

## **Charpy Energy Impact Test on Variable Nigerian Timber species short beams.**

**by**

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### **Abstract**

This work analyzed the plastic and elastic properties of some Nigerian timber as a structural material. Charpy impact test method was used to determine the impact energy/toughness of twenty locally available timber species, comprising of ten hardwoods and ten softwoods. Three sets of specimen (having dimension 125 mm by 12.5 mm by 12.5 mm) were obtained from each of the timber species. The first set had grain angle parallel to the longitudinal axis of the specimen, the second set had grain perpendicular to the longitudinal axis of the specimen and the third had grain at an angle of  $45^{\circ}$  to the longitudinal axis of the specimen. The toughness energies of the materials were observed to vary as the angle of the grain varied. The toughness energies of the materials were observed to vary as the angle of the grain varied, with the maximum strength obtained when the grain orientation was parallel to the axis of the tree trunk. The toughness energy obtained for the different softwood species was 1.49Kgf/cm<sup>2</sup> for Obia, 2.89Kgf/cm<sup>2</sup> for Okwe, 1.08Kgf/cm<sup>2</sup> for Avu, 2.2Kgf/cm<sup>2</sup> for Akpu, 2.4Kgf/cm<sup>2</sup> for Anyasualo, 2.26Kgf/cm<sup>2</sup> for Egba, 1.6Kgf/cm<sup>2</sup> for Owen, 1.23Kgf/cm<sup>2</sup> for Ojoo, 1.08Kgf/cm<sup>2</sup> for Yellow man, 1.4Kgf/cm<sup>2</sup> for Marima. While for the hardwood specimen, the following range of result was obtained; 2.22Kgf/cm<sup>2</sup> for UghiMmanu, 2.4Kgf/cm<sup>2</sup> for Ukpi, 2.62Kgf/cm<sup>2</sup> for UburuMmiri, 1.85Kgf/cm<sup>2</sup> for Iroko, 1.08Kgf/cm<sup>2</sup> for Oha, 1.6Kgf/cm<sup>2</sup> for Mango nkiti, 1.42Kgf/cm<sup>2</sup> for Egbu, 1.46Kgf/cm<sup>2</sup> for Meligna, 2.0Kgf/cm<sup>2</sup> for Obala and 1.6Kgf/cm<sup>2</sup> for Mahogany. A comparison of the toughness energy of the twenty timber specimen was made, which showed that Cordiamilleni (Okwe) possessed the highest impact energy/toughness which occurred when the grain orientation was parallel to the longitudinal axis of the specimen. Further comparison of the results with that of established steel showed a 59.3% drop in the toughness energy of Cordiamilleni with respect to that of an established X100 steel.

Keywords: Charpy, Energy, Impact Test, Timber, Toughness, Steel

**Introduction** : Over the years, there have been discoveries of different structural materials with high strength properties, and capable of carrying large amount of loads. This has led to a

decline in the use of traditional materials such as timber, clay, bamboo, thatch, stones, coconut tree, etc. in construction. However, the high cost of these new materials, and the adverse effect they have on the environment led to the demand for a new structural material, with low cost and a more environmentally friendly nature. Timber a material possessing these properties has been employed as a material of construction in recent times. Solid timber as well as engineered timber (which possesses much desirable properties) is being employed as structural material.

**Background of Study :** Unlike most engineering materials, Timber is an organic material that is anisotropic, hygroscopic and exhibits high variability of mechanical properties (Nwokoye 1999). These mechanical / structural properties include the elastic, plastic and elasto-plastic (viscoelastic) properties this timber species possess, which forms the basis of the timber design. The combined elastic and plastic energy of a material gives the toughness energy of that material Toughness of a material is defined as the ability of the material to absorb energy and plastically deform before failure occurs. It is the ability of a material to absorb sudden shock without breaking or shattering. Toughness of a material is also a measure of the plasticity and plasticity of a material in terms of energy absorbed. Toughness of timber material is inversely proportional to the temperature of the timber material, this can be attributed to the decrease in moisture content of the material when exposed to high temperature. The toughness of a material can be determined using two main methods; By finding the area under a stress-strain curve of the material and From an impact energy test of the material. Despite the appreciable toughness energy observed in timber, Europe and most other parts of the world, still design timber structures for the ultimate limit state with the old, conservative concept of full elastic behaviour till failure. The situation is rather funny for two main reasons. First, it is well known that under compressive loading, timber exhibits a much better ductile behaviour than concrete. Despite this, timber is still underutilized as a structural material, especially in Nigeria, where concrete has been embraced as the main construction material. No wonder Ede et al (2015), noted that timber is rarely utilized except for temporary structures, structures of low value and in the riverine areas. This is surprising considering its strength properties and the cost advantage it has over concrete structures (According to the cost analysis performed by Ede et al (2015)).

