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FINITE ELEMENT ANALYSIS AND MODIFICATIONS IN PLYWOOD STRUCTURE TO ENHANCE IT'S STRENGTH

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Abstract: **This paper explains the plywood. The available sizes, stresses developed, force distribution of plywood in different conditions. It outline the mechanics of plywood, and calculations that relates the in-plane strain and curvature of a plywood to the forces and bending moments imposed on it.**

As plywood are not suitably used where temperatures are higher, and it is a brittle material so temperature effect and viscoelastic response is not considered. The analysis is done by using Ansys software.

Analysis is done by using softwoods, and it is observed that the plywood are less strong in the radial or bending. To improve its strength various combinations are done by using hardwood, softwood and ABS and the result obtained is 27.5% decreased stress developed in combination 3. Minimum deformation is observed in combination2. And minimum strain intensity in combination2 and 4. By making use of polymers like ABS it is also possible to change the properties of plywood.

*Keywords:***Ply, laminates, composite, stress, strain, deformation.**

I. INTRODUCTION

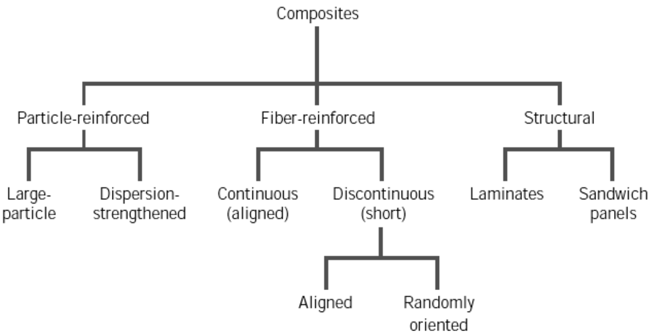
Many of our modern technologies require materials with unusual combinations of properties that cannot be met by the conventional metal alloys, ceramics, and polymeric materials. This is especially true for materials that are needed for aerospace, underwater, and transportation applications.

Frequently, strong materials are relatively dense; also, increasing the strength or stiffness generally results in a decrease in impact strength.

Material property combinations and ranges have been, and are yet being, extended by the development of composite materials. Generally speaking, a composite is considered to be any multiphase material that exhibits a significant proportion of the properties of both constituent phases such that a better combination of properties is realized. According to this principle of combined action**,** better property combinations are fashioned by the combination of two or more distinct materials.

A composite, in the present context, is a multiphase material that is artificially made, as opposed to one that occurs or forms naturally.

In addition, the constituent phases must be chemically dissimilar and separated by a distinct interface. Chart shows classification of laminates.



STRUCTURAL COMPOSITES

A **structural composite** is normally composed of both homogeneous and composite materials, the properties of which depend not only on the properties of the constituent materials *but also on the geometrical design of the various structural elements*. Laminar composites and sandwich panels are two of the most common structural.

LAMINAR COMPOSITES

A **laminar composite** is composed of two-dimensional sheets or panels that have a preferred high-strength direction such as is found in wood and continuous and aligned fiber-reinforced plastics. The layers are stacked and subsequently cemented together such that the orientation of the high-strength direction varies with each successive layer (Fig.1). *For example, adjacent wood sheets in plywood are aligned with the grain direction at right angles to each other.* Laminations may also

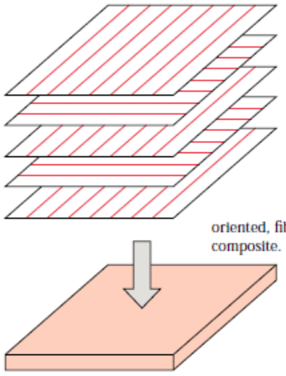


Fig.1

be constructed using fabric material such as cotton, paper, or woven glass fibers embedded in a plastic matrix. Thus a laminar composite has relatively high strength in a number of directions in the two-dimensional plane; however, the strength in any given direction is, of course, lower than it would be if all the fibers were oriented in that direction.

PLYWOOD*:*

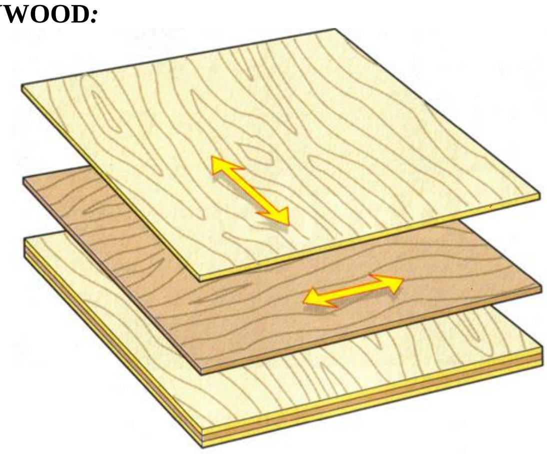


Fig.2 Alternate piles at 90 degree

Plywood is a building material consisting of veneers (thin wood layers or plies) bonded with an adhesive. There are two types of plywood: *softwood plywood and hardwood plywood. Softwoods* generally correspond to coniferous species. The most commonly used softwoods for manufacturing plywood are firs and pines. *Hardwoods* generally correspond to deciduous species. For hardwood plywood, commonly used wood species include oak, poplar, maple, cherry, and larch.
Softwood plywood is manufactured by gluing several layers of dry softwood veneers together with an adhesive. Softwood plywood is used for wall siding, sheathing, roof decking, concrete form boards, floors, and containers. *Softwood plywood is classified under Standard Industrial Classification (SIC) code 2436, and North American Industrial Classification System (NAICS) code 321212 for "Softwood Plywood and Veneer".*

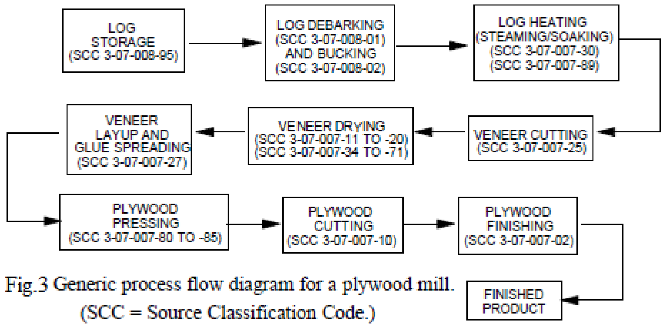


Fig.3 Generic process flow diagram for a plywood mill.
(SCC = Source Classification Code.)

Hardwood plywood is made of hardwood veneers bonded with an adhesive. The outer layers (face and back) surround a core which is usually lumber, veneer, particleboard, or medium density fiberboard. Hardwood plywood may be pressed into panels or plywood components (e.g., curved hardwood plywood, seat backs, chair arms, etc.). Hardwood plywood is used for interior applications such as furniture, cabinets, architectural millwork, paneling, flooring, store fixtures, and doors. Hardwood plywood is classified under SIC code 2435 and NAICS code 321211, for "Hardwood Plywood and Veneer".
Plywood mostly faces loads in two dimensions. , As plywood are not suitably used where temperatures are higher, and it is a brittle material so temperature effect and viscoelastic response is not considered. So for mathematical model development the stress analysis and bending of plate is considered.

