RANKING OF WOOD SPECIES FOR AUTOMATED ORNAMENTAL CARVING ON CNC ROUTER USING MADM APPROACH

A Dissertation Report

Submitted in partial fulfilment of the requirement for the award of degree of

MASTER OF ENGINEERING
IN
PRODUCTION AND INUSTRIAL ENGINEERING

Submitted by

VIKRANT BANSAL
ROLL NO: 801182025

Under the guidance of

Mr. Sandeep Sharma
Assistant Professor
Mechanical Engineering Department

Mr. Ravinder K. Duvedi
Assistant Professor
Mechanical Engineering Department

MECHANICAL ENGINEERING DEPARTMENT

THAPAR UNIVERSITY

PATIALA-147004, INDIA

JULY-2013

CERTIFICATE

This is to certify that the work done in the dissertation titled "**Ranking of wood species for automated ornamental carving on CNC router using MADM approach**", being submitted by **Mr.Vikrant Bansal,** Registration number - 801182025, in partial fulfillment of requirement for the award of Master of Engineering degree in Production and Industrial Engineering in the Mechanical Engineering Department of Thapar University, Patiala, is an authentic record of work carried out by me under the guidance of **Mr. Ravinder Kumar Duvedi,** Assistant Professor and **Mr. Sandeep Kumar Sharma,** Assistant Professor, Mechanical Engineering Department, Thapar University, Patiala.

Vikrant Bansal

Dated 15th July, 2013

(Vikrant Bansal)

(Mr. Ravinder Kumar Duvedi)
Assistant Professor, MED,
Thapar University, Patiala

(Mr. Sandeep Kumar Sharma)
Assistant Professor, MED,
Thapar University, Patiala

(Dr. Ajay Batish)
Professor & Head of Department, MED,
Thapar University, Patiala

(Dr. S.K. Mohapatra)
Dean of Acadamic affairs,
Thapar University, Patiala

ACKNOWLEDGEMENT

I express my sincere gratitude to my guides **Mr. Sandeep Sharma**, **Assistant Professor, Mechanical Engineering Department** and **Mr. Ravinder K. Duvedi, Assistant Professor, Mechanical Engineering Department, Thapar University**, **Patiala,** for their valuable guidance, proper advice and constant encouragement during the course of my thesis work. I would also like to thank **DR. V.P.Agrawal, Visiting Professor,** for his guidance in **MADM APPROACH**

I do not find enough words with which I can express my feeling of thanks to the entire faculty and staff of **Mechanical Engineering Department**, **Thapar University**, for their help, inspiration and moral support which went a long way in successful completion of thesis work.

(VIKRANT BANSAL)

ABSTRACT

The wood has been recognized as one of the best alternative material for ornamental carving since time immemorial. It has got anisotropic properties as well as occurrence of random defects in different extents depending upon the species. In the present work, an attempt has been made to grade the wood varieties (domestic and imported) that are generally used for ornamental as well as furniture making in India. Also there are some wood species which may find usefulness in making furniture or some industrial applications may not be suitable for CNC carving. Therefore, while selecting a wooden raw material for CNC carving operation, one must possess good knowledge about the desired carvability properties of wood so that high machining rates and good surface finish can be realized simultaneously. Thus based upon local requirements of a particular geographic location, a scientific grading system can be applied for ranking of available wood varieties for CNC router based carving operations. The grading of woods has been done in order to get an exclusive carvability data about the wooden species for CNC wood machining, so that one can get maximum possible surface finishing and maximum material removal rate form selected wooden stock. The MADM-TOPSIS approach has been used in order to rank different types of domestic and imported timbers available in India, taking care of factors such as carvability properties, cost and availability. This ranking can be used for getting better results for carving operations, and the logical conclusions of the study has been presented in our dissertation.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVATIONS

CNC	COMPUTER NUMERICAL CONTROL
MADM	MULTIPLE ATTRIBUTE DECISION MAKING
MC	MOISTURE CONTENT
FSP	FIBRE SATURATION POINT
SG	SPECIFIC GRAVITY
MOR	MODULUS OF RUPTURE
MOE	MODULUS OF ELASTICITY
MCS	MAXIMUM CRUSHING STRENGTH
WPC	WOOD PLASTIC COMPOSITES
HDPE	HIGH DENSITY POLYETHYLENE
ASTM	AMERICAN SOCIETY FOR TESTING AND MATERIALS
DIN	DEUTSCHES INSTITUT FUR NORMUNG
ISO	INTERNATIONAL ORGANIZATION FOR STANDARDIZATION
VS	VOLUMETRIC SHRINKAGE
OD	OVEN DRY

CHAPTER 1

INTRODUCTION

In today's modern world, automation of wood carving is becoming a topic of wide interest for the different industries. Wood carving from earlier times is done by means of cutting tool or a chisel and mallet leading to ornamentation of wooden object. Nowadays due to lure of their profits, Industries are slowly moving towards automation of carving of wood. The selection of appropriate wood variety based upon availability, quality and cost is a major factor owing to large number of options available. Thus in the present work a study for grading of different wooden species using MADM approach has been done ,so as to give a scientific basis for selection of appropriate wooden raw materials for CNC based automated carving. This exclusive data will help in ranking different locally available Indian and international wooden species, which could be used with CNC router for 3-D ornamental carving.

1.1 METHODS OF WOOD CARVING

Carving in different materials like metals, stone and wood has been done since ages. Different applications and based upon taste of people at different places artisans used variety of combinations of materials and craft designs to attract customers for their finished products. The various ways of realizing art in wood have been used by various artisans around the world, because workability and durability in wood permits any kind of complicated shape to be carved out of it. The wood carving process can be classified into following ways:

1.1.1 Manual Wood Carving

Traditional wood carving begins with selecting suitable plank of wood. The choice of type of wood depends upon details of carving to be realized, quality, cost and availability. Traditionally, selection of wood by sculptor begins with general shaping process to get a appropriate shape of raw stock for convenience of carving process. The manual carving process makes use of traditional cutting tools such as chisels, knives and mallets. The experienced carvers can very well avoid randomly occurring defects in wooden raw material which is nearly impossible if automatic CNC carving is used. After carving process is finished some textures improving processes like polishing or applying lacquer for longer lifetime of work material is done. The traditional way of working has its disadvantages, like it is loud, dusty, traditional tools being unsafe and it takes very long time to complete the job. Moreover, accuracy and repeatability of manual carving process is not very good. Additionally, often it takes several months before even a small production batch is ready for dispatch. The artist generally first create outline of the design to be produced, and then create a master figure/ template/ shape of raw skeleton, after this phase manufacturing/ carving of the final product begins. For customized carving operations where the number of parts per order are very few or may be single unit, it takes much longer time that sometimes the orders gets cancelled and carvers have to suffer losses far more than expected returns.

1.1.2 Automated Wood Carving

The automation of carving process has been made possible by the invent of technologies like reverse engineering, 3D scanning, user friendly design automation techniques, rapid prototyping, special CAM packages which can create NC tool paths for complicated shapes and use of automated 3D dimensional CNC machining centers. The CNC machining centers can carve complicated shapes in metal, stone, synthetic/composite materials and wood with high degree of precision and repeatability.

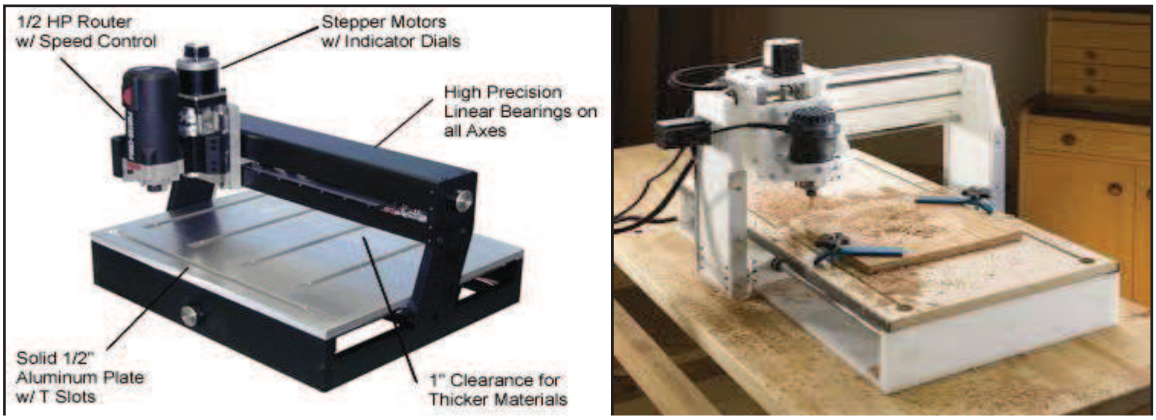
The CAD packages along with suitable reverse engineering tools can be used as tools for assistance in creation of 3-dimensional designs for ornamental carvings. These designs can be used as input for creation of NC toolpath data using suitable CAM packages. Once the toolpath is ready for a particular cutting tool, we can use the CNC machining centers to carve the part. Using the simulation environment in CAM packages, the machining processes can be simulated under all operating conditions, which ensure that there is no milling cutter crash during simulation operations. Then, cutting and processing operation of the work pieces is started.

For automated carving in wood, special machines called CNC router tables are used. The router is one of the most commonly used power tools used in wood working. As in technical sense for wood carving the spindle should have high rpm and low torque. In wood machining low chip thickness is desired to avoid local burning, while maintaining the high material removal rates. This is possible using the wood router tables, which use high speed spindle having speed range from 5000 to 55000 rpm. Moreover the design of high speed spindle is such that it throws air at high velocity over the cutting region so that the cutting tool remains cool, and it also helps removal of chips.

The wood carving/cutting tools used with CNC routers are also having special shapes to get the required shapes cut in the wood, but the straight flute ball end mills have been extensively used for 3-dimensional carving in wood. One of the main advantages of a CNC wood carving is that the special shaped cutout stock, called initial carving skeleton, is not required before carving process can be started as need in manual carving, rather machine can cut out any desired shapes from the wood piece directly.

1.2 USE OF CNC ROUTER FOR AUTOMATED CARVING

The CNC router is an ideal machine tool for hobbies, engineering prototyping, product development, art, and production work and it use special cutters for material removal compared to conventional machine tools. Of course CNC router tables can be used for machining of other softer materials like plastic based materials, aluminum, and brass etc. with controlled machining parameters like feed speed and depth of cut. A conventional general purpose router table used for machining of softer metals and special router used exclusively for wood have appearance as shown in figure 1.1(a) and special wood working router tables have appearance as shown in figure 1.1(b). Figure 1.2 shows the main components of a CNC router table.



(a) (b)

Figure 1.1: (a) Conventional general purpose CNC router [34], (b) Wood carving routers [34]

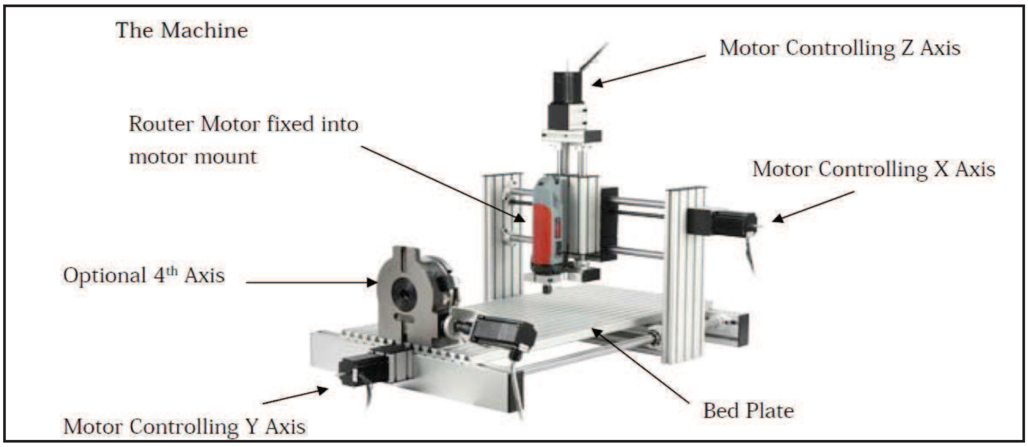


Figure 1.2: Components Of CNC Machine Solution [31]

The general CNC router machining works on the Cartesian coordinate system for 3D motion control, which means the cutting tool can be moved along any one or more than one controlled axis (X-axis, or Y-axis, or Z-axis) simultaneously. The CNC carving router having 3-axis simultaneous control can execute the carving operations very effectively. And major advantage of using CNC router for wood carving is that it cuts at higher rpm which help in chiseling of wooden material without burning and affecting the global or local properties of wooden stock.

1.2.1 Operation of CNC wood router

A standard CNC wood router typically has four axes: three feed axes and one spindle axis. Axes labeled as X and Y, are used for moving cutting tool relative to the workpiece, which are responsible for horizontal movement, whereas Z-axis motion is used for moving cutting tool vertically with respect to the workpiece, as shown in figure 1.2. The X, Y and Z axis motion is used like a three-axis vertical milling machine, whereas for machining of pseudo-symmetrical parts the spindle axis (the optional 4^{th} axis) can move synchronously with the Z-axis and perform complicated cutting as shown in figure 1.3.

Figure 1.3: Machining of a pseudo-symmetrical part on a CNC router

1.2.2 Challenges encountered while machining wood with CNC router

As discussed in above section, while machining for carving operations on a CNC router can move the cutter in X, Y and Z-axis directions independently or simultaneously. The machining results such as surface finish for isotropic materials like metals or materials like nylon etc. will be uniform for both the cases; when tool motion is in single feed direction or along multi-feed directions simultaneously. This is because of the reason that the reaction forces encountered while machining will be almost same in both the cases. Thus the carving results on isotropic materials will better compared to wood as later is an orthotropic/anisotropic material. The orthotropic properties of wood are because of the orientation of the wood fibers, the density of wood, seasoning and the growth pattern of the tree. Thus the machinability properties, particularly for carving operations, in case of wood vary sometimes significantly along three mutually perpendicular axes: longitudinal, radial, and tangential as shown in figure 1.4. Thus a CNC router will experience different cutting forces and machining behavior while moving through wood-stock in different directions and hence giving different surface properties after caving operation.

While selecting wood as engineering material for carving operations one must be aware of random natural defects which are very predominant in case of wood. Moreover, different wooden species possess random defects and changes in directional properties in different magnitudes. Moreover the natural textures of different wood species are unique and their ability for retention of polish, or texture improving chemicals is different.

Thus some wood species which may find usefulness in making furniture or some industrial applications may not be suitable for CNC carving. Therefore, while selecting a wooden raw material for CNC carving operation, one must possess good knowledge about the desired carvability properties of wood so that high machining rates and good surface finish can be realized simultaneously.

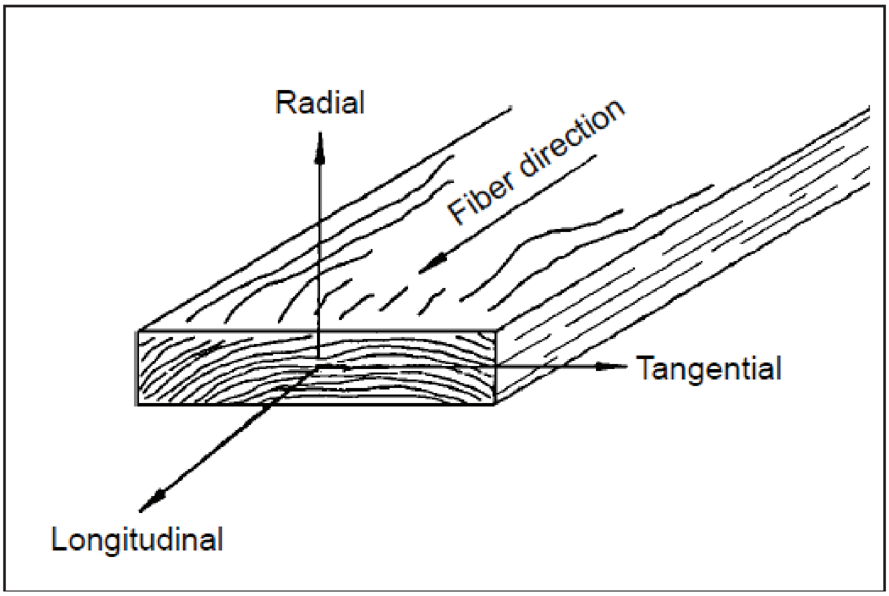


Figure 1.4: The orientation of grain direction and growth rings of wooden planks used for general furniture applications [28]

1.2.3 Need for grading of wood for automatic machining applications

As discussed in the previous section, it is important to understand the carvability properties of different wooden species, so as to get good results from an automated CNC carving operation. Thus based upon local requirements of a particular geographic location a scientific grading system can be applied for ranking of available wood varieties for CNC router based carving operations. This grading system of wood can help in maintaining an exclusive stock of wood based on its cost, quality and availability.

1.2.4 Scientific Approached used for ranking/ grading of alternatives

A number of approaches can be used for grading/ ranking of alternatives based upon scientifically collected data, like Taguchi method, graph-theoretical approach, and MADM approach. In the present work of grading wood species and ranking selected wood species based upon the properties required for CNC router based ornamental wood carving operation, an approach which can handle multi-attribute decision criterion is required. Hence we used an approach called MADM-TOPSIS approach. This technique can handle virtually any number of performance parameters for ranking of any number of alternatives (like wood species in this case) [25].

1.3 PRESENT WORK

The wood has been recognized as one of the best alternative material for ornamental carving since time immemorial. It has got anisotropic properties as well as occurrence of random defects in different extents depending upon the species. In the present work, an attempt has been made to grade the wood varieties (domestic and imported) that are generally used for ornamental as well as furniture making in India. The grading of woods has been done in order to get an exclusive carvability data about the wooden species for CNC wood machining, so that one can get maximum possible surface finishing and maximum material removal rate form selected wooden stock. Such an identification technique for ranking of wood is available in literature [27], but no such work has been reported in Indian context. The MADM-TOPSIS approach has been used in order to rank different types of domestic and imported timbers available in India, taking care of factors such as carvability properties, cost and availability. There are 50 different properties of wood which has been selected for present study and are explained in chapter 2.

