Ultrasonic Characterization of Different Wood Samples

A Dissertation submitted in partial fulfillment of the Requirements for the award of degree of

Master of Engineering
In
Electronics Instrumentation and Control

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Place : Thapar University, Patiala

Date :

DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled, **"Ultrasonic characterization of different wood samples"** in partial fulfilment of the award of degree of **Master of Engineering in Electronics Instrumentation and Control** submitted in the Electrical and Instrumentation Engineering Department, Thapar University, Patiala is an authentic record of my own work under the supervision of **Dr. Ravinder Aggarwal**, Professor and **Dr. Deepti Mittal** , Assistant Professor, Department of the Electrical and Instrumentation Engineering, Thapar University, Patiala, Punjab.

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SUMMARY

Wood is a natural raw material having both orthotropic anisotropy and its variability. Wood is a biological material integrating a very large variability of its physical and mechanical properties. The variability is strongly dependent on the direction of grains and other quality parameters like velocity, density *etc*. Physical appearance of the variability is due to ring average width and density of wood. For industrial applications, like structural applications or timber construction, the micro-structural basic variability associated to a macroscopical variability induced by singularities like knots, cracks, local decay or even local dynamic compression failure. To improve the wood quality grading in several steps of the industrial wood transformation, ultrasonic characterization readings would be useful.

In first experimental study, Eight different wood samples like Acacia auriculaeformis (Bengaljali), Eucalyptus tereticornis (Eucalypts) Heveabrasiliensis (Rubber wood), Mangiferaindica (Mango), Melia composite (Malabar neem), Radiata pine (Pine) and Shorearobusta (Sal) were computed for ultrasonic parameters like velocity, specific gravity, acoustic impedance, adiabatic compressibility and modulus of elasticity at different frequencies of 1MHz, 2.25MHz and 3.25MHz. Ultrasonic velocity, adiabatic compressibility, acoustic impedance, modulus of elasticity, modulus of rupture, and maximum crushing stress parallel to grain were found varying between 1000 m/s to 1667 m/s, 0.180×10^{-6} to 0.67×10^{-6} Pa^{-1} , 1400 to 3334 N-s/m^2, 437 to 1066 kg/m^2, 200 to 599 kg/m^2 respectively. The results of the study will be helpful to characterize the different wooden samples. Moreover, properties of different samples can be expressed by their acoustical behaviour.

In second experimental study five different wood samples like Acacia auriculaeformis (Bengaljali), Eucalyptus tereticornis (Eucalypts), Melia composite (Malabar neem), Shorearobusta (Sal) and Teak were used for study. Non-destructive technique (NDT) was employed for study the physical parameters and Scanning electron microscopy (SEM) was employed to capture image from the surface of the wood in longitudinal and transverse direction. These images were used to study the wood fibrous structure in different pattern 20 to 120 µm, pores size (vessel element) 50 to 400 µm, fiber size 5 to 30 µm and compare with ultrasonic physical parameters like ultrasonic velocity, acoustic impedance and elasticity along the grain were found varying between 3466 m/s to 4929 m/s, 0.699×10^{-6} to 2.92×10^{-6} N-s/m^2, 2.89×10^{-9} to 12.58×10^{-9} Pa and in transverse direction 1733.33 m/s to 2571.42 m/s, 0.292×10^{-6} to 1.209×10^{-6} N-s/m^2, 0.507×10^{-9} to 2.99×10^{-9} Pa respectively. The aim of this study was to understand the ultrasonic behaviour in different wood structure. The results of the study will be helpful to characterize the different wooden samples.

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CHAPTER 1

INTRODUCTION

1.1 Overview

Wood is a natural raw material having both orthotropic anisotropy and its variability. Wood is a biological material integrating a very large variability of its physical and mechanical properties. The anatomical structure of wood affects strength properties and appearance of wood. Ultrasonic is a versatile non-destructive technique (NDT) and highly useful for the investigation of various physical properties such as ultrasonic velocities, densities, acoustic impedance etc.

NDT research includes measurement of physical and mechanical properties, grading of materials and monitoring of defects in trees, logs, solid wood and composite products. By definition Non-destructive Testing is the science of identifying physical and mechanical properties or defects of a piece of material or structure, without altering its end use capabilities. Various NDT technologies, such as ultrasonic-based methods, radiographic methods, dynamic methods, acoustic emission techniques, and acousto-ultrasonic techniques etc. The NDT methods used in the forest products industry can be classified to the following groups: Defect detection in solid wood, Sorting or grading of structural products, Health monitoring of living trees.

This dissertation deals with the measurement of ultrasonic velocities, densities, acoustic impedance, elasticity and adiabatic compressibility of different wood samples like Acacia auriculaeformis (Bengaljali), Eucalyptus tereticornis (Eucalypts), Melia composite (Malabar neem), Shorearobusta (Sal) and Teak etc. to understand the acoustical behavior of wood. Scanning electron microscopy of the wooden samples was employed to capture image from the surface of the wood.

1.2 Aim

The aim of this study is to characterize the different wooden samples and find out the relation between acoustical behavior and fibrous structure on the surface of wood. Non-destructive technique was employed for study the physical parameters and Scanning electron microscopy was employed to capture image from the surface of the wood in longitudinal and transverse direction.

1.3 Methods

Ultrasonic technique was employed to study the wood samples. In ultrasonic technique two type of methods are used in the present study namely; Pulse echo and Pulse transmission (Through transmission).

In through transmission method two transducers are used. One transducer transmitted a signal through the sample, another transducer on the opposite side receive the signal.

1.4 Organization of the dissertation

Chapter 1 gives the brief introduction and overview of the work.

Chapter 2 gives an literature survey. It also presents the history and techniques used for NDT .

Chapter 3 discusses ultrasonic technique in detail.

Chapter 4 discusses Scanning electron microscopy test in detail.

Chapter 5 gives the brief detail of wood materials which is used for experiment.

Chapter 6 the brief detail of experiment set-up and methodology.

Chapter 7 discusses the result and discussion by comparing ultrasonic parameters with SEM images

Chapter 8 gives the conclusion and future scope of the dissertation and also explores the future aspect of the subject.

CHAPTER 2

LITRATURE SURVEY

2.1 History

NDT research on wood and wood materials was spurred in the United States by a symposium in Pullman, Washington, in 1980 organized by Roy F. Pellerin (Washington State University) and Kent McDonald (USDA Forest Service, Forest Products Laboratory). NDT research includes measurements of physical and mechanical properties, grading of materials and monitoring of defects in trees, logs, solid wood, sawn timber and lumber, engineered wood and composite products. Although some investigations describe AE/AU techniques as useful in detecting flaws in metals, polymers, and ceramics, these techniques have had only limited success in wood [2]. More fundamental research is required to identify wood properties that affect wave propagation and attenuation, such as density, defects, and moisture content. The AE investigations for wood products can be classified into five fields: monitoring and control during drying, prediction of deterioration, estimation of strength properties, fracture analysis, and machining control. Ultrasound is a high frequency sound at the inaudible frequency range. In case of wood the frequency is between 20 kHz-500 kHz. This comparatively low frequency range is used because of the high wave attenuation in wood. The acoustic velocity and the acoustic attenuation coefficient is used as strength predictors, and the increase of transit time between two transducers can locate defects. Several standard ultrasonic methods emerged to measure the ultrasonic properties of materials. The two most frequently used methods are the through transmission and the pulse-echo methods.

2.2 NDT Techniques

NDT stands for non-destructive testing. In other words it is a way of testing without destroying. This means that the component weld or forging, the casting, can continue to be used and that the non -destructive testing method has done no harm.

In today's world where new materials are being developed, bonding methods and older materials are being subjected to higher pressures and loads, NDT ensures that materials can continue to operate to their highest capacity with the assurance, that they will not fail within predetermined time limits. Apart from ensuring the structural quality, integrity and reliability of components and plants, today NDT finds extensive applications for condition monitoring, residual life assessment etc. There are many NDT techniques/methods used, depending on material type, defect size, defect location, defect type.

Common NDT Methods :

In NDT research some common methods which are used for different applications. There are some common methods discussed below :

2.2.1 Volumetric Examination Method

Ultrasonic Testing - UT Ultrasonic inspection uses high frequency sound waves to detect changes or imperfections in properties within the materials. It can also be used to measure the thickness of a wide range of metallic and non-metallic materials where access from one side only is available.

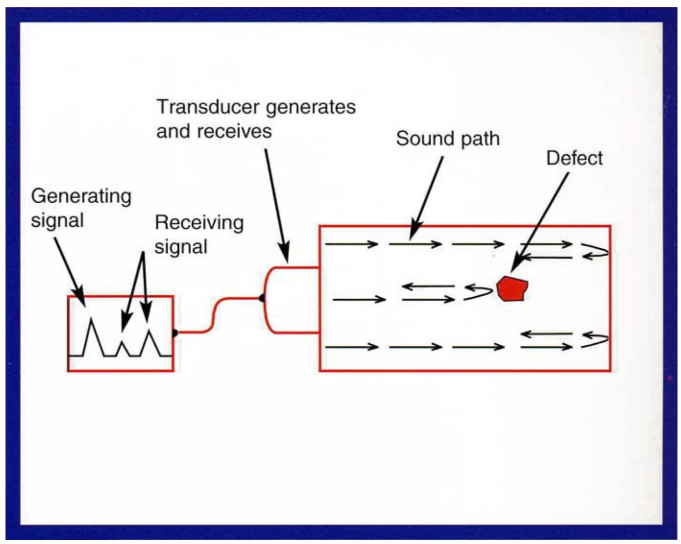

Fig.2.1: Set -up of ultrasonic testing

Radiography Testing -RT Radiography uses an radioactive isotope or x-ray device as a source of radiation which passes through the material and is captured on digital device or film. After processing the film an image of varying density is obtained. Possible imperfections are identified through density changes.

2.2.2 Surface Examination Method

Visual Inspection -VT The oldest of all the methods. Components are scanned visually, sometimes with the aid of high or low power lenses, cameras and video equipment to determine surface condition.

Liquid Penetrant -PT In Liquid Penetrant the testing material is coated with a visible or fluorescent dye solution. The excess dye is removed from the surface and a developer which acts like a blotter is applied drawing penetrant out of imperfections open to the surface. With visible dyes, the vivid colour contrast between the developer and the penetrant is used. With fluorescent dyes an ultraviolet lamp is used to make the 'bleed out' fluoresce brightly allowing the imperfection to be seen readily.

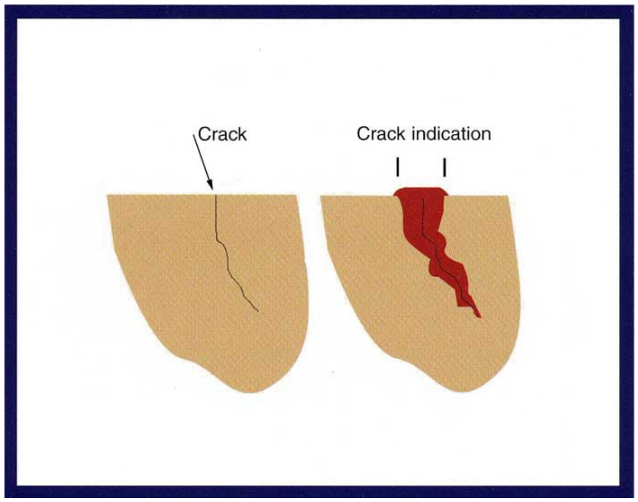

Fig.2.2: Liquid penetrant method

Magnetic Particle -MT Magnetic Particle inspection is used to identify surface and near surface discontinuities in ferromagnetic materials such as iron and steel. The technique uses the principle that magnetic lines of force will be distorted by the presence of a discontinuity. Discontinuities are located from the flux distortion following the application of fine magnetic particles to the area under test.

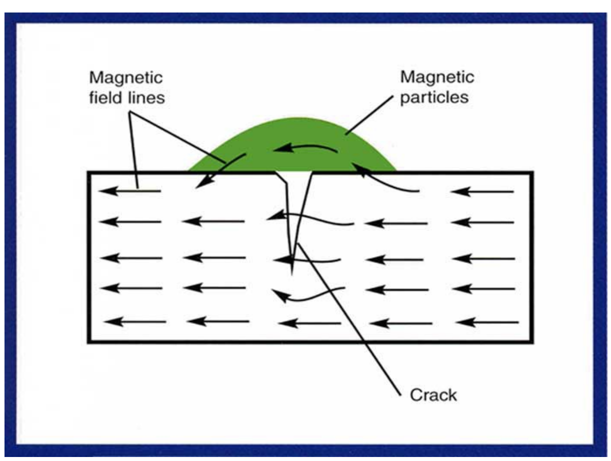

Fig.2.3: Magnetic particle inspection method

Eddy Current -ET In eddy current testing electrical currents are generated in a conductive material by an induced magnetic field. Distortions in the flow of the electric current (eddy currents) caused by changes or imperfections in a material's conductive properties will cause changes in the induced magnetic field. when these changes detected, indicate the presence of the imperfection or change in the test material.

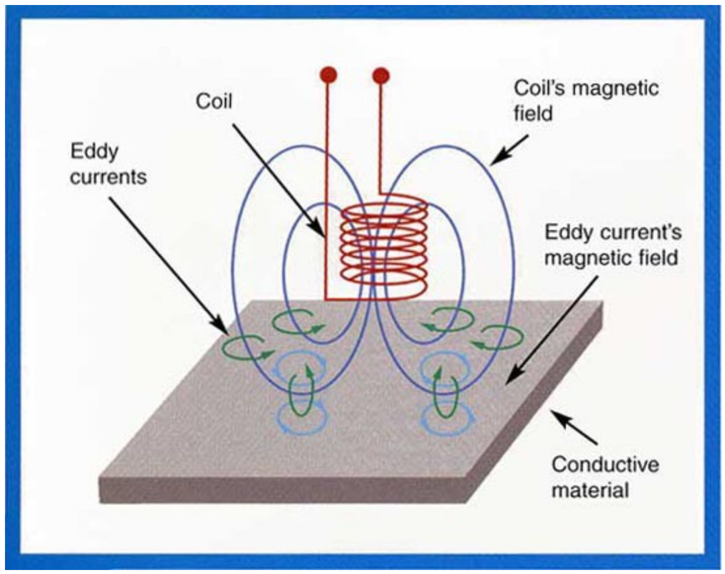

Fig.2.4: Eddy current testing

2.2.3 Integrity Examination Method

Leak Testing - LT Leaks can be detected by using electronic listening devices, pressure gauge measurements, gas and liquid penetrant techniques or a simple soap-bubble test. Several techniques are used to detect and locate leaks in pressure retaining components such as pressure vessels and pipe-lines.

