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INFLUENCE OF ACTIVATED CARBON FILLER ON THE MECHANICAL PROPERTIES OF WOOD COMPOSITES

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ABSTRACT

This study is conducted to investigate the influence of activated carbon as filler on the mechanical properties of wood composite. It mainly focused on the strength, stress, and displacement of the wood composites. A composite material is defined as a combination of two or more materials that results in better properties than the individual components are used alone. The wood composite have certain advantages over wood, as they are affordable and have the potential for versatile designs. The materials possess good mechanical properties and have a long service life. Due to the excellent of mechanical properties, wood composite materials have been widely used throughout the last four decades. Structural and non-structural engineered wood composites based on plywood, medium density fibreboard (MDF), laminated veneer lumber (LVL), thermoplastic or wood fiber blends, and are now used in both interior and exterior applications. With advances in existing technology, especially in engineering field in which the use of computer software such as solid work simulation is used to test model digitally for valuable technical insight early in the design process. This type of software reduces weight and materials cost, improve durability and manufacture ability of the product. Simulation also enables representation of the modelled real system and its behaviour in real time by means of computer. From both simulation and experimental method used in this study, MDF composite samples show higher strength value than plywood composite samples due to the increasing of thickness of the activated carbon filler. Overall, the percentage differences between simulation and experimental method is lower than 10% which indicate that simulation is suitable tool use to predict the strength of wood composites.

Keywords: bio-composites, durability, mechanical properties, impact test.

INTRODUCTION

Wood properties are varying among each tree species and even between pieces from the same tree. Solid wood cannot match reconstituted wood in the range of properties that can be controlled in processing. The properties of solid wood are studied at the cellular level, with reconstituted wood materials, changes in properties are studied at the fiber, particle, flake, or veneer level. Properties of such materials can be changed by combining, reorganizing, or stratifying these elements (Youngquist, 1999).

A composite material is defined as a combination of two or more materials that results in better properties than the individual components are used alone. The wood composite have certain advantages over wood, as they are affordable and have the potential for versatile designs. The materials possess good mechanical properties and have a long service life (Kumar, 2013).

Due to the excellent of mechanical properties, wood composite materials have been widely used throughout the last four decades. Wood-based composite products are commonly substituted for solid wood in today's building structures. Structural and non-structural engineered wood composites based on oriented strand board (OSB), plywood, medium density fibreboard (MDF), laminated veneer lumber (LVL), thermoplastic or wood fiber blends, are now used in both interior and exterior applications (Laks, 2002).

However, use is often limited due to high sensitivity to moisture and decay (Baileys *et al*., 2003). Although the wood composite material can last up to a very long time, but as panelling, which is stretched over a firm surface there is an inevitable risk of ruin. Once a panel is damaged from an influence or a sharp stab the panel will need to be replaced as a whole.

The use of activated carbon as formaldehyde absorbent has been investigated by many researchers. Activated carbon is used as bio-scavenger for decreasing the formaldehyde emission from melamine formaldehyde resin (Kim, 2006). The activated carbon act by absorbs the free formaldehyde from the wood panel (Darmawan, 2010).

Recently, with advances in existing technology, especially in engineering field which the use of computer software such as solid work simulation is used to test model digitally for valuable technical insight early in the design process. This type of software reduce weight and materials cost, improve durability and manufacturability of the product. Simulation enables representation of the modelled real system and its behaviour in real time by means of computer. The simulation also enables visualization and editing of the model (Hubalovsky, 2013).

This study is conducted to investigate the influence of activated carbon as filler on the mechanical properties of wood composite. It mainly focused on the strength, stress, and displacement of the wood composites. It is divided into two main parts which are experimental and simulation.

Bio composite material

Bio-composites are composite materials that consist of biodegradable matrix and bio-degradable natural fibers as reinforcement. The development of bio-composites has attracted great interest due to their environmental benefit and improved performance. Application of bio composites in building industry can be classified into two main groups: Structural and nonstructural bio composites (Rowell, 1995).

