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# The Effect of Temperature and Moisture Content on the Mechanical Properties of Wooden Cross-Arms from Cengal (Balanocarpus haemii)

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**Abstract:** Samples of wooden cross-arms from cengal (*Balanocarpus haemic*) loaded in compressions in the radial direction were studied and compared with those swollen by moisture or water. The modulus of elasticity at various Moisture Contents (MC) was measured from 0 to 100°C. Compared with the Environmental Moisture Content (EMC), the Fiber Saturated Point (FSP) samples swollen by moisture showed extensive decreased in the modules of Elasticity (E) than the Fully Water Saturated (FWS) samples swollen by water.

**Keywords:** Wooden Cross-arms, Modules of Elasticity (E), Moisture Content (MC), Fully Water Saturated (FWS), Fiber Saturated Point (FSP)

## Introduction

When wooden cross-arms is exposed to rainy weather the unprotected surfaces of wood absorb mixtures. As a result of weathering, the moisture will sustain for sometime before it is dried out. The amount of Moisture Content (MC) in the wood greatly depends on the amount and time of the rainfalls. For example, during the rainy season the weathered wood will be Fully Water Saturated (FWS). On a very cloudy day the MC might reach the Fiber Saturation Point (FSP). The amount of MC at a particular time will affect the strength of the cross-arms. Thus the strength shall change as the level of MC change. There is a possibility to relate the quality of the wood in terms of strength with the amount of its MC at a particular time.

Water is present in wood in two forms, one as free water in the cell cavities and pores and the other as bound water in cell walls. The free water is that held by capillary force whereas bound water is chemically bonded to the cell walls. At this stage the wood is said to be FWS. When the wood is dried, the first water to be removed is the free water, and eventually a stage is reached when the cell cavities and pores are empty but the cell wall is still saturated. This is the FSP, generally ranging from 15 to 35% MC depending on species (Torgovnikov, 1993).

The objective of the present investigation was to study the influence of water and temperature on the mechanical properties of cengal (*Balanocarpus heimii*) cross-arms subjected to radial compression. Cengal is a primary hardwood and is under the genus of *Hopea*. It is well defined and is pale brown in color with air-dry density ranging from 915-980 kg/m$^3$ and averaging 945 kg/m$^3$. It is naturally durable and heavy constructional timber that is also known of being a standard by which all other timbers of the peninsular Malaysia are judged (Lopez, 1983). The work deals with the determination of modules of Elasticity (E) of weathered cross-arms at 3 levels of MC namely as received with Environment Moisture Content (EMC), FSP and FWS. The temperature range tested is between 0 and 100°C. The knowledge from these properties is useful for predicting the mechanical strength of wooden cross-arms and to understand how wood strength should be determine in the severe weather condition. Knowledge of how moisture affects properties would be useful for determining the quantitative limits of the moisture parameter required in order to improve the quality of solid wood with minimum energy costs before strength and surface properties are change deleteriously.

## Materials and Methods

The sample from sound wooden cross-arms were taken from the Electricity Board depot. Rectangular samples of approximately 2cmx2cmx2cm were prepared. Great care has to be taken when cutting these pieces so that it followed perfectly the grain direction. The FSP samples were prepared by steaming the samples at 120°C for 30 minutes in an autoclave, cooled slowly in about 10 hours to room temperatures in the moisture saturated autoclave. Then the samples are kept over $KNO_3$ vapor in a closed chamber at room temperature for at least three weeks prior to the compression. The FWS samples were prepared by immersing the samples into water in a vacuum desiccator. The air in the desiccator was pump out under the pressure of 76mm Hg using a vacuum pump. When the samples are fully saturated with water it sank to the bottom of the desiccator and considered ready for testing.

