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PHYSICAL, ANATOMICAL AND TREATMENT CHARACTERISTICS OF THE WOOD OF *COLA GIGANTEA* AND *FICUS SUR*

By

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BSc (Hons) Natural Resources Management

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by

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DECLARATION

I thereby declare that this submission is my own work towards the MPhil award and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University , except where due acknowledgement has been made in the text.

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ABSTRACT

A nation – wide market survey study discovered that more than 47 timber species are being sold on Ghanaian market whose technological properties are not known. Therefore to ensure efficient utilization and promotion of these timber resources, their technological properties must be determined. Two species namely *Cola gigantea* and *Ficus sur* were selected to determine their technological properties. This study focused on the green and air – dried moisture contents, basic density, anatomical properties and the treatment characteristics of *Cola gigantea* and *Ficus sur* from Pra – Anum Forest Reserve in the Moist Semi Deciduous Forest Zone of Ghana. The green and air – dried moisture contents were determined using ASTM D4442 – 07; basic density of the species was done using the immersion method ASTM D2395 – 07a and the anatomical description using IAWA committee, 1989 protocols. The treatability studies was conducted using 0.5 % Copper Chrome Arsenate type C (CCA – C) preservative AWPA P5 – 08 and vacuum-pressure impregnation method by varying the pressure magnitudes (600 kPa to 1200 kPa) and treatment durations (30 to 240 minutes). The depth of penetration was done by AWPA A3 - 08, the assessment of permeability of the wood species by Fougerousse, 1976 method and preservative oxide retentions by AWPA A9 - 01. The heartwood of *C. gigantea* has significantly higher green moisture than its sapwood at $P<0.05$. There was no significant difference in green moisture content between the sapwood and heartwood of *F. sur* at $P\geq0.05$. Green moisture content varied along the bole of both species. Air – dried moisture content varied slightly within and between species but the differences was not significant. Mean basic densities were

479 kg/m^3 for *Cola gigantea* and 386 kg/m^3 for *F. sur*. The mean basic density values for sapwood of both species were significantly different at $P< 0.05$ from their respective heartwood. The mean basic densities varied from the butt to the top portions of both species. The ground tissue proportions namely vessels: parenchyma: fibres were 8 %: 43 %: 49 % for *C. gigantea* and

9 %: 47 %: 44 % for *F. sur*. The fibre length, lumen diameter and double wall thickness were 2.0 mm, 14.8 µm and 9.9 µm for *C. gigantea* and 1.5 mm, 23.9 µm 7.5 µm for *F. sur*. There was no significance between sapwood and heartwood volumetric retention of both species. *F. sur* significantly has higher volumetric retention than *C. gigantea* at $P \leq 0.05$. The ratio of mean longitudinal to transverse penetrations was about 32 to 1 for *C. gigantea* sapwood and 39 to 1 for its heartwood and those of *Ficus sur* sapwood and its heartwood were 22 to 1 and 24 to 1 respectively. The ratio of longitudinal to transverse penetrations was 36 to 1 for *Cola gigantea* and 23 to 1 for *Ficus sur*. The sapwood of *F. sur* and heartwood of both species were rated as moderately resistant when treated at 1200 kPa for 30 minutes or more whilst the sapwood of *C. gigantea* was rated as moderately resistant when treated at 1200 kPa for at least 60 minutes. The heartwood of both species is relatively more permeable than their respective sapwoods. For the same range of pressure magnitude and duration as well as 0.5 % CCA-C concentration used in this study, the mean oxide retention of *Cola gigantea* sapwood ranges were 1.41 to 2.21 kg/m^3 and its heartwood were 1.39 to 2.29 kg/m^3 and those of *Ficus sur* sapwood were 1.86 to 3.21 kg/m^3 and 1.89 to 3.19 kg/m^3 for its heartwood. *Ficus sur* can also be used as substitute for *Triplochiton scleroxylon* (wawa), *Pycnanthus angolensis* (otie) and *Antiaris toxicaria* (kyenkyen). Both species are treatable and therefore can be impregnated with adequate amount of preservative to prolong their service life.

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TABLE OF CONTENT

LIST OF TABLES

LIST OF PLATES

LISTS OF FIGURES

CHAPTER ONE

1.0 Introduction

The forest provides several good and services to maintain the integrity of the ecological system and human wellbeing. The formal timber industry sector employs about 100,000 people and contributes about 6% to Ghana's Gross Domestic Products (GDP) (Marfo, 2010). Ghana earned averagely about USD 224 million annually from 2004 to 2009 (TIDD, 2011). Ghana's forest resources are being depleted at an alarming rate of about 5% per annum through unsustainable logging, bushfire, mining activities etc (Marfo, 2009). This has led to reduction in wood products exported from 455,180m^3 in 2004 to 426,222m^3 in 2009 with associated reduction in foreign exchange from USD 216 million in 2004 to USD 192 million in 2009 (TIDD, 2011). The Government of Ghana is seeking to increase the use of local raw materials (including bamboo and less used species) in the building and construction industry to at least 60% by the year 2015 (National Housing Policy, 2010). Therefore, it has become necessary to generate scientific information on the available lesser used species (LUS) to augment and / or replace those species that are being overexploited. In 2009, Timber Industry Development Division (TIDD) and Council Scientific and Industrial Research – Forestry Research Institute of Ghana (CSIR - FORIG) conducted nation – wide survey to gather data on timber species that are available on Ghanaian market and are being utilized. It was found that over 47 timber species whose technological properties are not known are being sold and utilized in Ghana and sometimes exported to neighbouring countries. CSIR – FORIG therefore designed the second phase of utilization of LUS in Ghana focusing on determination of the physical, technological and working properties of those species to ensure their efficient utilization and promotion. In 2010, CSIR – FORIG selected two species namely *Cola gigantea* (Watapuo) and *Ficus sur*

(Kotreamfo) which were among the common timber species being used by Ghanaians for roofing members and other applications. The Institute therefore decided to work on wood from Pra-Anum Forest Reserve in the Moist Semi-Deciduous Forest Zone for 2010 and the subsequent work will consider the wood from other ecological zones. This thesis therefore centered on the physical, anatomical and treatment characteristics of *Cola gigantea* and *Ficus sur*, an aspect of the CSIR – FORIG Government of Ghana 2010 Project. Scheffer (1973) stated that annual losses of over $1billion in the United State resulted from only fungal deterioration of untreated or inadequately treated wood and Hamer (1983) also reported that annual losses and control costs for subterranean termites in nine states of the southeastern United State were estimated at $435 million. Hence the need to study treatment characteristics cannot be underestimated. Brazier (1995) listed five factors one has to consider when selecting wood for permanent applications in hazardous environment. One of the five factors was; the wood must be naturally resistance to bio-deteriorators or non durable wood species must be permeable and capable of receiving preservative. This statement buttresses the need to generate information of the permeability classes of these species. *Cola gigantea* belongs to Sterculiaceae family and is very common in Ghana. The tree can grow to about 50m high and 5m in girth with 90cm as the prescribed minimum felling diameter (Oteng-Amoako, 2006a). According to Oteng-Amoako (2006a), the wood is rated non-durable and Frimpong – Mensah (2008) quoted 671kg/m^3 as its density at 19% moisture content. *Ficus sur* is a member of Moraceae family and can grow to about 45m high and 3m girth. It is sparsely distributed on farmlands and degraded forest in Ghana. The wood is rated perishable with density at 12% moisture content ranges 300 – 650kg/m^3(Lumbile and Mogotsi, 2008). The major objective of the study is to determine some physical and anatomical properties as well as the treatment characteristics of *Cola gigantea* and *Ficus sur* using Copper Chromium Arsenate type – C (CCA - C) preservative and full cell vacuum-pressure impregnation method.

The studies have the following specific objectives:

- To determine the basic density, green moisture content and air-dried moisture content and the extent of variation (radially and axially) of the selected species
- To determine the fiber wall thickness, lumen diameter, length, various tissue proportions and describe the anatomical features of *Cola gigantea* and *Ficus sur* based on International Association of Wood Anatomist (IAWA) list of microscopic features for hardwood identification.
- To determine the permeability variation between the sapwood and the heartwood of *Cola gigantea* and *Ficus sur*
- Assess the effect of pressure magnitude and pressure duration on permeability and on both volumetric and oxide retentions

CHAPTER TWO

2.0 Literature review

2.1 Timber supply in Ghana

Forest play major role in Ghana's economy through employment creation, revenue generation and other unquantifiable environment and ecological services. According to Marfo (2010), the formal timber industry contributes about 6% to Ghana's Gross Domestic Product (GDP) and the chain – saw milling industry though illegal, contributes additional GHC 279 million to Ghana's economy. The formal timber industry employs about 100,000 and additional 130,000 are engaged in Chain – saw milling operation. Timber industry was the fourth contributor to Ghana's foreign exchange (Marfo, 2010). Ghana's forest resources are being depleted at an alarming rate of about 5% per annum through unsustainable logging, bushfire, mining activities etc (Marfo, 2009). This has led to reduction in volumes of the primary species and the 'acceptable' lesser used timber species in both the reserve and off – reserved forests areas, thus posing threat to the raw material base of the timber industry which could lead to unemployment and decreased foreign exchange from timber export (Owusu *et al*, 2010). According to the National Housing Policy (2010), Ghana faces acute housing deficit of one million units especially in the urban centers and therefore the government seeks to increase the utilization of local raw materials in the building and construction industry(including bamboo and lesser used species) to at least 60% by the year 2015. This policy direction will put more pressure on already degraded forest resources, hence the need for increasing the number of utilizable timber species as well as expansion of plantation development cannot be overemphasized. In order to increase the number of timber species for the timber industry and domestic consumption, it is necessary to generate information on the standing volumes, physical, technological as well as the working properties of the available species to ascertain their suitability for specific end-uses. Utilizing more of the LUS which are in considerable volumes in the natural forest could be considered as one of the possible solutions to arrest the shortage of wood which may intend save the timber industry from total collapse. Foli *et al* (2009) noted that for Ghana to meet the expected future demand for wood, the planting rate of 10,000 – 20,000 hectares must be embarked upon annually. Unfortunately, most of the known durable species have extremely long rotational period to attain harvestable girth. According to Foli *et al* (2009) *Nauclea diderrichii* (Kusia), a very durable timber species will require between 52 – 64 years and non-durable *Terminalia superba* will take 34 years to attain 60cm girth at breast height whilst *Cedrela odorata* attains 50cm within 20years, all under plantation establishment. Therefore the country has to make a choice either to rely on the durable timbers with longer rotational periods or fall on the fast growing but non-durable lesser used species for her lumber supply. Relying on the fast growing species will however increase the vegetation cover within fastest possible time so as to perpetuate the environmental and ecological services rendered by the forest both locally and globally as well as sustaining the timber supply to the industries for export and domestic market. Non-durable but fast growing timber species whether from the natural forest or plantation can be treated with appropriate wood preservative to increase their service life which sometimes may last longer than naturally durable species. Wood as a valuable and versatile renewable natural resource with an extremely wide range of uses are liable to degrade by physico-mechanical, chemical and most importantly biological agents. Scheffer (1973) stated that annual losses of over $1billion in the United State result from only fungal deterioration of untreated or inadequately treated wood. Zabel and Morrell (1992) added that decay caused by mushroom fungi is the most prevalent and destructive type of wood deterioration because it can cause rapid structural failure and well over

10% of the annual volume of timber harvested in US is used to replace wood that has deteriorated in service. Therefore, resistance of wood to these degrading agents has been a yard stick for selecting timber species for any permanent end use.

2.2 Wood degrade

Wood degrade is the decline in quality and quantity of wood substance by biological, chemical, physico – mechanical and fire (FAO 1986; Desch and Dinwoodie 1996). According to Desch and Dinwoodie (1996) biological degradation is the most destructive among the known wood degradation agents and has received much attention in both wood research and industry

2.3 Bio-deterioration

Bodig and Jayne (1982) noted that, microorganisms responsible for deterioration of plant tissues are an essential part of all terrestrial ecosystems. The ecosystem cannot function without them. Not only would all growing space be occupied by an enormous accumulation of undecayed plant tissues but most importantly the chemical elements essential for plant growth would be locked up in the existing plants. Although, microorganisms are essential to the continuation of life processes, it is necessary to exclude them from the environment of wood and wood composite in use. The degradation of wood which results from the decaying fungi and insects can limit the function and even endanger the integrity of wood structures. Several living organisms attack wood for different purposes which eventually decline its structural integrity. Notable among them are:

a. Fungi
    i. Stainers and moulds
    ii. Basiodiomycetes (brown rot and white rot)

iii. Soft rot

b. Bacteria

c. Wood destroying animals

i. Wood boring beetles

ii. Termites

iii. Marine borers

2.3.1 Fungi

Scheffer (1973) stated that annual losses of over $1billion in the United State resulted from only fungal deterioration of untreated or inadequately treated wood. Zabel and Morrell (1992) confirmed that decay fungi is the most prevalent and destructive type of wood deterioration because it can cause rapid structural failure and over 10% of the annual volume of timber harvested in US is used to replace wood that has deteriorated in service.

2.3.1.1 Stainers and moulds

Staining fungi do not attack lignin and cellulose in the wood but live on the carbohydrates present in parenchyma cells, especially in rays. They thrive in moist, warm and humid condition. The sapwood of most species of timber is susceptible to fungal staining which can occur in both logs and sawn wood. They can rapidly discolour sawn timber and the sapstain (blue stain) is the most commonly occurring stains (Kollman and Côte 1984; Viitanen and Ritschkoff 1991)

Moulds are caused by fungi which produce powdery or wooly mycelia growth and masses of spores on timber surfaces. The most common colours of these surface moulds are black, brown, shades of green and occasionally orange (Kollman and Côte, 1984; Viitanen and Ritschkoff, 1991). Stainers and moulds are very prolific and have no capacity to utilize cellulose and lignin content of wood hence they have negligible effect on the strength of timber. However, they can cause severe damage to paintings, textiles and surfaces of different materials. Sapstains causes significant economic losses but improves water permeability (Kollman and Côte 1984; Viitanen and Ritschkoff 1991; Clausen and Kartal 2003).

2.3.1.2 Basidiomycetes

2.3.1.2.1 Brown rot

Brown- rot fungi is the most destructive and prevalent type of wood deterioration because it can cause rapid structural failure. Initial colonization of the fungi can cause considerable strength reductions before measurable weight loss occurs (Imamura 1993; Kim *et al* 1996; Clausen and Kartal 2003). Highley (1999) stated that toughness is reduced by between 6% and more than 50% before 1% weight loss is recorded, and strength losses may exceed 50% before 10% weight loss is realized. Brown rots attack mainly the cell wall carbohydrates and early losses in hemicelluloses mainly arabinan and galactan were associated with early strength loss (Winandy and Morrell, 1993). Viitanen and Ritschkoff (1991) explained that the rate of depolymerization of cellulose occurs rapidly in the earlier stages of decay causing dramatic change in the overall strength properties of wood. The S_2 layer is usually intensively degraded whilst the tertiary layer remain relatively unattacked, therefore the wood shrinks, cracks and turns brown in the advanced stages of decay.

2.3.1.2.2 White rot

White rot fungi attack both lignin and cellulose and degradation proceeds from the S_3 layer outwards. Degradation products are consumed as they are produced leaving behind a spongy mass with the wood surface remaining unchecked during drying. Hardwoods and wood in ground contact are very susceptible and are the major cause of joinery decay (Kollman and Côte, 1984; Viitanen and Ritschkoff 1991; Desch and Dinwoodie, 1996)

2.3.1.3 Soft rot decay

Soft rots are caused by Ascomycetes and fungi imperfecti. The surface of the affected wood is typically softened. Both softwoods and hardwoods may be attacked but hardwoods are very susceptible. They are characterized by hyphae which produce tunnels in the cell walls that run along the grain and are generally confined to the less lignified S_2 layer of the secondary walls. In hardwoods, soft rot fungi attack fibers in preference to other types of cells. Soft rot occur on the surfaces exposed to persistently wet conditions and in warm humid places. Wood attacked by soft rot retains its original shape, but the surface becomes discoloured, softened and eroded. The rotted surface is crumbly and shows numerous fine cracks and fissures on drying (Kollman and Côte 1984; Desch and Dinwoodie, 1996; Clausen and Kartal 2003)

2.3.2 Bacteria

They are usually early colonizers of wood in wet conditions. The bacteria degrade pectin and hemicelluloses in the pore membranes of wood cells and permeability of wood is increased (Viitanen and Ritschkoff 1991). Wood storage in water or water spraying of wood is used to prevent fungal attack but improves bacteria hydrolysis which is very essential for the treatment of refractory species.

2.3.3 Wood destroying animals

According to FAO (1986), there are three categories of wood destroying animals namely boring beetles, termites and marine borers. They are generally insects with most of them relying on micro fungi for their nutrition in a symbiotic way. In many tropical countries, they cause serious damage to all kinds of timber structures.

2.3.3.1 Ambrosia beetles

Ambrosia beetles or pinhole borers present serious problem in the tropics than they are in the temperate countries. They attack freshly felled logs and are characterized by their peculiar form of feeding. They do not derive any nourishment from the wood itself but feed on certain moulds (ambrosia fungi) which grow on the walls of the tunnels which they make in the wood. Since this mould can grow only in unseasoned and air dried timbers with high moisture content the beetles themselves cannot breed or survive for long in seasoned timber (FAO 1986; Farrel *et al* 2001; Price 2005; Sittichhaya and Beaver 2009). When the beetles are active, their attack may be recognized by the fact that only fresh logs are attacked, by the roundedness of the hole, by the size (pin hole), and by the powdery frass that are ejected from the tunnels, sometimes in a short strings. In dry or converted timber, damage by ambrosia beetles is recognized by the black staining of the tunnels which is caused by the fungus. The Ambrosia fungus does not destroy the wood but only lives on the starch and sugars of the sap (FAO 1986, Farrel *et al* 2001; Price 2005; Sittichhaya and Beaver 2009; Kangkamanee *et al* 2010)

2.3.3.2 Powder Post Beetles

These beetles are so called because of the powdery frass produced by the adults boring into the wood. They are capable of attacking dry timbers and their attack is confined to the sapwood since the starch constitutes an essential element in their diet. There are a number of insects that produce so called ‘powder post’ defects in wood. Both the adult and larvae or grubs of these insects bore through the wood for food and shelter, leaving the undigested parts of the material in the form of a fine powder. The major powder post beetles are the Lyctus and Bostrychids (FAO 1986; Halperin and Geis 1999; Ivie 2002; Cookson 2004; Liu *et al* 2008; Sittichaya and Beaver 2009; Kangkamanee *et al* 2010)

2.3.3.3 Longhorn beetles

In most cases, longhorn beetles start their attack on living trees. Eggs are laid in the bark and the larvae bore tunnels into wood parallel to the longitudinal axis of the tree. The larvae may persist in the wood after the tree is felled since they can tolerate dry conditions. Longhorn beetle's attack can be recognized by the fact that larvae tunnels are much larger and elliptical in cross section, instead of rounded as from other beetles. Longhorn beetles are usually larger than other wood borer (FAO 1986)

2.3.3.4 Carpenter Bees

These are not very common type of pest in buildings but when they do occur, they continue for generations in the same timber and complete structural destruction may be caused. Generally, attack is confined to the exposed timber therefore attack is visible as soon as it starts. They do not feed on the timber but construct tunnels for shelter which are partitioned into cubicles in which eggs are laid. The larva feed on bee-bread or pollens and pupates in that cubicle. The adults emerge by gnawing its way out of the wood. With such a short life cycle, severe damage can occur in a short time. (FAO, 1986)

2.3.3.5 Termites

Creffield (1996) stated that termites are among the few insects capable of utilizing cellulose as a source of food. Since cellulose is a major component of tissues, majority of plant products are very susceptible to termite damage. Termites are very important wood destroying insect because of the active role they play in nutrient recycling. Termites, sometimes called ‘white ants’, are found in virtually all parts of the world with the exception of the Arctic and Antarctic regions (Kollman and Côte, 1984; AWPA U1 – 08, 2008). Damage caused by termites is generally far more serious when they occur in the tropical and sub-tropical areas. It is estimated that there may be as many as 5000 species of termites in five families of order Isoptera (Kollman and Côte 1984). Termites are gregarious insects living in large colonies with a well-developed caste system (soldiers, workers and queen). Termites invade wood for purpose of obtaining shelter and securing food. They are able to attack both seasoned and unseasoned timbers but are unable to utilize this material directly but rely on protozoa that swarm in the intestines of all the common species of termites for the digestion of cellulose. According to FAO (1986), there are two main categories of termite namely subterranean termites and dry - wood termites.

2.3.3.5.1 Subterranean termites

Subterranean termites dwell underground and enter wood from the ground. They require constant supply of moisture for their survival and access their food by constructing with soil, covered runways between their source of food and the ground (Kollman and Côte, 1984). They readily attack both sound and decaying timbers in contact with the ground and can also extend their attack to roofing timbers in high buildings. They are responsible for most of the severe termite damage to structural timbers and cause severest structural weakening at the ground lines of poles, bridge timbers, towers and in the foundation members of buildings (Kollman and Côte, 1984; Ofori, 1994b). Subterranean termites avoid light and conceal themselves in wood thereby making it difficult to discover their presence. The occurrence of earthlike runaways on stones, bricks, wooden structure and concrete foundations are evidence of their presence.

The annual losses and control costs for subterranean termites in nine states of the southeastern United State were estimated at $435 million (Hamer (1983)

2.3.3.5.2 Dry wood termites

Dry wood termites live their whole life in wood and requires no contact with the ground as the subterranean termites do. They are attracted by light and enter sound wood directly from the air at the time of swarming through cracks, checks, crevice in buildings or small natural openings in wood. Dry wood termites are able to fly and attack very dry and well seasoned wood without external supply of moisture. They are insidious operators and the accumulation of characteristic pellets at the base of the attacking wood is evidence of their presence. The colonies of dry-wood termites are much smaller than those of subterranean termites, therefore their rate of structural destruction is slower (FAO, 1986; Ofori, 1994b).

2.3.3.6 Marine borers

The destruction of wood in the sea is mainly due to the activities of marine borers which are widely distributed throughout most parts of the world but more prevalent and destructive in the warm regions rather than in the cold regions (FAO, 1986). There are two main types of marine borers which differ widely in their structure and habit of destruction. They are molluscans and the crustaceans.

2.3.3.6.1 Molluscans

Molluscans are responsible for the rapid destruction of wood exposed in the marine environment. Some important genera of molluscans belong to teredinidae and pholads. Teredo and bankia of the family teredinidae and martesia and xylophaga belong to pholads. The molluscans start life as tiny worm-like larva with two small plates fitted fine tooth-like projections on their edge which files away the wood in front of the animal. They lined their tunnel with chalky substance as they bore holes through the wood thereby concealing them in the wood. The surface of the affected wood remains practically intact yet the inside might be severely damaged. Molluscans damage is sporadic and its intensity seems to depend mainly on the temperature of the water. They can cause rapid damage in warm water and they cannot live in fresh water but can survive in brackish water if it is salty. Damage typically occurs from the mean tide-water mark below the water (FAO, 1986; Ofori, 1994b).

2.3.3.6.2 Crustaceans

Some of the important genera of crustaceans are limnoria, chelura and sphaeroma. Crustaceans are mobile throughout their whole life-cycle and their damage to the wood superficial. Crustaceans attack wood in great numbers hence the outer shell of the infested wood becomes thoroughly honeycombed at the point of attack. The attack is severe between the half-tide and the low-tide levels. The cumulative effect of repeated attacks results in the destruction of the exposed surface layer at a given time which wears away the infested portion of a pile (Ofori, 2004b). According to FAO (1986), the damage caused by crustaceans are less spectacular and serious than that of molluscans, not only because crustaceans damage is more evident to inspection but also excavation of wood proceeds less rapidly.

2.4 Effect of decay on wood properties

Decay fungi are the most destructive wood destroying organisms because considerable damage can be caused while no visible damage to the wood is observed. It really reduces the enviable aesthetic, physical and mechanical properties of wood (Wilcox, 1978; Imamura, 1993; Kim *et al*, 1996; Clausen and Kartal, 2003)

2.4.1 Permeability

Fungal decay occurs shortly after initial colonization and release of enzymes but no visible evidence of damage to wood is noticed. However, chemical changes during initial colonization results in measurable strength reduction before weight loss incurred (Kim *et al*, 1996; Clausen and Kartal, 2003). This according to Winandy and Morrell (1993) and Curling *et al* (2001) is due to the progressive degradation of hemicelluloses (arabinan, galactan, xylan, mannan, rhamnan). The progressive removal of these materials from the wood make decayed wood absorbs more fluid and at rapid rate than sound wood. The increased absorption by decayed wood may be due also to boring of new cavity in the cell walls or the enlargement of the pit cavity by the hyphae of the fungi (Panshin and DeZeeuw 1980; TRADA 1986a; Desch and Dinwoodie 1996).

2.4.2 Density and strength properties

Highley (1999) stated that by the time 1% weight loss occurred, 6 - 50% reduction in toughness might have occurred. Curling *et al* (2001) emphasized that 3% reduction in MOR and 6% reduction in maximum compression strength is incurred with no weight loss noticed. This according to Winandy and Morrell (1993) and Curling *et al* (2001) is due to the progressive degradation of hemicelluloses (arabinan, galactan, xylan, mannan, rhamnan). Clausen and Kartal (2003) realized that the removal of galactan from the cell walls has profound effect on the strength than loss in weight. They stated that 30% reduction in galactan resulted in 9% loss in MOE and 19% reduction in MOR but produces no significant loss in weight. However, 30% reduction in arabinan, rhamana and xylan resulted in 18% weight loss, 34% loss in MOE and

53% reduction in maximum compression strength (Clausen and Kartal (2003). The strength of wood depends on the cell wall thickness which dictates the density of wood. Therefore the progressive removal of cell wall materials reduces the weight of the wood. Hence the infected wood becomes less dense as decay progresses faster than in the sound wood. This is because wood constituents are constantly being destroyed thereby making the wood more porous (Panshin and deZeeuw, 1980)

2.5 Wood preservatives

Oteng – Amoako (2006b) defined wood preservative as various types of chemicals which when applied effectively to the wood, protect it against agents of biological deterioration. It is also defined as a chemical or mixture of chemicals in a form suitable for application to timber and wood based panel products for the purpose of usefully prolonging their service life by rendering them resistant to attack by wood destroying organisms (TRADA 1986b; Eaton and Hale, 1993; Desch and Dinwoodie, 1996). Preservatives vary widely in cost, effectiveness and suitability for use under different conditions of service (FAO 1986). Generally, chemical preservatives can be categorized into three main classes, namely tar oils, organic solvent and water borne preservatives (FAO 1986; Richardson, 1997; Ofori 2004b; Oteng-Amoako 2006b).

2.5.1 Tar oil preservatives

The tar oils include coal tar creosote and water gas creosote which are obtained by pyrolysis and distillation of organic materials such as coal, peat or wood. The portion of the tar boiling from 200-400^{0}C forms the creosote used in timber preservation (Ofori, 2004b). They are very resistant to leaching hence they are applied to timber to be used under severe hazard conditions like railway sleepers, marine piles, mining props, transmission poles.

2.5.2 Organic solvent preservatives

The organic solvent preservatives consist of various toxic chemicals dissolved in an organic solvents mainly petroleum distillates. They usually contain water repelling agents to develop good weathering characteristics and may be suitable for both exterior and/or interior, ground or above ground contact hazard situation depending on the formulation and type. They are resistant to leaching and can be painted over. Their concentrations cannot be easily altered as can be for the water borne preservatives. Organic solvent type of preservatives is applied by brush, spray, dipping or low pressure processes. Some of the organic solvents used are heavy oils, light oils and liquefied petroleum gas. Common examples are copper, zinc and sodium napthenates; pentachlorophenol and its derivatives, sodium orthophenylphenate, tributyl-tin-oxides (FAO 1986; Ofori 2004b)

2.5.3 Water – borne preservatives

These are soluble or miscible in water which carries them into the wood. These types of preservatives consist of certain compounds of copper, zinc, mercury, sodium, potassium, or chromium dissolved in water to generate toxic solution (Fortin and Poliquin, 1976). There are two types, namely, fixed and non-fixed, based on the ability of the salts to resist leaching (FAO 1986; Oteng-Amoako 2006b). The non-fixed water borne preservatives are intended for indoor and dry conditions since the preservatives easily leached out of the treated wood in service in ground contact, wet or external conditions. The most used ones are boron compounds, mercury chloride, sodium fluoride and zinc sulphate. The fixed water borne preservatives are intended for external or ground contact situation and contain compounds which mainly protect the toxic preservatives from leaching out of the treated wood in service. Some examples are Copper/

Chrome/ Boron, Copper/ Chrome/ Fluoride; Chromated / Zinc / Chloride; Fluorine / Chrome / Arsenic; Copper / Chrome / Arsenic; Ammoniacal / Copper / Arsenate (FAO 1986). Copper/ chromium/ arsenic (CCA) is the most widely accepted and is effective preservative for the protection of wood against fungi, insects, and marine borers and ranked along side creosote for proper protection in all hazard conditions with the service life of 30 years or more (Eaton and Hale, 1993). One of the advantages of CCA is its fixation capability and leaching resistance (Eaton and Hale, 1993; Desch and Dinwoodie, 1996). The American Wood Protection Association classifies CCA preservatives into type A, B and C based upon the relative amount of the active oxides (CuO, CrO_3 and AS_2O_5) present in the formulation as presented in table 2.1.

