was in direct proportion to WH fiber rise of % wt. Increasing of % wt. of UD fiber from 0 % to 35 % wt., increase the impact strength of composite about 28 %. The impact strength of woven fiber composite increases about 22 % when the % wt. of fiber increase from 0 % to 35 % wt. The highest impact strength is about 0.82 kJ/cm^2 at the UD fiber composite with 35 % wt. of fiber. Figure 10 also shows specifics impact strength of composite. Graph in Figure 10 shown that specific impact strength of composite with 35 % wt. woven WH fiber higher than specific impact strength of 35 % wt. of UD composite. The porosity on woven composite produced lighter composite than UD composite. Woven WH fibers increase the impact strength of the composite and produce a tougher composite. Woven WH fibers have good ability to absorb large share kinetic energy so fibers role should be crack stopper [35]. The UD composite fibers break at the impact axis and the failure of the woven specimen is caused by shear stress [36]. The increase in composite impact strength is due to the interface strength between the woven WH fiber and epoxy - resin matrix contributes to the transfer load from the matrix fiber. This characteristic allows the WH fiber composites to absorb more energy. The fiber flexibility that slides out of the matrix did not break but increased the energy needed to rupture the specimen [37].

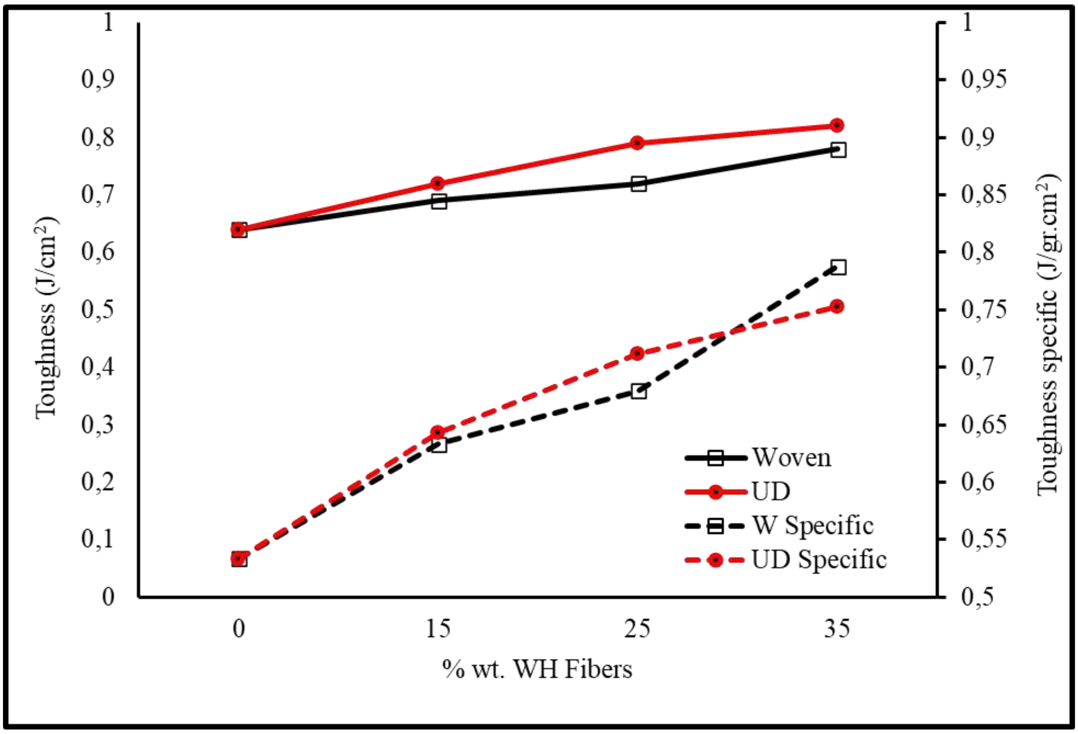
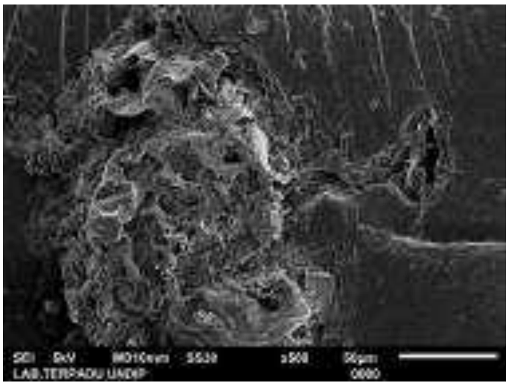
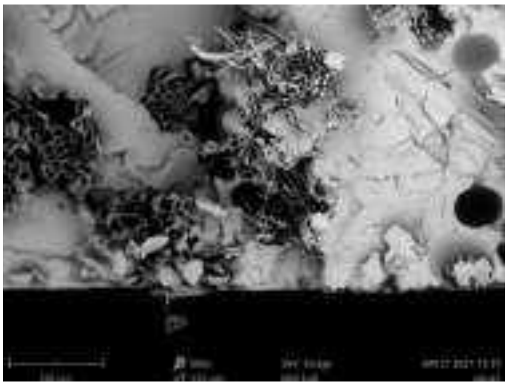


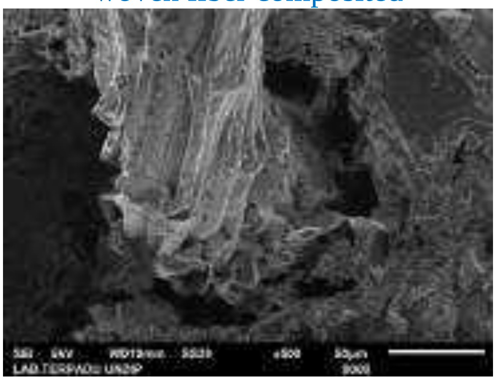
Figure 10. Impact Strength of Composites WH Fibers reinforced Epoxy-Resin

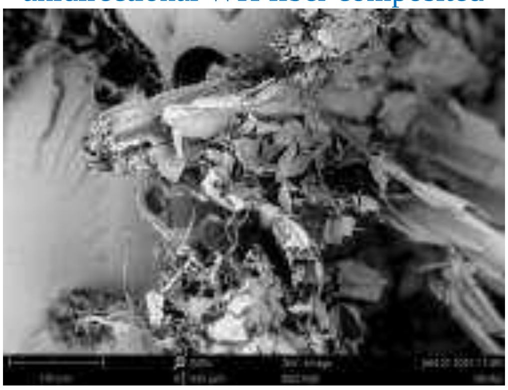


a. Fracture surface of 15 % WH woven fiber composited



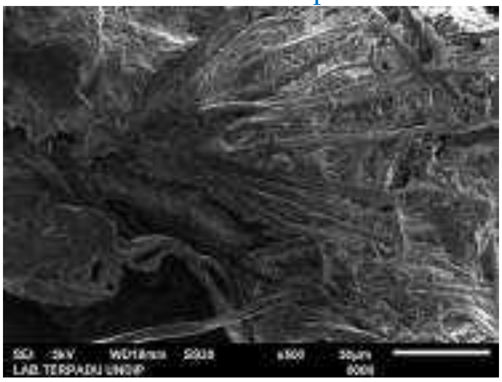
d. Fracture surface of 15 % unidirectional WH fiber composited

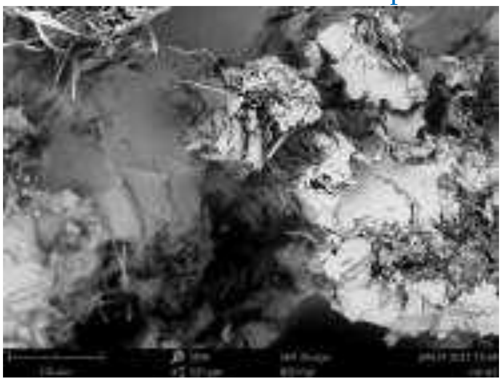




b. Fracture surface of 25 % WH woven fiber composited

e. Fracture surface of 25 % unidirectional WH fiber composited





c. Fracture surface of 35 % WH woven fiber composited

f. Fracture surface of 35 % unidirectional WH fiber composited

Figure 11. SEM Micrograph Surface Fracture of Composites WH Fibers reinforced Epoxy-Resin

Furthermore, the SEM photomicrographs of the fracture surface were used to analyze the WH fiber and matrix adhesion in the composites. The cross-section of these tensile-tested specimens was selected for analysis. Figure 11.a – 11.f shows the fracture surface SEM images of the WH fiber-reinforced epoxy resin composite. Meanwhile, figure 11.a, 11.b and 11.c shows the samples with 15, 25, 35 % of WH woven fiber. Figure 11.d, 11.e and 11.f shows the composite with 15, 25, 35 % of UD WH fiber. From the fractographic examinations by SEM, the fracture behavior of composite was brittle. Some pores, which originated from the fiber pull-out phenomena were found in all cases, while fracture phenomena were also observed in the UD WH fiber. SEM images showed that the WH fiber and epoxy resin were mechanically bound, however, there was no chemical bonding between the WH fiber and epoxy resin. Furthermore, similar natural fiber and polymer adhesion were experimented with and discussed within natural fiber-reinforced plastic composites [38,39]. For this reason, the mechanical properties of UD WH fiber epoxy resin composites had a 60% increase.

CONCLUSION

Previous researchers that used water hyacinth fiber as a composite reinforcement in the form of stem, stem chopped, sawdust, and powder produced mechanical properties under the tensile strength of the matrix material. The use of UD WH fiber as reinforcement results in an increasing of strength of composite. The lowest tensile strength produced in this research is also higher than the highest tensile strength produced by previous researchers. Increasing the % wt. of the WH woven fibers decreased the tensile strength of the epoxy resin composites. Furthermore, the % wt. of WH woven fibers was in direct proportion to the number of pores or voids between the fibers and matrix which led to a delamination mode fracture. The rise of % wt. of fibers increases the tensile and impact strength of unidirectional WH fibers epoxy resin composite. The utilization of WH fibers obtained an increased effective reinforcement. The impact strength of composites was in direct proportion to the rise of % wt. of WH woven fibers. The mechanical properties of unidirectional WH fiber higher than mechanical properties of woven WH fiber composite.

