Wear of Wood Polymer Composite for Journal Bearing Materials

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Abstract

Wood is broadly used for automotive parts, construction materials, and equipment for leisure-time amusement; however, its application for journal bearings has been restricted due to its low strength and poor tribological characteristics. In this work, *Falcataria moluccana* or *Paraserianthes moluccana*, locally known as Batai wood, which have low density and high porosity were impregnated with motor oil, (SL/CF 15W-50), hexamethylene diisocyanate, and diphenylmethane-4, 4'-diisocyanate to improve their compressive strength and tribological characteristics. A vacuum-pressure method was used to impregnate the wood specimens. From scanning electron microscopy (SEM) analysis, wear test, and compression test results, it was found that the hexamethylene diisocyanate was a promising material to improve the physical properties of wood for journal bearings.

Key words: wood-polymer composites; tribological; impregnated; compressive strength.

Introduction

Journal bearing is a primary mechanical component that is used to support and position an object, while at the same time allowing that object to rotate. In industries, machinery with high loads and high horsepower, such as centrifugal compressors, steam turbines, pumps, and motors use journal bearings as rotor supports. One of the basic functions of a journal bearing is to provide a frictionless condition to support a rotating shaft. Properly installed and maintained, journal bearings have essentially infinite life. Wood journal bearings were extensively used for power transmission shafts in factories during the early industrial revolution. In Russia, bearings made of compressed wood have been applied since the 1940s in industrial applications including water pumps on the Moscow Canal (Apostol and Yanin 1990) and roller veneer dryers. In production, wood is first plasticized by immersion in steam or hot machine oil, compressed under high temperature and pressure to about half its original volume, and then machined to shape using metal-working equipment. These bearings reportedly performed with low friction and wear, and have high resistance to abrasive particles. Even wood has been used since the invention of the wheel, but the price of the needed type of wood is high due to the fact that lignum vitae takes three to four hundred years to mature and only small sections of the wood are available. The impregnated oil in the wood bearing to improve tribological characteristic contaminates sea water, because the wood bearing of small fishing boats operate under water lubricating condition (Kim *et al*. 2008). Now new bearing materials suitable for water lubrication are urgently needed to replace the wood bearing, which has a very short life, e.g. three months (Kim *et al*. 2008). Wood-polymer composites (WPC) are materials in which wood is impregnated with monomers that are then polymerized in the wood to tailor the material for special applications (Oksman 2009). WPCs are also known as "liquid wood", wood-plastic composites. WPCs may be the materials having the greatest potential to replace the wood bearings. A variety of chemicals have been used to change wood's physical characteristic. From 1930 to 1960 a number of new wood treatments have been introduced, the phenol formaldehyde treatment, ethylene oxide addition to the hydroxyl groups, and acetylating of hydroxyl groups (Kim *et al*. 2008). Various types of chemical compounds have been used for the modification of wood, including anhydrides, acid chlorides, carboxylic acids, isocyanides, aldehydes, alkyl chlorides, lactones, nitrides, and epoxies. In marine applications WPCs have been used as structural materials of fender systems to cover docking structures and vessels during berthing (Hoyle and Woeste 1989). Because woods have doubtful self-lubricating properties and high moisture content, the application of WPCs in marine vessels as structural element has been restricted (Kim *et al*. 2008). In this research, the wear of WPCs, which have better tribological characteristics than the conventional materials for journal bearings, were investigated.

Materials and Methods

Materials

The wood specimens used in this experiment, *Falcataria moluccana* or *Paraserianthes moluccana* locally known as Batai wood were obtained from Sarawak Tree Seedling Centre, Kuching, Sarawak, Malaysia. The timber is a deciduous tree capable of achieving very high growth rates up to 40m tall under favorable conditions; it is a fast-growing tree with 12% moisture content level. Three types of liquid solutions used were motor oil, SL/CF15W-50 (Toyota), hexamethylene diisocyanate, and diphenylmethane-4, 4'-diisocyanate. Hexamethylene diisocyanate with the molecular formula $C_8H_{12}N_2O_2$ is an organic compound in the class known as isocyanates. More exclusively, it is an aliphatic diisocyanate. Aliphatic diisocyanates are used in special applications, such as enamel coatings that are resistant to abrasion and degradation from ultraviolet light. These properties are particularly desirable for the exterior paint applied to aircraft (Smith *et al*. 2001). Diphenylmethane-4,4-diisocyanate with the molecular formula $C_{15}H_{10}N_2O_2$ is a light yellow colored solid. It is used to make plastics. The positions of the isocyanate groups influence their reactivity's. 4,4'-MDI is a symmetrical molecule and thus has two groups of equal reactivity. 4,4'-MDI is used as an industrial strength adhesive, which is available to end consumers as various high-strength bottled glue preparations (Smith *et al*. 2005).