The properties of a large variety of international and national wood species which have been used for furniture or industrial applications, have been studied from the published literature, and finally 6 different species from the selected data have been analyzed using MADM approach for their suitability for CNC carving as discussed in section 4.6 Further carving properties of a group of another 13 locally available wood species which are extensively being used for timber applications have been experimentally determined. Using the experimental data for carving properties, this group of 13 wood species have been ranked using MADM approach as discussed in section 5.10. This ranking can be used for getting better results for carving operations, and the logical conclusions of the study has been presented in chapter 6.

CHAPTER 2

STRUCTURE, PROPERTIES AND TYPES OF WOOD USED FOR ENGINEERING APPLICATIONS

2.1 STRUCTURE OF WOOD

There are different types of properties which would affect the carvability of a wooden species. Also there are some defects which naturally occur in wood and need attention before its use. For that first of all overall structure of the wood has been studied as discussed below. Since wood is an orthotropic material, it can be used for wood machining/carving with CNC wood router. The anatomical structure of wood affects strength properties and appearance of wood. Wood is either hardwood or softwood, hardwood trees (angiosperms) [28] and softwood trees include the conifers (gymnosperm) [28]. Ultrasonic is a versatile non-destructive technique and highly useful for the investigation of various physical properties such as residual stress, hardness, and elastic constant. To define botanically, softwoods are those woods that come from gymnosperms (mostly conifers), and hardwoods are woods that come from angiosperms (flowering plants) [28].Softwoods and hardwoods differ in terms of the types of trees from which they are derived; they also differ in terms of their component cells. The single most important distinction between the two general kinds of wood is that hardwoods have a characteristic type of cell called a vessel element (or pore), whereas softwoods lack these as shown in figure 2.1.The naturally occurring defects in wood have been discussed below.

2.2 INHERENT DEFECTS IN WOOD

There are different types of defects in core and its different structure of wood**.** Most defects or problems that develop in wood products during and after drying can be classified under one of the following categories. Defects in any one of these categories are caused by an interaction of wood properties with processing factors. Wood shrinkage is mainly responsible for wood ruptures and distortion of shape.

2.2.1 Rupture of wood tissue

In particular, the defects result from uneven shrinkage in the different directions of a board (radial, tangential, or longitudinal) or between different parts of a board, such as the shell and core. Rupture of wood tissue is one category of drying defects associated with shrinkage.

(i) Surface checks

Surface checks are failures that usually occur in the wood rays on the flat sawn faces of boards.

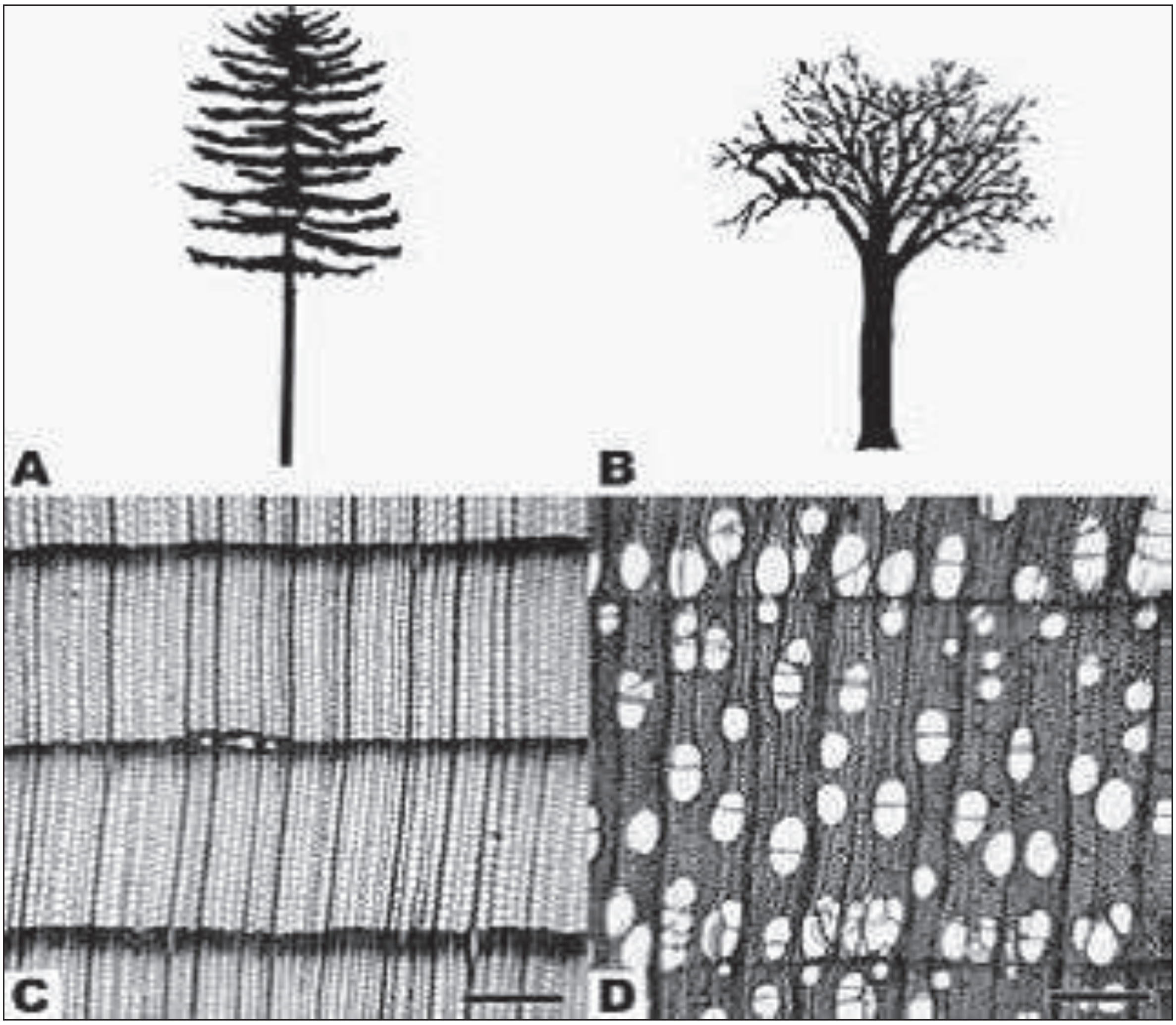


Figure 2.1: Softwood and hardwood [28], (A) the general form of a generic softwood tree, (B) The general form of a generic hardwood tree, (C) Transverse section of Pseudotsugamensiezii, typical softwood and the three round white spaces are resin canals,(D) Transverse section of Betulaalleghenensis, a typical hardwood and the large round white structures are vessels or pores which is characteristic feature of a hardwood. Scale bars = 300 µm.

(ii) Collapse

Collapse is a distortion, flattening, or crushing of wood cells. Collapse may be caused by compressive drying stresses in the interior parts of boards that exceed the compressive strength of the wood or by liquid tension in cell cavities that are completely filled with water.

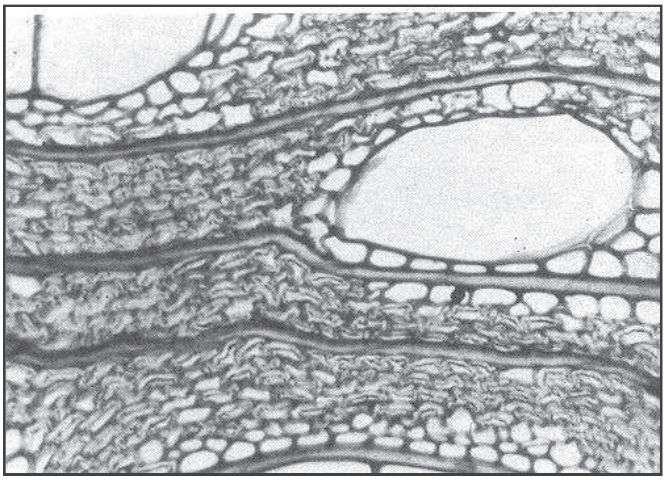


Figure 2.2: Photomicrograph showing collapsed wood cells. (M 69379) [28]

(iii) Checked knots

Checked knots are often considered defects. The checks appear on the end grain of knots in the wood rays .They are the result of differences in shrinkage parallel to and across the annual rings within knots.

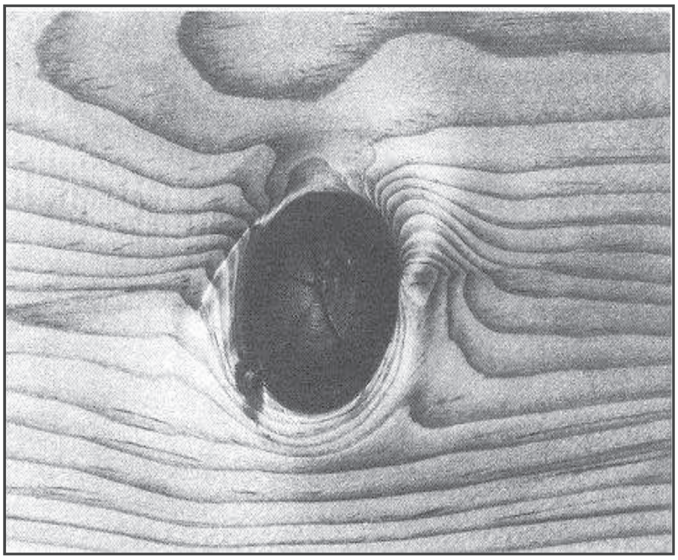


Figure 2.3: Diagram showing checked knots in a wood [28]

2.2.2 Warp

Warp in lumber is any deviation of the face or edge of a board from flatness or any edge that is not at right angles to the adjacent face or edge (squares).

2.2.3 Uneven moisture content

Uneven moisture content refers to a condition where individual boards in a kiln charge have a level of moisture content that deviates greatly from the target moisture content.

2.2.4 Discoloration

Discolorations may also develop when light, water, or chemicals react with exposed surfaces of dried wood. This section is mainly concerned with discolorations that develop in clear, sound wood before or during drying.

2.3 ENGINEERING PROPERTIES OF WOOD

To classify and rank the properties of wood for CNC router machining for 3-D ornamental carving a 50 number of properties of wood as engineering material have been identified from the published literature [30]. The selected list of properties has been classified in to three categories as shown in figure 2.4. The data for the selected properties have been recorded for finding out the order/rank of these properties for wood related to CNC router machining. As discussed in section 2.2, there are number of inherent defects in wood which may occur in the selected wooden raw material. The defects are also related to the basic properties of wooden species and effect of different environmental conditions and growth pattern of the plant. Hence an overall study of different types of properties of wood has been done in order to get exclusive information about the relative significance of each wood property and species from which the wood is to be selected.

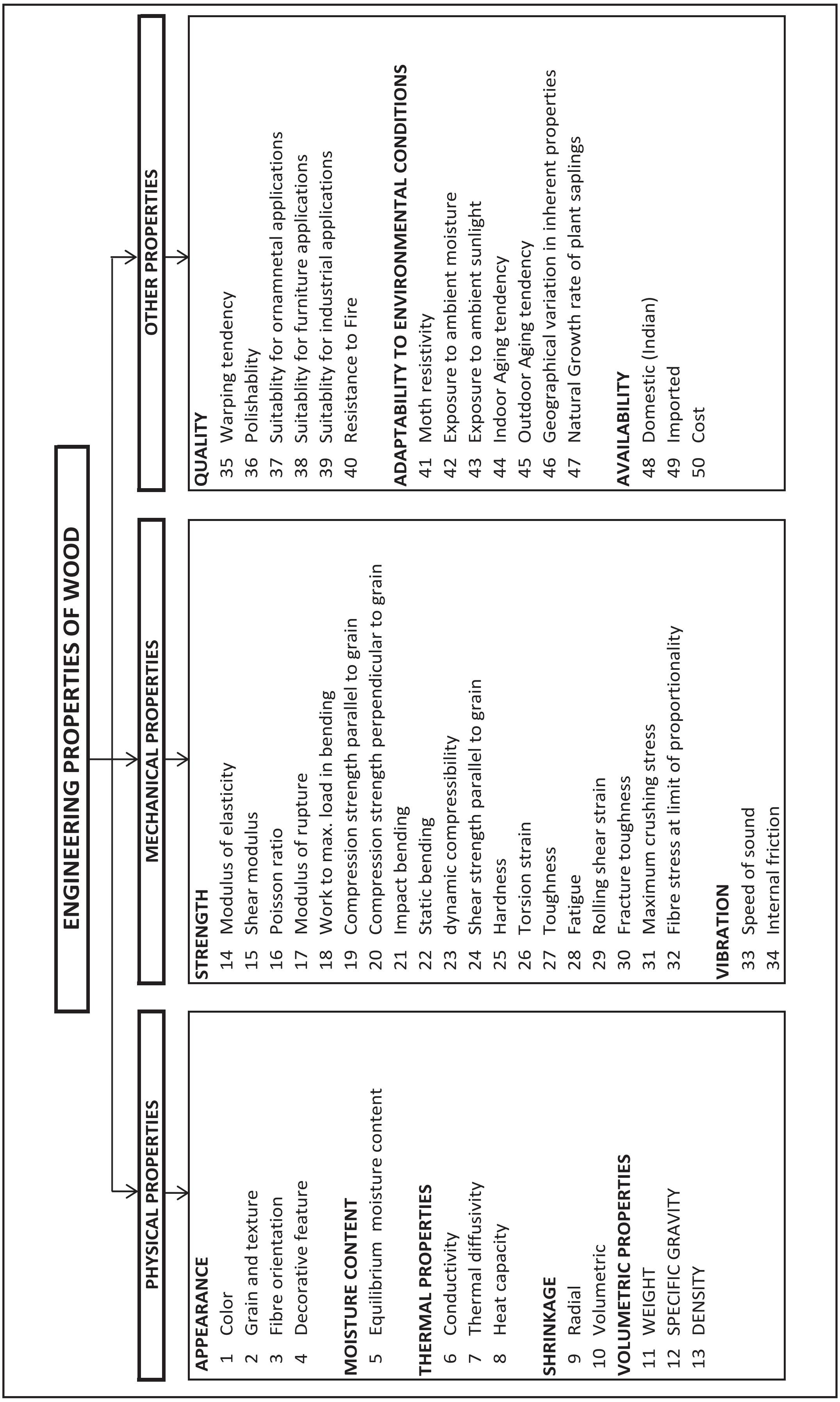


Figure 2.4: Hierarchical model for engineering properties of wood

2.3.1 Physical properties

- **Colour**

Colour covers a wide range like yellow, green, red, brown, black, and nearly pure white woods exist, but most woods are shades of white and brown. Variations may show on a single piece of wood, depending on colour differences between heartwood, sapwood, early wood, latewood, rays, and resin canals. [37] Natural colour is subject to change by prolonged exposure to the atmosphere and by bleaching or dyeing. Some woods (for example, black locust, honey locust, and several tropical species) are fluorescent.

- **Grain and texture**

Grain is often used in reference to annual rings, as in fine grain and coarse grain, but it is also used to indicate the direction of fibers, in straight grain, spiral grain, and curly grain. The difference in cells results in difference between appearance of the growth rings, and the resulting appearance is the texture of the wood. Coarse texture can result from large bands of large vessels, such as in oak.

- **Fiber orientation**

It basically tells us about the orientation of wooden species. it tells us whether it is straight grained, parallel grained. so it basically tells us about the direction of wooden grain along its structure

- **Decorative features**

The decorative value of wood depends upon its color, figure, and luster and also the way in which it bleaches .Because of the combinations of color and also because of shades found in wood, it is very difficult to give detailed report on color descriptions of the various kinds of wood. Sapwood of most species is light in color; in some species, sapwood is practically white.

- **Moisture content**

Moisture content of wood is defined as the weight of water in wood expressed as a fraction, usually a percentage, of the weight of oven-dry wood. Weight, shrinkage, strength, and other properties depend upon the moisture content of wood.

- **Equilibrium moisture content**

Equilibrium moisture content (EMC) is defined as that moisture content at which the wood is neither attaining nor losing moisture; an equilibrium condition has been reached.

- **Shrinkage and swelling**

Wood exhibits variation in dimensions mainly due to the change in moisture content. In the longitudinal direction, the movement of water in the vapor form is greatly assisted by the tubular structure of the cells. As a consequence, water moves about 13 to 16 times faster along the grain than it does across it. This also affects the dimensional changes in wood while it dries. Figure 2.5 shows the dimensional variation of wood with moisture content. It can be observed that tangential shrinkage for air-dried wood is about twice as large as radial shrinkage at the exact same moisture content. The shrinkage can be found using the following relationship: **Shrinkage (%)= (change of dimension from swollen size)/(Swollen size)* 100**.

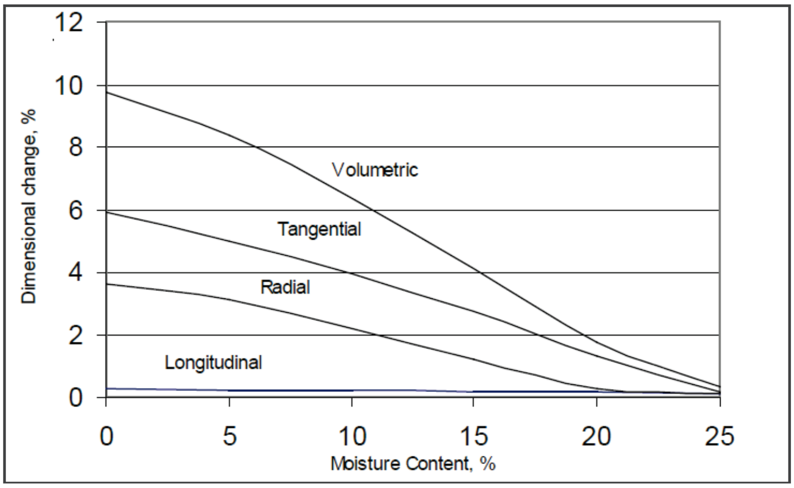


Figure 2.5: Dimensional variation of wood with moisture content [28]

- **Weight, density, and specific gravity**

Two primary factors that affect the weight of wood products: density of the basic wood structure and moisture content. A third factor, minerals and extractable substances, has a marked effect only on a limited number of species

- **Specific gravity**

Specific Gravity is found as the ratio of the density of a material to the ratio of the density of water at 4°C.