A structural bio-composite can be defined as one that is needed to carry a load in use. For instance, load bearing walls, stairs, roof systems, and subflooring in building industry are examples of structural bio composites. Structural bio-composites can range widely in performance from high to low performance materials, while a nonstructural bio composite can be defined as one that is not needed to carry a load during service. In terms of the reinforcement, this could include plant fibres such as cotton, flax, hemp and the like, or fibres from recycled wood or waste paper, or even by-products from food crops (Mallick, 1997).

Malaysia has vast amounts of untapped natural fibre materials available from the agricultural sector and natural products such as thermoplastics and other semiconductor materials (Mazlan *et al*., 2013; Mazlan *et al*., 2014). Beside that wood particles, and textiles are used to make the products like ceiling tiles, furniture, windows, doors, and so on. These fibre and biomass materials range from rice husks, coconut trunk fibres, kenaf to oil palm biomass.

Fundamental of Activated Carbon

Recently, carbon is one of the magnificent elements in revolutionized material science. Activated carbon is porosity (space) enclosed by carbon atoms. It is a microcrystalline, non-graphitic form of carbon that has been processed to develop internal porosity. This porosity yield the surface area that provides ability to absorb gases and vapours from gases and to adsorb dissolved or dispersed substances from liquid. Activated carbon which is characterized by a vast system of pore of molecular size within the carbon particles resulted in the formation of a material with extensive surface area (Chilton *et al*., 2002).

Activated carbon is one of the most important microporous adsorbents due to its tremendous adsorptive capacity, an affinity for variety of dissolved organics and ability to be custom-tailored to suit specific application (Ismadji *et al*., 2005). Any carboneous materials (animal, plant, or mineral origin) with high concentration of carbon can be simply changed into activated carbon (Ansari, 2009). Activated carbon is a carbonaceous material which is predominantly amorphous in nature. The high degree of porosity is developed by the process of manufacturing and treatment (Abechi *et al*., 2013).

Properties of Activated Carbon

Its large specific surface area of (500 - 2000 m^2/g) is in fact the most important physical property of activated carbon which allows the physical adsorption of gases or vapors and dissolved or dispersed substances from liquids. It has large number of very fine pores (microspores) gives the activated carbon a large inner surface, which is the basis of its remarkable adsorption properties (Ansari, 2009).

According to Bansal *et al.* (1988), the effectiveness of activated carbon as an adsorbent is attributed to its unique properties, including large surface area, a high degree of surface reactivity, universal adsorption effect and favourable pore size. It is extremely large surface area often characterizes activated carbon. The source and quality of the carbon may play a role in the quality and consistency of activated carbon produced, but to reduce ecological impact, local agricultural waste byproducts can be used as a replacement in the activated carbon production process (Cobb *et al*., 2012).

The high adsorptive capacities of activated carbons are associated with their internal porosity and are related to properties such as surface area, pore volume and pore size distribution. Generally, activated carbons are mainly microporous. In addition to micropores, they contain meso and macropores, which are very important in facilitating access of the adsorbate molecules to the interior of carbon particles (Ahmadpour, 1995).

Classification of Activated Carbon

Activated carbons are complex products which are difficult to classify on the basis of their behaviour, surface characteristics and preparation methods. However, classification is made for general purpose based on their physical characteristics.

a) Powdered Activated Carbon

Traditionally, active carbons are made in particular form as powders or fine granules which less than 100 mm in size with an average diameter in range between 15 mm and 25 mm (Figure-1). Thus, they present a large internal surface with a small diffusion distance (Manocha, 2003).

Figure-1. Texture of powdered activated carbon (Aznar, 2011).

b) Granular Activated Carbon

Granular activated carbons (GAC) are versatile absorbents with a wide range of applications (Vijayan *et al*., 2012). By refer to Figure-2, GAC has a relatively larger particle size compared to powdered activated carbon and consequently, presents a smaller external surface. Therefore, these carbons are preferred for all adsorption of gases and vapors as their rate of diffusion are faster (Manocha, 2003).

Figure-2. Texture of granular activated carbon (Aznar, 2011).