II. MATHEMANTICAL MODELLING

Isotropic linear elastic material [Refer to S. S. Rao book]

$\sigma = D\varepsilon$

Where,

$$\sigma = \begin{vmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{vmatrix}, \qquad \varepsilon = \begin{vmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{vmatrix}, \qquad D = \frac{E}{1-\vartheta^2}\begin{vmatrix} 1 & \vartheta & 0 \\ \vartheta & 1 & 0 \\ 0 & 0 & \frac{1-\vartheta}{2} \end{vmatrix}$$

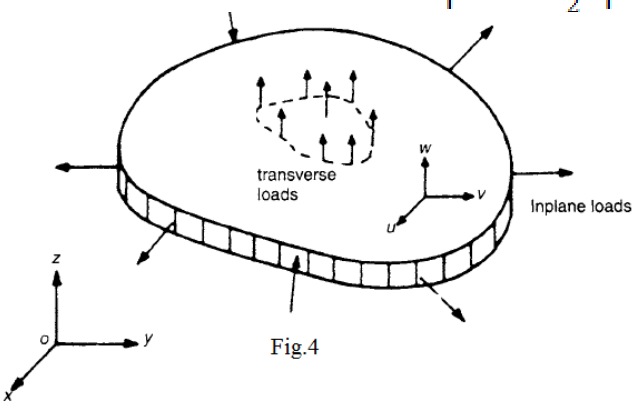


Fig.4

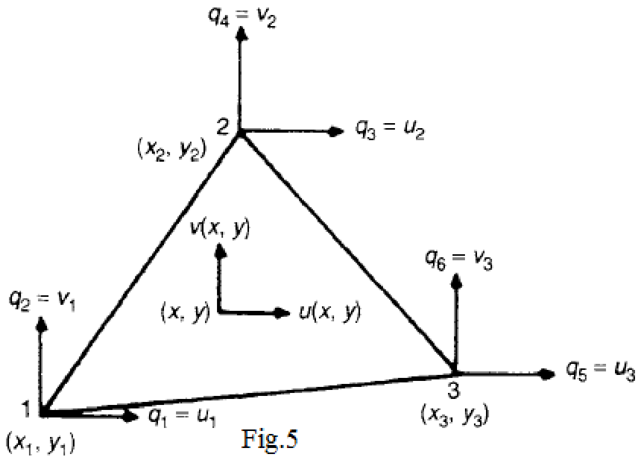


Fig.5

Where $D=S^{-1}$ is the stiffness matrix. Note that the young's modulus can be recovered by taking the reciprocal of the 1,1 element of the compliance matrix S, but that the 1,1 position of the stiffness matrix D contains Poisson effects and is not equal to E.

Transformation of axes

The rotation of axes is shown in fig.6

Cartesian Quazy stresses are,

$\sigma_1 = \sigma_x cos^2\theta + \sigma_y sin^2\theta + 2\tau_{xy} sin\theta cos\theta$

$\sigma_2 = \sigma_x sin^2\theta + \sigma_y cos^2\theta - 2\tau_{xy} sin\theta cos\theta$

$\tau_{12} = (\sigma_y - \sigma_x) sin\theta cos\theta + \tau_{xy}(cos^2\theta - sin^2\theta)$

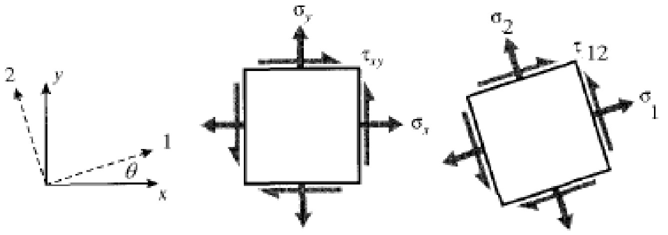


Fig.6

Where Θ is as shown in fig. 6

$$\begin{vmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{vmatrix} = \begin{vmatrix} c^2 & s^2 & 2sc \\ s^2 & c^2 & -2sc \\ -sc & sc & c^2 - s^2 \end{vmatrix} \begin{vmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{vmatrix}$$

Where $c = cos\theta$ and $s = sin\theta . This$ can be $abbreviated$ as

$\sigma' = A\sigma$

Where A is the transformation matrix.

Computation of stresses:

Convert the global displacement nodes into local displacement,

$q^{(e)} = [\lambda] Q^{(e)} \quad [6 \times 1 = 6 \times 6, 6 \times 1]$

$$q^{(e)} = \begin{vmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \\ u_3 \\ v_3 \end{vmatrix}, Q^{(e)} = \begin{vmatrix} Q_{2i-1} \\ Q_{2i} \\ Q_{2j-1} \\ Q_{2j} \\ Q_{2k-1} \\ Q_{2k} \end{vmatrix},$$

$$[\lambda] = \begin{vmatrix} l_{pk} & m_{pk} & 0 & 0 & 0 & 0 \\ l_{ij} & m_{ij} & 0 & 0 & 0 & 0 \\ 0 & 0 & l_{pk} & m_{pk} & 0 & 0 \\ 0 & 0 & l_{ij} & m_{ij} & 0 & 0 \\ 0 & 0 & 0 & 0 & l_{pk} & m_{pk} \\ 0 & 0 & 0 & 0 & l_{ij} & m_{ij} \end{vmatrix}$$

Where,

$$l_{pk} = \frac{X_k - X_p}{d_{pk}}, m_{pk} = \frac{Y_k - Y_p}{d_{pk}}, n_{pk} = \frac{Z_k - Z_p}{d_{pk}},$$

$$l_{ij} = \frac{X_j - X_i}{d_{ij}}, m_{ij} = \frac{Y_j - Y_i}{d_{ij}}, n_{ij} = \frac{Z_j - Z_i}{d_{ij}}$$

$$d_{ij} = [(X_j - X_i)^2 + (Y_j - Y_i)^2 + (Z_j - Z_i)^2]$$

Using local displacement vector $q^{(e)}$ of the element e. Find the stresses inside the element in the local system ,

$$\sigma = \begin{vmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{vmatrix} = [D][B]q^{(e)}$$

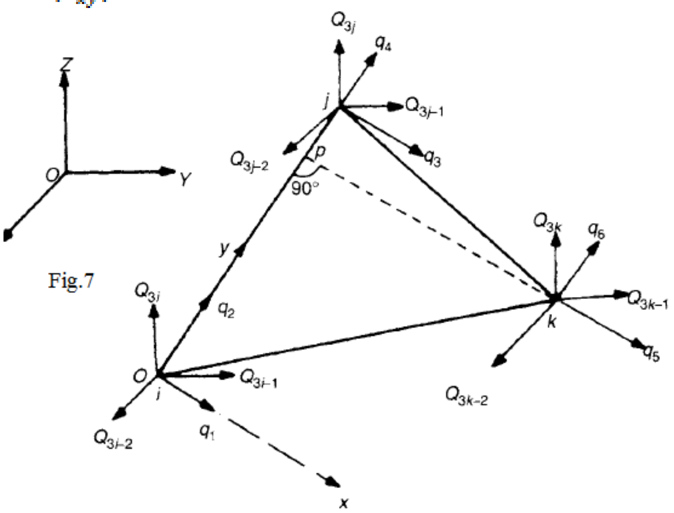


Fig.7

Convert local stresses into global stresses.