- **Density**

Wood density is calculated using weight and volume at time of measurement. Weight and volume are both a function of MC. It is commonly expressed as g/cm^3, kg/m^3, or lb/ft^3.Wood density increases with increasing wood MC. As MC increases, weight increases at a greater rate than volume, therefore, the density increases. However, there is an inflection point at the FSP because for ΔMC>FSP, volume does not change.

Calculation of specific gravity

$$SG_{MC,\ Wood}=\rho_{wood}/\rho_{water}= \frac{W_{OD,wood}/V_{MC,wood}}{\rho_{water}}$$

Where SGwood = specific gravity of wood

ρ_{wood} = density of wood calculated using the oven-dry weight (0%MC) and the volume at some specified MC

ρ_{water} = density of water (1000 kg/m^3 , 1 g/ml, 62.4 lb/ft^3)

- **Conductivity**

Thermal conductivity is a measure of the rate of heat flow through one unit thickness of a material subjected to a temperature gradient. The thermal conductivity of common structural woods is much less than the conductivity of metals with which wood often is mated in construction. It is about two to four times that of common insulating material.

- **Thermal diffusivity**

Thermal diffusivity is a measure of how quickly a material can absorb heat from its surroundings; it is the ratio of thermal conductivity to the product of density and heat capacity. Because of the low thermal conductivity and moderate density and heat capacity of wood, the thermal diffusivity of wood is much lower than that of other structural materials, such as metal, brick, and stone.

- **Heat capacity**

Heat capacity is defined as the amount of energy needed to increase one unit of mass (kg or lb) one unit in temperature (K or °F). The heat capacity of wood depends on the temperature and moisture content of the wood but is practically independent of density or species.

2.3.2 Mechanical properties of wood

- **Elastic properties**

Twelve constants (nine are independent) are needed to describe the elastic behavior of wood: three moduli of elasticity E, three moduli of rigidity G, and six Poisson's ratios m.

- **Modulus of elasticity**

Modulus of elasticity relates the stress applied along one axis to the strain occurring on the same axis. The three moduli of elasticity for wood are denoted E_L, E_R, and E_T to reflect the elastic moduli in the longitudinal, radial, and tangential directions, respectively. For example, E_L relates the stress in the longitudinal direction to the strain in the longitudinal direction.

- **Shear modulus**

Shear modulus relates shear stress to shear strain. The three shear moduli for wood are denoted with G_{LR}, G_{LT} and G_{RT} for the longitudinal-radial, longitudinal-tangential and radial-tangential planes respectively. For example, GLR is the modulus of rigidity based on the shear strain in the LR plane and the shear stress in the LT and RT planes.

- **Poisson's ratio**

Poisson's ratio relates the strain parallel to an applied stress to the accompanying strain occurring laterally. For wood, the six Poisson's ratios are denoted μ_{LR},μ_{LT},μ_{RL},μ_{RT},μ_{TL},μ_{TR} refers to the direction of applied stress; the second subscript refers to the direction of the accompanying lateral strain [30]. For example, μ_{LR} is the Poisson's ratio for stress along the longitudinal axis and strain along the radial axis.

- **Strength properties**

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.[30] Additional measurements are often made to evaluate work to maximum load in bending, impact bending strength, tensile strength perpendicular to grain, and hardness.

- **Modulus of rupture**

It reflects the maximum load carrying capacity of a member in bending and is proportional to maximum moment borne by the specimen. Modulus of rupture is an accepted criterion of strength, although it is not a true stress because the formula by which it is computed is valid only to the elastic limit.

- **Work to maximum load in bending**

It is an ability to absorb shock with some permanent deformation and more or less injury to a specimen. Work to maximum load is a measure of the combined strength and toughness of wood under bending stresses.

- **Compressive strength parallel to grain**

It is defined as maximum stress sustained by a compression parallel-to-grain specimen having a ratio of length to least dimension of less than 11.

- **Compressive stress perpendicular to grain**

It is reported as stress at proportional limit. There is no clearly defined ultimate stress for this property.

- **Impact bending**

In the impact bending test, a hammer of given weight is dropped upon a beam from successively increased heights until rupture occurs or the beam deflects 154 mm (7 in.) or more. The height of the maximum drop or the drop that causes failure is a comparative value that represents the ability of wood to absorb shocks that cause stresses beyond the proportional limit.

- **Tensile strength perpendicular to grain**

It is a resistance offered by wood to the forces acting across the grain that tend to split a member. Values presented are the average of radial and tangential observations.

- **Hardness**

It is defined as resistance to indentation using a modified Janka hardness test. In janka hardness test hardness is calculated by using the load required to embed a 11.28-mm (0.444 in.) ball to one-half of its diameter. Values presented are the average of radial and tangential penetrations.

- **Torsion strength**

It is defined as resistance to twisting about a longitudinal axis. For solid wood members, torsional shear strength may be taken as shear strength parallel to grain. Two-thirds of the value for torsional shear strength may be used as an estimate of the torsional shear stress at the proportional limit.

- **Toughness**

It is an energy required to cause rapid complete failure in a centrally loaded bending specimen.

- **Creep and duration of load**

It is defined as time-dependent deformation of wood under load. If the load is sufficiently high and the duration of load is long, failure (creep–rupture) will eventually occur. The time required to reach rupture is commonly called duration of load. Duration of load is an important factor in setting design values for wood.

- **Fatigue**

Resistance to failure under specific combinations of cyclic loading conditions: frequency and number of cycles, maximum stress, ratio of maximum to minimum stress, and other less-important factors.

- **Rolling shear strength**

Shear strength of wood where shearing force is in a longitudinal plane and is acting 90 degree to the grain. Few test values of rolling shear in solid wood have been reported. In limited tests, rolling shear strength averaged 19% to 29% of parallel-to-grain shear values. Rolling shear strength is about the same as in the longitudinal–radial and longitudinal–tangential planes.

- **Maximum crushing strength**

This property is a good indicator of the wood's strength in applications such as deck posts, chair legs, or other circumstances where the load being applied is parallel rather than perpendicular to the grain [36]. It is also sometimes known as Compression Strength parallel to the grain and it is also a measurement of the wood's maximum crushing strength when weight is applied to the ends of the wood (compression is parallel to the grain).

- **Fiber stress at limit of proportionality**

It is defined as highest stress at which stress is directly proportional to strain. It is the highest stress at which the curve in a stress-strain diagram is a straight line. Proportional limit is equal to elastic limit for almost all wood varieties [36].

- **Fracture toughness**

It is an ability of wood to withstand causes that is responsible for failure. Measurement of fracture toughness helps identify the length of critical flaws that initiate failure in materials.

- **Vibration properties**

The vibration properties of primary interest in structural materials are speed of sound and internal friction (damping capacity).

- **Speed of sound**

The speed of sound in a structural material is a function of the elasticity modulus and density. In wood, the speed of sound also varies with grain direction because the transverse modulus of elasticity is much less than the longitudinal value (as little as 1/21); the speed of sound across the grain is about one-fifth to one-third of the longitudinal value.

- **Internal friction**

When solid material is strained, some mechanical energy is dissipated as heat. Internal friction is the term used to denote the mechanism that causes this energy dissipation. The internal friction mechanism in wood is a complex function of temperature and moisture content. In general, there is a value of moisture content at which internal friction is minimum. On either side of this minimum, internal friction increases as moisture content varies down to zero or up to the fiber saturation point.

2.3.3 Other important properties of wood

- **Polish ability**

Polishing is the process of creating a smooth and shiny surface by rubbing it or using a chemical action, leaving a surface with a significant specular reflection. 2-Part polyurethane, wax other types of chemicals are used for polishing in wooden materials [36].

- **Resistance to fire**

Large wood members have long been recognized for their ability to maintain structural integrity while exposed to fire. Early mill construction from the 19th century utilized massive timbers to carry large loads and to resist structural failure from fire.

- **Suitability for industrial and furniture applications**

Wood often mixed with high grade of composite materials can be easily used for various technical and furniture applications. Also for various furniture applications, wood can be used with the help of resins and chemicals are used

- **Availability**

Just as every individual wood species is dynamic and prone to change in response to its environment, so too is the market for all wood flooring species. Availability of wood can be classified into three types as: easily available, readily available, moderately available, and limited availability. This factor affects the cost of finished goods made out of wood.

- **Indoor and outdoor ageing**

Sometimes wood are often left unused in warehouses or sometimes in outdoor location can be easily subjected to hazardous environmental conditions which could easily lead to ageing of wood.

- **Cost**

Cost of wood is also an important factor in selection of a wooden material. Decision to export or import of wood is also dependent on cost of a particular wooden species

2.4 SELECTION OF SIGNIFICANT WOOD PROPERTIES FOR 3-AXIS ROUTER CARVING

All of the above listed properties of wood are not significant in relation to CNC based carving. Hence the significant properties which affect wood machining using a CNC router has been identified from the published literature [2-3],[19-20], [6], [12], [21-23], [26]. From overall study of literature, these properties have been ranked in order of their significant effect on carving/machining in descending order as shown in table 2.1, along with their desired range.

Table 2.1: Range of values for desired wood properties for CNC router machining [30]

S. No.	Wood properties	Desired range
1	Hardness	45 to 98 (HRB)
2	Specific gravity	0.20 to 0.80
3	Modulus of elasticity	5000to18000 (MPa)
4	Volumetric shrinkage (green wood to oven dry)	6 to 19 (%)
5	Modulus of rupture	27 to 140 (MPa)
6	Maximum crushing strength	12.8 to 61.0 (MPa)

2.5 WOODEN SPECIES GENERALLY USED FOR ENGINEERING APPLICATIONS

A large number of wood species that are found around the world, but not all of them are suited for furniture or industrial use. The plant species whose wood is used for engineering applications and which are referred in published literature, as well as some wood varieties that are commonly used in India has been studied are presented in this section. Overall data has been summarized into a tabular form as depicted in table 2.2.

Table 2.2: Different species of wood

S. No.	Wood species	Properties
1.	Acacia Auriculiformis (Bengaljali)	• Common name: akash mono • The wood has a high basic density (500-650 kg/m³) • A major source of firewoodis a dense wood and high calorific value of 4500-4900 kcal/kg.[35] • The root is used to treat aches and pains • **Availability:** Locally available
2.	Shorearobusta (Sal)	• The Sal tree (Shorearobusta) is a hardwood timber tree, up to 30-35 m tall. • It is resistant to fire, coarse grained, hard and of fibrous structure. • The Sal tree is native to India, Myanmar and Nepal
3.	Pine	• Pines are evergreen, coniferous resinous trees growing 3–80 m tall, with the majority of species reaching 15–45 m tall. • They are fast-growing softwood that will grow in relatively dense stands.[29] • It is widely used in high-value [28] carpentry items such as furniture, window frames, paneling, floors and roofing • The density is (240-440 kg/m³) • **Availability:** Locally available • **Approximate cost –**Rs .1200/Cubic feet
4.	Mangifera Indica (Mango)	• Mangifera Indicagrow up to 35–40 m (115–130 ft) tall, with a crown radius of 10 m (33 ft) • It grow quickly into round, multi-branched, dense, spreading shade trees • **Availability** : Locally available • **Approximate cost** –Rs. 550 /cubicfeet
5.	Hevea Brasiliensis (Rubber wood)	• The tree can reach a height of up to 100 feet (30 m) • It is used for the production of charcoal or as fuel wood • Grain straight to shallowly inter locked • The density of the rubber wood is 592 kg/m^3

		• Most of the timber is used to manufacture furniture. Other uses include interior finish, molding etc. • **Availability** : Imported/Domestic wood • **Approximate cost** : Rs.100/ cubicfeet
6.	Eucalyptus Tereticornis (Eucalyptus)	• Eucalyptus Tereticornis is a tree up to 45 m tall or taller; trunk erect, 1-1.8 m in diameter • The wood is uniform in texture and has an interlocked grain • Eucalyptus tereticornis has strong, hard and durable heartwood, with a density of about 1100 kg m^{-3} • **Availability** : Imported and domestic wood • **Approximate cost** : Rs 500/cubic feet
7.	Melia Composita (Malabar neem)	• Melia Composita is a deciduous tree up to 45 m tall; bole fluted below when old, up to 30-60 (max. 120) cm in diameter • Fuel wood is a major use of Melia Composita. It has a calorific value is 5100 kcal/kg • The density is 510-660 kg/m^3 • **Availability** : Locally Available • **Approximate cost**: Rs. 600/cubic feet
8.	Kikar	• It is an evergreen, thorny, moderate-size tree, 25 m tall and diameters are varied up to 1.5 m. • It has a close grained structure, sapwood is white, and heartwood is pinkish white turning to reddish brown. • Specific gravity is approximately 0.76, • This wood is durable, heavy, hard and very strong. • **Availability** : Locally available • **Approximate cost** : Rs. 500/cubic feet

9.	Maple wood	• Maple is heavy, strong, stiff and hard and also it has a high resistance to shock. • The wood turns well on a lathe and is markedly resistant to abrasive wear and it takes strain satisfactorily and is capable of a high polish. • The wood of soft maples is not as heavy, as hard, or as strong as that of the hard maples • **Availability** : Local as well as imported wood • **Approximate cost** : Rs 900/cubic feet

The detailed list of wooden species and their properties as discovered from literature are listed in table 2.2. The use of MADM approach for ranking these wood varieties has been detailed in chapter 5.Some additional wood species which are not listed in literature and are commercially available in India have also been included in the present study. The methodology used for finding their properties and MADM approach used for ranking them have been detailed in chapter 6.

Table 2.3 attached data sheet shows different types of wood species studied from published literature and their properties. In this preference of wooden species are given according to the large number of parameter values they possessed.

CHAPTER 3

LITERATURE REVIEW

In this chapter the literature relevant to the present work has been explored. Objective of the present work is to design a procedure which can be used to rank wood species with respect to their mechanical, physical properties and other relevant properties for CNC carving operations. Our literature review has been divided in three sections as explained below:

3.1 TYPES OF WOODS AND THEIR PROPERTIES

R. Gnanaharan& T.K. Dhamodaran[1] studied about the mechanical properties of air-dried rubber wood (Heveabrasiliensis) from a 35 year old plantation in the central region of Kerala. The physical and mechanical properties of 35-years old teak wood were found out with the help of 'Amsler' Universal Testing Machine. It was found that the mechanical properties tested, namely, modulus of rupture (MOR), modulus of elasticity (MOE) and maximum compressive stress (MCS) were getting higher values for the more year old material than for lower age material. The study showed that rubber wood possesses medium strength properties. Also **Florent Eyma et al. [2]** studied different characteristics: Physical (specific gravity, shrinkage) and Mechanical (hardness, fracture toughness, shearing, and compression parallel to the grain) of thirteen tropical wooden species for predicting their cutting forces in mode B. The mechanical properties of 13 tropical wood species were found out with help of longitudinal shearing test and particularly hardness was found out using Monnin Hardness test and also by combining both specific gravity and all mechanical parameters, machining parameters were found out .Results obtained showed good correlations, particularly with very good results for fracture toughness parameters.

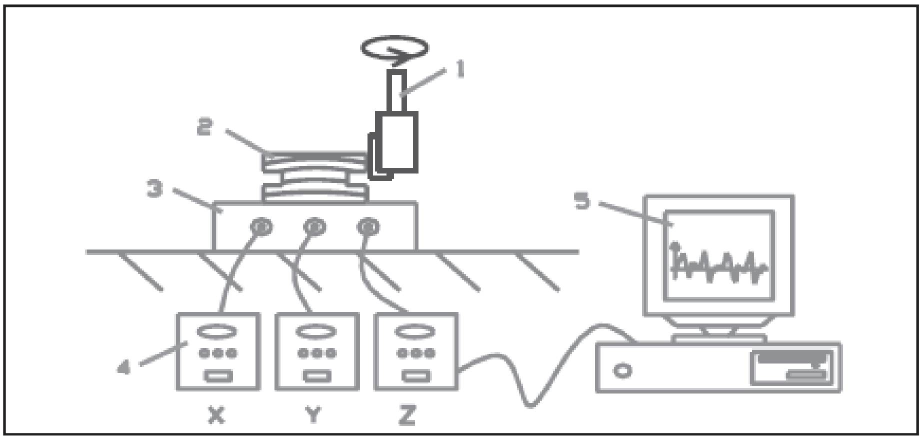


FIGURE 3.1: Sketch of router's table with its cutting forces measuring device, where: (1) is the cutting tool; (2) is the wood specimen; (3) is a Piezo-electric sensors; (4) is an amplificators, and (5) is the cutting forces measurement system.