Preparation of Activated Carbon

Activation is a physical change through which the surface of the carbon is tremendously increased by the removal of hydrocarbon. The properties of the finished materials are governed not only by the raw materials but the method of activation (Aloko and Adebayo, 2007).

Activated carbons are commonly prepared by two basic processes which are physical or gas activation method, and chemical activation. During physical activation, the lignocellulosic material as such or the previously carbonized materials can undergo gasification with water vapor, Carbon dioxide, or the same combustion gases produced during the carbonization. Ammonium persulfate, Nitric acid, and Hydrogen peroxide have also been used as oxidizing agents (Salame and Bandoz, 2001).

Chemical activation consists of impregnating the lignocellulosic or carbonecous raw materials with chemicals such as Zinc chloride, Phosphoric acid, Nitric acid, Sulfuric acid, Sodium hydroxide, or Potassium (Elizalde-Gonzalez and Hernandez-Montoya, 2007; Girgis *et al*., 2002). Then, they are carbonized (a process now called "pyrolysis") and finally it was washed to eliminate the activating agent. The choice of activation method is also depending upon the starting material and whether a low or high density, powdered or granular carbon is desired. Activation process sweeps the tarry materials, opens the pores, develop porosity, and increase surface area significantly (Ansari, 2009).

Renewable Sources of Activated Carbon

Special emphasis on the preparation of activated carbons from several agricultural by-products has been given due to the growing interest in low cost activated carbons from renewable resources. The advantage of using agricultural by-products as raw materials for manufacturing-activated carbon is that these raw materials are renewable and potentially less expensive to manufacture (Juang, 2005).

a) Sawdust

In Malaysia, residues from oil palm and wood based industries are the main biomass source. Currently, large volume of these residues in the form of sawdust, offcut and wood barks were produced by wood based industries. Due to the shortage of wood supply, some of the waste minimization programs were implemented in these industries in order to maximize the use of the wood residue. Thus, one of the cost effective way is to convert the wood residue to activated carbon (Lam & Zakaria, 2008).

Filler

Composite materials are made simultaneously by two or more materials with vastly different mechanical and chemical properties which remain separate and are clearly observable in macroscopic or microscopic scale inside the finished part. There are two categories of materials involved which are reinforced and filler. At least one piece from each category must necessarily be present. Filler surrounds and supports the reinforcement to maintain mutual relative position. Reinforcement is adding its special mechanical properties in order to improve the mechanical properties of filler (Duleba & Greskovic, 2013).

Fillers can be classified into two major groups, particulate and fibrous. Particulates are generally classified as fillers or reinforcing fillers if interphase adhesion is high. Particulate have dimensions that are approximately equal in all directions and can be any shape. Filler or particles can be used to increase mechanical properties; however they are more commonly used as extenders to lower polymer use (Matthews and Rowling, 1994).

The fillers can be classified according to their specific function, such as their ability to modify mechanical, electrical or thermal properties, flame retardancy, processing characteristics, solvent permeability, or simply formulation costs. It needs to be recognized that fillers are multifunctional and may be characterized by a single, primary function and a surplus of other, additional functions (Xanthos, 2010).

The low thermal conductivity of wood fiber limits the production rates in existing production lines. The carbon fibers can be used as a filler to improve the thermal and mechanical properties of wood composite. Carbon fibers are widely employed in various fields because of their unique properties including adsorptive capacity, chemical stability, thermal conductivity and electrical conductivity (Youssef *et al*., 2008; Yun *et al*., 2008; Kim *et al*., 2008; Roh *et al*., 2008).

Wood Composite

Materials that are classified as ‘composite wood products’ have wide-ranging chemical and physical properties. This variation originates from the fast paced development of technologies that aim to make these products more resilient to physical, chemical and biological stresses. In general terms however, composite wood products may be constructed using wood fibres, flakes, chips or shavings, veneers or paper (Eaton and Hale, 1993).

The development of wood-based composite materials, mostly within the 20th century, had a significant effect on wood use and opened new opportunities for creative and versatile products from a changing wood resource. The capability to make engineered structural panels in a variety of forms provides incentives for further development and application of the concept of wood composites (Robert, 2006).