$\sigma_{XX} = \sigma_{xx} l_{pk}^2 + \sigma_{yy} l_{ij}^2 + 2\sigma_{xy} l_{pk} l_{ij}$

$\sigma_{YY} = \sigma_{xx} m_{pk}^2 + \sigma_{yy} m_{ij}^2 + 2\sigma_{xy} m_{pk} m_{ij}$

$\sigma_{XY} = \sigma_{xx} l_{pk} m_{pk} + \sigma_{yy} l_{ij} m_{ij} + 2\sigma_{xy}(l_{pk} m_{ij} + m_{pk} l_{ij})$

III. PLYWOOD COMPOSITE PLATES

Adjacent wood sheets in plywood are aligned with the grain direction at right angles to each other as indicated in Fig. 2 and 3 above. The laid-up assembly of veneers then is sent to a hot press in which it is consolidated under heat and pressure. Hot pressing has two main objectives: (1) to press the glue into a thin layer over each sheet of veneer; and (2) to activate the thermosetting resins. Typical press temperatures range from 132° to 165°C (270° to 330°F) for softwood plywood, and 107° to 135°C (225° to 275°F) for hardwood plywood. Press times generally range from 2 to 7 minutes. The time and temperature vary depending on the wood species used, the resin used, and the press design.

In this section we outline how such plies are designed and analyzed.

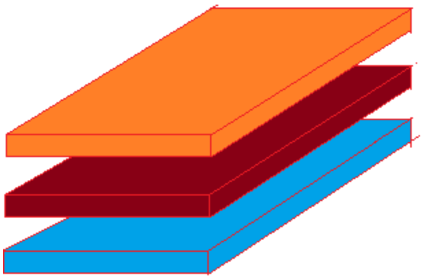


Fig.8: 3-ply symmetric plywood

"Classical Laminate Theory" is an extension of the theory for bending of homogeneous plates, but with an allowance for in-plane tractions in addition to bending moments, and for the varying stiffness of each ply in the analysis.

The tractions N and moments M applied to a plate at a position x; y, as shown in Fig.9

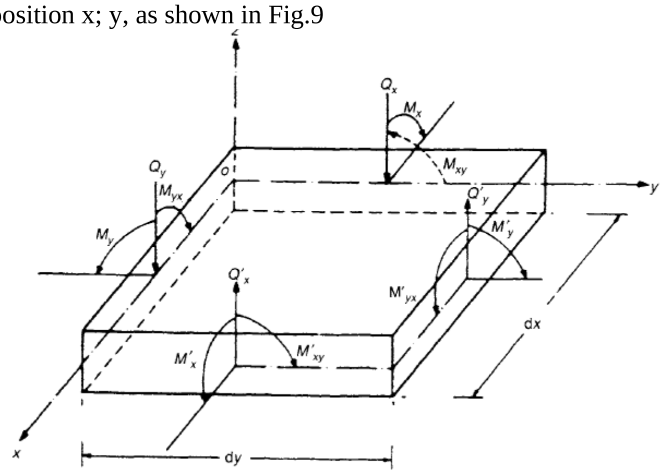


Fig.9 forces and moments in a plate

$$\mathbf{N} = \begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix} \quad \mathbf{M} = \begin{Bmatrix} M_x \\ M_y \\ M_{xy} \end{Bmatrix}$$

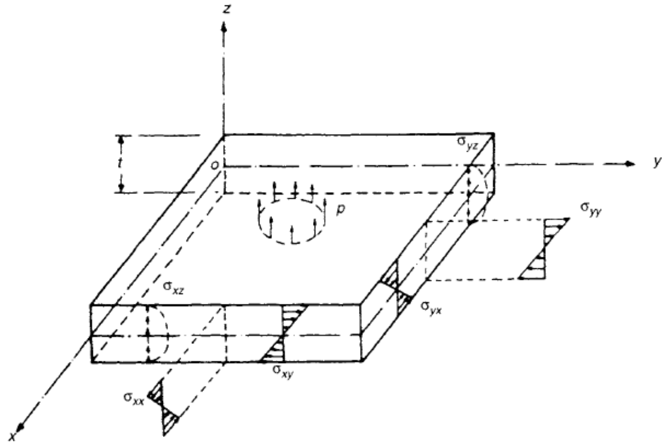


Fig.10 Stresses in a plate

As shown in Fig.10, the horizontal displacements u and v in the x and y directions due to rotation can be taken to a reasonable approximation from the rotation angle and distance from mid plane, and this rotational displacement is added to the mid plane displacement (u0; v0):

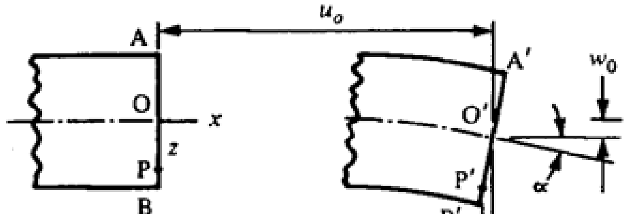


Fig. 11

u = u0 − z w0;x

v = v0 − z w0;y

The strains are just the gradients of the displacements; using matrix notation these can be written

$$\epsilon = \begin{pmatrix} \epsilon_x \\ \epsilon_y \\ \gamma_{xy} \end{pmatrix} = \begin{bmatrix} u_x \\ v_y \\ v_y + v_x \end{bmatrix} = \begin{vmatrix} u_{0,x} - z w_{0,zz} \\ v_{0,y} - z w_{0,yy} \\ (u_{0,y} + v_{0,x}) - 2z w_{0,xy} \end{vmatrix} = \epsilon^0 + zk$$

where ϵ^0 is the midplane strain and K is the vector of second derivatives of the displacement, called the curvature:

$$\boldsymbol{\kappa} = \begin{Bmatrix} \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{Bmatrix} = \begin{Bmatrix} -w_{0,xx} \\ -w_{0,yy} \\ -2w_{0,xy} \end{Bmatrix}$$

The component kxy is a twisting curvature, stating how the x-direction mid plane slope changes with y (or equivalently how the y-direction slope changes with x).

The stresses relative to the x-y axes are now determined from the strains, and this must take consideration that each ply will in general have a different stiffness, depending on its own properties and also its orientation with respect to the x-y axes. This is accounted for by computing the transformed stiffness matrix D as described in the previous section.

Recall that the ply stiffness as given, are those along the wood and transverse directions of that particular ply. The properties of each ply must be transformed to a common x-y axes, chosen arbitrarily for the entire laminate. The stresses at any vertical position are then:

$$\sigma = D\varepsilon = D\varepsilon^{\circ} + zDk$$

where here D is the transformed stiffness of the ply at the position at which the stresses are being computed.

Each of these ply stresses must add to balance the traction per unit width N:

$$\mathbf{N} = \int_{-h/2}^{+h/2} \boldsymbol{\sigma}\, dz = \sum_{k=1}^{N} \int_{z_k}^{z_{k+1}} \boldsymbol{\sigma}_k\, dz$$

where σk is the stress in the kth ply and zk is the distance from the laminate midplane to the bottom of the kth ply. Using above Eqn. to write the stresses in terms of the mid-plane strains and curvatures:

$$\mathbf{N} = \sum_{k=1}^{N} \left(\int_{z_k}^{z_{k+1}} \overline{\mathbf{D}} \boldsymbol{\epsilon}^0\, dz + \int_{z_k}^{z_{k+1}} \overline{\mathbf{D}} \boldsymbol{\kappa} z\, dz \right)$$

The curvature k and mid plane strain ε^0 are constant throughout z, and the transformed stiffness D does not change within a given ply. Removing these quantities from within the integrals:

$$\mathbf{N} = \sum_{k=1}^{N} \left(\overline{\mathbf{D}} \boldsymbol{\epsilon}^0 \int_{z_k}^{z_{k+1}} dz + \overline{\mathbf{D}} \boldsymbol{\kappa} \int_{z_k}^{z_{k+1}} z\, dz \right)$$

After evaluating the integrals, this expression can be written in the compact form:

$$\mathbf{N} = \mathcal{A} \boldsymbol{\epsilon}^0 + \mathcal{B} \boldsymbol{\kappa}$$

where A is an \extensional stiffness matrix" defined as:

$$\mathcal{A} = \sum_{k=1}^{N} \overline{\mathbf{D}} (z_{k+1} - z_k)$$

and B is a \coupling stiffness matrix" defined as:

$$\mathcal{B} = \frac{1}{2} \sum_{k=1}^{N} \overline{\mathbf{D}} (z_{k+1}^2 - z_k^2)$$

When the plate is pulled, the more compliant plies above the mid plane will tend to stretch more than the stiffer plies below the mid plane. The top half of the plywood stretches more than the bottom half, so it takes on a concave-downward curvature.