A. Shanavas and B.M. Kumar [3] also studied about wood properties of three locally important fast growing tree species (Acacia auriculiformis, Acacia mangium and Grevillearobusta) occurring as scattered and boundary planted trees on the agricultural lands of Kerala were evaluated. Basic wood density of A. auriculiformis was greater than that of A.mangium and G.robusta. Attributes such as work to limit of proportionality and work to maximum load in static bending, compressive stress at limit of proportionality in parallel to grain, compressive stress at limit of proportionality in perpendicular to grain, and end hardness of A. Auriculiformis were also greater than the values reported for teak (Tectona grandis). However, the physical and mechanical properties of A. mangium and G. robusta, except shrinkage, were found inferior to teak. **Yue wang et al. [4]** studied about the physical and mechanical properties of steam-treated wood, hemicelluloses-extracted wood, and delignified wood, which were treated at different levels of experimentation. They further reported that at high weight loss, destabilization will decreased because capillary condensed water gathered in the voids and obstructed the motion of adsorbed water. **S.R. shukla et al. [5]** assessed the physical and mechanical properties of timber of plantation-grown 8-, 12- and 13-y-old trees of Acacia auriculiformis, A.Cunn. exBenth from Sirsi, Karnataka, India. The found that the timber of the 13 year old trees was dense, very strong, moderately tough, stable in service and hard, and it compared favorably with teak in several properties, which also suggest that it can be used for tool handles, oars, paddles, packing cases, ammunition boxes, etc. **George I. mantanis and Dimitrios birbilis[6]** determined the main physical and mechanical properties of athel wood (Tamarix aphylla), one of the least studied non-commercial wood species. Wood samples of Tamarix aphylla were collected from a small tree stand in Molyvos coastal area (Lesvos, Greece) and standard test methods were followed on small green specimens. The results showed that the mechanical properties of this wood species are very low as compared with those of ash wood, a known commercial species with equivalent density. **M. Hakan Akyildiz and Hamiyet Sahin Kol[7]** determined some physical and mechanical properties of Paulownia tomentosa wood grown in Turkey. He concluded that paulownia grown in Turkey have same physical and mechanical properties because most mechanical properties of wood are closely correlated to density. He also concluded because of higher values of MOE, rockwell hardness that paulownia wood can be widely used for various purposes such as house construction, furniture making, pulp and paper and handicrafts. **TrairatNeimsuwan and Nikhom Laemsak[8]** studied about the anatomical and mechanical properties of wood samples from the Bur-flower tree, Anthocephalus chinensis were tested from two different localities and at three different ages. He also concluded that A. chinensis was evaluated as a low strength and naturally durable wood. **Mehraj a. sheikh et al. [9]** carried study to estimate their specific gravity; wood samples were collected from a total of 34 tree species, 30 from lower elevations and 4 from upper elevations in the Garhwal Himalayas, India. The average wood specific gravity for the upper elevation species was 9.6% greater than that for the species at lower elevations. **Majid Kiaei and Ahmad Samariha[10]** studied about various wood fiber dimensions (fiber length, fiber width, cell wall thickness and lumen diameter), physical (oven-dry density) and mechanical properties (modulus of rupture, modulus of elasticity, compression parallel to the grain) of five hardwood plants such as oak (Quercus Castaneaefolia), beech (Fagus Orientalis), hornbeam (Carpinus Betulus), alder (Alnusg Lutinosa) and ash (Fraxinus Excelsior) with dimensions of 2 ×2 × 2 cm and prepared according to ASTM-D143 (ASTM D143, Standard Methods of Testing Small Clear Specimens of Timber) and they performed statistical analysis using the SPSS programming method in conjunction with the analysis of variance (ANOVA) techniques. The lowest of mechanical strength properties was found in alder wood. Analysis of variance (ANOVA) indicated that the hardwood plant species had significant difference on wood density, fiber properties and mechanical strength properties. **Luis Cristovao et al. [11**] investigated the relationship between tool wear and some chemical and physical properties for four different Mozambican lesser known tropical species. The wear mechanism was investigated using a scanning electron microscope which showed that the chemical properties of the wood species have a great effect on tool wear. They concluded that Tool wear did not increase with increase of wood density. **Artemio Carrillo et al.[12]** studied about wood from fourteen native species were studied with regard to their basic density (BD), modulus of elasticity (MOE), and modulus of rupture (MOR), as well as the relationships between these three properties. Values of modulus elasticity and rupture of studied species make them a promising general utility wood that can be recommended for a variety of structural and non-structural uses. **P. K. Thulasidas and K. M. Bhatt et al. [13]** investigated mechanical properties of teak wood grown in home-garden forestry and the anatomical factors influencing timber strength in comparison with that of a typical forest plantation. They concluded that the short rotation teak harvested from homesteads was found to have strength properties similar to mature teak wood of forest plantation sites. Except for slightly higher longitudinal compressive stress of dry site home-garden teak, no significant variation was noticed in timber stiffness.

Also some of properties related to wood composite materials have been studied like by **Andrea Wechsler and Salim Hiziroglu [14]** who studied some of the important properties of experimentally manufactured wood–plastic composites (WPC). Specimen having 60% and 80% particle and fiber of radiata pine (Pinusradiata) were mixed with polypropylene (plastic) and four different additives, namely Structor TR 016 which is coupling agent, CIBA anti-microbial agent (IRGAGUARD F3510) as fungicide, CIBA UV filter coating (TINUVIN 123S), CIBA blue pigment (Irgalite), and their combinations .They concluded that using less than 1.2% anti-microbial agent as fungicide would yield better properties of the samples. **Ergun Baysal et al. [15]** investigated some physical, biological, mechanical, and fire properties of WPC pretreated with boric acid and borax mixture. They concluded that WPC is an alternative structural material for exterior use, where high physical, biological, and mechanical properties required. But, these products have low fire properties. Thus, boron–monomer combination may be of advantage in fire resistance as well as decay resistance.

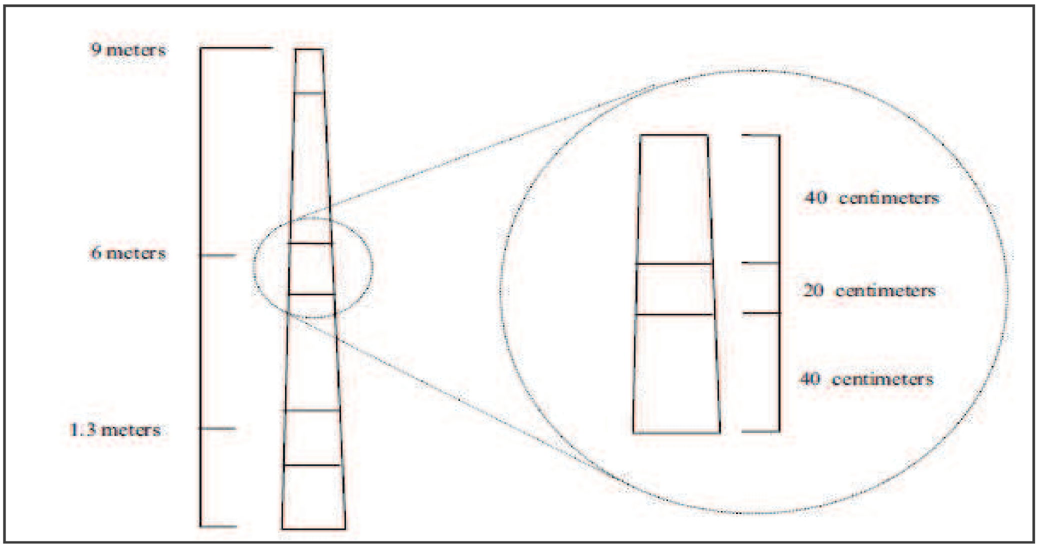


Figure 3.2: Diagram showing positions where 1-meter logs were cut from the trunk of Anthocephalus Chinensis and where 20-cm-thick disk and two 40-cm logs were cut from each 1 meter log.

Yali Li [16] experimented in which WPC samples were prepared with poplar wood-flour, HDPE, and polyethylene maleic anhydride copolymer (MAPE) as coupling agent. He also observed that the best mechanical properties of wood/HDPE composites can be reached with larger particle size in the range studied, while too-small particle size was adverse for the mechanical properties of wood/HDPE composites. **Khandkar-Siddikur Rahman et al. [17]** presented the manufacturing of bamboo mat-wood veneer plywood for higher strength purposes using muli bamboo (Melocanna Baccifera), mat and simul (Bombaxceiba) wood veneer and urea formaldehyde resin, and its basic physical and mechanical properties. Compared to the commercial plywood, BW_{ply} showed higher physical and mechanical properties except the edge screw withdrawal. **Nazmul Alam D.M. et al. [18]** carried out study to determine and compare the physical and mechanical properties of plywood produced with veneers of eucalyptus and simul tree. Physical properties i.e., density, moisture content, water absorption and thickness swelling; and mechanical properties i.e., modulus of elasticity (MOE) and modulus of rupture (MOR) of the panels were determined according to the procedure of ASTM standards. He further concluded that the obtained variation in physical and mechanical properties of eucalyptus and Simul plywood were due to the difference in inherent characteristics of veneer wood species (Eucalyptus and Simul wood. **E. obataya et al. [19]** studied about the vibration properties of spruce wood with respect to their relative acoustic conversion efficiency and a ratio reflecting anisotropic nature of wood. This model predicted that the essential requirement for an excellent soundboard is smaller fibril angle of the cell wall, which yields higher values of cutting angles. **Julien ruelle et al. [20]** carried out study of Wood specimens which were cut in the vicinity of the growth strains measurements in order to measure some mechanical and physical properties. As suspected, tensile growth strains was very much higher in tension wood zone, because longitudinal modulus of elasticity was slightly higher. Longitudinal shrinkage was also much higher in tension wood than in opposite wood.

3.2 SURFACE MACHINING PROPERTY

Florent Eyma et al. [21] studied about 14 wood species in the following cutting process: routing, i.e. peripheral milling parallel to the longitudinal direction. The influence of main mechanical characteristics was studied and a formulation was obtained which allowed us to estimate more precisely strains involved and the general behavior of wood during machining. Relationship between these properties, specific gravity and cutting forces were obtained. It was appeared that mechanical properties could explain some exceptions in the relationship between density and cutting forces. **Murat Kilic et al. [22]** studied surface characteristics of sawn, planed, and sanded samples of both species (beech and aspen lumber) employing a stylus type profilometer. It was concluded that surface roughness of the samples exposed to different relative humidity levels and other machining properties of such species could be evaluated to provide an initial data for finishing applications. **J. Lawrence Katz et al.[23]** studied and done some calculations to determine anisotropic technical moduli for both soft and hard woods derived from the technical moduli measured by traditional mechanical testing, i.e., quasi-static stress–strain measurements. It was concluded that measurement of the elastic properties of living tissues such as bone and wood are not identical from sample to sample or when made by different techniques. **Iris Bremaud et al. [24]** contribute to overcoming the critical lack of data on the diversity of wood dynamic mechanical/viscoelastic and vibrational properties by testing lesser known species. The variations in specific gravity, in stiffness or in “viscosity” appear to be predominantly linked to different levels of diversity: between species or between wood types.

3.3 WOOD GRADING/IDENTIFICATION

A wood identification and grading system has been studied in our literature review. Some of researchers have studied about some techniques like **P.P. Bhangale et al. [25]** carried out study to generate and maintain reliable and exhaustive database of robot manipulators based on their different pertinent attributes. The selection procedure was used to rank the alternatives in the shortlist by employing different attributes based specification methods and graphical methods. In the end it was concluded that MADM-TOPSIS provides coding scheme to produce electronic database of globally available robots. But another work in terms of wood identification has been done by **Ruggero donida labati et al. [26],** where they have studied and presented a novel approach for wood kinds classification based on a neural network system which exploits the emitted spectrum of the wood samples filtered with a bank of low-cost optical filters coupled with a set of photo detectors**.** A low cost wood identification method was based on the analysis of the florescence spectrum achieved without the usage of any spectrometer. Lasers, photo detectors etc. were used and an optical fibre bank was formed as basis for finding out right type of wood to be used.

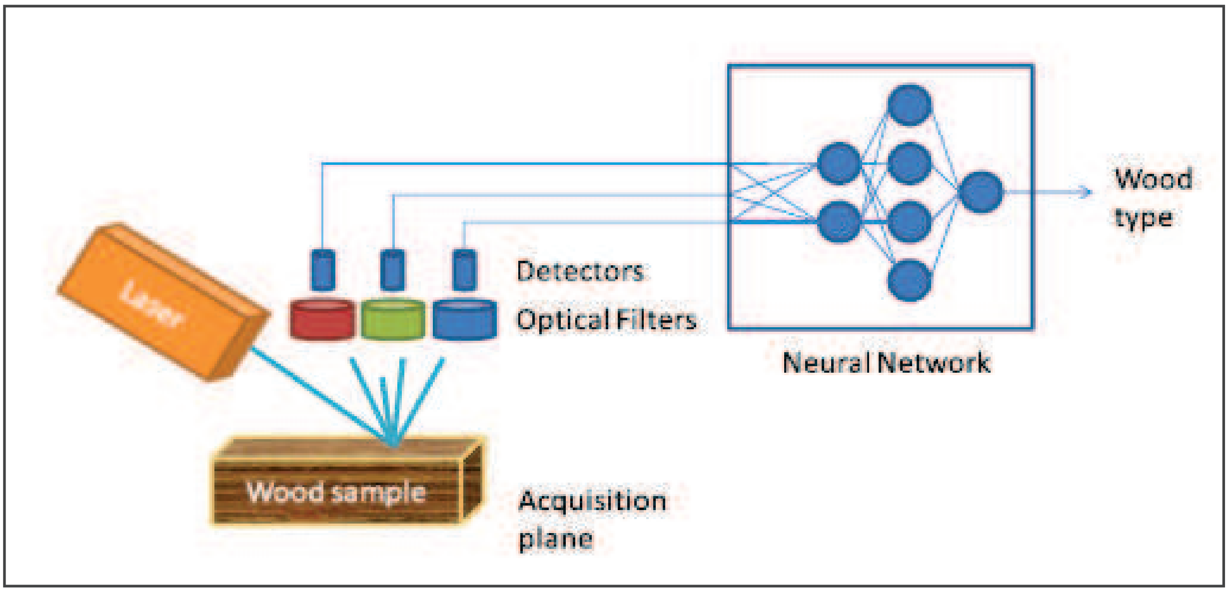


Figure 3.3: Scheme of the Proposed Approach.

Marzuki Khalid et al. [27] also designed an automatic wood recognition system based on image processing, feature extraction and artificial neural networks. The system can be very beneficial for wood identification within seconds, eliminating the need for laborious human recognition. Image processing was carried out using our newly developed in-house image processing library referred to as "Visual System Development Platform". The results obtained showed that a high rate of recognition accuracy proving that the techniques used is suitable to be implemented for commercial purposes. A block diagram showing the procedures of the wood recognition system has been depicted in figure 3.4

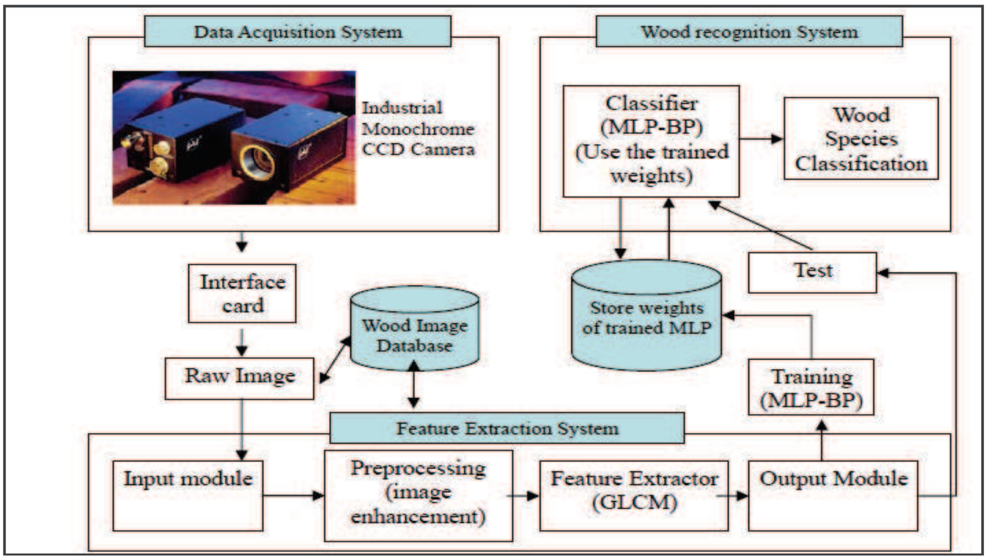


Figure 3.4: A block diagram showing the procedures of the wood recognition system.

3.4 SUMMARY OF LITERATURE SURVEYED

As discussed above, it is evident from the published literature that although various types of wood species and their properties have been independently investigated, but no attention has been made for study of wood properties and wood species together for identification of relatively best species for ornamental carving using CNC router. Moreover such a study will be very important for Indian context as work related to finding the wood properties and their relative suitability has not been explored. Thus there is a strong need for scientific study for grading of the wooden species based upon their engineering properties for ornamental carving.

CHAPTER 4

MULTIPLE ATTRIBUTE DECISION MAKING (MADM) APPROACH

4.1 MADM APPROACH

MADM is an approach employed to solve problems involving selection from among the finite number of alternatives. An MADM method specifies how attribute information is to be processed in order to arrive at a choice. MADM techniques present the selection of an alternative from a set of alternatives based on prioritized attributes of the alternatives. The complexity of problem can be better appreciated when one realizes that there are over 75 attributes [25] that have to be considered in the selection of system for particular application. Implementation of MADM approach includes following steps.

STEP 1: For the given problem, the attributes which have direct effect on the selection procedure are called pertinent attributes. Identify the pertinent attribute for X-abilities. The threshold values to these pertinent attributes may be assigned by obtaining information from the user or/and the group of experts. On the basis of the threshold values of the pertinent attributes, a shortlist of alternatives is obtained.

STEP 2: Formation of Decision Matrix 'D'. This is matrix that contains all the magnitude of the specifications. Decision Matrix in MADM method has four parts namely

(a) Alternatives

(b) Attributes

(c) Weight or relative importance of each attribute

(d) Measures of performance of alternatives with respect to the attributes.

Organize the m alternatives and n attributes into decision matrix. An element d_{ij} of the decision matrix D gives the value of j^{th} attribute for the i^{th} alternative.

STEP 3: Calculate the normalized decision (specification) matrix. The decision (specification) matrix will have the magnitudes of all the attributes of the alternatives on the common scale of 0 to 1. An element n_{ij} of the normalized matrix N can be calculated as

$$n_{ij} = d_{ij} / \left(\sum_{i=1}^{m} d_{ij}^{2}\right)^{1/2} \qquad 4.1$$

STEP 4: Construct a relative importance matrix A. The relative importance of the attributes with respect to each other has been identified based upon the published literature and the experience of the experts working in this area. Information on all such pair-wise comparisons is stored in a matrix called as relative importance matrix, A, which is $n \times n$ matrix. Here a_{ij} will contain the relative importance of i^{th} attribute over the j^{th} attribute. The symmetric terms of this matrix will be reciprocals of each other while the diagonal will be unity.