**Aim and Objective :** The aim of this project is to analyse the plastic and elastic properties of twenty common timber materials used in construction.

### **The Objectives of the Work are:**

- i. To review the behaviour of timber qualifying it as a structural material
- ii. To conduct charpy impact test to determine the impact strength (toughness energy) of twenty Nigerian Timber consisting of ten hardwoods and ten softwoods.
- iii. To compare the plastic and elastic properties of twenty Nigerian timber using their toughness energy.
- iv. To compare the plastic and elastic properties of the timber specimen to an established steel.

**Scope of Work :** This work is focused on the elastic and plastic analysis of Nigerian timbers upon the application of impact load. The work includes a charpy impact test on the twenty Nigerian timbers consisting of ten softwood and ten hardwoods.

**Limitation:** The variability in properties observed in timber, makes it impossible for the properties of a small piece cut off from a large log to be representative of the whole log. Also the properties in the areas affected by knot and other strength reducing factors are quite different from that observed in other parts, due to the distortion in the grain reorientation in those areas.

**Justification:** Most of the structures being designed, especially in Nigeria are made of concrete and steel. Timber is mostly not utilized except in roof trusses and sub-standard and simple structures. This is due to the doubts on the ability of timber to withstand high amount of loads. Steel and concrete even though possess high strength properties, is marked by high cost, especially in Nigeria where steel is imported. The excessive harvest of raw materials for the production of cement leads to a rapid depletion of the countries raw materials. Wood on the other hand is a renewable raw material that grows back naturally.

There are different Wood species in Nigeria with varying strengths. If properly sawn and treated these timbers species can be used as a more economical alternative to steel and concrete in the construction of building, bridges and other infrastructures.

Obtaining the timber with the most desirable strength properties requires that tests be conducted on the timber species. Charpy impact test is used to obtain the impact strength of timber materials. These impacts strength obtained in the form of toughness energy gives the amount of energy the timber can absorb before undergoing plastic deformation. With the help of charpy Impact test, the timber with the highest toughness energy can be identified.

## II. Literature review

The strength property of timber qualifying it as a structural material comes from the macro and microscopic structure of the wood cell. Timber is made of fibre materials, which are oriented so that their length is parallel to the axis of the tree trunk, the strength of wood parallel with the grain is different from the strength across the grain (Ezeagu and Nwokoye 2008). The grain orientation makes wood an orthotropic material possessing different strength in different directions.

### Plastic and Elastic Analysis of Structures

The two approaches adopted in the analysis of structures are the elastic and the plastic method of analysis. The elastic design approach assumes that at design loads structures behaves in a linearly elastic manner and the structure fails when loaded beyond this design load. Further studies shows that structures designed using the elastic method possess considerable reserve strengths beyond the elastic limit until they reach their ultimate strength, this reserve strengths exhibited by these materials is due to the plastic properties possessed by them.

### Behaviour of Timber on the Application of Load

Dinwoodie(1981)wrote that the behaviours of timber material on the application of load can be explained as follows;

- i. Timber does not behave in a truly elastic mode, rather its behaviour is time dependent
- ii. The magnitude of the strain is influenced by a wide range of factors. Some of these are property dependent, such as density of the timber, angle of the grain relative to direction of load application and angle of the micro fibrils within the cell wall. Others are environmentally dependent, such as temperature and relative humidity.