Similarly, the moment resultants per unit width must be balanced by the moments contributed by the internal stresses:

$$\mathbf{M} = \int_{-h/2}^{+h/2} \boldsymbol{\sigma} z\, dz = \mathcal{B} \boldsymbol{\epsilon}^0 + \mathcal{D} \boldsymbol{\kappa}$$

where D is a bending stiffness matrix" defined as:

$$\mathcal{D} = \frac{1}{3} \sum_{k=1}^{N} \overline{\mathbf{D}} (z_{k+1}^3 - z_k^3)$$

The complete set of relations between applied forces and moments, and the resulting mid plane strains and curvatures, can be summarized as a single matrix equation:

$$\begin{Bmatrix} \mathbf{N} \\ \mathbf{M} \end{Bmatrix} = \begin{bmatrix} \mathcal{A} & \mathcal{B} \\ \mathcal{B} & \mathcal{D} \end{bmatrix} \begin{Bmatrix} \boldsymbol{\epsilon}^0 \\ \boldsymbol{\kappa} \end{Bmatrix}$$

The A/B/B/D matrix in brackets is the plywood stiffness matrix, and its inverse will be the plywood compliance matrix. The presence of nonzero elements in the coupling matrix B indicates that the application of an in-plane traction will lead to a curvature or warping of the ply, or that an applied bending moment will also generate an extensional strain. These effects are usually undesirable. However, they can be avoided by making the laminate symmetric about the mid plane, can reveal. (In some cases, this extension-curvature coupling can be used as an interesting design feature.

The above relations provide a straightforward (although tedious, unless a computer is used) means of determining stresses and displacements in plywood subjected to in-plane traction or bending loads:

1. For each material type in the stacking sequence, obtain by measurement or micromechanical estimation the four independent anisotropic parameters appearing in: (E1, E2, V12, and G12).
2. Transform the compliance matrix for each ply from the ply's principal material directions to some convenient reference axes that will be used for the laminate as a whole.
3. Invert the transformed compliance matrix to obtain the transformed (relative to x-y axes) stiffness matrix D.
4. Add each ply's contribution to the A, B and D matrices
5. Input the prescribed tractions N and bending moments M, and form the system equations.
6. Solve the resulting system for the unknown values of in-plane strain ε° and curvature k.
7. To determine the ply stresses for each ply in the laminate in terms of ε^0, k and z. These will be the stresses relative to the x-y axes.
8. To transform the x-y stresses back to the principal material axes (parallel and transverse to the ply).
9. If desired, the individual ply stresses can be used in a suitable failure criterion to assess the likelihood of that ply failing. The Tsai-Hill criterion is popularly used for this purpose:

$$\left(\frac{\sigma_1}{\hat{\sigma}_1}\right)^2 - \frac{\sigma_1\sigma_2}{\hat{\sigma}_1^2} + \left(\frac{\sigma_2}{\hat{\sigma}_2}\right)^2 + \left(\frac{\tau_{12}}{\hat{\tau}_{12}}\right)^2 = 1$$

Here σ1 and σ2 are the ply tensile strengths parallel to and along the fiber direction, and τ12 is the intra ply strength. This criterion predicts failure whenever the left-hand-side of the above equation equals or exceeds unity.

IV. CONCLUSION

-As we observe the ansys result the plywood has good strength in tension and compression.

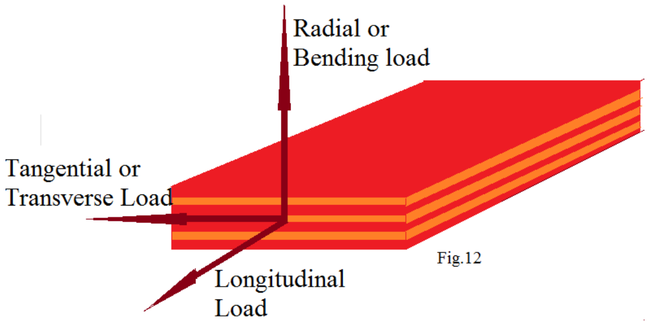
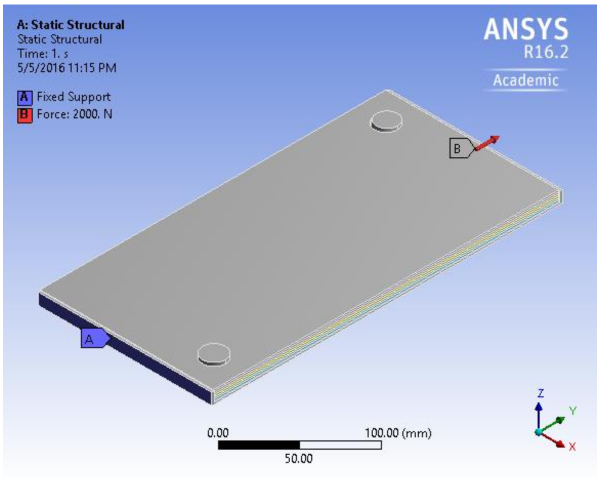


Fig.12

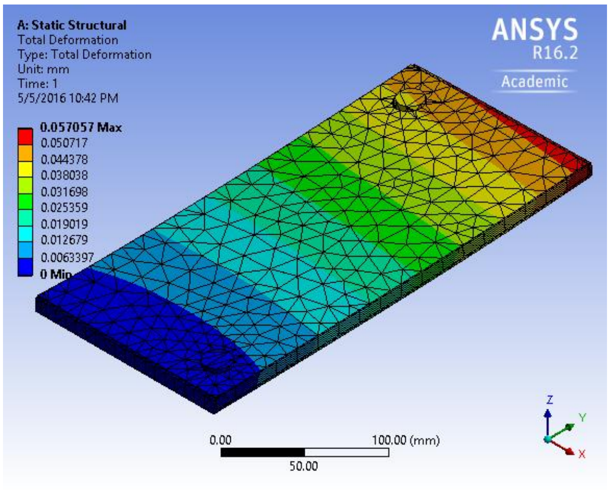
- It also stronger [less than in tension and compression] when the load applied is in transverse direction.
- It is not having so much strength in bending (deformation).
- The results are shown in table.