Table 2.1 Types of Copper Chromium Arsenate (CCA) based on percentage oxides

Oxides	Type A	Type B	Type C
CuO	18.1	19.6	18.5
CrO_3	65.5	35.3	47.5
AS_2O_5	16.4	45.1	34.0

After AWPA P5 – 08 (2008)

The Ghana Standard Board (GS 11:1992) recommends the CCA oxide formulation type C for the treatment of overhead transmission poles in Ghana. Generally, water-borne preservatives are odourless, clean and paintable. The water borne preservatives can easily be combined with fire retardant chemicals. Although water borne preservatives have the above stated merits, they are able to raise the grains of the treated wood and thus sometimes cause slight losses in strength of wood (Eaton and Hale, 1993; Desch and Dindoodie, 1996). The presence of arsenic as a component of chromated copper arsenate has raised environmental concerns thereby leading to the withdrawal of CCA from residential markets in several parts of the world since 2003 (Archer and Preston, 2006)

2.5.4 New generation wood preservatives

Copper-based preservatives have been widely and successfully used for more than a century (Richardson 1997). The volume of wood products treated with copper-based preservatives grew exponentially during the 1970s and 1980s and remains high today (Archer and Preston, 2006). The focus on predominantly copper-based preservatives has increased following the voluntary withdrawal from the residential market of chromated copper arsenate (CCA) in 2003. Much of the early work on copper-based formulations forms the basis for the ammoniacal and amine copper-based systems currently in the marketplace as CCA replacements. These formulations include quats or azoles as co-biocides (fungicides). The present invention provides wood preservative compositions comprising micronized particles, thus dispersions of micronized metal or metal compounds. In preservation of wood, the micronized particles can be observed as uniformly distributed within the wood and there is minimal leaching of the metal and biocide from the wood. Micronized copper preservative system is estimated to be about 80% of the lumber treated with waterborne preservatives in the USA today (McIntyre and Freeman 2010). Recently micronized copper formulations with the same co-biocides (azole and quat) have come into use. Micronized particles are produced by mechanical grinding of water- or oil-insoluble copper compounds with the aid of dispersing/wetting agents in a carrier using a commercial grinding mill or by chemical means resulting in 90 percent or more of the particles being less than 1000 nm size. The commonly used dispersing agents are polymeric dispersants, which attach to the surface of particles and repel the particles away from each other. Also, the presence of dispersing/wetting agents improves particle size reduction during milling and stabilizes the particles during storage and treating. The size of these particles can range from 1 to 25000 nm, and the particulate character may affect penetration of wood cell walls and reaction with wood's molecular constituents. The biological efficacy of micronized copper formulations is as good as or better than the amine counterparts. Other properties such as strength and corrosion resistance also make the micronized products to perform well. Generally, there is no reason to suspect that micronized copper formulations will not give service lives equivalent to their amine counterparts (McIntyre and Freeman 2010). Some of these new generation preservatives are micronized copper Azoles, micronized copper quats and Alkaline copper quat (Oteng-Amoako 2006b)

2.6 Preservation process

The method of getting the preservative chemical into the wood in required quantity and retention is as critical in successful wood preservation as the selection of the preservative chemical. The method to use will depend on the hazard situation where treated wood is to be used, timber species and availability of equipment. Wood preservation methods are generally grouped into two classes namely: Non-pressure and pressure methods. Non-pressure methods vary considerably according to the procedure and equipments used (FAO 1986; Oteng – Amoako 2006b). Some of the non-pressure preservative treatment methods are dipping, soaking, dip diffusion, spraying, double diffusion, hot and cold bath and sap displacement (FAO 1986;Ofori 2004b; Oteng-Amoako 2006b). Pressure method is a method in which the wood is impregnated with the preservative solution in closed vessels under pressure, considerably above the atmospheric pressure (FAO 1986; Oteng – Amoako 2006b). There are variations in the pressure methods based on the magnitude of the pressure applied and/ or the application of initial vacuum. There are high pressure method (Full cell and Empty cell), low pressure, oscillating or alternating pressure method. This study will focus on a pressure treatment method, the full cell impregnation method. In the method, the pressure is applied to the charge in a sealed cylinder. The pressure methods are the most preferred approach because of their greater efficiency and effectiveness (Kollman and Côte 1984; Ofori and Bamfo 1994). The effectiveness of the pressure method is due to the deep penetration, greater retention and the uniform distribution of the preservative in the treated material, which other preservation methods cannot offer. FAO (1986) also indicated that the pressure method generally provides closer control over the preservative retention and penetration. The cylinder is the heart of the pressure treatment method. The cylinder is a steel tank (usually in horizontal orientation) designed to withstand high working pressures. Openings may be installed at either or both ends of the cylinder depending on its size, nature of the materials to be treated and the loading systems used (Kollman and Côte 1984; FAO 1986; Desch and Dinwoodie 1996). In the treatment of timbers, the charge may be rolled into the cylinder on a standard or narrow gauge rail trams and rolled out of the cylinder to the yard. Hand or crane systems loading may be used for small materials and small treatment cylinders. Some accessory materials may be attached to the cylinder for heating and storing preservatives, transferring loads in- and – out of the cylinder and for measuring the amount of preservatives consumed in treating any charge (Kollman and Cote 1984; Eaton and Hale, 1993). In addition, compressors and pumps are required for vacuum and pressure phase of the treatment schedule with gauges installed to monitor these parameters. Where heating is required, it is achieved by use of steam (Kollman and Côte, 1984; FAO 1986). Preservatives like coal-tar creosote and water-borne are usually applied effectively by pressure impregnation methods (Desch and Dinwoodie 1996)

2.7 Anatomical characteristics of wood

There is a good correlation between wood permeability and penetrability and the structure of wood. Vessels are the major means of getting preservative into the wood hence their sizes, distribution and condition affect the treatability of hardwood.

2.7.1 Vessel

Vessels are composed of vessel elements connected end to end through perforation plates in a continuous tube-like structure of about 200-650μm in length (Thomas 1981; Desch and Dinwoodie, 1996; Oteng - Amoako, 2006b; Ahmed and Chun, 2010). The vessels form about 4% to 50% of the total volume of hardwood species and the diameter of the vessel of diffuse porous species is generally between 20 and 300μm. Average vessel diameter in the ring porous species varies conspicuously between the earlywood and latewood. In earlywood, it ranges between 20 – 400μm, while in the latewood, the range is 20 - 50μm (Wang and DeGroot 1996). The typical concentration of vessels when counted in the cross section is in the order of 15000/cm^2 (Siau 1984). Tyloses, gummy, resinous and chalky exudates usually form in the vessel lumen within the heartwood and transition zones (Hillis 1987). The formation of these materials within vessels substantially reduces treatability of heartwood and transition zone (Ofori and Bamfo 1994; Kumar and Dobriyal 1993). Teesdale and MacLean (1918) in their pioneer work confirmed by Thomas (1976) found that the treatability of wood was directly related to whether the vessels contained tyloses, and if the tyloses were present, the completeness of vessel blockage by the tyloses. Côte (1990) cited the use of white Oak to make whisky and wine barrel as the practical example of the role tyloses play in blocking fluid flow. Ahmed and Chun (2010) stated that, the longitudinal pathway of fluid in wood will be related to the vessel diameter, length, frequency and inter-vessel pit size and number.

2.7.2 Pit

The walls of the xylem elements have minute openings through which fluid from one element reach the adjacent ones. These minute openings are called pits. Hardwood pits have diameters between 3 and 12μm and the aperture elongated. The pits differ considerably in distribution and shape; they may be scalariform, opposite, alternate; and alternate polygonal. Pit may be simple, bordered or semi-bordered due to the presence or absence of the overarching cell wall. Bordered pits are usually found between vessels, semi-bordered pit pairs are found between vessel and parenchyma cells; simple pit pair is found between parenchyma cells (Desch and Dinwoodie, 1996) Pits provide one of the main pathways for the liquid flow between cells and are of great importance in wood treatment. The structure and distribution of pits affect the penetration and subsequent distribution of fluid in wood (Desch and Dinwoodie, 1996; Oteng-Amoako, 2006b; Ahmed and Chun, 2010).

2.7.3 Fibres

The fibres are elongated structures of 600-2300μm in length, 10-30μm in diameter with wall thickness varying within thin to very thick wall, narrow lumen and pointed ends. The side walls basically have simple pits which are slit-like in nature and facilitate lateral fluid movement from among the xylem elements. Fibres often account for between 15-40% of tropical hardwood in volume and are mainly responsible for mechanical support of the tree. The specific gravity of the wood depends on the fibre wall thickness (Desch and Dinwoodie, 1996; Wang and DeGroot, 1996; Oteng-Amoako, 2006b). Although, fibres constitutes the bulk of woody tissues, they are not important in initial liquid penetration but the subsequent distribution of the liquid from the vessels depends on the permeability of fibres in terms of number of sidewall pits and lumen diameter (Ahmed and Chun, 2010).

2.7.4 Axial parenchyma

Axial parenchyma is parenchyma cells arranged longitudinally in either brick-shaped or square-shaped cells with thin wall, small lumen and numerous simple pits in their walls. They constitute about 10-50% of the woody tissues of tropical hardwoods and are responsible for the axial transport and storage of photosynthetic products. Axial parenchyma cells facilitate the liquid penetration mainly through the simple pits (Desch and Dinwoodie, 1996)

2.7.5 Ray parenchyma

Rays are brick-shaped, radially arranged parenchyma cells with thin wall, small lumen and numerous simple pits in their walls. The cells are aggregated into ribbon-like shapes of one to 30 or more cells wide. In some hardwoods, the ray cells occur in two distinct sizes with the larger cells enclosing the central smaller cells. Ray tissues constitute between 10-25% of the tropical hardwood in volume and are responsible for the transport and storage of food in the radial direction (Desch and Dinwoodie, 1996). According Ahmed and Chun (2007), the liquid penetration depth is influenced by the ray lumen diameter and length as well as the end wall pit number and diameter. It is well documented that body ray has higher permeability than marginal ray parenchyma due to cell length variation.

2.8 Concept of wood treatability

Siau (1995), Ofori (2004b) define treatability as the ease with which fluid flow under pressure through porous materials. Oteng-Amoako (2006b) further explained that it is a measure of the ease with which a wood species is amenable to preservative treatment. Since drying involves the movement of fluids in wood, permeability is often used as an indicator of drying rates. Chemical penetration and retention has been the index to measure the treatability of wood species. According to Kamdem and Chow (1999) the challenge encountered with the preservative treatment of hardwoods is the inability to obtain even distribution of the chemicals and the difficulty in achieving the desired chemical retention. The effectiveness of preservative treatment depends on chemical formulation selected, method of application, wood species, moisture content before and after treatment, pretreatment methods, amount of preservative retained, depth of penetration and distribution, viscosity and temperature of the treating solution, vacuum and/ or pressure regimes and their durations are some of the parameters that influence wood treatability (Ofori and Bamfo, 1994; Kamdem and Chow, 1999; Oteng – Amoako, 2006b; Larnøy *et al*, 2008; Islam *et al*, 2008)

2.8.1 Variation in treatability of wood

There are several wood specific factors which influence treatability of wood and these factors vary within and between tree species. According to Siau (1984); Ofori and Bamfo, (1994); Maturbongs and Schneider (1996), and Larnøy *et al (*2008), some of the factors are grain direction, radial positions, axial positions, density, moisture content and various anatomical properties such as proportions of the tissue composition significantly influence treatability of wood.

2.8.1.1 Grain direction

Treatability of wood varies significantly with the direction of grains. The penetration in the longitudinal direction is about 20-50 times greater than penetration in the transverse direction. This according to Larnøy *et al* (2008) was as result of vessels being the major avenue for conducting treating fluid and the fact that vessels are aligned in the longitudinal direction. Again penetration in the radial direction is believed to be greater than in the tangential direction (Ofori and Bamfo, 1994; Wang and DeGroot, 1996; Larnøy *et al*, 2008)

2.8.1.2.1 Radial position

At the same treatment schemes and duration, sapwood of most tree species is more permeable to preservative than the heartwood (Stamn, 1970; Côte, 1990; Ofori and Bamfo, 1994; Kamdem and Chow, 1999; Oteng – Amoako, 2006b; Islam *et al*, 2008; Larnøy *et al*, 2008). This is due to the small pore sizes, irreversible nature of aspirated pits, the amount and type of extractives deposited on the pit membrane, the presence of tyloses, resinuous and gummy materials in heartwood vessels (Stamm, 1970; Panshin and DeZeeuw, 1980; Côte, 1990; Ofori, 2004b; Larnøy *et al*, 2008). Larnøy *et al*, 2008) further stated that outer sapwood is more permeable than the inner sapwood.

2.8.1.3 Axial position

Larnøy *et al* (*2008*) stated that there is significant difference in permeability in the axial positions along the stem. The bottom sapwood is more permeable than that of the top and the middle parts.

2.8.1.4 Density of wood

According to Siau (1971) and McQuire (1975), the maximum absorption or the porosity of wood is the function of void volume which also is dependent on the density of the wood. McQuire's Equation: Maximum absorption = 1000 – {BD (MC + 66.7)}/100 litre / m^3 where BD and MC are basic density and moisture of the wood to be treated respectively

Siau's Equation: P = {1 – (BD/1.5)} X 100 where P is Porosity, BD is basic density in gcm^{-3} and 1.5 is relative density of the cell wall material. Generally, the lower the density, the higher the void volume and the higher the treatability, the faster liquid will fill the void volume (Larnøy *et al*, 2008).

2.8.1.5 Moisture content

The amount of water in the wood is dependent on the empty spaces in the wood hence the higher the moisture content of the wood to be treated, the lower the available void spaces and therefore lower treatability. Higher moisture content is a specific requirement in diffusion and sap displacement treatment methods (Larnøy *et al*, 2008).

2.8.2 Evaluation of treatability

The effectiveness of any preservative treatment depends on the amount of preservative the wood can absorb, the depth of penetration and the distribution of the preservative within the various cells (FAO, 1986; Oteng –Amoako, 2006b; Ofori, 2008b). According to FAO (1986); Ofori (2004b); Matsunaga *et al* (2004); Oteng –Amoako, (2006b); AWPA U1-08 (2008); the amount of preservative necessary for adequate protection is mainly governed by the end use of the timber. They further stated that absorption alone is not a complete measure of adequate protection of wood as it is important for complete and uniform penetration and subsequent distribution of preservative.

2.8.2.1 Retention

The amount of preservative required to protect a unit volume of wood against any particular type of bio-deteriorators is the threshold value. The threshold value is used to compare the toxic effect of different preservatives and acts as a guide to the retention required when treating wood. The retention of water borne preservative salts is expressed as either the amount of active ingredient as a percentage of oven-dry weight of wood or as a net dry salt retention. However, individual retention can be determined by evaluating the difference between the weight before and after the treatment process (FAO 1986). Table 2.2 presents the hazard conditions of wood products and preservative retentions required.

2.8.2.2 Preservative Penetration

Penetration is the depth to which the preservative has reached from the surface of the wood. Permeability has been classified on the basis of either the surface area penetrated, lateral penetration or the number of vessels penetrated (Building Research Establishment (BRE), 1972; Fougerosse, 1976; TRADA, 1986b; Ofori, 2004b)

2.8.2.3 Preservative Distribution

According to Oteng-Amoako (2006b) successful treatment is characterized by the uniform distribution of preservative in all cells and tissues including cell walls. The ability of preservatives to prevent deterioration of wood in contact with soil depends in part on their uniform distribution in the porous microstructure of the wood and on the capacity of bioactive component to penetrate cell wall and to react with the hemicelluloses and lignin (Eaton and Hale, 1993; Zhang and Kamdem, 2000; Matsunaga *et al*, 2004). Uniform preservative distribution signifies satisfactory treatment while spotty, scattered or non-uniform preservative distribution indicates poor treatment (Ofori and Bamfo, 1994; Oteng-Amoako, 2006b)

Table 2.2 Typical overall average preservative retentions

Hazard conditions	Timber product	Creosote kgm^{-3}	CCA kgm^{-3}
Interior timbers	Roofing timbers, joinery, etc	50	6
Exterior timbers not in ground contact	Exterior building timbers, cladding bridge, railings etc	60	8
Timber in ground contact	Transmission poles, railway sleepers, fence posts etc	100	12
Timbers frequently or permanently immersed in fresh water	Bridge piling, cooling towers, etc	120	16
Timbers frequently or permanently immersed in sea water	Groynes, jetties, boat building timbers	150	24

After FAO (1986)

2.8.3 Treatability classification of wood

Ofori (2004b) stated that, wood have been grouped into four categories in order to have a convenient index of the extent to which they can be impregnated with preservative under pressure. He further stated that with resistant wood, there is difference in the extent of penetration between creosote and CCA preservative applied under pressure. The area penetrated can be detected by chemical reagent which when reacted with the chemical constituent of the preservative produces a diagnostic colour of the treated wood (Ofori and Bamfo 1994; Oteng-Amoako 2006b; AWPA A3 – 08, 2008). Fougerousse (1976) used the percentage surface area penetrated as the basis for classifying treatability of wood into the classes or groups as presented in Table 2.3. On the other hand, Building Research Establishment (1972) classified timber into four categories based upon the ease with which heartwood can be penetrated using creosote and full cell impregnation process as follows.

Table 2.3 Classification of penetrability based on percentage area treated

Percentage area penetrated	Classification
Greater than (>) 90	Permeable
50---90	Moderately resistant
10---50	Resistant
Less than (<) 10	Extremely resistant

After Fougerousse (1976)

Table 2.4 Classification of penetrability based on depth treated

Lateral penetration	Classification
Complete penetration under pressure without difficulty	Permeable
Lateral penetration of 6-18mm (softwoods) obtained in 2-3 hours under pressure or penetration of large proportions of the vessels (hardwoods).	Moderately resistant
Difficult to impregnate under pressure and require a long period of treatment. Lateral penetration rarely exceeds 3-6mm	Resistant
These timbers absorb only a small amount of preservative even under long pressure treatments. Timbers cannot be penetrated to an appreciable depth laterally and only a very small extent longitudinally	Extremely resistant

After Building Research Establishment (1972)

2.9 Species selection for studies

From a study conducted by TIDD and CSIR-FORIG (2009) on the domestic lumber supply, it was found that over 47 timber species available in natural forests are being sold and utilized in Ghana and sometimes exported to neighbouring countries whose technological properties are not known. This revelation implies that there are more timber species available in the natural forest capable of replacing and / or complementing the traditionally known timber species and the 'accepted' lesser used species available on the international market. CSIR – FORIG therefore designed the second phase of utilization of the Lesser Used Species (LUS) in Ghana focusing on determination of the physical, technological and working properties of those species to ensure their efficient utilization and promotion. In 2010, CSIR – FORIG selected two species namely *Cola gigantea* (Watapuo) and *Ficus sur* (Kotreamfo) which were among the commonest timber species being used by Ghanaians for roofing, wall cladding and other applications. The research materials for this thesis which form part of the CSIR-FORIG 2010 were extracted from Pra-Anum Forest Reserve in the Moist Semi-Deciduous Forest zone.

2.9.1 *Ficus sur* Forssk

Ficus sur belongs to the family Moraceae and widely distributed throughout tropical Africa, from Cape Verde in the east to Somalia, and in the south to Angola and South Africa (Oteng-Amoako, 2006a). In Ghana, *Ficus sur* is found on farmland, degraded forestlands as well as fallow land in the evergreen, moist and dry semi-deciduous forest types (Hawthorne and Ntim-Gyakari, 2006). The wood is used for construction, furniture, mortar for grinding flour, kitchen utensils, pots, boxes, beer troughs, drums, and beehives. It is also suitable for sporting goods, agriculture implements, hardboards, and particleboard. The wood was formerly used for making brake blocks and bed boards for ox wagon. Wood from the branches of the tree is used in making knife handles in the central Africa Republic. The wood is also use as fuel – wood (Lumbile and Mogotsi, 2008). The heartwood is white to yellow and not clearly demarcated from the sapwood. The grain is fairly straight or interlocked with moderately coarse to coarse texture (Oteng-Amoako, 2006a). The wood is slightly sticky when freshly sawn due to the latex. The wood is porous and lightweight with density between 300 – 650 kg/m^3 at 12% moisture content. The shrinkage rates from green to oven dry are 4.5% and 7.6% in the radial and tangential directions respectively. *Ficus sur* occurs from sea-level to 2500 m altitude, on riverbanks and in riverine forest, but also in upland forest, woodland and wooded grassland. The tree prefers full sun and grows on a wide range of soil type and can tolerate partial shade. This species can be propagated by seed and stem cutting (Lumbile and Mogotsi, 2008)

2.9.2 *Cola gigantea* A. Chev.

Cola gigantea belongs to Sterculiaceae family and very common in both the Dry and Moist Semi- Deciduous forest types but not so common in the Evergreen forest type in Ghana (Hawthorne and Ntim-Gyakari, 2006). The tree can grow to about 50 m high and 5m in girth with 90 cm as the prescribed minimum felling diameter (Oteng-Amoako, 2006a). Uetimane *et al* (2008b) rated the wood as medium density with the basic density between 400-750 kgm^{-3}. It is an excellent wood for furniture, cabinet, artifacts, handicrafts and carvings as well as for bridge construction works.

CHAPTER THREE

3.0 Materials and methods

3.1 Materials

Five matured trees each of *Cola gigantea* and *Ficus sur* were selected from Pra-Anum Forest Reserve in the Moist Semi-Deciduous (–South-east type) Forest Zone of Ghana which lies between 6^0 12’-$6^0$19’N and $1^0$9’-$1^0$17W. The average diameters of the trees at 1.3 meter above ground (dbh) were 63.8cm for *Cola gigantea* and 48.4cm for *Ficus sur*. The selected trees were harvested using chain-saw. The mean lengths of the clear bole between where the first branch begins and the terminal point of buttresses of each species were measured and recorded. The average lengths were 1797cm and 1140cm for *Cola gigantea* and *Ficus sur* respectively. The full lengths of the trees were divided into three equal parts and demarcated with permanent makers. The clear boles were cut into logs of about 2.5m long and discs of 25cm long along the bole (plate 3.1). The first disc taken from the bottom end of the whole tree was labeled as Butt (Plate 3.1) and the disc terminal end of the clear bole was labeled as Top (Plate 3.1). The middle disc was taken from the bottom end of the middle log as indicated in Plate 3.1. The logs were sawn longitudinally into two parts for easy carting and the freshly exposed surfaces were given prophylactic treatment with 0.5% Dursban immediately to prevent insect attack during transportation from the forest to the laboratory. The logs and the discs were then transported to CSIR- FORIG log yard for further processing.

3.1.2 Conversion and sampling

The logs were converted on a horizontal bandmill (woodmizer) to 27mm and 53mm thick boards. The boards meant for the treatability studies were straight grains, free from knots and other defects which were selected from the processed boards. The selected boards were temporarily stacked at the CSIR-FORIG drying shed to allow for air-drying and further processing to the required dimensions for the treatability studies. The 25cm long discs were processed into 25mm thick stripes and quadrants (Plate 3.2). Quadrants ‘a’ and ‘b’ in plate 3.2 meant for the anatomical studies were immediately sent to the Wood Anatomy Laboratory and kept in a freeze to prevent loss of moisture. The stripes meant for the basic density and green moisture content studies were immediately sent to CSIR-FORIG wood processing workshop for further processing into the required dimensions. The sample selection for the whole studies was in accordance with the ASTM D143-94 (2008).

3.2 Methodology

3.2.1 Determination of Physical Properties

3.2.1.1 Specimen Preparation for Basic Density Determination

Two strips of 25mm thick each from the butt, middle and the top portions were selected from stripes meant for this study for each of *Ficus sur* and *Cola gigantea* and were planned to 20mm thickness. Each strip was then sawn to 20mm X 20mm sections and cross cut into 20mm cubes (Plate 3.2). Out of the 240 samples per species used for the study, 80 were taken from each of the three heights, thus the top, middle and butt portions of the tree. The mass of the samples were taken immediately after preparation using a digital electronic balance (Mettler Toledo, PB 1502) to obtain the initial mass (W_I). The samples were soaked in water overnight to obtain the swollen volume (V_s) which was then determined by the immersion method. According to Archimedes’s principle, the volume of the mass of water displaced by the submerged wood sample is equal to the volume of water displaced. Afterwards, the wood samples were oven-dried at 105 ^{0}C (with intermittent weighing) until constant weight, oven –dry mass (W_0) was attained (ASTM D 2395-07a). The basic density of the samples was obtained from the formulae:

Basic density (BD) =Oven dried mass (W_0)/ Swollen volume (V_s)

3.2.1.2 Specimen Preparation for Green Moisture Content (GMC) Determination

Two strips of 25mm thick each from the butt, middle and the top portions were selected from strips meant for this study for each of *Ficus sur* and *Cola gigantea* and were planned to 20mm thickness. Each strip was then sawn to 20mm X 20mm sections and cross cut into 20mm cubes (Plate 3.2). In all, 240 (120 each of sapwood and heartwood) samples per species were used for this study. 80 samples were taken from each of the three heights, thus the top, middle and butt portions of the tree. The weights of the samples were taken immediately after preparation using a digital electronic balance (Mettler Toledo, PB 1502) to obtain the initial weight (W_I). The wood samples were oven-dried at 105 ^{0}C to constant weight, oven –dry weight (W_0) (ASTM D4442-07). The green moisture content of the samples was obtained from the formulae:

$$\text{GMC} = \frac{\text{Initial weight } (W_I)\text{-Oven-dried weight } (W_0) \text{ X } 100}{\text{Oven- dried weight } (W_0)}$$

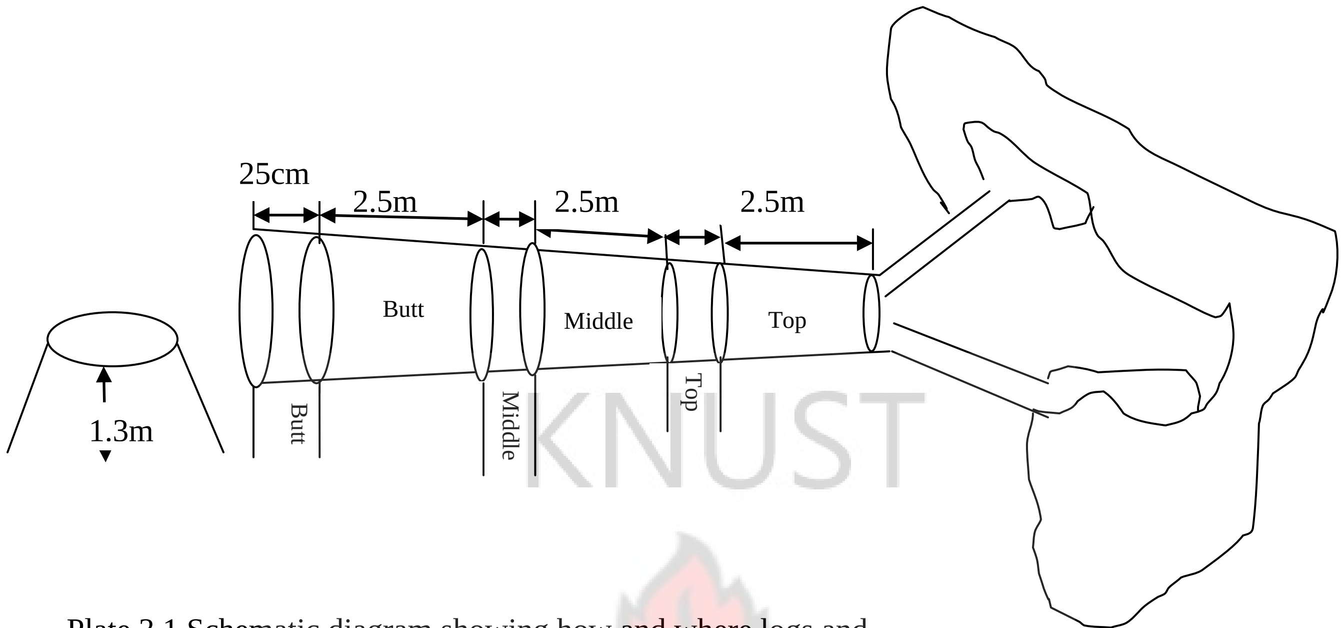

Plate 3.1 Schematic diagram showing how and where logs and discs samples were taken from trees

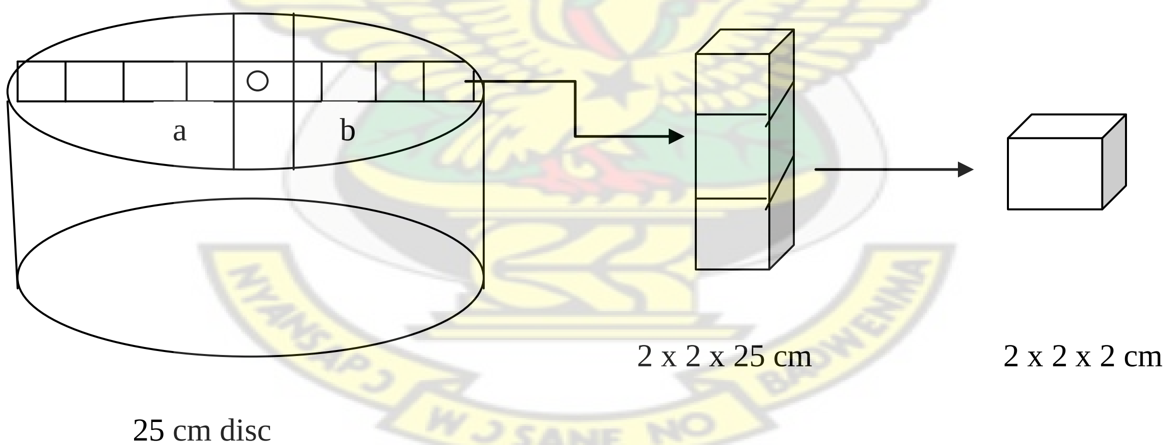

Plate 3.2 Schematic diagram showing steps for samples preparation for determination of moisture content and density as well as quadrant samples (a and b) for anatomical studies

3.2.1.3 Specimen Preparation for Air-Dried Moisture Content (ADMC) Determination

Some samples from the butt, middle and the top portions were randomly selected from about seven (7) months (August, 2010 – February, 2011) air-dried samples of *Ficus sur* and *Cola gigantea* meant for the treatability test to determine the air-dried moisture. Samples of dimension 20mm X 20mm X 20mm were prepared. 90 samples were taken from each of the two heights, thus middle and butt portions, and 60 samples from the top portion of the tree. The weights of the samples were taken immediately after preparation using a digital electronic balance (Mettler Toledo, PB 1502) to obtain the initial weight (W_I). The wood samples were oven-dried at 105 ^{0}C and weighed intermittently until constant mass, oven –dry mass (W_0) attained (ASTM D 4442-07).

$$\text{ADMC (\%)} = \frac{\text{Initial weight } (W_I)\text{-Oven-dried weight } (W_0) \text{ X } 100}{\text{Oven- dried weight } (W_0)}$$

3.2.2 Determination of anatomical properties of *Cola gigantea and Ficus sur*

3.2.2.1 Slide preparation

Samples measuring 20 mm x 20 mm x 40 mm were prepared from the quadrant 'a' (see Plate 3.2) for the anatomical studies. The samples were taken from the sapwood and heartwood of the trees of each species. The samples were softened by first saturating them with water and later keeping them in a mixture of ethanol and glycerol (1:1) for between 14-30 days depending on the species and position from which the samples were obtained. *Cola gigantea* took longer time, between 21-30 days to soften while the *Ficus sur* took between 14-18 days to soften. Longitudinal, radial and tangential sections between 12-20μm thick were microtomed on a sliding microtome (low profile feather microtome). The prepared sections were first washed in water and stained in a solution of 1% safranin in 50% alcohol for about 30 minutes, after which they were washed in water and dehydrated in increasing concentrations of ethanol: 30; 50; 85; 90

and 100%. They were then mounted in Canada balsam on glass slide and were oven-dried at 60 ^{0}C for 36 hours.

3.2.2.2 Maceration

Materials for the morphological studies of the fibres of the species were taken from the quadrant 'b' of the discs cut from the butt, middle and top parts of each tree. At each axial height, samples were prepared from the sapwood and heartwood of the tree. Each sample measured 2 mm x 2mm x 30 mm was macerated. Materials from different heights and radial zones were kept in separate vial containing 60ml solution of 6% hydrogen peroxide and 97% acetic acid. The specimens were incubated at 60 ^{0}C for seven (7) days to obtain complete macerations. The macerates were rinsed with water and mounted temporarily in diluted glycerol for measurements of cell dimensions.

3.2.2.3 Microscopic examinations and measurements

All the anatomical examinations and measurements were done under light microscope platform (Fisher Scientific Micromaster premier equipped with computer software for live image captioning). The nature and arrangement of various tissues, the presence of tyloses, crystals, druses and other inclusions were described based upon the prepared terminologies of IAWA hardwood identification checklist (IAWA, 1989). Anatomical measurements were done using the eyepiece scale of 100 divisions and 10x objective lens. The number of vessels per square millimeter was determined on the slides by counting the number of vessels using scale grid eyepiece with the field area of 1.4963mm^2. An average of five (5) counts per section were converted to correspond to an area of 1mm^2. Vessels, parenchyma and fibres proportions were determined on the slides for each sample using 10x objective lens and 10x eyepiece with a dot grid scale of 20 points. The dot scale was placed five times at different areas on the slide and at each placement; the number of points covering any tissue was counted and expressed as a percentage of the total number of points. The tangential diameter of vessel lumen was determined on the slides by measuring the diameter of sixty (60) vessels for each species. Fibre length, lumen width and the double wall thickness were determined on the macerates by measuring at least 210 complete and straight fibres per species. Hundred and five (105) each of sapwood and heartwood and seventy (70) each from the top, middle and butt portions.

