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The Effect of Mesh Size on Mechanical and Thermal Properties of Bamboo Composites

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Abstract

Bamboo is a material from nature that can be engineered as biomaterial. One of its engineering results is composite. Bamboo composite can be an alternative of Styrofoam for food packaging. The foam material is containing styrene that its exposure can contaminate food packed. The objective of the research is to investigate the feasibility black bamboo-composite as a cool-box material. In this research, there were three sizes of mesh 40, 30 and 20. The materials were composed of 30% black bamboo fiber and 70% SHCP 2668 resin. Six sheets of composite were combined using adhesive. The several tests performed are tensile test, compressive test, impact test, and thermal conductivity test based on ASTM D638, ASTM D6411, ASTM D6110, and ASTM C1004. The mesh size of 40 has the highest tensile test, compressive test, and impact test where the value is 17.4 MPa, 54.13 MPa, and 0.085 Joule/mm^2 respectively. Mesh size of 20 has the best thermal conductivity where the value is 7.36 W/m.^{o}C. Cool-box testing on mesh 20, 30, 40 compared with the same dimensions was given box styrofoam with a temperature of -2 ^{o}C. The results of the coolbox composite test against a mesh size of 20 have slower ice cube melting compared to mesh 30 and 40.

***Keywords**: Coolbox composite of black bamboo fiber; tensile test; compressive test; impact test; thermal conductivity test*

1. INTRODUCTION

Nowadays, the use of polystyrene foam or styrofoam is very common in society, especially for food packaging and cool-box. Polystyrene foam, or known as Styrofoam, is often misused by the public. Styrofoam is a trading name whose patents are owned by the Dow Chemical Company (1). In that factory, it was produced to be used as an insulator for building. Styrofoam was chosen as a food package because it is able to maintain the food temperature in hot or cold, remained comfortable to handle, could keep the freshness and integrity of packaged food, and light. Off its advantages, Styrofoam has a negative effect. It is difficult to be composed by the soil. Therefore, its waste can pollute the environment. If styrofoam is used continuously in on a large scale, it will disturb ecosystem sustainability. Besides, it cannot be decomposed by soil; styrofoam used waste will accumulate in landfills without being recycled. Therefore, alternative materials are needed to replace the foam material (1).

Composite material technology is being developed currently. Various types of materials have been widely used and studied to get the properties of appropriate material and according to requirement. Composite materials have advantages compared to metal materials which are better corrosion resistance compared to metals and for certain composite materials have better strength and stiffness

The development of composite materials is not only based on synthetic fibers, but natural fibers can be used as a substitute for synthetic composites and make it a renewable natural composite. Thereby, it can reduce the level of environmental contamination (2). One of the natural fibers is bamboo. Bamboo can grow without having to be planted and it grows anywhere since it has excellent mechanical properties. By its natures, bamboo is appropriate for base composite material application (3). The bamboo price cheaper than the price of other natural materials. Natural fiber composites such as bamboo is renewable, recyclable and biodegradable in the environment. However, bamboo fiber contains high sugar content of 42,4-53.6%, lignin 19,8-26.6% and moisture content of 15-20%. Bamboo fiber also has tangled properties and easy to absorb water (4). Therefore in this research, a composite of black bamboo fiber is composed to obtain the mechanical properties and thermal conductivity in cool-box application.

2. MATERIAL AND METHODS

Composite is a combination of two or more materials that have new properties. This combination forms mechanical bonds with macroscopic and heterogeneous homogeneous structures. The mixture material will produce a new material that has superior properties than the forming material. By combining two or more different materials, the mechanical and physical properties of these materials can be improved and developed including strength, stiffness, corrosion resistance, friction resistance, thermal conductivity, electrical insulation, fatigue resistance, weight, appearance, and heat insulation. Composite property is a combination of reinforcing material and matrix material in the calculation of volume fraction which is written as follows: composite properties = (amplifier properties × amplifier volume fraction) + (matrix properties × matrix volume fraction). However, the fact is not in accordance with the theory stated, because at the time of composite formation is influenced by several factors including the interaction of the matrix with the reinforcement, the interaction of the matrix with the catalyst, the interaction with environmental temperature (5).

