EFFECTS OF CHEMICAL AND PHYSICAL CHANGES CAUSED BY TEMPERATURE AND GRAIN SIZE ON MECHANICAL BEHAVIOR OF COMPOSITE MATERIALS (CASE-STUDY: BAMBOO WOOD)

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ABSTRACT

This paper studying and analyze the effects of changing the chemical and physical properties on the mechanical behavior of composite parts composing such materials especially composites woods like bamboo wood. Any chemical or physical change of the elements composing any composite material will lead to a change in its mechanical properties and so a new application of such materials will be created. The modulus of indentation (E_{IT}), the elastic index (η_{IT}), also the Hardness index (Martens index) (H_M) and the creep factor of indentation (C_{IT}) are evaluated due to the change in chemical or physical values.

KEYWORDS: Chemical Change, Physical Change, Mechanical Properties, Composite Materials, Elastic Index & Wood

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INTRODUCTION

Composite materials in general, are composed of two main parts: matrix and fibers. Such materials are divided into natural or artificial composites. The microstructure of any composite material specifying its properties and also the interface properties or properties of the area between the fiber and the matrix or interface area. Such properties are affected by chemical and physical changes and also the behavior of such materials is changed too during application. The first step in this study is to understand the difference between physical and chemical changes. Chemical reaction and physical reaction have a difference which is related to the percentages of substances or composition of the material. In chemical reactions a change in the composition of the compound or the substance in the level of the material or the compound has occurred; also in physical changes, the change occurred in the appearance, simple display of a sample of matter but without a change in the composition. However, these changes can be considered physical "reactions," no reaction actually occurred, but really some converting occurs. For any chemical reaction to take place, a change in the elemental composition of the substance during the reaction has occurred. Chemical changes will occur when the composition of the substances is changed or when bonds connected such compounds or elements are broken and new ones are formed. The following changes in the status of materials are considered as chemical changes: changing in temperature, changing in color, odor sensing or change (after reaction begun), a precipitate formation, and also bubbles creation. On the other hand, the following are considered as physical changes and are limited to changes that result in a difference in display without changing the composition like: texture change, color converting, temperature of the material change, shape changes, and change of state (Boiling Point and Melting Point) also there are some other changes include: luster changes, malleability changes, ability to be drawn into a thin wire changes, density changes, viscosity changes, solubility changes, mass changes, and volume changes. It is found that any rate of change in such physical properties can be considered a

physical change. On the contrary, chemical changes occurred when two or more substances or elements are mixed and a change in temperature, color, state or phase can be noticed; in this case, chemical reaction is probably occurring.

On the other hand-here in the studied case- any chemical change of the wood cell wall polymers composition will cause a change in the physical and mechanical properties of the wood (especially in bamboo wood). The level of change in such properties is vary from the color change of the wood to a changes in modulus properties of the wood like: working to maximum loads, brittleness property, hardness of the wood, strength to wet, wet stiffness, strength of impact, compressive strength, gas permeability, density, also moisture sorption, Poisson's ratio, indentation modulus and other properties. All materials are composed of grains, and the mechanical characteristics of any material are affected directly by the grain size, the heat treatment performed during material manufacturing and preparing, and any exposed to low or high temperature. If the grains size of the materials is small or fine which are usually called a fine-grained material, while if such grains are large they usually called a coarse-grained material. For fine-grained material which usually has both tensile and fatigue strength greater than that of coarse-grained materials, and also they can be easily work hardened. While for coarse-grained materials they usually have a more surface roughness which causes a difficulty in polishing processes, also such materials have relatively low toughness and have more tendency to create a distortion than those having fine grains. Materials with coarse grains have better workability property comparing with fine grains materials, and better harden ability and forge ability. For fine-grained material-at room temperature- the grain boundary is clearer than that of coarse-grained materials. The coarse-grained materials at high temperatures have more creep resistance than the fine-grained materials. It is also found that the strength materials have an inverse proportionality as a one over square root of the grain size [4-6].

Heat Treatment Effects

Some mechanical properties can be improved or enhanced by making heat treatment to bamboo samples like ductility property, the hardness of the surface of the material, a tensile strength of the material, toughness and shock resistance properties. Such treatments carried on bamboo samples to increase or improve machinability, to decrease the internal or residual stresses in the materials either at cold working or hot working materials, also the corrosion resistance can be improved for either coarse-grained or fine-grained materials, which finally improving chemical, magnetic, electrical and thermal properties of the materials.