3.2.3 Treatability determination

3.2.3.1 Determination of absolute preservative retention of *Cola gigantea and Ficus sur*

The samples meant for the treatability test were selected from the top, middle and bottom portion of the trees of the species. The sample boards were air-dried to 17% average moisture content under the air drying shed at CSIR-FORIG for seven months (August, 2010 to February, 2011). The boards were processed into samples of dimension of 25 mm tangentially x 50 mm radially x 500 mm longitudinally in order to assess the penetration of preservative in those directions. The sample dimensions were in accordance with the AWPA E7-07 (2008) recommendations. The prepared samples were conditioned in air drying room to help stabilize the moisture in the wood. 288 samples comprising 96 each from the top, middle and the bottom portions of the trees of each species; and 144 samples each of the sapwood and heartwood were used for the work. The selected samples for each species were grouped into 16 (sixteen) batches with each batch made up of 18 (eighteen) samples. The samples were weighed and one-third each of the samples in a batch sealed either at all four sides or at both radial faces and ends, or both tangential faces and ends with two coats of an epoxy resin paint depending on whether penetration was being studied in the longitudinal ‘a’ in Plate 3.3, tangential- longitudinal ‘b’ in Plate 3.3 or radial - longitudinal ‘c’ in Plate 3.3. The coated samples were air dried and the weight (W_I) taken prior to treatment. Each batch was loaded into the experimental vacuum-pressure impregnation plant conforming to the AWPA standard M3-05(2008) and treated with 0.5 % Copper Chromium Arsenate Type C (CCA- C), conforming to the AWPA standard P5-08 (2008) to refusal using full cell method. Vacuum of -75kPa was created by opening the vacuum valve, at -75kPa the valve was closed for 15 minutes to extract air from both the chamber and the wood. The chamber was then fully filled with the 0.5% CCA-C by opening the solution tank inlet valve while all the other valves remain closed. The inlet valve was then closed and the pressure valve opened. The pressure magnitudes of 600 kPa, 800 kPa, 1000 kPpa, and 1200 kPa were built in the chamber and maintained for 30, 60, 120, and 240 minutes. Each charge was treated to refusal and no final vacuum was applied after the treatment process. After each treatment process, the samples were removed from the chamber. The excess preservatives on the treated wood were cleaned with tissue paper and the wood weighed to obtain final mass (W_f). The dimensions of each of the treated sample were determined at three different points, namely the two ends and the midpoint. Average of the three readings and the length were used to compute the volume of the samples. The Absolute Volumetric retention was estimated by the formulae:

Absolute Volumetric Retention (AVR) = $\{(W_f - W_I)/ \text{samples volume}\}$

3.2.3.2 Determination of theoretical maximum absorption (liter/cubic meter) of the species

The theoretical maximum absorption of the species were determined using all the 180 (90 each of sapwood and heartwood; and 60 each from the butt, middle and top) samples per species. Theoretically, the maximum possible amount of preservative in liter a cubic meter of wood can absorb can be closely estimated from the basic density (BD, kg/m^3) of the species and the moisture content (mc, %) of the wood prior to the treatment process by following McQuire's (1975) equation: Maximum Absorption (l/m^3) = 1000- [BD x (mc+ 66.7)/100]

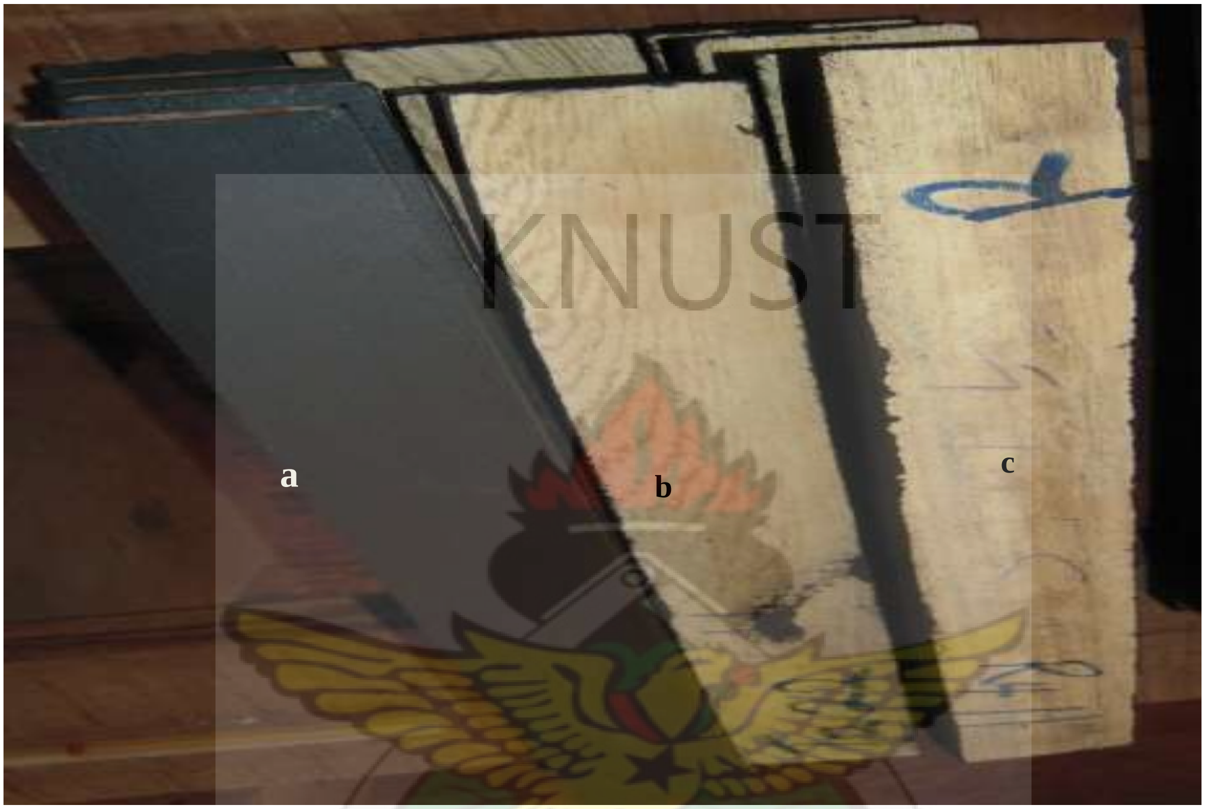

Plate 3.3 Epoxy coated samples for penetration studies. 'a' samples for longitudinal penetration, 'b' samples for tangential- longitudinal penetration and 'c' samples for radial- longitudinal penetration determination

3.2.3.3 Determination of relative volumetric retention (l/m^3) of *Cola gigantea and Ficus sur*

Relative volumetric retention is the quantity of preservative absorbed as compared with the maximum possible absorption potentials of the species expressed as percentage. In this study, the mean theoretical maximum absorption of sapwood and heartwood of the whole tree per species were used as the denominator (Maximum absorption).

Relative volumetric retention = [(Absolute volumetric retention/ Maximum absorption) x 100]

3.2.3.4 Determination of preservative penetration of *Cola gigantea and Ficus sur*

The treated samples were close piled for three weeks to allow fixation of the preservative (Plate 3.4), then stacked and air – dried on the fourth week (Plate 3.5). Nine treated samples (comprising 3 each of radial 'a' in plate 3.6; tangential 'a' in plate 3.7 and longitudinal 'a' in plate 3.8) each per charge were selected and cut into two equal parts transversely ('b' in plate 3.6, 'b' in plate 3.7, and 'b' in plate 3.8 for radial, tangential and longitudinal respectively). One half of the two halves was used to determine preservative penetrability and the other half to determine the preservative oxides retention. The one half meant for the preservative penetrability was split in the radial-longitudinal direction 'c' in plate 3.6; tangential- longitudinal direction 'c' in plate 3.7 and longitudinal direction 'c' in plate 3.8 for the assessment of longitudinal, radial and tangential penetrability of the species. The freshly cut surfaces were sprayed with Chrome Azurol S to indicate the presence of copper in the treated samples in accordance with the AWPA standards A3-08 (2008). The preservative penetrated areas of the treated wood turn greenish-blue whereas the untreated areas turn reddish – brown as in 'd' in plates 3.6, 'd' in plate 3.7 and 'd' in plate 3.8. The depth of preservative penetration was assessed in the longitudinal, radial and tangential directions. Fougerousse's (1976) method was adopted in assessing the penetrability of the species to CCA preservative impregnation. This method was based on the percentage surface area penetrated by the preservative (Table 2.3).

Plate 3.4. Treated samples close piled to allow fixation of the preservative after treatment

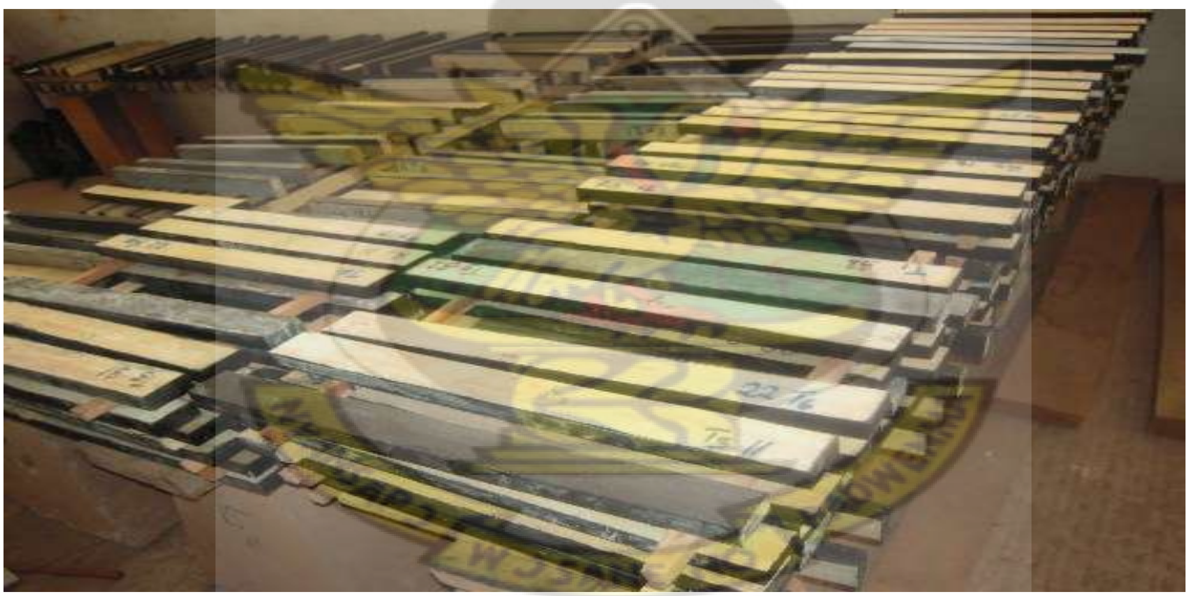

Plate 3.5. Treated samples stickered to allow air-drying after three weeks of fixation.

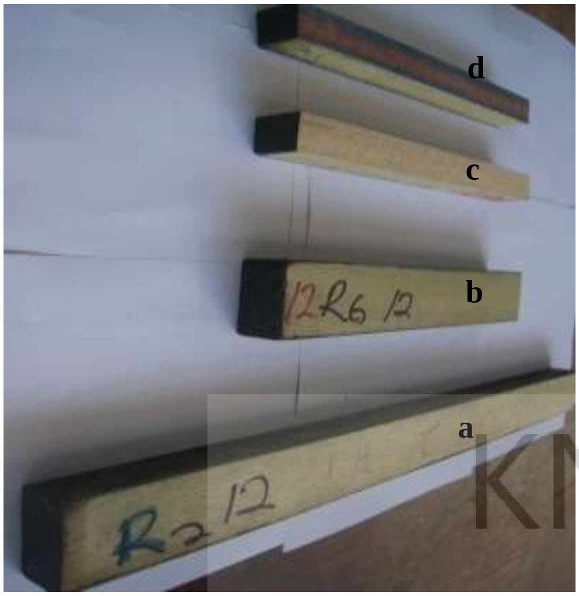

Plate 3.6. Radial –longitudial penetration assessment

Plate 3.7. Tangntial –longitudial penetration assessment

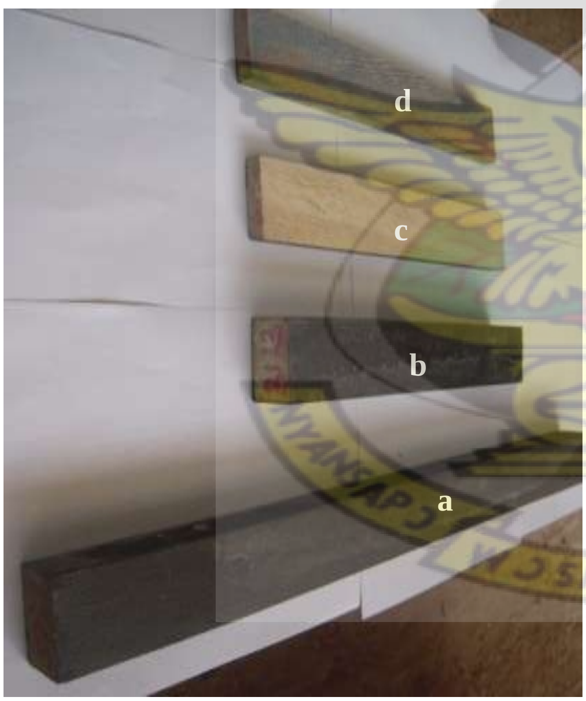

Plate 3.8. longitudial penetration assessment

3.2.3.5 Determination of preservative oxides retention in treated samples using X – ray fluorescence spectroscopy

Specimens of dimension 25 mm x 50 mm x 10 mm were cut from the freshly exposed portion of the one half samples meant for the oxides retention analysis. Total samples of 144 per species comprising 72 each of sapwood and heartwood were used for the oxide retention analysis. The samples were dried using the reheat mode on the microwave (Sanyo module EM C6786V) with intermittent weighing until constant mass (zero percent moisture content) attained. The dried samples were cut into smaller pieces and grinded to powder passing the 30 mesh sieve (aperture diameter of 600µm) as required by AWPA A9 – 01(2008) (Plate 3.9). The wood powder was immediately transferred in the analyzer sample container and the wood powder compressed into pellet using compactor (Plate 3.10). The sample container was then mounted on the sample holder of the Oxford X – ray analyzer (AWPA standard A9 – 01, 2008) (Plate 3.11). The sample was then irradiated and the characteristic X – rays of the copper, chromium and the arsenic atoms emitted were measured by the sensitive detectors in the X – ray analyzer. The detector output being the preservative retention of copper, chromium and arsenic components in the treated specimen was automatically converted and displayed as their oxides (CuO, CrO_3 and As_2O_5 respectively)(AWPA standard A9 – 01, 2008).

Plate 3.9 25mmx50mmx10mm treated sample grinded into powder

Plate 3.10 Powdered treated wood compacted into pellet

Plate 3.11 Oxford X-ray fluorescence spectrometer

3.3 Data Analysis

Excel 2007 analysis tool pack and Statistical Package for Social Sciences (SPSS) version 15 package were used to perform the Analysis of Variance (ANOVA), bar graphs and Least Significant Difference (LSD) post-hoc-test to determine the variation in the quantitative anatomical features, physical properties and the treatability within and between species.

CHAPTER FOUR

4.0 Results

4.1 Anatomical properties variations in *Cola gigantea* and *Ficus sur*

4.1.1 Ground tissue proportions in *Cola gigantea* and *Ficus sur*

Table 4.1.1 shows the mean percentage ground tissue proportions of the *Cola gigantea* and *Ficus sur*. The mean percentage ground tissues proportion varied slightly within each species. The proportion of vessel was 8% in both sapwood and heartwood of *C. gigantea*. The mean percentage proportions of parenchyma and fibres varied slightly between the sapwood and heartwood of *C.* gigantea. Parenchyma proportion was 44% in sapwood and 42% in heartwood. The fibre proportion varied from 48% in sapwood to 50% in heartwood of *Cola gigantea*. The mean vessel proportion was 9% in both sapwood and heartwood of *F. sur*. Parenchyma proportion varied from 49% in sapwood to 44% in heartwood. Fibre proportion was 42% in sapwood and 47% in heartwood of *Ficus sur*. The mean percentage tissues proportion varied slightly between *Cola gigantea* and *Ficus sur*. The vessel proportion varied from 8% in *Cola gigantea* to 9% in *Ficus sur*. Proportion of parenchyma varied from 43% in *C. gigantea* to 47% in *F. sur* and fibre proportion was 49% in *Cola gigantea* and 44% in *Ficus sur*. From Table 4.1.2, the vessel frequency was 4.0mm^{-2} for both *C. gigantea* and *Ficus sur*. Inter-vessel pit sizes were 3.0µm for *C. gigantea* and 8.0 µm for *Ficus sur*. The tangential vessel diameter varied from 184 µm in *C. gigantea* to 225µm in *Ficus sur.* Ray parenchyma height varied from 1224 µm in *C. gigantea* to 729µm in *Ficus sur* and the ray width was 139 µm in *C. gigantea* and 121µm in *Ficus sur*

Table 4.1.1 Percentage ground tissues proportion (%) in *Cola gigantea* and *Ficus sur*

Tissues	Vessel		Parenchyma		Fibres	
	Mean ± α	Range	Mean ± α	Range	Mean ± α	Range
Cola gigantea						
Sapwood	8 ± 3	5 – 10	44 ± 8	30 – 55	48 ± 6	40 – 60
Heartwood	8 ± 3	5 – 15	42 ± 11	20 – 65	50 ± 11	30 – 70
Whole tree	8 ± 3	5 – 15	43 ± 9	20 – 65	49 ± 9	30 – 70
Ficus sur						
Sapwood	9 ± 5	5 – 20	49 ± 10	30 – 65	42 ± 8	30 – 55
Heartwood	9 ± 4	5 – 15	44 ± 7	30 – 55	47 ± 8	35 – 65
Whole tree	9 ± 4	5 – 20	47 ± 9	30 – 65	44 ± 8	30 – 65

α = standard deviation

Table 4.1.2 Vessel and ray morphology of *Cola gigantea and Ficus sur*

Anatomical features	*Cola gigantea*		*Ficus sur*	
	Mean ± α	Range	Mean ± α	Range
Vessels				
Frequency (mm^{-2})	4.0 ± 0.3	3.0 – 5.0	4.0 ± 0.2	3.0 – 5.0
Pit size (µm)	3.0 ± 0.4	2.9 - 3.4	8.0 ± 0.7	3.8 - 10.1
Tangential vessel diameter (µm)				
Sapwood	180 ± 30	125 – 238	216 ± 25	163 – 263
Heartwood	188 ± 25	150 – 238	236 ± 35	163 – 300
Whole tree	184 ± 28	125 – 238	225 ± 31	163 – 300
Rays height (µm)				
Sapwood	1320 ± 400	563 – 2800	793 ± 178	500 – 1375
Heartwood	1078 ± 321	563 – 1873	665 ± 128	400 – 1063
Whole tree	1224 ± 453	563 – 2800	729 ± 167	400 – 1375
Ray width (µm)				
Sapwood	140 ± 31	75 – 225	126±21	88 – 163
Heartwood	139 ± 20	88 – 188	117 ± 32	50 – 163
Whole tree	139 ± 31	75 – 225	121 ± 27	50 – 163

α = standard deviation

4.1.2 Fibre morphological variation within *Cola gigantea* and *Ficus sur*

The mean fibre morphological parameters of *Cola gigantea and Ficus sur* studied are presented in Tables 4.1.3 and 4.1.4 respectively and Analysis of variance (ANOVA) presented in Table 4.1.5. From Table 4.1.3, the mean fibre length was 2.1 mm for sapwood and 1.9 mm for heartwood of *Cola gigantea*; fibre diameter varied from 24.2 µm in sapwood to 25.1 µm in heartwood; fibre lumen diameter was 13.9 µm for sapwood and 15.6 µm for heartwood; and the double cell wall thickness was 10.3 µm for sapwood and 9.5 µm for heartwood of *Cola gigantea*. These fibre morphological parameters of *Cola gigantea* also varied along the bole from butt to top. All the parameters of *Cola gigantea* studied except fibre lumen diameter increased from the top to the butt. The fibre lumen diameter of *Cola gigantea* however, increased from top to middle and decreased towards the butt. From Table 4.1.4, the mean fibre length varied from 1.7 mm in sapwood to 1.4 mm in heartwood of *Ficus sur*; fibre diameter varied from 31.7 µm in sapwood to 30.9 µm in heartwood; fibre lumen diameter was 23.9 µm for sapwood and 23.8 µm for heartwood; and double cell wall thickness was 7.8 µm for sapwood and 7.1 µm for heartwood of *Ficus sur*. The fibre diameter and the fibre lumen diameter of *Ficus sur* increased from top to the middle and decreased towards the butt. Fibre length and double cell wall thickness of *Ficus sur* seems to increase from the top to the butt. Fibre length and wall thickness of *C. gigantea* were longer and thicker than those in *F. sur* whilst the fibre diameter and the fibre lumen diameter of *Ficus sur* was wider than those of *Cola gigantea*. For *Cola gigantea* from Table 4.1.5, except the double cell wall thickness across and fibre lumen diameter along the bole, all the other fibre morphological parameters studies varied significantly across and along the bole at $P \leq 0.01$. For *F. sur* however, except the lumen diameter across the bole, all the other fibre morphological parameters studies varied significantly across and along the bole at $P \leq 0.05$.

Table 4.1.3 Fibre length (FL, mm), double wall thickness (DWT, µm), Fiber lumen diameter (FLD, µm) and fiber diameter (FD, µm) variation in *Cola gigantea*

	Sections	Top Mean ± α (n)	Middle Mean± α (n)	Butt Mean ± α (n)	Whole tree Mean ± α (n)
Fibre length (mm)	Sapwood	1.7±0.14 (35)	2.3±0.28 (35)	2.4±0.26 (35)	2.1^{n}±0.39(105)
	Heartwood	1.8±0.18 (35)	1.9 ±0.18 (35)	1.9±0.26 (35)	1.9^{m}±0.21(105
	Whole tree	1.8^{a}±0.17 (70)	2.1^{b}±0.29 (70)	2.1^{b}±0.37 (70)	2.0±0.33 (210)
Fibre diameter (µm)	Sapwood	22.6±2.8 (35)	24.7±3.9 (35)	25.3±3.4 (35)	24.2^{s} ±3.5(105)
	Heartwood	24.7±2.4 (35)	24.8±3.1 (35)	26.1±4.0 (35)	25.1^{t} ±3.3(105)
	Whole tree	23.5^{c}±2.8 (70)	24.8^{d}±3.5(70)	25.7^{d}±3.7(70)	24.7±3.4 (210)
	Sapwood	13.9±2.9 (35)	14.7± 2.9 (35)	13.2±3.1 (35)	13.9^{v}±3.0(105)
FLD	Heartwood	14.6±3.2 (35)	16.4±2.9 (35)	15.9±3.8 (35)	15.6^{u}±3.4(105)
(µm)	Whole tree	14.3^{e}±3.0(70)	15.5^{f}±3.0(70)	14.6^{ef}±3.7(70)	14.8±3.3 (210)
	Sapwood	9.8±2.0 (35)	10.0±2.8 (35)	12.0±3.0 (35)	10.3^{w}±3.0(105)
DWT	Heartwood	8.7±2.3 (35)	8.5±1.8 (35)	10.3±3.1 (35)	9.5^{w}±2.5(105)
(µm)	Whole tree	9.3^{g}±2.8(70)	9.2^{g}±2.5(70)	11.1^{h}±3.1(70)	9.9±2.8 (210)

Means of the whole tree with the same letters per parameter are not significant at 0.01<P≥0.05

Table 4.1.4 Fibre length (FL, mm), double wall thickness (DWT, µm), Fibre lumen diameter (FLD, µm) and fibre diameter (FD, µm) variation in *Ficus sur*

	Sections	Top Mean ±α (n)	Middle Mean ± α (n)	Butt Mean ± α (n)	Whole tree Mean ± α (n)
Fibre length (mm)	Sapwood	1.3± 0.13 (35)	1.7±0.27(35)	2.0±0.16 (35)	1.7^{a}±0.34 (105)
	Heartwood	1.6±0.15 (35)	1.1±0.11(35)	1.7±0.15 (35)	1.4^{b}±0.30 (105)
	Whole tree	1.4^{m}±0.19 (70)	1.4^{m}±0.38(70)	1.8^{n}±0.23(70)	1.5±0.34 (210)
Fibre diameter (µm)	Sapwood	33.8±4.9 (35)	34.5±3.9(35)	26.9±3.1 (35)	31.7^{c}±5.3 (105)
	Heartwood	31.1±3.8 (35)	32.7±3.9(35)	29.1±3.0 (35)	30.9^{c}±3.9 (105)
	Whole tree	32.4^{d}±4.6 (70)	33.6^{d}±4.0(70)	28.0^{e}±3.2 (70)	31.3±4.6 (210)
	Sapwood	26.5±4.7 (35)	25.8±3.9(35)	19.5±3.3 (35)	23.9^{j}±5.1 (105)
FLD	Heartwood	22.2±3.9 (35)	27.6±4.1(35)	21.6±3.2 (35)	23.8^{j}±4.6 (105)
(µm)	Whole tree	24.3^{f}±4.8 (70)	26.7^{h}±4.1(70)	20.6^{g}± 3.4(70)	23.9±4.8 (210)
	Sapwood	7.3±1.4 (35)	8.6±2.0 (35)	7.4±1.9 (35)	7.8^{x}±1.9 (105)
DWT	Heartwood	8.9±2.1 (35)	5.1±1.1 (35)	7.4±2.5 (35)	7.1^{y}±2.5 (105)
(µm)	Whole tree	8.1^{u}±1.9 (70)	6.7^{v}±2.4 (70)	7.4^{vu}±2.2 (70)	7.5±2.2 (210)

Means of the whole tree with the same letters per parameter are not significant at P≥0.05

Table 4.1.5 Analysis of variance (ANOVA) of the fibre morphological parameters in *Cola gigantea* and *Ficus sur*

Species	Sections	Sources of variation	F-value	F-crit	df
Cola gigantea	Radial (sapwood & heartwood)	Fibre length	32.75^{**}	6.76	1, 208
		Fibre lumen diameter	14.05^{**}	6.76	1, 208
		Double wall thickness	3.48^{ns}	3.89	1, 208
	Axial (butt, middle, top)	Fibre length	34.29^{**}	4.71	2, 207
		Fibre lumen diameter	2.77^{ns}	3.04	2, 207
		Double wall thickness	10.84^{**}	4.71	2, 207
F. sur	Radial (sapwood & heartwood)	Fibre length	29.16^{**}	6.76	1, 208
		Fibre lumen diameter	0.04^{ns}	3.89	1, 208
		Double wall thickness	4.51^{*}	3.89	1, 208
	Axial (butt, middle, top)	Fibre length	56.65^{**}	4.71	2, 207
		Fibre lumen diameter	39.24^{**}	4.71	2, 207
		Double wall thickness	5.40^{**}	4.71	2, 207
	Whole *C. gigantea & Ficus sur*	Fibre length	174.78^{**}	6.70	1, 418
		Fibre lumen diameter	500.21^{**}	6.70	1, 418
		Double wall thickness	94.81^{**}	6.70	1, 418

** = Significant at $0.001<P\leq 0.01$, * = significant at $0.01<P\leq0.05$, ns = not significant at $P\geq0.05$

4.2 Anatomical description of the species

4.2.1 Description of *Fius sur*

The wood is diffuse porous and has no distinct growth rings boundary (Plate 4.1). Vessels constitute about 9 % of the ground tissues, mainly solitary vessels (SV in Plate 4.1) with simple perforation plates. Vessel distribution is scanty vessels about 4 per $mm^2$and vessel has mean tangential diameter of 225 µm. Tyloses present in the vessels (TY in Plates 4.1 and 4.6). The inter-vessel pits are bordered, alternate, polygonal shape and non-vestured with average size of 8.0 µm (Plate 4.5). Fibres constitute about 42 % of the ground tissues with the mean double wall thickness of 7.5 µm, mean lumen diameter of 23.9 µm, mean diameter of 31.3 µm and mean length of 1.5 mm (FIB in Plates 4.1, 4.2 and 4.7). The fibres have simple to minutely bordered pits (FIB in Plate 4.7). The parenchyma cells constituting about 49 % of the ground tissues are paratracheal, confluent and having bands more about eight cells wide (AP in Plate 4.1). The rays have relatively uniform sizes with 4-10 seriate (RP in Plate 4.2). Body ray cells procumbent with mostly 2-4 rows of upright and / or square marginal cells (PBR in Plate 4.3). Vessel-ray pits with much reduced borders to apparently simple; pits in horizontal orientations (gash-like) and rounded pit outline (arrowhead in Plate 4.4). Prismatic crystals present in chambered axial parenchyma cells (arrowhead in Plate 4.7).