Acoustic Emission Testing - AET When a solid material is stressed, growing imperfections, if any within the material emit short burstsof acoustic energy called emissions. In ultrasonic testing, acoustic emissions can be detected by special receivers. Emission sources can be evaluated through the study of their intensity, rate and other characteristics. The growing defects can be located by triangulation technique , similar to earthquake epicenter location.

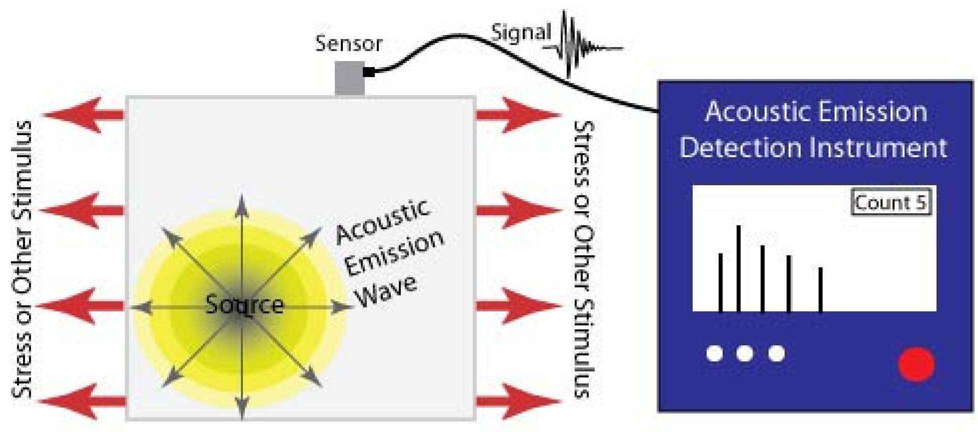

Fig.2.5: Acoustic emission testing

2.2.4 Condition Monitoring Method

Thermography – Infrared Testing - IR Thermography enables the thermal profile of an item, machine or building to be presented in a graphic form which allows a working temperature assessment to be derived. From this, variations in the material or component temperature are identified, enabling working limits or corrective actions to be identified.

Vibration Analysis - VA The vibration noise produced by rotatory machine. By monitoring the frequency, amplitude etc. of the vibration the condition of the machine can be estimated.

Special NDT methods

NDT engineers and technicians also use magnetic resonance imaging, vibration monitoring, laser ultrasonics, holography, computed tomography as well as many other specialized methods for specialized applications

A Career in NDT Careers can be in a variety of areas:

- Service Inspection Companies
- Smelters & Foundries
- Rolling & Forging Mills
- Petro Chemical & Refineries
- Mining & Mineral Processing
- Aircraft Maintenance & Manufacturing

• Vehicle Maintenance & Manufacturing

• Engineering Firms

• Research & Development Facilities

2.3 Literature Survey

Fabiana Goia Rosa de Oliveira, (2005) ultrasonic velocity is sensitive to changes in moisture content of brazilian hardwood Goupia glabra [1]. The longitudinal velocity under dry conditions was always higher than the velocity under more humid conditions, in both directions: parallel and perpendicular to the fibers. The parallel and perpendicular ultrasonic velocities decreased as the moisture content increased. During drying, the velocity perpendicular to the fibers displayed a slighter increase with equilibrium moisture content than it did parallel to the fibers, indicating that the sensitivity of ultrasonic measurement was greater in the longitudinal velocity.

M. Tiitta, (2010) electrical impedance spectroscopy (EIS) is quite a novel method for characterising and imaging the electrical properties of materials [2]. The samples were measured in frozen, green, conditioned and unconditioned dry moisture state to find out the potential of dielectric spectroscopy to determine the wood characteristics at different stages of wood processing. The combined Acoustic emission and EIS technique method is based on using electrical method for moisture gradient monitoring and acoustic emission method for detection of micro-cracking. EIS and FTIR are feasible non-destructive techniques to detect early stages of mould and monitor the growth of mould.

Sumire Kawamoto, (2002) this review focuses on the feasibility of acoustic emission (AE) and acousto-ultrasonic (AU) techniques for monitoring defects in wood, particularly during drying. The advantages and disadvantages of AE and AU techniques are described [4]. Particular emphasis is placed on the propagation and attenuation of ultrasonic waves in wood and the associated measurement problems. The review is divided into two sections, acoustic emission techniques and acousto-ultrasonic techniques. It includes historical background on the techniques as well as applications for wood and wood products.

Akiko Minamisawa, (1990) ultrasonic velocity measurements proved to be very effective in determining moisture contents of wood, even when the contents were not uniform in woods [5]. the ultrasonic velocity versus moisture content relation in woods velocity is reduced greatly with increasing moisture contents up to about 30% but beyond the point the velocity change becomes very dull. From many experimental results it is believe that this point, which varies in the range from 20 to 50%

according to wood species, is the FSP of the corresponding wood. Up to FSP wood fibers which are composed entirely of cellulose absorb water molecules. and hence cell walls swell and soften, resulting in a decrease of M . Beyond FSP, however, the fibers cannot absorb any more water molecules. In consequence the molecules have to be accommodated in vacant spaces inside the wood cells. This can occur only through the replacement of air in the cells with free water. Since the longitudinal modulus of water is much higher than that of air, it seems very natural that an increase in moisture content over FSP should significantly raise the bulk-averaged longitudinal modulus of woods.

Mark E. Schafer, (2000) ultrasound is well suited to applications in the Forest Products industry [6]. The unusual acoustical properties of wood present both problems and opportunities, and give rise to unique applications of the technology. Through-transmission ultrasound in the 80-200kHz range has been used to performrealtime defect image generation and analysis, suitable for in-plant use. This required new transducer configurations, signal processing methods, and detection algorithms. Compounding the problem, wood is a highly anisotropic material, with sound speeds from 1200 to 5000 m/s depending upon wood fiber (grain) orientation.

Ronnie Y. Vun, (2004) direct contact ultrasonic transmission method was used to differentiate the effects of particle size on panel properties for oriented strand board, redcedar particleboard , and bagasse particleboard [7]. The measurements were done after conditioning samples at 50 and 70 percent relative humidity at 24°C. velocity is a good indicator of physical impediments due to particle attributes in these types of panels. an appropriate ultrasonic system calibration of these material factors is essential for optimization of desired properties and a technological bridge for these reconstituted composites.

Ismail Hakki Sarpun, (2007) the mean grain size of different ceramic-metal composites made from tungsten carbide and boron carbide, have been determined with ultrasonic velocity technique [8]. In addition, electro less coating method was used to coat tungsten carbide samples. Prepared samples were sintered at the different temperatures ranging from 1200°C to 1400°C in an Argon atmosphere. Powders were placed in a 30mm diameter mold and pressed using a hydraulic press at a pressure of 200 bar. The results were compared to the mean grain size obtained from SEM (Scanning Electron Microscopy). This study has shown a clear dependence of ultrasonic velocity on grain size in composites of boron carbide and tungsten carbide composite. Especially, temperature dependence of mean grain size for tungsten carbide composites can be seen very clearly.

Balazs Zombori, (2001) the objective of the paper is to give an overview of the most widely used non destructive testing techniques in the forest products industry, while focusing on the methods feasible to assess the integrity of built in wooden members [9].

E. L. Schneider, (2007) SEM studies of pit membranes of cycad tracheids revealed porosities in some, but not most of the tracheid pits examined [10]. Porosities, where present, are mostly varied in size and density. Porosities do not extend through pit membranes and appear limited to the first-formed portion of the primary wall. Because of inconsistency in porosity presence within a secondary xylem sample, as well as between stems and roots of a species, and among species, interpretation is difficult.

Adya P. Singh, (2010) Pinus radiata wood was impregnated with chitosan as an environmentally compatible organic biocide to protect wood against wood deteriorating microorganisms and to thus prolong the service life of wooden products [11].The developed sample preparation techniques targeted to visualise impregnated chitosan within wood tissues using light microscope and field emission scanning electron microscope (FE-SEM).

Light microscopy was also undertaken on sections that had been stained with 1% aqueous osmium tetroxide (OsO4). For SEM observations, the sections were treated with OsO4 and then examined with the FE-SEM, first in the secondary electron imaging mode and then in the backscattered electron imaging mode, imaging the same areas of a section in both SEI and BEI modes. The preparation techniques employed and the combined use of light and scanning electron microscopy provided valuable complementary information, revealing that chitosan had penetrated into the cavities (cell lumens, intercellular spaces) of all sizes present within wood tissues and had also impregnated early wood cell walls.

G. Wrobel, (2007) the main objective of this work was to study efficiency and ability of the pulse-echo ultrasonics in comparison with through-transmission technique to evaluate the local fiber content in glass/epoxy composites [12]. The variation of fiber content was clearly identified by the use of both considered techniques. Two different ultrasonic non-destructive techniques were employed to measure the mechanical wave velocity in glass/epoxy composites. The study was performed on various specimens with different glass content at the range from 30 to 65%. The exact glass content in examined materials was determined using the standard destructive analysis.

Jorge Fromm, (2003) the biology and chemistry of the wood cell wall plays a key role in the determination of properties of solid wood and products derived from wood [3]. The lignin distribution in cell walls of spruce and beech wood was determined by high-voltage transmission-electron-microscopy

(TEM) in sections stained with potassium permanganate as well as by field-emission-scanning-electron-microscopy (FE-SEM) combined with a back-scattered electron detector on mercurized specimens. by using TEM as well as SEM it is observed that lignin closely follows the cellulose microfibril orientation in the secondary cell wall.

Peter Kitin, (2009) wood structure was investigated by light microscopy and scanning electron microscopy of traditional wood anatomical preparations and by a new method of exposed tangential faces of growth-ring boundaries [14]. Although the lateral movement of water and gas in tree stems is an important issue for understanding tree physiology, as well as for the development of wood preservation technologies, little is known about the vascular pathways for radial flow. The aim of this study was to understand the occurrence and the structure of anatomical features of sugi (Cryptomeria japonica) wood including the tracheid networks, and area fractions of intertracheary pits, tangential walls of ray cells and radial intercellular spaces that may be related to the radial permeability (conductivity) of the xylem.

Caroline R. Cartwright, (2013) this article presents the results of the anatomical identification of wood charcoal from pre-Still Bay, Still Bay and Howiesons Poort assemblages at Diepkloof Rock Shelter (South Africa) using scanning electron microscopy [15]. In the earliest phases, with pre-Still Bay stone tools, the charcoal shows a predominance of Afromontane forest taxa, some riverine woodland species, mesic thicket and proteoid fynbos vegetation. With a change in lithic technology in Still Bay contexts, the balance of Afromontane and thicket taxa shifts towards favouring the latter. A more diverse array of proteoid fynbos species emerges, and there is evidence for the use of plants from the local wetlands of the Verlorenvlei.

S. R. Shukla, (2007) assessed the physical and mechanical properties of timber of plantation-grown 8, 12 and 13-yr-old trees of Acacia auriculiformis A.Cunn. ex Benth. from Sirsi, Karnataka, India. The timber of the 13-yr-old trees was dense, very strong, moderately tough, stable in service and hard, and it compared favourably with teak in several properties [16]. It can also satisfy the requirements of the rural construction industry where timbers of small diameter can be used. If the trees are allowed to grow to greater age and size, the wood will have an expanded range of applications.

Majid Kiaei, (2011) the 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 (Alnus glutinosa) and ash

(Fraxinus excelsior) were investigated [17]. The relationship between physical properties (wood density) and anatomical characteristics with mechanical strength traits were determined by Pearson correlation.

William Simpson, moisture content of wood is defined as the weight of water in wood expressed as a fraction, usually a percentage, of the weight of ovendry wood [18]. Weight, shrinkage, strength, and other properties depend upon the moisture content of wood. In trees, moisture content can range from about 30% to more than 200% of the weight of wood substance. In softwoods, the moisture content of sapwood is usually greater than that of heartwood.

Ratih Damayanti, (2010) observations on anatomical structures covered macroscopic and microscopic characteristics were carried out through the sectioned and macerated wood samples [19]. The observed characteristics of the anatomical features were defined conforming to the LAWA List of Microscopic Features for Hardwood Identification. Based on the scrutiny on those observed characteristics and linked to the fiber quality, it was judged that the fiber in all the five wood species could be classified as class I for pulp and paper processing.

Sandeep K. Sharma, (2012) this study presents a non-destructive technique for damage detection in plates using guided ultrasonic waves [20]. plate specimen with a notch like defect geometries were tested with varying defect depth and location. Two ultrasonic testing techniques pulse transmission and pulse echo were effectively used in the experiment. Time of flight (using phase velocity) measurement in pulse echo and amplitude attenuation measurement in pulse transmission were metrics of exact location and extent of damage in the specimens.

T. Sumathi, (2010) the ultrasonic velocity, density and viscosity measurements have been carried out for L-Methionine in aqueous sodium chloride, potassium chloride and lithium chloride as a function of composition at 303K [21]. Experimental data have been used to estimate the adiabatic compressibility (β), change ($\Delta\beta$) and relative change in adiabatic compressibility ($D\beta/\beta°$), acoustic impedance (z), limiting apparent metal compressibility limiting apparent molal volume and the constants (Sk, Sv) and viscosity B co-efficient. The results are discussed in terms of structure-making (or) structure -breaking effects of amino acids in the mixtures.

M. Kazayawoko, (1997) the main objectives of the present study was to investigate the surface chemistry of different wood fibers, and evaluate its relative importance with respect to mechanical properties of wood fiber-polypropylene composites, and ascertain other factors of wood fibers that may affect the mechanical properties [22].

F. C. Bao, (2001) this study examined the intrinsic differences in various wood properties between juvenile wood and mature wood in 10 major reforestation species in china [23]. comparisons between juvenile wood and mature wood were made in both plantation and naturally grown trees.