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Code	Meaning
E(0)	Epoxy – resin, 0 % WH fibers
E(15)	Epoxy – resin, 15 % WH fibers
E(25)	Epoxy – resin, 25 % WH fibers
E(35)	Epoxy – resin, 35 % WH fibers

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Abstract:	The high growth of Water Hyacinth/ Eichhornia crassipes (WH) led to several problems such as ecosystem, irrigation, and sedimentation. The rapid growth of water hyacinth in natural rivers, reservoir, lake and canals causes drainage problems in many nations. As a result, local offices must spend significant annual budgets to dispose of water hyacinth wastes. Meanwhile, cellulose fiber from WH had a potential application in natural fiber composite (NFC). This study investigated the development and use of water hyacinth wastes for the production of unidirectional dan weaved fiber epoxy resin composites. The purpose of this research is to investigate at the mechanical and physical properties of unidirectional WH and woven fiber reinforced epoxy resin composites in variation of 0 % wt., 15 % wt., 25 % wt. and 35 % wt. of WH fibers. The WH fiber was obtained from a mechanically processed WH plants. The composites were manufactured through the hand lay-up method. The tensile and impact tests were carried out based on ASTM D3039 and ASTM D6110 respectively, while the density of composites was tested based on the Archimedes rule. The results of this study showed that increasing of % wt. of the WH woven fiber, the tensile strength of composite decrease. The impact strength of composites increases by the rise of % wt. of the WH woven fibers. The % wt. of WH woven fibers was in direct proportion to the amount of pore or void between the fibers and matrix, which led to a delamination mode fracture. Tensile and impact strength of unidirectional WH fiber increase by increasing the % wt. of WH fibers.
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2. Please can you combine the individual captions for Figures 7 and 11 into single captions for both figures (e.g. 'Figure 11. a)...b)...c)...d)...e)...f)...').
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The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites

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ABSTRACT

The high growth of Water Hyacinth/*Eichhornia crassipes* (WH) led to several problems such as ecosystem, irrigation, and sedimentation. The rapid growth of water hyacinth in natural rivers, reservoir, lake and canals causes drainage problems in many nations. As a result, local offices must spend significant annual budgets to dispose of water hyacinth wastes. Meanwhile, cellulose fiber from WH had a potential application in natural fiber composite (NFC). This study investigated the development and use of water hyacinth wastes for the production of unidirectional dan weaved fiber epoxy resin composites. The purpose of this research is to investigate at the mechanical and physical properties of unidirectional WH and woven fiber reinforced epoxy resin composites in variation of 0 % wt., 15 % wt., 25 % wt. and 35 % wt. of WH fibers. The WH fiber was obtained from a mechanically processed WH plants. The composites were manufactured through the hand lay-up method. The tensile and impact tests were carried out based on ASTM D3039 and ASTM D6110 respectively, while the density of composites was tested based on the Archimedes rule. The results of this study showed that increasing of % wt. of the WH woven fiber, the tensile strength of composite decrease. The impact strength of composites increases by the rise of % wt. of the WH woven fibers. The % wt. of WH woven fibers was in direct proportion to the amount of pore or void between the fibers and matrix, which led to a delamination mode fracture. Tensile and impact strength of unidirectional WH fiber increase by increasing the % wt. of WH fibers.

Keywords: Composite, Epoxy-resin, Water Hyacinth, Woven fiber, Unidirectional fiber.

1. INTRODUCTION

Natural fibers are a useful class of materials that are environmentally clean, renewable, and biodegradable resources. They are also used in manufacturing natural fiber composites with advantages which include low impact on the environment, renewability, inexpensive and easily degraded [1-4]. However, the use of natural fibers as a reinforcement of composites is still experiencing several

problems such as, low mechanical properties, hydrophilic properties, limited processing temperatures, low matrix and fiber binding forces that are easily degraded [5,6]. Furthermore, studies on the development of natural fiber properties were carried out by pretreating or engineering the manufacturing method [7,8].

Water hyacinth (Eichhornia crassipes) is a type of aquatic plant that floats on the surface of the water. It grows aggressively and was a nuisance on almost all continents for more than 100 years. Furthermore, its high population growth led to several problems related to ecosystem balance, decreased fish production, loss of endemic organisms and sedimentation [9-11]. Numerous studies were carried out to utilize water hyacinth plants as absorbers of heavy metals, absorbing dye waste, biofuel and biogas production, composite catalyst and reinforcing composites [12-19].

Based on previous studies, the problem associated with the utilization of WH materials for composite reinforcement includes, low mechanical strength, ease of water absorption leading to a reduced fiber bond with the matrix and weak compatibility of the WH fiber with the polymer matrix [20-22]. The results of this study show that for these composites, the mechanical properties were relatively low. Although the use of WH fiber as composite reinforcement still requires further studies, it has several advantages which include, increased acoustic, damping ability and good thermal resistance [23].

Previous researchers on the use of water hyacinth fiber as reinforcement composite still uses WH in the form of stem, stem chopped, sawdust, and powder [22, 24-26]. No research has been found that uses water hyacinth in the form of fiber or woven fibers. The use of natural fiber as a composite reinforcement, the shape of the reinforcement affects the mechanical properties of composite. This research uses water hyacinth in the form of fibers, either unidirectional or woven fibers. WH fiber can be obtained by extracting WH stem. The WH plant extraction process affected the mechanical properties of the fiber composite. This process aims to separate plant fibers from the wax, pectin, hemicellulose and lignin layers. Also, there were several methods used to extract plant fibers from the parent plant, namely: immersion, chemical methods or mechanical methods [27]. Therefore, this study aims to investigate the mechanical and physical properties of composites reinforced with unidirectional and woven WH fibers.

2. MATERIALS AND METHODS

2.1. Materials

The water hyacinth plants used, were obtained from swamps in Tanggul Village, Mijen District, Demak Regency, Central Java, Indonesia with 50-70 cm length of stems. These plants were mechanically extracted to yield the WF fibers (Figure 1). The fiber extraction was carried out by brushing the WH stems using an iron brush. The fiber is then dried in the sun. After that, 10 strands of the dry WH fibers were twisted to produce yarn (Figure 2). The water hyacinth yarns were prepared by yarn craftsmen using a traditional yarn spinner. The WH yarns were then woven using a loom. The weaving process was carried out by traditional cloth craftsmen. This process produced WH mat with dimensions of 30 x 40 cm with

direction of yarn 0°/90° (Figure 3). The natural composite was manufactured using epoxy Bakelite® EPR 174 and resin hardener V-140 as a matrix.

2.2. Preparation of Composites

The hand lay-up method was used to fabricate the unidirectional WH fiber composite and woven WH composites. This was conducted by applying an epoxy-resin matrix to the WH fibers in the mold specimens with dimension of 30 x 40 cm using a paintbrush and roller. The composite tensile and impact test specimens were manufactured in variations of the WH fiber reinforcement of 0%, 15 %, 25 % and 35 % wt. The coding of these specimens is shown in Table 1.

Table 1. Specimens testing code

Code	Meaning
E(0)	Epoxy – resin, 0 % WH fibers
E(15)	Epoxy – resin, 15 % WH fibers
E(25)	Epoxy – resin, 25 % WH fibers
E(35)	Epoxy – resin, 35 % WH fibers

Afterward, the composites were compressed and vacuumed to remove voids and obtain a smoothen surface. After removing the produced composite specimen from the mold, specimens of appropriate dimensions were made in accordance with ASTM D3039 requirements. Water jet cutting technique is used for cutting the test specimen as per the required shape. The test specimen having dimension of length 250 mm, width of 25 mm and thickness of 3 mm were prepared for tensile testing.

Figure 1. Water Hyacinth Fibers

Figure 2. Water Hyacinth Yarn

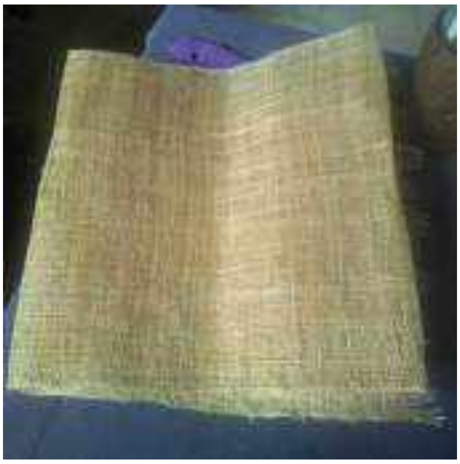

Figure 3. Water Hyacinth Woven Yarn

2.3. Characterization of Composites

The actual density of composites was measured using a densimeter based on Archimedes law according to ASTM D792. According to ASTM D2734 the porosity can be obtained by the relative difference between theoretical density of composite and measured density of composite (ρm). The density of composite (ρm) can be measured through water buoyancy by Archimedes Principle (ASTM D792). This leads to the following equation for calculation of the porosity (eq. 1).

$$\text{Porosity} = 100 - \rho m\{(Wr/\rho r) + (Wf/\rho f)\} \qquad (1)$$

where W and ρ represent the weight percentage and the density, and r and f stand for resin and fiber, respectively.

The tensile test of composites was carried out according to the ASTM D3039 standard (Figure 4). Furthermore, the impact tests were carried out through the Charpy methods according to the ASTM D6110 standard. Figure 5 shows the

dimensions of the impact test specimens. Six identical test specimens were prepared for tensile and impact test to ensure the uniformity of the test. Scanning Electron Microscopy (SEM) was used to investigate the tensile test fracture surface of the composite.