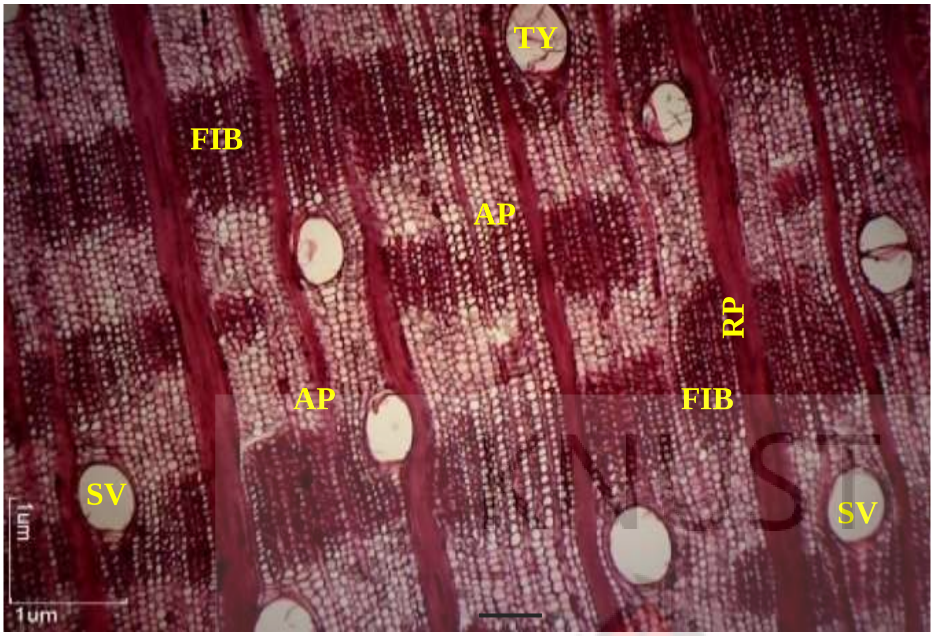

Plate 4.1 Cross section of *F. sur* showing solitary vessels (SV), tyloses (TY), ray parenchyma (RP), fibres (FIB) and axial parenchyma (AP)

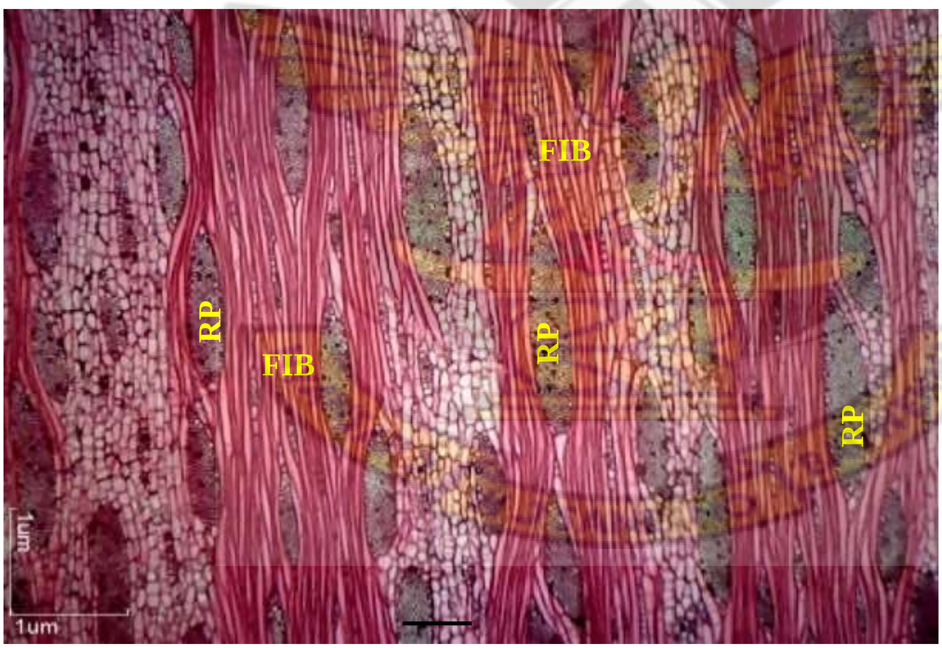

Plate 4.2 Tangential-longitudinal section of *F. sur* showing 4-10 seriate rays (RP) and fibres (FIB)

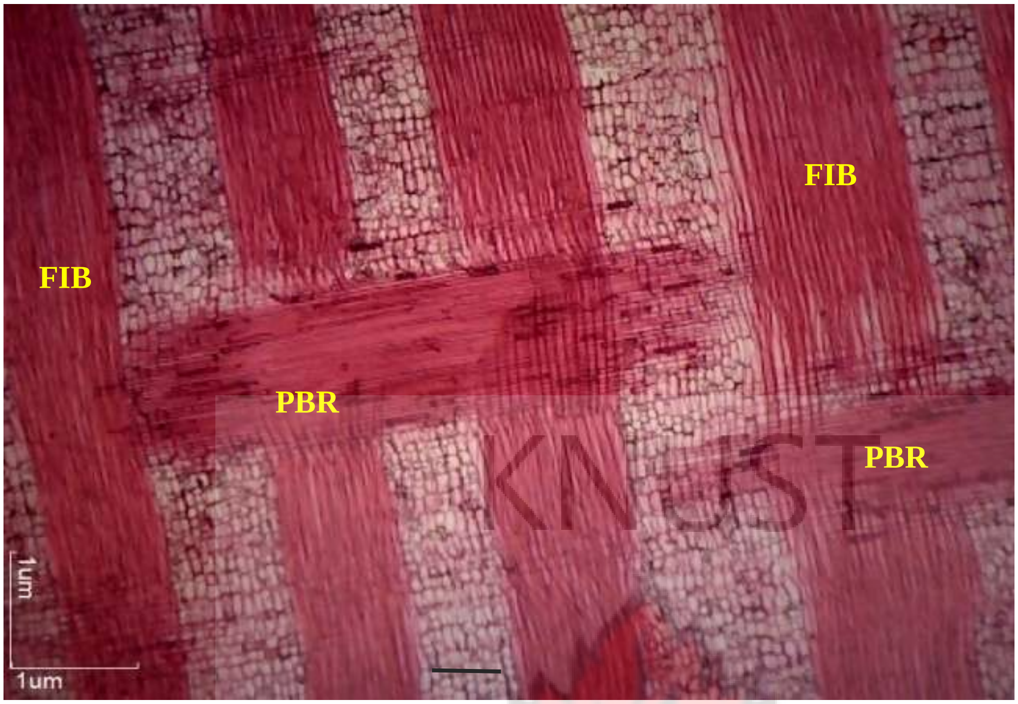

Plate 4.3 Radial-longitudinal section of *F. sur* showing procumbent ray (PBR) and fibres (FIB)

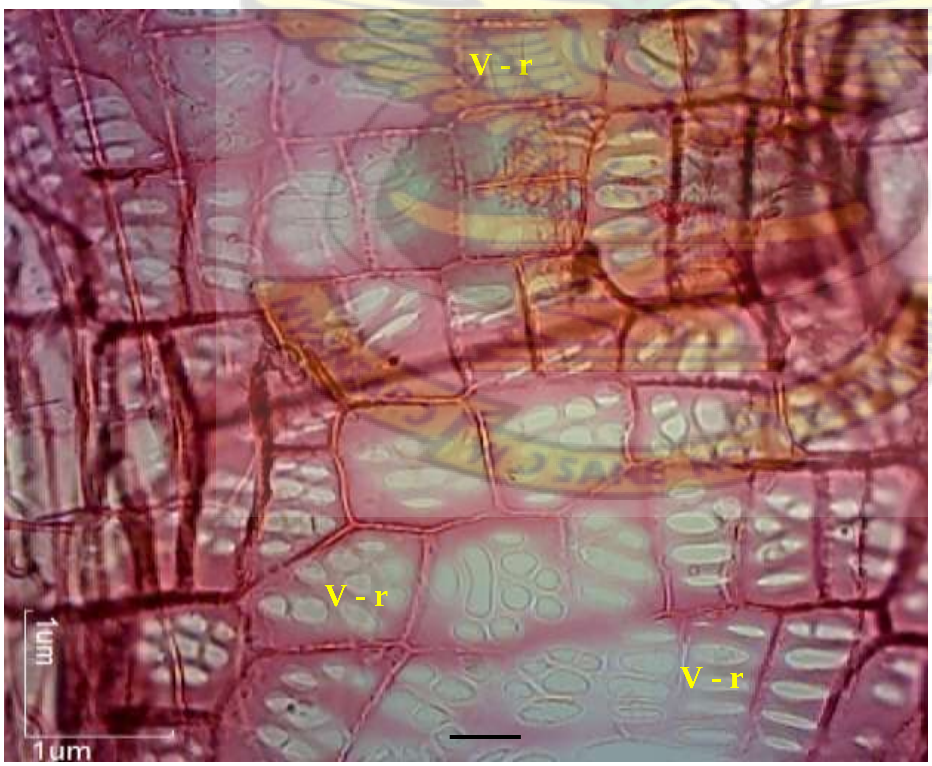

Plate 4.4 Radial-longitudinal section of *F. sur* showing gash-like vessel-ray pits (v-r)

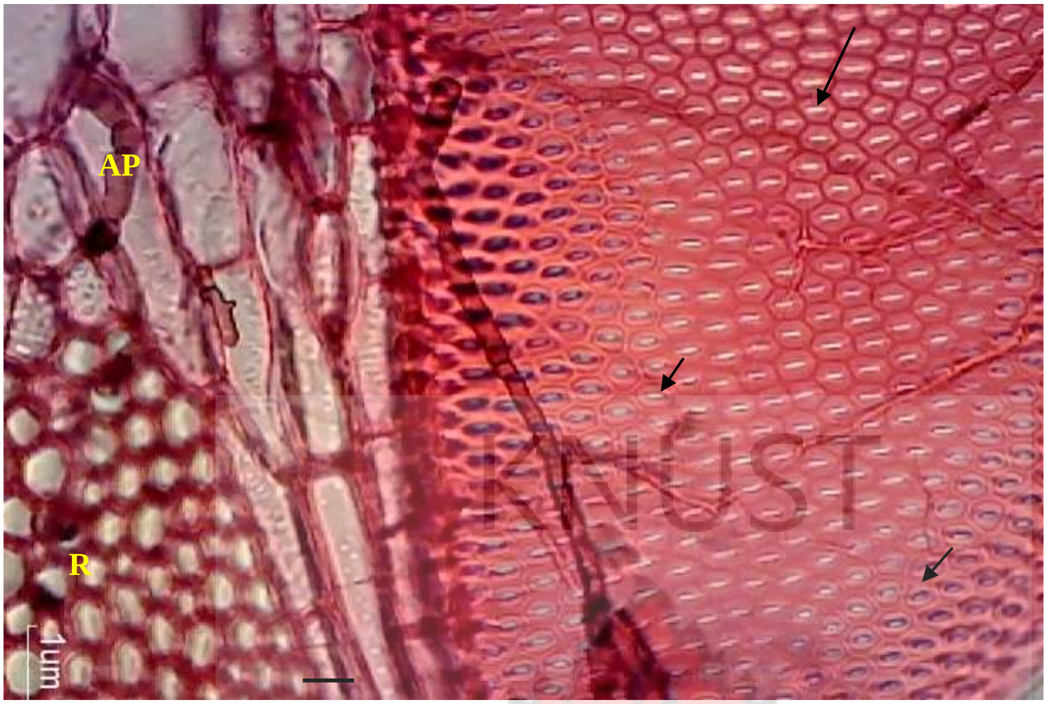

Plate 4.5 Tangential-longitudinal section of *F. sur* showing inter-vessel bordered pits (arrowheads), ray (R) and axial parenchyma (AP)

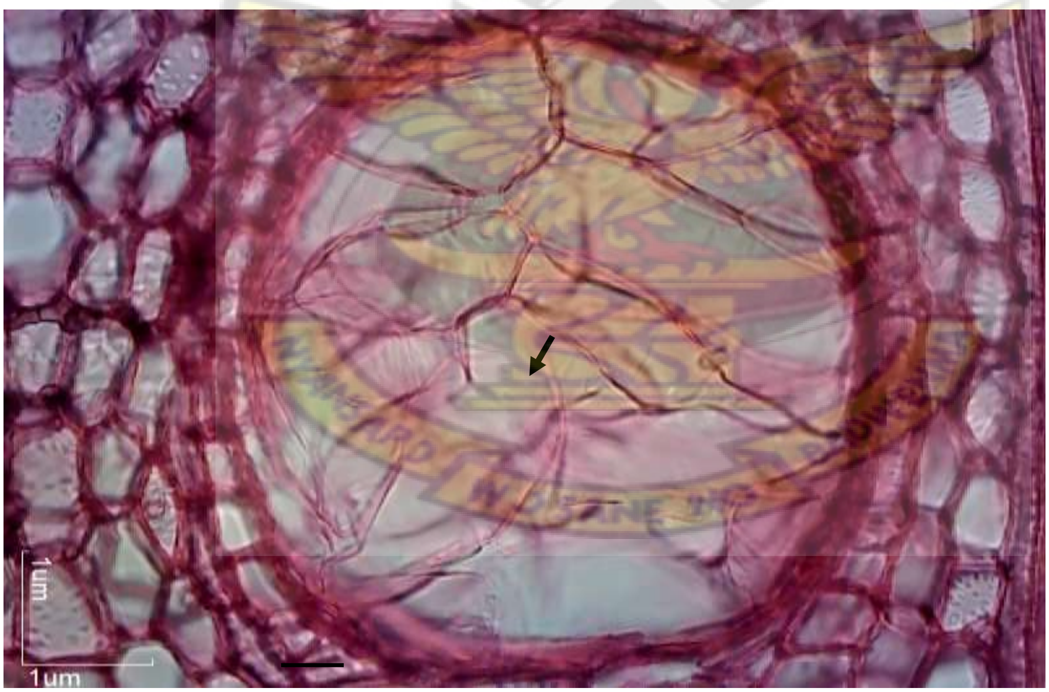

Plate 4.6 Cross section of *F. sur* showing vessel occluded with tyloses (arrowhead)

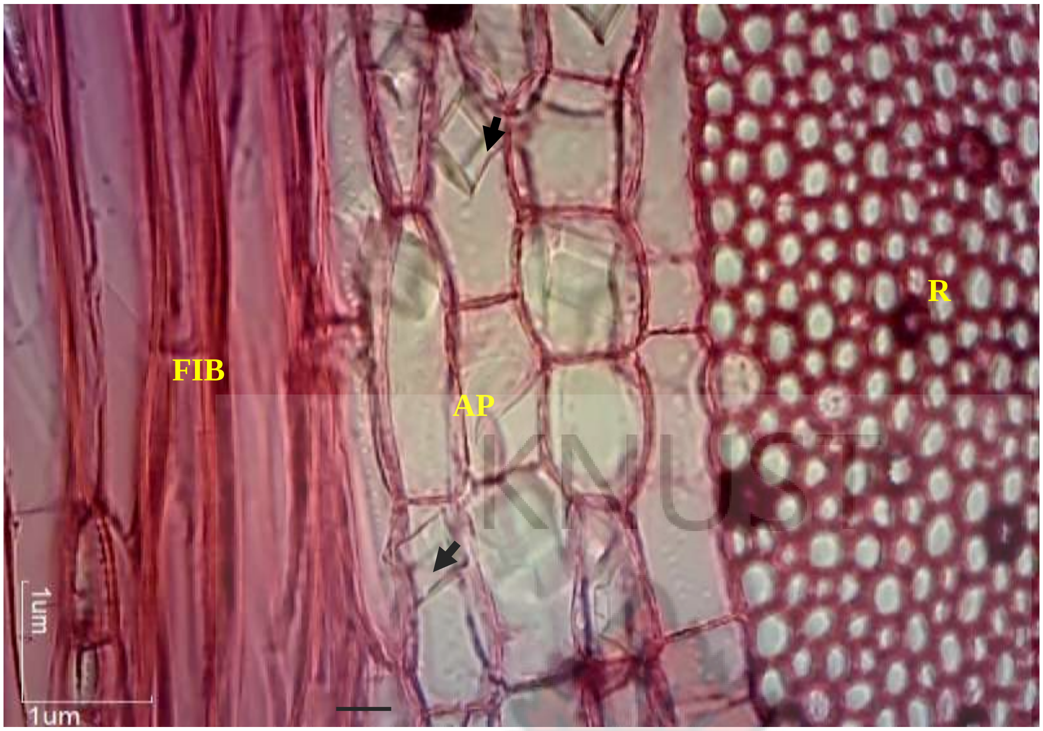

Plate 4.7 Tangential-longitudinal section of *F. sur* showing crystals (arrowhead) in chambered axial parenchyma, fibres (FIB), axial parenchyma (AP) and ray (R)

4.2.2 Description of *Cola gigantea*

Wood is diffuse porous and growth ring boundary not distinct (Plate 4.8). Vessels constitute about 8 % of the tissues, mostly solitary (SV) with few radial multiples of two (DV) to three cells (TV) in Plate 4.8. Vessels are scanty about 4 vessels per mm^2 with mean tangential diameter of 184µm. the vessel outline is mostly rounded in cross section (SV, DV and TV in Plate 4.8). The vessel perforation plates are predominately simple in oblique end walls. Inter-vessel pits are reduced to simple and are arranged mostly in alternate patterns with mean size of 3.0µm and are non-vestured (arrowheads in Plate 4.12). Vessel-ray pits are reduced to simple similar to that of inter-vessel pits. However, vessel-ray pits are relatively wider in size and shape than that of inter-vessel pits and are located throughout the ray cell (arrowheads in Plate 4.13). Gum inclusions are present in the vessels (GM in Plate 4.8; 4.10 and 4.11). Fibres constitute about

49% of the ground tissues with the mean double cell wall thickness of 9.9µm, mean lumen diameter of 14.8 µm, mean fibre diameter of 24.7 µm and mean fibre length of 2.0 mm long (FIB in Plates 4.8 and 4.9). The axial parenchyma constituting about 43% of the ground tissues and are arranged in paratracheal, vasicentric, reticulate with respect to the vessels and bands more than three cells wide (AP in Plate 4.8). Axial parenchyma cells are mostly in 3-4 cells per strand. Silica bodies are present in the chambered axial parenchyma cell (arrowheads in Plate 4.14). The rays are commonly arranged in 4-10 seriate with two distinct sizes (LR and SR Figure 4.9). The body ray cells are procumbent with mostly 2-4 marginal rows of upright, sheath cell present (PBR in Plate 4.10)

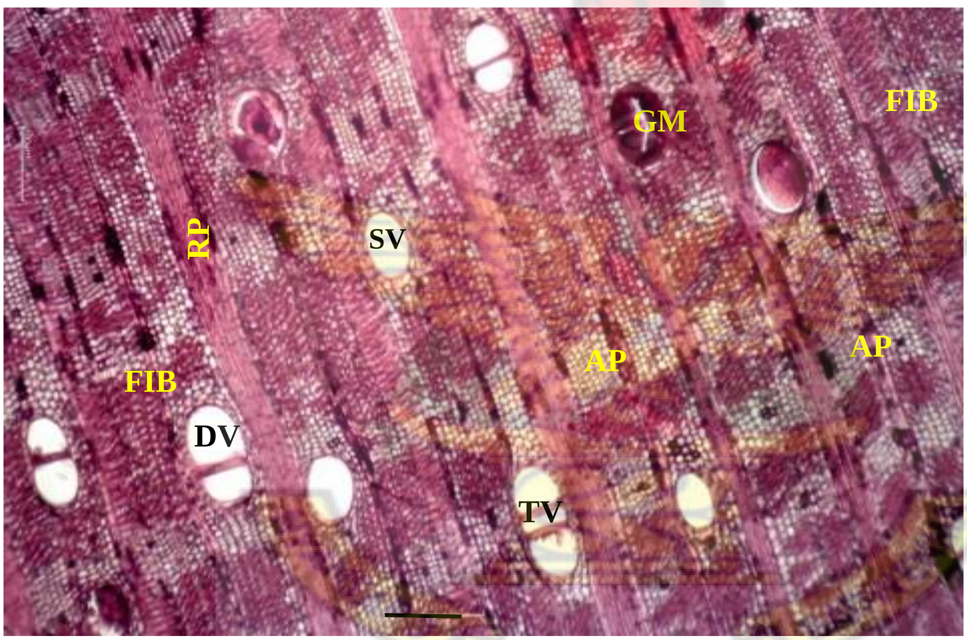

Plate 4.8 Cross section of *C. gigantea* showing solitary (SV) and multiples (DV & TV) vessels, gums (GM), fibres (FIB), Ray parenchyma (RP) and axial parenchyma (AP)

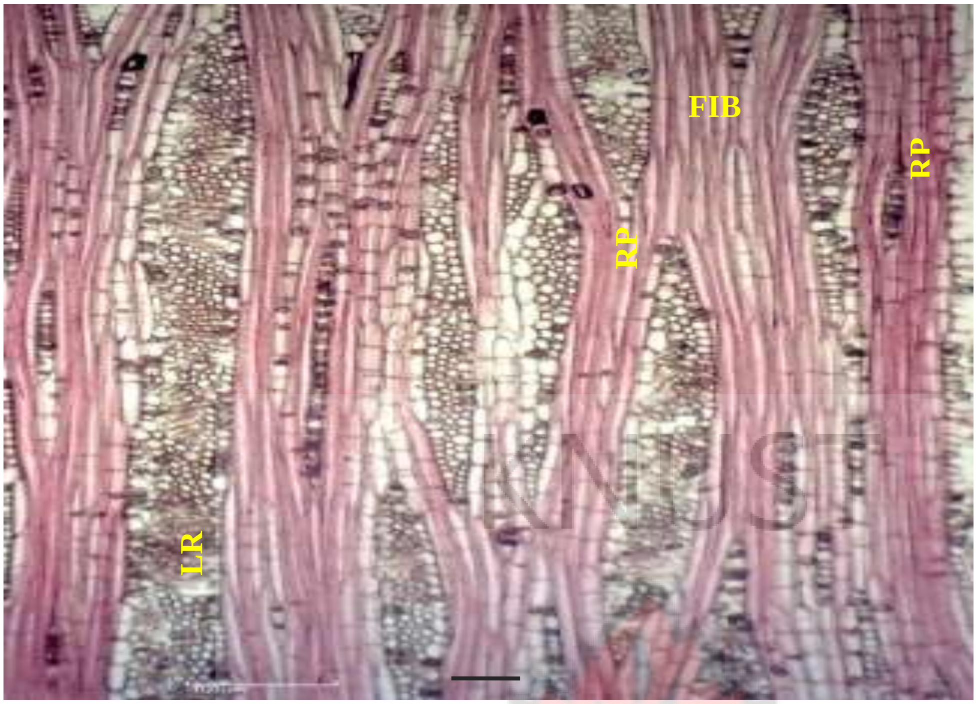

Plate 4.9 Tangential-longitudinal section of *C. gigantea* showing 4-10 seriate rays(RP), rays of two distinct sizes- Larger ray (LR) and fibres (FIB)

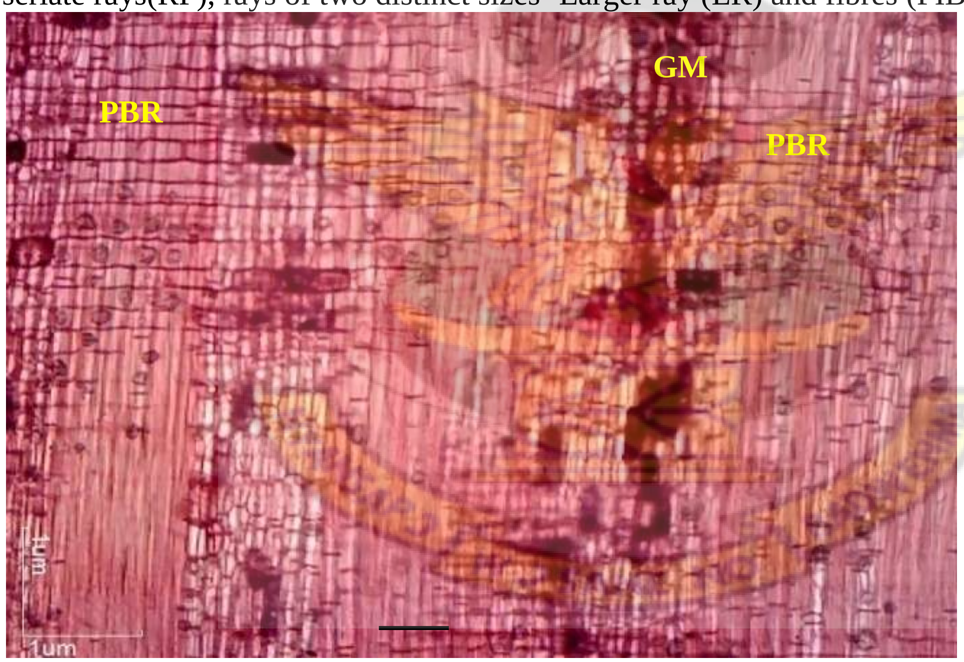

Plate 4.10 Radial-longitudinal section of *C. gigantea* showing procumbent rays (PBR) and gums (GM)

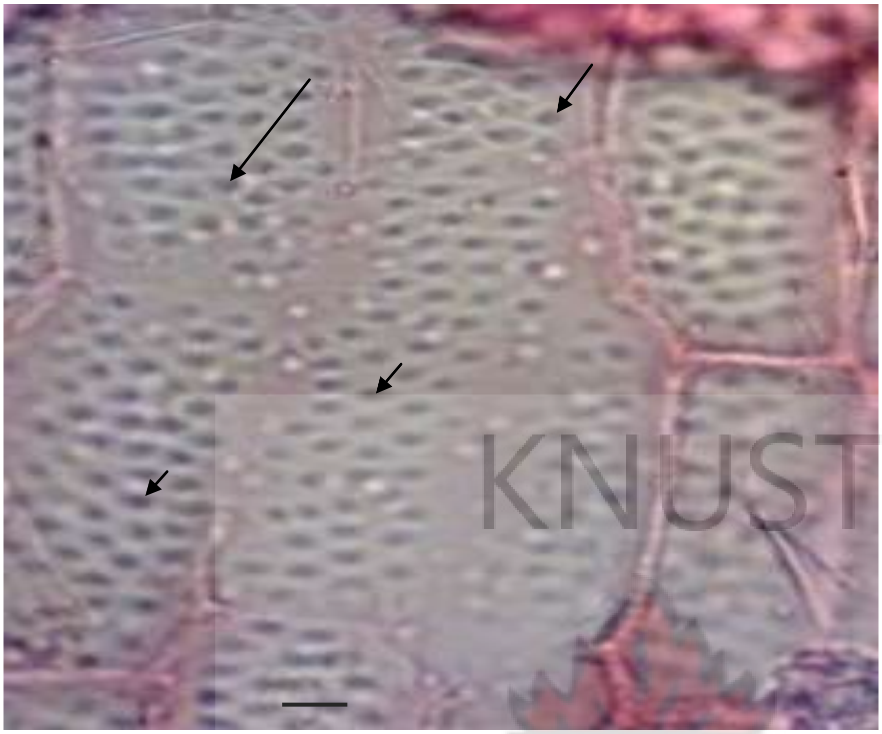

Plate 4.11 Radial-longitudinal section of *C. gigantea* showing vessel-ray pits (arrow heads)

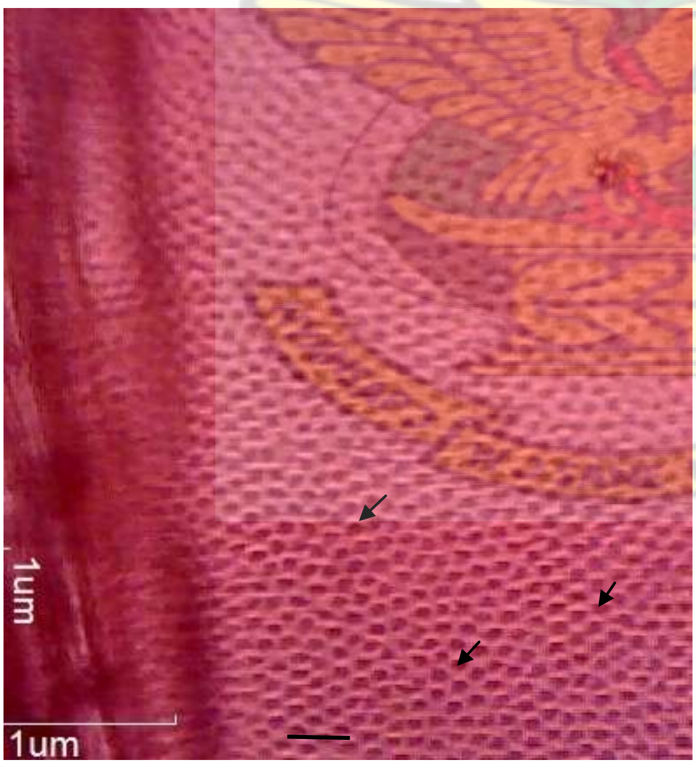

Plate 4.12 Tangential-longitudinal section showing inter-vessel pits (arrow heads)

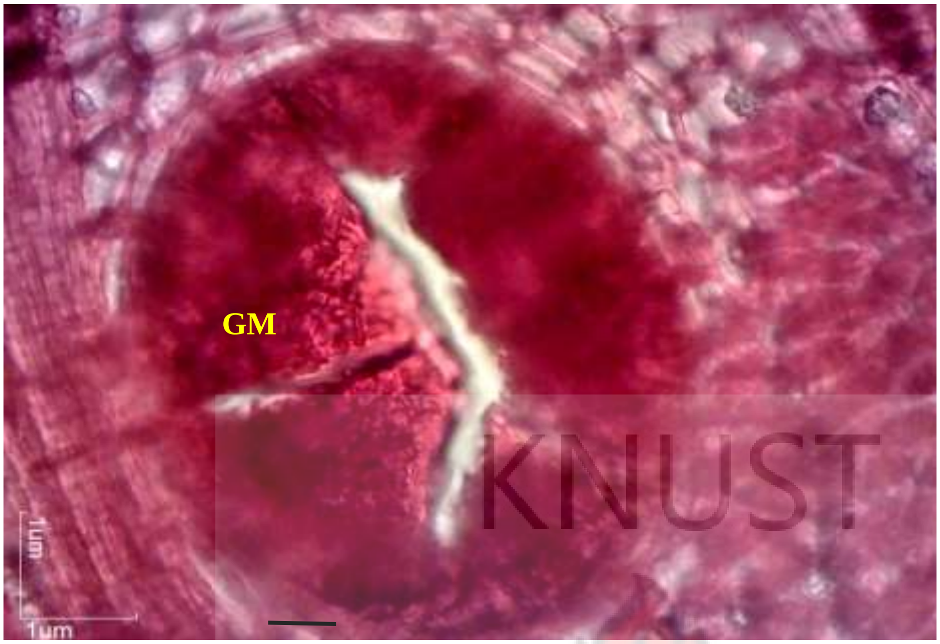

Plate 4.13 Cross section showing vessel occluded with gum (GM)

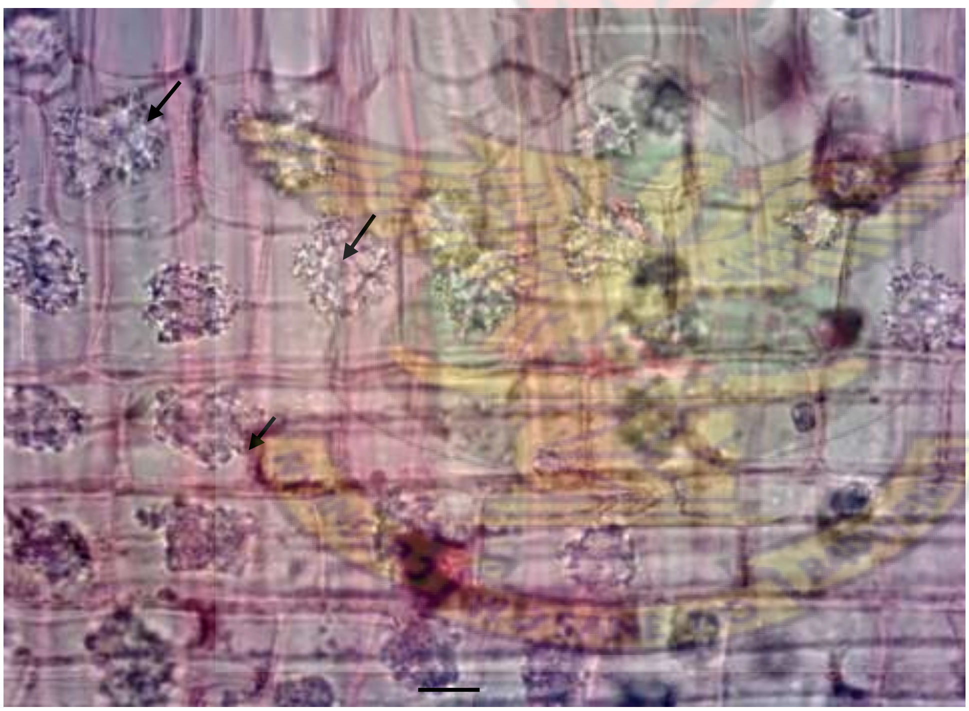

Plate 4.14 Radial-longitudinal section showing Silica bodies (arrowhead) in chambered axial parenchyma

4.3 Physical properties variations within and between species

4.3.1 Basic Density variations in *Cola gigantea* and *Ficus sur*

The mean basic densities for both species are presented in Table 4.3.1 and the Analysis of variance (ANOVA) is presented in Table 4.3.2. The mean basic density of the whole *Cola gigantea* sapwood was 501 kg/m^3 and that of its heartwood was 456 kg/m^3. The sapwood of the whole *Cola gigantea* was significantly denser than its heartwood at $P< 0.01$ (Table 4.3.2). Mean basic density of the whole *Cola gigantea* also varied significantly along the bole from the top through to the butt at $P < 0.01$(Table 4.3.2). The basic density of the whole *Cola gigantea* increased from the top to middle and decreased towards the butt portion. The middle portion of the whole tree was significantly denser than those of the butt and the top portions at $P\leq 0.05$ and the butt portion was significantly denser than the top portion at $P\leq 0.05$ (Table 4.3.1). The mean basic density values for sapwood and heartwood of the whole *Ficus sur* were 383kg/m^3 and 366kg/m^3 respectively (Table 4.3.1). The sapwood of the whole *Ficus sur* was significantly denser than its heartwood at $P< 0.01$(Table 4.3.2). Basic density varied along the bole of the whole *Ficus sur* and it decreased from the top portion to the middle and increased slightly towards the butt portion (Table 4.3.1). The top of the whole *Ficus sur* was significantly denser than the other two portions at $P\leq 0.05$ but there was statistically no significant difference between the butt and the middle portions at $P\geq 0.05$(Table 4.3.1). From Table 4.3.2, the mean basic density of the whole *Cola gigantea* was significantly higher than that of the whole *F. sur* at $P<0.01$. The basic density values varied from 479 kg/m^3 in *Cola gigantea* to 376 kg/m^3 in *Ficus sur*.