Black bamboo has a density between 0,40-0,62 g/cm^3; dry air content of 12-13%; air shrinkage of 4-15%; The static bending firmness of MOE 85170,96 kg/cm^2, and MOR 278,19 kg/cm^2, pressure parallel 329.74 kg/cm^2, shear force 27,27 kg/cm^2, and pull parallel 434,94 kg/cm^2. Wulung Bamboo has chemical components, there are lignin content 32,35%, pentosan 18,50%, holocellulose 63,32%, alphacellulose 42.32%, hemicellulose 21%; solubility in cold water 3,41%, in hot water 5,14%, in alcohol benzene 2,24%, in NaOH 1% 17,42%; while the water content is 9,61%, ash is 2,94%, and silica is 1,55%, and starch content is 11,90% (6).

SHCP (Singapore Highpolymer Chemical Product) is one type of polyester resin that has non-thixotropic properties and has a clear appearance. SHCP 2668 shows that the mixing of fibers is good for impregnation and shows an excellent transparency effect on the product. SHCP 2668 has the characteristics of a clear appearance, viscosity at temperatures of 30^{o}C 6-9ps, acceleration (6% Cobalt) of 0,5%, time at 30^{o}C 8-12 minutes, curing time at 30^{o}C 20-40 minutes and has an exothermic peak temperature of 130-140 ^{o}C (7).

One method for making composites is the hand lay-up method. This method is done by placing the reinforcement in a mold and the liquid resin that has been mixed with the catalyst is poured over the reinforcement. The reinforcement and the still wet resin are manually rolled to remove air bubbles, distribute the resin evenly and to assist the absorption of the resin into the reinforcement. This procedure is conducted with the desired thickness. Thereafter, the structure is allowed to dry and harden (the polymerization process) (8).

A tensile test is one of the mechanical tests to determine the strength of the material against the tensile force. In this tensile test, the value of tensile strength, modulus of elasticity and strain value are obtained (9). This tensile test follows the ASTM D638 standard and for specimens based on type I (10).

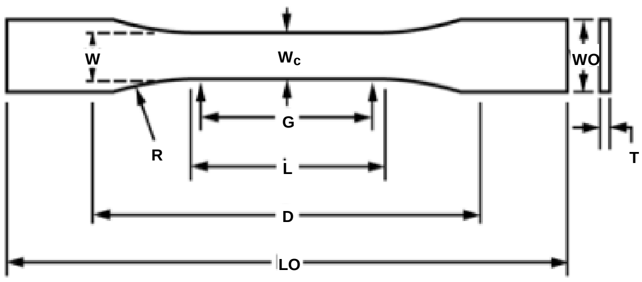


Figure 1. Tensile Test Specimen of ASTM D638 Type I [10]
Source: ASTM D 638 for Standard Test Method for Tensile Properties of Plastics

A compressive test is used to determine the compressive strength value of a composition. The compressive loading occurs on a material which in turn needs to know how compressive strength must be prepared. It is also to know the compressive strength of a material in order to know the maximum loading limit (11). Compressive testing follows the ASTM D6641 standard with the following size specifications (12).

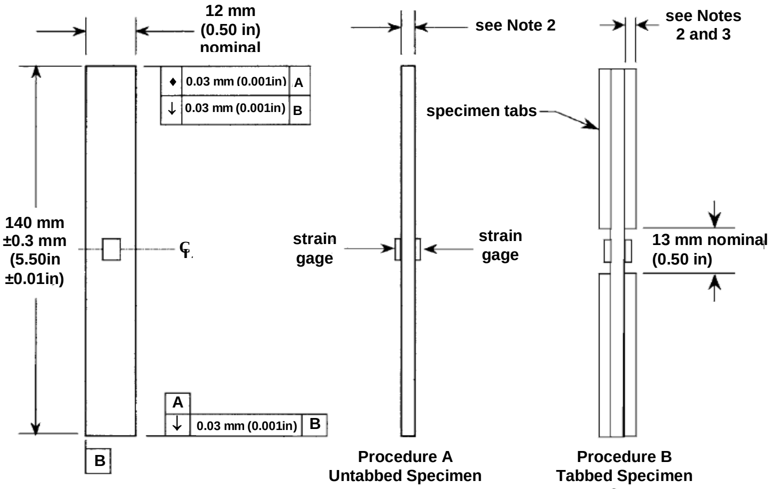


Figure 2. Specimens and Dimensions of Compressive Test Specimens [12]
Source: ASTM D6641 for Standart Test Method of Compressive Test

Impact testing is a test to determine the mechanical properties of material toughness. This test is conducted to determine whether the material has clay, ductile, or brittle properties (13). This impact test follows the ASTM D6110 standard with images and specimen sizes (14).