V. Bucur, (2002) mechanical behaviour of wood considered as an orthotropic solid can be determined with ultrasonic technique [24]. The propagation phenomena in wood are complex and theoretically are regulated by Christoffel's equation. Three type of waves can propagate in wood. During the propagation phenomena three slowness sheets are observed, corresponding to a fast longitudinal wave (inner sheet) and two shear waves, one fast and one slow (outer sheet). These waves are submitted continuously to mode conversion phenomena.

A. K. Bledzki, (2004) wood fibre reinforced polypropylene composites of different fibre content (40,50 and 60% by weight) have been prepared and wood fibres (hard and long fibre) were treated with compatibiliser (MAH-PP) to increase the interfacial adhesion with the matrix to improve the dispersion of the particles and to decrease the water sorption properties of the final composite. Results indicated that impact properties were affected by moisture content [25].

Gowdra K. Prakash, (2008) Hevea brassiliensis (rubber wood) was esterified with palmitoyl chloride, prepared from the reaction of palmitic acid with thionyl chloride [26]. The weight gain of the wood increased with increasing reaction time and temperature, the esterified wood were evaluated for their photostability and dimensional stability. Fourier transform infrared spectroscopy (FTIR), solid-state cross-polarization/magic angle spinning 13C nuclear magnetic resonance spectroscopy (CP/MAS 13C NMR) were used to elucidate the characteristics of wood after esterification.

Bremananth R, (2009) the proposed system identifies the species of the wood using the textural features present in its barks [27]. Each species of a wood has its own unique patterns in its bark, which enabled the proposed system to identify it accurately. In this work, a wood recognition system has been designed based on pre-processing techniques, feature extraction and by correlating the features of those wood species for their classification.

David Hunt, (2012) these include the densities and mechanical properties of some typical species [28]. This is followed by a résumé of the moisture relations in wood, and their consequences for dimensional changes and/or the development of restraining stresses. A third important property of wood is its susceptibility to various kinds of biological degradation, including effects of insects, fungi and bacteria.

CHAPTER 3
ULTRASONIC

3.1 Introduction

The standard ultrasonic instrument is used for non-destructive flaw testing and thickness gauging of metallic and non-metallic materials. The instrument uses the principles of sound propagation to detect, locate and evaluate defects such as porosity, cracks, deterioration, corrosion, and foreign inclusions found in material. It is also used for thickness gauging of material, to determine the location of defects, and to measuring the physical thickness of the testing material. By measuring transmission and attenuation properties, the UT scope can be used as an aid to certain physical and metallurgical characteristics of the material under test. The tester can operate in the normal mode or in the thru-transmission mode (dual transducer). The instrument is usually capable of performing direct contact (straight or angle beam) or immersion testing examination and can be used with single, dual or delay line transducers.

3.2 Ultrasonic Principles

The UT scope mainframe generates ultrasonic vibrations and sends them through the test object in a beam of short bursts of energy. Any discontinuity in the path of the ultrasonic beam, as well as the far side of the test object, reflects the vibrations back to the instrument. The time required for the initial pulse to travel through the material and subsequently return as an echo is displayed on a cathode ray tube as a thickness or distance measurement. Ultrasonic vibrations have two basic characteristics:

a. They are reflected by discontinuities occurring in the medium through which they are traveling.

b. They tend to travel in a straight line, as do light waves, due to the shortness of the wave length employed.

3.3 Applications of Ultrasonic Principles

All ultrasonic testers manufactured by NDT International, generate an electrical signal that changes at an ultrasonic frequency. A transducer works on piezoelectric principle to convert the electrical energy into mechanical vibrations that penetrate through the material.

The scope will detect any discontinuity or lack of elasticity in a material under test. It will detect and locate holes or cracks within a solid of elastic material within sensitive limits. The nature of the discontinuity that causes a variation in material elasticity does not influence the detection ability of the instrument. A hole or a flaw such as a blowhole of equal projected area will be indicated in the same manner. The size of defect that can be detected is also dependent upon the grain size of the material.

3.4 Operating Techniques of Ultrasonic

The various operating techniques are used for ultrasonic flaw detection and thickness gauging, the method selected is determined by the geometry of the testing material, location and orientation of the suspected defect, and the material characteristics. In some cases, multiple techniques are required for a complete investigation. The selection of the exact technique and transducer to be used are dependent on a number of factors that are interrelated. The physical geometry of the test material also determines the testing technique and the transducer to be used. There are five primary applications for the testing of materials using the instrument:

a. Straight-Beam (single transducer)
b. Straight-Beam (thru-transmission)
c. Angle-Beam
d. Immersion Testing
e. Thickness Gauging (single or dual element and delay-line)

3.4.1 Straight-Beam

The single transducer (pulse-echo) technique is the simplest and most common form of flaw detection. Sound waves from the instrument are transmitted through the material by a transducer and reflected back by the far side surface of the material. The Initial Pulse (IP) appears on the left hand side of the CRT screen. The back reflected pulse from the far side of the material appears on the right hand side of the CRT screen. Presence of a flaw shows up as a reduced amplitude pulse anywhere between the initial pulse and the back reflected pulse. When a flaw is large enough to intercept the sound wave completely, there is no back-reflected pulse from the far side of the testing material displayed on the CRT.

The thru-transmission technique requires two transducers; one transducer operating as a transmitter, the other as a receiver, with each positioned at opposite sides of the material. This technique is used where the geometry or internal condition of the material prevents a round trip of the sound wave as described for the straight-beam technique. The initial pulse appears on the left hand side of the CRT screen and the received pulse appears at the right side of the screen. The presence of a flaw within the material causes a reduction in amplitude of the sound wave pulse intercepted by the receiving transducer. Complete lack of a received sound wave pulse indicates that the flaw is large enough to block (or absorb) the transmitted sound wave completely.

3.4.2 Angle-Beam

The angle-beam (Shear Wave) technique is used for testing plate, pipe, sheet & welds. A plastic wedge is placed between the test material and the transducer with a film of couplant between the transducer and wedge. The plastic wedge permits the sound wave to enter the material at an angle. The sound-beam is then reflected back to the transducer as in straight-beam testing. The angle-beam technique without the plastic wedge can also be used in immersion testing.

3.4.3 Immersion Testing

Immersion testing provides testing flexibility since the transducer can be moved underwater to introduce a sound wave at any desired angle. Immersion testing is suitable for high speed scanning systems because the transducer does not contact the test object and, therefore, is not subject to wear. The initial pulse appears on the left hand side of the CRT. A second pulse, immediately to the right of the initial pulse, of less amplitude, indicates the near surface of the test object.

3.4.4 Thickness Gauging

These measurement techniques are used to determine the thickness of an object. Single element, dual element or delay line transducers may be used for this technique. The instrument is first adjusted for a thickness range using comparison test blocks of the same material and material condition of the item under test. Then the instrument can reliably measure any unknown distance within this calibrated range. Delay line transducer thickness gauging permits measuring the thickness of thin samples.

Thickness gauges for industrial use operate at frequencies in the Megahertz range, typically from 1 to 20 MHz. ultrasound at high frequencies, because of its very short wave-length has the advantage that it can make very accurate measurements on most engineering materials. Even more important, measurements can be made from one side only as the ultrasound waves inside a material will reflect back from the opposite surface (like an echo). Thus, thickness measurements can be made instantly and accurately when the other side of the test part is impossible or difficult to reach, with no need to cut parts of material for access.

3.4.5 Thickness Range

Thickness ranges will also dictate the type of gauge and transducer to be selected. In general, thin materials require high frequency transducers and thick or attenuating materials require lower frequencies. Very thin material may not be within the range of a gauge utilizing contact transducers; a delay line transducer may then be the answer. Similarly, gauges with delay line and immersion transducers have limited maximum thickness capabilities primarily due to potential interference from a multiple of the interface echo.

3.4.6 Geometry

A contact transducer is preferred for most ultrasonic measurements, unless sharp curvature or small part size makes contact measurements impractical. As the surface curvature of the test piece increases, the coupling efficiency from the transducer to the test material is reduced. As the surface curvature increases, the size of the contact transducer should be reduced. Extreme curvature or inaccessibility of the test surface requires a system with a delay line or an immersion transducer.

3.4.7 Temperature

Contact transducers can be safely used on material surfaces up to 120 F (50^{o} C). Thickness measurements with contact transducers on material surfaces in excess of these temperatures will result in transducer failure. Transducers with special heat-resistant delay lines are recommended on hot or warm surfaces especially, if more than a few measurements will be taken.

It should be considered that many factors may affect accuracy: sound attenuation and scattering, sound velocity variations, poor coupling, surface roughness, non-parallelism, curvature, echo polarity etc. Selection of the possible combination of gauge and transducer should take into account all these factors. With proper calibration, measurements can usually be made to an accuracy of 0.001 inch or 0.01 mm.

3.5 Transducer Selection

An ultrasonic flaw and thickness scope may be used for testing many materials under a variety of test conditions, using selected test frequencies. For optimum results, the transducer must be selected to match the application.

3.5.1 Contact Transducers

Contact transducers are applied directly to the surface of the material under test to measure thickness or detect flaws. Applications include plate, bar, forgings, castings, and extrusions. Contact transducers have polished aluminium oxide wear plates that provide excellent wear resistance to assure long transducer life.

3.5.2 Delay Line Contact Transducers

Delay line contact transducers are used primarily in thickness gauging where high resolution is required on thin materials such as tubing and sheet or where test surface temperatures are high, to insulate the transducer face. Delay tips do not have the same wear resistance as aluminium oxide therefore removable delay tips are available for replacement purposes. They can be easily shaped for gauging or inspecting curved surfaces.

3.5.3 Dual Element Transducers

Dual element transducers overcome the problem of a single element probe. Dual elements tend to focus very close to the surface and are ideal for the detection of small pits and thickness gauging on corroded surfaces. Applications include thickness gauging, flaw detection and corrosion detection of thin materials, especially where near-surface contact resolution is desirable.

3.5.4 Immersion transducers

Immersion transducers are used for examining irregularly shaped objects, when submerged in a liquid in an inspection tank. They also make possible rapid continuous testing of materials (through an ultrasonic beam) by means of high speed materials handling systems.

3.5.5.Angle beam transducers

Angle beam transducers are modified contact transducers devised to direct the sound beam at an angle to the surface of a material. This is accomplished with a plastic wedge. Angle beam transducers are used to test welded materials and in other applications where angular direction of the sound beam is essential. They are also valuable for detecting minute surface flaws in stressed or loaded surfaces such on aircraft wing spars, propeller blades etc. NDT International offers removable angle wedge so that different shear wave angles can be generated with a given angle-beam transducer.

3.5.6 Broadband Transducers

Broadband, high damped, untuned transducers are recommended where high resolution flaw testing is a prime consideration. Such type of transducers are also used for thickness gauging applications. A transducer's resolving power is determined by the period required for vibration to stop after pulse excitation. Long-term vibration will cause an excessive front surface echo within the material being tested. If a transducer is poorly damped, the amplitude of the front surface echo will be greater than a small near-surface discontinuity and can cause the near surface discontinuity to be masked and remain undetected; therefore, it is essential that the transducers be highly damped where high resolution is mandatory.

3.5.7 Narrowband Transducers

Narrowband, untuned transducers provide material penetration, resolution, and high sensitivity and are recommended for the majority of ultrasonic flaw detection applications. They are ideal for flaw evaluation, where known frequency specifications exist. Narrowband transducers contain matching tuning networks that are sealed within the transducer housing. Circuit tuning assures optimum frequency matching of transducer to the flaw detector that maximizes the sensitivity bandwidth product for flaw evaluation.

3.6 Handling the Transducers

The transducer operates efficiently only when making contact over the full surface area of the transducer face. Obtaining the proper contact with the transducer, a few basic rules must be followed:

- Cover the area of the surface to which the transducer is to be applied.
- Place the transducer on the testing surface gently. Do not bang it down; as such treatment may damage the crystal.
- Rub the transducer face against the testing surface to get complete contact and to spread the couplant evenly over the surface.
- Hold the transducer gently but firmly. Excessive pressure is not necessary.
- Clean the surface of the material before using the transducer.
- Handle the transducer with care. Avoid dropping on the floor or bench. Do not leave it where other tools may damage it.
- The transducer cable should also be treated with care. Avoid making sharp bends in the cable. When finished testing, clean and coil the cable

CHAPTER 4

SCANNING ELECTRON MICROSCOPY (SEM)

4.1 Introduction

Electron Microscopes are scientific instruments that use a beam of highly energetic electrons to examine objects on a very fine scale. This examination can yield information about the topography (surface features of an object), morphology (shape and size of the particles making up the object), composition (the elements and compounds that the object is composed of and the relative amounts of them) and crystallographic information (how the atoms are arranged in the object).

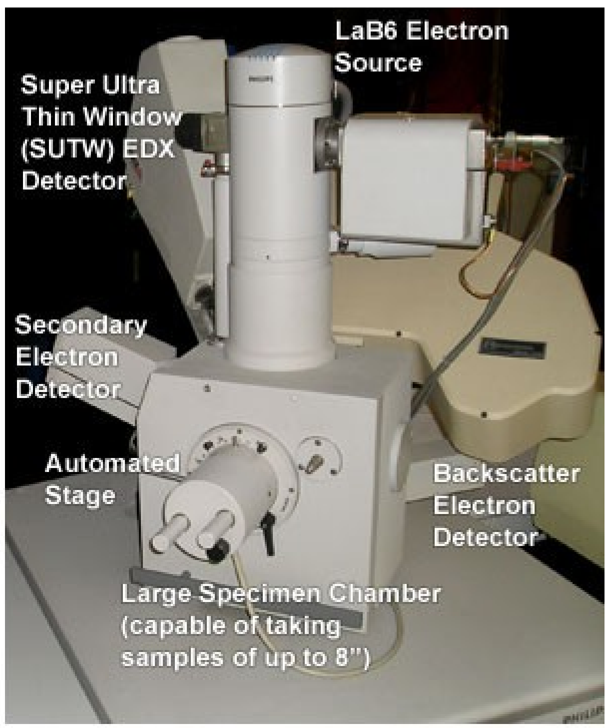

Fig.4.1: Scanning Electron Microscope (SEM)

Scanning Electron Microscope (SEM) was debuted in 1942 with the first commercial instruments around 1965. Its late development was due to the electronics involved in "scanning" the beam of electrons across the sample. Electron Microscopes (EMs) function exactly as their optical counterparts except that they use a focused beam of electrons instead of light to "image" the specimen and gain information as to its structure and composition. The basic steps involved in all EMs are the following: A stream of electrons is formed in high vacuum (by electron guns). This stream is accelerated towards the specimen (with a positive electrical potential) which is confined and focused using metal apertures and magnetic lenses into a thin, focused, monochromatic beam. The sample is irradiated by the beam and interactions occur inside the irradiated sample, affecting the electron beam. These interactions and effects are detected and transformed into an image.