STEP 5: Find out the maximum Eigen value of the relative importance matrix $A_{n\times n}$. This could be found by using the formula given below:

$$(A - ƛ_{max}\ I) = 0 \qquad 4.2$$

STEP 6: Calculating weights for each attribute using the Eigen vector associated with maximum Eigen value form the equations given below:

$$(A - ƛ_{max}\ I).w = 0 \qquad 4.3$$

and $\sum_{i=1}^{n} W_i = 1$ 4.4

STEP 7: Calculate the weighted normalized decision matrix V. The matrix which combines the relative weights and normalized specification of attribute is weighted normalized matrix V. It will give the true comparable values of the attributes.

STEP 8: Ranking and Selection Procedure can be done either mathematically (TOPSIS method) or graphically (Line graph and Spider diagram methods). These approaches have been discussed briefly below:

4.2 TOPSIS METHOD

The weighted normalized attribute for +ive and –ive benchmark alternatives, that is V^+ and $V-$ by finding highest and lowest values from each column of weighted normalized matrix, using relation given below:

$$V_i^* = \{[_{j=1;i=1,m}^{max} v(i,j)], [_{j=2;i=1,m}^{max} v(i,j)], \dots \dots [_{j=n;i=1,m}^{max} v(i,j)]\} \qquad 4.5$$

$$V_i^- = \{[_{j=1;i=1,m}^{min} v(i,j)], [_{j=2;i=1,m}^{min} v(i,j)], \dots \dots [_{j=n;i=1,m}^{min} v(i,j)]\} \qquad 4.6$$

The procedure used for determination of separation from ideal solution of TOPSIS method has been discussed below:

- Determine separation from positive ideal solution S_i^* by using formula given below

  $$S_i^* = [\sum_{j=1}^{n} (v_{ij} - v_1^*)^2]^{1/2} \quad (i = 1,2 \dots m) \qquad 4.7$$

- Determine separation from negative ideal solution S_i^- by using formula given below

  $$S_i^- = [\sum_{j=1}^{n} (v_{ij} - v_1^-)^2]^{\frac{1}{2}} \quad (i = 1,2 \dots m) \qquad 4.8$$

- The relative closeness to the ideal solution is calculated using formula given below:

  $$C_i^* = \frac{S_i^-}{(S_i^- + S_i^*)} \qquad 4.9$$

- Candidate alternatives are ranked in accordance with the decreasing values of indices C^*, as found using equation 4.9. This ranking indicates the most preferred and the least preferred feasible optional solutions.

4.3 IDENTIFICATION OF ATTRIBUTES FOR WOOD GRADING SYSTEM

The attributes for ranking of wood species under consideration have been categorized under the following headings: physical, mechanical and other quality related properties, as shown in figure 2.4 in chapter 2. A proper identification of wood surface machining parameters/attributes is critically important. The coding is done so as to find out which attribute affect the performance parameter (carvability) and which attribute does not. The properties listed in figure 2.4, have been divided into Qualitative and Quantitative properties.

Quantitative Properties: These parameters are also called deterministic parameters as these parameters can be given the value. Wood grading system can be rated on the scale 1-5. If the parameter affects surface machining of wood, it is rated as of highest importance and given rank value 5. If the parameter does not effect at all, then it is ranked lowest by assigning rated value of 0. Accordingly all parameters are rated from 0 to 5.

Qualitative Properties: All the parameters are not quantitative. These parameters are also called subjective or fuzzy parameters. As all the parameters cannot be given the value so these parameters have been categorized as qualitative parameters based on whether the parameter is related to surface machining of wood or not. If the parameter is related to surface machining of wood then it is coded as Y and if the parameter is not used in the machine then it is coded as N.

4.4 CODING FOR ATTRIBUTES EFFECTING WOOD CARVING

All the important engineering properties of wood listed in figure 2.4 have been grouped into major sections as indicated in table 4.1. This set of properties of any wood species, has to be considered for determining its suitability for 3-D machining/carving application. These identified attributes may be quantitative and qualitative in nature. For ease of understanding and handling to huge database comprising of varieties of woods, these identified attributes need to be coded. Table 4.2 shows such a coding scheme for each parameter i.e. Hardness. In this work, code numbers (0-5) have been assigned according to the corresponding value of that attribute.

Table 4.1: Numbering scheme of the different set of properties of wood (derived from figure 2.4)

Appearance	1	2	3	4															
Moisture content	5																		
Thermal properties	6	7	8																
Shrinkage	9	10																	
Volumetric properties	11	12	13																
Strength	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Vibration	33	34																	
Quality	35	36	37	38	39	40													
Adaptability to environmental	41	42	43	44	45	46	47												

conditions																			
Availability	48	49	50																

Table 4.2 values give range of values of hardness for wood species. Their codes have been assigned depending upon maximum and minimum values.

Table 4.2: Example of coding scheme for hardness (HRB)

Range of values of Hardness in (HRB)	Code given
Unspecified	0
33.50-40.50	1
40.50-47.00	2
47.00-53.50	3
53.50-60.50	4
60.50-67.00	5

This methodology has been extended to all attributes of all wood species under consideration. The unknown parameters have been assigned '0' value. Table 4.3 shows different attributes with their coding as discussed above for Acacia mangium [3] as an example.

Table 4.3: Example of attributes coding for Acacia Mangium [3]

Sr. No	Attribute	Information	Code
1.	Color	-	0
2.	Grain and texture	-	0
3.	Fiber orientation	-	0
4.	Decorative feature	-	0
5.	Equilibrium moisture content (EMC)	12 %	Y
6.	Conductivity	-	0
7	Thermal diffusivity	-	0
8	Heat capacity	-	0
9	Radial shrinkage (green to oven dry)	3.51 %	Y
10	Volumetric shrinkage	-	3
11	Weight	-	0
12	Specific Gravity	-	4
13	Density	500 kg/m^3	Y
14	Modulus of elasticity	-	5
15	Shear modulus	-	0
16	Poisson ratio	-	0
17	Modulus of rupture	-	2
18	Work to max. load in bending	0.45 kg/cm^2	Y
19	Compression strength parallel to grain	25.28 MPa	Y
20	Compression strength perpendicular to grain	7.786 MPa	Y
21	Impact bending	-	0
22	Static bending	-	0
23	Dynamic compressibility	-	0

24	Shear strength parallel to grain	-	0
25	Hardness	-	5
26	Torsion strain	-	0
27	Toughness	-	0
28	Fatigue	-	0
29	Rolling shear strain	-	0
30	Fracture toughness	-	0
31	Maximum crushing stress	-	3
32	Fibre stress at limit of proportionality	41.86 MPa	Y
33	Speed of sound	-	0
34	Internal friction	-	0
35	Warping tendency	-	0
36	Polishablity	-	0
37	Suitability for ornamental applications	-	0
38	Suitability for domestic /furniture applications	-	0
39	Suitability for industrial applications	-	0
40.	Resistance to Fire	-	0
41	Moth resistivity	-	0
42	Exposure to ambient sunlight	-	0
43	Exposure to ambient moisture	-	0
44	Indoor Aging tendency	-	0
45	Outdoor Aging tendency	-	0
46	Geographical Variation in inherent Properties	-	0
47	Natural Growth rate of plant saplings	-	0
48	Domestic	-	0
49	Imported	-	0
50	Cost	-	0

The properties of wood varieties under consideration as per the pattern of Table 4.3 have been used for MADM approach to rank them and evaluate the best alternative for 3D machining applications.

Table 4.4 lists values of shortlisted parameters of different wooden species studied in published literature. They are coded according to the coding scheme of Table 4.2

Table 4.4: Different types of wooden species studied from published literature and their ranking

Sr. No.	Wood type / Properties/ attributes	Redwood[32]	A. auriculiformis [3]	Tectona grandis [3]	TAMARIX APHYLLA [15],[41]	G. ROBUSTA[3]	A. MANGIUM[3]	Min value	Max Value	Range
1	Hardness (HRB)	2100.00	6549	4786.00	3334.00	3189.00	3788.00	2100.00	6549.00	4449.00
	coding	1	5	4	2	2	2			
2	SPECIFIC GRAVITY	0.4	0.63	0.60	0.62	0.48	0.5	0.40	0.63	0.23
		1	5	5	5	2	3			
3	Modulus of elasticity(MPa)	9200	8433.00	11676.00	7533.00	2552	7868.20	2552.00	11676.00	9124.00
		4	4	5	3	1	3			
4	Volumetric Shrinkage(%)	2.4	6.50	6.90	14.00	9.40	7.50	2.40	14.00	11.60
		5	4	4	1	2	3			
5	Modulus of rupture(MPa)	69	72	94	88.5	24.6	56	24.60	94.00	69.40
		4	4	5	5	1	3			
6	Maximum crushing stress(MPa)	42.4	43.7	52.20	40.90	21.20	31.70	21.20	52.20	31.00
		4	4	5	4	1	2			

4.5 CAUSE AND EFFECT DIAGRAMS

Cause-and-effect diagrams are causal diagrams, created by Kaoru Ishikawa (1968) that shows the causes of a specific event. Common uses of the Ishikawa diagram are product design and quality defect prevention, to identify potential factors causing an overall effect. Each cause or reason for imperfection is a source of variation. Causes are usually grouped into major categories to identify these sources of variation.

Figure 4.1, 4.2 and 4.3 tells about the cause and effect diagram of different engineering properties of wood. It basically tells about relative importance of each performance parameter with each other.