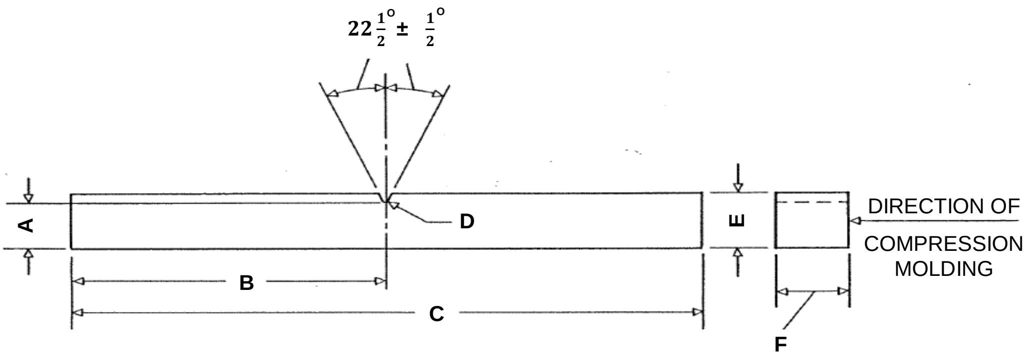


Figure 3. Impact Test Specimens (14)
Source: ASTM D 6110 for Standard Test Method Charpy Impact

Thermal conductivity testing is conducted to determine the value of the thermal conductivity in a composite material. In this test, the material placed between two plates and treated with a specific temperature on one side. The measurement for temperature is conducted in 4 points, starting from the heating point to the end of the plate (15).

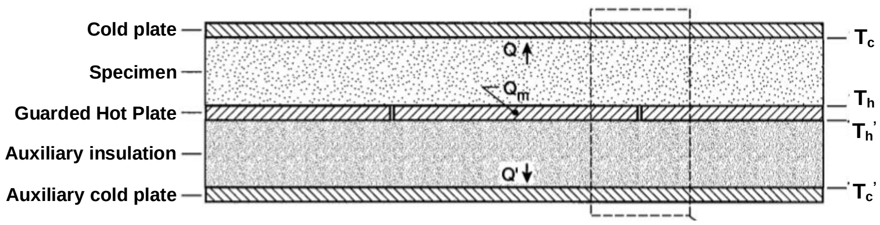


Figure 4. Thermal Conductivity Testing (15)
Source: ASTM C1044 for Standard Practice for Using a Guarded-Hot-Plate Apparatus or Thin-Heater Apparatus in the Single-Sided Mode

Figure 5. Thermal Conductivity Testing Method

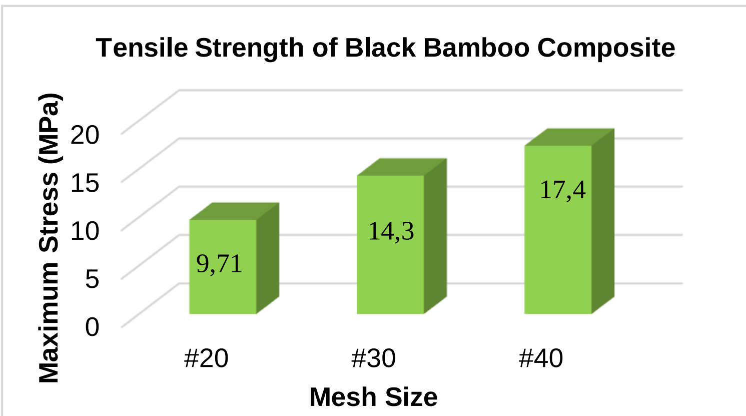
Where:

A: Infrared thermometer 1
B: Infrared thermometer 2
C: Infrared thermometer 3
D: The specimen that will be thermal tested
E: Heat source

Adhesive bonding is a method to connect the side sheets of the composite being a box using epoxy adhesive. Many parts and components can be combined and assembled with glue with one or more of the adhesive methods. Adhesives are available in various forms: liquid, paste, solution, emulsion, powder, tape, and film. When it is applied, the adhesive is usually around 0.1 mm - 0.5 [16]. The adhesive which used is epoxy resin.