Property	Longitudinal		Trans.	Radial
	Tensile	Comp.		
Deform mm	0-0.057	0-0.057	0-0.87	102
Strain	0.0002	0.0002	0.0028	0.0611
Stress N/mm^2	1.23	1.23	12.11	364

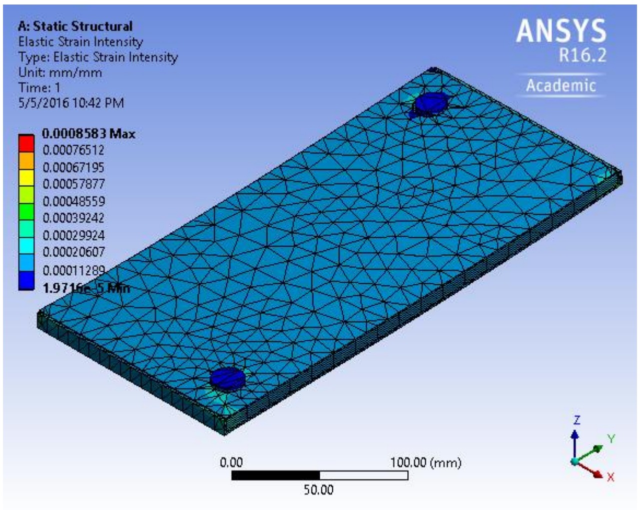
V. FINITE ELEMENT ANALYSIS



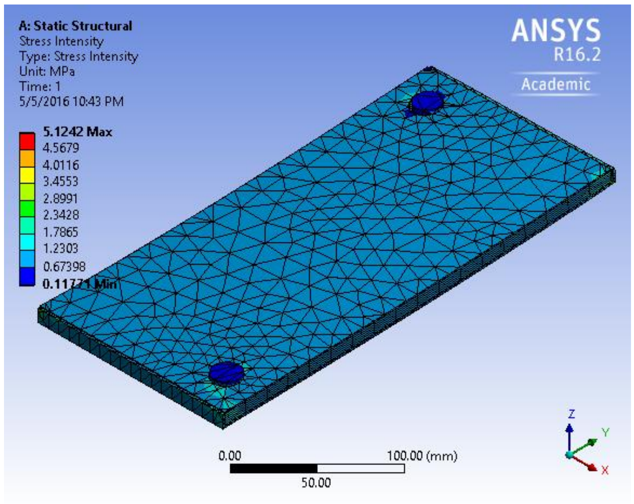
Geometry and longitudinal force



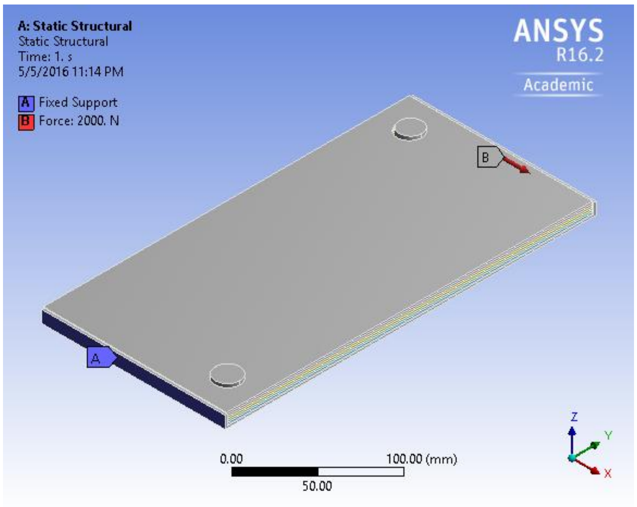
Deformation



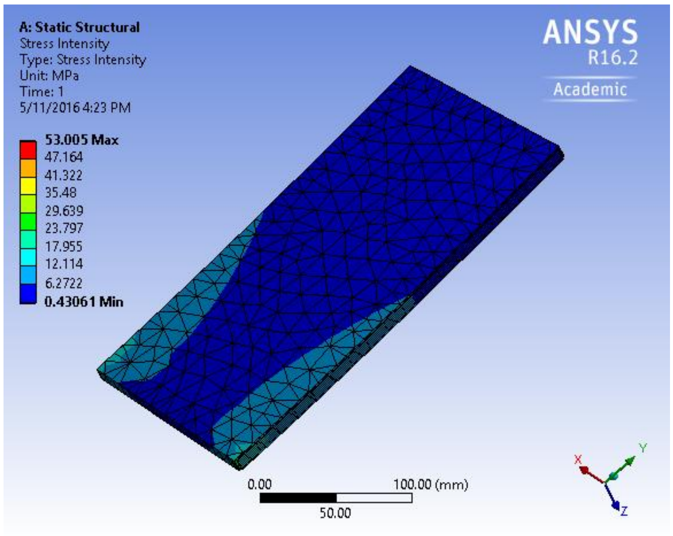
Elastic Strain rate



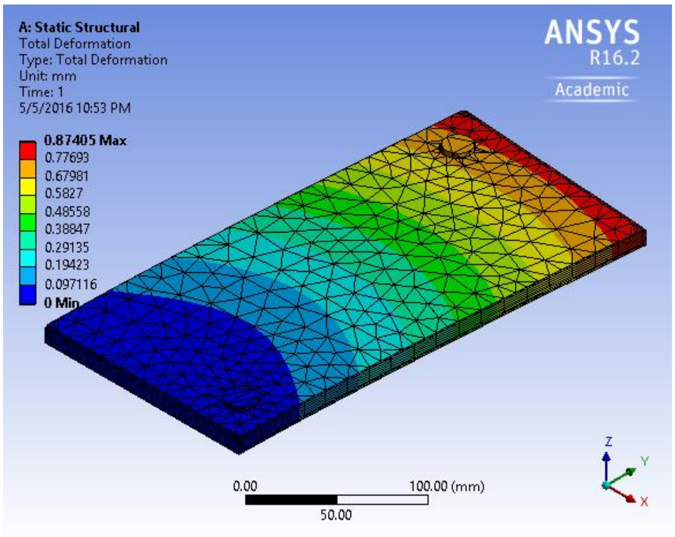
Stress intensity



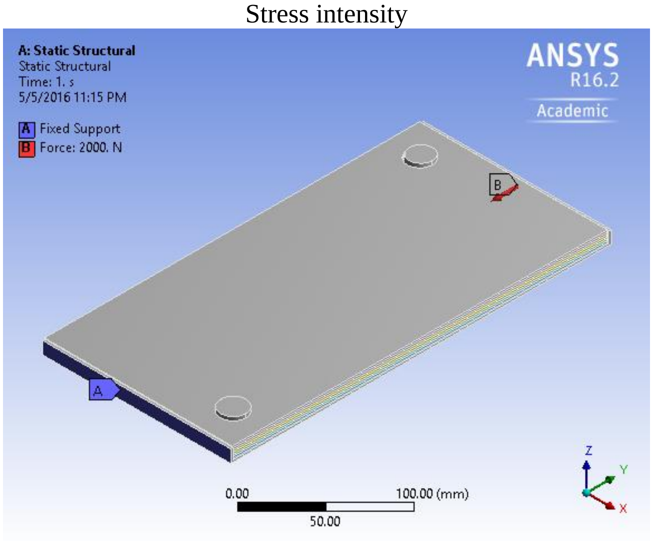