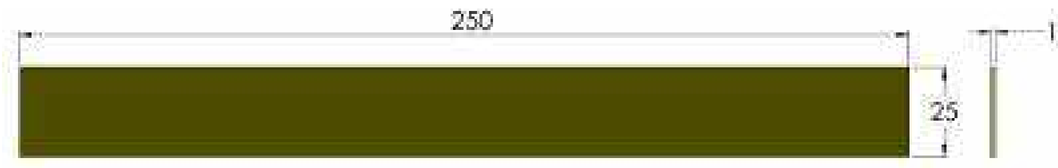

Figure 4. Dimension of Tensile Test Specimen

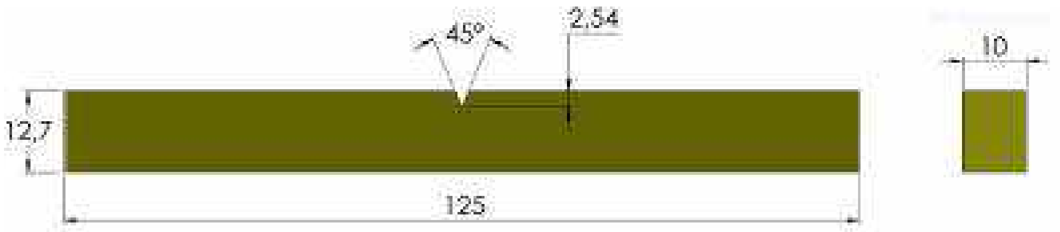

Figure 5. Dimension of Impact Test Specimen of Composite

3. RESULTS AND DISCUSSIONS

The density and porosity test results in Figure 6, shows that both the unidirectional and woven composites increased in mass fraction, while 0, 15, 25 and 35 % wt. increase in the porosity of the composites was observed. Furthermore, figure 6 also shows that for the woven fiber composite, there was an increase in porosity almost linearly from 0.35% to 13.82% with the addition of 35% fiber. The unidirectional WH fiber composite, increased from 15 % to 35 % wt., afterwards, the porosity did not increase significantly. Composites woven fibers also provided more voids than composites UD fibers. For woven fibers, the voids form inside tows, in resin-rich regions or at tow corners, and between plies in composites. Meanwhile, for UD fibers, the voids form within and between the plies [28, 29]. The difference in the direction of the fibers for the composites woven fiber leads to air entrapment and increased porosity. The main source of air entrapment is the inhomogeneous fiber architecture, which leads to a non-uniform fiber permeability carried out with subsequent local variations in resin velocity [30].

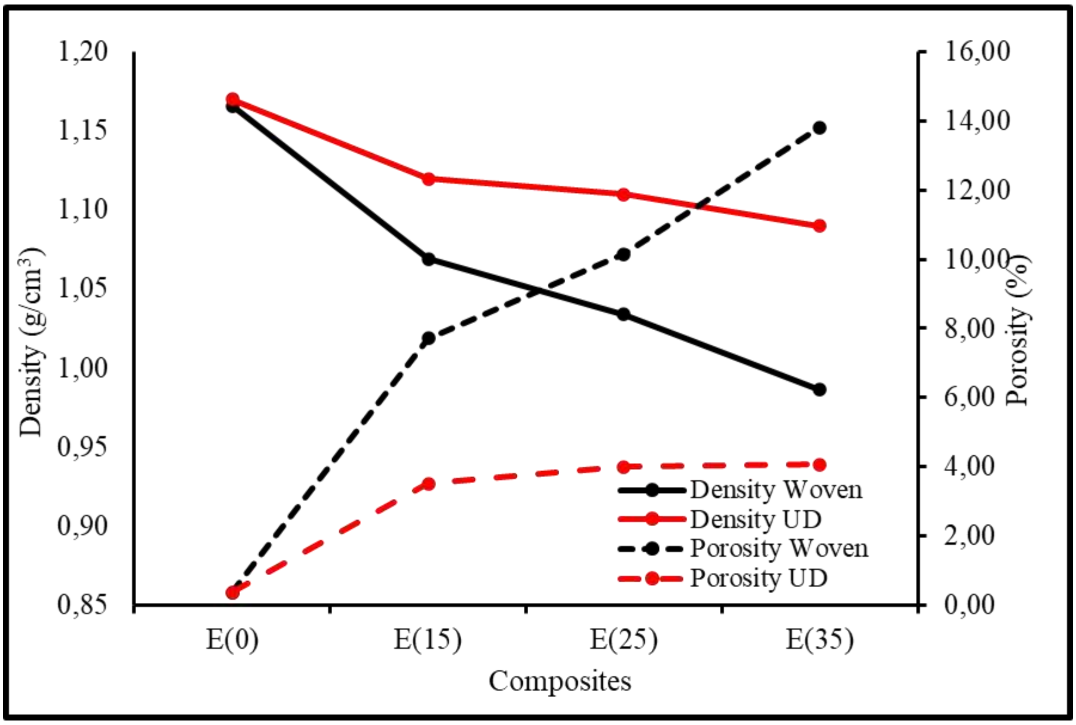

Figure 6. Density and Porosity of WH fibers Composites

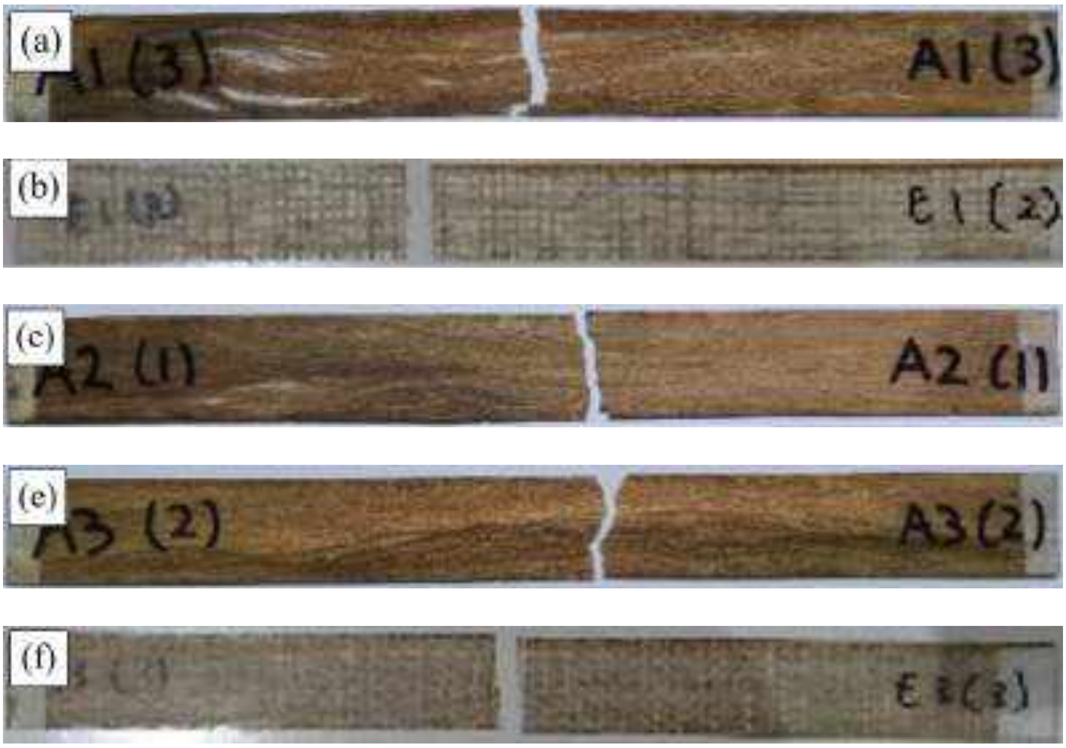

Figure 7. Fracture specimens (a) 15 % unidirectional WH fiber composite (b) 15 % WH woven fiber composite (c) 25 % unidirectional WH fiber composite (d) 25 % WH woven fiber composite (e) 35 % unidirectional WH fiber composite (f) 35 % WH woven fiber composite

Figure 7 shows the specimen after it was tensile tested, with fracture in the gauge length area. Figure 8 shows the tensile test results of the woven and unidirectional WH fiber composites reinforced with epoxy resin. The tensile strength of the woven WH fiber composite was in inverse proportion to the percentage of WH fibers in the composite. An increased fiber mass fraction from 0 to 15%, led to an insignificant decrease in the tensile strength of the composite. Furthermore, with a 35% addition, for every 10% increase in fiber mass fraction, the tensile strength of the composite decreases by about 11-13%. Composite elongation also decreased with the increase in % wt. of WH woven fibers, which also showed that its tensile strength was in direct proportion to the percentage weight of the WH fiber. This tensile strength increased by approximately 10% as the % wt. of WH fibers increased from 15% to 25%. For addition of 35% wt. of WH fiber, the tensile strength of composites increased by about 37%. Compared to the tensile strength of epoxy resin, the composite tensile strength of 35 % wt. for unidirectional WH fiber increased from 41 MPa to 60 MPa or by about 46 %. Furthermore, the lowest composite tensile strength for WH fibers in this study was 30 MPa for woven WH fibers composites containing 35% wt. This result was higher than that of Saputra et al., which discovered that the highest tensile strength was 28.36 MPa [31]. Figure 9 shows the specific tensile strength of composites, which shows that there were no significant differences in the tensile strengths of WH woven fibers composites. Furthermore, reinforcement by WH fibers compensates for the decreasing tensile strength of the composite from porosity. The UD WH fiber composites of 35 % wt., increases in specific tensile strength by about 60 %, which means that, it is in direct proportion with the specific tensile strength of composites.