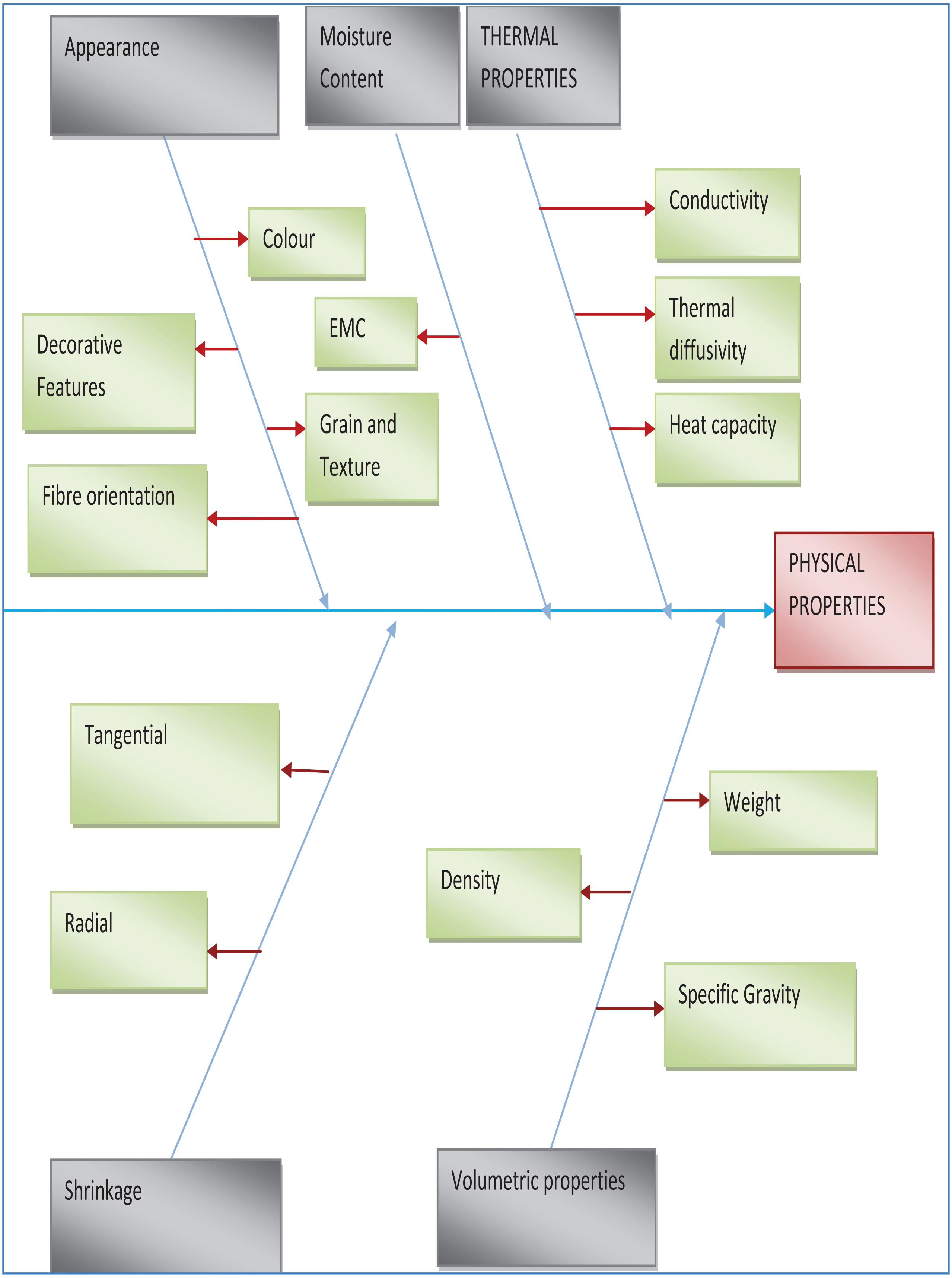


Figure 4.1: Cause and effect diagram showing physical properties of wood

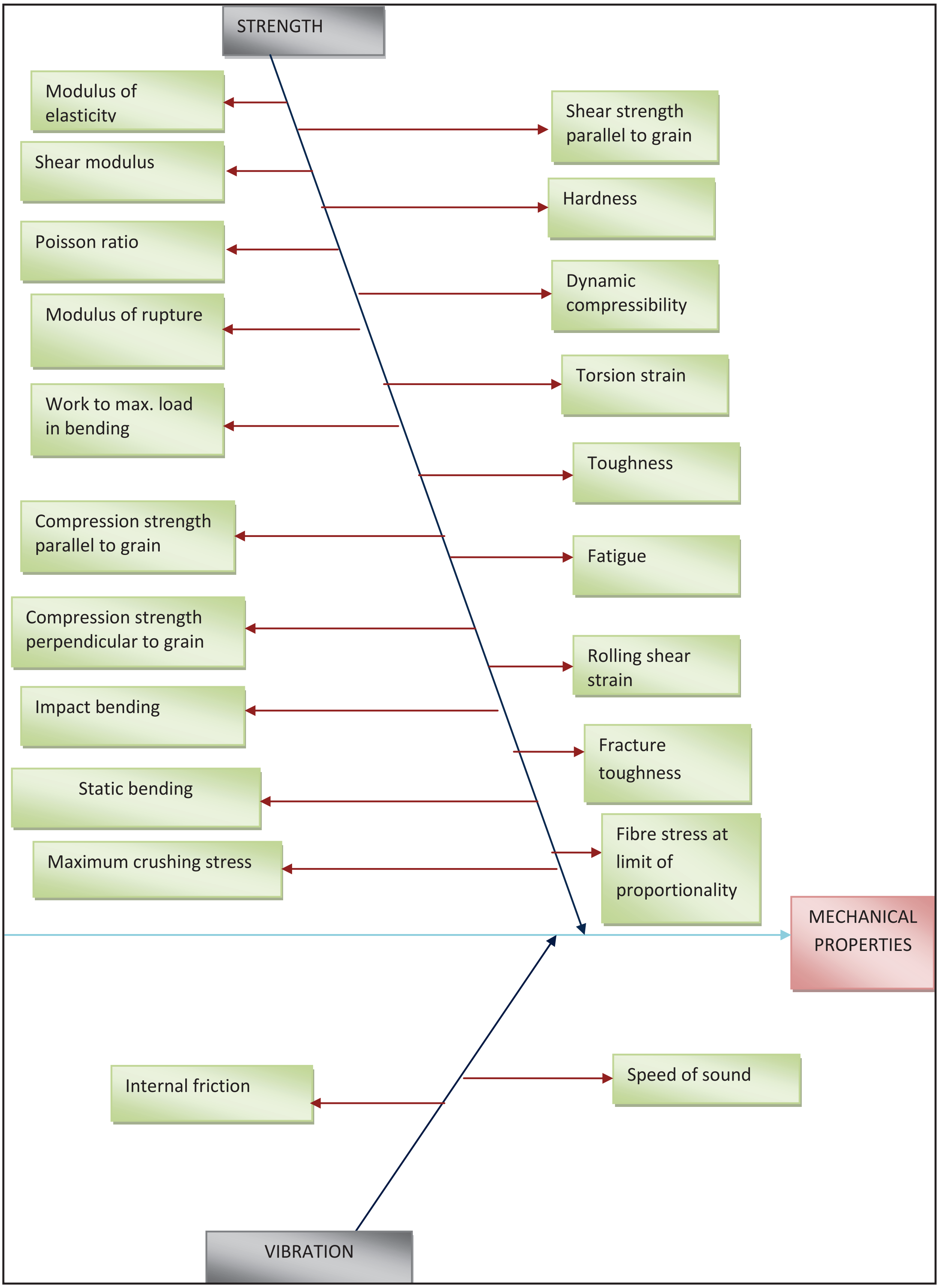


Figure 4.2: Cause and effect diagram showing mechanical properties of wood

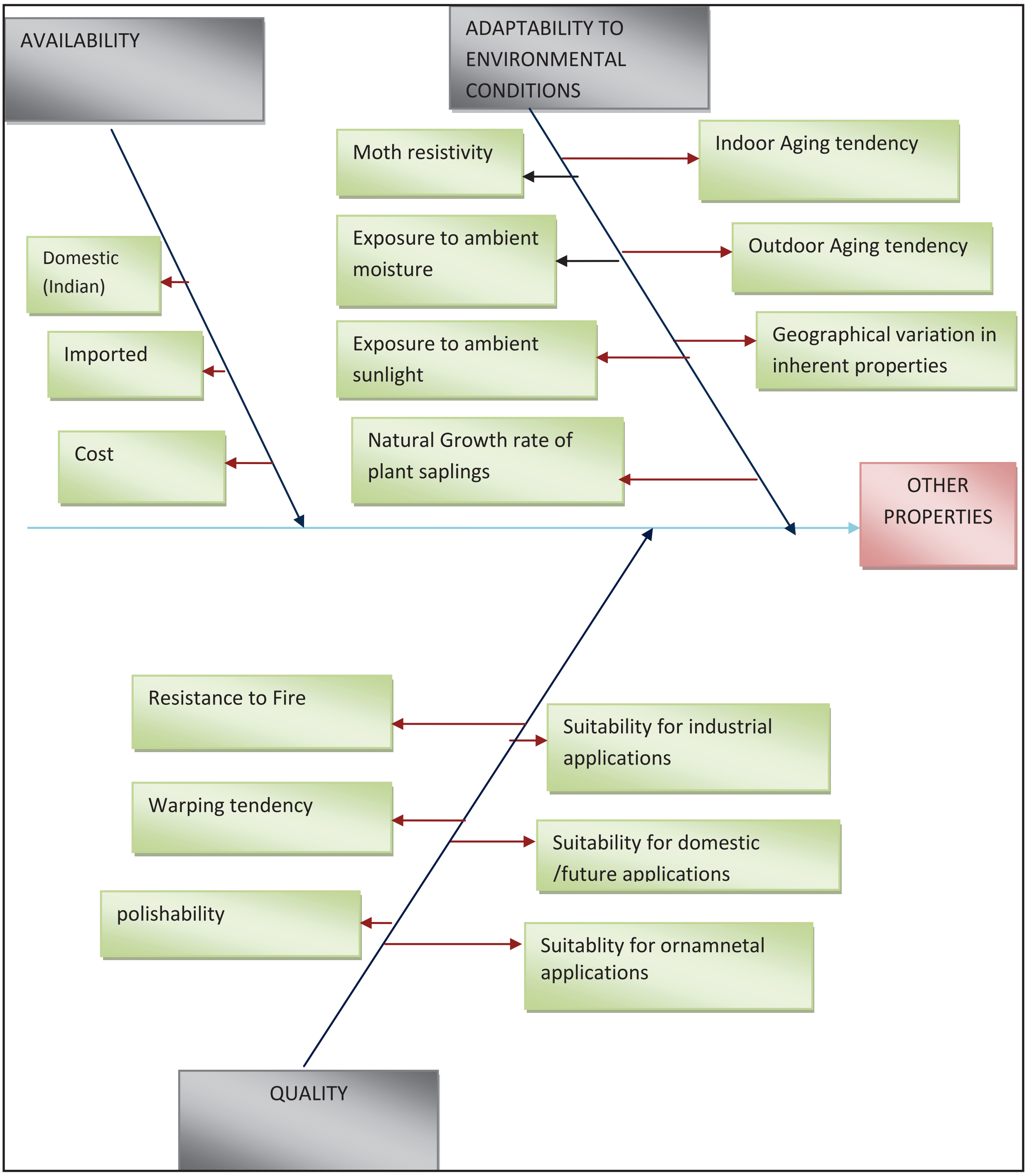


Figure 4.3: Cause and effect diagram showing other important properties of wood

4.6 APPLICATION OF MADM APPROACH ON INTERNATIONALLY AVAILABLE WOODS SAMPLES

The data given below has been studied from our literature. Some samples of international woods have been considered and compared on the basis of their properties. MADM-TOPSIS approach is used in order to find out best wood for surface 3-D machining**.** This is explained in order to find best wooden species for CNC wood machining

Table 4.5: Showing values of different properties of some international woods

S. No.	PARAMETERS / WOODS	Hardness (N)	Modulus Of Rupture (MPa)	Specific Gravity	Volumetric Shrinkage (%)	Maximum Crushing Strength (MPa)	Modulus Of elasticity (MPa)
1	Redwood[30]	2100	69	0.4	2.4	42.4	9200
2	A. auriculiformis [3]	6549	72	0.63	6.5	43.7	8433
3	Tectona grandis [3]	4786	94	0.60	6.9	52.2	11676
4	Tamarix Aphylla [10], [38]	3334	88.5	0.62	14	40.9	7533
5	G. robusta[3]	3189	24.6	0.48	9.4	21.2	2552
6	A. mangium[3]	3788	56	0.5	7.5	31.7	7868.2

Table 4.5 shows important properties of the selected species. Following steps of MADM approach have been incorporated to rank these internationally available woods.

Step1 Formation of Decision matrix,$\boldsymbol{D}$, i.e. matrix will contain all magnitudes of specifications. The rows of matrix are type of wood piece material i.e. Redwood, A. auriculiformis, Tectona grandis, Tamarix Aphylla, G. robusta, A. mangium and column represent performance parameters i.e. Hardness, MOR, specific gravity, max. Crushing strength and modulus of elasticity

$$D = \begin{bmatrix} 2100 & 69 & 0.4 & 2.4 & 42.4 & 9200 \\ 6549 & 72 & 0.63 & 6.5 & 43.7 & 8433 \\ 4786 & 94 & 0.60 & 6.9 & 52.2 & 11676 \\ 3334 & 88.5 & 0.62 & 14 & 40.9 & 7533 \\ 3189 & 24.6 & 0.48 & 9.4 & 21.2 & 2552 \\ 3788 & 56 & 0.5 & 7.5 & 31.7 & 7868.2 \end{bmatrix}$$

Step 2 Calculation of the normalized specification matrix. This normalization helps to provide the dimensionless elements of the matrix in the 0-1 range. It is a sort of value, which indicates the standing of that particular attribute magnitude when compared to the whole range of the magnitudes for all candidate woods.

$$n_{i,j} = \frac{d_{ij}}{\sqrt{\sum_{i=1}^{m} d_{ij}^2}}$$

$$N = \begin{bmatrix} 0.204 & 0.396 & 0.299 & 0.115 & 0.434 & 0.450 \\ 0.637 & 0.413 & 0.472 & 0.311 & 0.447 & 0.413 \\ 0.465 & 0.540 & 0.452 & 0.330 & 0.534 & 0.572 \\ 0.324 & 0.508 & 0.464 & 0.670 & 0.418 & 0.369 \\ 0.310 & 0.141 & 0.358 & 0.450 & 0.217 & 0.125 \\ 0.368 & 0.321 & 0.374 & 0.359 & 0.324 & 0.385 \end{bmatrix}$$

Step 3 Construction of Relative importance matrix*A*.

A group of expert establishes the relative importance of the parameter with respect to each other. The extent to which these parameters affect the carvability is recommended in ranking form by group of experts. This information is sought in terms of a ratio. Information on all such pair-wise comparisons is stored in a matrix called as relative importance matrix, A, which is n× n matrix. Here a_{ij} will contain the relative importance of *ith* attribute over the *jth* attribute. The symmetric terms of this matrix will be reciprocals of each other while the diagonal will be unity. The information stored in A matrix is on pair-wise basis.

For example value 1 in matrix A shows given to the relative importance of hardness with respect to hardness and 1.125 shows relative importance of hardness with respect to modulus of rupture and so on.

$$A = \begin{bmatrix} Hardness & MOR & Specific\ gravity & volumetric\ shrinkage & MCS & MOE \\ 1 & 1.125 & 3 & 1.2857 & 4.5 & 1.8 \\ 0.8889 & 1 & 2.667 & 1.1429 & 4 & 1.6 \\ 0.3333 & 0.3750 & 1 & 0.4286 & 1.5 & 0.6 \\ 0.7778 & 0.8750 & 2.333 & 1 & 3.5 & 1.4 \\ 0.2222 & 0.25 & 0.667 & 0.2857 & 1 & 0.4 \\ 0.5556 & 0.6250 & 1.667 & 0.7143 & 2.5 & 1 \end{bmatrix}$$

Step 4 Finding out the maximum Eigen value of the relative importance matrix A

It is to be modified into representation that gives the relative weights of all attributes taken together so that the cumulative sum of the weights is equal to unity. The eigen vector method, which allows for some inconsistencies in the judgment of relative importance of attributes while making pair-wise comparisons is used to find the weights.

$$(A - \lambda_{max}\ I) = \begin{bmatrix} -4.9648 & 1.125 & 3 & 1.2587 & 4.5 & 1.8 \\ 0.8889 & -4.9648 & -2.667 & 1.1429 & 4 & 1.6 \\ 0.3333 & 0.3750 & -4.9648 & 0.4286 & 1.5 & 0.6 \\ 0.7778 & 0.8750 & 2.333 & -4.9648 & 3 & 1.4 \\ 0.2222 & 0.25 & 0.667 & 0.2857 & -4.9648 & 0.4 \\ 0.5556 & 0.625 & 1.667 & 0.7143 & 2.5 & -4.9648 \end{bmatrix}$$

Further, $(A - \lambda_{max}\ I).w = 0$

$$\begin{bmatrix} -4.9648 & 1.125 & 3 & 1.2587 & 4.5 & 1.8 \\ 0.8889 & -4.9648 & -2.667 & 1.1429 & 4 & 1.6 \\ 0.3333 & 0.3750 & -4.9648 & 0.4286 & 1.5 & 0.6 \\ 0.7778 & 0.8750 & 2.333 & -4.9648 & 3 & 1.4 \\ 0.2222 & 0.25 & 0.667 & 0.2857 & -4.9648 & 0.4 \\ 0.5556 & 0.625 & 1.667 & 0.7143 & 2.5 & -4.9648 \end{bmatrix} \times \begin{bmatrix} w1 \\ w2 \\ w3 \\ w4 \\ w5 \\ w6 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Also, $\sum_{i=1}^{n} w_i = 1$

We got

$$\begin{bmatrix} w1 \\ w2 \\ w3 \\ w4 \\ w5 \\ w6 \end{bmatrix} = \begin{bmatrix} 0.2647 \\ 0.2353 \\ 0.0882 \\ 0.2059 \\ 0.0588 \\ 0.1471 \end{bmatrix}$$

Step 5.Calculating the weighted normalized specification matrix

The weights obtained from the relative importance matrix have to be applied to the normalized specifications since all attributes have different levels of importance while selecting the wood for CNC wood carving. The matrix, which combines the relative weights and normalized specification of the candidates, is called as weighted normalized matrix, V. It will give the true comparable values of the attributes.

[V]= [N]×[W]

$$V = \begin{bmatrix} 0.054 & 0.093 & 0.026 & 0.024 & 0.025 & 0.066 \\ 0.168 & 0.097 & 0.042 & 0.064 & 0.026 & 0.061 \\ 0.123 & 0.127 & 0.040 & 0.068 & 0.031 & 0.084 \\ 0.086 & 0.120 & 0.041 & 0.138 & 0.025 & 0.054 \\ 0.082 & 0.033 & 0.031 & 0.093 & 0.013 & 0.018 \\ 0.0975 & 0.076 & 0.033 & 0.074 & 0.019 & 0.056 \end{bmatrix}$$

This weighted normalized specification matrix is all- inclusive matrix, which takes care of the parameter values and their relative importance

Step6. TOPSIS method for ranking

The TOPSIS method is based on the concept that the chosen option (optimum) should have the shortest distance from the +ive benchmark wood (best possible wood) and be farthest from the -ive benchmark wood (worst possible wood).

$V_i^* = \{[{}_{j=1;i=1,m}^{max} v(i,j)], [{}_{j=2;i=1,m}^{max} v(i,j)], \dots \dots . [{}_{j=n;i=1,m}^{max} v(i,j)]\}$

$V_i^- = \{[{}_{j=1;i=1,m}^{min} v(i,j)], [{}_{j=2;i=1,m}^{min} v(i,j)], \dots \dots . [{}_{j=n;i=1,m}^{min} v(i,j)]\}$

V^{*T}= [0.1685, 0.1270, 0.0416, 0.1380, 0.0314, 0.0841]

V^{-T}= [0.0540, 0.0332, 0.0264, 0.0237, 0.0127, 0.0184

Here, we calculate separation measures from +ive and -ive benchmark wood species, is given as respectively, as

$$\begin{bmatrix} S_1^* \\ S_2^* \\ S_3^* \\ S_4^* \\ S_5^* \\ S_6^* \end{bmatrix} = \begin{bmatrix} 0.1670 \\ 0.8370 \\ 0.0835 \\ 0.0885 \\ 0.1519 \\ 0.1129 \end{bmatrix}$$

and

$$\begin{bmatrix} S_1^- \\ S_2^- \\ S_3^- \\ S_4^- \\ S_5^- \\ S_6^- \end{bmatrix} = \begin{bmatrix} 0.077 \\ 0.145 \\ 0.143 \\ 0.152 \\ 0.075 \\ 0.088 \end{bmatrix}$$

Step 7 Relative closeness to the ideal solution

Then the relative closeness to the +ive benchmark wood, C^*, which is a measure of the suitability of the wood for the chosen application on the basis of attributes considered, is calculated. A wood with the largest C^* is preferable. Below are the values of closeness ratios for 16 alternatives. Least values of closeness indices will not be preferred at all.

$$C_i^* = \frac{S_n}{(S_b + S_n)}$$

C_1^*=0.3177

C_2^*= 0.6355

C_3^*=0.6311

C_4^*=0.6323

C_5^*=0.3295

C_6^*= 0.438

C_2^* Has largest value and C_1^* has least value. So wood A. auriculiformis is most preferable and Redwood is least preferred. So it can be concluded that for given 6 properties of wood, A. auriculiformis will give best surface finish, while redwood will give poor surface finish during automated wood carving by using CNC router.

CHAPTER 5

MADM APPROACH FOR RANKING OF AVAILABLE INDIAN WOOD VARIETIES

Similar study has been conducted on locally available wood species to rank them for good carvability in 3D machining. In this chapter, attributes on the basis of which the ranking is to be done have been first evaluated experimentally. This is followed by application of MADM approach for ranking of these wooden species. Values of different required parameters have been found out experimentally as discusses below:

5.1 CUTTING OF SAMPLES FROM LARGE LOG OF WOOD

The testing of wooden samples for different parameters are found using techniques like rockwell Hardness testing, tensile testing and flexural testing etc. Although there are different requirement of size and shape for different experiments, but there should not be any defects like Warp, Knot etc. in the specimen being tested

From large piece of logs, small samples for our experimental work. Details about all sizes of wood are discussed in following section.

Figure 5.1: Logs of different wooden samples

There are different types of machines which would be used for cutting large logs of wooden samples. Also after process of sawing of wood has been performed, planing of wood samples would be done in order to meet the requirements of various testing processes.

5.1.1 Band Saw

Timber mills use very large band saws for cutting lumber. They are preferred over circular saws for cutting because they can accommodate large-diameter timber and because of their smaller kerfs (cut size), resulting in less waste.

5.1.2 Circular saw

In circular saw, the wood to be cut is securely clamped or held in a vice and the saw is advanced slowly across it. In variants such as the table saw, the saw is fixed and wood is slowly moved into the saw blade.

5.1.3 Wood planer

A thickness/wood planer is used to reduce thickness on a table saw and clean the edges with the jointer. This process is lot simpler and safer. The wood planer has a rotating cylindrical cutting head that contains from 2-3 dual sided removable blades.

5.2 HARDNESS OF VARIOUS SAMPLES OF INDIAN WOODS

Samples of wood are taken for testing of hardness using rockwell hardness testing machine. The indenter used a steel ball with dia of 1/16” inch diameter and a load 100 kg is applied. Values of Hardness are obtained in units of HRB. 13 wooden samples of size (3cm×2.5cm×2 cm) are taken. Hardness of samples indented at three different locations was measured, recorded and averaged as shown in table 5.1. This has been done to avoid local variations in the property.

Values obtained after performing the experiments are as follow**:**

Table 5.1: Hardness of different wooden samples

S. No.	Type of wood	Hardness (HRB)			Average hardness (HRB)
		Reading 1	Reading 2	Reading 3	
1	Mango	**54.9**	**52.5**	**55**	**54.13**
2	Neem	**54.5**	**54.6**	**55.5**	**54.86**
3	Imported Teak	**52**	**58**	**55**	**55**
4	Babool	**53.5**	**56**	**54.6**	**54.7**
5	Jamoha	**55**	**57.5**	**55**	**54.5**
6	Dake	**55.2**	**47.3**	**49.2**	**50.57**
7	Kikar	**54**	**57.5**	**56.2**	**55.9**
8	Ccally	**54**	**55.5**	**55**	**54.83**
9	Maple	**59**	**58**	**58**	**58.33**

10	Pine	**51**	**51**	**49**	**50.3**
11	M.P.Teak	**58**	**61**	**58**	**59**
12	Sheesham	**53**	**58**	**57**	**56**
13	Assam Teak	**58**	**55**	**58**	**57**

It was observed that value of hardness of M.P.Teak is found to be highest (59 HRB) and for pine it is lowest (50.3 HRB) out of these 13 wooden samples. It also means that M.P.Teak will show maximum resistance to indentation and Pine wood will show least resistance to indentation

5.3 MOISTURE CONTENT OF WOOD

Moisture content of wood is defined as the weight of water in wood expressed as a fraction of the weight of oven-dry wood. Weight, volumetric shrinkage, strength, and other mechanical properties depend upon the moisture content of wood. Moisture content of wood is calculated using baking oven machine. Sample sizes (3cm×2cm×2.5 cm) have been prepared for all wooden varieties. Initial weight of these specimens has been recorded. It is termed as "green weight". Subsequently these specimens were put in oven (at 103°C) for 24-48 hours. Then these dried specimens have been taken out and again weighed using a weighing machine. This is termed as "oven dry weight". Moisture content has been computed using following formula:

$$\mathbf{MC}=\frac{\boldsymbol{GREEN\ WEIGHT-OVEN\ DRY\ WEIGHT(AT\ 103°\ C)}}{\boldsymbol{OVEN\ DRY\ \ WEIGHT\ AT\ (103°\ C)}}$$

Table 5.2: Weights of all 13 wood species in this pre-drying and post drying conditions

S. No.	Type of wood	Green weight (g) (1)	Oven Dry weight (at 103° C) (g) (2)	MOISTURE CONTENT = $\frac{(1)-(2)}{(2)}$ (%)
1	Mango	10.12g	9.27 g	9.2 %
2	Neem	9.42 g	8.56 g	10 %
3	Imported Teak	8.73 g	7.96 g	9.7 %
4	Babool	12.33 g	11.21 g	10 %
5	Jamoha	11.51 g	10.40 g	10.7 %
6	Dake	9.52 g	8.66 g	10 %
7	Kikar	13.53 g	12.34 g	9.6 %
8	Ccally	11.52 g	11.21 g	8.9 %

9	Maple	8.19 g	7.69 g	6.5
10	Pine	6.32 g	5.93 g	6.6 %
11	M.P.Teak	9.89 g	9.36g	5.7%
12	Sheesham	12.63 g	12.03 g	5 %
13	Assam Teak	9.48 g	8.84 g	7.2

Now values obtained above also establish fact that moisture content should be between 5 to 10.8 % which has already been mentioned in [30]. Jamoha is getting maximum moisture content (10.7 %) and Sheesham have least moisture content (5 %).