Table 4.3.1 Basic density (kg/m^3) variation within *Cola gigantea* and *Ficus sur*

Wood spp/ Sections	Sapwood Mean ± α	Range	Heartwood Mean ± α	Range	Whole tree Mean ± α	Range
C. gigantea						
Top	462 ± 50	387 – 523	425 ± 76	306 - 512	443^a ± 24	306 – 523
Middle	548 ± 18	513 – 587	490 ± 45	411– 553	519^b ± 45	411 – 587
Butt	495 ± 32	450 – 594	455 ± 42	317– 665	475^c ± 42	317 – 665
Whole tree	501^n ± 50	387 – 594	456^m ±62	306– 665	479 ± 61	306 – 665
Ficus sur						
Top	424 ± 69	342 – 539	378 ± 17	332 – 409	401^a ± 55	332 – 539
Middle	367 ± 24	323 – 419	352 ± 30	283 – 441	360^b ± 28	283 – 441
Butt	359 ± 18	331 – 412	367 ± 30	325 – 466	363^b ± 25	325 – 466
Whole tree	383^n ± 56	323 – 539	366^m± 29	283 – 466	375 ± 51	325 – 539

Means of the whole tree with the same letters on the same row and column under the same species are not significant at 0.01<P≥0.05. α = Standard deviation

Table 4.3.2 Analysis of variance (ANOVA) of the basic density and green moisture content in *Cola gigantea* and *Ficus sur*

Species	Sections	Sources of variation	F-value	F-crit	df
Cola gigantea	Radial (sapwood & heartwood)	Basic density	43.17**	6.74	1, 238
		Green moisture content	7.34**	6.74	1, 238
	Axial (butt, middle, top)	Basic density	47.98**	4.69	2, 237
		Green moisture content	16.99**	4.69	2, 237
F. sur	Radial (sapwood & heartwood)	Basic density	8.03**	6.74	1, 238
		Green moisture content	1.18^{ns}	3.88	1, 238
	Axial (butt, middle, top)	Basic density	27.31**	4.69	2, 237
		Green moisture content	9.88**	4.69	2, 237
	Whole *F. sur* and *C. gigantea*)	Basic density	491.15**	6.69	1, 478
		Green moisture content	1088**	6.69	1, 478

** = Significant at 0.001<P≤0.05, * = significant at 0.01<P≤0.05, ns = not significant at P≥0.05.

4.3.2 Variations in Green Moisture Content in *Cola gigantea* and *Ficus sur*

Table 4.3.3 shows the mean green moisture content values for *Cola gigantea* and *Ficus sur*. The mean green moisture content varied across and along the bole in both *Cola gigantea* and *Ficus* *sur*. The mean green moisture of the whole *Cola gigantea* heartwood was 110 % and that of its sapwood was 98 % (Table 4.3.3). From Table 4.3.2, the heartwood of the whole *Cola gigantea* significantly contains higher green moisture than its sapwood at P≤ 0.01 (Table 4.3.2). The middle portion of the whole *Cola gigantea* significant contains lower green moisture than the other portions at P≤ 0.05 but there was no statistical difference between the top and the butt portions at P≥0.05 (Tables 4.3.3). From Table 4.3.3, the mean green moisture content for the whole *Ficus sur* heartwood was 170 % and that of its sapwood was 167 %. Though there was difference in the mean green moisture content values between the heartwood and sapwood of *Ficus sur,* statistically, there was no significant difference between them at P≥0.05 (Table 4.3.2). The top portion of the whole *Ficus sur* has significantly lower green moisture content than those of the middle and butt portions at P ≤ 0.05 but there was no difference between the mean green moisture of the middle and the butt portions at P ≥ 0.05 (Table 4.3.3). Generally, mean green moisture content varied significantly between the two species. *Ficus sur* has significantly higher green moisture content than *Cola gigantea* at P≤ 0.01 (Table 4.3.2).

Table 4.3.3 Green moisture content (%) variation profile in *Cola gigantea* and *F. sur*

Wood spp/	Sapwood		Heartwood		Whole tree	
sections	Mean ± α	Range	Mean ± α	Range	Mean ± α	Range
C. gigantea						
Top	101 ± 4	91 – 111	111 ± 13	95 – 135	106^a ± 11	91 – 135
Middle	84 ± 6	75 – 95	107 ± 24	81 – 143	96^b ± 21	75 – 143
Butt	108 ± 7	97 – 122	115 ± 14	50 – 133	111^a ± 11	50 – 133
Whole tree	98^a ± 12	75 – 122	110^b ± 18	50 – 143	104 ± 16	50 – 143
Ficus sur						
Top	152 ± 29	121 – 224	159 ± 9	147 – 177	155^a ± 22	121 – 177
Middle	168 ± 16	138 – 201	173 ± 18	126 – 210	170^b ± 17	126 – 210
Butt	173 ± 11	148 – 197	172 ± 20	125 – 207	172^b ± 16	125 – 207
Whole tree	167^b ± 19	121 – 224	170^b ± 18	125 – 210	168 ± 19	121 – 210

Means of the whole tree with the same letters on the same row and column under the same species are not significant at 0.01<P≥0.05. α = Standard deviation

4.3.3 Variations in Air – dried Moisture Content in *Cola gigantea and Ficus sur*

The mean air – dried moisture content is shown on Table 4.3.4 for both *Cola gigantea and Ficus sur*. Generally, the mean air – dried moisture for *Cola gigantea* varied from 20.7 % in heartwood to 19.1 % in sapwood. The mean air – dried moisture content of the whole *Cola gigantea* decreased from the top portion to the middle portion and increased towards the butt portion. The mean air-dried moisture content of the top portion of the whole *Cola gigantea* was 19.6 %, the middle portion was 19.4 % and the butt portion was 20.7 %. The air – dried moisture in the whole *Ficus sur* heartwood was 15.3 % and that of its sapwood was 16.7 %. The air – dried moisture content of the whole *Ficus sur* increased from top to the butt portion along the bole. The mean air-dried moisture content of the top portion of the whole *Ficus sur* was 14.3 %, the middle portion was 15.1 % and the butt portion was 17.7 %. The whole *Ficus sur* has relatively lower air – dried moisture content averaged 16.0 % than that of *Cola gigantea* which averaged 19.9 %.

Table 4.3.4 Air-dried moisture content (%) variation in *Cola gigantea* and *F. sur*

Wood spp /	Sapwood		Heartwood		Whole tree	
section	Mean ± α	Range	Mean ± α	Range	Mean ± α	Range
C. gigantea						
Top	19.2 ± 3.2	13.7 - 33.4	20.1 ± 2.5	15.5 - 30.6	19.6 ± 2.9	13.7 - 33.4
Middle	18.8 ± 0.7	16.9 - 21.6	19.9 ± 1.5	15.5 - 25.8	19.4 ± 1.3	15.2 - 25.8
Butt	19.2 ± 0.5	15 - 22.4	22.2 ± 3.6	14.6 - 32.5	20.7 ± 3.4	14.6 - 32.5
Whole tree	19.1 ± 2.4	13.7 - 33.4	20.7 ± 2.8	14.6 - 32.5	19.9 ± 2.7	13.3 - 33.4
Ficus sur						
Top	14.4 ± 0.4	13.7- 14.9	14.2 ± 2.8	11.0 - 23.6	14.3±1.9;	11 - 23.6
Middle	15.7 ± 5.9	7.2 - 32.3	14.4 ± 2.7	11.5 - 20.9	15.1±4.6;	7.7 - 32.3
Butt	18.8 ± 5.5	7.3 - 29.4	16.6 ± 6.7	8.3 - 42.7	17.7±6.2;	7.3 - 42.7
Whole tree	16.7 ± 5.4	7.2 - 32.3	15.3 ± 4.8	8.3 - 42.7	16 ± 5.1;	7.3 - 42.7

4.4 Treatability

4.4.1 Theoretical maximum absorption (l/m^3) variation in *Cola gigantea* and *F. sur*

The theoretical maximum absorption was estimated based upon McQuire's (1975) equation: Maximum Absorption (l/m^3) = 1000 - [BD x (mc+ 66.7)/100]. 'BD' is basic density and 'mc' is the air-dried moisture content after seven months air-drying (August, 2010 to February, 2011). Theoretical maximum absorption values for *C. gigantea* and *F. sur* is presented on Table 4.4.1. The theoretical maximum absorption for the whole *Cola* gigantea heartwood was 582 l/m^3 and that of its sapwood was 565 l/m ^{3}. It also decreased from the top portion to the middle and increased towards the butt portion of the tree. The theoretical maximum absorption for the whole *Ficus sur* heartwood was 692 l/m^3 and that of its sapwood was 656 l/m^3. It also varied along the bole of *Ficus sur*. It increased from 638 l/m^3 at the top to 696 l/m^3 in the middle and decreased slightly (688 l/m^3) towards to the butt of the tree. *Ficus sur* has higher absorption capacity than *Cola gigantea.*

Table 4.4.1 Theoretical maximum absorption (l/m^3) variation in *C. gigantea* and *F. sur*

Wood species	Heartwood		Sapwood		Whole tree	
/ section	Mean ± α	Range	Mean ± α	Range	Mean ± α	Range
C. gigantea						
Top	587 ± 21	561 – 625	573 ± 19	496 – 611	580 ± 21	496 – 625
Middle	576 ± 48	503 – 642	536±15	509 – 559	556 ± 41	503 – 642
Butt	583 ± 42	396 – 630	587 ± 14	551 – 615	585 ± 31	396 – 630
Whole tree	582 ± 39	396 – 642	565 ± 27	496 – 615	574 ± 34	396 – 642
Ficus sur						
Top	685 ± 16	644 – 713	591 ± 58	500 – 712	638 ± 64	500 – 713
Middle	703 ± 23	629 – 735	690±33	600 – 740	696 ± 29	600 – 740
Butt	689 ± 18	588 – 737	687 ± 24	643 – 732	688 ± 31	588 – 737
Whole tree	692 ± 29	588 – 737	656 ± 53	500 – 740	674 ± 44	500 – 740

Table 4.4.2 Mean and standard deviation values of Basic density (BD, kg/m^3), Air dried Moisture Content (%) and Maximum absorption (l/m^3) of *Cola gigantea* and *Ficus sur*

Wood species	Sections	Air dried MC	Basic density	Maximum absorption
Cola gigantea	Sapwood	19.1 ± 2.36	501 ± 50	565 ± 27
	Heartwood	20.7 ± 2.84	456 ± 62	582 ± 39
Ficus sur	Sapwood	16.7 ± 5.36	383 ± 56	656 ± 53
	Heartwood	15.3 ± 4.83	366 ± 29	692 ± 29

4.4.2 Effect of treatment duration and pressure magnitude on absolute preservative volumetric retention (AVR) in *Cola gigantea* and *F. sur*

The effect of pressure magnitude and duration on absolute preservative volumetric retentions and relative volumetric retentions within the species are shown in Table 4.4.3, those between the species is presented on Table 4.4.4, the summary statistics of the absolute volumetric retentions along and across each species for the range of pressure magnitude and treatment duration were combined and analyzed, result is presented on Table 4.4.5 and the ANOVA on the effect of pressure magnitude and duration on volumetric retentions presented Table 4.4.6. The relative volumetric retention (RVR, %) was determined for the sapwood and heartwood of both species by dividing AVR at each treatment schedule in Table 4.4.3 by the respective Maximum absorption values for sapwood and heartwood of the specific species in Table 4.4.2 and expressed as percentage. For instance treatment schedule 600 kPa and 30 minute; AVR for *Cola gigantea* sapwood was 233 (Table 4.4.3), Maximum absorption for *Cola gigantea* sapwood = 565 (Table 4.4.2) RVR = [(233/565) x 100]; RVR= 41%. From Table 4.4.3, the mean absolute volumetric retentions (AVR) and the RVR increased with increasing pressure magnitude and time treatment for the sapwood and heartwood of both *Cola gigantea* and *Ficus sur*. For instance, the mean absolute volumetric retention for *Cola gigantea* sapwood was 233 kg/m^3 at 30minutes and increased to 320 kg/m^3 at 240 minutes at the same 600 kPa pressure and those of its heartwood was from 234 kg/m^3 at 30minutes and increased to 409 kg/m^3 at 240minutes for the same 600 kPa pressure. In the same scenario, the mean absolute volumetric retention for *Cola gigantea* sapwood was 233 kg/m^3 at 600 kPa and increased to 350 kg/m^3 at 1200 kPa at the same 30 minutes treatment time and those of its heartwood was from 234 kg/m^3 at 600 kPa and increased to 312 kg/m^3 at 1200 kPa at the same 30 minutes treatment time. The trend was the same for sapwood and heartwood of *Ficus sur* and it varied from 380 kg/m^3 for 30 minutes to 471 kg/m^3 for 240minutes for sapwood at the same 600 kPa pressure and those of its heartwood varied from 357 kg/m^3 at 30 minutes to 451 kg/m^3 at 240 minutes for 600 kPa pressure. The *Ficus sur* sapwood AVR varied from 380 kg/m^3 at 600 kPa to 510 kg/m^3 at 1200 kPa for 30 minutes treatment time and those of its heartwood varied from 357 kg/m^3 at 600 kPa to 463 kg/m^3 for 30 minutes treatment time. From Table 4.4.4 for example, absolute volumetric retention for *Cola gigantea* increased from 234 kg/m^3 at 30 minutes to 365 kg/m^3 at 240 minutes for the same 600 kPa pressure. Similarly, it increased from 234 kg/m^3 at 600 kPa to 325 kg/m^3 at 1200 kPa for the same 30 minutes treatment duration. For *Ficus sur*, mean absolute volumetric retention increased from 369 kg/m^3 at 30 minutes to 461 kg/m^3 at 240 minutes for the same 600 kPa pressure. Similarly, it increased from 369 kg/m^3 at 600 kPa to 487 kg/m^3 at 1200 kPa for the same 30 minutes treatment duration. From Table 4.4.5, the mean AVR varied slightly between the whole tree heartwood and sapwood for both species for the same range of treatment schedules thus from 30 to 240 minutes and 600 to 1200 kPa used for this study. The mean AVR of the heartwood of *Cola gigantea* was 354 kg/m^3 and that of its sapwood was 342 kg/m^3. The mean AVR varied from 469 kg/m^3 in *Ficus sur* heartwood to 467 kg/m^3 in its sapwood. Mean absolute volumetric retention varied along the bole of both species. For *Cola gigantea*, absolute volumetric retention increased with increasing height from the whole tree butt to top but it decreased with increasing height from butt to top in *Ficus sur* (Tables 4.4.5). For *Cola gigantea* whole tree, the mean absolute volumetric retention was 348 kg/m^3 and that of *Ficus sur* whole tree was 468 kg/m^3(Table 4.4.5). With the exception of *Ficus sur* sapwood where treatment time had no significant effect on the mean absolute volumetric retention between batches at P≥ 0.05, the pressure magnitude and treatment time significantly increased absolute volumetric retentions between batches for the sapwood and heartwood of both *Cola gigantea* and *Ficus sur* at P<0.01 (Table 4.4.6).

4.4.3 The effect of treatment duration and pressure magnitude on the mean absolute volumetric retention (AVR, kg/m^3) and the relative volumetric retention (RVR, %) of *Cola gigantea* and *Ficus sur*

Wood species / sections	Treatment duration (min)	AVR(kg/m^3) at various pressure magnitude (kPa)				RVR (%) at varoius pressure magnitude (kPa)			
		600	800	1000	1200	600	800	1000	1200
C. gigantea	30	233	288	311	350	41	51	55	62
Sapwood	60	240	294	344	356	42	52	61	63
	120	302	312	400	408	53	55	71	72
	240	320	404	410	422	57	72	73	75
Heartwood	30	234	293	302	312	40	50	52	54
	60	241	353	364	372	41	61	62	64
	120	342	376	393	408	59	64	68	70
	240	409	425	430	462	70	72	73	79
Ficus sur	30	380	394	459	510	58	60	70	78
Sapwood	60	409	418	487	522	62	64	74	79
	120	443	448	486	528	67	68	74	80
	240	471	496	508	548	72	76	77	83
Heartwood	30	357	419	430	463	51	60	62	67
	60	395	468	513	548	57	68	74	79
	120	445	480	530	561	64	69	76	81
	240	451	487	539	567	65	70	78	82

Table 4.4.4 The effect of treatment duration and pressure magnitude of the mean absolute volumetric retention (AVR, kg/m^3) and the relative volumetric retention (RVR, %) between *Cola gigantea* and *Ficus sur*

Wood species	Treatment duration (mins)	AVR (kg/m^3) at various pressure magnitude (kPa) 600	800	1000	1200	RVR (%) at various pressure magnitude (kPa) 600	800	1000	1200
C. gigantea	30	234	291	306	325	41	51	54	58
	60	241	324	354	364	42	57	62	64
	120	322	344	397	408	56	60	70	71
	240	365	415	420	442	64	72	73	77
F. sur	30	369	407	445	487	55	60	66	73
	60	402	443	500	535	60	66	74	80
	120	444	464	508	545	66	69	75	82
	240	461	492	524	558	69	73	78	83

Table 4.4.5 Mean AVR (kg/m^3) variation in *Cola gigantea* and *Ficus sur*

Wood spp/ sections	Heartwood Mean ± α	Range	Sapwood Mean ± α	Range	Whole tree Mean ± α	Range
C gigantea						
Top	390 ± 108	83 – 561	342 ± 121	93 – 598	366 ± 116	83 – 598
Middle	340 ± 112	138 – 523	343 ± 104	74 – 506	342 ± 107	74 – 523
Butt	332 ± 123	95 – 537	342 ± 113	146 – 537	337± 120	95 – 537
Whole tree	354 ± 103	83 – 561	342 ± 135	74 – 598	348± 110	83 – 598
Ficus sur						
Top	459 ± 138	158 – 623	456 ± 154	100 – 683	457 ± 142	100 – 683
Middle	456 ± 124	149 – 643	477 ± 118	180 – 660	467 ± 121	149 – 660
Butt	492 ± 107	162 – 693	467 ± 126	132 – 632	480 ± 115	132 – 693
Whole tree	469 ± 145	149 – 693	467 ± 154	100 - 683	468 ± 155	100 – 693

Table 4.4.6 ANOVA of the effect of pressure magnitudes and durations on preservative volumetric retention of *Cola gigantea* and *Ficus sur*

Species	Sections	Sources of Variation	F– value	F-crit	df
C. gigantea	Heartwood	Pressure magnitude between batches	4.71**	3.95	3, 140
		Treatment time between batches	14.69**	3.95	3, 140
	Sapwood	Pressure magnitude between batches	6.24**	3.95	3, 140
		Treatment time between batches	5.09**	3.95	3, 140
	Whole tree	Pressure magnitude between batches	10.60**	3.85	3, 284
		Treatment time between batches	17.88**	3.85	3, 284
F. sur	Heartwood	Pressure magnitude between batches	9.21**	3.95	3, 140
		Treatment time between batches	5.24**	3.95	3, 140
	Sapwood	Pressure magnitude between batches	4.73**	3.95	3, 140
		Treatment time between batches	1.29ns	2.85	3, 140
	Whole tree	Pressure magnitude between batches	13.86**	3.85	3, 284
		Treatment time between batches	5.50**	3.85	3, 284

** = Significant at $0.001<P \leq 0.01$; ns = not significant at $P \geq 0.05$

4.4.3 Effect of pressure magnitude and treatment duration on the mean percentage surface area of *Ficus sur* and *Cola gigantea* penetrated by the CCA preservative

The result of the mean percentage surface area of each species penetrated is presented in Tale 4.4.7 and the summary statistics of combined results for the range of pressure magnitude and treatment duration used for this study is presented on Table 4.4.8. The mean percentage surface area penetrated increased with increasing pressure magnitude and duration for both species. From Table 4.4.7, penetrability for *Cola gigantea* sapwood increased from 14 % at 600 kPa to 44 % at 1200 kPa and those for its heartwood varied from 31 % at 600 kPa to 56 % at 1200 kPa for the same treatment duration of 30 minutes. Similarly it increased from 14 % at 30 minutes to 50% at 240 minutes for *Cola gigantea* sapwood and 31 % at 30 minutes to 50 % at 240 minutes for its heartwood for the same 600 kPa pressure magnitude (Table 4.4.7). On the other hand, *Ficus sur* sapwood penetrability increased from 38 % at 600 kPa to 59 % at 1200 kPa for 30 minutes pressure duration and those of its heartwood varied from 39 % at 30 minutes to 55 % at 1200 kPa for the 30 minutes treatment duration (Table 4.4.7). Again, *Ficus sur* sapwood penetrability varied from 38 % at 30 minutes to 57 % at 240 minutes and those of its heartwood varied from 39 % at 30 minutes to 52 % at 240 minutes for the same 600 kPa pressure magnitude. From Table 4.4.8, the mean percentage surface area penetrated in *Cola gigantea* whole tree sapwood was 43 % and that of its heartwood was 55 %. The mean percentage surface area penetrated varied slightly along the bole of *Cola gigantea*. Considering the whole tree, it increased from the tree top to the middle and decreased towards the butt (Table 4.4.8). In the case of *Ficus sur*, penetrability varied from 53 % in sapwood to 57 % in the heartwood of the whole tree. Penetrability was constant at 55 % along the bole of *Ficus sur*. *Ficus sur* penetrability was 55 % relatively higher than that of *Cola gigantea* which averaged 49 % (Table 4.4.8).

4.4.7 Effect of pressure magnitude and treatment duration on mean percentage surface area (%) penetrated by the CCA preservative in sapwood and heartwood of *Cola gigantea* and *Ficus sur*

Radial sections	Treatment duration (min)	*Cola gigantea* Surface area penetrated (%) at pressure magnitude (kPa)				*Ficus sur* Surface area penetrated (%) at pressure magnitude (kPa)			
		600	800	1000	1200	600	800	1000	1200
Sapwood	30	14	23	37	44	38	38	43	59
	60	32	39	48	50	38	44	54	59
	120	40	44	51	58	44	55	56	65
	240	50	52	55	61	57	59	64	78
Heartwood	30	31	43	46	56	39	44	47	55
	60	34	45	61	66	40	52	58	64
	120	47	55	67	69	51	56	68	69
	240	50	60	76	77	52	62	69	71

Table 4.4.8 Mean percentage surface area penetration (%) variation in *Cola gigantea* and *Ficus sur*

Wood spp/ section	Heartwood Mean ± α	Range	Sapwood Mean ± α	Range	Whole tree Mean ± α	Range
C. gigantea						
Top	48 ± 26	5 – 95	43 ± 28	5 – 95	46 ± 27	5 – 96
Middle	60 ± 28	10 – 95	45 ± 30	7 – 95	52 ± 30	7 – 95
Butt	58 ± 32	5 – 98	42 ± 23	5 – 90	50 ± 29	5 – 98
Whole tree	55 ± 29	5 – 98	43 ± 27	5 – 95	49 ± 26	5 – 98
Ficus sur						
Top	61 ± 17	28 – 98	49 ± 18	20 – 75	55 ±18	20 – 98
Middle	55 ± 17	30 – 80	55 ± 17	10 – 92	55 ± 17	10 – 92
Butt	55 ± 17	20 – 90	55 ± 22	15 – 89	55 ± 19	15 – 90
Whole tree	57 ± 17	20 – 98	53 ± 19	10 – 92	55 ± 23	10 – 98

4.4.4 The effect of pressure magnitude and duration on the depth of penetration (mm) variation along and across the stems of *Cola gigantea* and *Ficus sur*

The mean percentage surface area penetrated by the preservative was converted to a linear scale based on the dimensions of the specimen used for the study [500 mm (long) x 50 mm (wide) x 25 mm (thick)]. The longitudinal penetration was set at 500 mm long and the transverse penetration (radial and tangential) was at 25 mm depth and the results of combined sapwood and heartwood of each species at various pressure magnitudes and treatment durations are presented in Table 4.4.9, summary of statistics on the depth of penetration for the range of pressure magnitude and treatment duration are presented in Table 4.4.10 for *Ficus sur* and Table 4.4.11 for *Cola gigantea*. The results indicated that, both the longitudinal and transverse penetration increased with increasing pressure magnitude and treatment duration (Tables 4.4.9). From Tables 4.4.10 and 4.4.11, there was wide difference between the longitudinal and transverse penetrations for both species. The ratio of longitudinal to transverse penetrations was about 22 to

1 for *Ficus sur* sapwood and that of its heartwood was 24 to 1 (Table 4.4.10) and it was 32 to 1 for *C. gigantea* sapwood and 39 to 1 for its heartwood (Tables 4.4.11). The ratio of longitudinal to transverse penetrations was about 36 to 1 for *C. gigantea* (Tables 4.4.11) and 23 to 1 for *F. sur* (Table 4.4.10). The depth of penetration both longitudinally and transversely was relatively higher in the heartwood than in the sapwood for both species (Tables 4.4.10 and 4.4.11). The depth of longitudinal penetration decreased from the top of the tree (345 mm) to the middle (276 mm) and increase towards the butt (299 mm) of the stem of *Ficus sur* (Tables 4.4.10). The transverse depth of penetration of *Ficus sur* was relatively constant along the bole from top to butt (Table 4.4.10). From Table 4.4.11, whole tree longitudinal depth of penetration for *C. gigantea* seems to increase from the butt to the top and the transverse depth of penetration was relative constant along the bole.

Table 4.4.9 Mean depth (mm) of penetrated by the CCA preservative in longitudinal, radial and tangential sections of *Cola gigantea* and *Ficus sur*

Section orientation	Treatment duration (min)	*Cola. gigantea* Depth of penetration (mm) Pressure magnitude (kPa)				*Ficus sur* Depth of penetration (mm) Pressure magnitude (kPa)			
		600	800	1000	1200	600	800	1000	1200
Longitudinal (500mm)	30	135	290	338	348	150	151	167	295
	60	310	316	396	400	160	258	348	373
	120	332	345	398	463	238	330	368	378
	240	372	373	457	470	312	340	410	426
Radial (25mm)	30	4.0	5.4	5.9	10.6	8.8	9.3	9.5	12.5
	60	4.4	6.8	10.0	10.9	8.9	10.0	12.0	14.3
	120	7.5	10.9	13.8	15.0	10.0	12.4	14.2	15.6
	240	12.5	13.3	15.0	19.0	12.1	13.9	17.3	17.5
Tangential (25mm)	30	3.8	5.0	7.8	11.6	9.0	9.2	11.4	14.2
	60	3.8	6.6	11.6	11.9	11.5	11.7	13.5	14.3
	120	4.3	7.1	12.8	13.8	12.0	13.0	15.1	15.5
	240	7.1	10.0	15.6	15.9	13.1	15.6	16.7	17.0

Table 4.4.10 Summary statistics of the depth of penetration (mm) variation along and across the stem of *Ficus sur* (Mean ± standard deviation)

Orientations	Sections	Top Mean ± α	Middle Mean ± α	Butt Mean ± α	Whole tree Mean ± α
Longitudinal (mm)	Sapwood	331 ± 95 (275-375)	264 ± 101 (50-460)	286 ± 106 (100-445)	286 ± 106 (50-460)
	Heartwood	358 ± 104 (140-490)	289 ± 108 (150-400)	317 ± 108 (200-450)	321 ± 109 (140-490)
	Whole tree	345 ± 104 (140-490)	276 ± 108 (50-460)	299 ± 108 (100-450)	304 ± 110 (50-490)
Tangential (mm)	Sapwood	13 ± 3(8-18)	12 ± 4(8-16)	13 ± 4(5-20)	13 ± 4(5-20)
	Heartwood	14±2(10-18)	14± 3(12-16)	15±4(10-21)	14 ±4(10-21)
	Whole tree	14 ± 2(8-18)	13 ± 4(8-16)	14 ± 4(5-21)	14 ± 4(5-21)
Radial (mm)	Sapwood	9 ± 4(5-14)	13± 4(10-15)	14 ± 4(5-22)	12 ± 4(5-22)
	Heartwood	13 ± 4(8-18)	12 ± 4(9-16)	12 ± 4(5-18)	12 ± 4(5-18)
	Whole tree	11 ± 4(5-18)	12 ± 4(9-16)	13 ± 4(5-22)	12 ± 4(%-22)

Range values in brackets

Table 4.4.11 Summary statistics of the depth of penetration variation along and across the stem of *Cola gigantea* (Mean± standard deviation)

Orientations	Sections	Top Mean ± α	Middle Mean ± α	Butt Mean ± α	Whole tree Mean ± α
Longitudinal (mm)	Sapwood	371 ± 107 (225-480)	363 ± 123 (50-475)	249 ± 100 (150-445)	328 ± 120 (50-480)
	Heartwood	369 ± 117 (220-480)	384 ± 100 (200-470)	438 ± 50 (315-485)	397 ± 90 (220-485)
	Whole tree	370 ± 110 (220-480)	373 ± 110 (50-475)	355 ± 120 (150-485)	364 ± 110 (50-485)
Tangential (mm)	Sapwood	8 ± 6 (3-18)	4 ± 3 (3-9)	10 ± 3 (3-9)	8 ± 6 (3-18)
	Heartwood	11 ± 6 (2-16)	12 ± 6 (3-20)	8 ± 5 (3-13)	10 ± 6 (2-20)
	Whole tree	10 ± 6 (2-18)	8 ± 5 (3-20)	9 ± 7 (3-13)	9 ± 6 (2-20)
Radial (mm)	Sapwood	10 ± 6 (3-21)	7 ± 4 (3-15)	8 ± 4 (5-13)	8 ± 5 (3-21)
	Heartwood	10 ± 6 (3-19)	12 ± 6 (4-18)	10 ± 6 (3-18)	11 ± 6 (3-19)
	Whole tree	10 ± 6 (3-21)	10 ± 5 (3-18)	9 ± 5 (3-18)	10 ± 5 (3-21)

Range values in brackets

4.4.5 The effect of pressure magnitude and duration on preservative oxide retentions (kg/m^3) within species

In a batch, the oxide retention by the sapwood samples were combined (added) irrespective of the axial position (butt, middle and top) in the bole and the average taken. A similar thing was done for oxide retention in the heartwood samples and the results are presented in Table 4.4.12. Table 4.4.13 showed results of the combined longitudinal, radial and tangential oxide retentions in a batch irrespective whether heartwood or sapwood. Preservative oxide balance for the sapwood and heartwood irrespective of the orientation is presented in Table 4.4.14. The preservative oxide retentions increased with increasing pressure and duration for sapwood and heartwood of both species (Table 4.4.12). The oxide retention values varied slightly within species for the same treatment schedules used. From Table 4.4.12 for instance, oxide retention of *Cola gigantea* sapwood increased from 1.41 kg/m^3 at 600 kPa to 1.99 kg/m^3 at 1200 kPa for 30 minutes treatment time and those of its heartwood varied from1.39 kg/m^3 at 600 kpa to 1.91 kg/m^3 at 1200 kPa for 30 minutes treatment time. Similarly, it varied from 1.41 kg/m^3 at 30minutes to 1.80 kg/m^3 at 240 minutes for 600 kPa pressure for sapwood and 1.39 kg/m^3 at 30minutes and 1.91 kg/m^3 at 240 minutes for 600 kPa pressure for heartwood. On the same Table 4.4.12, oxide retention of *Ficus sur* sapwood increased from 1.86 kg/m^3 at 600 kPa to 2.20 kg/m^3 at 1200 kPa for 30 minutes treatment time and those of its heartwood varied from1.89 kg/m^3 at 600 kpa to 2.13 kg/m^3 at 1200 kPa for 30 minutes treatment time. Again, oxide retention varied from 1.89 kg/m^3 for 30 minutes to 2.37 kg/m^3 for 240 minutes for 600 kPa pressure for sapwood and 1.89 kg/m^3 for 30 minutes and 2.25 kg/m^3 for 240 minutes for 600 kPa pressure for heartwood. Preservative oxide retention also varied with the Longitudinal, radial and tangential orientations (Table 4.4.13). From Table 4.4.14, the oxide balance obtained for *Cola gigantea* sapwood ranges were [(CuO =16.0 – 20.5 %), (CrO_3 = 46.1 – 53.9 %) and (As_2O_5 = 29.6 – 33.3 %)] and those of its heartwood were [(CuO =16.2 – 19.2 %), (CrO_3 = 49.1 – 54.0 %) and (As_2O_5 = 28.3 – 31.8 %)] From the same Table 4.4.14, the oxide balance for *Ficus sur* sapwood ranges were [(CuO =18.4 – 21.9 %), (CrO_3 = 48.1 – 52.9 %) and (As_2O_5 = 28.0 – 31.3 %)] and those of its heartwood were [(CuO =18.8 – 23.2 %), (CrO_3 = 45.4 – 53.3 %) and (As_2O_5 = 26.9 – 32.0 %)].