Transverse load



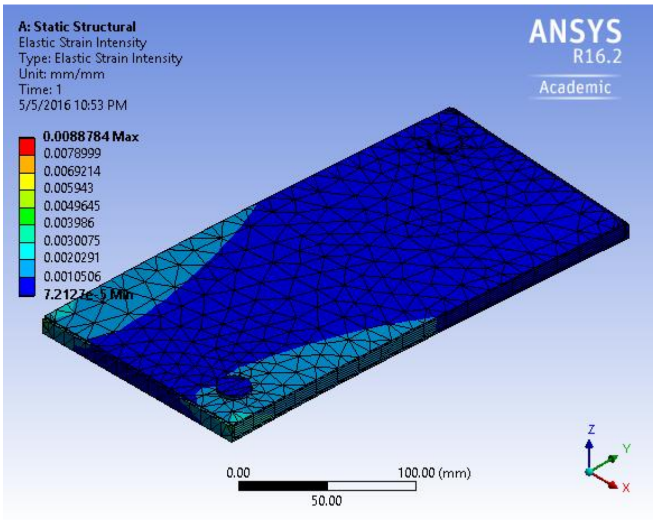
Stress intensity



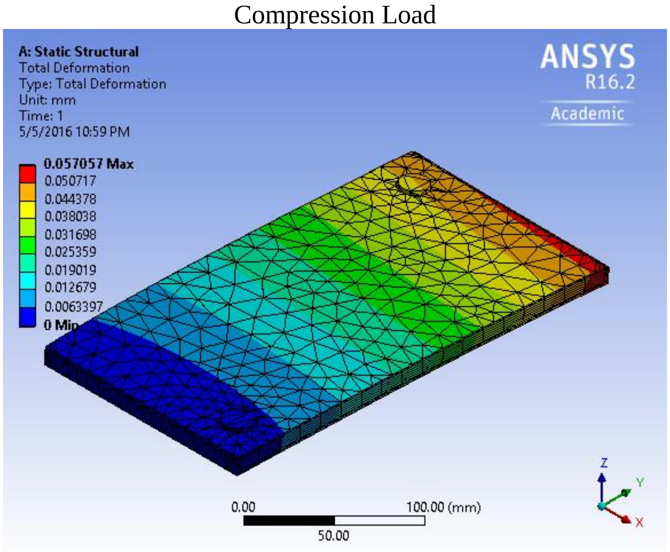
Deformation



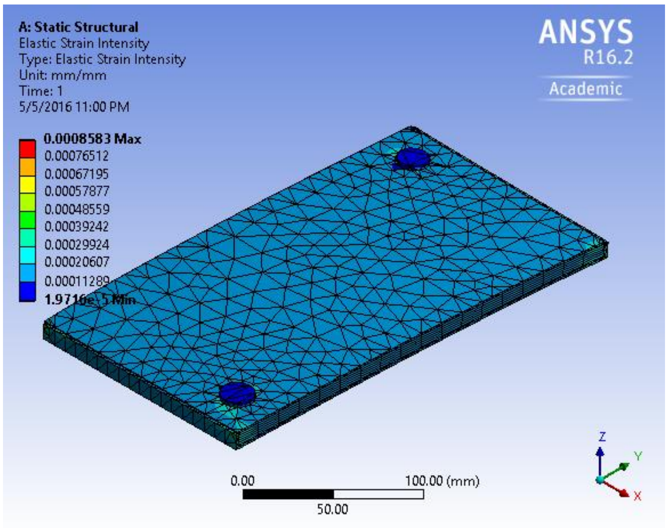
Compression Load



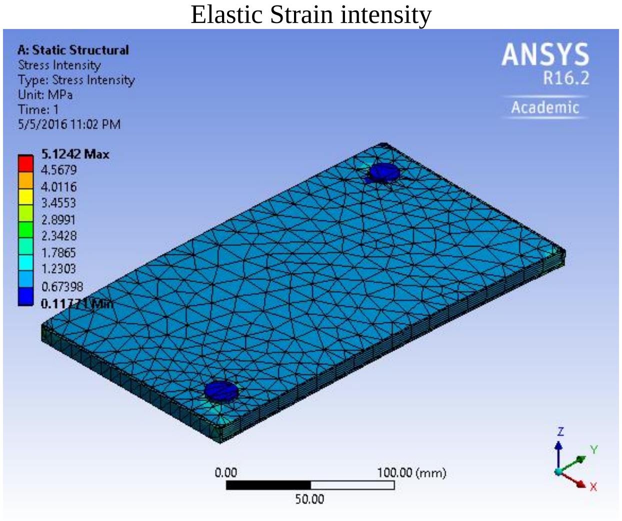
Elastic Strain Rate



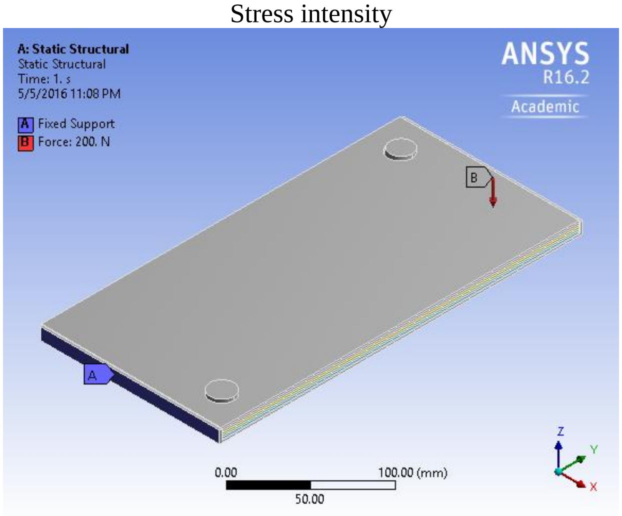
Total Deformation



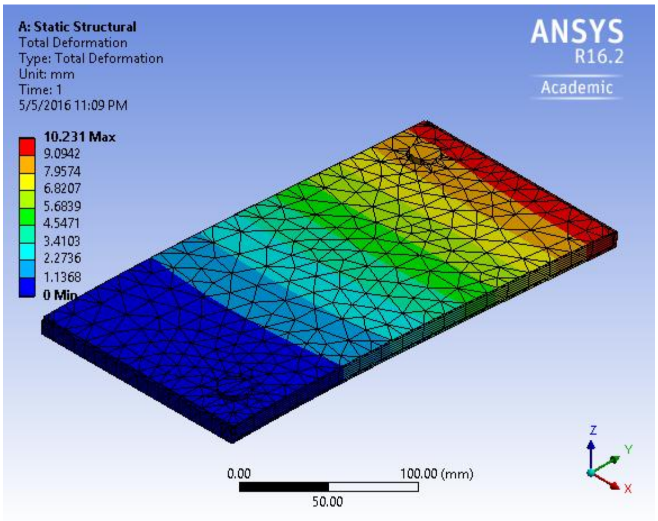
Elastic Strain intensity



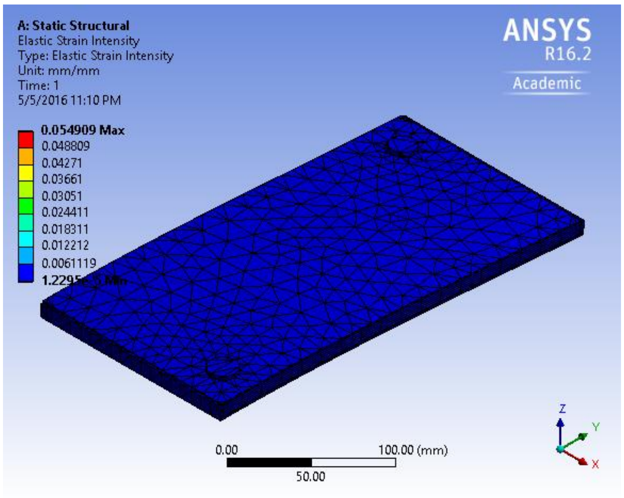
Stress intensity



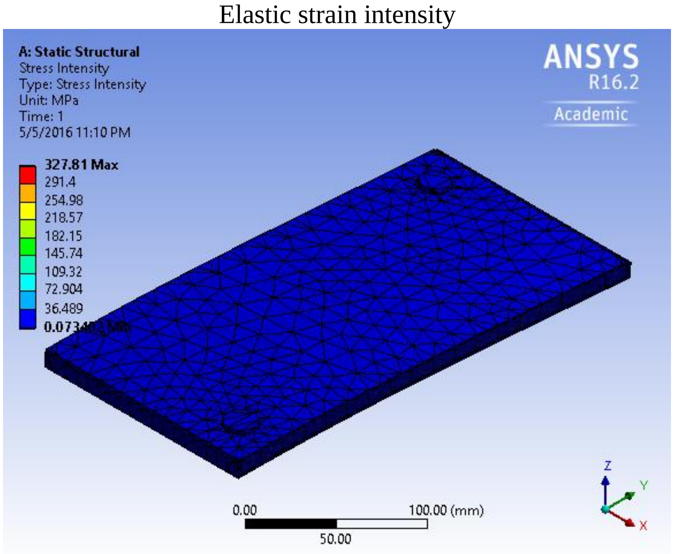
Z direction load [not so much strength 200N]