On the application of load timber deforms,these deformations can be divided into the elastic, delayed elastic and viscous-deformation. The elastic deformation appears directly after loading, after which the deformation increase slowly under a constant load. This increase in deformation is made up of delayed elastic and viscous deformation. The difference between these two is that the delayed elastic deformation is recoverable after unloading, but the viscous-deformation is permanent (Marie2015). The delayed elastic deformation together with the viscous deformation is called creep. The viscous deformation which is a permanent deformation is also termed a plastic deformation since its effect is irreversible. In materials

such as timber where such behaviours are observed, they are treated as viscoelastic (elastic-plastic) material.

**Elastic Behaviour of Timber:** The elastic behaviour of timbers is based on Hooke's law of elasticity, in which the application of load (stresses) either in tension, compression, or bending produces an instant deformation (strain) in the timber structure. This deformation obtained increases gradually in a manner approximately proportional to the values of the applied load. The elastic behaviour of materials is that which allows those materials to regain its original shape and size after the applied force have been removed. Timber undergoes elastic deformation in two stages when loaded. The first stage of the elastic deformation occurs instantly on the application of the load, the second stage occurs when the timber is left under this constant load for some time. This second type of deformation that occurs is the delayed elastic deformation and is also recoverable on the removal of the applied load. According to [Green et al \(1999\)](#) twelve constants (nine are independent) are needed to describe the elastic behaviour of wood: three Moduli of Elasticity  $E$ , three Moduli of Rigidity  $G$ , and six Poisson's Ratios  $\nu$ .

**Plastic Behaviour of Timber:** Timber exhibits plastic behaviour due to the excessive application of load in compression. When solid wood is subjected to compression load, its stress strain diagram is initially linear, and it successively demonstrates non linearity similar to that of ductile materials such as metals. After the non-linearity is introduced the stress strain relationship of solid wood should be described using a theory other than anisotropic elasticity, such as plasticity ([Yoshihara 2014](#)). Plasticity is the ability of certain solids to change shape permanently when subjected to stresses of intermediate magnitude between those producing temporary deformation or elastic behaviour and those causing failure of the material or rupture ([Britannica 2018](#)). In compression parallel to the fibre direction the main stress will be parallel with the axial direction of the fibres. Fibres loaded axially are very stable and can withstand a high load level. When the load is too high some fibres will start to buckle and be driven into the other fibres. When the buckling behaviour in the wood starts the possibility to take higher load will diminish and the behaviour can be classified as plasticizing ([Marie 2015](#)). The plastic behaviour according to [Euro code 5](#) is adopted in design when no strength reduction occurs and when slenderness is low in the member. Another form of plasticity observed in timber is time dependent and depends on the duration of loading. This time dependent plastic deformation is also termed viscous deformation.

**Viscoelastic Behaviour of Timber:** Most structural engineering materials are described by Hooke's law in which stress strain relationship is linear, but in reality all materials deviate from Hooke's law in various ways. This deviation is also observed in timber whose behaviour on the application of load can neither be said to be purely elastic or truly viscous, rather it can be said to be a combination of both. Such behaviour is said to be viscoelastic behaviour. Other materials such as concrete, bitumen, and thermoplastics that contain polymeric materials also exhibit this viscoelastic property. Viscoelasticity is a time dependent property of timber, this means that the deformation of the timber for a constant load will gradually increase with time.

According to Dinwoodie(1981), in a material such as timber, time-dependent behaviour manifests itself in a number of ways of which the more common are creep, relaxation, damping capacity, and the dependence of strength on duration of load. When the load on a sample of timber is held constant for a period of time, the increase in deformation over the initial instantaneous elastic deformation is called creep (delayed elastic deformation). Creep can be divided into the reversible and the irreversible components. The reversible creep is also referred to as the delayed elastic deformation or primary creep. Irreversible creep is also referred to as plastic or secondary creep.

An increase in moisture content reduces the strength and stiffness properties of timber and wood based materials and increases the amount of creep that occurs,(institution of structural engineers2007).