Specimen Preparation

Batai wood (*Paraserianthes moluccana*) was felled and cut into three bolts of 1.2 m long. Each bolt was quarter sawn to produce planks of 4 cm thickness and subsequently conditioned to air-dry in a room with relative humidity of 60% and ambient temperature of around 25°C for one month prior to testing. The planks were ripped and cut to the hexahedral shape of dimensions with 60mm x 20mm x 20mm specimens for this experiment.

Manufacturing of Wood-Polymer Composites

The specimens for impregnation were made by cutting a long flat-grain plank uniformly polished with sand paper to clean the surface. The method used to impregnate the monomer-initiator solution was a vacuum-pressure application, as shown in Figure 1. By this method, vacuum is created to remove air from the wood and admit a lot of monomers absorption and retention of polymers.

Figure 1. Vacuum-pressure method for impregnation of wood.

The wood cells are almost filled and make the wood polymer composite very hard to work (Bodig and Jayne 1992). By using this method, a relatively short time is taken to impregnate specimen, compared to the natural soaking method (Kim *et al*. 2008). The impregnation process was continued for 2 hours, during which time the specimens became fully soaked with solutions. After the impregnating process, the specimens were dried at 40°C for 72 hours in an oven chamber to evaporate water.

Wear Test and Volume Reduction (%) of Wood Composite

Pin-on-disk methods were used to accomplish the wear test in this project. The wood specimens soaked in the three types of impregnating solution were cut to the hexahedral shape of dimensions with 20mm x 8mm x 5mm. Two-body sliding abrasive wear tests were carried out using a pin-on-disk type arrangement on the prepared specimens, as shown in Figure 2. This wear test pin-on-disk device, was constructed at the Mechanical Engineering Department workshop based on ASTM G99 design by Seong Su Kim (Kim *et al*. 2008). These devices were constructed to subject wooden bearings to a load while rotating at constant speed. The shaft was rotated by an AC induction three phase motor. One specimen at a time is place on the disk for 25 seconds. Downward force was applied to the bearings by weights suspended from the lever arms attached to the machine frame. The advantage of this machine is the load, disk rotating speed, and surface contact with the specimen can be changed according to the user.

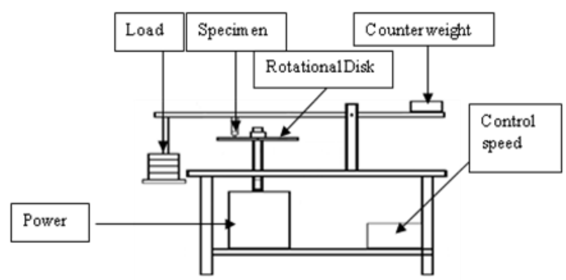

Figure 2. Schematic diagram of the pin-on-disk wear test device.

The device uses a fixed load to balance the lever arm. The wood specimens were sliding against the silicon carbide (SiC) abrasive paper grit 120 at constant speeds for selected times. The SiC particles of the abrasive paper act as multiple micro tools that wear the material to be tested. This abrasive wear depends on the hardness of the two contacting materials, cutting properties of the hard particles and micro cracking resistance of the softer material (Koh *et al*. 2003). These were performed at low speed and low pressure to avoid vibration and excessive heating (Koh *et al*. 2003).

Compression Test

The compressive strengths of the specimens had been soaked in the three different types of solutions were measured. The impregnated wood specimens were cut to the compressive specimen size. The length, width, and thickness of the specimen are based on the British Standard BS 2782 (British Standard BS 2782, Method 345A 1979) which are 15mm x 15mm x 15mm. The specimens were compressed between two steel collars using a Shimadzu universal testing machine at the cross head speed of 2.0 mm/min. Three readings were taken to obtain the average compressive strength.

Results and Discussion

Weight Percentage Gain (%)

Figure 3 shows the chemical solution content in percent. It is evident that hexamethylene diisocyanate had the highest weight percentage gain after impregnation, and the specimens impregnated with diphenylmethane-4,4'-diisocyanate had the lowest, compared with motor oil (SL/CF 15W-50). Due to the higher molecular weight, diphenylmethane-4,4'-diisocyanate was less impregnated compared with hexamethylene diisocyanate and motor oil, respectively. This is due to the lower solution content in specimen treated with diphenylmethane-4, 4'-diisocyanate.