During the manufacturing process, these materials are often combined with different glues, resins, water repellents and preservatives to produce sheet boards. Some examples of major composite wood products include the fibreboard (constructed from fibres of wood), particleboard or chipboard (constructed from wood flakes, shavings or splinters) and plywood (constructed from one or more veneers) (Eaton & Hale, 1993).

Each of these composite wood product types can be manufactured in a variety ways, comprising different physical or chemical attributes that may affect composting procedures and end-product applications. Furthermore, the prior use of these wood products will determine the presence or absence of such components as fasteners, nails, screws, bolts, plastic coatings and paint. It is therefore critical for the production of quality compost to be aware of how a wood residual was manufactured, its prior use, and its condition at time of recycling (for examples the presence of fasteners, paint and moisture content) (Angus, 2007).

Plywood

Plywood (Figure-3) is laminated wood, the layers glued together so that the grains in successive layers are at right angles, giving stiffness and strenght in both directions. High quality of plywood is bonded with synthetic resin (Ashby, 2013). Plywood can be made from either softwoods or hardwoods. It is always constructed with an odd number of layers with the grain direction of adjacent layers oriented perpendicular to one another (Youngquist, 1999). Plywood is lighter and stronger than solid wood, is more flexible, and has a high shear value (Table-1). In the 19th century, plywood was made of thin strips of saw-cut wood and was typically used for furniture and door panels (Ashby, 2013).

Compared with solid wood, the chief advantages of plywood are that the properties along the length of the panel are more nearly equal to properties along the width, there is greater resistance to splitting, and the form permits many applications where large sheets are desirable. The use of plywood may result in improved utilization of wood. The properties of plywood depend on the quality of the different layers of veneer, order of layer placement, adhesive used, and control of bonding conditions (Youngquist, 1999).

Table-1. General property values for sheathing-grade plywood (Youngquist, 1999).

Property	Value	ASTM method
Flexure		
Modulus of rupture	20.7-48.3 MPa(3000-7000 lb/in^2)	D3043
Modulus of elasticity	6.89-13.1 GPa(1-1.9×10^6 lb/in^2)	
Tensile strength	10.3-27.6 MPa(1500-4000 lb/in^2)	D3500
Comprehensive strength	20.7-34.5 MPa(3000-5000 lb/in^2)	D3501

Figure-3. Plywood (Ashby, 2013).

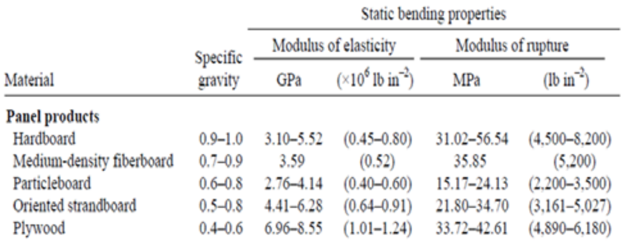
Figure-4. MDF (Ashby, 2013).

Medium Density Fibreboard

Medium-density fibreboard (MDF) is an engineering wood product composed of fine ligno-cellulostic fibers combined with a synthetic resin and subjected to heat and pressure to form panels. MDF made up of wood fibers and can be used as a building material similar in application to plywood. It is stronger and much denser than normal particleboard (Irle and Barbu,2010). Static bending properties of MDF is shown in Table-2.

The resin is one of the most important factors affecting the mechanical properties of MDF board. The MDF has structural integrity because the cured resin binds with the fiber matrix (Ashby, 2013). MDF is frequently used in place of solid wood, plywood, and particleboard in many furniture applications. It is also used for interior door skins, mouldings and interior trim components (Youngquist *et al*., 1997). Example of MDF is shown in Figure-4.

Table-2. Static bending properties of wood-based composites (Robert, 2006).