4.2 Principle

Accelerated electrons in an SEM carry significant amount of kinetic energy, and this energy is dissipated by the variety of signals produced by electron-sample interactions, when the incident electrons are decelerated in the solid sample. These signals include secondary electrons (that produce SEM images), backscattered electrons (BSE), diffracted backscattered electrons (EBSD that are used to determine crystal structures and orientations of minerals), photons (characteristic X-rays that are used for elemental analysis and continuum X-rays), visible light, and heat. Secondary electrons and backscattered electrons are commonly used for imaging samples. Secondary electrons, the most valuable for showing morphology and topography on samples and backscattered electrons are most valuable for illustrating contrasts in composition in multiphase samples (i.e. for rapid phase discrimination). X-ray generation is produced by inelastic collisions of the incident electrons with electrons in discrete orbital's (shells) of atoms in the sample. As the excited electrons return to lower energy states, they yield X-rays that are of a fixed wavelength (that is related to the difference in energy levels of electrons in different shells for a given element). Thus, characteristic X-rays are produced for each element in a mineral that is "excited" by the electron beam. SEM analysis is considered to be "non-destructive"; that is, x-rays generated by electron interactions do not lead to volume loss of the sample, so it is possible to analyze the same materials repeatedly.

4.3 Scanning Electron Microscopy (SEM)

Essential components of all SEMs include the following:

- Electron Source ("Gun")
- Electron Lenses
- Sample Stage
- Detectors for all signals of interest
- Display / Data output devices
- Infrastructure Requirements:

a) Power Supply
b) Vacuum System
c) Cooling system
d) Vibration-free floor
e) Room free of ambient magnetic and electric fields

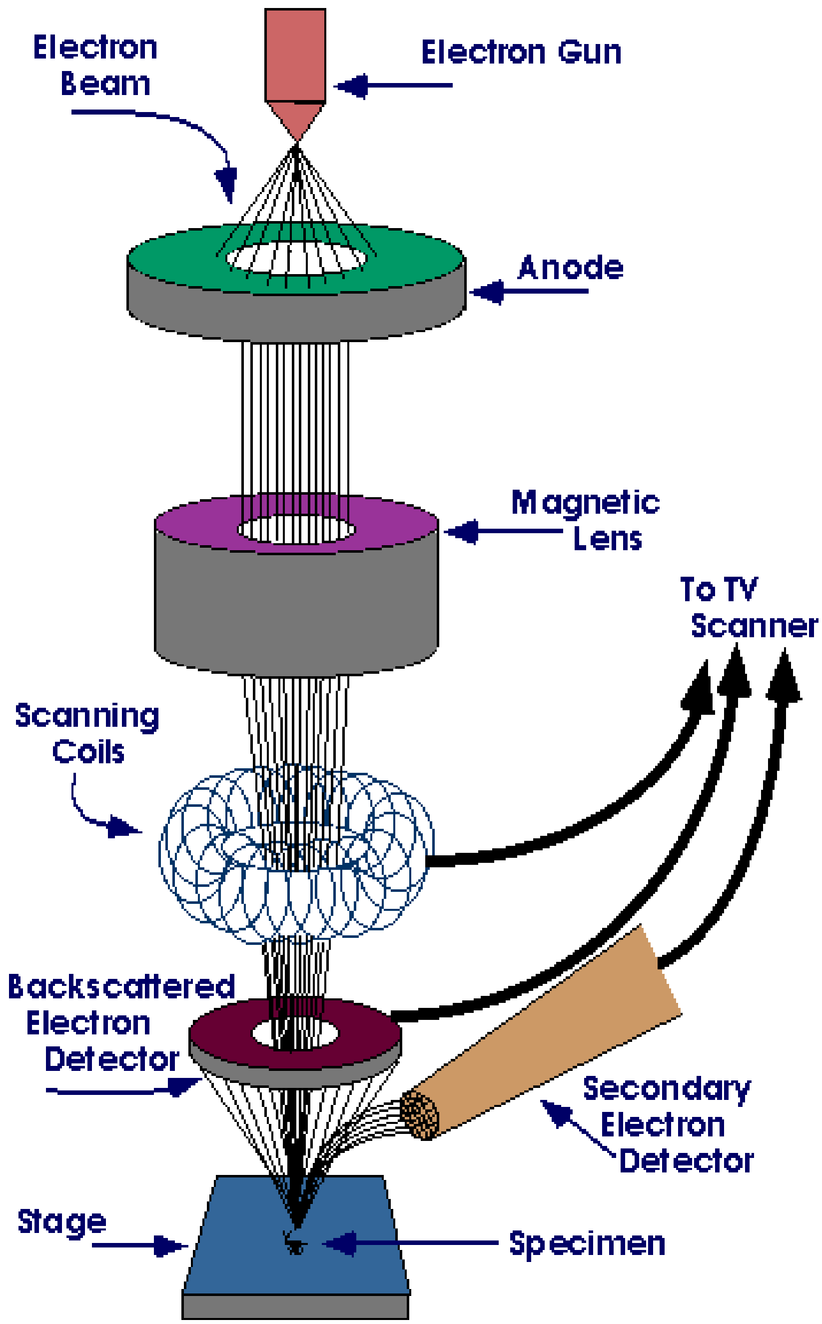

Fig.4.2: Essential components of scanning electron microscope

SEMs always have at least one detector (usually a secondary electron detector), and most have additional detectors. The specific capabilities of a particular instrument are critically dependent on which detectors it accommodates.

4.4 Applications

The SEM is routinely used to generate high-resolution images of shapes of objects (SEI) and to show spatial variations in chemical compositions:

- acquiring elemental maps or spot chemical analyses using EDS
- discrimination of phases based on mean atomic number (commonly related to relative density) using BSE
- compositional maps based on differences in trace element "activitors" (typically transition metal and Rare Earth elements) using CL.

The SEM is also widely used to identify phases based on qualitative chemical analysis and/or crystalline structure. Precise measurement of very small features and objects down to 50 nm in size is also accomplished using the SEM. Backscattered electron images (BSE) can be used for rapid discrimination of phases in multiphase samples. SEMs equipped with diffracted backscattered electron detectors (EBSD) can be used to examine micro fabric and crystallographic orientation in many materials.

4.5 Strengths and Limitations of Scanning Electron Microscopy (SEM)

The SEM is critical in all fields that require characterization of solid materials. Strength and limitations of the scanning electron microscopy are discussed below:

4.5.1 Strengths

There is no other instrument with the breadth of applications in the study of solid materials that compares with the SEM. While this contribution is most concerned with geological applications, it is important to note that these applications are a very small subset of the scientific and industrial applications that exist for this instrumentation. Most SEM's are comparatively easy to operate, with user-friendly "intuitive" interfaces. Many applications require minimal sample preparation. For many applications, data acquisition is rapid (less than 5 minutes/image for SEI, BSE, spot EDS analyses.) Modern SEMs generate data in digital formats, which are highly portable.

4.5.2 Limitations

Samples must be solid and they must fit into the microscope chamber. Maximum size in horizontal dimensions is usually on the order of 10 cm, vertical dimensions are generally much more limited and rarely exceed 40 mm. For most instruments samples must be stable in a vacuum on the order of 10^{-5} - 10^{-6} torr. Samples likely to outgas at low pressures (rocks saturated with hydrocarbons, "wet" samples such as coal, organic materials or swelling clays, and samples likely to decrepitate at low pressure) are unsuitable for examination in conventional SEM's. However, "low vacuum" and "environmental" SEMs also exist, and many of these types of samples can be successfully examined in these specialized instruments. EDS detectors on SEM's cannot detect very light elements (H, He, and Li), and many instruments cannot detect elements with atomic numbers less than 11 (Na). Most SEMs use a solid state x-ray detector (EDS), and while these detectors are very fast and easy to utilize, they have relatively poor energy resolution and sensitivity to elements present in low abundances when compared to wavelength dispersive x-ray detectors (WDS) on most electron probe micro analyzers (EPMA). An electrically conductive coating must be applied to electrically insulating samples for study in conventional SEM's, unless the instrument is capable of operation in a low vacuum mode.

CHAPTER 5
MATERIALS

5.1 Wooden samples

The

Sample	Botanical Name	Trade Name
AC	Acacia auriculiformis	Bengaljali
EU	Eucalyptus tereticornis	Eucalyptus
MD	Melia composita	Malabar Neem
RW	Hevea brasiliensis	Rubber Wood
MG	Mangifera indica	Mango
SA	Shorea robusta	Sal
Pine	Radiata pine	Pine

research work has been done on different wood samples. The thickness of the samples is 5 mm. Eight different wood samples like Acacia auriculaeformis (Bengaljali), Eucalyptus tereticornis (Eucalypts) Heveabrasiliensis (Rubber wood), Mangiferaindica (Mango), Melia composite (Malabar neem), Radiata pine (Pine) and Shorearobusta (Sal) are used for compute the ultrasonic parameters like velocity, specific gravity, acoustic impedance, adiabatic compressibility and modulus of elasticity.

Table-5.1: Botanical name of different wooden samples

5.2 Sample 1: Acacia auriculiformis (Bengaljali)

Botanical Description: Evergreen, unarmed tree to 15 m (50 ft) tall, with compact spread, often multi-stemmed; young growth glaucous. Leaves alternate, simple, reduced to phyllodes (flattened leaf stalks), these blade-like, slightly curved, 11-20 cm (5-8 in) long, with 3-7 main parallel veins and a marginal gland near the base; surfaces dark green.

Fig. 5.1: Acacia Auriculiformis

- Fuel: A major source of firewood, its dense wood and high energy (calorific value of 4500-4900 kcal/kg) contribute to its popularity. It provides very good charcoal that glows well with little smoke and does not spark.
- Fibre: The wood is extensively used for paper pulp. Plantation-grown trees have been found promising for the production of unbleached kraft pulp and high-quality, neutral, sulphite semi-chemical pulp.
- Timber: The sapwood is yellow; the heartwood light brown to dark red, straight grained and reasonably durable. The wood has a high basic density (500-650 kg/m^3)

5.3 Sample 2: Shorea robusta (Sal)

The sal flowers, whitish in color, appear in early summer. The sap wood in Sal is of small thickness. It is whitish in color and less durable. Heart wood is pale when freshly cut and tends to grow dark brown on exposure. It is coarse grained, hard and of fibrous structure. Annual rings are visible in young trees or on freshly cut wood. Its pores are of moderate size. The sal tree (Shorea robusta) is a hardwood timber tree, up to 30-35 m tall. The crown is spreading and spherical. Leaves are 20 cm long, simple, shiny and glabrous, delicate green, broadly oval at the base.

Fig. 5.2: Shorea robusta

Distribution: The sal tree is native to India, Myanmar and Nepal. It occurs in deciduous dry and moist forests and in evergreen moist forests. It is sensitive to frost and water logging. It flourishes best in deep, sandy, moist soils.

Environmental impact: As it is resistant to fire, Shorea robusta is often a dominant tree in Indian forests. For artificial regeneration it can be combined with upland rice, maize, sesame and mustard.

5.4 Sample 3: PINE

Pines are evergreen, coniferous resinous trees (or rarely shrubs) growing 3–80 m tall, with the majority of species reaching 15–45 m tall. The smallest are Siberian Dwarf Pine and Potosi Pinyon, and the tallest is a 268.35-foot (81.79-meter) tall. Pines are long-lived, typically reaching ages of 100–1,000 years, some even more. The longest-lived is the Great Basin Bristlecone Pine, Pinus longaeva. One individual of this species, dubbed Methuselah, is one of the world's oldest living organisms at around 4,600 years old.

- Juvenile leaves, which follow immediately on seedlings and young plants, 2–6 cm long, single, green or often blue-green, and arranged spirally on the shoot. These are produced for six months to five years, rarely longer.
- Scale leaves, similar to bud scales, small, brown and non-photosynthetic, and arranged spirally like the juvenile leaves.

Fig. 6 Pine

Pines have four types of leaf:

Fig. 5.3: Pine

Pines are among the most commercially important of tree species, valued for their timber and wood pulp throughout the world. In temperate and tropical regions, they are fast-growing softwoods that will grow in relatively dense stands, their acidic decaying needles inhibiting the sprouting of competing hardwoods. Commercial pines are grown in plantations for timber that is denser, more resinous, and therefore more durable than spruce. Pine wood is widely used in high-value carpentry items such as furniture, window frames, panelling, floors and roofing, and the resin of some species is an important source of turpentine.

5.5 Sample 4: Mangifera indica (Mango)

Mango trees (Mangifera indica) grow up to 35–40 m (115–130 ft) tall, with a crown radius of 10 m (33 ft). The trees are long-lived, as some specimens still fruit after 300 years. In deep soil, the taproot descends to a depth of 6 m (20 ft), with profuse, wide-spreading feeder roots; the tree also sends down many anchor roots, which penetrate several feet of soil.

Fig. 5.4: Mangifera indica

The leaves are evergreen, alternate, simple, 15–35 cm (5.9–14 in) long and 6–16 cm (2.4–6.3 in) broad; when the leaves are young they are orange-pink, rapidly changing to a dark, glossy red, then dark green as they mature. The flowers are produced in terminal panicles 10–40 cm (3.9–16 in) long.

5.6 Sample 5: Hevea Brasiliensis (Rubber wood)

Hevea brasiliensis, the Pará rubber tree, often simply called rubber tree, is a tree belonging to the family Euphorbiaceae, and the most economically important member of the genus Hevea. It is of major economic importance because its sap-like extract (known as latex) is the primary source of natural rubber. In plantations, the trees are kept smaller, up to 78 feet (24 m) tall, so as to use most of the available carbon dioxide for latex production. The tree requires a climate with heavy rainfall and without frost. If frost does occur, the results can be disastrous for production. One frost can cause the rubber from an entire plantation to become brittle and break once it has been refined.