Compression Strength

Figure 4 shows the compressive strength of WPC and raw wood. From the figure, all impregnated specimens had higher compressive strengths than that of raw wood. Once again the specimen impregnated with diphenylmethane-4,4'-diisocyanate had higher compressive strength than raw ones. The compressive strength of specimen impregnated with hexamethylene diisocyanate had higher value than that of motor oil and diphenylmethane-4,4'-diisocyanate impregnated WPC respectively. It is known that the impregnation process or polymerizations can increase the strength of the wood because the addition of polymer places a coating on the cell wall, which increases the stability due to the increase of wall thickness (Kim *et al*. 2008; Vasconcelos *et al*. 2006). The specimens impregnated in hexamethylene diisocyanate had the highest strength among the treated specimens with the increase of 57.5%. The compressive strength of wood exists from the interaction between the cellulose and lignin. In the case of the specimen impregnated with hexamethylene diisocyanate, the strength increased because the solidified hexamethylene diisocyanate acted as an adhesive with the lignin since it filled the pores in the wood; therefore it showed the highest strength compared to that of the neat wood. Research had been done by another researcher regarding polymer content, and it has been known that there is a linear relationship between the polymer content and the compression strength for all polymer types (Archard 1953).

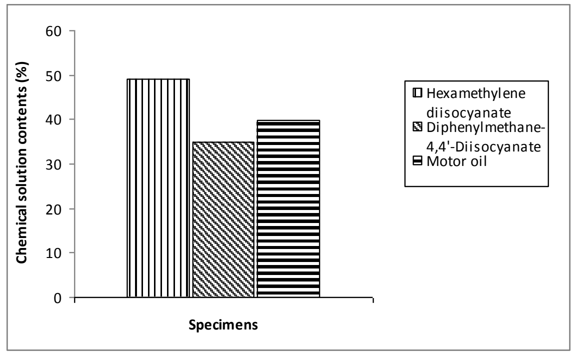

Figure 3. Chemical solution content (%) adsorbed in 2 hours.

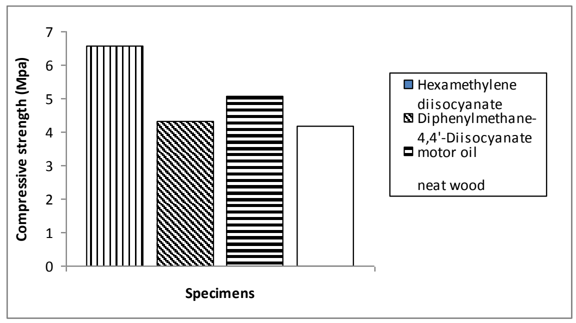

Figure 4. Compressive strength of the WPC and raw wood.

Scanning Electron Microscopy (SEM)

The surface morphologies of the WPC and raw wood were observed with a scanning electron microscope (SEM), as shown in Figure 5. The surface of the specimen impregnated with hexamethylene diisocyanate and motor oil showed pores filled with the solution, as indicated in Figure 5(a), and 5(b), respectively. However, many voids were observed in the pores filled with diphenylmethane-4,4'-diisocyanate, as shown in Figure 5(c). Moreover, Figure 5(d) clearly shows a lot of void space inside the raw wood. The voids will affect the mechanical properties during compression testing, since wood belongs to a class of bio-molecular composites that are rich in cellulose and lignin (Koh *et al*. 2003). It was clearly seen that hexamethylene diisocyanate greatly reduced the void space and waxy substances, followed by motor oil and diphenylmethane-4,4'-diisocyanate.