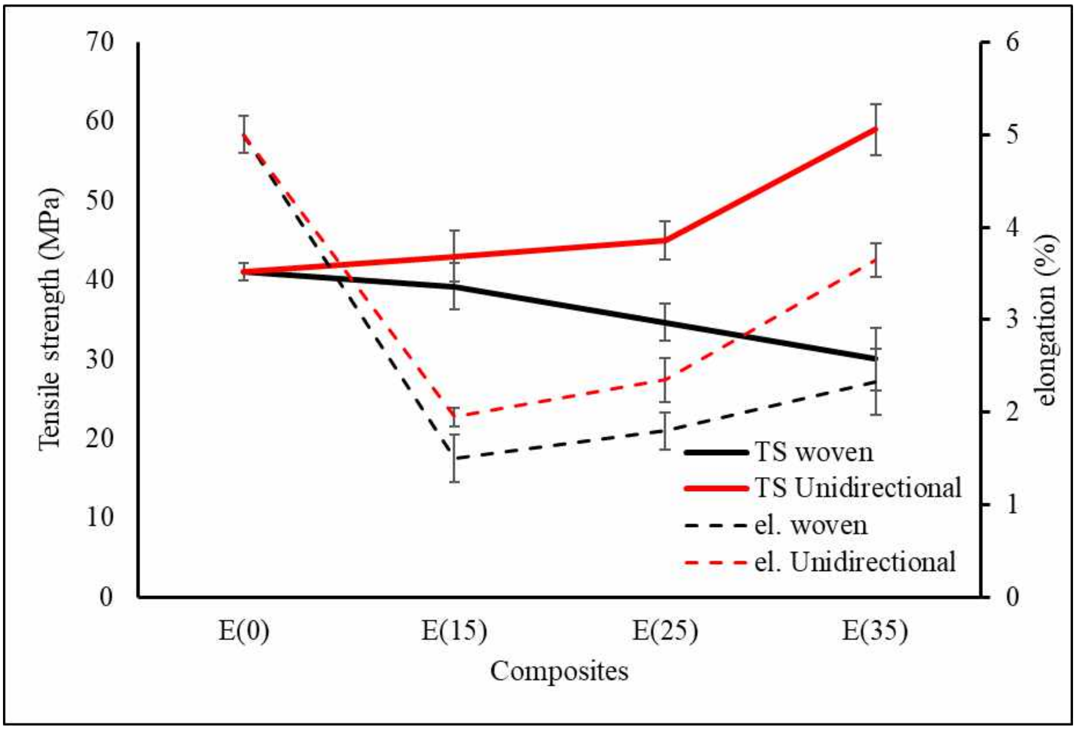

Figure 8. Tensile strength and elongation WH Fibers Reinforced Epoxy-Resin

The single fiber of water hyacinth has a tensile strength of around 105 - 313 MPa [32]. The results of the tensile test show that woven water hyacinth did not provide an effect of increasing strength on uniaxial tensile loads. Furthermore, the increased mass percentage of the WH reinforcing fibers led to increased composite porosity. A larger volume of woven reinforcing fibers leads to an increase in voids [30, 33], due to the pores being trapped causing a void between the matrix and fibers [34]. The increasing porosity also caused by the incomplete infiltration of resin in the hand lay-up process. Voids of composite produce stress concentration on the matrix. For the longitudinal fibers, voids lead to the potential change in stress transfer and redistribution and the cracking of the transverse plies [28]. The voids between fiber and matrix lead to a fiber pull-out fracture as shown in Figure 11a, 11b and 11c.

Composites had an increased tensile strength due to the unidirectional properties of the WH fiber. The unidirectional fiber has a higher percentage of fiber in the direction of tensile load than woven fiber. Based rule of mixture theory, higher % wt. of fiber on axis direction of load yields higher values of tensile strength than the combination of axial and transversal fiber direction in woven fiber. Additionally, an increase in the percentage weight of these fiber composites also improves tensile strength. This is coherent with the density and porosity test results in Figure 6, which shows that the composites with directional woven fiber exhibited a significant increase in porosity as the fiber percentage weight is increased. The porosity of UD WH fiber composites remained constant as the weight percentage of WH fibers increased. Hence, composites with directional woven fiber increased in % wt. and porosity significantly.

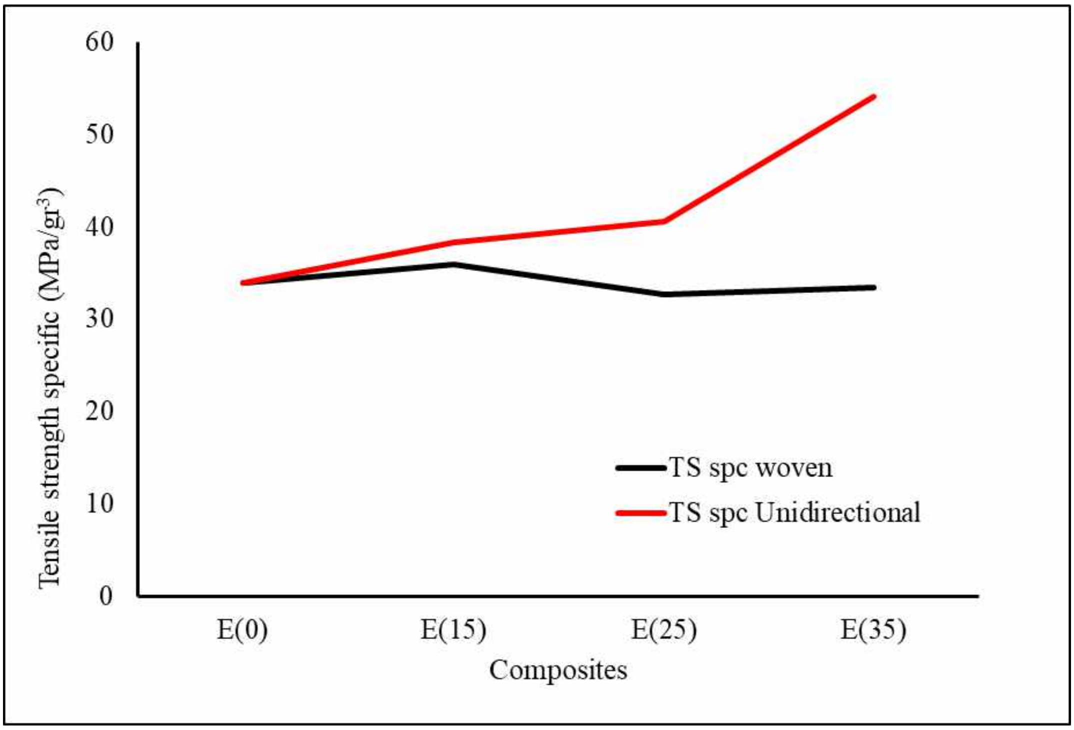

Figure 9. The specific tensile strength of WH Fiber Reinforced with Epoxy-Resin

Figure 10 shows the impact strength of WH fiber reinforced with epoxy-resin. This composite strength was in direct proportion to WH fiber rise of % wt. Increasing of % wt. of UD fiber from 0 % to 35 % wt., increase the impact strength of composite about 28 %. The impact strength of woven fiber composite increases about 22 % when the % wt. of fiber increase from 0 % to 35 % wt. The highest impact strength is about 0.82 kJ/cm^2 at the UD fiber composite with 35 % wt. of fiber. Figure 10 also shows specifics impact strength of composite. Graph in Figure 10 shown that specific impact strength of composite with 35 % wt. woven WH fiber higher than specific impact strength of 35 % wt. of UD composite. The porosity on woven composite produced lighter composite than UD composite. Woven WH fibers increase the impact strength of the composite and produce a tougher composite. Woven WH fibers have good ability to absorb large share kinetic energy so fibers role should be crack stopper [35]. The UD composite fibers break at the impact axis and the failure of the woven specimen is caused by shear stress [36]. The increase in composite impact strength is due to the interface strength between the woven WH fiber and epoxy - resin matrix contributes to the transfer load from the matrix fiber. This characteristic allows the WH fiber composites to absorb more energy. The fiber flexibility that slides out of the matrix did not break but increased the energy needed to rupture the specimen [37].