		Static bending properties			
		Modulus of elasticity		Modulus of rupture	
Material	Specific gravity	GPa	($\times 10^6$ lb in^{-2})	MPa	(lb in^{-2})
Panel products					
Hardboard	0.9–1.0	3.10–5.52	(0.45–0.80)	31.02–56.54	(4,500–8,200)
Medium-density fiberboard	0.7–0.9	3.59	(0.52)	35.85	(5,200)
Particleboard	0.6–0.8	2.76–4.14	(0.40–0.60)	15.17–24.13	(2,200–3,500)
Oriented strandboard	0.5–0.8	4.41–6.28	(0.64–0.91)	21.80–34.70	(3,161–5,027)
Plywood	0.4–0.6	6.96–8.55	(1.01–1.24)	33.72–42.61	(4,890–6,180)

METHODS AND MATERIALS

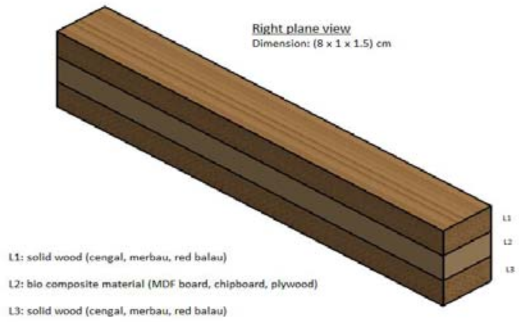
Design of the Sample

A sandwich construction as here considered is comprised of a combination of composite materials assembled alternately and intimately fixed in relation to each other so as to use the properties of each to specific structural advantage for the whole assembly. This type of construction permits the fabrication of strong lightweight panels, which are growing steadily in importance. The control variable of this panel is the thickness of the wood composite. Figure-5 and Figure-6 show the sandwich design used for this study.

Model Description

a) Top plane view (unit in cm)

b) Front plane view (unit in cm)



c) Isometric view

Preparation of Sample

Wood composite which consist of plywood and MDF are cut into desired sizes that acquired by Charpy impact test. Then, the activated carbon samples were added into the wood samples. The specimen that fits into the Charpy impact tester is rectangular with a notch cut in one side. The notch allows for a predetermined crack initiation location. The V-notches of specimens are marked by using sample preparation machine (refer to Figure-5).

(a) (b)

Figure-5. (a) Activated carbon was added into the wood composite, (b) the specimen notches then was mark using sample preparation machine.

Charpy Impact Test

Impact tests consist of striking a suitable specimen with a controlled blow and measuring the energy absorbed in bending or breaking the specimen. The energy value indicates the toughness of the material under test. By refer to Fig. 6, impact testing machine has a hammer that is suspended like a pendulum and a vice for holding the specimen in the correct position relative to the hammer and a dial for indicating the energy absorbed in carrying out the test in joules (J).

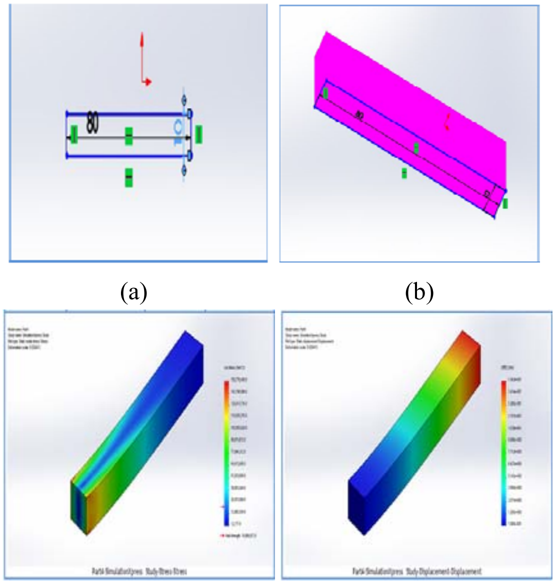
From knowledge of the mass of the pendulum and the difference between the initial and final heights, the energy absorbed in fracture can be calculated. The Charpy impact test method works by placing a notched specimen (with the notch facing away from the point of contact) into a large machine with a pendulum of a known weight. The pendulum is raised to a known height and allowed to fall. As the pendulum swings, it impacts and breaks the specimen, rising to a measured height.

(a) (b)

Figure-6. (a) Charpy impact test used in laboratory, (b) the samples fracture after test.