Atmospheric Effects

Atmospheric conditions which include moisture, temperature change, and others have considerable effects on chemical and physical properties of bamboo woods. Moisture percentage, sulphur dioxide percentage, hydrogen sulphide, and other corrosive conditions work on decreasing the electrical resistivity of materials, which depends on the many parameters like materials characteristics, value of the protective film or layer on the metal surface, existing or absent of some specific reducing agents, local cells formed due to development of cracks and discontinuity on the protective film surface. Chang in temperature caused by atmosphere may change some mechanical properties which may includes field stress or strain and ultimate tensile or compression strength which may decrease with temperature rise, also stiffness and fracture stress of many metals also decrease with increasing temperature [4-6]. For composites like bamboo woods, the strength of such composite materials does not only depend on the substrate strength but it also depends on the interface between the matrix and fiber strength. This may be observed when the force increases to some specific value or ratio of the force required to break or make a crack on the strong bond and threatens to break the backbone of the specimen. Thus, the

strong bond in the backbone of the wood should avoided [6].

MATERIALS AND METHODS

Bamboo Wood

Bamboo wood is considered a natural composite, its microstructure and hence its properties are specified compared to the artificial or industrial composites. Bamboo woods are used to fabricate structural elements and also as an alternative to steel in reinforced concrete [2]. Most bamboo culms take cylindrical and hollow shapes, with diameters ranging from 0.25 - 12 inches. Bamboo woods are considered as natural composite materials and are made up of non-uniformly distributed longitudinal fibers. The main structure part of bamboo culms is cellulose, hemicelluloses and lignin part, which composed 90% of the total mass. The distinguished fiber-matrix ratio and distribution give bamboo exceptional strength characteristics and so the chemical composition and chemical ratio changes between matrix and fibers of such composite change its chemical properties and hence its mechanical properties. It was proved that temperature changes affect wood or wood-based composites. Both the physical and mechanical properties of the wood are affected strongly by the thermal degradation of the bonds in the material and also the water content or water percentage in the product during a fire are changed. Recently because of the increased usage of bamboo woods and its composites, specifying the mechanical performance of full-sized bamboo structural members, when subjected to extreme heat loads, is a difficult task because of the high cost and complexity of the material and high cost testing methods, for example thermo-mechanical testing of bamboo sample is required to determine its mechanical characteristics at high temperature, which is usually assesses the safety of structural members exposed to fire, it can be noticed that the chemical composition and properties are changed during such these tests due to temperature and other environmental effects which is finally affect the mechanical properties of the bamboo wood composites [3].

Alpha-cellulose percent is a very important value to be calculated for bamboo wood fibers, which can be calculated as:

$$\text{Alpha-cellulose \%} = \frac{W_4 - W_3}{100W_2} * W_1 \quad (1)$$

Where W_1 : is the holo cellulose content %, W_2 : is the weight of oven-dried holocellulose mass, W_3 : is the mass of oven-dried crucible percentage, and W_4 : is the weight of oven-dried residue-crucible mass.

The following quantities will be calculated for Bamboo wood composites.

-The indentation modulus (E_{IT})

$$E_{IT} = \frac{1 - (v_s)^2}{\frac{1}{E_r} - \frac{1 - (v_i)^2}{E_i}} \quad (2)$$

Where v_s : is the Poisson's ratio of the sample which is taken as 0.43, v_i : is the Poisson's ratio of the indenter and = 0.07, E_i : is the modulus of the indenter and equal to 1140 GPa. Whereas the E_r : is the reduced modulus and given as:

$$E_r = \frac{\sqrt{\pi}}{2C\sqrt{A_p}} \quad (3)$$

Where C is the compliance of the contact, and A_p is the projected area defined by ISO14577-2(15).

In this case, it will be taken as a constant value of 500 MPa.

The elastic index (η_{IT}) which is defined as the ratio of the elastic work to the total work which can be expressed as:

The η_{IT} can be given as

$$\eta_{IT} = \frac{W_{elast}}{W_{total}} * 100\% \quad (4)$$

Where W_{elast} : is the area under the loading curve, and W_{total} : is the sum of elastic and plastic work determined by the total area below the loading curve.

The Martens Hardness (HM) can be calculated using Vickers indenter as:

$$H M = \frac{F}{26.43 * h^2} \quad (5)$$

Where F: is tests force and h: is the indentation depth.

The indentation creep (C_{IT}) can be calculated as:

$$C_{IT} = \frac{h_2 - h_1}{h_1} * 100\% \quad (6)$$

Where h_1 and h_2 are the indentation depths at time $t_1=8$ seconds and $t_2=128$ seconds respectively.