Fig. 5.5: Hevea brasiliensis

- Fuel: Rubber wood was formerly regarded as a byproduct of the rubber plantations and used for the production of charcoal or as fuel wood, for brick making, tobacco drying and rubber drying.
- Fibre: Off cuts and other rubber wood residues have been used successfully in Malaysia for the production of particle board, wood-cement board, and medium-density fibre board.
- Timber: Heartwood pale cream, often with a pink tinge when fresh, darkening on exposure to pale straw-coloured or pale brown, not clearly demarcated from the sapwood. Grain straight to shallowly inter locked.

5.7 Sample 6: Eucalyptus tereticornis (Eucalyptus)

Eucalyptus tereticornis is a tree up to 45 m tall or taller; trunk erect, 1-1.8 m in diameter; crown large, open or fairly dense, variable; bark smooth, whitish, peeling in irregular thin sheets or large flakes, becoming mottled with white, grey or bluish patches, often some rough, dark grey bark at base; twigs reddish or yellowish-green.

- Timber: The wood is red, hard, heavy, strong, durable and 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}. It is used for construction in heavy engineering, such as for railway sleepers.

Fig.5.6: Eucalyptus tereticornis

- Fuel: Eucalyptus tereticornis is popular and widely used for firewood and charcoal.
- Fibre: In India, the most important use of Eucalyptus tereticornis is for its good quality pulp and paper. The strength properties of the paper improve after the tree reaches 9 years of age, but the dark colour of the heartwood, in comparison with some other Eucalyptus species, is a disadvantage.

5.8 Sample 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, with a spreading crown and sparsely branched limbs. Bark smooth, greenish-brown when young, turning grey and fissured with age. Leaves alternate, 20-40 cm long, bipinnate or occasionally tripinnate. Leaflets 3-11, serrate and with a pungent odour when crushed.

- The density is 510-660 kg/cubic m.
- Poison: Aqueous and alcoholic extracts of leaves and seed reportedly control many insect, mite and nematode pests. However, because they contain toxic components, care is needed in their use.

Fig. 5.7: Melia Composita

- Fuel: Fuelwood is a major use of Melia composita. It has a calorific value is 5100 kcal/kg.
- Timber: which resembles mahogany, is used to manufacture agricultural implements, furniture, plywood, boxes, poles, tool handles; it is used in cabinet making and in construction because of its resistance to termites.

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CHAPTER 6
EXPERIMENTAL SET-UP AND METHODOLOGY

6.1 Introduction

A typical ultrasonic testing inspection system consisting of pulser/receiver, transducer and display/recording device is used for testing. Conventional technique of pulse transmission method is used for ultrasonic testing. In the present study, ultrasonic technique is used on different wooden samples for calculate the different parameters. Pulse-echo is better method for finding the notch location but here through transmission is considered as a better method for characterize the wooden samples because transmission method provide better variations in acoustical parameters (velocity, impedance, elasticity) then pulse-echo.

6.2 Experimental process

Different mathematical parameters are calculated using ultrasonic techniques on different wooden samples. Transducers with frequency of 1 MHz, 2.25 MHz, and 3.25 MHz are used for the experiment. The transducers are driven by a Panametrics-NDT™ Model 5800 pulser/receiver system with maximum gain of 40 db. An external digital storage oscilloscope (DSO) is used to capture the received signal. The experiment was performed on 8 samples of 5 mm thickness of dry wood. These samples are Bengaljeli, Sal, Pine, Mango, Rubber wood, Eucalyptus, Malabar neem, ACD. Through transmission method requires two transducers on each side of the subject being inspected. One transducer transmitted a signal through the sample, another transducer on the opposite side receive the signal. The transducers are coupled transversely with silicon gel onto the samples for better contact, which reduces the signal loss.

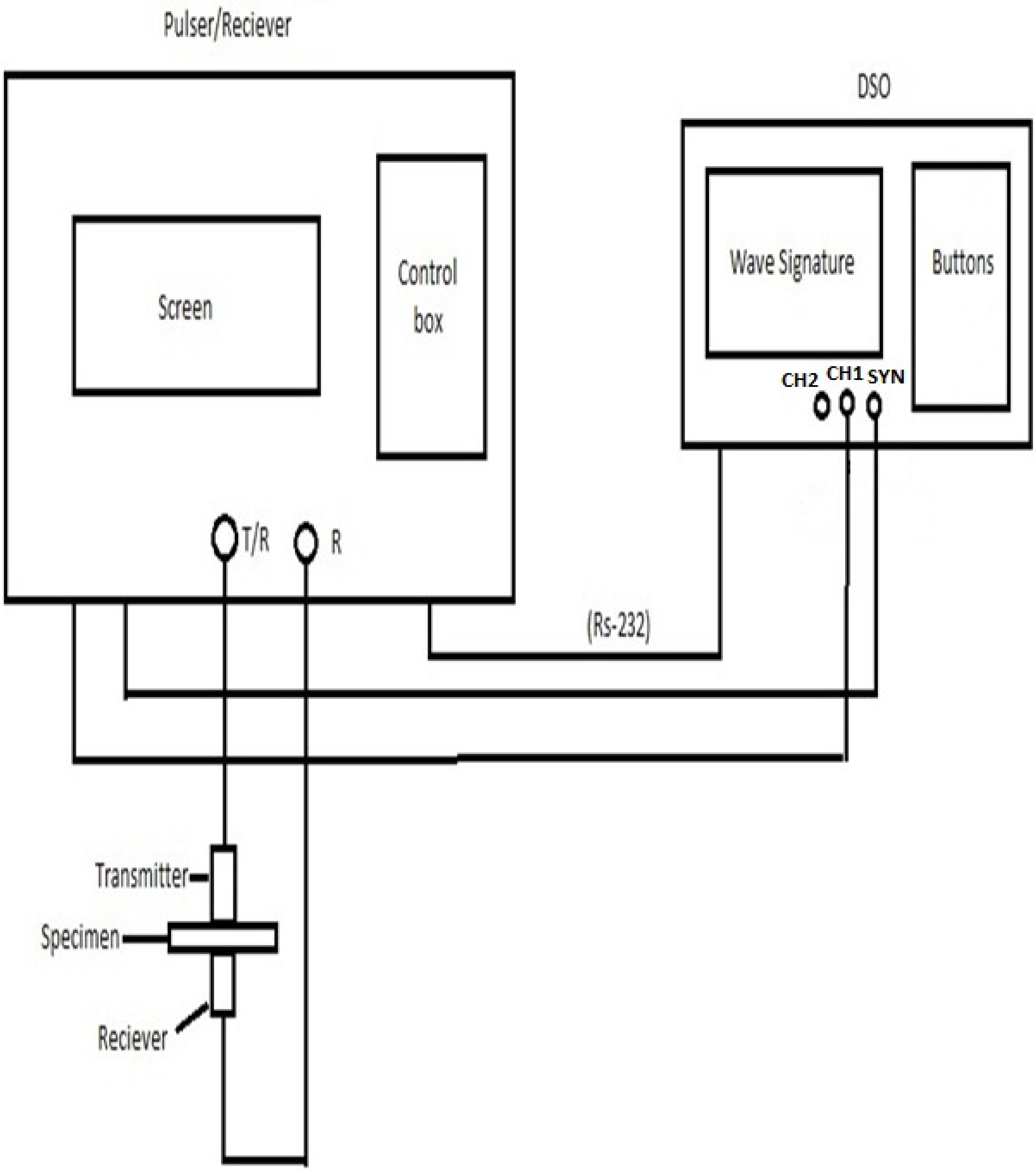


Fig. 6.1: Experimental set-up used (P/R)

6.3 Methods

The parameters measured in this techniques are velocity (v), Density (ρ), impedance (z), adiabatic compressibility (β) and elasticity(η). Ultrasonic velocity depends upon the grain direction, velocity changes with change in grain angle. Ultrasonic velocity (v) is calculated by the relation

$$v = D/T, \quad m/s \tag{6.1}$$

where, D is the thickness of the material and T is the time taken by the signal from transmitter to receiver. Density of the wooden material is determined by Archimedes principle using the relation of mass and volume.

The acoustic impedance (z) of a material is defined as the product of its density and acoustic velocity (v).Acoustic impedance is used to determine the transmittance behavior of acoustic wave in wooden samples. Acoustic impedance (z) is evaluated using formula

$$z = \rho\, v, \quad N\text{-}s/m^3 \tag{6.2}$$

Adiabatic compressibility is the fractional decrease in volume per unit raise in pressure. The value of adiabatic compressibility increase with the decrease in velocity. Adiabatic compressibility (β) is obtained using the relation

$$\beta = 1/\rho v^2, \quad Pa^{-1} \tag{6.3}$$

Elasticity implies that deformations produced by low stress are completely recoverable after loads are removed. Elasticity is calculated by the relation

$$\eta = \rho v^2, \quad Pa \tag{6.4}$$

In anisotropic materials, Young's modulus may have different values depending on the direction of the applied force with respect to the material's structure.

The specific gravity of wood samples calculated by means of the formula.

$$\text{sp. Gr.} = \text{weight of the sample/ weight of equal volume of water} \tag{6.5}$$

The specific gravity of a piece of wood is used to measure the volume of oven dried wood and green wood, when the moisture content of the sample is at any desired arbitrary value.

Modulus of rupture is a material's ability to resist deformation under load.

$$\sigma = FL/ bd^2 \tag{6.6}$$

where, F is the load (force) at the fracture point, L is the length of the support (outer) span, b is width and d is thickness of wood sample.

Maximum crushing stress, which is the measurement of the largest compression force the material can withstand before it loses its shape or fails.

$$\text{maximum crushing stress} = P/A \quad (6.7)$$

The maximum compressive stress a material can withstand without failure.

Wood is a biological material integrating a very large variability of its physical and mechanical properties. In the present study five different wood samples like Acacia auriculaeformis (Bengaljali), Eucalyptus tereticornis (Eucalypts), Melia composite (Malabar neem), Shorearobusta (Sal) and Teak were used for study. Non-destructive technique (NDT) was employed for study the physical parameters and Scanning electron microscopy (SEM) was employed to capture image from the surface of the wood in longitudinal and transverse direction. These images were used to study the wood fibrous structure in different pattern, pores size (vessel element), fiber size and compare with ultrasonic physical parameters like ultrasonic velocity, acoustic impedance and elasticity.

CHAPTER 7
RESULTS AND DISCUSSION

In the present study was carried out in two phases. In the first phase ultrasonic parameters at different frequency for wood characterization and in the second phase combination of ultrasonic parameters and wood structural parameters by using SEM images was studied.

7.1 Ultrasonic characterization of different wood samples

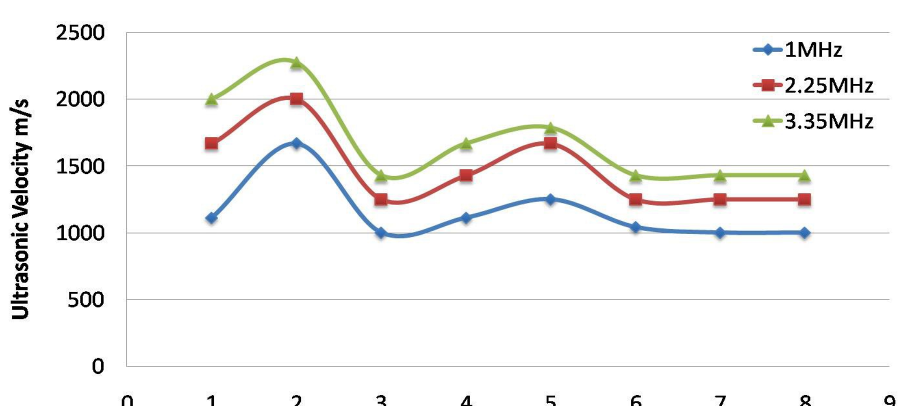
In the first phase variations of the parameters depend upon the wooden material was studied. Strength and hardness of the material depend upon the density of wood. The parameters obtained from the above study are summarized in Table-7.1.

Table-7.1: Acoustical Properties of Wooden Samples

The ultrasonic velocity, acoustic impedance, density and elasticity of wood vary with samples. Different wooden samples have different fiber length and vessel elements in various sizes affect these parameters. Elasticity shows a trend similar to the ultrasonic velocity. Variability in the speed of sound in wood is directly related to the variability of modulus of elasticity and density.