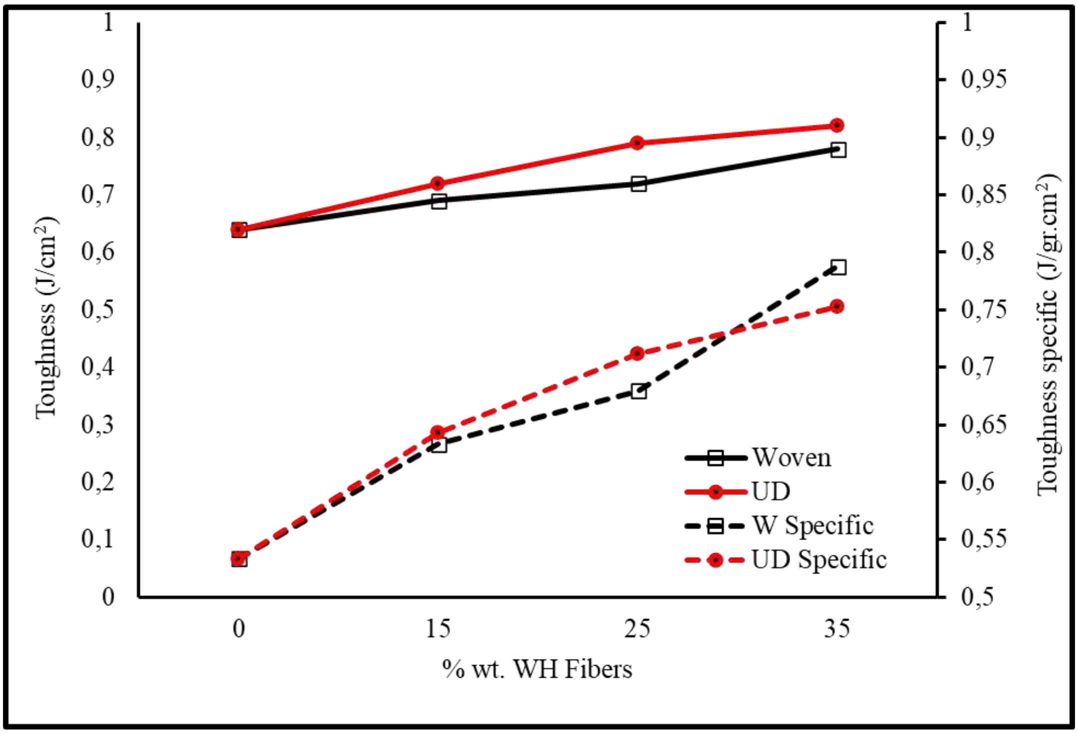

Figure 10. Impact Strength of Composites WH Fibers reinforced Epoxy-Resin

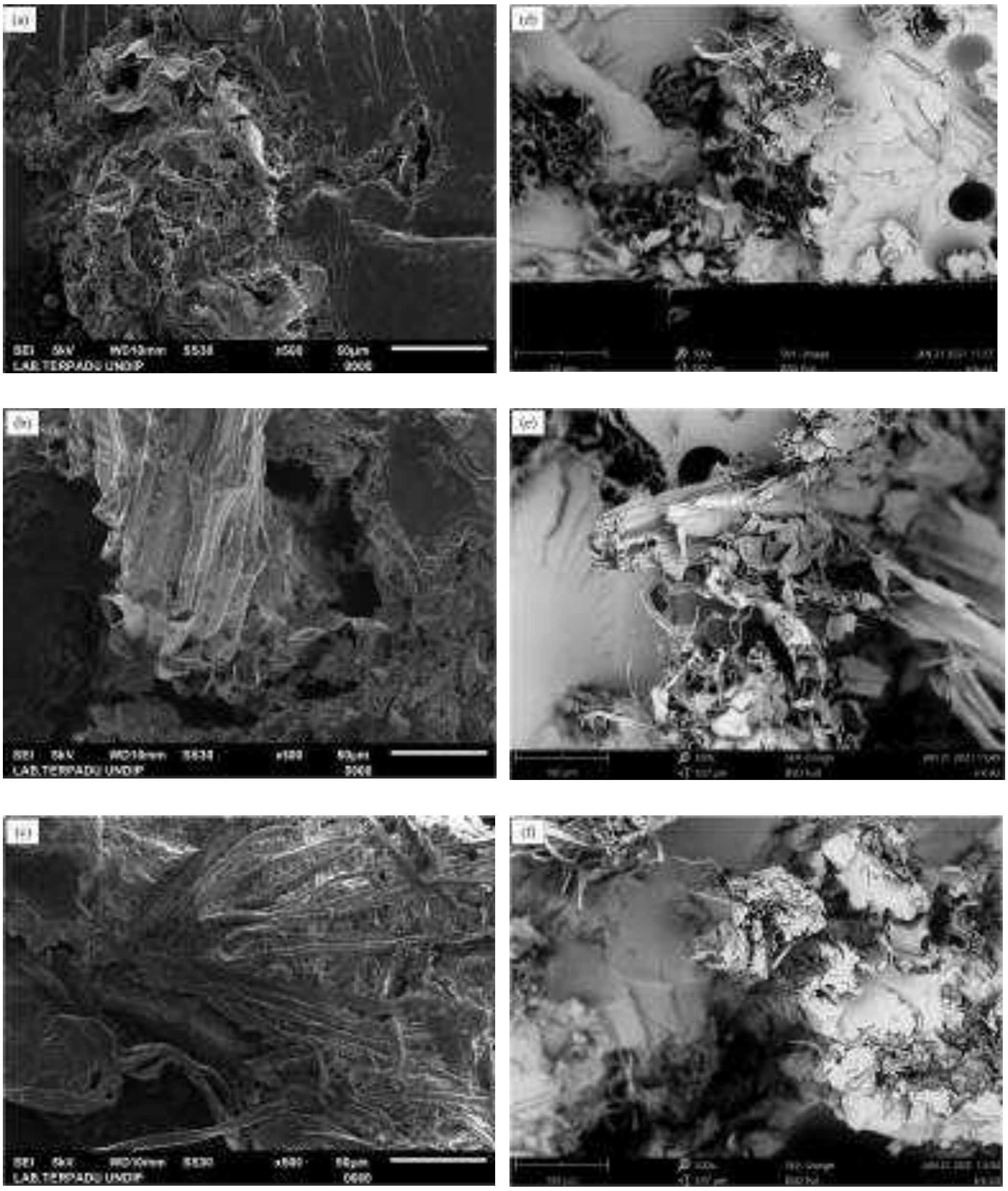

Figure 11. SEM Micrograph Surface Fracture of Composites (a) 15 % WH woven fiber composite (b) 25 % WH woven fiber composite (c) 35 % WH woven fiber composite (d) 15 % unidirectional WH fiber composite (e) 25 % unidirectional WH fiber composite (f) 35 % unidirectional WH fiber composite.

Furthermore, the SEM photomicrographs of the fracture surface were used to analyze the WH fiber and matrix adhesion in the composites. The cross-section of these tensile-tested specimens was selected for analysis. Figure 11.a – 11.f shows the fracture surface SEM images of the WH fiber-reinforced epoxy resin composite. Meanwhile, figure 11.a, 11.b and 11.c shows the samples with 15, 25, 35 % of WH woven fiber. Figure 11.d, 11.e and 11.f shows the composite with 15, 25, 35 % of UD WH fiber. From the fractographic examinations by SEM, the fracture behavior of composite was brittle. Some pores, which originated from the fiber pull-out phenomena were found in all cases, while fracture phenomena were also observed in the UD WH fiber. SEM images showed that the WH fiber and epoxy resin were mechanically bound, however, there was no chemical bonding between the WH fiber and epoxy resin. Furthermore, similar natural fiber and polymer adhesion were experimented with and discussed within natural fiber-reinforced plastic composites [38,39]. For this reason, the mechanical properties of UD WH fiber epoxy resin composites had a 60% increase.

CONCLUSION

Previous researchers that used water hyacinth fiber as a composite reinforcement in the form of stem, stem chopped, sawdust, and powder produced mechanical properties under the tensile strength of the matrix material. The use of UD WH fiber as reinforcement results in an increasing of strength of composite. The lowest tensile strength produced in this research is also higher than the highest tensile strength produced by previous researchers. Increasing the % wt. of the WH woven fibers decreased the tensile strength of the epoxy resin composites. Furthermore, the % wt. of WH woven fibers was in direct proportion to the number of pores or voids between the fibers and matrix which led to a delamination mode fracture. The rise of % wt. of fibers increases the tensile and impact strength of unidirectional WH fibers epoxy resin composite. The utilization of WH fibers obtained an increased effective reinforcement. The impact strength of composites was in direct proportion to the rise of % wt. of WH woven fibers. The mechanical properties of unidirectional WH fiber higher than mechanical properties of woven WH fiber composite.

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The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites

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Abstract:	The high growth of Water Hyacinth/ Eichhornia crassipes (WH) led to several problems such as ecosystem, irrigation, and sedimentation. The rapid growth of water hyacinth in natural rivers, reservoir, lake and canals causes drainage problems in many nations. As a result, local offices must spend significant annual budgets to dispose of water hyacinth wastes. Meanwhile, cellulose fiber from WH had a potential application in natural fiber composite (NFC). This study investigated the development and use of water hyacinth wastes for the production of unidirectional dan weaved fiber epoxy resin composites. The purpose of this research is to investigate at the mechanical and physical properties of unidirectional WH and woven fiber reinforced epoxy resin composites in variation of 0 % wt., 15 % wt., 25 % wt. and 35 % wt. of WH fibers. The WH fiber was obtained from a mechanically processed WH plants. The composites were manufactured through the hand lay-up method. The tensile and impact tests were carried out based on ASTM D3039 and ASTM D6110 respectively, while the density of composites was tested based on the Archimedes rule. The results of this study showed that increasing of % wt. of the WH woven fiber, the tensile strength of composite decrease. The impact strength of composites increases by the rise of % wt. of the WH woven fibers. The % wt. of WH woven fibers was in direct proportion to the amount of pore or void between the fibers and matrix, which led to a delamination mode fracture. Tensile and impact strength of unidirectional WH fiber increase by increasing the % wt. of WH fibers.
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The Characterization of Unidirectional and Woven Water Hyacinth Fiber Reinforced with Epoxy Resin Composites

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ABSTRACT

The high growth of Water Hyacinth/*Eichhornia crassipes* (WH) led to several problems such as ecosystem, irrigation, and sedimentation. The rapid growth of water hyacinth in natural rivers, reservoir, lake and canals causes drainage problems in many nations. As a result, local offices must spend significant annual budgets to dispose of water hyacinth wastes. Meanwhile, cellulose fiber from WH had a potential application in natural fiber composite (NFC). This study investigated the development and use of water hyacinth wastes for the production of unidirectional dan weaved fiber epoxy resin composites. The purpose of this research is to investigate at the mechanical and physical properties of unidirectional WH and woven fiber reinforced epoxy resin composites in variation of 0 % wt., 15 % wt., 25 % wt. and 35 % wt. of WH fibers. The WH fiber was obtained from a mechanically processed WH plants. The composites were manufactured through the hand lay-up method. The tensile and impact tests were carried out based on ASTM D3039 and ASTM D6110 respectively, while the density of composites was tested based on the Archimedes rule. The results of this study showed that increasing of % wt. of the WH woven fiber, the tensile strength of composite decrease. The impact strength of composites increases by the rise of % wt. of the WH woven fibers. The % wt. of WH woven fibers was in direct proportion to the amount of pore or void between the fibers and matrix, which led to a delamination mode fracture. Tensile and impact strength of unidirectional WH fiber increase by increasing the % wt. of WH fibers.

Keywords: Composite, Epoxy-resin, Water Hyacinth, Woven fiber, Unidirectional fiber.

1. INTRODUCTION

Natural fibers are a useful class of materials that are environmentally clean, renewable, and biodegradable resources. They are also used in manufacturing natural fiber composites with advantages which include low impact on the environment, renewability, inexpensive and easily degraded [1-4]. However, the use of natural fibers as a reinforcement of composites is still experiencing several

problems such as, low mechanical properties, hydrophilic properties, limited processing temperatures, low matrix and fiber binding forces that are easily degraded [5,6]. Furthermore, studies on the development of natural fiber properties were carried out by pretreating or engineering the manufacturing method [7,8].

Water hyacinth (Eichhornia crassipes) is a type of aquatic plant that floats on the surface of the water. It grows aggressively and was a nuisance on almost all continents for more than 100 years. Furthermore, its high population growth led to several problems related to ecosystem balance, decreased fish production, loss of endemic organisms and sedimentation [9-11]. Numerous studies were carried out to utilize water hyacinth plants as absorbers of heavy metals, absorbing dye waste, biofuel and biogas production, composite catalyst and reinforcing composites [12-19].

Based on previous studies, the problem associated with the utilization of WH materials for composite reinforcement includes, low mechanical strength, ease of water absorption leading to a reduced fiber bond with the matrix and weak compatibility of the WH fiber with the polymer matrix [20-22]. The results of this study show that for these composites, the mechanical properties were relatively low. Although the use of WH fiber as composite reinforcement still requires further studies, it has several advantages which include, increased acoustic, damping ability and good thermal resistance [23].

Previous researchers on the use of water hyacinth fiber as reinforcement composite still uses WH in the form of stem, stem chopped, sawdust, and powder [22, 24-26]. No research has been found that uses water hyacinth in the form of fiber or woven fibers. The use of natural fiber as a composite reinforcement, the shape of the reinforcement affects the mechanical properties of composite. This research uses water hyacinth in the form of fibers, either unidirectional or woven fibers. WH fiber can be obtained by extracting WH stem. The WH plant extraction process affected the mechanical properties of the fiber composite. This process aims to separate plant fibers from the wax, pectin, hemicellulose and lignin layers. Also, there were several methods used to extract plant fibers from the parent plant, namely: immersion, chemical methods or mechanical methods [27]. Therefore, this study aims to investigate the mechanical and physical properties of composites reinforced with unidirectional and woven WH fibers.