5.4 SPECIFIC GRAVITY

Specific gravity of wood is calculated using the following procedure:

- Cut the different wooden species in size of approximate (3cm×2cm×2.5cm).
- Volume of each wooden sample is calculated
- Then wood samples are placed in an oven baking machine for about 24 hours at 103°C and then their weights were measured.
- Density of wood and specific gravity of wood is calculated with following formula:

$$Density = \frac{Mass}{Volume}$$

And

$$Specific\ gravity = \frac{Density\ of\ wood}{Density\ of\ water}$$

Table 5.3: Specific gravity of different wooden samples

S. No.	Type of wood	Sample Dimensions (L×B ×H) m^3			Volume (m^3)	Mass (kg)	Density (kg/m^3)	Specific gravity
1	Mango	0.03	0.027	0.021	0.00001701	0.00927	544.17	0.544
2	Neem	0.03	0.025	0.02	0.000015	0.00856	570.66	0.571
3	Imported Teak	0.03	0.026	0.02	0.0000156	0.00796	510.26	0.510
4	Babool	0.03	0.0265	0.021	0.000016695	0.01121	671.46	0.671
5	Jamoha	0.03	0.026	0.02	0.0000156	0.01040	666.66	0.666
6	Dake	0.03	0.027	0.02	0.0000162	0.00866	534.56	0.535
7	Kikar	0.03	0.027	0.02	0.0000162	0.01234	761.73	0.761
8	Ccally	0.03	0.026	0.021	0.00001638	0.01121	684.37	0.684
9	Maple	0.03	0.025	0.018	0.0000135	0.00593	569.62	0.569

10	Pine	0.03	0.025	0.02	0.000015	0.00593	395.33	0.395
11	M.P.teak	0.03	0.025	0.02	0.000015	0.00936	624.00	0.624
12	Sheesham	0.03	0.025	0.019	0.00001425	0.01203	844.20	0.844
13	Assam Teak	0.0308	0.025	0.02	0.0000154	0.00884	574.03	0.574

From the results, it was obtained that Sheesham has maximum value of specific gravity (0.844) and Imported teak has minimum value of specific gravity (0.510). Sheesham has highest value of density relative to density of water as compared to other woods.

5.5 TENSILE AND FLEXURAL TESTING

All these tests have been carried out on wood species for finding out properties like maximum crushing strength, modulus of rupture and modulus of elasticity.

5.5.1 Universal testing machine

A universal testing machine (ZWICK ROELL UTM shown in Figure 5.2) has been used to test the tensile strength, flexural strength and compressive strength of wooden species. Important components of the universal testing machine are load frame, load cell, cross head etc. Load frame consists of two strong supports for the machine. In load cell, a force transducer or other means of measuring the load is used. A movable cross head (crosshead) is handled to move up or down at a constant speed which also sometimes called a constant rate of extension (CRE) machine. Extensometers are sometimes used for measurement of the response of the test specimen to the movement of the cross head. It provides output of the test result when needed with help of dial or digital displays and chart recorders. But nowadays, many newer machines are using computer interface for printing and analyzing. Capacity of ZWICK-ROELL UTM machine is 100 KN.

Figure 5.2: ZWICK ROELL universal testing machine

5.5.2 Specimen details for flexural testing

Specimen had been cut and prepared as per DIN 52186 standard for flexural test and ISO 1924-1/2 standard was used for tensile testing. The dimensions of specimen are as shown below in table 5.4 for different tests. Figure 5.3 shows pictures of flexural test specimen and tensile test specimen.

Table 5.4: Specimen details for testing

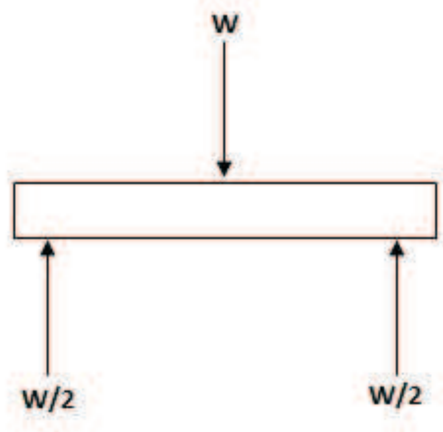
Parameters for specimen	Specimen for tensile testing	Specimen for flexural testing
Length (mm)	150	100
Width(mm)	25	5
Thickness(mm)	3	5

(a) **(b)**

Figure 5.3: Specimen shape for (a) flexural testing, (b) tensile testing

5.5.3 Flexural Testing

The test specimen has been prepared according to DIN 52186 standards. Fig 5.4 shows a figure depicting the flexure test of a wooden specimen in which wooden sample is placed between two non movable jaws. The force is applied at the mid span in a direction perpendicular to the direction of grains of wood as shown in figure 5.4(b).

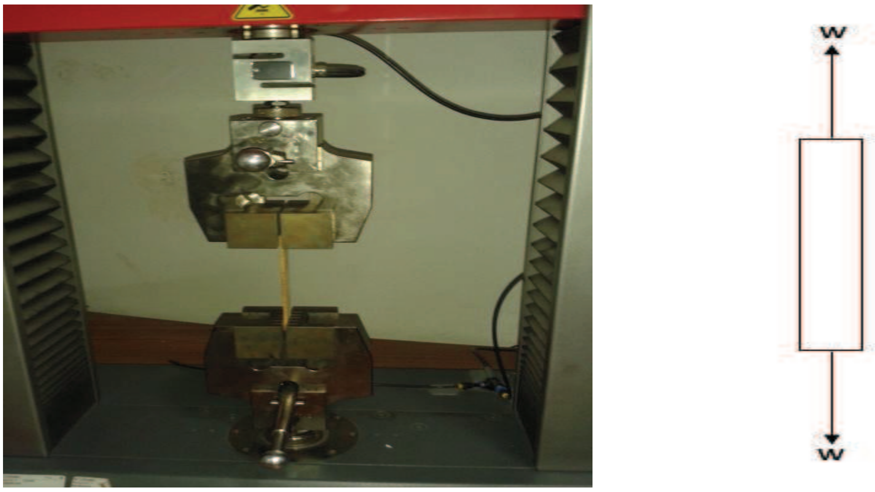


(a) **(b)**

Figure 5.4: (a) Flexural test of a wooden sample, (b) direction of forces perpendicular to the direction of grain

5.5.4 Tensile Testing

The preparation of specimen had been done according to ISO 1924-1/2 standard. The test on specimen is carried out until they break indicating the peak load and ultimate stress value. Figure 5.5(a) shows the tensile test of a wooden specimen in which wooden sample is placed between one movable and one stationary jaw. The direction of force is acting in parallel direction as shown in Figure 5.5(b). After that according to ISO 1924-1/2standard, process was performed and values are found out.



(a) (b)

Figure 5.5: (a) Tensile testing of wooden sample, (b) direction of forces acting parallel to the direction of grain

5.5.5 Compressive strength testing

In the compressive strength testing, Loads are applied till the limits of the strength are reached and the materials break. A Universal testing machine (HUNG Ta Instrument Go., Ltd UTM) was used in order to find out values of maximum load. It is fully computerized servo controlled universal testing machine, with 1000 KN capacity. A load rate of 100 KN/minute is applied. Fig 5.6(a) shows the test procedure used for calculating maximum compressive strength, in which a force is perpendicular to the direction of grains parallel to wood as shown in Figure 5.6(b).

(a) (b)

Figure 5.6: (a) Compressive strength test of a wooden sample, (b) direction of force acting parallel to the grain

5.6 MODULUS OF RUPTURE

It is a maximum load-carrying capacity of a member in bending, and is proportional to maximum moment borne by the specimen. For this test, specimen of 100 mm length is supported on both sides with distance of 15mm. So effective length is 70 mm. Flexural tests were performed using universal testing machine already explained above in section 5.5. Formula for calculating modulus of rupture has been given below:

Modulus of rupture = $\frac{\mathbf{1.5 \times Maximum\ load\ applied \times Effective\ length}}{\boldsymbol{Breadth \times thickness^2}}$

Table 5.5: Modulus of rupture of different samples of woods

S. No.	Type Of Wood	Maximum load applied(N)	Effective Length (mm)	Breadth $\times$width^2 (mm^3)	Modulus of rupture (MPa)
1	Mango	220	70	216	106.94
2	Neem	124	70	216	60.28
3	Imported Teak	144	70	216	70
4	Babool	127	70	216	61.74
5	Jamoha	101	70	216	49.10
6	Dake	146	70	216	70.97
7	Kikar	258	70	216	125.42
8	Ccally	122	70	216	59.31
9	Maple	260	70	216	126.39
10	Pine	107	70	216	52.01
11	M.p. Teak	181	70	216	87.99
12	Sheesham	158	70	216	76.81
13	Assam Teak	124	70	216	60.28

From the results obtained above, Maple has maximum value of modulus of rupture (126.39 MPa) and Jamoha is having least modulus of rupture (49.10 MPa).

5.7 MODULUS OF ELASTICITY

Modulus of elasticity is defined as a measure of how a material or structure will deform and strain when placed under tensile stress.

Table 5.6: Modulus of elasticity of different samples of woods

S. No.	Type Of Wood	Modulus of Elasticity(MPa)
1	Mango	11300
2	Neem	11200
3	Imported Teak	10340
4	Babool	13200
5	Jamoha	11000
6	Dake	8200
7	Kikar	15600
8	Ccally	12300
9	Maple	12600
10	Pine	9400
11	M.p. Teak	13900
12	Sheesham	13700
13	Assam Teak	11500

Kikar has been found to have maximum value of modulus of elasticity (15600 MPa) and Dake has least value of Modulus of elasticity (8200 MPa).

5.8 MAXIMUM CRUSHING STRENGTH

Maximum crushing strength of wood is the capacity of a material or structure to withstand axially directed pushing forces. It is the maximum stress that a material can sustain under crush loading. A sample size of (10.6cm×2.6cm×6.2cm) is taken. It can be calculated by using following formula:

Maximum crushing strength= $\frac{maximumloadapplied}{lengt\ h * breadt\ h}$

Table 5.7: Maximum crushing strength of different samples of woods

S. No.	Wood type	Load (N)	Length(mm)	Breadth(mm)	Maximum crushing strength (N/mm^2)
1	Mango	70345	62	26	43.64
2	Neem	45540	59	26	26.69
3	Imported Teak	60235	67	27	33.30
4	Babool	47160	62	26	29.25

5	Jamoha	42460	62	26	26.34
6	Dake	56430	62	26	35.00
7	Kikar	89695	62	26	55.64
8	Ccally	37100	62	26	23.01
9	Maple	39055	62	18	35.00
10	Pine	39125	62	26	24.30
11	M.P. Teak	62015	62	26	38.47
12	Sheesham	43050	62	26	26.70
13	Assam Teak	42480	62	26	26.35

It was concluded that Kikar has maximum value of maximum crushing strength (55.64) and Ccally has least value of maximum crushing strength (23.01).

5.9 VOLUMETRIC SHRINKAGE OF WOOD

Volumetric shrinkage of wood is defined as a reduction in overall volume of a piece of wood, when it is dried. This reduction is very slight along the grain, but a reduction of 5 to 6% in volume is common for dry flat-sawn boards. Following formula has been used for volumetric shrinkage of wood:

Volumetric Shrinkage= $\frac{\text{Original volume} - \text{volume after drying}}{\text{Original volume}}$

Table 5.8: Volumetric Shrinkage of different samples of woods

S. No.	Type Of Wood	Original volume (cm^3)	Volume after drying(cm^3)	Volumetric shrinkage (%)
1	Mango	17.95	17.01	5.2
2	Neem	16.695	15	10.1
3	Imported Teak	16.38	15.6	4.8
4	Babool	17.82	16.695	6.3
5	Jamoha	17.01	15.6	8.3
6	Dake	17.415	16.2	7
7	Kikar	18.228	16.2	11.1
8	Ccally	17.01	16.38	3.7
9	Maple	14.82	13.85	6.5
10	Pine	15.75	15	4.8
11	M.P.Teak	15.6	15	4
12	Sheesham	15	14.25	5

13	Assam Teak	16.4	15.4	6.1

Kikar has been found to have maximum volumetric shrinkage and ccally have least value of volumetric shrinkage. It also means that Kikar will have maximum tendency to shrink volumetrically, when it gets dried quickly.

5.10 MADM –TOPSIS APPROACH ON INDIAN WOODS

The studies of thirteen locally available species of woods are done experimentally with the methods which are already explained above. We basically took 13 different Indian wooden species and found out following six properties which mostly affect the 3-D machining. Then MADM-TOPSIS approach is used to found out best possible solution.

Table no.5.9: Showing values of different properties of 13 different samples of Indian woods

Parameters / Woods	Specific Gravity (kg/m^3)	Volumetric Shrinkage (%)	Maximum crushing strength (MPa)	Modulus of Rupture (MPa)	Modulus of Elasticity (MPa)	Hardness (HRB)
Mango	0.544	5.2	43.64	106.94	11300	54.13
Neem	0.571	10.1	26.69	60.28	11200	54.86
Imported Teak	0.51	4.8	33.3	70	10340	55
Babool	0.671	6.3	29.25	61.74	13200	54.7
Jamoha	0.666	8.3	26.34	49.10	11000	54.5
Dake	0.535	7	35	70.97	8200	50.57
Kikar	0.761	11.1	55.64	125.42	15600	55.9
Ccally	0.684	3.7	23.01	59.31	12300	54.83
Maple	0.569	6.5	35	126.39	12600	58.33
Pine	0.395	4.8	24.3	52.01	9400	50.3
M.P.teak	0.624	4	38.47	87.99	13900	59
Sheesham	0.844	5	26.7	76.81	13700	56
Assam teak	0.574	6.1	26.35	60.28	11500	57

Table 5.9 shows important properties of the selected species. Following steps of MADM approach have been incorporated to rank these available woods.

Step 1 Formation of Decision matrix, *D*, it is that matrix which will contain all magnitudes of specifications. The rows of matrix are type of wood piece material i.e. Maple, Pine, Sheesham, Assam teak and M.P. teak and column represent performance parameters i.e. Hardness, Modulus of rupture, specific gravity, Maximum crushing strength and modulus of elasticity.

$$D = \begin{bmatrix} 0.544 & 5.2 & 43.64 & 106.94 & 11300 & 54.13 \\ 0.571 & 10.1 & 26.69 & 60.28 & 11200 & 54.86 \\ 0.51 & 4.8 & 33.30 & 70.00 & 10340 & 55 \\ 0.671 & 6.3 & 29.25 & 61.74 & 13200 & 54.7 \\ 0.666 & 8.3 & 26.34 & 49.10 & 11000 & 54.5 \\ 0.535 & 7 & 35.00 & 70.97 & 8200 & 50.57 \\ 0.761 & 11.1 & 55.64 & 125.42 & 15600 & 55.9 \\ 0.684 & 3.7 & 23.01 & 59.31 & 12300 & 54.83 \\ 0.569 & 6.5 & 35.00 & 126.39 & 12600 & 58.33 \\ 0.395 & 4.8 & 24.30 & 52.01 & 9400 & 50.3 \\ 0.624 & 4 & 38.47 & 87.99 & 13900 & 59 \\ 0.844 & 5 & 26.70 & 76.88 & 13700 & 56 \\ 0.574 & 6.1 & 26.35 & 60.28 & 11500 & 57 \end{bmatrix}$$

Step 2 Calculation of the normalized specification matrix. This normalization helps to provide the dimensionless elements of the matrix in the 0-1 range. It is a sort of value, which indicates the standing of that particular attribute magnitude when compared to the whole range of the magnitudes for all candidate woods.

$$n_{i,j} = \frac{d_{ij}}{\sqrt{\sum_{i=1}^{m} d_{ij}^2}}$$

$$\mathbf{N} = \begin{bmatrix} 0.243 & 0.214 & 0.358 & 0.364 & 0.262 & 0.273 \\ 0.255 & 0.416 & 0.219 & 0.205 & 0.258 & 0.276 \\ 0.228 & 0.198 & 0.273 & 0.238 & 0.239 & 0.277 \\ 0.299 & 0.259 & 0.240 & 0.210 & 0.305 & 0.276 \\ 0.297 & 0.342 & 0.216 & 0.167 & 0.254 & 0.275 \\ 0.239 & 0.288 & 0.287 & 0.241 & 0.189 & 0.255 \\ 0.340 & 0.457 & 0.457 & 0.427 & 0.360 & 0.282 \\ 0.305 & 0.152 & 0.189 & 0.202 & 0.284 & 0.276 \\ 0.254 & 0.268 & 0.287 & 0.430 & 0.291 & 0.294 \\ 0.176 & 0.198 & 0.200 & 0.177 & 0.217 & 0.253 \\ 0.279 & 0.165 & 0.316 & 0.299 & 0.321 & 0.297 \\ 0.377 & 0.206 & 0.219 & 0.261 & 0.316 & 0.282 \\ 0.256 & 0.251 & 0.216 & 0.205 & 0.265 & 0.287 \end{bmatrix}$$

Step 3 Construction of a relative importance matrix *A*.