Samples	Ultrasonic velocity (v) m/s			Acoustic Impedance (Z) N-s/m^3			Adiabatic Compressibility (β)Pa^{-1} ×10^6			Elasticity(E) Pa/10^6			Standard specific gravity (OD wt / Geenvol)	Mo-dulus of rupture (kg/cm^2)	Maxi. Crushing stress parallel to grain (kg/cm^2)
	1 MHz	2.25 MHz	3.25 MHz	1 MHz	2.25 MHz	3.25 MHz	1 MHz	2.25 MHz	3.25 MHz	1 MHz	2.25 MHz	3.25 MHz			
Bengaljeli (AC)	1111	1666	2000	2222	3333	4000	0.405	0.179	0.125	2.4	5.5	8.0	0.616-0.645	1007-1066	450- 500
(SA)Sal	1666	2000	2272	3333	4000	4545	0.180	0.125	0.096	5.5	8.0	10.3	0.700-0.709	883-1038	478-599
PINE	1000	1250	1428	1400	1750	1999	0.714	0.457	0.350	1.4	2.1	2.8	0.553	474	240
Mango (MG)	1111	1428	1666	1111	1428	1666	0.810	0.490	0.359	1.2	2.0	2.7	0.581-0.588	506-612	231-294
Rubber Wood (RW)	1250	1666	1785	1500	2000	2142	0.533	0.299	0.261	1.8	3.3	3.8	0.521-0.599	437-585	200-278
Eucalyptus (EU)	1041	1250	1428	1874	2250	2571	0.512	0.355	0.272	1.9	2.8	3.6	0.822	931	631
Malabar Neem (MD)	1000	1250	1428	2000	2500	2857	0.500	0.320	0.245	2.0	3.1	4.1	0.392-0.394	0.460-0.510	194-370
ACD	1000	1250	1428	1500	1875	2142	0.667	0.426	0.326	1.5	2.3	3.1	-	-	-

Fig. 7.1: Shows the relation between samples and ultrasonic velocity



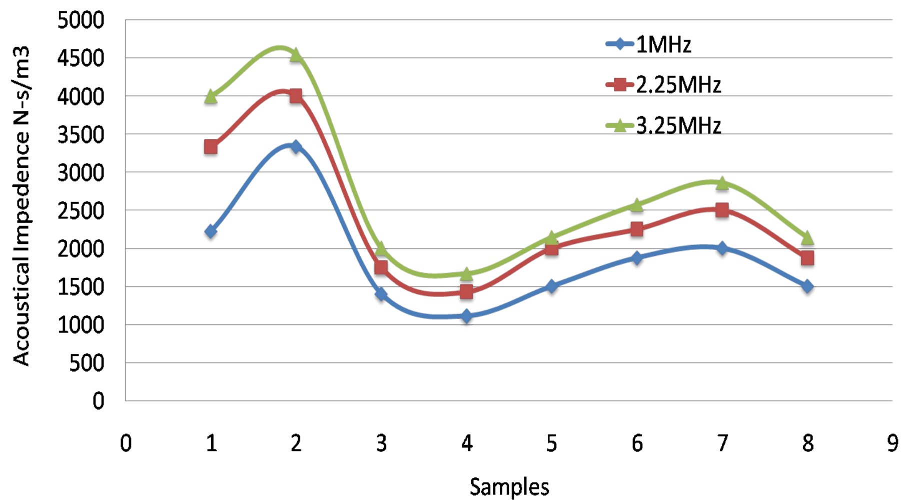


Fig. 7.2: Shows the relation between samples and Acoustic impedance

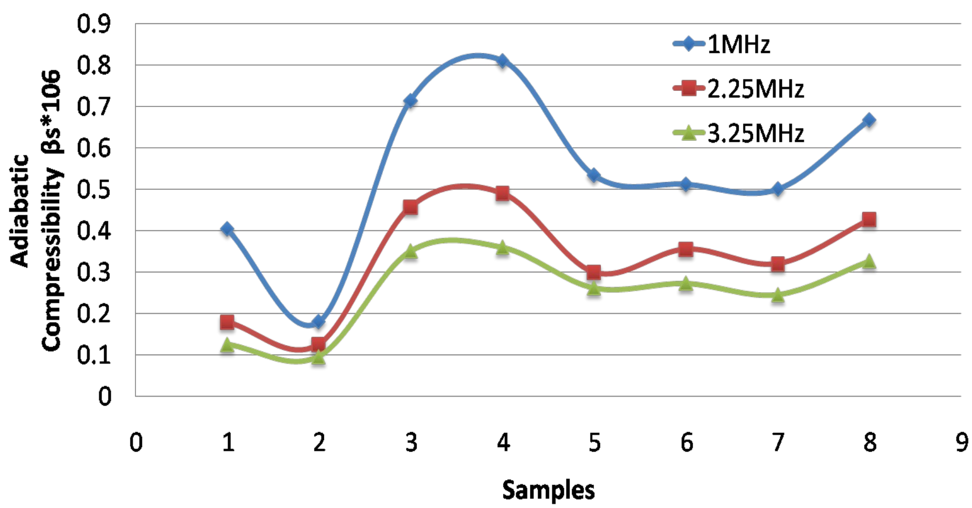


Fig. 7.3: Shows the relation between samples and adiabatic compressibility

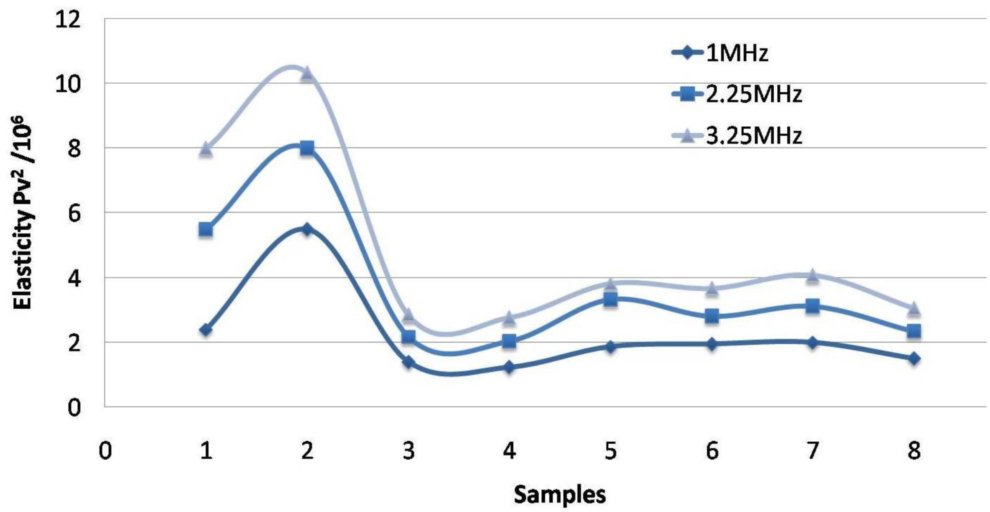


Fig. 7.4: Shows the relation between samples and elasticity

Ultrasonic velocity of Bengaljeli and Mango shows similar response at low frequency but at high frequency shows slightly greater variations. In acoustic Impedance, Adiabatic compressibility and Elastic behavior of both the samples have different and shows greater variations. Ultrasonic velocity of Pine, malabar neem and ACD shows similar response at both low and high frequency. These wooden samples also shows better variation in acoustic Impedance, Elasticity and Adiabatic compressibility. Sal, Rubber wood and Eucalyptus shows better response in all the parameters mention in the Table-7.1. As compare to ultrasonic velocity the greater variability in acoustic Impedance, Elasticity, Adiabatic compressibility, Specific gravity and Modulus of rupture of wooden material.

It is observed that ultrasonic velocity of different wooden samples increase with increase in density and elasticity. In Fig 7.1 sample (SA, AC) has maximum value of ultrasonic velocity and sample (ACD, MG, PINE) has minimum value. Which shows less variations at low frequency such as bengaljeli and mango but at high frequency (2.25 and 3.25 MHz) shows better variations. Pine, Malabar neem and ACD shows almost similar response. Different wooden samples have different fiber length and vessel elements in various sizes affect these parameters. The value of the velocity of sound in a material depends on the appropriate elastic modulus, which is characteristic of the nature of the vibrational stress applied to it and also on the density of material. In Fig 7.2 sample (PINE, EU,MD,ACD) shows better variations. Acoustic Impedance of wooden material give better response then ultrasonic velocity. Fig 7.3 shows Adiabatic compressibility has inverse response with greater variations. Fig 7.4 shows the elastic behavior of different wooden samples.

In this experiment thickness of the test samples are 5 mm and at different frequency 1MHz, 2.25MHz, and 3.25 MHz the variation of ultrasonic parameters like ultrasonic velocity, adiabatic compressibility, acoustic impedance, modulus of elasticity, modulus of rupture, and maximum crushing stress parallel to grain were found varying between 1000 to 1667 m/s, 0.180 x 10^{-6} to 0.67 x 10^{-6} Pa^{-1} , 1400 to 3334 N-s/m^2, 437 to 1066 kg/m^2, 200 to 599 kg/m^2 respectively. On the basis of ultrasonic velocity, bengaljeli, sal, pine, rubber and eucalyptus wood having different range from each other and it is easy to characterize but pine, malabar neem and ACD wood having same velocity range so it is difficult to characterize by this parameter. Therefore, we use other parameter like acoustic impedance, elasticity, specific gravity which having different range to characterize these wooden samples.

7.2 Ultrasonic characterization of five different wood using SEM

In second phase for feature extraction of wooden samples, ultrasonic parameters are given below in Table-7.2. The size of the test samples are nearly 1 inch and the parameters are found in longitudinal and transverse direction of five different wood. For SEM test the size of the samples are 8 x 8 mm and thickness of the samples are 2 to 4 mm and cut from the upper part of the samples. The variations in ultrasonic parameters of different wood samples depends on their fibrous structure. Ultrasonic velocity in longitudinal direction depends on the size of fiber. High dense fiber structure wood like sal having maximum ultrasonic velocity because denser fiber structure of wood require less reflection of ultrasonic wave. Those wood having less dense and swallon fibrous structure, such type of wood reflects the large amount of ultrasonic wave. But in transverse direction vessel elements and different pattern of fiber structure effected on the ultrasonic parameters. The size of vessel elements of acacia, teak and sal are almost same but vessels of acacia wood are slightly more than sal and teak. Therefore the variation occurs in the transverse ultrasonic velocity. Fibrous pattern difference in the wood structure also effected the ultrasonic wave in both the directions.

Table-7.2: Acoustical parameters of five different wood

Samples	Ultrasonic Velocity (V) m/s		Acoustic impedance (Z) N-s/m^3		Elasticity (E) Pa/10^9	
	(V_L)	(V_T)	(Z_L)	(Z_T)	(E_L)	(E_T)
Acacia auscriculformis	4142.85	1733.33	0.699	0.292	2.898	0.507
Eucalyptus	3466.67	2235.29	1.126	0.726	3.904	1.623
Malia Dubia composita	4375	2571.42	1.984	1.166	8.68	2.99
Sal	4929.57	1812.5	2.09	0.772	10.35	1.399
Teak Wood	4300	1777.77	2.925	1.209	12.58	2.150

V_L^{*} - Longitudinal velocity , V_T^{*} - Transverse velocity

Z_L^{**} - Longitudinal impedance , Z_T^{**} - Transverse impedance

E_L^{***} - Longitudinal elasticity, E_T^{***} - Transverse elasticity

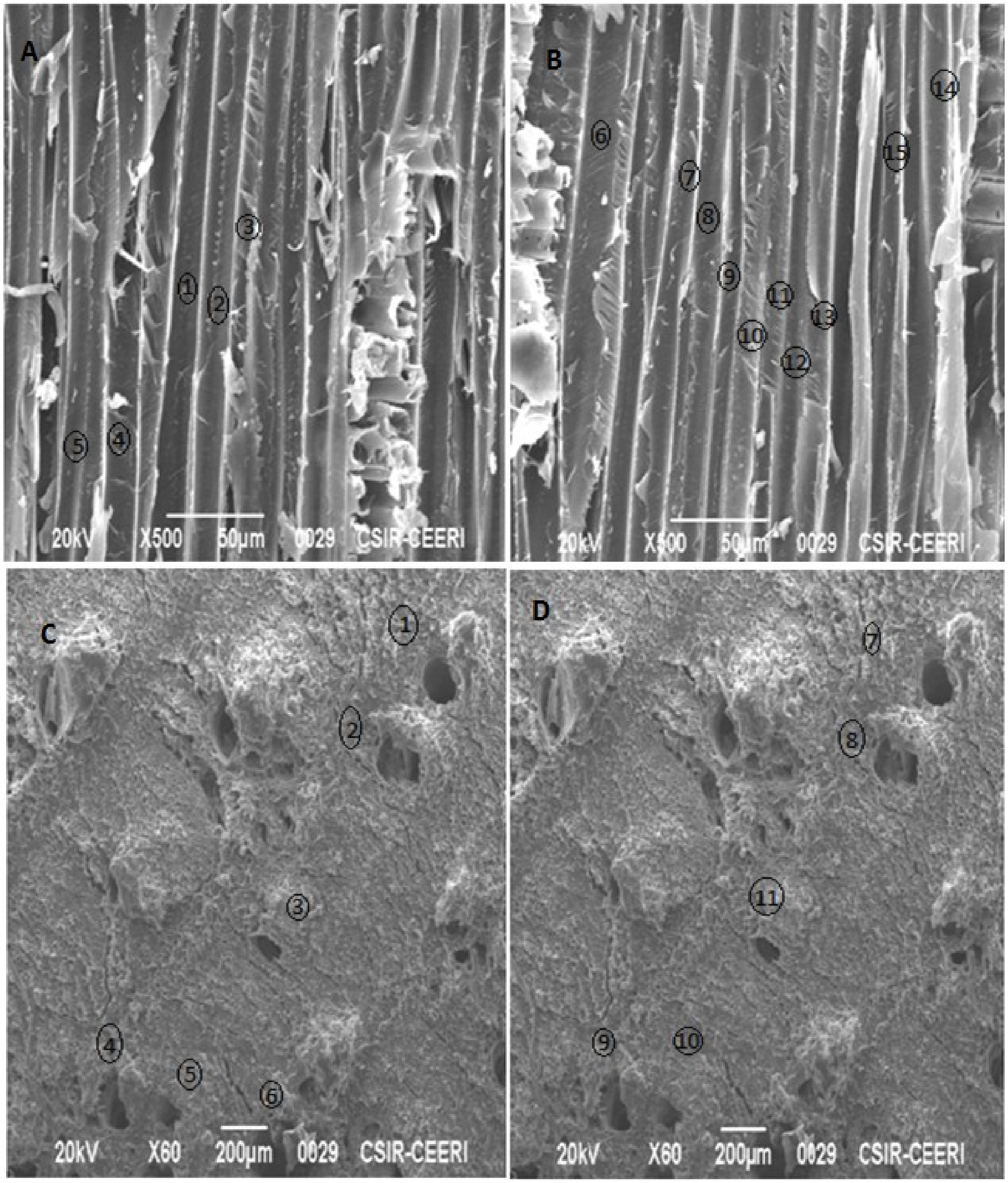


Fig- 7.5: SEM images of acacia wood A,B,C,D shows the structure of fiber and vessel elements.

Image (A) shows thickness of the radially fibrous pattern structure is small approximately 20-50 µm. (B) show the size of fiber, it is less swallon than (malidubia and eucalyptus) and similar to the sal. Image (C &D) the size of vessel elements 100-200 µ and distance between two vessel elements are less than 200 µm.