Solid Works Simulation

SolidWorks simulation is the method to estimate the result of certain experiment by using software (Figure-7). First step is the product design was sketched by using SolidWorks. Secondly, the product design was extruded from 2-D to 3-D. Next, the method or process used on product was specified. Then, the boundary condition on the model was also specified. The defined model was simulated before the preliminary result was displayed.



(a) (b)

(c)

Figure-7. (a) Product design sketched, (b) extruded of product design, (c) preliminary result displayed.

RESULT AND DISCUSSIONS

Result and Discussion of Experimental Method

From the experiment that was done by using Charpy impact test, the result obtained is in the energy form (Table-3).

Table-3. Properties of wood composites based on experimental.

a) Plywood

Energy (ΔE) (J)	Thickness (Δx) (m)	Forces (N)	Area (m^2)	Stress (N/m^2)
3.352	0.01	335.2	0.0012	279,333.33
8.361	0.011	760.1	0.0012	633,416.67
12.109	0.013	931.5	0.0012	776,250.00
6.172	0.015	411.5	0.0012	342,916.67

b) MDF

Energy (ΔE) (J)	Thickness (Δx) (m)	Forces (N)	Area (m^2)	Stress (N/m^2)
1.061	0.01	106.1	0.0012	88,416.67
7.229	0.011	657.2	0.0012	547,666.67
26.225	0.013	2017.3	0.0012	1,681,083.33
54.263	0.015	3617.5	0.0012	3,014,583.33

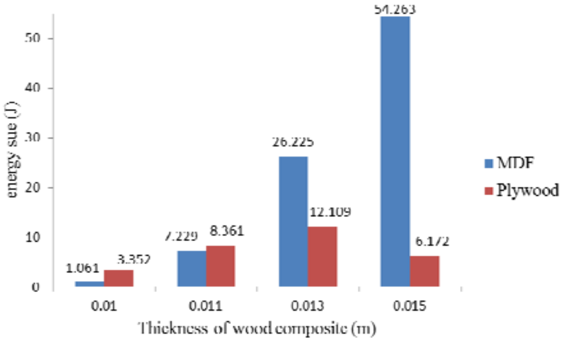


Figure-8. Comparison between energy value of plywood and MDF.

Figure-8 show that the energy value of plywood without addition of activated carbon filler is 3.352 J. When the activated carbon filler of plywood was added and increased from 0.011 until 0.013 m, the energy value also increased from 8.361 J to 12.109 J. But, due to the thickness of activated carbon was increase to 0.005 m, the energy value of plywood sample decreased into 6.172 J. Wolcott and Adcock (2001) stated that the aspect ratio of the wood particles also had little effect on impact strength.

Meanwhile, MDF samples show that the without addition of activated carbon filler, the energy of the samples was 1.061 J. But, due to the addition and increases of the filler thickness, the energy value of MDF samples also increase from 7.229 J to the 54.263 J. The resin is one of the most important factors affecting the mechanical properties of MDF board. The MDF has structural integrity because the cured resin binds with the fiber matrix (Ashby, 2013). The impact resistance often decreases as an effect of wood reinforcement similarly to many particulate filled composites (Bledzki and Farok, 2004).

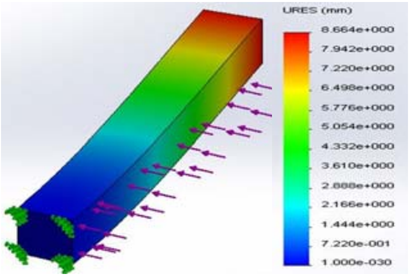
The result from Figure-8 can be used to calculate the percentage of difference occured due to the addition of the activated carbon filler. Here, the addition of activated carbon filler in MDF (thickness of 0.005 m) has increased the percentage of difference about 98%. While, for plywood sample the percentage of difference is increased until 72%. But when the thickness of filler is increase to 0.005 m, the percentage of difference is reduced to 46% compared to when the thickness is 0.003 m in which the percentage of difference is 72%. High percentage of differences show that the improvement of the strength properties of wood composites.