Timber beams are also observed to exhibit both elastic and plastic properties simultaneously when subjected to bending. When the beams are loaded the bending that occurs leads to the development of two regions subjected to compressive and tensile stress. The compressive stress are observed in the region closer to the surface where the forces is applied (top surface in many cases), while the tensile stress is generated on the region farther away from the surface where the force was applied.

## **Research Methodology**

### **Material preparation**

Twenty different locally available timber species consisting of ten softwood and ten hardwoods were used for this research. The materials used were obtained from Timber shed in Umuokpu Anambra State Nigeria. The twenty timbers comprises of 10 locally available softwood and 10 locally available hardwoods which can easily be obtained from different parts of the country. The timber was cut into the required dimension which is 125mm X 12.5

X 12.5mm. with a V-notch at the centre of the length with depth of 2.5mm and a width of 5mm, so as to give a maximum concentration of impact stress in a cross section of 12.5mm X 10mm.

**The process used to obtain the specimen is as follows**

1. The trees are felled and loaded into transport trucks which transports the logs to the sawmill facility (Timber shed at UmuokpuAnambra State).
2. Logs are properly scaled before entering the saw mill, this involves measuring, inspection for defects.
3. The logs are then sorted in terms of species.
4. The logs are then taking into the saw mill where they are debarked and then cut into planks using the circular sawmill machine.
5. The air drying process removes naturally occurring moisture from the planks.
6. Using a pencil, ruler, square, and equipment for angle measurement three diagrams are drawn on the surface of the timber,
  - a. The first being parallel to the direction of the fibres
  - b. The second being perpendicular to the direction of the fibres
  - c. The third being at an angle of 45<sup>0</sup>
7. Using a vertical band saw machine the specimens were cut out of the plank using the drawings on the plank as a guide.

Table 3.0 gives a list of 10 softwoods to be used in the charpy impact test, while table 3.1 gives a list of 10 hardwoods to be used for the test.

**Table 3.0 Showing Softwood specimens used**

S / N	Botanical name	Classification	Igbo Name	Yoruba Name	Hausa Name
1	Uapacaguineensis	Softwood	O b i a		W a w a n K u r m i i
2	Cordiamilleni	Softwood	O k w e	O k w e	
3	Albiziaadianthifolia	Softwood	A v u	Anyimebona	G a m b a
4	Banbaxbonopozense	Softwood	A k p u	P u o p o l a	
5	Glyphaeabrevis	Softwood	A n y a s u a l o	E s o , s h i s h i	B o l u k o n u K a n a n a
6	Anogeissusleiocarpus	Softwood	E g b a	O r o g b o	G u t h i f e r a e e k u
7	Mitragyna ciliate	Softwood	O w e n		
8	Erythrophleum spp	Softwood	O j o o		
9	PterocarpusErinaceus	Softwood	Y e l l o w m a n		

1	0	L o p h i r a a l a t a	S o f t w o o d	M a r i m a		
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**Table 3.1 Showing Hardwood specimens used**

S / N	Botanical name	Classification	I g b o n a m e	Yoruba name	HausaName	
1	A f z e l i a s p p	Hardwood	U g h i m m a n u			
2	M a n i l k a r a	Hardwood	U k p i			
3	Naucleapobeguini	Hardwood	U b u r u m m i r i	O p e p e		
4	Chlorophoroexelsa	Hardwood	O r j i	I r o k o	L o k o	
5	Pterocarpussoyauxii	Hardwood	O h a			
6	Mangiferabanganpalli	Hardwood	M a n g o n k i t i			
7	Alstoniacongensis	Hardwood	E g b u			
8	Swieteniamacrophylla	Hardwood	M a h o g a n y		M a d a c u	
9	Gmelinaarborea	Hardwood	M e l i n a			
1	0	CylicodiscusGabunesis	H a r d w o o d	O b a l a		

## Methodology

### Impact test

Impact test determines the amount of energy absorbed by a material during fracture. This energy absorbed indicates the toughness of the material which can be defined as the capacity of materials to absorb energy and deform plastically before fracturing. The toughness of a material is related with both the strength and ductility of the material.

Impact testing of material involves the sudden and dynamic application of the load. Generally a pendulum is made to swing from a fixed height and strike the standard impact specimen.