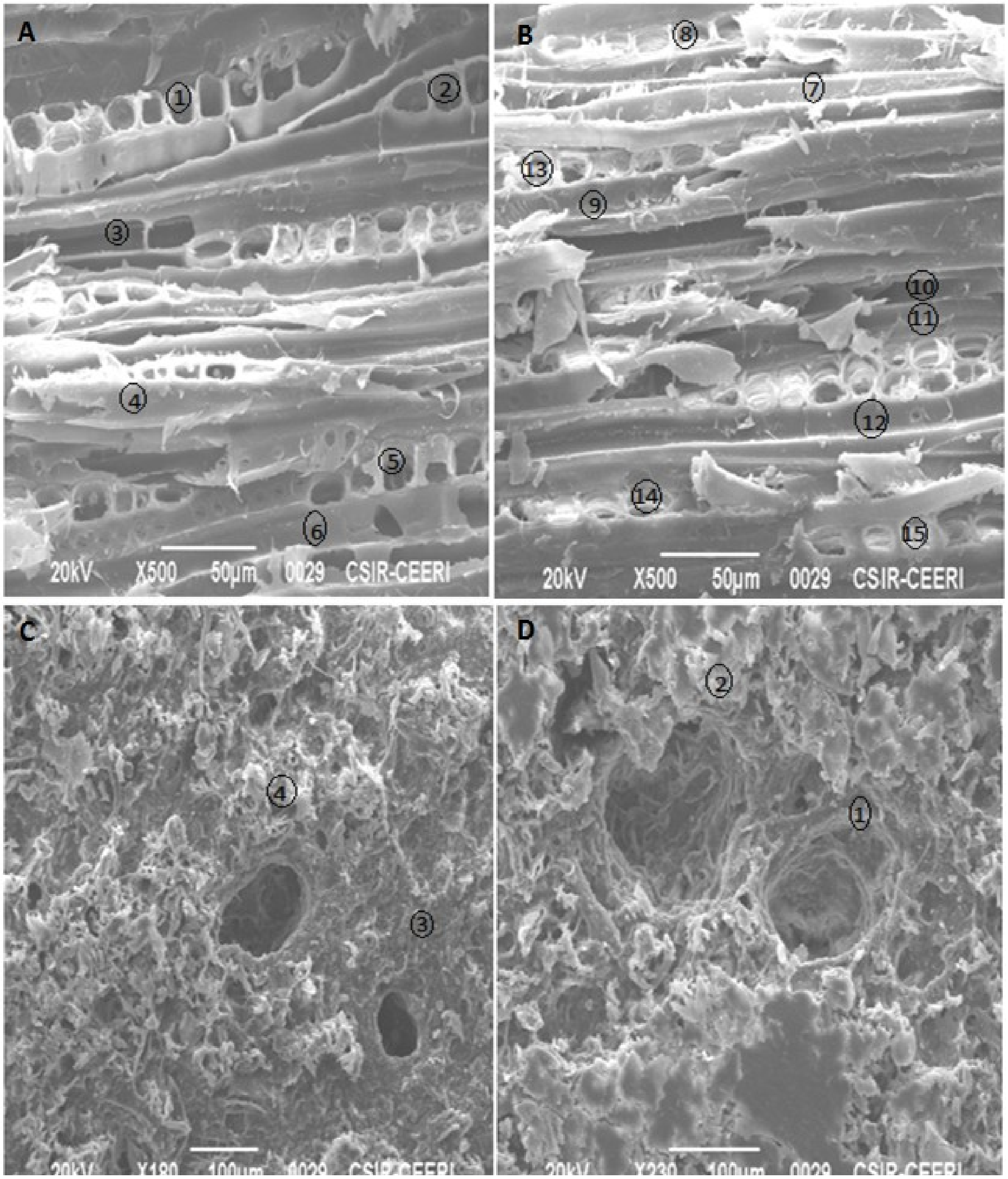


Fig-7.6: SEM images of eucalyptus wood A,B,C,D shows the structure of fiber and vessel elements.

Image (A & B) show eucalyptus wood having different type of pattern from others. It looks like a lattice type fibrous structure. Size of fibers are similar to the maliadubia composita wood. Image (C) vessel elements size are varies from 50-200 µm. (D) shows distance between vessel elements are more than 100 µm.

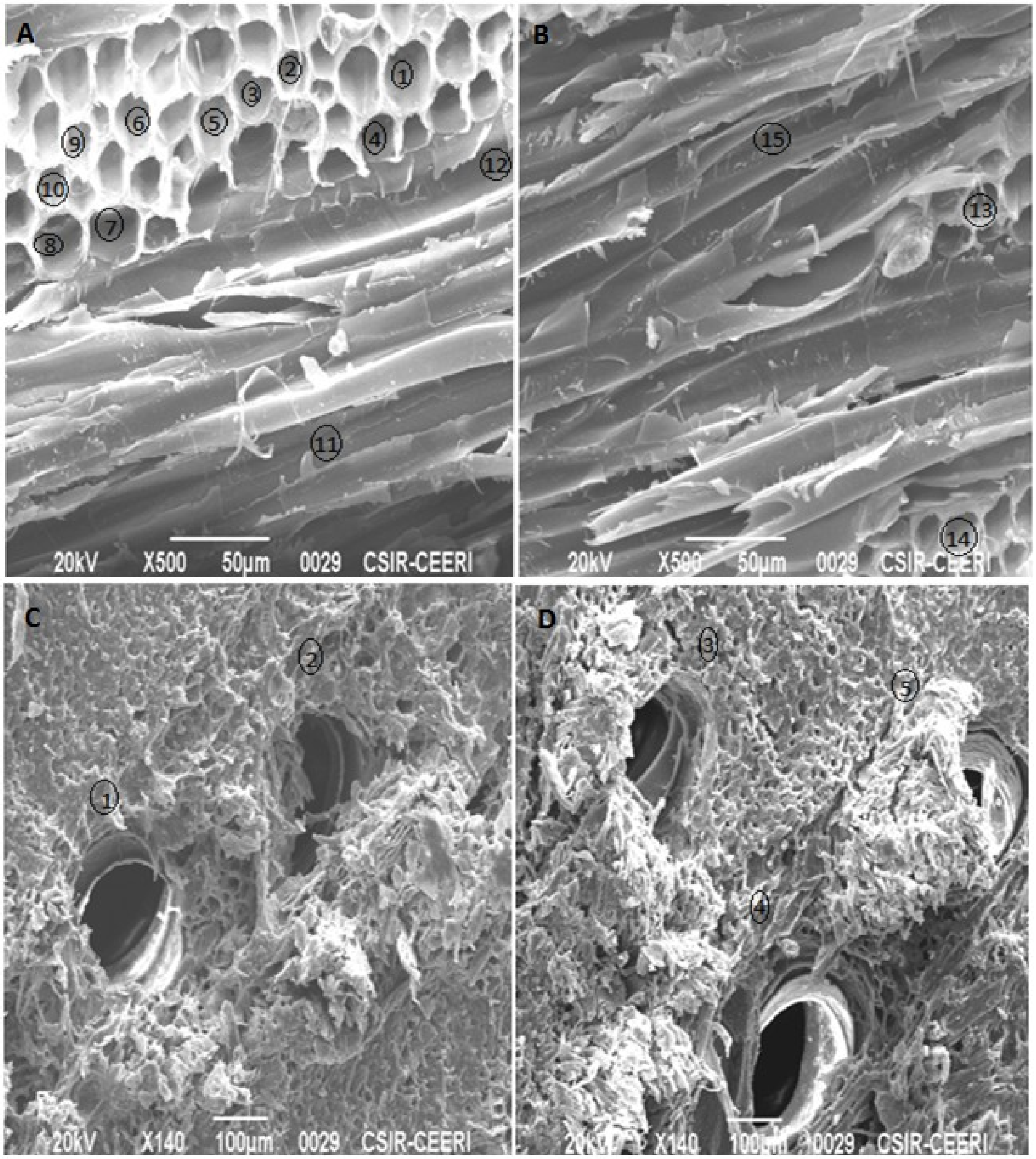


Fig- 7.7: SEM images of maliadubia composita wood A,B,C,D shows the structure of fiber and vessel elements.

Image (A) shows pattern difference between longitudinal and radially. Thickness of the radially pattern are 120 µm in size and (B) shows the size of fiber, thickness of maliadubia composita is simillar to the eucalyptus. It looks like a swallon fibrous structure as compare to other wood. Images(C&D) show vessel element (pores size) - 200-300 µm (less no of pores) and distance between vessel elements are nearly 250 µm.

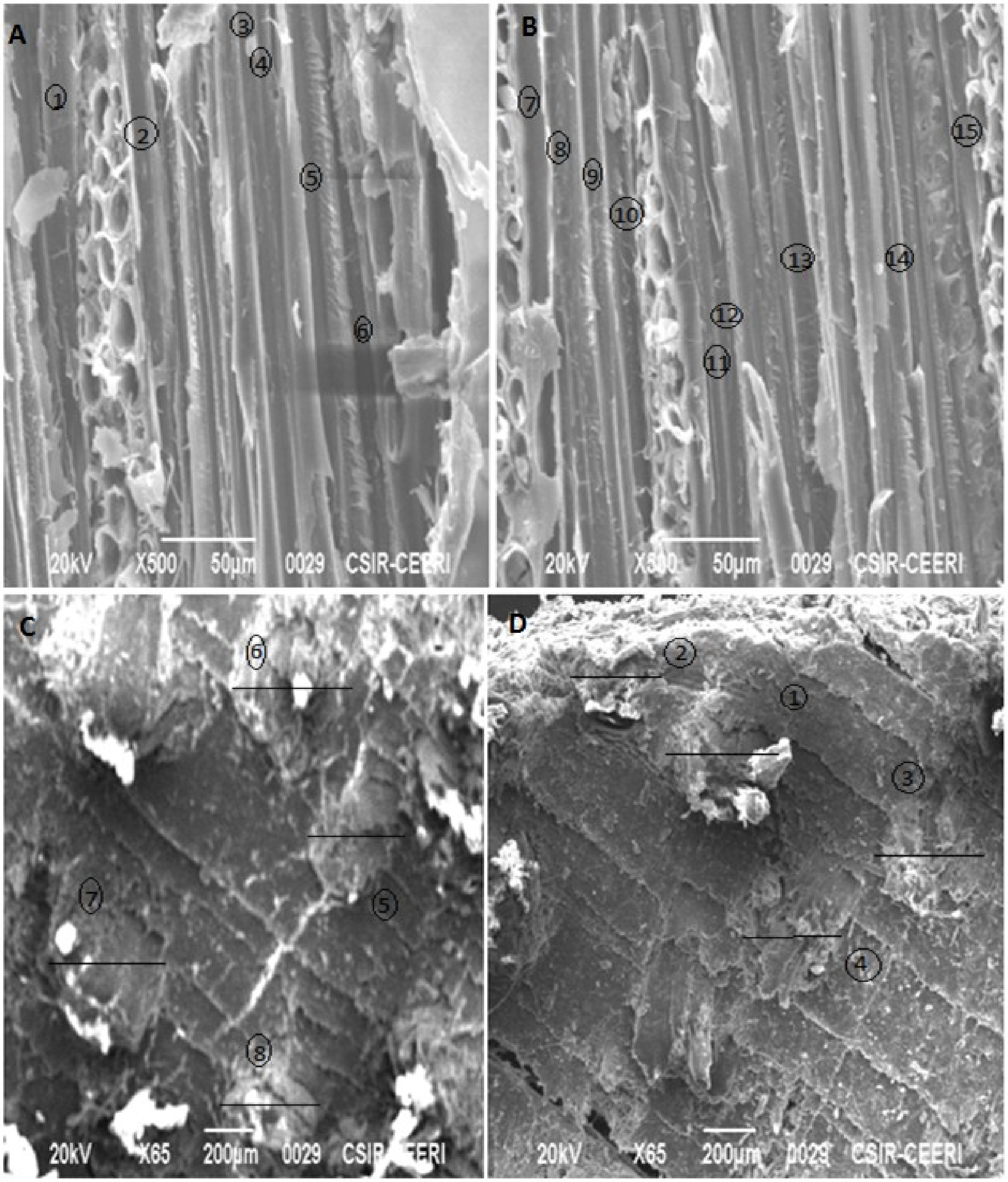


Fig-7.8: SEM images of sal wood A,B,C,D shows the structure of fiber and vessel elements.

Image (A) gives the information about fiber structure, which is small in size and dense. (B) thickness of the pattern (radially) is small nearly 20-50 µm but repeated number of times.(C) The size of vessel elements are varies from 300-400 µm. (D) distance between two vessel elements are 150-250 µm.

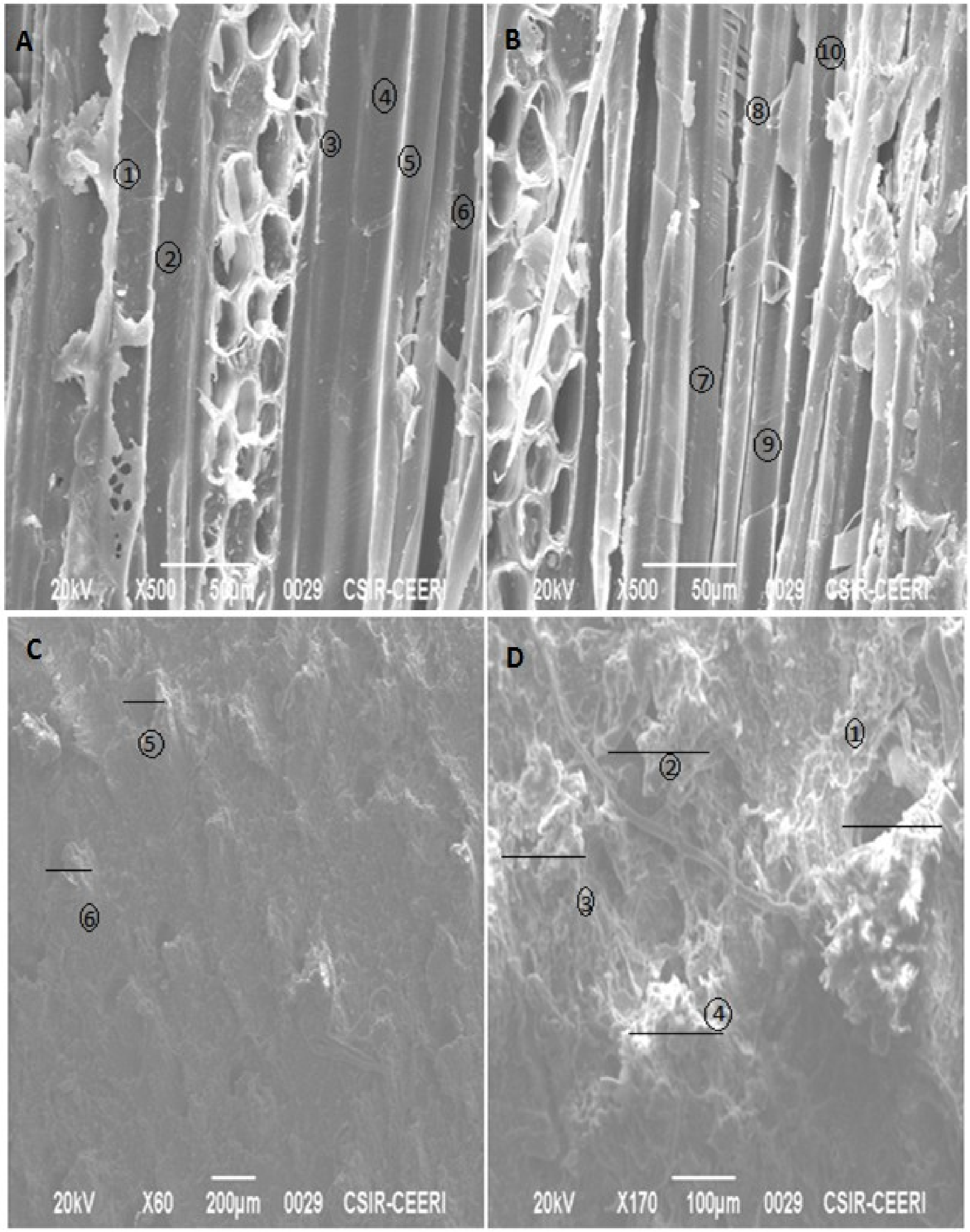


Fig-7.9: SEM images of teak wood A,B,C,D shows the structure of fiber and vessel elements.