2. MATERIALS AND METHODS

2.1. Materials

The water hyacinth plants used, were obtained from swamps in Tanggul Village, Mijen District, Demak Regency, Central Java, Indonesia with 50-70 cm length of stems. These plants were mechanically extracted to yield the WF fibers (Figure 1). The fiber extraction was carried out by brushing the WH stems using an iron brush. The fiber is then dried in the sun. After that, 10 strands of the dry WH fibers were twisted to produce yarn (Figure 2). The water hyacinth yarns were prepared by yarn craftsmen using a traditional yarn spinner. The WH yarns were then woven using a loom. The weaving process was carried out by traditional cloth craftsmen. This process produced WH mat with dimensions of 30 x 40 cm with

direction of yarn 0°/90° (Figure 3). The natural composite was manufactured using epoxy Bakelite® EPR 174 and resin hardener V-140 as a matrix.

2.2. Preparation of Composites

The hand lay-up method was used to fabricate the unidirectional WH fiber composite and woven WH composites. This was conducted by applying an epoxy-resin matrix to the WH fibers in the mold specimens with dimension of 30 x 40 cm using a paintbrush and roller. The composite tensile and impact test specimens were manufactured in variations of the WH fiber reinforcement of 0%, 15 %, 25 % and 35 % wt. The coding of these specimens is shown in Table 1.

Table 1. Specimens testing code

Code	Meaning
E(0)	Epoxy – resin, 0 % WH fibers
E(15)	Epoxy – resin, 15 % WH fibers
E(25)	Epoxy – resin, 25 % WH fibers
E(35)	Epoxy – resin, 35 % WH fibers

Afterward, the composites were compressed and vacuumed to remove voids and obtain a smoothen surface. After removing the produced composite specimen from the mold, specimens of appropriate dimensions were made in accordance with ASTM D3039 requirements. Water jet cutting technique is used for cutting the test specimen as per the required shape. The test specimen having dimension of length 250 mm, width of 25 mm and thickness of 3 mm were prepared for tensile testing.

Figure 1. Water Hyacinth Fibers

Figure 2. Water Hyacinth Yarn

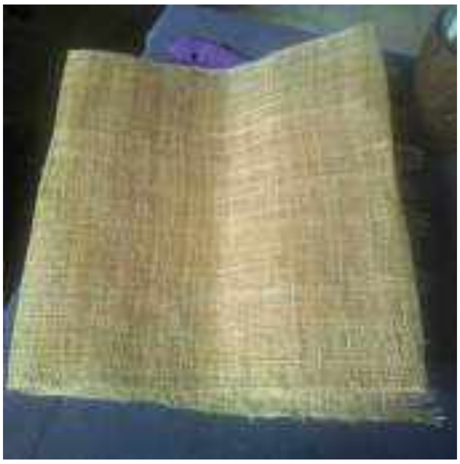


Figure 3. Water Hyacinth Woven Yarn

2.3. Characterization of Composites

The actual density of composites was measured using a densimeter based on Archimedes law according to ASTM D792. According to ASTM D2734 the porosity can be obtained by the relative difference between theoretical density of composite and measured density of composite (ρm). The density of composite (ρm) can be measured through water buoyancy by Archimedes Principle (ASTM D792). This leads to the following equation for calculation of the porosity (eq. 1).

$$\text{Porosity} = 100 - \rho m\{(Wr/\rho r) + (Wf/\rho f)\} \quad (1)$$

where W and ρ represent the weight percentage and the density, and r and f stand for resin and fiber, respectively.

The tensile test of composites was carried out according to the ASTM D3039 standard (Figure 4). Furthermore, the impact tests were carried out through the Charpy methods according to the ASTM D6110 standard. Figure 5 shows the

dimensions of the impact test specimens. Six identical test specimens were prepared for tensile and impact test to ensure the uniformity of the test. Scanning Electron Microscopy (SEM) was used to investigate the tensile test fracture surface of the composite.

Figure 4. Dimension of Tensile Test Specimen

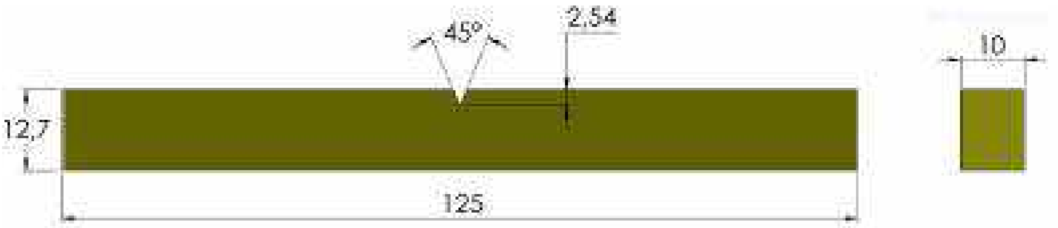


Figure 5. Dimension of Impact Test Specimen of Composite

3. RESULTS AND DISCUSSIONS

The density and porosity test results in Figure 6, shows that both the unidirectional and woven composites increased in mass fraction, while 0, 15, 25 and 35 % wt. increase in the porosity of the composites was observed. Furthermore, figure 6 also shows that for the woven fiber composite, there was an increase in porosity almost linearly from 0.35% to 13.82% with the addition of 35% fiber. The unidirectional WH fiber composite, increased from 15 % to 35 % wt., afterwards, the porosity did not increase significantly. Composites woven fibers also provided more voids than composites UD fibers. For woven fibers, the voids form inside tows, in resin-rich regions or at tow corners, and between plies in composites. Meanwhile, for UD fibers, the voids form within and between the plies [28, 29]. The difference in the direction of the fibers for the composites woven fiber leads to air entrapment and increased porosity. The main source of air entrapment is the inhomogeneous fiber architecture, which leads to a non-uniform fiber permeability carried out with subsequent local variations in resin velocity [30].

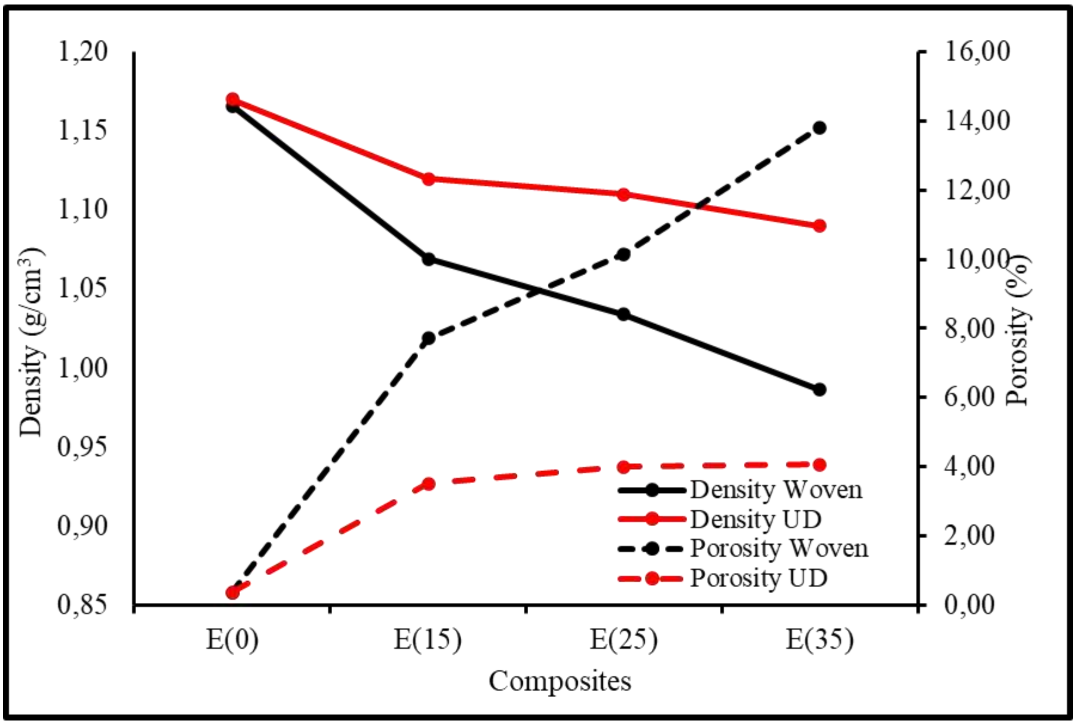


Figure 6. Density and Porosity of WH fibers Composites

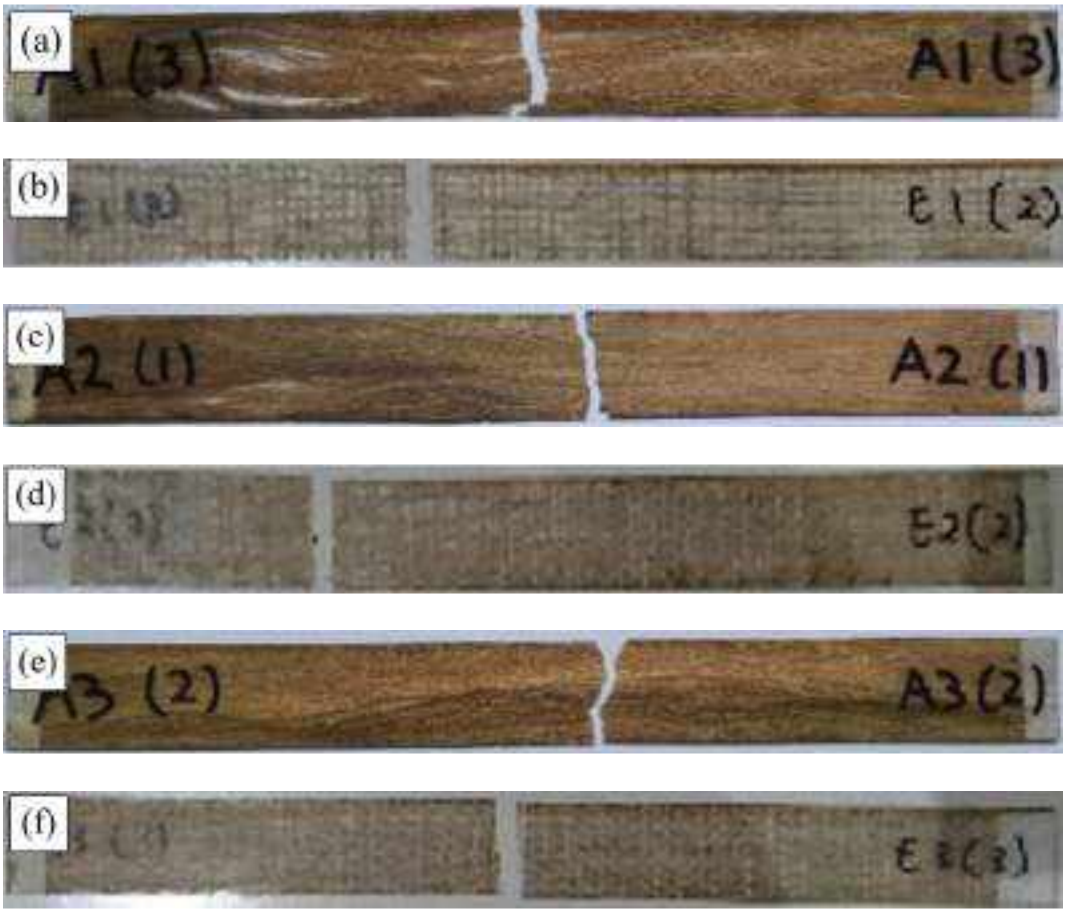


Figure 7. Fracture specimens (a) 15 % unidirectional WH fiber composite (b) 15 % WH woven fiber composite (c) 25 % unidirectional WH fiber composite (d) 25 % WH woven fiber composite (e) 35 % unidirectional WH fiber composite (f) 35 % WH woven fiber composite