There are two types of method to test impact strength of materials which are,

1. Charpy test
2. Izod test

In the Charpy test, the specimen is placed in a horizontal position with the notched (U or V shape) side facing a way from the pendulum, while in the Izod test the specimen is placed vertically and the notch area (V shape) is facing the pendulum. For the sake of this research work the Charpy test will be used for the determination of the impact strength of the timber materials.



## Theory and Scope (by M.LGambhir, 2014)

The test is performed with a pendulum-type single-blow impact apparatus wherein a standard size machined notched specimen of material is broken by a falling pendulum hammer (swinging through a fixed distance) one blow. In Charpy test a specimen with a V-notch at the centre is supported at both ends as a simple beam. The energy absorbed, as determined by the difference in the height of the hammer before and after fracture of specimen, is a measure of impact strength or notch toughness the impact test results are expressed in kilo joules as an assessment of toughness or energy absorption. In case of brittle fracture, the material breaks on a flat plane and in ductile fracture the material breaks with jagged edges or shear lips usually a material does not break in either way; thus comparing the jagged to flat surface area of the fracture will give an estimate of the percentage of ductile and brittle fracture.

## Apparatus

1. A single blow impact testing machine with a calibrated dial so as to give direct reading of energy absorbed in breaking specimen on a single blow as schematically illustrated.
2. A calibrated dial gauge to give direct reading of angle covered.
3. Ruler
4. Specimen setting fixtures

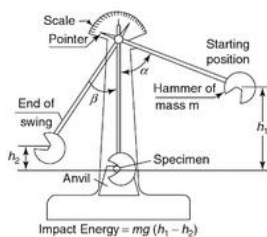
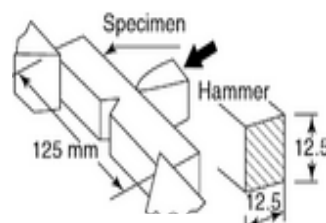


Figure 3.0 Charpy impact testing machine



Specimen dimension

A specimen of dimension 12.5 X 12.5 mm cross section and 125mm length is provided with a V type notch 2.5mm in depth and 5mm in width at the centre on the radial face so as to obtain maximum concentration of impact stress in a cross section of 12.5 X 10mm.

## Procedure (by M.LGambhir, 2014)

1. Measure the dimensions of the timber specimen.
2. Set the latching mechanism in the upper position.
3. Lift the pendulum to its upper position and secure it with the safety latching mechanism.
4. Check whether the testing machine has been adjusted accurately,
5. Using positioning gauge place the Charpy V-notch test specimen horizontally across supports on the anvil in the path of a pendulum with the V-notch test specimen with

the notch facing away from the hammer make sure the specimen is centred within the anvil jaws and tightened firmly in the position.

- Slide the indicator pointer to the left until it indicates the maximum energy range on the upper Charpy tension scale.
- Raise the pendulum arm to the right until it is firmly supported by the latching mechanism.

Caution: make sure the safety latch is the clear when raising the pendulum arm into this test position

- The test conductor or laboratory instructor shall then release the pendulum by pushing up on the release knob. The hammer will drop striking the specimen, with a swing through dependent on the amount of energy absorbed by the test specimen. The indicator will move and stop when peak swing through is registered, providing a direct reading of the energy absorbed by the test specimen. Read the indicated value from the charpy scale and record.
- Apply the hand brake when the pendulum has returned to its stable hanging vertical position.
- Remove the specimen from the testing area and examine the failure surface.
- Leave pendulum in the down hanging vertical position until another test is to be performed