Total deformation



Elastic strain intensity

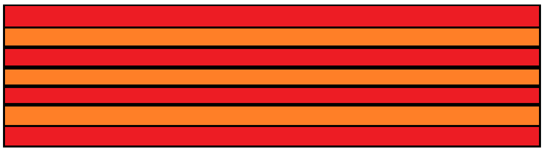


Stress intensity

VI. MODIFICATIONS

Here in this paper some modifications by combining the different woods layer like hardwood, softwood, ABS polymers are analyzed and the strength and other calculations are made on the same basis. Total six combinations are used. There combinations shows different properties and this becomes the basis for future research. By combining the different layers of different wood and polymers material it is possible to obtained plywood equally stronger in all directions i.e. equally stronger in bending also.
The various combinations used are shown in fig. below

Combination 1



Combination 1: each ply is 2mm thick and made of pine wood
The direction of grains parallel (pineL) to the load
The direction of grains perpendicular (pine T) to the load

Combination 2

Combination 2: each ply is 2mm thick and made of oak-cheryback red
The direction of grains parallel (oakL) to the load
The direction of grains perpendicular (oakT) to the load

Combination 3

Combination 3: Each Ply is 2mm thick and made of oak-cherryback red and pine Easten white
The direction of grains parallel (oakL) to the load
The direction of grains perpendicular (oakT) to the load
The direction of grains parallel (pineL) to the load
The direction of grains perpendicular (pine T) to the load

Combination 4

Combination 4: Each ply is 2mm thick and made of oak-cherryback red and Acrylonitrile butadiene styrene (ABS)
The direction of grains parallel (oakL) to the load
The direction of grains perpendicular (oakT) to the load
Acrylonitrile butadiene styrene (ABS)

Combination 5

Combination 5: Each ply is 2mm thick and made of Pine Easten white and Acrylonitrile butadiene styrene (ABS)
The direction of grains parallel (pineL) to the load
The direction of grains perpendicular (pine T) to the load
Acrylonitrile butadiene styrene (ABS)

Combination6

Combination 6: Each ply is 2mm thick and made of Pine Eastern and Acrylonitrile Butadiene Styrene (ABS) and oak cheryback red
The direction of grains parallel (pineL) to the load
The direction of grains perpendicular (pine T) to the load
Acrylonitrile butadiene styrene (ABS)
The direction of grains parallel (oakL) to the load
The direction of grains perpendicular (oakT) to the load

VII. MECHANICAL PROPERTIES OF SOME WOODS

The three moduli of elasticity, which are denoted by *EL*, *ER*, and *ET*, respectively, are the elastic moduli along thelongitudinal, radial, and tangential axes of wood.

Table 1.Elastic ratios for various species at approximately 12 % moisture content

Species	E_T/E_L	E_R/E_L	G_{LR}/E_L	G_{LT}/E_L	G_{RT}/E_L
Hardwood					
Ash, White	0.08	0.125	0.109	0.077	-
Balsa	0.015	0.046	0.054	0.037	0.005
Basswood	0.027	0.066	0.056	0.046	-
Birch, Yellow	0.050	0.078	0.074	0.068	0.017
Cherry, Black	0.086	0.197	0.147	0.097	-

Cottonwood, Eastern	0.047	0.083	0.076	0.052	-
Mahogany, African	0.050	0.111	0.088	0.059	0.021
Mahogany, honduss	0.064	0.107	0.066	0.086	0.028
Maple,sugar	0.065	0.132	0.111	0.063	-
Maple, red	0.067	0.140	0.133	0.074	-
Oak, red	0.082	0.154	0.089	0.081	-
Oak, White	0.072	0.163	0.086	-	-
Sweet gum	0.050	0.115	0.089	0.061	0.021
Walnut, Black	0.056	0.106	0.085	0.062	0.021
Yellow- poplar	0.043	0.092	0.075	0.069	0.011
Softwood					
Baldcypress	0.039	0.084	0.063	0.054	0.007
Cedar, Northern white	0.081	0.183	0.210	0.187	0.015
Cedar, western red	0.055	0.081	0.087	0.086	0.005
Douglass-fir	0.050	0.068	0.064	0.078	0.007
Fir, subalpine	0.039	0.102	0.070	0.058	0.006
Hemilock, western	0.031	0.058	0.038	0.032	0.003
Larch western	0.065	0.079	0.063	0.069	0.007
Pine Loblolly	0.078	0.113	0.082	0.081	0.013
Lodgepole	0.068	0.102	0.049	0.046	0.005
Longleaf	0.056	0.102	0.071	0.060	0.012
Pond	0.041	0.071	0.050	0.045	0.009
Pondersa	0.083	0.122	0.138	0.115	0.017
Red	0.044	0.088	0.096	0.081	0.011
Slash	0.045	0.074	0.055	0.063	0.010
Sugar	0.087	0.131	0.124	0.113	0.019
Western White		0.078	0.052	0.048	0.005
Redwood	0.089	0.087	0.036	0.077	0.011
Sprue,sitka	0.043	0.078	0.064	0.061	0.003
Sprue,Engelmann	0.059	0.128	0.124	0.120	0.010

These moduli are usually obtained from compression tests; however, data for *ER* and *ET* are not extensive. Average values of *ER* and *ET* for samples from a few species are presented in Table1 as ratios with *EL*;

The elastic ratios, as well as the elastic constants themselves, vary within and between species and with moisture content and specific gravity.

The modulus of elasticity determined from bending, *EL*, rather than from an axial test, may be the only modulus of elasticity available for a species.

As tabulated, *EL* includes an effect of shear deflection; *EL* from bending can be increased by 10% to remove this effect approximately.

Acrylonitrile butadiene styrene (ABS) Properties

Table 3: Acrylonitrile butadiene styrene (*ABS*) Properties

Physical Properties	Metric
Density	1.04g/cc
Melt flow	18-23g/10min
Mechanical Properties	
Hardness Rockwell	102-112
Tensile strength, Yeild	42.5-44.8 MPa
Elongation at break	23-25%
Flexural Modulus	2.25-2.28 GPa
Flexural Yeild Strength	60.6-73.1 MPa
Izod impact, Notched	2.46-2.94 J/cm
Poisson’s ratio	0.35

Poisson’s Ratio

When a member is loaded axially, the deformation perpendicular to the direction of the load is proportional to the deformation parallel to the direction of the load. The ratio of the transverse to axial strain is called Poisson’s ratio. The Poisson’s ratios are denoted by μ_{LR}, μ_{RL}, μ_{LT}, μ_{TL}, μ_{RT}, μ_{TR}. *The first letter of the subscript refers to direction of applied stress and the second letter to direction of lateral deformation.* For example, μ_{LR} is the Poisson’s ratio for deformation along the radial axis caused by stress along the longitudinal axis. Average values of Poisson’s ratios for samples of a few species are given in Table 2. Poisson’s ratios vary within and between species and are affected by moisture content and specific gravity.