The dimensions of the specimen were measured with a digital sliding caliper to the nearest 0.01mm at 30°C. Mechanical properties were measured in compression in the radial direction at 3 different moisture contents chosen with MC ranging from as received with EMC, FSP and FWS. The mechanical testing were carried out with an Automated Materials Testing System (Instron Universal Testing Machine Series IX) controlled by a computer. 5 compressions were carried out at each temperature. The average modules of Elasticity ($E_{av}$) was calculated from the mean of the best three curves. The dried testing between 30 to 100°C at 2.5 mm/min were carried out using an oven chamber capable of heating up to 600°C. The FSP and FWS samples compressions between 0 to 100°C were performed using a standard Hotech water bath 810 with the specimen placed in the circulating water.

## Results and Discussion

### Behavior of Dry Wood on Heating

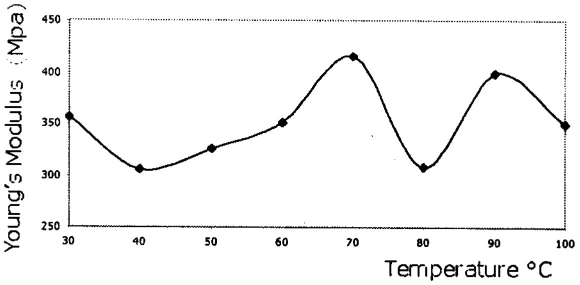


Fig. 1: The Relationship between the Average Young's Modulus and Temperature for Dried Sample

Fig. 1 shows the relationship between $E_{av}$ with temperature for dried cengal samples. From the plot, there is no significant decrease in the value of $E_{av}$ with temperatures. Because of the consistencies of the results the upper limit of the testing was 100°C. The value of $E_{av}$ at the lowest temperature at 30°C in the dried condition i.e. 356.0 MPa are similar with the value at the highest temperature at 100°C i.e.350.6 MPa. This indicates that the dried samples remain stiff and does not show a distinct transition or softening when compressed up to 100°C as confirmed earlier by Hillis and Rozsa. Cellusoses, hemicelluloses and lignin in dry wood are interlocked in a highly coordinated structure and are unlikely to show transition temperature. The glass transition temperature for dry wood is somewhat above 200°C (Ostman, 1985). Moreover the potential loss of moisture from the samples under such conditions reduces its validity above this temperature.

**Behavior of Wood at Fiber Saturated Point (FSP):** The influence of MC on the samples at FSP is shown in Fig. 2. From the plot, the $E_{av}$ values decrease

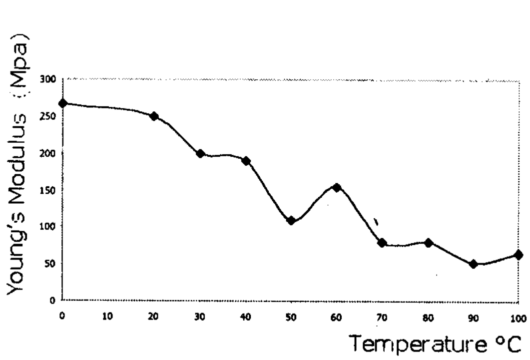


Fig. 2: The Relationship between the Average Young's Modulus and Temperature for Fiber Saturated Point Samples

gradually with increasing temperature at the early stage. At around 40°C the $E_{av}$ value decreases significantly until 50°C. This response suggested that some wood component changes to a rubbery state as cited earlier by Hillis and Rozsa for *radiata* pine in a rotation test. They assigned this as a transitional temperature. This is where the maximum rate of transition to the rubbery state occurs. At around 50°C the $E_{av}$ value increase again and showed rigid glassy state at around 60°C. Like pine, a different group of wood component also exist in cengal. These components begin to transform from the rigid glassy state above 60°C to its rubbery state until the changes is completed.