Table 4.4.12 Influence of pressure magnitude and treatment duration on mean oxide (CuO; CrO_3; As_2O_5) retention (kg/m^3) in sapwood and heartwood of *Cola gigantea* and *Ficus sur*

Sections	Treatment duration (min)	*Cola gigantea* Mean oxide retention (kg/m^3) Pressure magnitude (kPa)				*Ficus sur* Mean oxide retention (kg/m^3) Pressure magnitude (kPa)			
		600	800	1000	1200	600	800	1000	1200
Sapwood	30	1.41	1.52	1.83	1.99	1.86	1.96	2.11	2.20
	60	1.48	1.57	1.93	2.07	1.98	2.20	2.21	2.39
	120	1.56	1.79	2.01	2.18	2.09	2.23	2.29	2.85
	240	1.80	2.00	2.03	2.21	2.37	2.41	2.51	3.21
Heartwood	30	1.39	1.44	1.54	1.91	1.89	2.01	2.02	2.13
	60	1.54	2.00	2.06	2.16	2.04	2.11	2.14	2.15
	120	1.82	2.00	2.06	2.29	2.14	2.18	2.37	2.77
	240	1.91	2.03	2.13	2.29	2.25	2.28	2.46	3.19

Table 4.4.13 Influence of pressure magnitude and treatment duration on mean oxide (CuO; CrO_3; As_2O_5) retention (kg/m^3) in longitudinal, radial and tangential sections of *Cola gigantea* and *Ficus sur*

Orientations	Treatment duration (min)	*Cola gigantea* Mean oxide retention (kg/m^3) Pressure magnitude (kPa)				*Ficus sur* Mean oxide retention (kg/m^3) Pressure magnitude (kPa)			
		600	800	1000	1200	600	800	1000	1200
Longitudinal	30	1.02	0.82	1.62	1.16	1.23	1.50	1.13	1.65
	60	1.28	1.56	1.67	1.76	1.60	1.56	1.50	1.90
	120	1.09	1.58	1.99	2.01	1.22	1.78	1.98	2.38
	240	1.34	1.27	1.91	1.63	2.07	2.07	1.38	2.01
Radial	30	1.74	1.83	1.94	2.35	2.27	1.88	2.66	2.36
	60	1.59	1.74	2.06	2.33	2.36	2.50	2.23	2.42
	120	2.04	2.02	2.06	2.38	2.25	2.75	2.54	3.35
	240	2.15	2.21	2.29	2.67	2.43	2.54	3.46	3.27
Tangential	30	1.45	1.80	1.49	2.34	2.14	2.58	2.37	2.49
	60	1.66	2.06	2.26	1.92	2.07	2.42	2.81	2.50
	120	1.94	2.09	2.06	2.32	2.90	2.09	2.48	2.72
	240	2.07	2.56	2.04	2.46	2.45	2.43	2.63	3.83

Table 4.4.14 Mean preservative oxide (CuO; CrO_3; As_2O_5) balance (%) in sapwood and heartwood of *Cola gigantea* and *Ficus sur*

Wood species / Section	Treatment duration (min)	Preservative oxide balance (%) in treated samples at various pressure magnitude											
		600 kPa			800 kPa			1000 kPa			1200 kPa		
C. gigantea		CuO	CrO_3	As_2O_5	CuO	CrO_3	As_2O_5	CuO	CrO_3	As_2O_5	CuO	CrO_3	As_2O_5
Sapwood	30	18.6	50.3	30.8	19.1	50.6	30.3	17.6	52.0	30.4	17.5	52.8	29.7
	60	18.6	48.8	32.5	19.2	48.7	32.1	20.1	48.1	31.8	17.1	51.4	31.5
	120	20.5	46.1	33.3	18.1	48.6	33.2	18.1	52.3	29.6	19.4	49.7	30.9
	240	18.3	50.5	31.3	16.0	53.9	30.1	17.4	50.9	31.8	17.0	52.8	30.2
Heartwood	30	19.1	49.7	31.2	18.4	49.9	31.7	19.2	50.2	30.6	19.1	49.1	31.8
	60	18.4	51.8	29.8	17.3	54.0	28.7	18.8	52.8	28.4	18.2	52.2	29.6
	120	17.7	52.3	30.0	17.8	54.0	28.2	17.2	53.2	29.6	18.3	52.2	29.5
	240	18.1	50.3	31.6	17.3	52.2	30.5	17.6	53.4	29.0	16.2	53.9	29.9
Ficus sur	30	19.1	51.1	29.8	21.5	49.6	28.9	20.0	51.0	29.0	20.1	50.0	29.9
Sapwood	60	19.1	52.9	28.0	19.1	51.1	28.8	20.4	49.2	30.4	18.4	51.1	30.5
	120	21.6	48.1	30.3	21.2	48.4	30.4	20.4	49.0	30.6	21.9	48.2	29.9
	240	21.4	48.5	30.1	19.3	50.4	30.3	19.4	49.3	31.3	20.4	48.4	31.2
Heartwood	30	19.3	53.2	27.5	20.1	50.8	29.1	19.8	53.3	26.9	20.1	50.1	29.8
	60	20.5	50.7	28.8	21.5	48.6	29.9	20.7	49.2	30.1	19.7	49.8	30.5
	120	21.1	48.6	30.3	21.6	47.6	30.8	20.7	49.6	29.7	22.6	45.4	32.0
	240	18.8	52.2	29.0	23.2	46.0	30.8	19.7	49.8	30.5	22.1	47.0	30.9

CHAPTER FIVE

5.0 Discussions

5.1 Anatomical properties

The ground tissue proportion and their morphological variations form the basis for differences in most properties of wood (Maturbongs and Schneider, 1996). The distribution and arrangement of these tissues within the wood matrics and the morphological features with/ or without the presence of extraneous materials are essential tool in wood identification.

5.1.1 Tissue proportion variation in *Cola gigantea* and *Ficus sur*

Oteng-Amoako (2006b) stated that the variations in the relative proportions of wood ground tissues and their morphological geometry contribute to difference in wood density. From Table 4.1.1, the proportion of vessel was 8 % in both sapwood and heartwood of *C. gigantea*. Parenchyma proportion was 44 % in sapwood and 42 % in heartwood. The fibre proportion varied from 48 % in sapwood to 50 % in heartwood of *Cola gigantea* and the tangential vessel diameter varied from 180µm in sapwood to 188µm in heartwood (Table 4.1.2). These variations in sapwood and heartwood ground tissue proportions coupled especially with the vessel diameter may contribute to making *Cola gigantea* sapwood denser (501 kg/m^3) than its heartwood (456 kg/m^3). This is because the wider vessel diameter in the heartwood creates more spaces thereby increasing the volume in the heartwood as compared with the sapwood for the same unit mass. This reason may account for the higher green moisture content in *Cola gigantea* heartwood (110 %) as compared to its sapwood (98 %). From the same Table 4.1.1, the mean vessel proportion was 9 % in both sapwood and heartwood of *F. sur*. Parenchyma proportion varied from 49 % in sapwood to 44 % in heartwood. Fibre proportion was 42 % in sapwood and 47 % in heartwood of *Ficus sur* and vessel diameter was 216 µm for *Ficus sur* sapwood and 236 µm for its heartwood (Table 4.1.2). Although the tissue proportions favour *Ficus sur* heartwood in terms of density but the wider vessel diameter which greatly influences the buoyancy of wood favours the sapwood thereby making the *Ficus sur* sapwood (383 kg/m^3) denser than its heartwood (366 kg/m^3). The wider vessel diameters in heartwood of both species were expected since both species are fast-growing light "demander" species hence grows rapidly in the juvenile stages with larger cell lumen and thin cell walls but the growth rate relatively slows down as the plant aged thereby the plant produces cells with relatively thicker cell wall and smaller cell lumen. This may account for relatively smaller vessel diameter in sapwood as compared with that of the heartwood of both species. The mean percentage tissues proportion varied slightly between *Cola gigantea* and *Ficus sur.* The vessel proportion varied from 8% in *Cola gigantea* to 9 % in *Ficus sur*. Proportion of parenchyma varied from 43 % in *C. gigantea* to 47 % in *F. sur* and fibre proportion was 49 % in *Cola gigantea* and 44 % in *Ficus sur*. From Table 4.1.2, the vessel frequency was 4.0 mm^{-2} for both *C. gigantea* and *Ficus sur*. Inter-vessel pit sizes were 3.0 µm for *C. gigantea* and 8.0 µm for *Ficus sur*. The tangential vessel diameter varied from 184 µm in *C. gigantea* to 225µm in *Ficus sur.* Ray parenchyma height varied from 1224 µm in *C. gigantea* to 729µm in *Ficus sur* and the ray width was 139 µm in *C. gigantea* and 121 µm in *Ficus* sur. The relatively higher proportions of fibres (49 %) in *C. gigantea* may partly account for it higher density (479 kg/m$^{3)}$ as compared with that of *F. sur* (fibre proportion 44 % and basic density is 375 kg/m^3). The relatively higher proportions of vessels (9 %), parenchyma (47%), vessel diameter (225 µm), inter-vessel pit size (8.0 µm) as well as larger fibre lumen (24µm) in *F. sur* may partially account for its higher green moisture content (168 %) and volumetric retention (468 kg/m^3) as compared 8% vessels, 43 % parenchyma, 3.0 µm pit size, 184µm and 15µm lumen diameter resulting in 104 % moisture content and 348 kg/m^3 volumetric retention in *C.*

gigantea. Ramirez *et al* (2008) stated that vessels and fibres are essential in assessing the suitability of wood species for pulp and paper production. They further stated that *Eucalyptus globules,* a suitable pulp and paper raw material has around 4-6 vessels / mm^2. The average tissue proportions and the fibre morphologies of both *Cola gigantea* and *Ficus sur* (Tables 4.1.1, 4.1.3 and 4.1.4) coupled with vessel frequency of 4 vessels/ mm^2 (Table 4.1.2) may make them suitable species for pulp and paper production.

5.1.2 Fibre morphological variation in *Cola gigantea* and *Ficus sur*

From Table 4.1.3, the mean fibre length was 2.1mm for sapwood and 1.9mm for heartwood of *Cola gigantea*; fibre diameter varied from 24.2 µm in sapwood to 25.1 µm in heartwood; fibre lumen diameter was 13.9 µm for sapwood and 15.6 µm for heartwood; and the double cell wall thickness was 10.3 µm for sapwood and 9.5 µm for heartwood of *Cola gigantea*. These fibre morphological parameters of *Cola gigantea* also varied along the bole from butt to top. All the parameter studied on *Cola gigantea* except fibre lumen diameter seems to increase from the top to the butt. The fibre lumen diameter of *Cola gigantea* however, increased from top to middle and decreased towards the butt. Tables 4.1.3 and 4.1.5 indicated that the *Cola gigantea* sapwood had significantly longer fibres than its heartwoods ($P < 0 .01$). The lumen diameter of *C. gigantea* heartwood was significantly wider than that of its sapwood ($P<0.01$). Although the mean value of wall thickness of *C. gigantea* sapwood was higher than that of its heartwood, there was no statistical difference between them ($P\geq0.05$) (Tables 4.1.3 and 4.1.5). For *Cola gigantea* from Table 4.1.5, except the double cell wall thickness across and fibre lumen diameter along the bole, all the other fibre morphological parameters studied varied significantly across and along the bole ($P\leq0.01$). Generally, fibre lumen diameter of *C. gigantea* decreased from heartwood to the sapwood at any particular height (Table 4.1.3) and showed an increase from base to the middle and decreased to the top (Table 4.1.3). From Table 4.1.4, the mean fibre length varied from1.7mm in sapwood to 1.4mm in heartwood for *Ficus sur*; fibre diameter varied from 31.7 µm in sapwood to 30.9 µm in heartwood; fibre lumen diameter was 23.9 µm for sapwood and 23.8 µm for heartwood; and double cell wall thickness was 7.8 µm for sapwood and 7.1 µm for heartwood of *Ficus sur*. The fibre diameter and the fibre lumen diameter of *Ficus sur* increased from top to the middle and decreased towards the butt. Fibre length and double cell wall thickness of *Ficus sur* seems to increase from the top to the butt. Tables 4.1.4 and 4.1.5 showed that the *Ficus sur* sapwood had significantly longer fibres than its heartwoods ($P< 0 .01$) but there was no significant difference between the lumen diameter of *Ficus sur* sapwood and its heartwood ($P\geq0.05$). *F. sur* sapwood was significantly thicker than that of its heartwood ($P\leq0.05$) (Tables 4.1.4 and 4.1.5) For *F. sur* however on the same Table 4.1.5, except the lumen diameter across the bole, all the other fibre morphological parameters studies varied significantly across and along the bole ($P\leq0.05$). The general decrease in fibre length from the base to the top and its corresponding increase from the heartwood to the sapwood sections observed in this study has been reported in other species by Jorge *et al*, (2000); Izekor and Fuwape, (2011) when they studied *Eucalyptus globules* and *Tectona grandis* respectively. This trend according to the authors is due to increase in length in cambial initials with cambial age. The differences in fibre length associated with increase in height is mainly due to the differences in the juvenile and mature wood proportion in the tree, since the proportion of juvenile wood increases with an increase in height (Zobel and Buijtenen, 1989). Fibre length and wall thickness of *C. gigantea* were significantly longer and thicker than those in *F. sur* but the fibre diameter and lumen diameter of *F. sur* was significantly wider than those of *C. gigantea* at $P<0.01$ (Tables 4.1.3, 4.1.4 and 4.1.5). Izekor and Fuwape,(2011) stated that fibre morphological characters differed between species and even within species due to inherent physiological and genetic variations.

They further stated that silvicultural, environmental and edaphic conditions may modify fibre morphology of the same wood species growing under different ecological and climatic zones. Therefore variations between the fibre morphological parameters of *Cola gigantea* and *Ficus sur* may be due to differences in their genetic and physiological properties

5.1.2 Anatomical description

5.1.2.1 *Ficus sur*

The wood is diffuse porous and has no distinct growth rings boundary (Plate 4.1). Vessels constitute about 9 % of the ground tissues, mainly solitary vessels (SV in Figure 4.1) with simple perforation plates. It has scanty vessels about 4 vessels per $mm^2$and vessel has mean tangential diameter of 225 µm. Tyloses are present in the vessels (TY in Plates 4.1 and 4.6). The inter-vessel pits are bordered, alternate, polygonal in shape and non-vestured with average size of 8.0 µm (Plate 4.5). Fibres constitute about 42 % of the ground tissues with the mean double wall thickness of 7.5µm, mean lumen diameter of 23.9 µm, mean diameter of 31.3 µm and mean length of 1.5mm (FIB in Plates 4.1, 4.2 and 4.7). The fibres have simple to minutely bordered pits (FIB in Plate 4.7). The parenchyma cells constituting about 49 % of the ground tissues are paratracheal, confluent and having bands more about eight cells wide (AP in Plate 4.1). The rays have relatively uniform sizes with 4-10 seriate (RP in Plate 4.2). Body ray cells procumbent with mostly 2-4 rows of upright and / or square marginal cells (PBR in Plate 4.3). Vessel-ray pits with much reduced borders to apparently simple; pits in horizontal orientations (gash-like) and rounded pit outline (arrowhead in Plate 4.4). Prismatic crystals are present in chambered axial parenchyma cells (arrowhead in Plate 4.7). This description is in accordance with Uetimane *et al* (2008a) when they described *F. sur* from Northern and Central Africa. They observed laticifer or tanniniferous tubes but this feature was absent in the present description. The absence of this feature in the present description may be due to the difference in the sources of the study materials.

5.1.2.2 *Cola gigantea*

The wood is diffuse porous and growth ring boundary not distinct (Figure 4.8). Vessels constitute about 8% of the tissues, mostly solitary (SV) with few radial multiples of two (DV) to three cells (TV) in Plate 4.8. Vessels are scanty about 4 vessels per mm^2 with mean tangential diameter of 184 µm. The vessel outline is mostly rounded in cross section (SV, DV and TV in Plate 4.8). The vessel perforation plates are predominately simple in oblique end walls. Inter-vessel pits are reduced to simple and are arranged mostly in alternate patterns with mean size of 3.0 µm and are non-vestured (arrowheads in Plate 4.12). Vessel-ray pits are reduced to simple similar to that of inter-vessel pits (arrowheads in Plate 4.13). However, vessel-ray pits are relatively wider in size and shape than that of inter-vessel pits and are located throughout the ray cell. Gum inclusions are present in the vessels (GM in Plates 4.8; 4.10 and 4.11). Fibres constitute about 49 % of the ground tissues with the mean double cell wall thickness of 9.9µm, mean lumen diameter of 14.8 µm, mean fibre diameter of 24.7 µm and mean fibre length of 2.0 mm long (FIB in Plates 4.8 and 4.9). The axial parenchyma constituting about 43% of the ground tissues and are arranged in paratracheal, vasicentric, reticulate with respect to the vessels and bands more than three cells wide (AP in Plate 4.8). Axial parenchyma cells are mostly in 3-4 cells per strand. Silica bodies are present in the chambered axial parenchyma cell (arrowheads in Plate 4.14). The rays are commonly arranged in 4-10 seriate with two distinct sizes (LR and SR Plate 4.9). The body ray cells are procumbent with mostly 2-4 marginal rows of upright, sheath cell present (PBR in Plate 4.10). This description is in accordance with Uetimane *et al* (2008b) and Oteng-Amoako (2006a) when they described *C. gigantea* from Northern, Southern and Central Africa. Uetimane *et al* (2008b) observed helical thickening and intercellular canal of traumatic origin but these features were absent in the present description. The absence of this feature in the present description may be due to the difference in the sources of the studies materials. The presence of silica bodies in this species may account for occasional lighting sparks which occurs during sawing.

5.2 Physical properties

5.2.1 Basic density variations in *Cola gigantea* and *Ficus sur*

The mean basic density of *Cola gigantea* sapwood was 501 kg/m^3 and that its heartwood was 456 kg/m^3. *Cola gigantea* sapwood was significantly denser than its heartwood ($P \leq 0.01$) (Table 4.3.2 and Fig. 5.2.1). According to Antwi-Boasiako and Barnett (2009); Oteng-Amoako (2006b); Ofori (2004a); Wang and DeGroot (1996), the density of wood depends on fibre and vessel morphological properties. Therefore the observed variation between the sapwood and the heartwood may be due to the differences in the anatomical properties which varied between them. The *Cola gigantea* sapwood double cell wall thickness and fibre lumen diameter were 10.3µm and 13.9 µm and that of its heartwood was 9.5 µm and 15.6 µm respectively. The vessel lumen diameter of *Cola gigantea* sapwood was 180 µm and that of its heartwood was 188 µm. The sapwood of *F. sur* was significantly denser than its heartwood ($P \leq 0.05$) (Table 4.3.2 and Fig. 5.2.1). The *Ficus sur* sapwood double cell wall thickness and fibre lumen diameter was 7.8 µm and 23.9 µm and that of its heartwood was 7.1 µm and 23.8 µm respectively. The vessel lumen diameter of *Ficus sur* sapwood was 216 µm and that of its heartwood was 236 µm. These properties may account for *Ficus sur* sapwood been denser than its heartwood. Some data available on the light density wood species in the Moraceae family indicated that the sapwoods were denser than their respective heartwood. Usher and Ocloo (1979) studied *Ficus capensis* and Ofori and Bamfo (1994) studied *Antirias toxicaria* and reported that the sapwoods of these species were denser than their respective heartwood. The *Ficus species* are mostly pioneer species which grows fast in the juvenile stages thereby forming cells with wider cell lumen and thin cell wall. Since this juvenile wood formed the heartwood, its density is reduced as compared with the sapwood. The axial variations of these species were not consistent. The middle section of *C. gigantea* was significantly denser than the butt and top sections, while the butt section was denser than the top section (Table 4.3.1 and Fig. 5.2.2). This variation may be due to difference in the fibre wall thickness and fibre diameter for these sections (top is 9.3 µm and 23.5 µm; middle 9.2 µm and 24.8 µm; and butt 11.1 µm and 25.7 µm). The top section of *F. sur* was significantly denser than the other portions but there was no significant difference between the middle and the butt sections (Table 4.3.2). This may be due to difference in the fibre wall thickness and diameter for these sections (top is 8.1 µm and 32.4 µm; middle 6.7 µm and 33.6 µm; and butt 7.4 µm and 28.0 µm). According to Antwi-Boasiako and Barnett, (2009); Quilho and Pereira (2001); Panshin and deZeeuw (1980), other factors such as prevailing environmental conditions during wood formation, extractive content and secondary metabolites may also cause within species density variations.

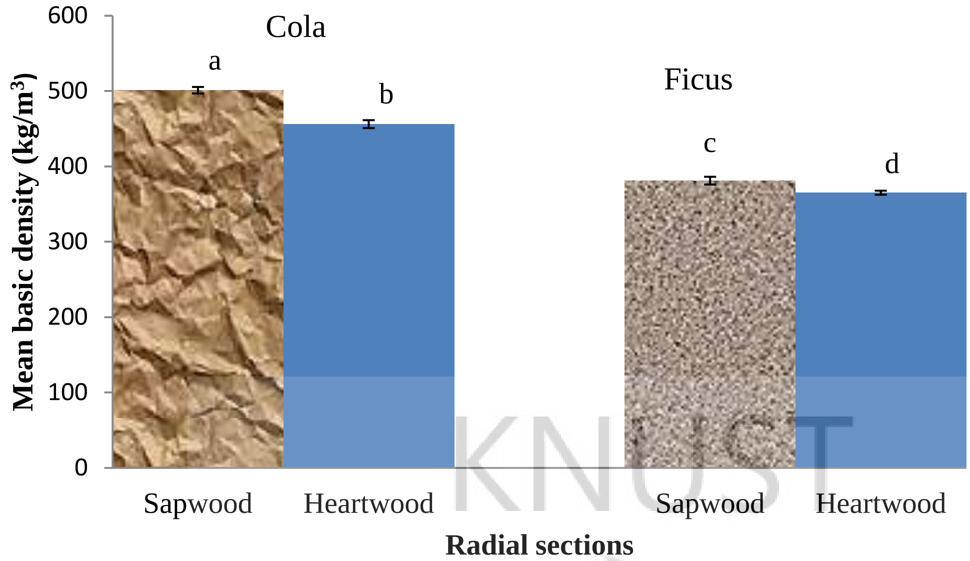

Figure 5.2. 1 Mean basic density radial section variation of *C. gigantea* and *F. sur*.

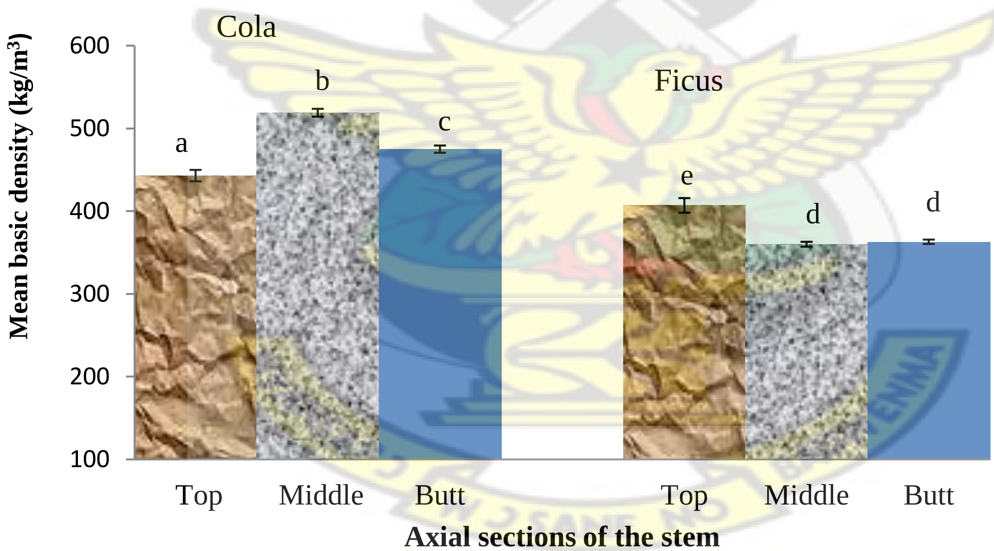

Figure 5.2. 2 Mean basic density axial section variation of *C. gigantea* and *F. sur*

5.2.2 Basic density variations between *Cola gigantea and Ficus sur*

The basic density values varied from 425 to 519 kg/m^3 in *Cola gigantea* and from 352 to 424 kg/m^3 in *Ficus sur* (Table 4.3.1). The basic density values recorded in this study for *F. sur* lies within the range quoted by Lumbile and Mogotsi (2008), thus 300 – 650 kg/m^3. This was classified as light density wood according to Building Research Establishment (1972). Similarly, the basic density value obtained in this study for *C. gigantea* was 479 kg/m^3 and lied within the range 400-750 kg/m^3 which had been quoted by Uetimane *et al* (2008b). The wood was rated as medium density by Building Research Establishment (1972). The basic density of the *C. gigantea* was significantly higher than that of *Ficus sur* ($P \leq 0.05$) (Table 4.3.2). These differences in density values may be due to the variations in the anatomical components. The density of wood depends on the fibre wall thickness, fibre diameter, vessel diameter or pore size and the type of extractive present (Antwi-Boasiako and Barnett, 2009; Oteng-Amoako, 2006b; Desch and Dinwoodie, 1996; Wang and DeGroot, 1996). Thicker fibre walls, smaller fibre diameter and smaller pore sizes increase the density of wood since these factors reduce the porosity. Hence, the relatively thicker fibre wall (10.3 µm), narrower fibre diameter (24.7 µm) and presence of silica inclusions in *C. gigantea* as compared with those of *F. sur* (6.9 µm and 31.0 µm for fibre wall thickness and diameter respectively) makes *C. gigantea* denser than *F. sur*. Furthermore, difference in the relative proportion of wood ground tissues in different wood species also contribute to between species density differnces (Wang and DeGroot, 1996; Higgins *et al* 1973). The percentage ground tissues proportion of vessel: parenchyma: fibre for *C. gigantea* was 8 %:43 %:49 % respectively and those for *F. sur* were 9 %: 47 %: 43 % respectively. This may also contribute to making *C. gigantea* denser.

5.2.3 Green moisture content variations within *Cola gigantea* and *Ficus sur*

The green moisture content obtained in this study varied from 98 % in sapwood of *Cola gigantea* to 110 % in its heartwood (Table 4.3.3 and Fig. 5.2.4). The moisture content in the sapwood of *Cola gigantea* was significantly lower than that in its heartwood ($P < 0.01$) (Table 4.3.2). Though, the mean value of the moisture content in *F. sur* heartwood (170 %) was higher than that of its sapwood (167 %), there was no significant difference between them ($P > 0.05$) (Tables 4.3.2 and 4.3.3, Fig. 5.2.4). This difference in the green moisture content of the sapwood and heartwood of both species may be due to the difference in fibre lumen diameter and pore sizes. According to Antwi-Boasiako and Barnett, (2009); Ofori, (2004a); Desch & Dinwoodie, (1996); Wang and DeGroot, (1996), increasing fibre lumen diameter and pore sizes creates more void spaces in the wood for air and moisture. Hence the wider fibre lumen diameter (15.6 µm) and pore size (188 µm) in *C. gigantea* heartwood would increase its potential for holding more moisture than its sapwood (13.9 µm and 180 µm for fibre lumen diameter and pore size respectively). Green moisture content variations in the axial direction of the trees of these species were not consistent. The moisture content of the top section (155 %) of *F. sur* has significantly lower moisture than those of the butt (172 %) and middle (170 %) portions ($P \leq 0.05$) but there was no significant difference between the middle and the butt sections (Table 4.3.3 and Fig. 5.2.3). This may be due to differences in the fibre lumen diameters of these sections (top - 24.3 µm; middle - 26.7 µm and butt - 20.0 µm). Similarly, the moisture content of the middle section (84%) of *C. gigantea* has significantly lower green moisture content than those of the butt (108%) and top (101%) sections ($P \leq 0.05$) (Table 4.3.3), but there was no significant difference between the butt and top sections ($P > 0.05$). This difference could be attributed to the differences in the fibre lumen diameters and fibre diameters for these sections (top - 14.3 µm and 23.5 µm; middle - 15.5 µm and 24.8 µm; and butt - 14.6 µm and 25.7 µm for fibre lumen diameter and fibre diameter respectively). According to Antwi-Boasiako and Barnett, (2009); Quilho and Pereira (2001) Panshin and deZeeuw (1980), other factors such prevailing environmental conditions during wood formation, extractive content and secondary metabolites may also contribute to within species green moisture content variations.