#### IV. Test Result

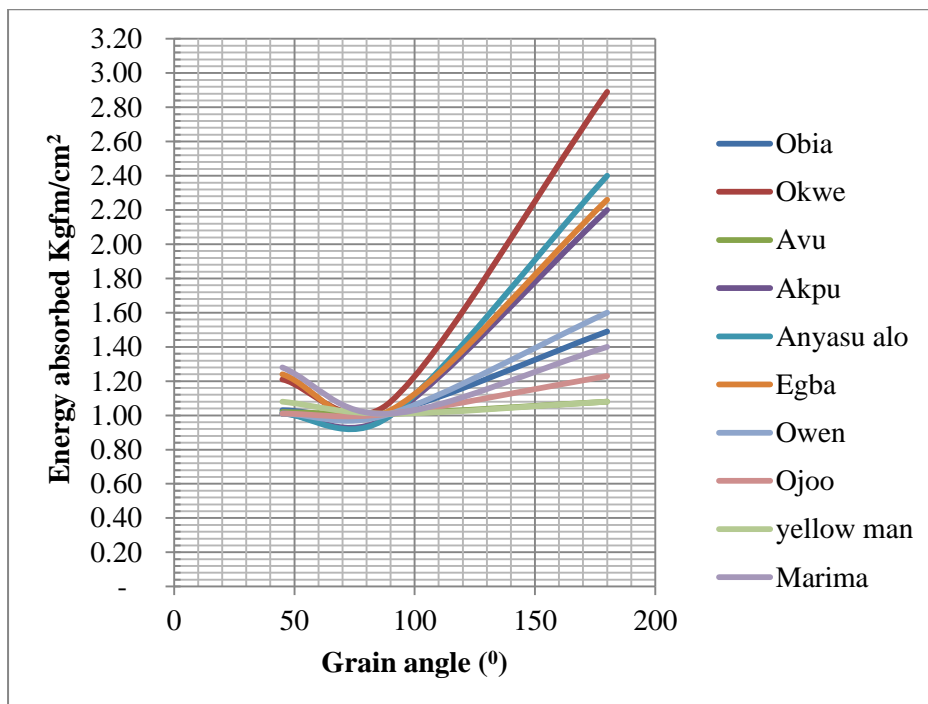
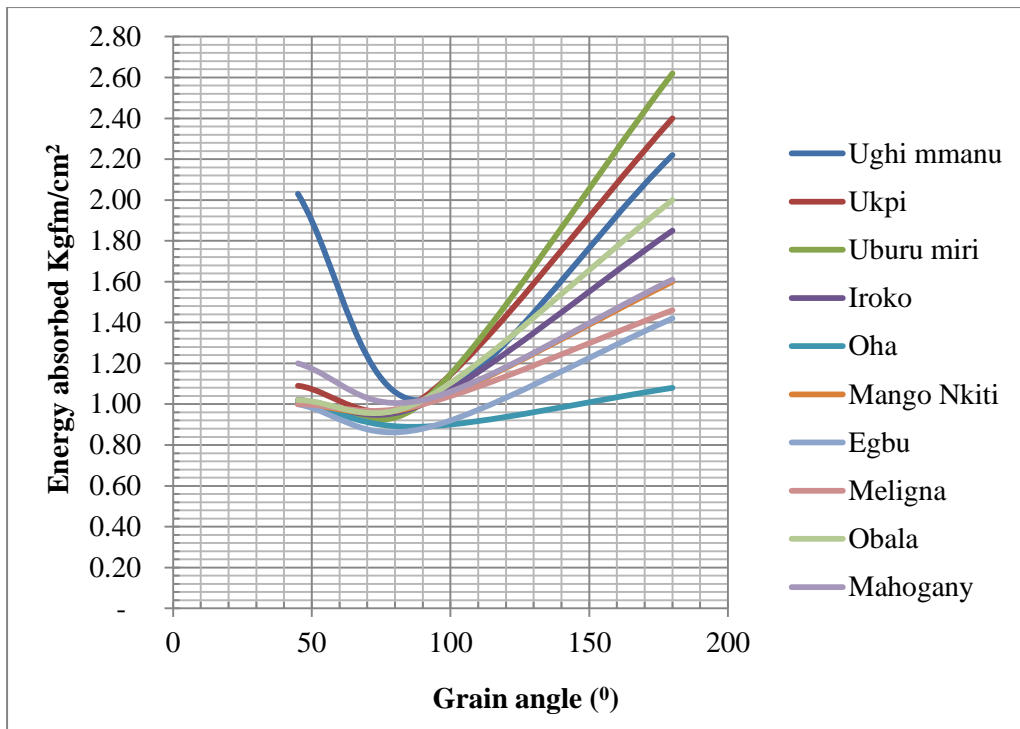