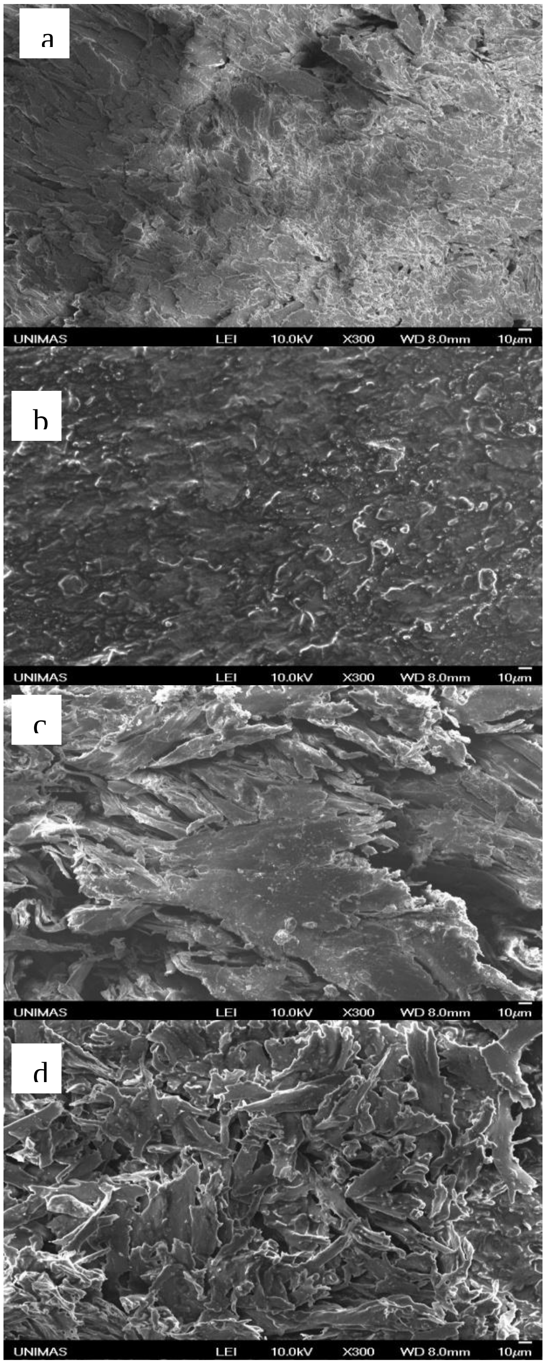

Figure 5. Scanning electron microscope of Hexamethylene diisocyanate (a), motor oil (b), diphenylmethane-4,4'-diisocyanate(c) impregnated WPC, and raw wood (d)

Wear Test and Volume Reduction (%) of Wood Composite

Figure 6 shows the volume reduction of the specimens after wear testing under different normal loads. For the entire specimen impregnated with solution, the length losses were less than those of the untreated wood. The impregnated specimens with motor oil showed second highest volume reduction loss rate among other treated specimens, because liquid additives such as motor oil in the wood was squeezed out due to the compressive loading during the test (Kim *et al*. 2008). The lowest value in the volume loss was observed in the specimen impregnated with hexamethylene diisocyanate. Possibilities are due to the low friction coefficient of hexamethylene diisocyanate that made the friction force small between the interface of the specimens and the abrasive paper. Furthermore, the compressive strength of specimen impregnated with hexamethylene diisocyanate is highest, thus making it hard to crack and the chemical acted like an adhesive in the wood wall structure and prevented the wood structure from exhibiting easy wear loss.

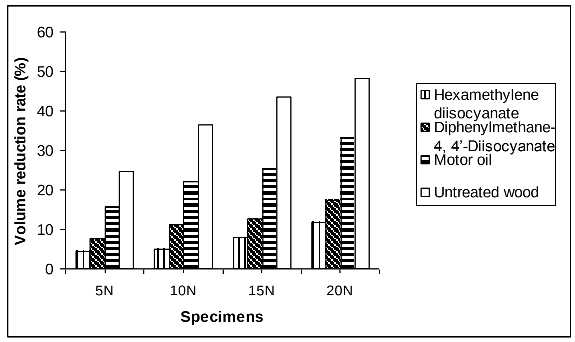

Figure 6. Volume reduction of the Batai WPC and raw wood after wear test in 25 second with different load.

Conclusions

In this work, Batai wood was impregnated with Motor oil, SL/CF 15W-50 (Toyota), hexamethylene diisocyanate, and diphenylmethane-4,4'-diisocyanate to improve compressive strength and tribological characteristics. The wood was chemically treated with a vacuum-pressure method, where the solution was filled inside the pores of the wood. From the result, it was found that all of the impregnated specimens had higher compressive strength than that of the untreated wood, and this was due to the addition of polymer coated the wall that eventually increase the cell wall thickness, which stabilized against the buckling of tissue of wood under compressive load. The amount of volume loss increased with increasing normal load. The specimen impregnated with hexamethylene diisocyanate showed the highest compressive strength among the treated specimens, with 57.5% higher strength than neat wood. The specimen impregnated with the hexamethylene diisocyanate also showed the highest increase in weight percentage, i.e. 49.2% increase after impregnated process compared to that of neat wood, and the small decrease of the material loss during the wear test was 21.9% respectively. The results illustrate the potential use of hexamethylene diisocyanate as the most promising solution to improve the physical properties for wood journal bearings.

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