3. RESULT AND DISCUSSION

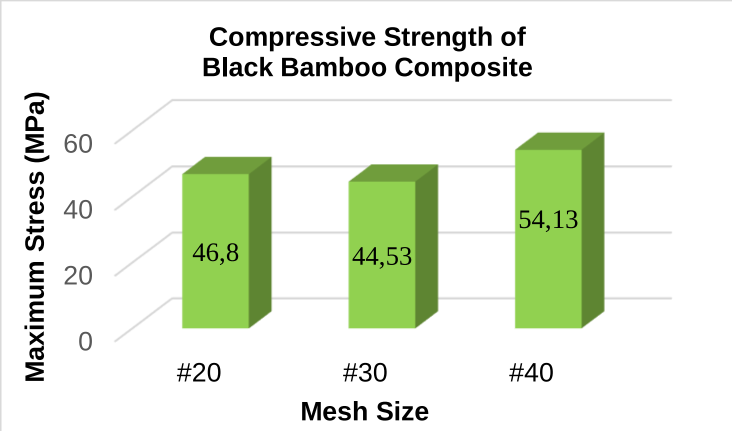
From the results of data processing, the values of tensile stress, modulus of elasticity and strain were obtained in each sample. Black bamboo composites in mesh 40 has a tensile strength of 17,4 MPa with an elastic modulus of 2228,71 MPa and a strain value of 1,50%. Mesh 30 has a tensile strength of 14,3 MPa with the elastic modulus of 1647,34 MPa and a strain of 1,64%. Mesh 20 has a tensile strength of 9,71 MPa with a modulus of elasticity of 1999,65 MPa and a strain of 0,99%.



Graphic 1. Stress graph - mesh size from tensile testing results

Graphic 1 shows the influence of mesh size on the tensile strength of black bamboo composite materials. The larger of mesh size will be smaller fiber size and increase the tensile strength of the composite material

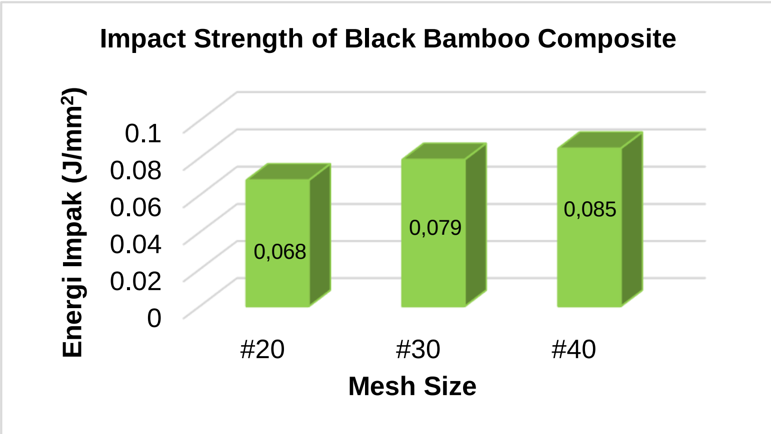
From the results of data processing, the values of compressive stress, modulus of elasticity and strain were obtained in each sample. Obtained compressive strength values on black bamboo composites in mesh 40 has a compressive strength of 54,13 MPa with a modulus of elasticity of 38982,4 MPa and strain value of 13,31%. Mesh 30 has a compressive strength of 44.53 MPa with the modulus of elasticity of 72251,72 MPa and strain of 14.23%. Mesh 20 has a compressive strength of 46.8 MPa with a modulus of elasticity of 54435,03 MPa and a strain of 12,02%.



Graphic 2. Stress graph - mesh size from compressive test results

Graphic 2 shows the influence of mesh size on the compressive strength of black bamboo composite materials. The larger the mesh size will be smaller fiber size and increase the compressive strength of the composite material. However, mesh 30 shows the lowest compressive strength value.