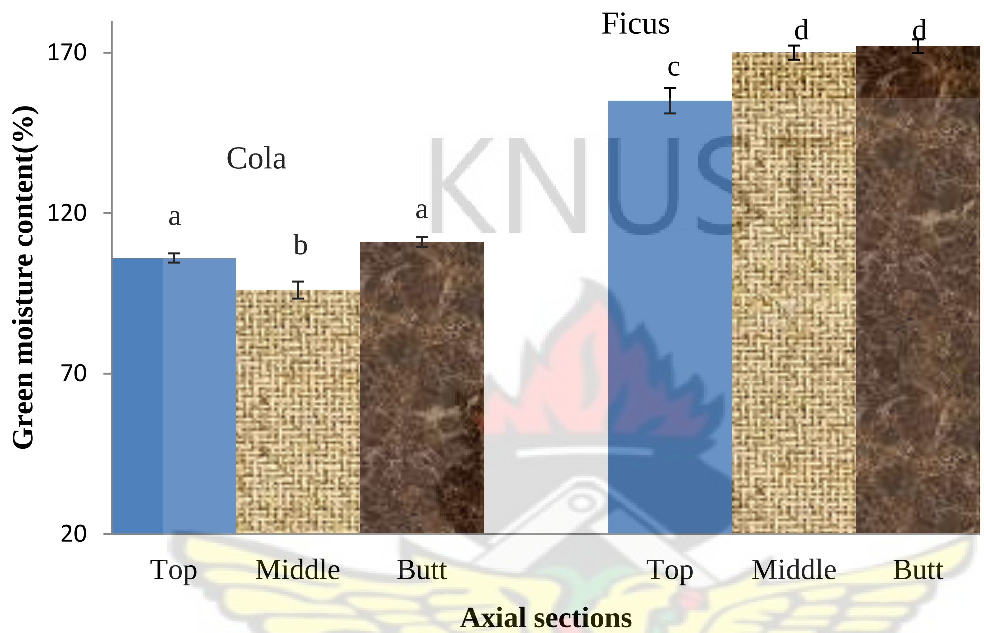

Figure 5.2.3 Mean moisture content profile along stems of *C. gigantea* and *F. sur*

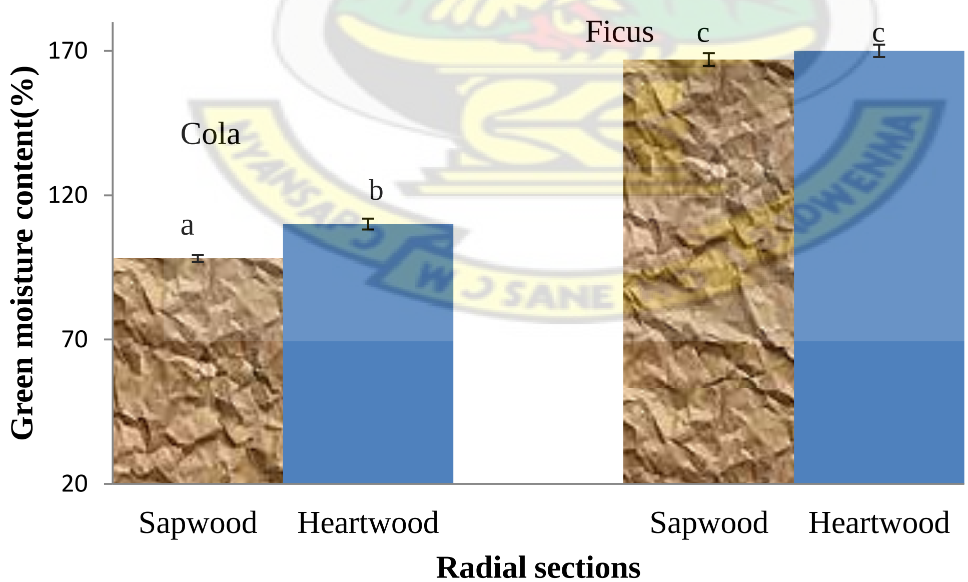

Figure 5.2.4 Mean green moisture content profile across stems of *C. gigantea* and *F. sur*

5.2.4 Green moisture content variations between *Cola gigantea* and *Ficus sur*

The green moisture content values recorded for the species in this study ranged from 50 % to 143 % for *C. gigantea* and 121 % to 219 % for *F. sur* (Tables 4.3.3). The green moisture content of *C. gigantea* was significantly lower than that of *Ficus sur* (P<0.01) (Table 4.3.2). This may be due to the variations in the anatomical components. The moisture in wood fill the void spaces hence depends on the fibre lumen diameter and vessel diameter or pore size (Oteng-Amoako, 2006b; Ofori 2004a; Desch and Dinwoodie, 1996; Panshin and deZeeuw,1980). Wider fibre lumen diameter and larger pore sizes increase the void space in wood thereby increasing the porosity and moisture holding capacity of the wood. Hence, the relatively smaller fibre lumen diameter (14.7µm) and smaller pore sizes (184 µm) in *C. gigantea* as compared with those of *F. sur* (23.9µm and 225 µm for fibre lumen diameter and pore size respectively) reduces the moisture holding capacity of *C. gigantea*. Furthermore, difference in the relative proportion of wood ground tissues in different wood species may also contribute to between species green moisture content differences (Panshin and deZeeuw, 1980). Parenchyma cells are capable of storing more moisture in their lumen; therefore high proportion of these cells in a particular species increases its tendency to hold more moisture. The relatively higher proportion of parenchyma in *F. sur* (47 %) as compared with that of *C. gigantea* (43 %) may also contribute to the higher green moisture in *F. sur*.

5.2.5 Air- dried moisture content variations within radial and axial sections of *Cola gigantea* and *Ficus sur*

Generally, the mean air – dried moisture in *Cola gigantea* varied from 20.7 % in the heartwood to 19.1 % in the sapwood (Table 4.3.4). The mean air-dried moisture content of the top portion of the *Cola gigantea* was 19.6 %, the middle portion was 19.4 % and the butt portion was 20.7

%. The air – dried moisture in the whole *Ficus sur* heartwood was 15.3 % and that of its sapwood was 16.7 %. The mean air-dried moisture content of the top portion of *Ficus sur* was 14.3%, the middle portion was 15.1 % and the butt portion was 17.7 %. The whole *Ficus sur* has relatively lower air – dried moisture content averaged 16.0 % than that of *Cola gigantea* which averaged 19.9 %. Though the green moisture content of *C. gigantea* was significantly lower than that of *Ficus sur* ($P<0.01$) (Table 4.3.3) there was no statistical difference within each species and also between the species in terms of the air-dried moisture content. According to Ofori (2004a) and Desch and Dinwoodie (1996), free water held in the cell lumen moves out first during the drying processes and continues to move out until fibre saturation point is reached. They further explained that, below the fibre saturation point and at the same drying conditions, the higher the fibre proportion and thicker walls in a particular species, the higher the moisture that species can retain. Other factors such as extractives can increase air-dried moisture. The higher proportions of fibres with thick cell walls as well as the presence of gummy inclusions and silica in *C. gigantea* can contribute to its higher air-dried moisture content as compared with that of *F. sur.*

5.3 Treatability

5.3.1 Maximum absorption (l/m^3) variation within *Cola gigantea* and *Ficus sur*

From Table 4.4.1, the theoretical maximum absorption for the whole *Cola* gigantea heartwood was 582 l/m^3 and that of its sapwood was 565 l/m ^{3}. It also decreased from the top portion to the middle and increased towards the butt portion in *Cola gigantea*. The theoretical maximum absorption for the whole *Ficus sur* heartwood was 692 l/m^3 and that of its sapwood was 656 l/m^3. It also increased from 638 l/m^3 at the top to 696 l/m^3 in the middle and decreased slightly 688 l/m^3 towards to the butt of *ficus sur.* These differences within the species may be due to the variations in fibre lumen diameter and pore sizes. According to Antwi-Boasiako and Barnett, (2009); Ofori, (2004a); Desch and Dinwoodie, (1996); Wang and DeGroot, (1996), increasing fibre lumen diameter and pore sizes creates more void spaces in the wood to accommodate air and moisture. Hence the wider fibre lumen diameter (15.6 µm) and pore size (188 µm) of *C. gigantea* heartwood increase its potential for holding more preservative than its sapwood with 13.9 µm fibre lumen diameter and 180 µm pore size. Similarly, the pore size of 236 µm of *Ficus sur* heartwood may be responsible for its relatively higher preservative absorption as compared with its sapwood with 216 µm pore size since the fibre lumen diameter for both the heartwood and sapwood of *Ficus sur* was the same (23.8 µm).

5.3.2 Maximum absorption (l/m^3) variation between *Cola gigantea* and *Ficus sur*

Ficus sur has higher absorption capacity of 674 l/m^3 as compared with 574 l/m^3 in *Cola* gigantea (Table 4.4.1). Theoretically, preservatives will fill all the available void spaces in the wood hence maximum absorption depends on the fibre lumen diameter, vessel diameter or pore size and the presence of extractives or inclusions (Oteng-Amoako, 2006b; Ofori 2004a; Desch and Dinwoodie, 1996; Panshin and deZeeuw, 1980). Wider fibre lumen diameter, larger fibre diameter and pore sizes increase the void space in wood thereby increasing the porosity and fluid holding capacity of the wood. Hence, the relatively smaller fibre lumen diameter (14.7 µm) and smaller pore sizes (184 µm) in *C. gigantea* as compared with those of *F. sur* (23.9 µm and 225 µm for fibre lumen diameter and pore size respectively) reduces its void spaces hence reduced fluid absorption capacity. Furthermore, difference in the relative proportion of wood ground tissues in different wood species may also contribute to between species absorption differences (Panshin and deZeeuw, 1980). The vessels are the main fluid transport in wood and parenchyma cells are also capable of storing moisture in their lumen; therefore high proportion of these cells in a particular species may contribute to increasing their absorption capacity. High proportion of vessels (9 %) and parenchyma (47 %) in *Ficus sur* may also account for its higher absorption potentials as compared with 8 % vessels and 43 % parenchyma in *C. gigantea*.

5.3.3 Effect of pressure magnitude and treatment duration on mean absolute volumetric retentions variation within *Cola gigantea* and *Ficus sur*

From Table 4.4.3, the mean absolute volumetric retentions (AVR) increased with increasing pressure magnitude and treatment duration for the sapwood and heartwood of both *Cola gigantea* and *Ficus sur*. For the same range of pressure (600 to 1200 kPa) and treatment durations (30 to 240 minutes), from Table 4.4.5, mean absolute volumetric retention varied from 354 kg/m^3 in *Cola gigantea* heartwood to 342 kg/m^3 in its sapwood. Similarly, it was 469 kg/m^3 for *Ficus sur* heartwood and 467 kg/m^3 for its sapwood. The effect of pressure magnitude and treatment duration significantly increased the retention of sapwood and heartwood of both species except for *F. sur* sapwood where treatment duration did not significantly influence retention (Table 4.5.6). According to Ofori, (2004a) and Desch and Dinwoodie, (1996), increasing fibre lumen diameter and pore sizes creates more void spaces in the wood and thus enables it to accommodate more air and moisture. Hence the wider fibre lumen diameter (15.6 µm) and pore size (188 µm) of *C. gigantea* heartwood increased its potential for absorbing more preservative than its sapwood with 13.9 µm fibre lumen diameter and 180 µm pore size. Similarly, the pore size of 236 µm of *Ficus sur* heartwood may be responsible for its relatively higher preservative absorption as compared with its sapwood with 216 µm pore size since the fibre lumen diameter for both the heartwood and sapwood of *Ficus sur* were the same (23.8 µm).

From Figures 5.3.1 and 5.3.2, generally, mean absolute volumetric retentions increased with increasing treatment duration for the sapwood and heartwood of both species except heartwood in Figure 5.3.1 where there was sharp rise in volumetric retentions from 30 to 60 minutes and relatively stabilize afterwards for all the pressure magnitudes used in this study. The increase in volumetric retention with treatment duration had long being observed by Kamdem and Chow (1999) and Hunt and Garratt (1938). They explained that under the same pressure magnitude, extending the treatment duration allow for gradual flow of preservative from the initially treated cells to the neighbouring untreated cells. This flow process according them proceed for sometime after which flow stabilizes after which extending treatment duration add little to absorption.

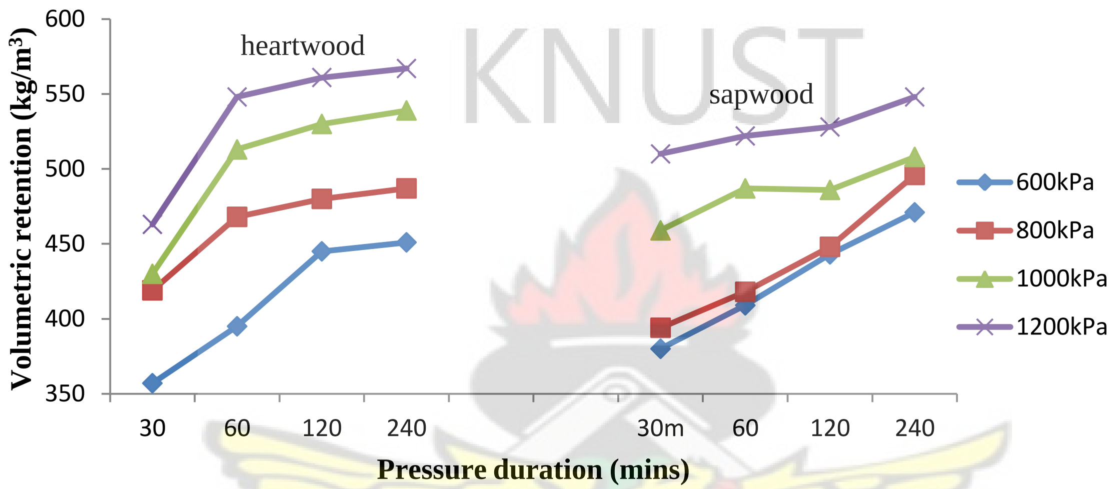

Figure 5.3.1 Effect of pressure duration on *F. sur* heartwood and sapwood volumetric retention

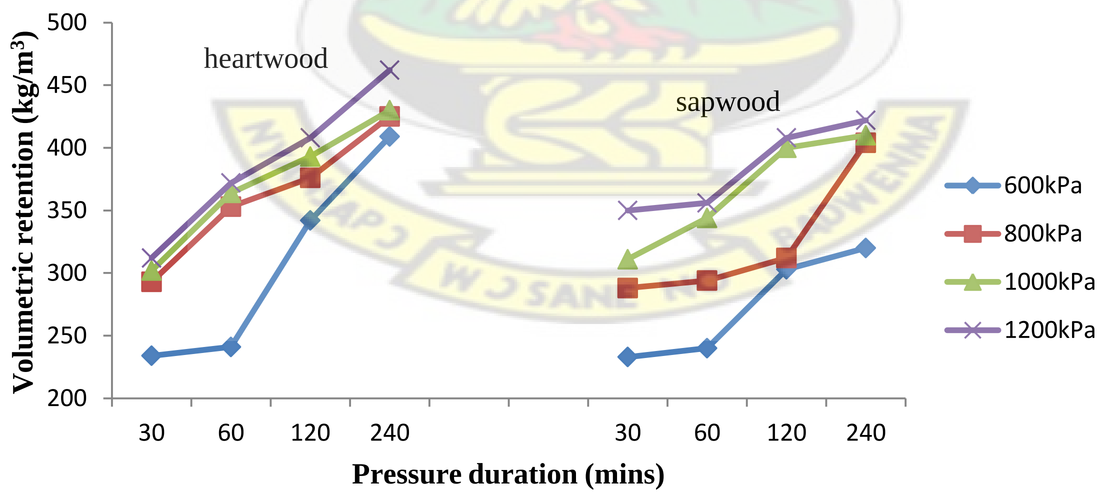

Figure 5.3.2 Effect of pressure duration on *C. gigantea* heartwood and sapwood volumetric retentions

5.3.4 Effect of pressure duration on volumetric retentions variation between *Cola gigantea* and *Ficus sur*

The mean absolute volumetric retention of *Cola gigantea* was 348 kg/m^3 and that of *Ficus sur* was 468 kg/m^3(Table 4.4.5). According to Ahmed and Chun (2007) the initial preservative conduction is mainly through the vessels along with fibres, thus the number of vessels, vessel lumen diameter, number of inter-vessel pits and its diameter are of paramount importance in preservative conduction. Therefore, the higher retentions by *F. sur* may be due to the relatively larger vessel diameter of 225 µm (Table 4.1.2 and Fig 4.1), larger pit sizes of 8.0 µm [Table 4.1.2, Fig. 4.4 and Fig 4.4)], thin walled fibres (7.5 µm) and larger fibre lumen (24 µm) as compared with those in *C. gigantea.* Other factors such as the relative high proportions of vessels and parenchyma (9 % and 49 % respectively) in *Ficus sur* can also positively increase the volumetric retention of *F.sur*. Generally, the pressure duration significantly ($P \leq 0.01$) increased the volumetric retention of both species for the same range of pressure magnitudes (Table 4.4.6). Generally, mean absolute volumetric retention increased with increasing treatment duration for both species. This observation has long been made by Kamdem and Chow (1999) and Hunt and Garratt (1938). The effect of treatment duration on *C. gigantea* was highly significant (F-value of 17.88) as compared with that of *F. sur* (F-value of 5.5) (Tables 4.4.6). This may be due to the presence of silica bodies (Fig 4.14), gum inclusions in vessels (Figs 4.8; 4.10 and 4.11) coupled with the minute pits size 0f 3.0µm [Table 4.1.2, Figs. 4.12. 4.1.6)] in *C. gigantea*. These conditions even at higher pressure may require relatively longer pressure duration to penetrate the occluded vessels and subsequent distribution to other cells. Ofori and Bamfo (1994) observed this trend when they treated *Celtis milbraedii* with varying pressure duration and magnitude. Therefore treating *F. sur* at high pressures 1200 kPa and above for short duration up to 60 mins and treating *C. gigantea* for extending pressure duration above 240 mins and pressure magnitude up to 1000 kPa may be appropriate for treating these species.

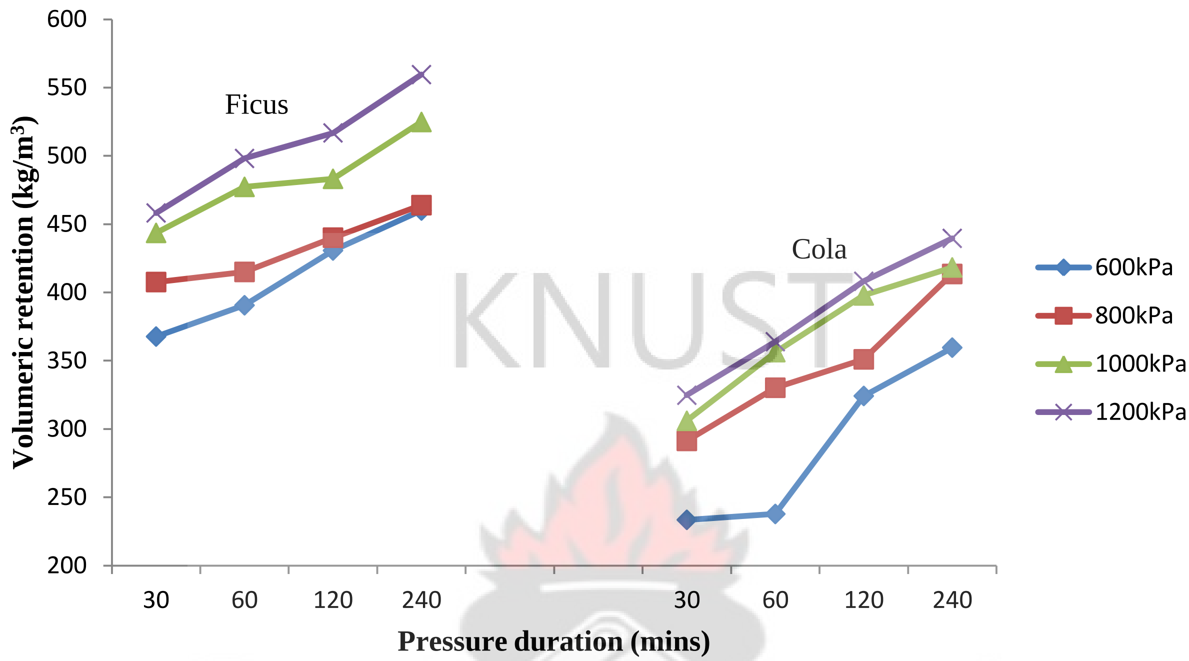

Figure 5.3.3 Effect of treatment duration on *F. sur* and *C. gigantea* volumetric retentions

5.3.5 Effect of pressure magnitude on volumetric retention variations within *Cola gigantea* and *Ficus sur*

From Figures 5.3.4 and 5.3.5, the mean absolute volumetric retentions generally increased with increasing pressure for heartwood and sapwood of both species. For *Ficus sur* sapwood however (Figure 5.3.4), increase in volumetric retention was relatively gradual between 600 to 800 kPa pressures (for treatment duration from 30 to 120 minutes) whilst its heartwood volumetric retentions increased more sharply with increasing pressure. The *Ficus sur* sapwood observation may be that since its initial preservative conduction is mainly through the vessels alongside the fibres, between 600 to 800 kPa pressure for 30 to 120 minutes treatment duration, the preservatives just flooded the pores and the fibre lumen in the wood (Ahmed and Chun, 2010). Increasing the magnitude of pressure above 800 kPa for the treatment duration range of 30 to 240 minutes forces the preservatives to other untreated portions through the pits thereby increasing the volumetric retention with increased pressure above 800 kPa For *Cola gigantea* heartwood on the other hand in Figure 5.3.5, the mean volumetric retention increased sharply between 600 to 800kPa for treatment durations 30 to 60 miniutes and stabilizes afterwards. Again, mean volumetric retention increased sharply at pressure magnitude of 800 kPa between 30 to 60 minutes treatment durations and this volumetric retention increment was more than increasing treatment duration from 60 minutes and above (Fig 5.3.5). This sharp rise in volumetric retention at pressure between 600 to 800 kPa and short duration of 30 to 60 minutes in *Cola gigantea* heartwood may corresponds to where all the available and accessible empty spaces in the wood are filled with preservatives. The inaccessible empty space may be due to the presence of gummy and silica inclusions coupled with the minute pit sizes which even at high pressure magnitudes will require relatively longer duration to penetrate. Hence relatively stabilizing volumetric retention at 800 kPa and above for duration for the treatment duration from 30 to 240 minutes. This practically implies that *Cola gigantea* heartwood should be treated for longer periods and at a pressure not more than 1000 kPa.

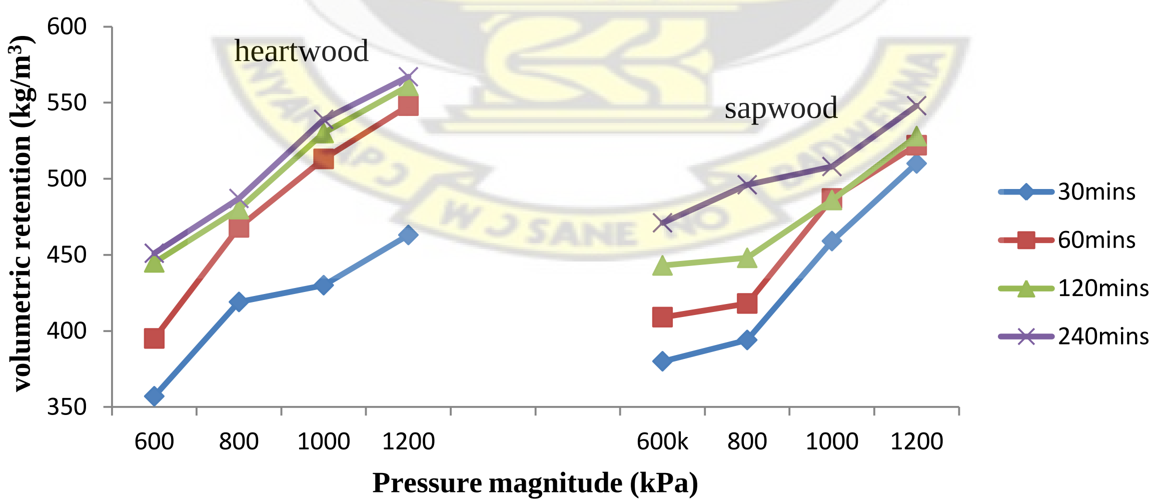

Figure 5.3.4 Effect of pressure magnitude on *F. sur* heartwood and sapwood volumetric retention

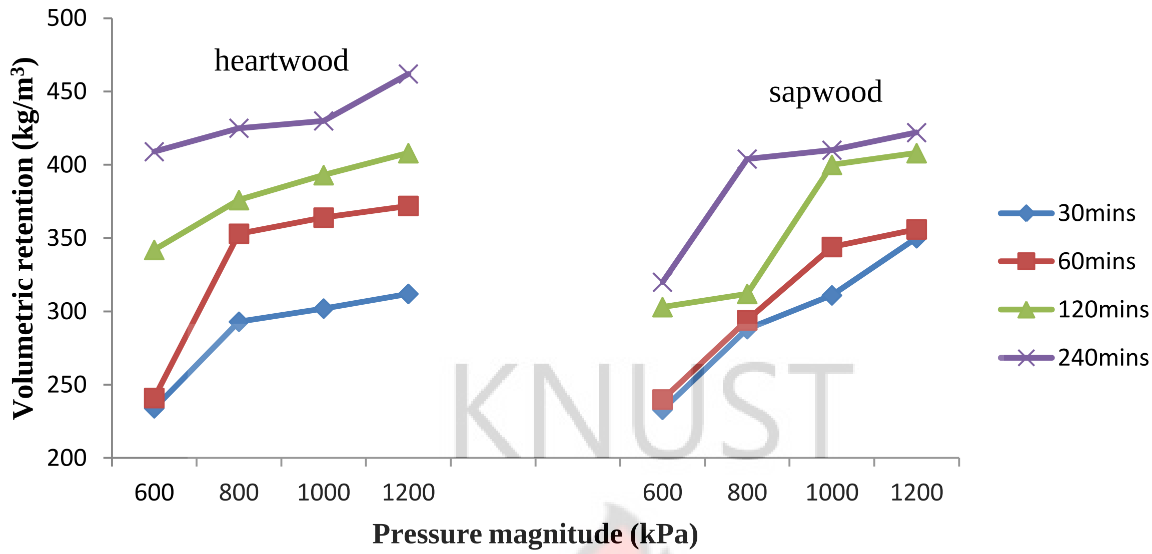

Figure 5.3.5 Effect of pressure magnitude on *C. gigantea* heartwood and sapwood volumetric retention

5.3.6 Effect of pressure magnitude on volumetric retention variations between *Cola gigantea* and *Ficus sur*

Generally, the mean volumetric retention increased with increasing pressure (Fig.5.3.6). However, the pattern differs. For Ficus (Fig 5.3.6), increase in volumetric retention was relatively gradual between 600 to 800 kPa and duration from 30 to 240 minutes but increased relatively faster with increasing pressures above 800 kPa. The gradual increase in volumetric retention values at low pressure 600 kPa for 30 to 240 minutes duration may correspond to flooding the pores and the fibre lumen with the preservatives (Ahmed and Chun, 2010). The high pressures from 800 kPa however force the preservatives through the pits to any available voids within the wood thereby increasing volumetric retention with pressure above 800 kPa. For Cola in the same Fig 5.3.6, generally, there was initial sharp rise in volumetric retention between 600 to 800 kPa for 30 to 240 minutes durations but relatively stabilized at 800 kPa and above for all the treatment durations. The sharp rise in volumetric retention may correspond to situation where all the accessible empty spaces are filled with preservative. The inaccessible empty space may be occupied by gummy and silica inclusions which even at high pressure magnitudes will require relatively longer duration to penetrate. Hence relatively stabilizing volumetric retention at 800 kPa and above for duration for the treatment duration from 30 to 240 minutes. For the same treatment duration (30-240 mins) and pressure magnitudes (600 to 1200 kPa), *F. sur* absorbed more preservative of 468 kg/m^3 than the 348 kg/m^3 absorbed by *C. gigantea* (Table 4.4.5). Preservatives will theoretically fill all the available void spaces in the wood hence volumetric retention depends on the fibre lumen diameter, vessel diameter or pore size, vessel pit sizes and conditions, and the presence of extractives or inclusions (Oteng-Amoako, 2006b; Ofori 2004a; Desch and Dinwoodie, 1996; Panshin and deZeeuw, 1980). Wider fibre lumen diameter, larger fibre diameter, pore sizes, large non-aspirated pits and absence of inclusions increase the void space in wood thereby increasing the porosity and fluid holding capacity of the wood. Hence, the relatively larger fibre lumen diameter 23.9 µm, wider pore size 225 µm, wider non- aspirated pit size of 8.0 µm and the absence of inclusions in *Ficus sur* as compared with smaller fibre lumen diameter (14.7 µm), smaller pore sizes (184 µm), minute pit size of 3.0 µm and the presence of gummy and silica in *C. gigantea*, could make *Ficus sur* absorb more fluid than *C. gigantea*. Furthermore, difference in the relative proportion of wood ground tissues in different wood species may also contribute to between species volumetric retention variations (Panshin and deZeeuw, 1980). The vessels are the main fluid transport in wood and parenchyma cells are capable for storing more moisture in their lumen; therefore high proportion of these cells in a particular species may contribute to increasing their volumetric retention capacity. The high proportion of vessels (9 %) and parenchyma (47 %) in *Ficus sur* may also account for its higher absorption potentials as compared with 8% vessels and 43% parenchyma in *C. gigantea*.