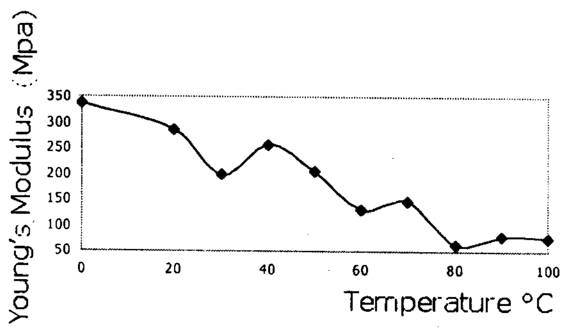


Fig. 3: The Relationship between the Average Young's Modulus and Temperature for Fully Water Saturated Sample

**Behavior of Wood at Fully Water Saturated Point (FWS):** The relationship between $E_{av}$ and temperature for FWS samples are shown in Fig. 3. From the Fig., the value of $E_{av}$ decreased gradually with temperature until 40°C. Beyond 40°C, $E_{av}$ decreased drastically up to 60°C (correspond to 50°C in FSP samples). Above 60°C once again the samples showed the rigid glass transition at 70°C and eventually to its rubbery state until the transformation from the rigid glassy state is completed.

**Comparison between EMC, FSP and FWS Samples:** Fig. 4 shows the relationship between $E_{av}$ values and temperature for EMC, FSP and FWS samples. The

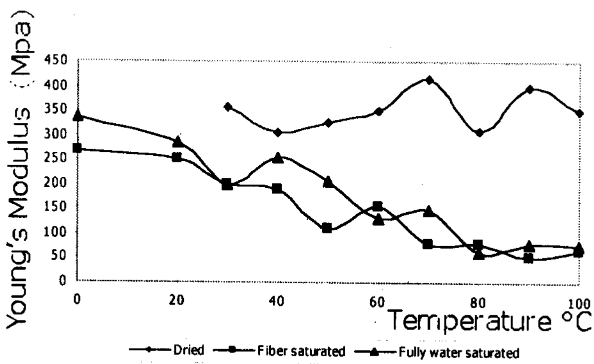


Fig. 4: Relationship between Average Young's Modulus and Temperature for Dried, Fiber Saturated Fully Water Saturated Samples

Fig. shows that the dried samples yield the highest $E_{av}$ values. It is obvious that the dried samples did not show any glass transition in the temperature range tested. This is due to the fact that the transition for dried wooden materials is somewhat above 200°C (attributed to the softening of hemicelluloses at 170°C, dry lignin at 205°C and cellulose at 230°C). Above 100°C there were indications that rupture between tracheid and fibers beginning to occur at these higher temperatures. Both the FSP and FWS samples showed the transitional and rigidity temperatures. The rapid decrease of $E_{av}$ for both FSP and FWS samples can be described as an effect of water acting as a softening agent or plasticizer for the wood polymer (Ostman 1985). In other word, the water promotes the plasticizing effect and lowered the softening temperature of the wood polymers. The plasticization of lignin by water is thought to result from the replacement of intermolecular hydrogen bonding within the lignin by lignin-water linkages (Hillis and Rozsa). Although both FSP and FWS samples had the same onset of softening temperature namely at 40°C, it is found that the $E_{av}$ of FWS is slightly higher than the FSP.

In other words the free water in cell cavities and pores increase the $E_{av}$ as well as the transitional and rigidity temperatures of the wood. With less water, i.e. with only bound water in the cell wall at FSP the elasticizing effect of water on wood polymer is less significant. This is shown by the lower $E_{av}$ values obtained from FSP samples. It is suggested that the excessive water in the cell cavities in FWS state thus avoid deformation of the cell wall easily whereas in the case of FSP state, trap air does not resist the deformation and thus lower $E_{av}$. In general cengal is more suitable for use either in EMC or FWS (for bridges and poles at dockyards) states rather than in FSP states.

## Conclusion

At temperature ranging from 0°C to 100°C, the $E_{av}$ of wooden cross-arms are significantly affected by MC. Based on the shape of the curve from EMC, FSP and FWS samples, the mechanical properties can be divided into 2 ranges of MC. At EMC the $E_{av}$ of dried samples was greater than those samples swollen by water. It is found that saturated water in the cell in FWS samples yield higher $E_{av}$ and higher transitional stress which occurs at higher temperature compared with FSP samples. These facts indicate that the amount of water that enter into the cell cavity and pores at FWS interact with the wood constituents and strengthen the wood. As with FSP samples the small amount of water in the cell wall are not able to fully plasticine the wood polymer and thus this interaction only reduces the strength.

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