From Figure-8 the energy value of plywood and MDF composite samples compare. When there is no addition of activated filler (thickness of 0.01 m of sample), the energy value of plywood (3.352 J) was higher than MDF (1.061 J). The same condition occur when the activated carbon is add about 0.001 m. But, when the thickness activated carbon was increased to 0.003 m, the MDF sample show higher energy value than plywood sample. Furthermore, the increase of activated carbon to thickness of 0.005 m show that the energy value of plywood was decreased from 12.109 J to 6.172 J but the energy value of MDF was increase considerably from 26.225 J to 54.263 J.

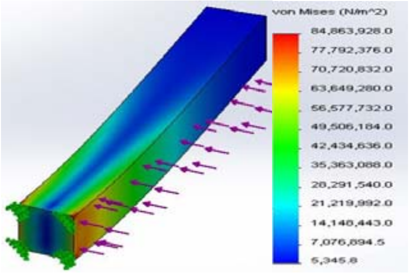
RESULT AND DISCUSSION OF SOLIDWORKS SIMULATION

Plywood

a) 0.01 m



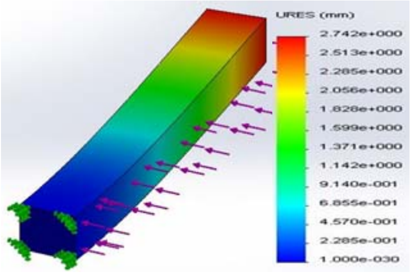
Average displacement: 8.66 mm



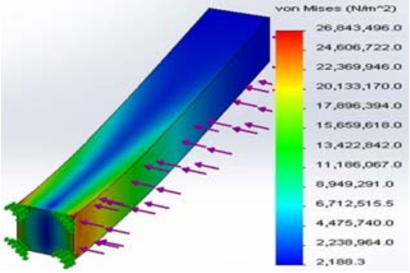
Average stress: 307, 682 N/m^2

MDF

a) 0.01 m



Average displacement: 2.74 mm



Average stress: 97,346 N/m^2

Table-3. Comparison between average displacement and average stress of plywood and MDF.

Thickness of samples (m)	Average displacement (mm)		Average stress (N/m^2)	
	Plywood	MDF	Plywood	MDF
0.01	8.6634	2.7420	307,682.37	97,346.26
0.011	17.8431	15.4247	651,572.27	564,892.78
0.013	18.4708	40.008	810,775.72	1,776,963.78
0.015	7.0583	62.048	369,407.63	3,240,315.5

From simulation, the mechanical properties of wood composite that can be identified were the average displacement and average stress. In this study, the average displacement was compared between the samples. Meanwhile, the average stress was compared between the samples and also between the experimental result to get the percentage differences between simulation and experimental method. The mechanical properties of a material are used to determine its suitability for a particular application.

CONCLUSIONS

It is proven in this study that how these objectives can be fulfilled by using the data from the Charpy impact test and SolidWorks simulation. Based on this study, it can be seen that the stress value was increased with the increasing forces apply to the samples. Other than that, the stress value of plywood without activated carbon as filler was higher than MDF without activated carbon filler. But, due to the addition of different thickness of activated carbon, the stress value of plywood become lower than MDF. This shows that activated carbon limiting the energy inside the plywood sample and thus, lowering the stress value of the sample.

On the other hand, the differences in term of percentage stress were also determined in this study. For plywood sample, the thickness of activated carbon filler about 30% of composite sample gave higher percentage of difference which is 72%. Meanwhile, the thickness of activated filler about 50% of MDF composite sample gave the higher percentage of difference which is 98% compare to other thickness.

SolidWorks simulation determines the sample that has high average displacement and average stress which indicate good performance of mechanical properties. The addition of activated carbon as filler increases the average displacement and average stress of MDF which is higher than plywood. Thus, both the method which are experimental and simulation show that the mechanical properties of MDF was higher compare to plywood with the addition of activated filler. It is proved that SolidWorks simulation is a suitable tool used to measure strength to get accurate result.

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