Figure 7 shows the specimen after it was tensile tested, with fracture in the gauge length area. Figure 8 shows the tensile test results of the woven and unidirectional WH fiber composites reinforced with epoxy resin. The tensile strength of the woven WH fiber composite was in inverse proportion to the percentage of WH fibers in the composite. An increased fiber mass fraction from 0 to 15%, led to an insignificant decrease in the tensile strength of the composite. Furthermore, with a 35% addition, for every 10% increase in fiber mass fraction, the tensile strength of the composite decreases by about 11-13%. Composite elongation also decreased with the increase in % wt. of WH woven fibers, which also showed that its tensile strength was in direct proportion to the percentage weight of the WH fiber. This tensile strength increased by approximately 10% as the % wt. of WH fibers increased from 15% to 25%. For addition of 35% wt. of WH fiber, the tensile strength of composites increased by about 37%. Compared to the tensile strength of epoxy resin, the composite tensile strength of 35 % wt. for unidirectional WH fiber increased from 41 MPa to 60 MPa or by about 46 %. Furthermore, the lowest composite tensile strength for WH fibers in this study was 30 MPa for woven WH fibers composites containing 35% wt. This result was higher than that of Saputra et al., which discovered that the highest tensile strength was 28.36 MPa [31]. Figure 9 shows the specific tensile strength of composites, which shows that there were no significant differences in the tensile strengths of WH woven fibers composites. Furthermore, reinforcement by WH fibers compensates for the decreasing tensile strength of the composite from porosity. The UD WH fiber composites of 35 % wt., increases in specific tensile strength by about 60 %, which means that, it is in direct proportion with the specific tensile strength of composites.

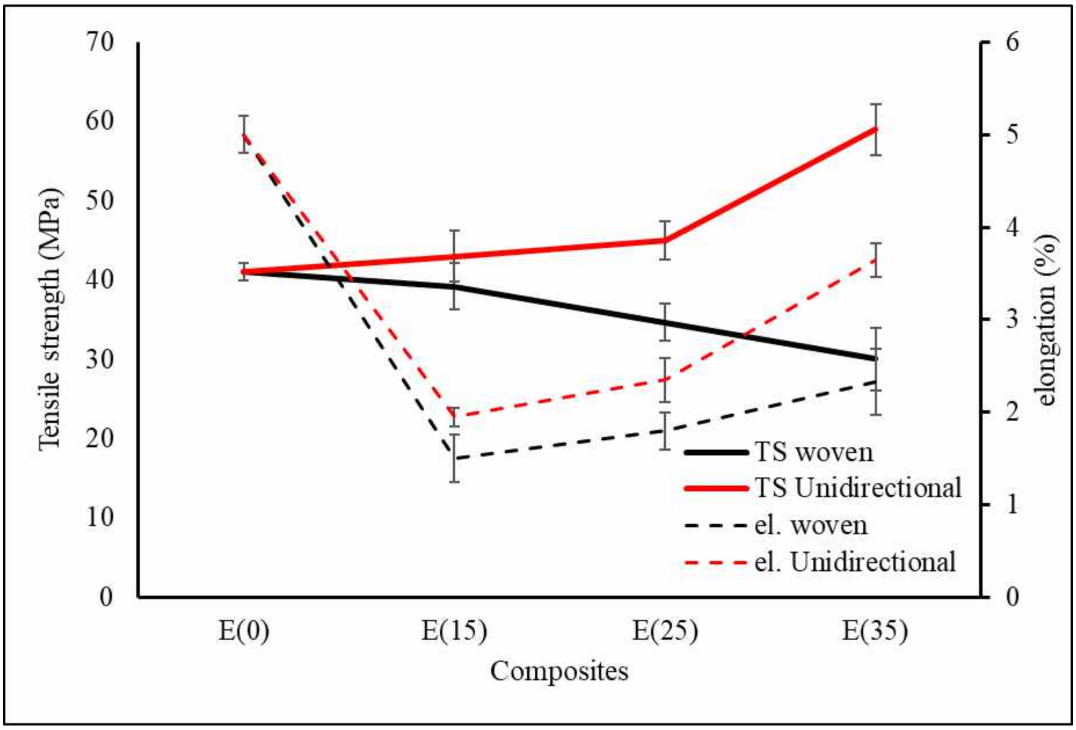


Figure 8. Tensile strength and elongation WH Fibers Reinforced Epoxy-Resin

The single fiber of water hyacinth has a tensile strength of around 105 - 313 MPa [32]. The results of the tensile test show that woven water hyacinth did not provide an effect of increasing strength on uniaxial tensile loads. Furthermore, the increased mass percentage of the WH reinforcing fibers led to increased composite porosity. A larger volume of woven reinforcing fibers leads to an increase in voids [30, 33], due to the pores being trapped causing a void between the matrix and fibers [34]. The increasing porosity also caused by the incomplete infiltration of resin in the hand lay-up process. Voids of composite produce stress concentration on the matrix. For the longitudinal fibers, voids lead to the potential change in stress transfer and redistribution and the cracking of the transverse plies [28]. The voids between fiber and matrix lead to a fiber pull-out fracture as shown in Figure 11a, 11b and 11c.

Composites had an increased tensile strength due to the unidirectional properties of the WH fiber. The unidirectional fiber has a higher percentage of fiber in the direction of tensile load than woven fiber. Based rule of mixture theory, higher % wt. of fiber on axis direction of load yields higher values of tensile strength than the combination of axial and transversal fiber direction in woven fiber. Additionally, an increase in the percentage weight of these fiber composites also improves tensile strength. This is coherent with the density and porosity test results in Figure 6, which shows that the composites with directional woven fiber exhibited a significant increase in porosity as the fiber percentage weight is increased. The porosity of UD WH fiber composites remained constant as the weight percentage of WH fibers increased. Hence, composites with directional woven fiber increased in % wt. and porosity significantly.

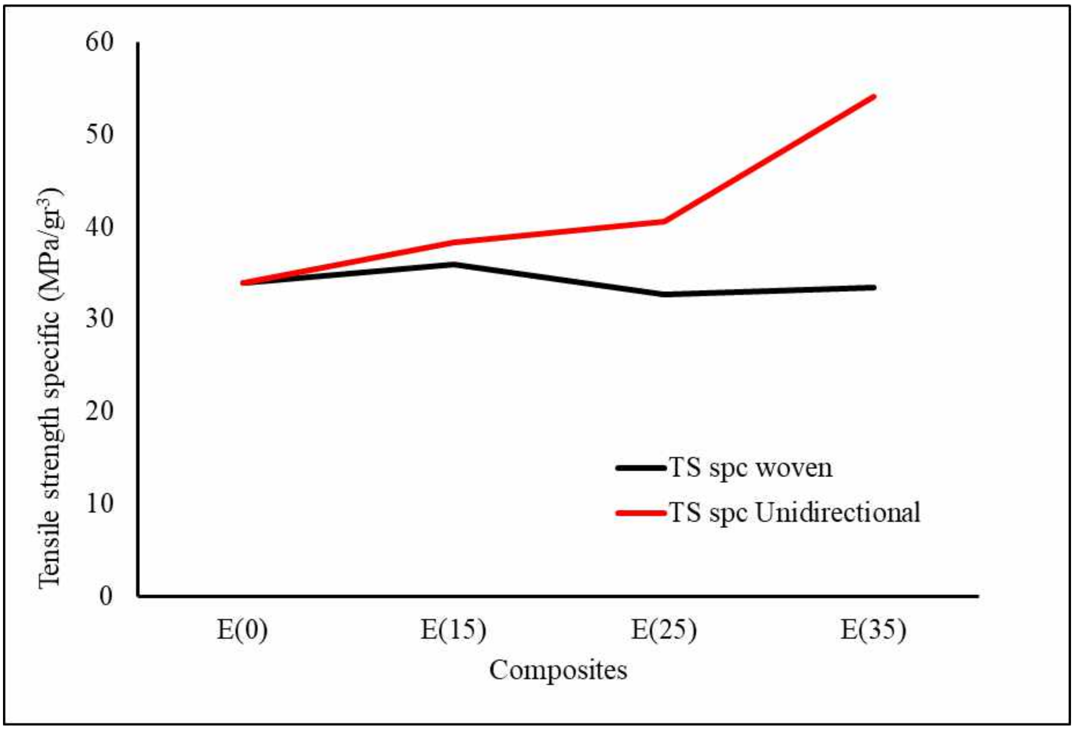


Figure 9. The specific tensile strength of WH Fiber Reinforced with Epoxy-Resin

Figure 10 shows the impact strength of WH fiber reinforced with epoxy-resin. This composite strength was in direct proportion to WH fiber rise of % wt. Increasing of % wt. of UD fiber from 0 % to 35 % wt., increase the impact strength of composite about 28 %. The impact strength of woven fiber composite increases about 22 % when the % wt. of fiber increase from 0 % to 35 % wt. The highest impact strength is about 0.82 kJ/cm^2 at the UD fiber composite with 35 % wt. of fiber. Figure 10 also shows specifics impact strength of composite. Graph in Figure 10 shown that specific impact strength of composite with 35 % wt. woven WH fiber higher than specific impact strength of 35 % wt. of UD composite. The porosity on woven composite produced lighter composite than UD composite. Woven WH fibers increase the impact strength of the composite and produce a tougher composite. Woven WH fibers have good ability to absorb large share kinetic energy so fibers role should be crack stopper [35]. The UD composite fibers break at the impact axis and the failure of the woven specimen is caused by shear stress [36]. The increase in composite impact strength is due to the interface strength between the woven WH fiber and epoxy - resin matrix contributes to the transfer load from the matrix fiber. This characteristic allows the WH fiber composites to absorb more energy. The fiber flexibility that slides out of the matrix did not break but increased the energy needed to rupture the specimen [37].