Images (A&B) show size of the fiber is less swallon than maliadubia composita and thickness of the radialy pattern vary from 50-70 µm.(C) size of vessel elements are vary from 150-200 µm. (D) distance between two vessels are nearly 100 µm.

Ultrasonic velocity of maliadubia composita is 4375 m/s along the fibers and 2571.42 m/s in transverse direction. If the values are compared with different wood structure, size of vessel elements (300 μm) is large as compare to other woods. Due to this spacing between the fibers, which reflects the ultrasonic wave. The number of vessels are less as compare to other type of wood like (acacia, sal and teak). The pattern which is created by fibrous structure are less complex but not simple, such type of structure also effect on the ultrasonic parameters. Acacia wood having ultrasonic velocity 4142.85 m/s in longitudinal direction and 1733.33 m/s in transverse direction. The vessel elements of this type of wood are small in size and more as compare to maliadubia and eucalyptus. The number of vessels create more reflection of ultrasonic waves. In transverse direction acacia and maliadubia shows greater variations than longitudinal direction because large difference between both the vessel elements and fibrous structure. But sal, teak and acacia wood having almost similar structure of vessel elements and fibrous pattern due to this the ultrasonic velocity (1812.5,1777.77,1733.33 m/s) of these wood in transverse direction shows less variations. In longitudinal direction ultrasonic properties depends on fiber size. The fiber size of sal wood is small and dense fibrous structure than teak and acacia. Therefore the ultrasonic velocity difference in sal (4929.57 m/s) and other wood like teak (4300 m/s) and acacia (4142.85 m/s) are greater but teak and acacia wood having less variations in ultrasonic velocity because fiber size of both the wood are almost same. The fibrous structure of eucalyptus wood are different from other woods like sal, acacia, teak and maliadubia. Fiber size is similar to the maliadubia composita.

Mean Average of Acacia Auscriculformis wood: fiber sizes from different places of wood are 12, 15, 6, 18, 9, 21, 12, 18, 9, 12, 12, 13, 13, 13, 10 μm and the vessel element sizes are 150, 200, 100, 200, 150, 200, 150, 200, 200, 100, 150 μm.

$$A= S/N \tag{7.1}$$

where, A is the average (or arithmetic mean), N is the number of terms (e.g., the number of items or numbers being averaged), S is the sum of the numbers in the set of interest.

Mean average of the fiber size are 12.86 μm and vessel size are 163.63 μm. The maximum and minimum size of the fiber are 21 μm and 6 μm respectively. The range of the fiber is (21-6) 15 μm. The maximum and minimum size of the vessel element are 200 μm and 100 μm. The variance of the wood samples (average of the squared differences from the Mean.) are calculated. So the mean (average) size of fiber is 12.86 μm. If s be the standard deviation, than s^2 is the Variance.

$$\text{Variance } (S^2) = \text{summation } [(x - \text{mean})^2] / n-1 \tag{7.2}$$

$= [(12 - 12.86)^2 + (15 - 12.86)^2 + (6 - 12.86)^2 + (18 - 12.86)^2 + (9 - 12.86)^2 + (21 - 12.86)^2 + (12 - 12.86)^2 + (18 - 12.86)^2 + (9 - 12.86)^2 + (12 - 12.86)^2 + (12 - 12.86)^2 + (13 - 12.86)^2 + (13 - 12.86)^2 + (13 - 12.86)^2 + (10 - 12.86)^2] / (15 - 1) = 211.7298/14 = 15.123$ µm

The mean average of the vessel element is 163.63 µm, the variance of the vessel element is 1545.44 µm. Standard deviation of the fiber and vessel element are 3.89 µm and 39.31 µm respectively.

Eucalyptus wood having fiber sizes are 24, 24, 18, 22, 30, 26, 15, 18, 20, 15, 22, 18, 18, 20, 18 µm and vessel element sizes are 156, 169, 52, 104 µm. The mean average of fiber size are 20.53 µm and vessels element size are 120.25 µm. The maximum and minimum size of the fiber are 30 µm and 15 µm respectively. The range of the fiber is (30-15) 15 µm. The maximum and minimum size of the vessel element are 169 µm and 52 µm so the variance of the fiber size and vessel element is 17.26 µm and 2858.91 µm. Standard deviation of the fiber and vessel element are 4.15 µm and 53.46 µm respectively.

Maliadubia composita wood fiber sizes are 42, 24, 30, 26, 30, 30, 30, 30, 26, 24, 30, 28, 24, 30, 24 µm and vessel element sizes are 200, 320, 300, 280, 300 µm. The mean average of fiber size are 28.53 µm and vessels element size are 280 µm. The maximum and minimum size of the wood fiber are 42 µm and 24 µm respectively. The range of the fiber is (42-24) 18 µm. The maximum and minimum size of the vessel element are 320 µm and 200 µm. so the variance of the fiber size and vessel element size are 20.83 µm and 2200 µm. Standard deviation of the fiber and vessel element are 4.56 µm and 46.90 µm respectively.

Sal wood fiber sizes are 15, 8, 7, 6, 8, 7, 8, 12, 6, 8, 6, 6, 12, 9, 10 µm and vessel element sizes are 400, 320, 320, 400, 400, 420, 360, 360 µm. The mean average of fiber size are 8.53 µm and vessels element size are 372.5 µm. The maximum and minimum size of the fiber are 15 µm and 6 µm respectively. The range of the fiber is (15-6) 9 µm. The maximum and minimum size of the vessel element are 420 µm and 320 µm. so the variance of the fiber size and vessel element is 7.12 µm and 1478.57 µm. Standard deviation of the fiber and vessel element are 2.66 µm and 38.45 µm respectively.

Teak wood having fiber sizes are 20, 24, 19, 22, 18, 12, 18, 15, 18, 15 µm and vessel element sizes are 153, 187, 200, 200, 200, 200 µm. The mean average of fiber size are 18.1 µm and vessels element size are 190 µm. The maximum and minimum size of the fiber are 24 µm and 12 µm respectively. The range of the fiber is (24-12) 12 µm. The maximum and minimum size of the vessel element are 200 µm and 153 µm. so the variance of the fiber size and vessel element is 12.32 µm and 355.6 µm. Standard deviation of the fiber and vessel element are 3.50 µm and 18.85 µm respectively.

Samples		Ultrasonic Velocity (V) m/s	Acoustic Impedance (Z) N-s/m^3	Elasticity (E) Pa/10^9	Vessel element size (µm)	Fiber size (µm)	Thickness of fibrous pattern (µm)	Density	Samples	Average v standard dev vessel (µm)	
Maliadubia composita	L	4375	0.699	2.898	-	20-30	120	Less dense	S_1	260 ±84.85	
	T	2571.42	0.292	0.507	200-300	-			S_2	293.33 ±11.54	
Acacia auscricalformis	L	4142.85	1.126	3.904	-	10-15	20-50	Medium dense	S_1	166.66 ±40.82	
	T	1733.33	0.726	1.623	100-200	-			S_2	160 ±41.83	
Teak	L	4300	1.984	8.68	-	15-20	50-70	Less dense	S_1	185 ±22.19	
	T	1777.77	1.166	2.99	150-200	-			S_2	210 ±14.14	
Sal	L	4929.57	2.09	10.35	-	5-10	20-50	High dense	S_1	360 ±46.18	
	T	1812.5	0.772	1.399	300-400	-			S_2	385 ±30	
Eucalyptus	L	3466.67	2.925	12.58	-	20-30	Like lattice type fibrous structure	Less dense	S_1	162.5 ±9.19	
	T	2235.29	1.209	2.150	50-200	-			S_2	78 ±36.76	

L^* - Longitudinal, T^{**} - Transverse, S_1^{***} - Sample1, S_2^{****} - Sample2

Table 7.3: Compare the acoustical parameters with structural parameters of five different wooden samples

In this Table-7.3, it is shown that five different samples like maliadubia composita, acacia auscricalformis, teak, sal, eucalyptus. Two samples of each wood is taken into consideration. The ultrasonic parameters of these five different samples are find out for characterization. Firstly; as shown in table it is considered three ultrasonic parameters like elasticity, ultrasonic velocity, acoustic impedance. These parameters are calculated in longitudinal and transverse directions. Now if the calculated range of two or more samples lies within a single ultrasonic parameter's range; then the other ultrasonic parameter is considered for characterization. Secondly the ultrasonic parameters are correlated with structural parameters for feature extraction of wood. The three different structural parameters taken in to consideration are fiber size, vessel element size and thickness of fibrous pattern. The structural parameters values are taken from the SEM images. The range of vessel element size and fibrous size is shown in Table- 7.3 and thickness is calculated in µm. The thickness of fibrous pattern is also helpful in determining the density of wood. In this study it is seen that the thickness of the material is inversely proportional to the density, therefore, thickness of fibrous size decreases as increases the density of the wood.

After correlation; the standard deviation of the wood sample is calculated which characterizes the particular sample range. The standard deviation is calculated by taking different fibrous sizes and different vessel sizes in to consideration. For standard deviation; firstly the mean is calculated by taking different values of fibre sizes and vessel element sizes of two different samples of single wood.

For feature extraction average , variance and standard deviation of different wood samples have been calculated. The average of fibers and vessel elements, where different wood samples lies are maliadubia composita (25.41-29.16 and 260-293.33), acacia (12.6-14.44 and 160-166.66), teak (17.16-19.16 and 185-210), sal (8.56-9 and 360-385), eucalyptus (18.22-23 and 78-162.5) in µm. The range of the variance in fiber and vessel element of five different wood samples are maliadubia composita (22.09-25.10 and 133.17-7199.52), acacia (11.08-13.3 and 1666.27-1749.74), teak (3.76-16.89 and 199.93-492.39), sal (5.76-7.95 and 900-2132.29), eucalyptus (5.15-14.44 and 84.45-1351.29) in µm. And the standard deviation of fiber and vessel element of different wood samples are maliadubia composita (±4.70 to ±5.01 and ±11.54 to ±84.85), acacia (±3.33 to ±3.80 and ±40.82 to ±41.83), teak (±1.94 to ±4.11 and ±14.14 to ±22.19), sal (±2.40 to ±2.82 and ±30 to ±46.18), eucalyptus (±2.27 to ±3.80 and ±9.19 to ± 36.76) in µm respectively.

By mathematical formulation, the extracted features are average, variance and standard deviation. Using these parameters particular wooden sample are distinguish from each other. This can be stated with the help of observations it is carried out. The database of several wooden samples like maliadubia composita, acacia, teak, sal and eucalyptus has been prepared .It can be seen that for a particular sample two measurements have been made (longitudinally as well as transversely). When a sample is treated longitudinally; two SEM images are taken so as to get the précised range of the thickness of the fiber and when it is treated transversely; two SEM images are taken so as to get the précised range of the vessel element size. So as a result have two ranges for an individual sample. The range so obtained is used to distinguish between the different samples taken.

7.3 Limitations

The limiting factor in current research is that the availability of required number of samples are less and better results can be obtained by using classifier over large number of samples and use of classifier is necessary for more feature extraction and for better results. The problem in the SEM test is sample preparation. Because hard finishing paper damage the surface of wood, so it required the soft finishing paper for preparation.

CHAPTER 8
CONCLUSION AND FUTURE SCOPE

8.1 Conclusion

The NDT method on different wooden samples namely acacia auscricalformis (Bengaljali), eucalyptus tereticornis (Eucalypts), meliadubia composite (Malabar neem), Shorearobusta (Sal), teak etc. has been implemented for finding the physical parameters like ultrasonic velocity, density, impedance, elasticity. In this it is compared these physical ultrasonic parameters with structural data of wood. It has been found that the variation occurs in the physical parameters depend on the fibrous structure and vessel element size. Given the above mentioned results, it is concluded that ultrasonic parameters in longitudinal direction is two times faster than transverse direction. This difference in longitudinal and transverse ultrasonic parameters has been determined by structural parameters of wood. It depends upon the fibrous pattern, vessel element size and fiber size of wood. By comparing these structural parameters with acoustical parameters, concludes that only the structural ranges cannot be the sole criteria for distinguishing different samples, so additional information is required. Parameters like average with standard deviation and variance are taken into consideration.

8.2 Future consideration

The NDT method is applied on wood samples to determine the physical parameters which is then compared with fibrous structures which further leads to satisfactory results but still work can be done in this field. In future if someone implement classifier over obtained results than someone might achieve better results, and for that it is require to have large number of samples for test, proper sample preparation and extra features such as texture, periodicity, regularity, surface- roughness have to be considered on large data samples.

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