From the results of data processing, the impact value, modulus of elasticity, and strain were obtained in each sample. Obtained the impact strength value on black bamboo composites in mesh 40 has an impact strength of 0,085 Joule/mm^2 with fracture energy of 13,87 Joules. In mesh 30 has an impact strength of 0,068 Joules/mm^2 with broken energy of 11,12 Joules.



Graphic 3. Stress graph - mesh size from impact test results

Graphic 3 shows the influence of mesh size on impact strength on black bamboo composite materials. The larger the mesh size will be smaller fiber size and increases the impact strength of the composite material.

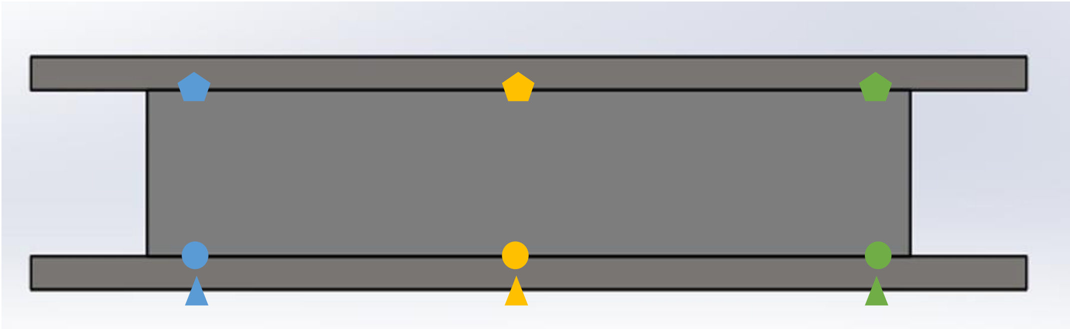
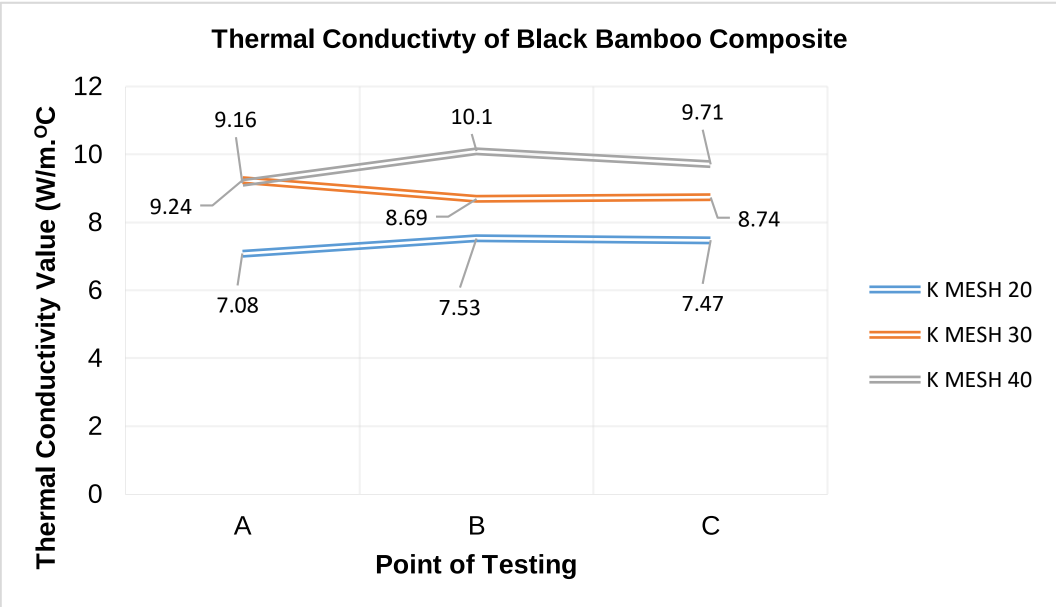


Figure 6. Thermal Conductivity Test

Where:

▲ : Point of Testing A
● : Point of Testing A'
⬟ : Point of Testing A''
▲ : Point of Testing B
● : Point of Testing B'
⬟ : Point of Testing B''
▲ : Point of Testing C
● : Point of Testing C'
⬟ : Point of Testing C''

The results of the average thermal conductivity testing and the heating value in mesh 20 have a thermal conductivity value of 7,36 W/m.ºC with the heat of 126,27 Joules. In mesh 30 has a thermal conductivity value of 8,89 W/m.ºC with heat of 151,21 Joules. In mesh 40 has a thermal conductivity value of 9,65 W/m.ºC with heat of 164,29 Joules.