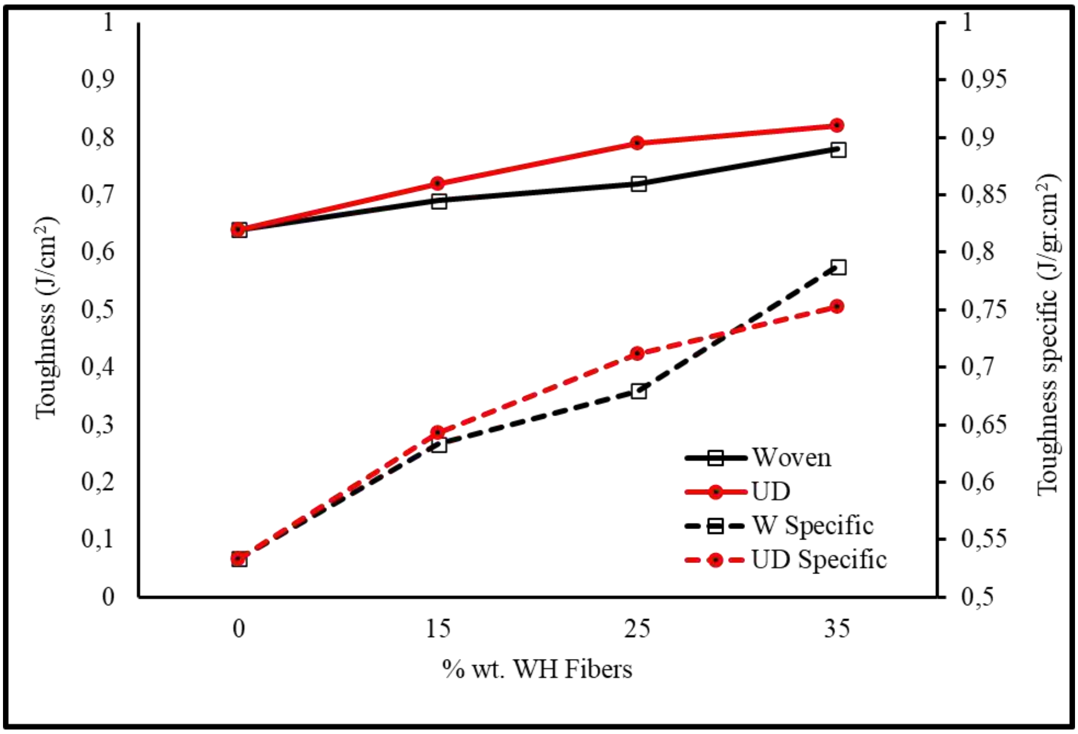
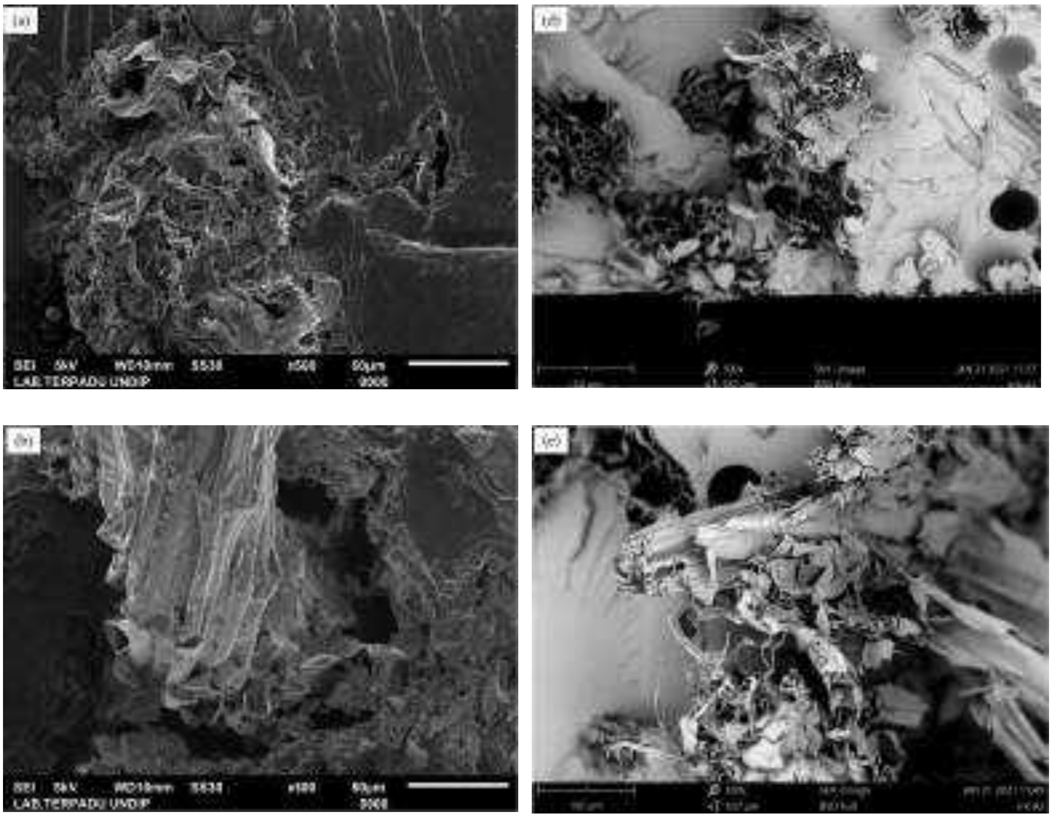


Figure 10. Impact Strength of Composites WH Fibers reinforced Epoxy-Resin



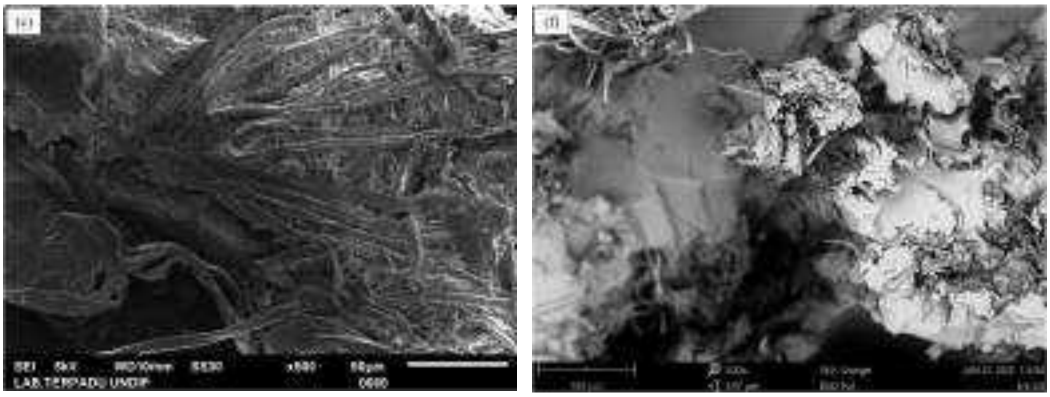


Figure 11. SEM Micrograph Surface Fracture of Composites (a) 15 % WH woven fiber composite (b) 25 % WH woven fiber composite (c) 35 % WH woven fiber composite (d) 15 % unidirectional WH fiber composite (e) 25 % unidirectional WH fiber composite (f) 35 % unidirectional WH fiber composite.

Furthermore, the SEM photomicrographs of the fracture surface were used to analyze the WH fiber and matrix adhesion in the composites. The cross-section of these tensile-tested specimens was selected for analysis. Figure 11.a – 11.f shows the fracture surface SEM images of the WH fiber-reinforced epoxy resin composite. Meanwhile, figure 11.a, 11.b and 11.c shows the samples with 15, 25, 35 % of WH woven fiber. Figure 11.d, 11.e and 11.f shows the composite with 15, 25, 35 % of UD WH fiber. From the fractographic examinations by SEM, the fracture behavior of composite was brittle. Some pores, which originated from the fiber pull-out phenomena were found in all cases, while fracture phenomena were also observed in the UD WH fiber. SEM images showed that the WH fiber and epoxy resin were mechanically bound, however, there was no chemical bonding between the WH fiber and epoxy resin. Furthermore, similar natural fiber and polymer adhesion were experimented with and discussed within natural fiber-reinforced plastic composites [38,39]. For this reason, the mechanical properties of UD WH fiber epoxy resin composites had a 60% increase.

CONCLUSION

Previous researchers that used water hyacinth fiber as a composite reinforcement in the form of stem, stem chopped, sawdust, and powder produced mechanical properties under the tensile strength of the matrix material. The use of UD WH fiber as reinforcement results in an increasing of strength of composite. The lowest tensile strength produced in this research is also higher than the highest tensile strength produced by previous researchers. Increasing the % wt. of the WH woven fibers decreased the tensile strength of the epoxy resin composites. Furthermore, the % wt. of WH woven fibers was in direct proportion to the number of pores or voids between the fibers and matrix which led to a delamination mode fracture. The rise of % wt. of fibers increases the tensile and impact strength of unidirectional WH fibers epoxy resin composite. The utilization of WH fibers obtained an increased effective reinforcement. The impact strength of composites was in direct proportion to the rise of % wt. of WH woven fibers. The mechanical properties of unidirectional WH fiber higher than mechanical properties of woven WH fiber composite.

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Code	Meaning
E(0)	Epoxy – resin, 0 % WH fibers
E(15)	Epoxy – resin, 15 % WH fibers
E(25)	Epoxy – resin, 25 % WH fibers
E(35)	Epoxy – resin, 35 % WH fibers

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