Fig 4.20 graph of impact energy against angle of grain of 10 softwood specimen

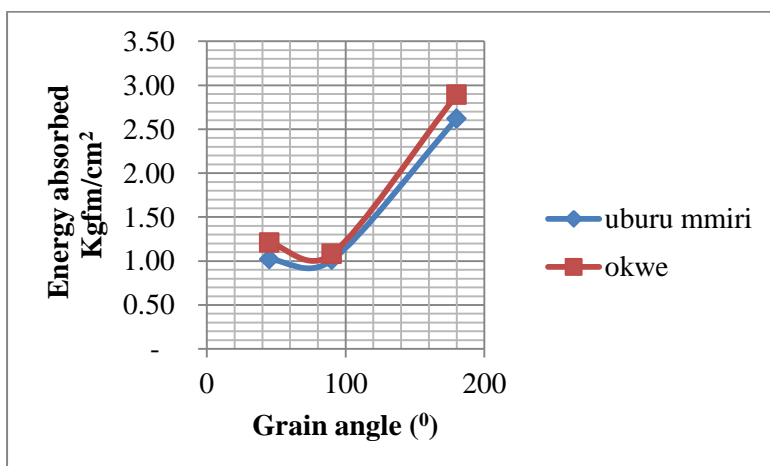
The figure above shows a collective plot of impact energy (toughness) against angle of grain for the ten (10) softwood specimen used for the test. The graphs generally have the same shape with the impact energy varying as the angle of grain relative to the longitudinal axes of the specimen varies from 0° to 180°. The pick strength for all the samples was observed to occur at a grain angle of 180° (i.e when the grain is parallel to the longitudinal axes of the

specimen). The lowest strength for the samples was observed to occur at a grain angle range of  $80^{\circ}$  to  $90^{\circ}$ , except that of anayasu alo (specimen 5S) whose lowest strength occur at a grain angle less than  $80^{\circ}$ . The softwood specimen with the highest toughness is okwe (specimen 2S) and this occurs when the angle of grain is parallel to the longitudinal axes of the specimen. the specimen with the highest toughness for when the grains are at an angle of  $45^{\circ}$  with respect to the longitudinal axes of the specimen is Marima (specimen 10S) with a grain energy of  $1.3\text{Kgfm/cm}^2$ . When the timber is to be used such that the angle of grain is perpendicular to the longitudinal axis of the specimen, then the specimen with highest toughness energy and most preferred to be used in this case is okwe with toughness energy of  $1.08\text{Kgfm/cm}^2$ . Different timbers specimen also possesses the same impact energy when they are cut at respective suitable angles.



**Fig 4.21 graph of impact energy against angle of grain of 10 Hardwood**

The graph of the impact energy ( toughness) of the ten (10) hardwood specimen used for the the test is shown above. In the same way as that of the softwood, the graphs generally have the same shapes, with the impact energy varying as the angle of grain relative to the longitudinal axes of the specimen varies from  $0^{\circ}$  to  $180^{\circ}$ . The maximum strength observed for the samples occurred at a grain angle of  $180^{\circ}$  (i.e when the grain is parallel to the longitudinal axes of the specimen). The lowest strength for the samples was observed to occur at a grain angle range of  $75^{\circ}$  to  $90^{\circ}$ . Uburu miri (specimen 3H) was observed to have the highest toughness energy which occurred when the angle of grain is parallel to the longitudinal axes of the specimen. for a grain angle of  $45^{\circ}$  with respect to the longitudinal axes, ughi mmanu was observed to possess the highest toughness energy with an impact energy of  $2.03\text{Kgf/cm}^2$ . When the grain is at an angle to the longitudinal section of the specimen, the most preferred specimen to use is ukpi with toughness energy of  $1.09\text{Kgf/cm}^2$ . Just like in the case of softwood, different hardwood specimen also possesses the same impact energy when they are cut at respective suitable angles.