Graphic 4. Graph of thermal conductivity at several points - mesh size

Graphic 4 shows the influence of the mesh size on the mesh size on the black bamboo composite. The smaller the mesh size, the bigger the fiber size and increase the value of thermal conductivity between mesh sizes 30 and 40.

The cool-box composites were made from the side sheets of the cooler box which are assembled using the adhesive bonding method within epoxy resin is a box as depicted in Figure 7.

Figure 7. Composite Results of Cooler Boxes

Testing was conducted by placing ice cubes in each cooler. The temperature measurement was performed two times, which after four and three hours. From the test results, the comparison value of the volume of melting ice and cold temperatures in the mesh 20, 30 and 40 with the comparison of the cool-box made of styrofoam material.

Table 1. Coolbox Composite Test Results

Coolbox	Melting Ice Volume (4 Hour)	Wall Temperature	Melting Ice Volume (7 Hour)	Wall Temperatur
Styrofoam	140 ml	24,6 °C	80 ml	24,6 °C
Mesh 20	200 ml	18,6 °C	82 ml	18 °C
Mesh 30	212 ml	20,4 °C	90 ml	20 °C
Mesh 40	220 ml	21,3 °C	96 ml	22,2 °C

Figure 8. The condition of the ice cubes on some mesh coolboxes composite and box styrofoam after 4 hours

Figure 8 shows that the ice cubes in the styrofoam box are still better in frozen condition compared with the cooler boxes in several meshes. The second better is coolbox composite in mesh 20, and the worse ice melting is in mesh 40.

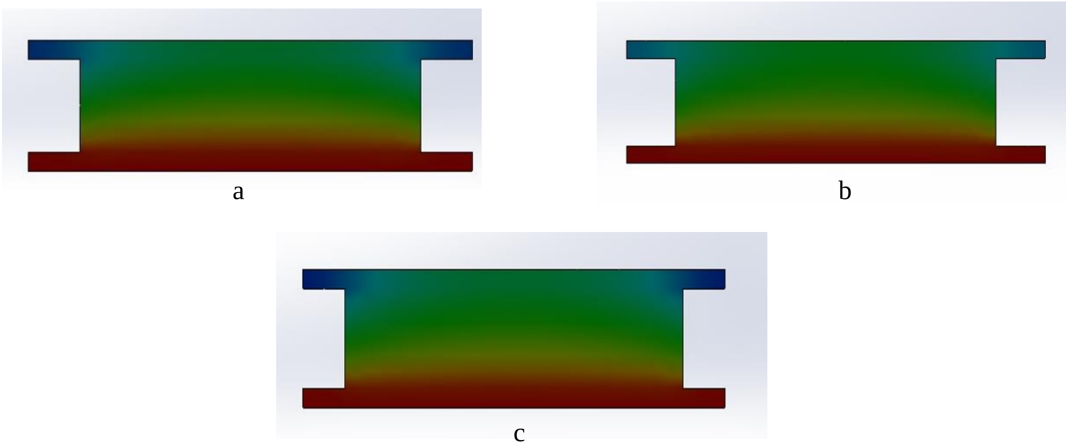


Figure 9. (a) Picture of simulation thermal conductivity in mesh 20, (a) Picture of simulation thermal conductivity in mesh 30, (a) Picture of simulation thermal conductivity in mesh 40

Figure 9 shows the simulation result of the heat spread using a SolidWorks application. The heat spread of mesh 20 looks like with mesh 30 and mesh 40.

Cool-box simulation used Solidworks application with a dimension of 1:1. The simulated condition is the cooler in a closed condition with ignoring heat from outside the cool-box