Table 2: Poisson's ratio for various species at approximately 12 % moisture content						
Species	μ_{LR}	μ_{LT}	μ_{RT}	μ_{TR}	μ_{RL}	μ_{TL}
Hardwood						
Ash, White	0.371	0.440	0.684	0.360	0.059	0.051
Balsa	0.229	0.488	0.665	0.231	0.018	0.009
Basswood	0.364	0.406	0.912	0.346	0.034	0.022
Birch, Yellow	0.426	0.451	0.697	0.426	0.043	0.024
Cherry, Black	0.392	0.428	0.695	0.282	0.086	0.048
Cottonwood, Eastern	0.344	0.420	0.875	0.292	0.043	0.018
Mahogany, african	0.297	0.641	0.604	0.264	0.033	0.032
Mahogany, honduss	0.314	0.533	0.600	0.326	0.033	0.034
Maple,sugar	0.424	0.476	0.774	0.349	0.065	0.037
Maple, red	0.434	0.509	0.762	0.354	0.063	0.044
Oak, red	0.350	0.448	0.560	0.292	0.064	0.033
Oak, White	0.369	0.428	0.618	0.300	0.074	0.036
Sweet gum	0.325	0.403	0.682	0.309	0.044	0.023
Walnut, Black	0.495	0.632	0.718	0.378	0.052	0.035
Yellow- poplar	0.318	0.392	0.703	0.329	0.030	0.019
Softwood						
Baldcypress	0.338	0.326	0.411	0.356	-	-
Cedar, Northern white	0.337	0.340	0.458	0.345	-	-
Cedar, western red	0.378	0.296	0.484	0.403	-	-
Douglass-fir	0.292	0.449	0.390	0.374	0.036	0.029
Fir, subalpine	0.341	0.332	0.437	0.336	-	-
Hemilock, western	0.485	0.423	0.442	0.382	-	-
Larch western	0.355	0.276	0.389	0.352	-	-
PIne: Loblolly	0.328	0.292	0.382	0.362	-	-
Lodgepole	0.316	0.347	0.469	0.381	-	-
Longleaf	0.332	0.365	0.384	0.342	-	-
Pond	0.280	0.364	0.389	0.320	-	-
Pondersa	0.337	0.400	0.426	0.359	-	-
red	0.347	0.315	0.408	0.308	-	-
Slash	0.392	0.444	0.447	0.387	-	-
Sugar	0.356	0.349	0.428	0.358	-	-
Western White		0.344	0.410	0.334	-	-
Redwood	0.360	0.346	0.373	0.400	-	-
Sprue,sitka	0.372	0.467	0.435	0.245	0.040	0.025
Sprue,Engelmann	0.422	0.462	0.53	0.255	0.083	0.058

Mechanical properties most commonly measured and represented as "strength properties" for design include modulus of rupture in bending, maximum stress in compression parallel to grain, compressive stress perpendicular to grain, and shear strength parallel to grain. Additional measurements are often made to evaluate work to maximum load in bending, impact bending strength, tensile strength perpendicular to grain, and hardness. These properties, grouped according to the broad forest tree categories of hardwood and softwood (not correlated with hardness or softness), are given in Table3 and 4.

Tabel 3: Strength properties of woods used for analysis				
Common Species	Specific Gravity	Static bending		
		Modulus of rupture(kPa)	Modulus of elasticity (MPa)	Work to maximum load
Hardwood-oak red				
Black	0.61	96000	11300	94
Cherrybark	0.68	125000	15700	126
Laurren	0.63	87000	11700	81
Northen red	0.63	99000	12500	100
Softwood-pine				
Eastern white	0.35	59000	8500	47
Jack	0.43	68000	9300	57
Lobiolly	0.51	88000	12300	72
Lodgepole	0.41	65000	9200	47
Longleaf	0.59	100000	13700	81

Table 4: Strength properties of woods used for analysis					
Common Species names	Impact bending (mm)	Comp. parallel to grain (kPa)	Compression perpendicular to grain(kPa)	Shear parallel to grain (kPa)	Tension perpendicular to grain (kPa)
Hardwood-oak red					
Black	1040	45000	6400	13200	-
Cherrybark	1240	60300	8600	13800	5800
Laurren	990	48100	7300	12600	5400
Northen red	1090	46600	7000	12300	5500
Softwood-pine					
Eastern white	460	33100	6200	2100	1700
Jack	660	39000	8100	2900	2500
Lobiolly	760	49000	9600	3200	3100
Lodgepole	510	37000	6100	2000	2100
Longleaf	860	58400	10400	3200	3900

VIII. CONCLUSION

-As we observe the ansys result the plywood has good strength in tension and compression.

- It also stronger [less than in tension and compression] when the load applied is in transverse direction.
- But by combinations it is possible to maximize the strength in radial direction also.

The property deformation of such plywood are varying in longitudinal direction as well as transverse directions but the changes are showing that it is stronger than initial plywood.

- The strain values decreases in combinations 2,3,4 and 6 but increases in combination 5 compare to combination 1.
- The stress values decreases in combinations 3 and 6 as well as increases in other combinations compare to combination 1.
- FEA is done for each combination and the results are shown in table for 2000N in each direction load.[For maximum values.]

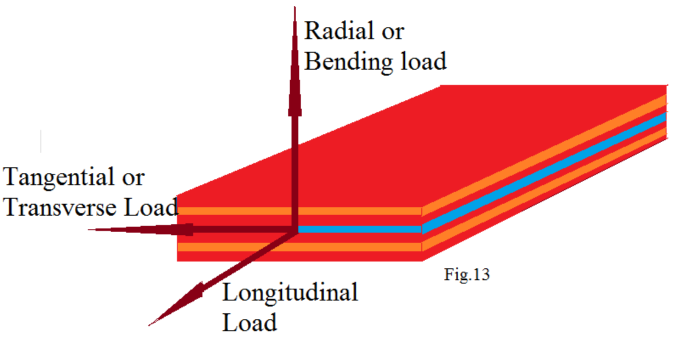


Fig.13

C	Deformation mm			Stress MPa			Strain		
	L	T	B	L	T	B	L	T	B
1	0.057	0.87	102	1.23	12.11	364	0.002	0.002	0.061
2	0.044	0.47	52	1.29	12.89	367	1E-3	1E-3	0.031
3	0.049	0.58	65	1.43	14.01	264	1E-3	1E-3	0.044
4	0.044	0.52	53	1.41	13.37	373	1E-3	1E-3	0.032
5	0.056	0.93	103	1.92	18.40	368	3E-3	3E-3	0.061
6	0.049	0.61	66	2.14	21	360	2E-3	2E-3	0.044

Where,
C- Combination Number
L- Longitudinal Loading
T- Transverse loading
B-Radial or Bending loading
-Future study is required to find such a combination which is still stronger in radial or bending loading.
-The bending stress safe value is approximately 60N/mm^2. So the safe load in bending is around 500-800N only. And plywood is unsafe for 2000N load in radial direction even thou safe in transverse and longitudinal direction loading.

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