**Fig 4.22 graph of impact energy against angle of grain of uburummiri and okwe**

The graph above shows a plot of impact energy (toughness) against angle of grain orientation for the two timber specimen uburu mmiri and okwe that has the highest impact energy for the softwood and hardwood specimens respectively, it can be observed from the graph that out of all the twenty (20) samples of locally available timber tested, okwe possess the highest amount of toughness energy.

### Comparison of the impact strength of okwe with that of X100 steel.

**Table 4.23 Showing Charpy impact test result for X100 steel at different temperatures**

Charpy energy for X100 steel measured on full and sub sized impact specimens												
Charpy specimen	1	2	3	4	5	6	7	8	9	10	11	12
test temperature <sup>0</sup> C	-20	-20	-10	-10	0	0	23	23	23	23	23	23
Charpy energy (J)	282	271	277	290	274	275	279	273	260	139	141	137
Average energy (J)	276(1 <sup>st</sup> set)									139 (2 <sup>nd</sup> set)		

Hashemi, Howard, Yates, Andrews 2006.

The table above shows the Charpy impact test result for an X100 steel at different temperatures, starting from -20<sup>0</sup>C to +23<sup>0</sup>C. The average impact energy for the samples at a temperature of 23<sup>0</sup>C (room temperature) is 139 joules, which is equivalent to 7.1 Kgfm/cm<sup>2</sup>. Percentage toughness of okwe timber with respect to the X100 steel can be given as

**Conclusion:** The Charpy impact test method was used in determining the impact energy/toughness energy for the timber specimens. These toughness energies gave an insight into the amount of energy absorbed before plastic deformation occurs. The results obtained from the Charpy impact test of the timber specimen showed a variation of impact energy of the timber specimens with a change in the angle of grain with respect to the longitudinal axis of the specimen. The lowest impact energy occurred in all specimens when the angle of grain orientation is at 90<sup>0</sup> with respect to the longitudinal axis of the specimen. The maximum toughness energy occurs when the grain is parallel to the longitudinal axis of the specimen (at 180<sup>0</sup>). This shows that it is more advisable to cut timber in a direction parallel to the tree trunk, when it is to be used for structural purpose.

A comparison of the impact energy for all softwood specimens, showed a highest impact energy of 2.89 Kgfm/cm<sup>2</sup> for Okwe, which occurred when the grain was parallel to the longitudinal axis of the specimen. Other softwood specimens such as Anyasualo, Egba and Akpu, also showed high impact energy of 2.4 Kgfm/cm<sup>2</sup>, 2.26 Kgfm/cm<sup>2</sup>, and 2.20 Kgfm/cm<sup>2</sup>, when compared to that of Okwe. Among the Hardwood specimens used, UburuMmiri showed the highest toughness energy of 2.62 Kgfm/cm<sup>2</sup>, which occurred when the grains are parallel to the longitudinal axis of the specimen. UghiMmanu, and Obala also showed high toughness energies of 2.22 Kgfm/cm<sup>2</sup>, and 2.00Kgfm/cm<sup>2</sup> when compared to that of UburuMmiri.

The impact energy of Okwe which was the highest obtained for the twenty timber specimen. A comparison to that of established X100 steel showed that Okwe possess an impact strength which is 59.3% less than that of the steel.

The timber species Okwe, Anyasualo, Egba, Akpu, UghiMmanu, Obala and Uburummiri all possess high toughness energies. When properly cut seasoned and treated with anti-decay chemicals, it can be used as an economical substitute for steel and concrete in the construction industry.

### **Recommendation**

This investigation was limited to only twenty timber species, further research needs to be conducted on other timber species not present in this research work, as they could possess more favorable properties than the ones studied above. A proper study of Nigerian timber species and its properties would also lead to a decrease in the importation of foreign timber.

The Government should set up well equipped research institutes to further research on the properties of timber and other locally available construction materials in Nigeria, as these materials might possess considerable strength and if used appropriately can lead to a reduction in construction cost. They should also provide funding for individuals who wish to research on this area, as conducting different tests needed for such research and analysis requires large sums of money.

Research should also be conducted on the use of engineered wood products and fibre reinforced timber as a means of improving the plastic properties of timber materials for structural purposes.

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