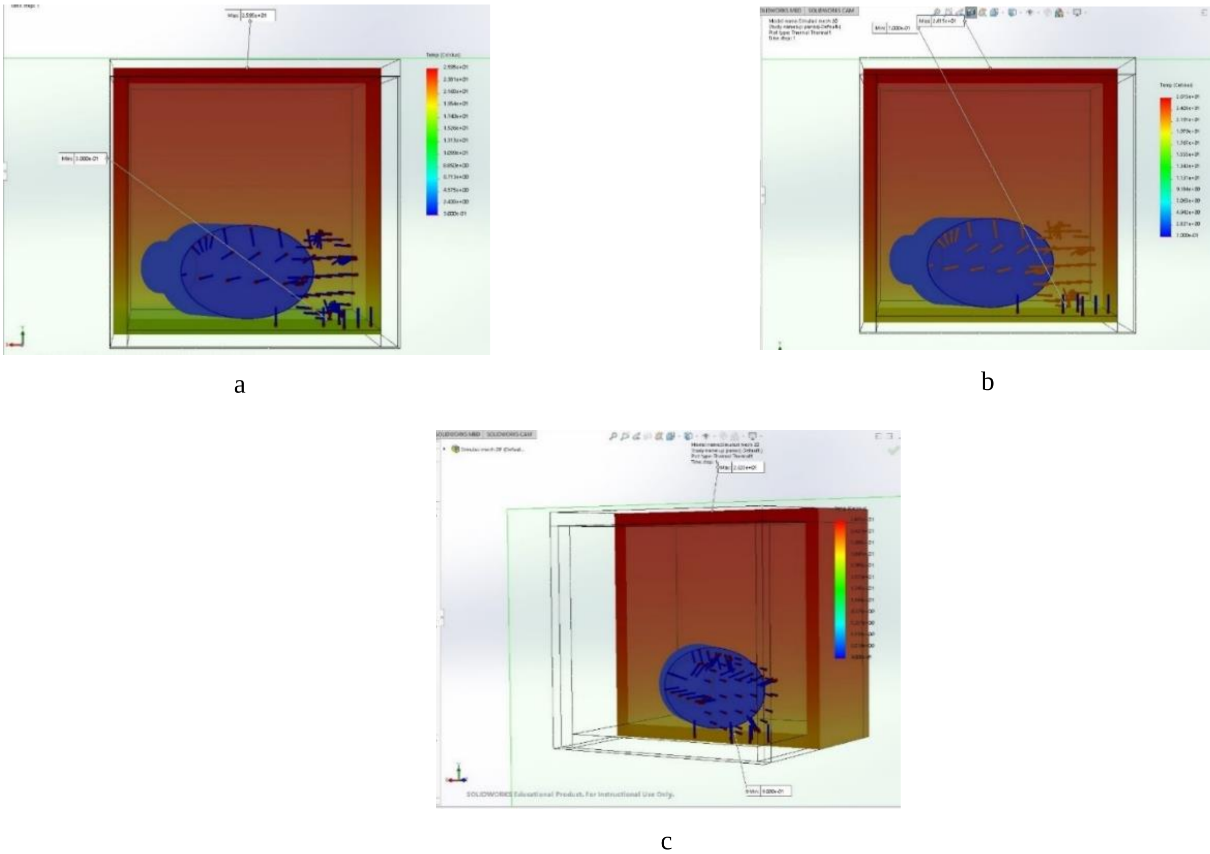


Figure 10. (a) Simulation picture of composite cool-box in mesh 20, (b) Simulation picture of composite cool-box in mesh 30, (c) Simulation picture of composite cool-box in mesh 40

In Figure 10, the spread of heat appears in composite cool-box of mesh 20. The heat distribution is seen from the change in color on the base of the cooler to green to yellow. When the color of the cooler turns red then the temperature is the same as the room temperature

4. Conclusion

Based on the experiment result, some conclusions are obtained, including the following:

1. There was an influence on the mesh size of bamboo fiber on the mechanical properties value of the tensile, compressive and impact strengths, which are the smaller the size of the fiber, there will be a homogeneous bond between the reinforcement and the matrix, so it causes more mechanical strength and prove the mechanical strength values as follows:
   a. The tensile strength of mesh 20 is 9.71 MPa, mesh 30 is 14.3 MPa, and mesh 40 is 17.4 MPa
   b. The compressive strength of mesh 20 is 46.8 MPa, mesh 30 is 44.53 MPa, and mesh 40 is 54.13 MPa.
   c. The impact strength of mesh 20 is 0.068 J/mm2, mesh 30 is 0.079 J/mm^2, mesh 40 is 0.085 J/mm^2.
2. There was an influence on the mesh size of bamboo fiber on the value of thermal conductivity is the more significant the size of the fiber, it is better to save the temperature of the heat, and it is proven on the thermal conductivity value as follows:
   a. The thermal conductivity at mesh 20 is 7.36 W / m.^{o}C
   b. The thermal conductivity at mesh 30 is 8.66 W / m.^{o}C
   c. The thermal conductivity at mesh 40 is 9.66 W / m.^{o}C.
3. The composite cooler was made with a ratio of 30% black bamboo fiber and 70% SHCP resin 2668. Composite was made into sheets consisting of 6 sides which are then coated on the surface using epoxy resin, and adhesive bonding is done by connecting the sides of the composite sheets. The cooler box is given rubber on the inside on the top side to reduce the air entering the composite cooler box.
4. The test results of ice-cooled boxes on mesh 20, 30 and 40 proved that mesh 20 was better at storing cold temperatures compared to mesh 30 and 40.