Many papers discussed the issue: **Ray (2005)**. Studied the effects of the change in hygro-thermal conditioning on fiber reinforced epoxy like glass and other polyester composites (matrix). It was found that mechanical performances were affected at different conditions and stages. Also, some shear values were found to be greater as crosshead speed increased for all undertaken situations. It was found that some mechanical responses depended strongly on matrix resin and type of hygro-thermal shock cycle. **Yong (2009)**. Discussed the effect of the interface structures of fiber reinforced composite materials on mechanical properties. Also, the effects of changing the matrices and nano-architecture interfaces on the mechanical properties of nano composite materials were examined. Nonlinear damage model for characterizing the deformation behavior of polymeric nano-composites was presented. **Kulasinski (2015)**. Investigated that the physical properties affected by moisture adsorption at atomistic scale, Molecular Dynamics (MD) simulations were chosen as a tool for wood. It was found that the diffusion of adsorbed water molecules is represented in a thermodynamics model which showed that the diffusion can be considered a critical process which enables calculation of system tortuosity and activation energy for hydrogen bonds.

Bradley, Teske, Lauren; Eliades, George; Zinelis, Spiros; Eliades, Theodore (2016). investigated the mechanical and chemical alterations of Invisalign appliances after intraoral aging. Indentation modulus (E_{IT}), elastic to

total work ratio also known as elastic index Martens Hardness (HM), and indentation creep (C IT) were measured for different types of materials.

Bui, Grillet, and Tran (2017). Studied the effects resulting from treating bamboo woods and its effects on its mechanical properties and durability. The tests carried on bamboo specimens summarized by decreasing their sensitivity to moisture and improve their durability. On the second stage, the mechanical and durability tests were performed on untreated and treated bamboos: different loads are applied on samples including uni-axial compression tests, three points bending tests, water immersion tests, and humidity tests. It was found that some treatment woods have more durability and the compressive strength of treated specimens, compared to untreated bamboo.

In this study, the relation between chemical properties change and its reflection in mechanical behavior is studied.

RESULTS AND DISCUSSIONS

By calculating The indentation modulus (EIT), the elastic index (ηIT), the Martens Hardness (HM) and the indentation creep (CIT), which depends strictly on Poisson's ratio which is depending on temperature and grain size of the material, i. e any chemical change in the structure of the material which can be also occurred by changing the temperature or humidity surrounding the material will cause a change in its mechanical and physical properties.

Only the indentation modulus (E_{IT}) will be calculated which is depending on the change of Poisson's ratio which depends originally on the change in chemical properties of the material. Data: $E_r=500 \times 10^6$ Pa, $\nu_i=0.07$, $E_i=1140$ GPa. And the following Poisson's ratio of the Bamboo sample is taken.

Table 1

Temp. (C)	20	30	40	60	80	100
ν	0.42	0.43	0.45	0.49	0.50	0.51

So after taking last data the indentation modulus related to Poisson's ratio of the bamboo wood samples as:

$$E_{IT}=500 \times 10^6 - 500 \times 10^6 * \nu_s \quad (7)$$

Figure 1 below shows the relation between the indentation modulus and poisson's ratio of the bamboo wood which is strictly depend on the change of the chemical composition of the material

Figure 1: EIT vs. Poisson's ratio

Figure 2 shows the effect of fine grains and coarse grains materials on mechanical properties.

Figure 2: Differences between Coarse Grain and Soft Grain Material and their Effect on Mechanical Properties

Table 2 shows the effect of some chemical and physical quantities changes and their effect on the mechanical properties of a paper produced from bamboo woods, [5-6].

Table 2: The Effect of Some Chemical and Physical Quantities Changes and their Effect on Mechanical Properties

Property	Effect
Wet Web Properties at Constant Solid Contents	
Tensile index	Increase
Stretch	Increase
TEA index	Increase
Dry Sheet Properties	
Formation	Decreases and then levels off
Density	Increases
Absorption coefficient	Increases and then levels off
Scattering coefficient	Increases and then levels off
Opacity	Increases and then levels off
Tensile index	Increases and then levels off
Elastic modulus	Increases and then levels off
Stretch at breaks	Increases and then levels off
Zero span	No effect
Tear index	Depends on furnish

CONCLUSIONS

In this paper the effects of chemical and physical changes on the mechanical properties of fibers or composite material like Bamboo woods are studied, it is found that the mechanical properties of such wood depend strictly on chemical composition and chemical properties of the material either grain size, change in temperature which causes change in Poisson's ratio and other chemical and physical changes.

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