A group of expert establishes the relative importance of the parameter with respect to each other. The extent to which these parameters affect the carvability is recommended in ranking form by group of experts. This information is sought in terms of a ratio. Information on all such pair-wise comparisons is stored in a matrix called as relative importance matrix, *A*, which is n× n matrix. Here a_{ij} will contain the relative importance of *ith* attribute over the *jth* attribute. The symmetric terms of this matrix will be reciprocals of each other while the diagonal will be unity. The information stored in A matrix is on pair-wise basis.

For example value 1 in matrix A shows given to the relative importance of hardness with respect to hardness and 1.125 shows relative importance of hardness with respect to modulus of rupture and so on.

$$A = \begin{bmatrix} Hardness & MOR & Specific\ gravity & volumetric\ shrinkage & MCS & MOE \\ 1 & 1.125 & 3 & 1.2857 & 4.5 & 1.8 \\ 0.8889 & 1 & 2.667 & 1.1429 & 4 & 1.6 \\ 0.3333 & 0.3750 & 1 & 0.4286 & 1.5 & 0.6 \\ 0.7778 & 0.8750 & 2.333 & 1 & 3.5 & 1.4 \\ 0.2222 & 0.25 & 0.667 & 0.2857 & 1 & 0.4 \\ 0.5556 & 0.6250 & 1.667 & 0.7143 & 2.5 & 1 \end{bmatrix}$$

Step 4 Finding out the maximum Eigen value of the relative importance matrix A

It is to be modified into representation that gives the relative weights of all attributes taken together so that the cumulative sum of the weights is equal to unity. The eigen vector method, which allows for some inconsistencies in the judgment of relative importance of attributes while making pair-wise comparisons is used to find the weights.

$$(A - \lambda_{max}\, I) = \begin{bmatrix} -4.9648 & 1.125 & 3 & 1.2587 & 4.5 & 1.8 \\ 0.8889 & -4.9648 & -2.667 & 1.1429 & 4 & 1.6 \\ 0.3333 & 0.3750 & -4.9648 & 0.4286 & 1.5 & 0.6 \\ 0.7778 & 0.8750 & 2.333 & -4.9648 & 3 & 1.4 \\ 0.2222 & 0.25 & 0.667 & 0.2857 & -4.9648 & 0.4 \\ 0.5556 & 0.625 & 1.667 & 0.7143 & 2.5 & -4.9648 \end{bmatrix}$$

Further, $(A - \lambda_{max}\, I).w = 0$

$$\begin{bmatrix} -4.9648 & 1.125 & 3 & 1.2587 & 4.5 & 1.8 \\ 0.8889 & -4.9648 & -2.667 & 1.1429 & 4 & 1.6 \\ 0.3333 & 0.3750 & -4.9648 & 0.4286 & 1.5 & 0.6 \\ 0.7778 & 0.8750 & 2.333 & -4.9648 & 3 & 1.4 \\ 0.2222 & 0.25 & 0.667 & 0.2857 & -4.9648 & 0.4 \\ 0.5556 & 0.625 & 1.667 & 0.7143 & 2.5 & -4.9648 \end{bmatrix} \times \begin{bmatrix} w1 \\ w2 \\ w3 \\ w4 \\ w5 \\ w6 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Also, $\sum_{i=1}^{n} w_i = 1$, we got

$$\begin{bmatrix} w1 \\ w2 \\ w3 \\ w4 \\ w5 \\ w6 \end{bmatrix} = \begin{bmatrix} 0.2647 \\ 0.2353 \\ 0.0882 \\ 0.2059 \\ 0.0588 \\ 0.1471 \end{bmatrix}$$

Step 5 Calculation of the weighted normalized specification matrix

The weights obtained from the relative importance matrix have to be applied to the normalized specifications since all attributes have different levels of importance while selecting the wood for CNC wood carving. The matrix, which combines the relative weights and normalized specification of the candidates, is called as weighted normalized matrix, V. It will give the true comparable values of the attributes.

$[\mathrm{V}] = [\mathrm{N}] \times [\mathrm{W}]$

$$V = \begin{bmatrix} 0.064 & 0.050 & 0.032 & 0.075 & 0.015 & 0.040 \\ 0.067 & 0.098 & 0.019 & 0.042 & 0.015 & 0.041 \\ 0.060 & 0.046 & 0.024 & 0.049 & 0.014 & 0.041 \\ 0.079 & 0.061 & 0.021 & 0.043 & 0.018 & 0.040 \\ 0.079 & 0.080 & 0.019 & 0.034 & 0.015 & 0.040 \\ 0.063 & 0.067 & 0.025 & 0.050 & 0.011 & 0.037 \\ 0.090 & 0.107 & 0.040 & 0.088 & 0.021 & 0.041 \\ 0.081 & 0.035 & 0.017 & 0.041 & 0.017 & 0.041 \\ 0.067 & 0.063 & 0.025 & 0.088 & 0.017 & 0.043 \\ 0.047 & 0.046 & 0.018 & 0.036 & 0.013 & 0.037 \\ 0.074 & 0.039 & 0.028 & 0.062 & 0.019 & 0.044 \\ 0.100 & 0.048 & 0.019 & 0.054 & 0.018 & 0.041 \\ 0.068 & 0.059 & 0.019 & 0.042 & 0.015 & 0.042 \end{bmatrix}$$

This weighted normalized specification matrix is all- inclusive matrix, which takes care of the parameter values and their relative importance.

Step 6 TOPSIS method for ranking

The TOPSIS method is based on the concept that the chosen option (optimum) should have the shortest distance from the +ve benchmark wood (best possible wood) and be farthest from the -ve benchmark wood (worst possible wood).

$V_i^* = \{[{}_{j=1;i=1,m}^{max} v(i,j)], [{}_{j=2;i=1,m}^{max} v(i,j)], \ldots\ldots [{}_{j=n;i=1,m}^{max} v(i,j)]\}$

$V_i^- = \{[{}_{j=1;i=1,m}^{min} v(i,j)], [{}_{j=2;i=1,m}^{min} v(i,j)], \ldots\ldots [{}_{j=n;i=1,m}^{min} v(i,j)]\}$

V^{*T}= [0.0997, 0.1075, 0.0403, 0.0885, 0.0212, 0.0437]

V^{-T}= [0.0467, 0.0358, 0.0167, 0.0344, 0.0111, 0.037]

Here, we calculate separation measures from +ive and -ive benchmark wood species, is given as respectively, as

S_i^*= {0.069, 0.061, 0.085, 0.071, 0.068, 0.069, 0.100, 0.091, 0.057, 0.099, 0.079, 0.071, 0.077}

S_i^-= {0.049, 0.066, 0.024, 0.043, 0.055, 0.040, 0.103, 0.035, 0.065, 0.011, 0.041, 0.059, 0.033}

Step 7 Relative closeness to the ideal solution

Then the relative closeness to the +ive benchmark wood, C^*, which is a measure of the suitability of the wood for the chosen application on the basis of attributes considered, is calculated. A wood with the largest C^* is preferable. Below are the values of closeness ratios for 16 alternatives. Least values of closeness indices will not be preferred at all

$$C_i^* = \frac{S_n}{(S_b + S_n)}$$

C_1= 0.41 C_2=0.52 C_3=0.22 C_4=0.38 C_5=0.45

C_6=0.37 C_7=0.91 C_8=0.28 C_9=0.53 C_{10}=0.1

C_{11}=0.34 C_{12}=0.45 C_{13}=0.30

So as obtained from the results, values of closeness ratio of different species of wood are given in Table 5.3

Table 5.3: Different values closeness ratios of Indian wooden species

S. No.	Type Of Wood	Closeness ratio
1	Mango	0.41
2	Neem	0.52
3	Imported Teak	0.22
4	Babool	0.38
5	Jamoha	0.45
6	Dake	0.37
7	Kikar	0.91
8	Ccally	0.28
9	Maple	0.53
10	Pine	0.1
11	M.p. Teak	0.34
12	Sheesham	0.45
13	Assam Teak	0.30

Value of C_7 is highest, while value C_3 of is lowest. Therefore, Kikar is most preferable wood and least preferred will be M.P.Teak. But Kikar will not be used for carving, instead Maple which is 2nd most preferable, because of its better grain orientation and less number of defects like warp, collapse etc. occurring in it. Hence Maple will give maximum surface finish during CNC automated carving, while M.P.Teak would be having poor surface machining characteristics.

CHAPTER 6

CONCLUSIONS AND FUTURE SCOPE OF WORK

6.1 CONCLUSION OF PRESENT WORK

In the present work a detailed study for the design development and evaluation has been done. It was apparent from the results that the evaluation of best wood on the basis of MADM-TOPSIS is Kikar. MADM-TOPSIS approach followed for optimum selection of wood species has many advantages like Quantification and measurement of the attributes, usefulness to the manufacturer, user, designer and maintenance personnel. The conclusions drawn from the present study are as follows:

(i) MADM-TOPSIS method is suitable for finding the best alternatives.

(ii) Kikar is found out from the study, best wood out of 13 woods for surface 3-D axis machining.

(iii)Some international wood samples were studied and MADM-TOPSIS approach was applied to found out suitable wood species for same application.

(iv) From the Tensile, Flexural and compression tests, Kikar was found maximum modulus of elasticity and maximum crushing strength and Maple had maximum modulus of rupture. rockwell hardness test was conducted on different wood samples, from the result M.P. Teak had maximum value of hardness.

(v) It was seen from the approach that A. auriculiformis was found to have same properties as that of Kikar. So it was concluded that Kikar can be used in place of A. auriculiformis on the basis that it has less cost

6.2 FUTURE SCOPE OF WORK

The present work has been more focused towards MULTIPLE ATTRBUTE DECISION MAKING analysis for the surface machining of wooden species. A lot of work can be carried out for the further refinements of the work carried out in this dissertation work as listed below:

(i) With help of MADM-TOPSIS approach, we can also extend our study to large number of wood varieties and with more new parameters.

(ii) From the results of MADM-TOPSIS approach, an exclusive data can be generated about list of different species of wood for industries which are more beneficial for ornamental carving or machining.

(iii) With the help of CNC dynamometer, cutting forces of various woods can be found out.

REFERENCES

[1] R. Gnanaharan and T.K. Dhamodaran, "Mechanical properties of rubberwood from a 35-year-old plantation in Central Kerala, India", *Journal of Tropical Forest Science*, vol.6 (2), pp.136-140, 1992.

[2] Florent Eyma, Pierre-Jean Meausoone and Patrick Martin, "Study of the properties of thirteen tropical wood species to improve the prediction of cutting forces in mode B", *Annals Forest Science*, vol.61, pp.55–64, 2004.

[3] A. Shanavas and B.M. Kumar, "Physical and mechanical properties of three agro forestry tree species from Kerala, India", *Journal of Tropical Agriculture*, vol.44 (1-2), pp.23-30, 2006.

[4] YueWang, Ikuho Lida and Kazuya Minato, "Mechanical properties of wood in an unstable state due to temperature changes, and analysis of the relevant mechanism IV: effect of chemical components on destabilization of wood", *Journal of wood Science*, vol.53, pp.31–38, 2007.

[5] S.R. Shukla, R.V. Rao, S.K. Sharma, P. Kumar, R. Sudheendra and S. Shashikala, "Physical and mechanical properties of plantation-grown Acacia auriculiformis of three different ages" *Australian Forestry*,vol.70 (2), pp.86–92, 2007.

[6] George I. Mantanis and Dimitrios Birbilis, "Physical and Mechanical properties of athel wood (tamarixaphylla)", pp.82-87.

[7] M. Hakan Akyildiz and Hamiyet Sahin Kol, "Some technological properties and uses of paulownia (Paulownia tomentosa Steud.) Wood", *Journal of Environmental Biology*, vol.31, pp.351-355, 2010.

[8] Trairat Neimsuwan and Nikhom Laemsak, "Anatomical and Mechanical Properties of the Bur-Flower Tree (Anthocephaluschinensis)", *Kasetsart J. (Nat. Sci.)*, vol.44, pp. 353 – 363, 2010.

[9] Mehraj A. Sheikh, Munesh Kumar and Jahangeer A. Bhat, "Wood specific gravity of some tree species in the Garhwal Himalayas", *India, Forest Studies of China*, vol.13(3), pp.225–230, 2011.

[10] Majid Kiaei and Ahmad Samariha, "Fiber dimensions, physical and mechanical properties of five important hardwood plants", *Indian Journal of Science and Technology*, vol.11, pp.1460-1463, 2011.

[11] Luis Cristavo, Inacio Lhate, Anders Gronlund, Mats Ekevad and Rui Sitoe, “Tool wear for lesser known tropical wood species”, *Wood Material Science and Engineering*, vol.6, pp.155-161, 2011.

[12] Artemio Carrillo, Miriam Garza, María De Jesus Nanez, Fortunato Garza, Rahim Foroughbakhch and Sadoth Sandoval, “Physical and mechanical wood properties of 14 timber species from Northeast Mexico”, *Annals of Forest Science*, vol.68, pp.675–679, 2011.

[13] P. K. Thulasidas and K. M. Bhat, “Mechanical properties and wood structure characteristics of 35-year old home-garden teak from wet and dry localities of Kerala, India in comparison with plantation teak”, *Journal of Indian Academy of Wood Science*, vol. 9, pp.23–32, 2012.

[14] Andrea Wechsler and Salim Hiziroglu, “Some of the properties of wood–plastic composites”, *Building and Environment*, vol.42, pp.2637–2644, 2007.

[15] Ergun Baysal, Mustafa Kemal Yalinkilic, Mustafa Altinok, Abdullah Sonmez, Huseyin Peker and Mehmet Colak, “Some physical, biological, mechanical, and fire properties of wood polymer composite (WPC) pretreated with boric acid and borax mixture” *Construction and Building Materials*, vol,21, pp.1879–1885, 2007.

[16] Yali Li, “Effect of Coupling Agent Concentration Fiber Content, and Size on Mechanical Properties of Wood/HDPE Composites”, *International Journal of Polymeric Materials*, vol.61, pp.882–890, 2011.

[17] Khandkar-Siddikur Rahman, Nazmul Alam D.M. and Md. Nazrul Islam, “Some Physical and Mechanical Properties of Bamboo Mat-Wood Veneer Plywood”, *ISCA Journal of Biological Science*s, vol.1 (2), pp. 61-64, 2012.

[18] Nazmul Alam D.M, Md. Nazrul Islam, Khandkar-Siddikur Rahman and Md. Rabiul Alam , “Comparative Study on Physical and Mechanical Properties of Plywood Produced from Eucalyptus (Eucalyptus camaldulensisDehn.) and Simul (BombaxceibaL.)Veneers”, *ISCA Research Journal of Recent Sciences*, vol.1 (9), pp 54-58, 2012.

[19] E. Obataya, T.Ono and M. Norimoto, “Vibrational properties of wood along the grain, *Journal of materials science*”, vol.35, pp.2993 – 3001, 2000.

[20] Julien Ruelle, Jacques Beauchene, Anne Thibaut and Bernard Thibaut, “Comparison of physical and mechanical properties of tension and opposite wood from ten tropical rainforest trees from different species”, *Annuals Forest Science,* vol.64, vol.503–510, 2007.

[21] FlorentEyma, Pierre-Jean Meausoone and Patrick Martin, “Strains and cutting forces involved in the solid wood rotating cutting process”, *Journal of Materials Processing Technology,* vol.148, pp.220–225, 2004.

[22] Murat Kilic, Salim Hiziroglu and Erol Burdurlu, “Effect of machining on surface roughness of wood”, *Building and Environment*, vol.41, pp.1074–1078, 2006.

[23] J. Lawrence Katz, Paulette Spencer, Yong Wang, Anil Misra, Orestes Marangos and Lisa Friis, “On the anisotropic elastic properties of woods”, *Journal of Material Science,* vol.43, pp.139–145, 2009.

[24] Iris Brémaud, Yves El Kaïm, Daniel Guibal, Kazuya Minato, Bernard Thibaut and Joseph Gril, “Characterisation and categorisation of the diversity in viscoelastic vibrational properties between 98 wood types”, *Annals of Forest Science* , vol.69, pp.373–386, 2012.

[25] P.P. Bhangale, V.P. Agrawal and S.K. Saha, “Attribute based specification, comparison and selection of a robot”, *Mechanism and Machine Theory*, vol.39, 1345–1366, 2004.

[26] Ruggero Donida Labati, Marco Gamassi, Vincenzo Piuri and Fabio Scotti, “A Low-cost Neural-based Approach for Wood Types Classification”, *International Conference on Computational Intelligence for Measurement Systems and Applications*, 2009.

[27] Marzuki Khalid, Eileen Lew Yi Lee and Rubiyah Yusof Miniappan Nadaraj, “Design of an Intelligent Wood species Recognition system”, *Centre For Artificial Intelligence And Robotics (Cairo)*, Vol. 9, pp. 9-19, 2008.

[28] Alex C. Wiedenhoeft and Regis B. Miller, “Structure and Function of Wood”, *Handbook of Wood Chemistry and Wood Composites*, pp. 9-33, 2005.

[29] http://shelf3d.com/i/pine.

[30] USDA Forest Service, “Wood handbook, wood as an engineering material”, general technical report, FPL-GTR-113, 51-117, 1999.

[31] Marchant dice limited, “CNC machine guide, www.marchantdice.com”, pp. 1-4, 2008.

[32] Delta Industrial Automation Products for CNC Wood Router, “CNC wood router”,(2012), pp.1-4.

[33] http://www.answers.com.

[34] http://www.scoopweb.com/Wood_Router

[35] http://www.worldagroforestrycentre.org/sea/products/afdbases/af/asp/SpeciesInfo.asp?SpID=10

[36] www.wikipedia.com

[37] http://www.britannica.com/EBchecked/topic/647253/wood/26157/Ultrastructure-and-chemical-composition#toc26158.

[38] http://globalspecies.org/ntaxa/850993