References

1. F. Kalanzi, C. Mwanja, H. Agaba, and R. T. Guuroh, “Potential of Bamboo as a Source of Household Income in South Western Uganda,” vol. 16, no. 1, pp. 33–45, 2017.
2. D. A. Porwanto and L. Johar, “Characterization of Bamboo Fiber and Fiber Glass Composite as an Alternative Raw Material for Industry,” *ITS Libr.*, 2011.
3. B. Hirmawan, J. M. Lizda, and I. Doty, “Sifat Mekanik Komposit Serat Bambu Akibat Pengaruh Musim Hujan Dengan / Tanpa Pelapisan,” *Inst. Sepuluh Novemb.*, pp. 1–8, 2013.
4. S. A. Irianto, “PENGARUH FRAKSI VOLUME BILAH BAMBU TERHADAP KEKUATAN IMPACT KOMPOSIT BILAH BAMBU / POLYESTER,” 2016. .
5. Sulistijono.Prof.Dr.Ir, *Mekanika Material Komposit*, Pertama. Surabaya: ITS Press, 2012.
6. E. Sutardi, Sri Rulliaty. Nadjib, Nurwati. Muslich, Muhammad. Jasni. Sulastiningsih I M. Komaryati, Sri. Suprapti, Sihati. Abdurrahman. Basri, *Informasi Sifat Dasar dan Kemungkinan Penggunaan 10 Bambu*. Bogor: PUSAT PENELITIAN DAN PENGEMBANGAN HASIL HUTAN BADAN PENELITIAN, PENGEMBANGAN DAN INOVASI KEMENTERIAN LINGKUNGAN HIDUP DAN KEHUTANAN, 2015.
7. S. Highpolymer, “SHCP 2668 CM-M POLYESTER RESIN FOR SHEET LAMINATING.”
8. P. Frederik, “Karakterisasi Sifat Mekanik Komposit Penguatan Bambu Hasil Fabrikasi Dengan Metode Hand Lay Up,” Jakarta, 2007.
9. Purnomo, *Material Teknik*, Pertama. Malang: CV. Seribu Bintang, 2017.
10. ASTM, “Standard Test Method For Tensile Properties Of Plastics 1,” *ASTM D 638*, Pp. 4–7, 2015.

11. S. Hadi, *Teknologi Bahan*. Yogyakarta: ANDI Yogyakarta, 2016.
12. ASTM, “Standard Test Method For Compressive Properties Of Polymer Matrix Composite Materials Using A Combined Loading Compression (CLC),” *ASTM D 6641*, No. Clc, Pp. 1–11, 2014.
13. I. I. Widya Emilia Primaningtyas, Suheni, “Pengaruh Orientasi Serat Kaca Terhadap Kekuatan Impact Pada Bodi Mobil Prototipe Mobil Listrik,” *J. IPTEK*, vol. 21, pp. 35–42, 2017.
14. ASTM, “Standard Test Method For Determining The Charpy Impact Resistance Of Notched,” *ASTM D 6110*, Vol. 1, Pp. 5–8, 2004.
15. ASTM, “Standard Practice for Using a Guarded-Hot-Plate Apparatus or Thin-Heater Apparatus in the Single-Sided Mode 1,”*ASTM C1044,* August, 1998, pp. 1–8.
16. S. and S. R. S. Kalpakjian, *MANUFACTURING ENGINEERING Illinois Institute of Technology*, Six Edition. Pearson, 2009.