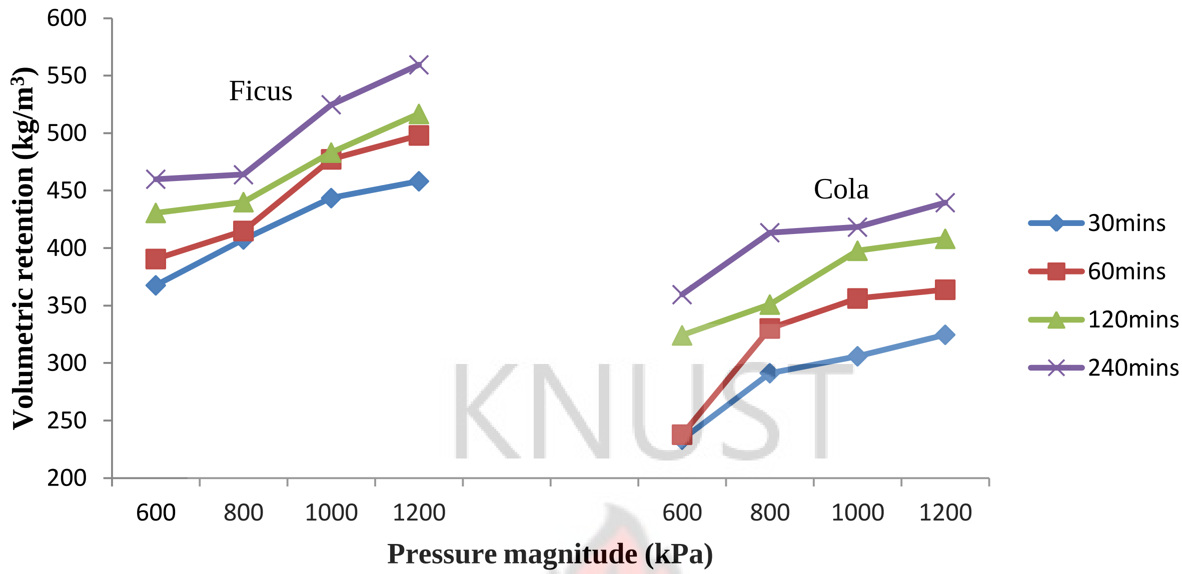

Figure 5.3.6 Effect of pressure magnitude on *F. sur* and *Cola gigantea* volumetric retention

5.3.7 Depth of preservative penetration variation within *Cola gigantea* and *Ficus. sur*

For the same range of pressure magnitude and treatment duration, the ratio of longitudinal to transverse penetrations was about 22 to 1 for *Ficus sur* sapwood and that of its heartwood was 24 to 1 (Table 4.4.10) and it was 32 to 1 for *C. gigantea* sapwood and 39 to 1 for its heartwood (Tables 4.4.11) The depth of penetration both longitudinally and transversely was relatively higher in the heartwood than the sapwood for both species (Tables 4.4.10 and 4.4.11). These ratios fall within the 20-50 longitudinal to one (1) transverse penetration quoted for hardwood by Larnoy *et al* (2008). The high longitudinal penetration is mainly due to the cell arrangement of vessels, fibres and axial parenchyma along which liquid flow easily with little interruptions (Larnoy *et al*, 2008; Leal *et al* 2007; Ofori and Bamfo, 1994). Heartwood penetration was relatively higher than sapwood penetration for both species (Tables 4.4.10 and 4.4.11). *C. gigantea* heartwood has higher penetration depth than its sapwood. This may be due to the relatively higher fibre proportion (Table 4.1.1) and wider fibre lumen (Table 4.1.5) which may conduct more liquid in the initial preservative uptake. Penetrability generally, appears to vary along the stems of both species. The depth of longitudinal penetration decreased from the whole tree top (345mm) to the middle (276mm) and increase towards the butt (299mm) end of the stem of *Ficus sur* (Tables 4.4.10). The depth of penetration in the transverse direction of the tree of *Ficus sur* was almost constant along the bole from top to butt (Table 4.4.10). From Table 4.4.11, whole tree longitudinal depth of penetration seems to increase from the butt to the top and the transverse depth of penetration was relatively constant along the bole. This observation confirms Larnoy *et al* (2008) statement that permeability varies along the stem of a tree. For the same range of pressure and treatment duration, the ratio of longitudinal to transverse penetrations for *Ficus sur* was about 23 to 1 (Table 4.4.10) and that of *C. gigantea* was about 36 to 1 (Tables 4.4.11). These ratios fall within the 20-50 longitudinal to one (1) transverse quoted for hardwoods by Larnoy *et al* (2008). The high longitudinal penetration in both species is mainly due to the cell arrangement of vessels, fibres and axial parenchyma along which liquid flow easily with little interruptions (Larnoy *et al*, 2008; Leal *et al* 2007; Ofori and Bamfo, 1994). Though the initial preservative volumetric retention of *F. sur* was higher than that of *C. gigantea* (Table 4.4.5), longitudinal penetration of *C. gigantea* was relatively higher than that of *F. sur* (Tables 4.4.10 and 4.4.11). Ahmed and Chun (2007) made the same observation when they impregnated *Gmelina arborea* with safranine and explained that, the initial preservative conduction is mainly through the vessels along with fibres, thus the vessel lumen diameter, length, pit diameter and number are of paramount importance in preservative conduction. They further stated that fibres though are not important in the initial preservative conduction as compared with vessels, they play decisive role in the spread of preservative from vessels. Thomas (1978) stated that though fibre structure does not facilitate easy penetration of liquid, it sometimes conducts more liquid than vessels. Narrow cell lumen has higher capillary pressure than wider ones. Therefore the relatively higher longitudinal penetration of *C. gigantea* may be due its smaller vessel diameter, longer fibre and narrower fibre lumen diameter as compared with those of *F. sur*. Transverse penetration on the other hand was relatively higher in *F. sur* than in *C. gigantea*. This may be due to relatively larger vessel-ray pits (Plate 4.4), larger inter-vessel pits (Plate 4.5) and the narrower ray cells of about 121µm (Plate 4.2 and Table 4.1.3) in *F. sur* which linked to form network with higher capillary pressure than the wider cells in *C. gigantea* (Plates. 4.9, 4.9 and Table 4.1.3)

5.3.8 Effect of pressure magnitude and duration on preservative oxide retention in *Coal gigantea* and *Ficus sur*

Generally, preservative oxide retention increased with increasing pressure magnitude and treatment duration for both species studied (Table 4.4.12). This trend has long being observed by Kamdem and Chow (1999) as well as Hunt and Garratt (1938). They explained that, at higher pressure magnitudes and durations, more preservatives were pushed into any available voids which may otherwise not be accessible at lower pressures magnitudes and treatment durations. Generally, the oxide retention for respective sapwood and heartwood of both species varied slightly at the same treatment schedule (Table 4.4.12). For the same range of pressure magnitude, treatment duration and 0.5 % CCA solution strength, the mean oxide retention in *Cola gigantea* sapwood ranges were 1.41 to 2.21 kg/m^3 and its heartwood were 1.39 to 2.29 kg/m^3 and those of *Ficus sur* sapwood were 1.86 to 3.21 kg/m^3 and 1.89 to 3.19 kg/m^3 for its heartwood. For instance, at 600 kPa, 30 minutes and CCA solution strength of 0.5%, the oxide retention values were 1.41 kg/m^3 for *Cola gigantea* sapwood and1.39 kg/m^3 for its heartwood and it was 1.86 kg/m^3 for *Ficus sur* sapwood and 1.89 kg/m^3 for its heartwood (Table 4.4.12). For the same pressure and treatment duration, the mean oxide retention of *Ficus sur* sapwood and heartwood were relatively higher than those of the *Cola gigantea* sapwood and heartwood. According to

Ahmed and Chun (2010) the initial preservative conduction is mainly through the vessels along with fibres, thus the vessel lumen diameter, length, pit diameter and number are of paramount importance in preservative conduction. Therefore, the high oxide retention values of *F. sur* sapwood and heartwood as compared with those of *Cola gigantea* sapwood and heartwood may be due to the relatively large vessel diameter, large pits size and large fibre lumen diameter (24 µm) in *F.sur* as compared with those in *C. gigantea.* Other factors such as the relative high proportions of vessels and parenchyma (9 % and 49 % respectively) can also positively increase preservative conduction to various cell types and their subsequent oxide retention in *F.sur* (Desch and Dinwoodie, 1996). If the CCA concentration is increased from the 0.5% to 5.0% (5.0 % CCA concentration is the average CCA concentration used for treating teak pole in Ghana) and with the same range of pressure magnitude and treatment duration, the mean oxide retention of *Cola gigantea* sapwood ranges will increase from 1.41 - 2.21 kg/m^3 to 14.1 – 22.1 kg/m^3 and its heartwood from 1.39 - 2.29 kg/m^3 to 13.9 – 22.9 kg/m^3 and those of *Ficus sur* sapwood will increase from 1.86 - 3.21 kg/m^3 to 18.6 – 32.1 kg/m^3 and 1.89 - 3.19 kg/m^3 to 18.9 – 31.9 kg/m^3 for its heartwood. The minimum values of the mean oxide retention ranges obtained in this study was more than the minimum retention of 9.6 kg/m^3 for Standard retention specified by the Ghana Standard (GS 11:1992). For the same range of pressure magnitude, treatment duration and 0.5 % CCA solution strength, the oxide balance obtained ranges were CuO = 16.0 – 20.5 %; CrO_3 = 46.1 – 53.9 % and As_2O_5 = 29.6 – 33.3 % for *Cola gigantea* sapwood and CuO = 16.2 – 19.1 %; CrO_3 = 49.1 – 54.0 % and As_2O_5 = 28.2 – 31.8 % for its heartwood (Table 4.4.14). Similarly, it was CuO =18.4 – 21.9 %; CrO_3= 48.1 – 52.9 % and As_2O_5 = 28.0 – 31.3 % for *Ficus sur* sapwood and CuO =18.8 – 22.6 %; CrO_3= 45.4 – 53.2 % and As_2O_5 = 26.9 – 32.0 % for its heartwood (Table 4.4.14). The normal range of preservative oxides balance according to AWPA Standard P5 – 06 (2008) are as follows: CuO = 17.0 – 21.0 %; CrO_3 = 44.5 – 50.5 %) and As_2O_5

= 30.0 – 38.0 %. Generally, the oxide balance of sapwood and heartwood of both species fall within the AWPA P5 – 06 specifications. In this study, the percentage copper oxide retained in the wood fall within the normal limits; the chromium oxide was towards or even more than the maximum acceptable limit whilst the Arsenate lies close to the lower acceptable limit. The recorded percentage dosage of copper and arsenic in the treated wood were good to effectively protect the treated wood in hazardous environments such as the direct external ground contact. The higher proportion of chromium oxide was to increase the fixation potentials of the preservative to help prevent leaching of the copper and arsenic oxides which will render the preservative effective and avoid any negative environmental impacts of the leachate.

5.3.9 Assessment of permeability

The mean surface area penetrated (Table 4.4.7) and the depth of preservative penetration (Table 4.4.9) increased with increasing pressure duration and magnitude when the species were treated with CCA preservative and by vacuum-pressure impregnation method. Fougerousse (1976) grouped wood into permeability classes based upon the percentage surface area penetrated by the preservative. According to his classification (Table 2.3), 50 – 90 % was classified as moderately resistant (thus, fairly easy to treat under pressure impregnation) and 10 – 50 % as resistant. The results of the percentage surface area penetrated are presented on Table 4.4.7. From the Table 4.4.7, *Cola gigantea* sapwood was classified as moderately resistant when treated at 1200 kPa for duration of at least 60 minutes. Lower pressure magnitudes below 1000 kPa and shorter treatment durations below 240 minutes will cause incomplete preservative penetration in *Cola gigantea* sapwood hence was classified as resistant. *Cola gigantea* heartwood on the other hand was rated as moderately resistant when treated at 1200 kPa for duration of at least 30 minutes or when treated at 1000 kPa for duration at of least 60 minutes. It was rated as resistant when treated at pressures from 600 to 800 kPa for durations less than 240 minutes (Table 4.4.7). Both the sapwood and heartwood of *Ficus sur* was classified as moderately resistant when treated at pressure magnitude of 1000 kPa for at least 60 minutes or 1200 kPa for duration of at least 30 minutes (Table 4.4.7). They were however classified as resistant when treated at pressures from 600 to 800 kPa for less than 120 minutes. The sapwood and heartwood of both *Ficus sur* and *Cola gigantea* were rated as moderately resistant when treated at 600 kPa for at least 240 minutes. These results implies that both species can be treated at lower pressure magnitude of 600 kPa for extended duration of 240 minutes or treated at high pressure magnitudes of at least 1000 kPa for at most 60 minutes. Building Research Establishment (1972) classified wood into permeability classed based upon the depth of lateral penetration (Table 2.4) and stated that lateral penetration of 6 – 18 mm is moderately resistant and 3 – 6 mm is resistant. In this study, the radial and tangential penetrations of both species were classified based upon the Building Research Establishment method. According to this classification, *Cola gigantea* was classified as moderately resistant when treated at pressure of 1200 kPa for at least 30 minutes pressure duration or when treated at least 800kPa for at least 60 minutes duration. It was also rated moderately resistant when treated at extended duration of 240 minutes at 600 kPa pressure magnitude (Table 4.4.9). *Ficus sur* however, was moderately resistant even when treated at 600 kPa for 30 minutes (Table 4.4.9).

CHAPTER SIX

6.0 Conclusions and recommendations

The following conclusions can be deduced from the results of the studies

1. The anatomical characteristics of the woods of both *Cola gigantea* and *Ficus sur* used in this study are similar to those found in the wood of the same species in other parts of Africa studied by Uetimane *et al* (2008), Lumbile and Mogotsi (2008). However, the *Ficus sur* used in this study lacks laticifer tubes which were present in the wood studied by Uetimane *et al* (2008). Uetimane *et al* (2008) found helical thickening of vessel elements and intercellular canal in *Cola gigantea* but these features were not found in the Ghanaian wood.

2. The mean fibre length was 2.1 mm for *Cola gigantea* sapwood and 1.9 mm for its heartwood; fibre diameter varied from 24.2 µm in *Cola gigantea* sapwood to 25.1 µm in its heartwood; fibre lumen diameter was 13.9 µm for *Cola gigantea* sapwood and 15.6 µm for its heartwood; and the double cell wall thickness was 10.3 µm for *Cola gigantea* sapwood and 9.5 µm for its heartwood. The mean fibre length of *Ficus sur* varied from 1.7 mm in sapwood to 1.4 mm in the heartwood; fibre diameter varied from 31.7 µm in sapwood to 30.9 µm in heartwood; fibre lumen diameter was 23.9 µm for sapwood and 23.8 µm for heartwood; and double cell wall thickness was 7.8 µm for sapwood and 7.1 µm for heartwood. The proportion of vessel was 8 % in both sapwood and heartwood of *C. gigantea*. Parenchyma proportion was 44 % in sapwood and 42 % in heartwood. The fibre proportion varied from 48 % in sapwood to 50 % in heartwood of *Cola gigantea* and the tangential vessel diameter varied from 180 µm in sapwood to 188µm in the heartwood. The mean vessel proportion in *Ficus sur* was 9 % in both sapwood and

heartwood. Parenchyma proportion varied from 49 % in sapwood to 44 % in heartwood. Fibre proportion was 42 % in sapwood and 47 % in heartwood of *Ficus sur* and vessel diameter was 216 µm in the sapwood and 236 µm in the heartwood. The fibre morphological properties and tissue proportion variations are the major factors that are likely to influence the preservative retention, basic density and moisture content variation within and between the two species. Other factors such as the presence of silica bodies in *Cola gigantea* may also influence the between species physical and treatment characteristics.

3. The basic density values of the wood of *C. gigantea* were 501 kg/m^3 for the sapwood and 456 kg/m^3 for its heartwood. Those for *Ficus sur* were 383 kg/m^3 for sapwood and 366 kg/m^3 for its heartwood. The sapwoods of both species were significantly denser than their respective heartwoods. The middle portion of *C. gigantea* was denser than the other portions; and the butt portion denser than the top portions. The top portion of *F.sur* was denser than the middle and the butt portions. The basic density was 479 kg/m^3 for *Cola gigantea* which was denser than 375 kg/m^3 for *Ficus sur*.
4. The mean green moisture for *Cola gigantea* heartwood was 110 % and that of its sapwood was 98 % and that for *Ficus sur* heartwood was 170 % and its sapwood was 167 %. The sapwood of *C. gigantea* has lower green moisture content than the heartwood. No significant difference existed between the sapwood and heartwood of *F. sur* in terms of green moisture content. The middle portion of *C. gigantea* had lower moisture than the top and the butt portions. The middle and the butt portions of *F.sur* had higher green moisture than the top. The green moisture content for *Cola gigantea* was 104 % which was significantly lower than 168 % for *Ficus sur*.

5. The mean absolute volumetric retention was 342 kg/m^3 for *Cola gigantea* sapwood and 354 kg/m^3 for its heartwood and those for *Ficus sur* were 467 kg/m^3 for sapwood and 469 kg/m^3 for heartwood. The mean absolute volumetric retention of *F. sur* was 468 kg/m^3, significantly higher than 348 kg/m^3 for *C. gigantea*. The volumetric retention did not differ significantly between the sapwood and heartwood of both species.
6. The ratio of mean longitudinal to transverse penetrations was about 32 to 1 for *C. gigantea* sapwood and 39 to 1 for its heartwood and those of *Ficus sur* sapwood and its heartwood were 22 to 1 and 24 to 1 respectively. The ratio of longitudinal to transverse penetrations was 36 to 1 for *Cola gigantea* and 23 to 1 for *Ficus sur*. Penetration appears to decrease from top to the butt portion of the trees of both species. Again, the heartwood penetration was relatively higher than the sapwood penetration.
7. The results obtained in this study implied that the mean oxide retention of *Cola gigantea* sapwood would range from 14.1 to 22.1 kg/m^3 and its heartwood from 13.9 to 22.9 kg/m^3 and those of *Ficus sur* sapwood would range from 18.6 to 32.1 kg/m^3 and 18.9 to 31.9 kg/m^3 for its heartwood if the CCA concentration used were increased to 5.0 % under the same pressure magnitude and treatment duration used in this study. With these preservative oxide retentions obtained in this study both species can be loaded with high concentration CCA – C preservative to withstand hazardous conditions
8. The sapwood and heartwood of both species is classified as moderately resistant when treated at 1200 kPa pressure for 60 minutes or more. The species can also be treated at 1000 kPa pressure for a period of 120 minutes or more. Though both species were moderately resistant at 1200 kPa for 60 minutes or more, low pressures up to 1000 kPa and longer pressure duration of more than 240 minutes is recommended for treatment of

C. gigantea while higher pressures above 1200 kPa and reduced pressure duration of up to 60 minutes is recommended for the treatment of *F. sur*.

Based on the results obtained in this study, the following recommendations are suggested:

1. Treatability studies on these species from other ecological zones in Ghana should be conducted to generate more information.
2. Since the colour, basic density and fibre morphological properties of both the sapwood and heartwood of the two species are similar, both section of the two species can be treated together.
3. Both species are good raw material for pulp and paper production based on the fibre and vessel morphological properties.
4. The wood of *Ficus sur* can be used as a suitable substitute for *Antiaris toxicaria* (Kyenkyen), *Pycnanthus angolensis* (Otie) and *Triplochiton scleroxylon* (wawa) based upon the density and texture of the wood
5. Both *Cola gigantea* and *Ficus sur* can be used for crates, cladding members in housing construction and rotary veneer production.
6. *Ficus sur* should be treated at high pressure of 1200 kPa for shorter duration of at most 60 minutes whilst *Cola gigantea* should be treated at pressures not more than 1000 kPa for at least 120 minutes.
7. Both *Cola gigantea* and *Ficus sur* can be treated with 5.0 % CCA preservative at 600 kPa pressure for 30 minutes and the minimum retention of 9.6 kg/m^3 required for transmission poles as standard dosage by the Ghana Standard will be obtained.

Implications of the results

The results obtained in this study will add to the information available on some of the properties of wood as a construction material. These results will fill the information gap on the anatomical and treatment characteristics of the two species. The fact that the sapwoods of these species are as dense as or even denser than their respective heartwood will maximize lumber yield for both species during log processing. This is because the sapwoods are often striped of as a slaps in most timber species during milling operations but in these two species, the sapwood can be retained as part of the yield from milling operations.

The observation that these species are moderately resistant when treated at 1200 kPa pressure for a period of 60minutes or more make them very useful even under high hazard condition. Both the sapwood and heartwood are treatable.

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Appendix 1: Descriptive statistics of percentage tissue proportion of the sapwood, heartwood and whole tree of *Cola gigantea*.

Sapwood tissue proportion

	%Vessel	%Parenchyma	%Fibre
Mean	8	44	48
Standard Error	1	3	2
Standard Deviation	3	8	6
Minimum	5	30	40
Maximum	10	55	60
Count	10	10	10
Confidence Level (95.0%)	2	6	5

Heartwood tissue proportion

	%Vessel	%Parenchyma	%Fibre
Mean	8	42	50
Standard Error	1	3	3
Standard Deviation	3	11	11
Minimum	5	20	30
Maximum	15	65	70
Count	10	10	10
Confidence Level (95.0%)	3	8	8

Whole tree tissue proportion

	%Vessel	%Parenchyma	%Fibre
Mean	8	43	49
Standard Error	1	2	2
Standard Deviation	3	9	9
Minimum	5	20	30
Maximum	15	65	70
Count	20	20	20
Confidence Level (95.0%)	1	4	4

Appendix 2: Descriptive statistics of percentage tissue proportion of the sapwood, heartwood and whole tree of *Ficus sur*

Sapwood tissue proportion

	%Vessel	%Parenchyma	%Fibre
Mean	9	49	42
Standard Error	1	2	2
Standard Deviation	5	10	8
Minimum	5	30	30
Maximum	20	65	55
Count	15	15	15
Confidence Level (95.0%)	3	5	4

Heartwood tissue proportion

	%Vessel	%Parenchyma	%Fibre
Mean	9	44	47
Standard Error	1	2	3
Standard Deviation	4	7	8
Minimum	5	30	35
Maximum	15	55	65
Count	10	10	10
Confidence Level (95.0%)	3	5	6

Whole tree tissue proportion

	%Vessel	%Parenchyma	%Fibre
Mean	9	47	44
Standard Error	1	2	2
Standard Deviation	4	9	8
Minimum	5	30	30
Maximum	20	65	65
Confidence Level (95.0%)	2	4	3

Appendix 3: Descriptive statistics of vessels and rays morphological properties of sapwood, heartwood and whole tree of *Cola gigantea*

Vessel lumen diameter (µm)

	Sapwood	Heartwood	Whole tree
Mean	180	188	184
Standard Error	6	5	4
Standard Deviation	31	25	28
Minimum	125	150	125
Maximum	238	238	238
Count	30	30	60
Confidence Level (95.0%)	12	11	8

Ray height (µm)

	Sapwood	Heartwood	Whole tree
Mean	1321	1078	1224
Standard Error	64	54	45
Standard Deviation	493	343	453
Minimum	563	563	563
Maximum	2800	1875	2800
Count	60	60	100
Confidence Level (95.0%)	127	110	90

Ray width (µm)

	Sapwood	Heartwood	Whole tree
Mean	138	139	139
Standard Error	4	5	3
Standard Deviation	30	32	31
Minimum	75	88	75
Maximum	225	188	225
Count	60	60	100
Confidence Level (95.0%)	8	10	6

Appendix 4: Descriptive statistics of vessels and rays morphological properties of sapwood, heartwood and whole tree of *Ficus sur*

Vessel lumen diameter (µm)

	Sapwood	Heartwood	Whole tree
Mean	239	217	225
Standard Error	7	5	4
Standard Deviation	35	25	31
Minimum	163	163	163
Maximum	300	263	300
Count	30	30	60
Confidence Level (95.0%)	15	11	8

Ray height (µm)

	Sapwood	Heartwood	Whole tree
Mean	793	665	729
Standard Error	23	17	15
Standard Deviation	178	128	167
Minimum	500	400	400
Maximum	1375	1063	1375
Count	60	60	120
Confidence Level (95.0%)	46	33	30

Ray width (µm)

	Sapwood	Heartwood	Whole tree
Mean	126	117	121
Standard Error	3	4	2
Standard Deviation	21	32	27
Minimum	88	50	50
Maximum	163	163	163
Count	60	60	120
Confidence Level (95.0%)	5	8	5

Appendix 5: Descriptive statistics of fibre morphological properties (μm) variation along and across *Cola gigantea* bole

Bottom heartwood

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	1864	26	16	10
Standard Error	45	1	1	1
Standard Deviation	262	4	4	3
Sample Variance	68452	16	15	10
Minimum	1435	15	9	3
Maximum	2520	32	23	17
Count	35	35	35	35

Middle heartwood

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	1908	25	16	8
Standard Error	32	1	0	0
Standard Deviation	184	3	3	2
Sample Variance	33839	10	8	3
Minimum	1610	19	12	6
Maximum	2275	32	23	12
Count	35	35	35	35

Top heartwood

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	1820	24	15	10
Standard Error	30	0	1	0
Standard Deviation	179	2	3	2
Sample Variance	32000	6	10	4
Minimum	1418	20	9	5
Maximum	2100	29	20	15
Count	35	35	35	35

Appendix 5: Descriptive statistics of fibre morphological properties (μm) variation along and across *Cola gigantea* bole

Bottom sapwood

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	2401	25	13	12
Standard Error	44	1	1	1
Standard Deviation	257	3	3	3
Minimum	1939	17	8	6
Maximum	2870	30	17	18
Count	35	35	35	35

Middle sapwood

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	2256	25	15	10
Standard Error	47	1	0	0
Standard Deviation	277	4	3	3
Minimum	1785	17	9	6
Maximum	2870	33	23	17
Count	35	35	35	35

Top sapwood

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	1690	23	14	9
Standard Error	24	0	0	0
Standard Deviation	140	3	3	2
Minimum	1428	17	9	4
Maximum	2048	29	20	13
Count	35	35	35	35

Appendix 5: Descriptive statistics of fibre morphological properties (μm) variation along and across *Cola gigantea* bole

all heartwood

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	1864	25	16	10
Standard Error	21	0	0	0
Standard Deviation	212	3	3	2
Minimum	1418	15	9	3
Maximum	2520	32	23	17
Count	105	105	105	105
Confidence Level (95.0%)	41	1	1	0

All sapwood

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	2112	24	14	10
Standard Error	38	0	0	0
Standard Deviation	385	4	3	3
Minimum	1428	17	8	4
Maximum	2870	33	23	18
Count	105	105	105	105
Confidence Level (95.0%)	75	1	1	1

Whole tree

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	1988	25	15	10
Standard Error	23	0	0	0
Standard Deviation	334	3	3	3
Minimum	1418	15	8	3
Maximum	2870	33	23	18
Count	210	210	210	210
Confidence Level (95.0%)	46	0	0	0

Appendix 6: Descriptive statistics of fibre morphological properties (μm) variation along and across *Ficus sur* bole

Bottom heartwood

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	1668	29	22	7
Standard Error	25	1	1	0
Standard Deviation	149	3	3	3
Sample Variance	22102	9	10	6
Minimum	1435	25	15	3
Maximum	2065	38	29	12
Count	35	35	35	35

Middle heartwood

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	1062	33	28	5
Standard Error	19	1	1	0
Standard Deviation	112	4	4	1
Sample Variance	12606	16	17	1
Minimum	875	26	23	3
Maximum	1295	39	35	9
Count	35	35	35	35

Top heartwood

	Fibre length	fibre diameter	fibre lumen dia	Double wall thickness
Mean	1557	31	22	9
Standard Error	26	1	1	0
Standard Deviation	153	4	4	2
Sample Variance	23293	15	15	4
Minimum	1295	23	15	6
Maximum	1820	44	33	12
Count	35	35	35	35

Appendix 6: Descriptive statistics of fibre morphological properties (µm) variation along and across *Ficus sur* bole

Bottom sapwood

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	2001	27	19	7
Standard Error	28	1	1	0
Standard Deviation	164	3	3	2
Sample Variance	26781	9	11	4
Minimum	1715	21	12	3
Maximum	2300	32	26	12
Count	35	35	35	35

Middle sapwood

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	1691	34	26	9
Standard Error	46	1	1	0
Standard Deviation	270	4	4	2
Sample Variance	72936	15	15	4
Minimum	1050	29	20	6
Maximum	2240	44	36	12
Count	35	35	35	35

Top sapwood

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	1315	34	26	7
Standard Error	22	1	1	0
Standard Deviation	132	5	5	1
Sample Variance	17503	24	22	2
Minimum	1085	23	17	6
Maximum	1575	44	37	12
Count	35	35	35	35

Appendix 6: Descriptive statistics of fibre morphological properties (μm) variation along and across *Ficus sur* bole

All heartwood

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	1429	31	24	7
Standard Error	29	0	0	0
Standard Deviation	298	4	5	3
Minimum	875	23	15	3
Maximum	2065	44	35	12
Count	105	105	105	105
Confidence Level (95.0%)	58	1	1	0

All sapwood

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	1669	32	24	8
Standard Error	33	1	0	0
Standard Deviation	343	5	5	2
Minimum	1050	21	12	3
Maximum	2300	44	37	12
Count	105	105	105	105
Confidence Level (95.0%)	66	1	1	0

Whole tree

	Fibre length	fibre diameter	fibre lumen diameter	Double wall thickness
Mean	1549	31	24	7
Standard Error	24	0	0	0
Standard Deviation	342	5	5	2
Minimum	875	21	12	3
Maximum	2300	44	37	12
Count	210	210	210	210
Confidence Level (95.0%)	47	1	1	0

Appendix 7: Descriptive statistics of basic density (kg/m^3), air dried moisture content (%), green moisture content (%) and maximum absorption (l/m^3) variation within *C. gigantea*

Butt heartwood

	Basic Density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	455	22	115	584
Standard Error	6	1	3	8
Standard Deviation	42	4	14	42
Minimum	317	15	50	396
Maximum	665	32	133	630
Count	40	30	40	30
Confident Level (95.0%)	12	1	5	16

Middle heartwood

	Basic Density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	490	20	107	576
Standard Error	7	0	4	9
Standard Deviation	45	2	24	48
Minimum	411	15	81	503
Maximum	553	26	143	642
Count	40	30	40	30
Confident Level (95.0%)	13	1	9	18

Top heartwood

	Basic Density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	425	20	111	587
Standard Error	11	0	2	4
Standard Deviation	76	3	13	21
Minimum	306	16	96	561
Maximum	512	31	135	625
Count	40	30	40	30
Confident Level (95.0%)	22	1	5	8

Continued

Butt sapwood

	Basic Density (kg/m³)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m³)
Mean	495	19	108	587
Standard Error	5	0	1	3
Standard Deviation	32	2	7	14
Minimum	450	15	97	551
Maximum	594	22	122	615
Count	40	30	40	30
Confident Level (95.0%)	9	1	2	5

Middle sapwood

	Basic Density (kg/m³)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m³)
Mean	548	19	84	536
Standard Error	3	0	1	3
Standard Deviation	18	1	6	15
Minimum	513	17	75	509
Maximum	587	22	95	559
Count	40	30	40	30
Confident Level (95.0%)	5	0	2	6

Top sapwood

	Basic Density (kg/m³)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m³)
Mean	462	19	101	573
Standard Error	7	1	1	4
Standard Deviation	50	3	5	19
Minimum	387	14	91	496
Maximum	523	33	111	611
Count	40	30	40	30
Confident Level (95.0%)	14	1	2	7

Continued

All butt

	Basic Density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	475	21	111	585
Standard Error	4	0	1	4
Standard Deviation	42	3	12	31
Minimum	317	15	50	396
Maximum	665	32	133	630
Count	80	60	80	60
Confident Level (95.0%)	8	1	3	8

All middle

	Basic Density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	519	19	96	556
Standard Error	5	0	3	5
Standard Deviation	45	1	21	41
Minimum	411	15	75	503
Maximum	587	26	143	642
Count	80	60	80	60
Confident Level (95.0%)	13	0	5	11

All top

	Basic Density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	443	19	96	556
Standard Error	7	0	3	5
Standard Deviation	66	1	21	41
Minimum	306	15	75	503
Maximum	523	26	143	642
Count	80	60	80	60
Confident Level (95.0%)	13	0	5	11

Continued

Whole tree

	Basic Density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	479	20	104	574
Standard Error	4	0	1	3
Standard Deviation	61	3	16	34
Minimum	306	14	50	396
Maximum	665	33	143	642
Count	240	180	240	180
Confident Level (95.0%)	7	0	2	5

All heartwood

	Basic Density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	456	21	111	582
Standard Error	5	0	2	4
Standard Deviation	62	3	18	39
Minimum	306	15	50	396
Maximum	665	32	143	642
Count	120	90	120	90
Confident Level (95.0%)	10	1	4	8

All sapwood

	Basic Density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	501	19	98	565
Standard Error	4	0	1	3
Standard Deviation	50	2	12	27
Minimum	387	14	75	496
Maximum	594	33	122	615
Count	120	90	120	90
Confident Level (95.0%)	9	0	2	6

Appendix 8: Descriptive statistics of basic density (kg/m^3), air dried moisture content (%), green moisture content (%) and maximum absorption (l/m^3) variation within *Ficus sur*

Butt heartwood

	Basic density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	367	17	172	689
Standard Error	5	1	4	7
Standard Deviation	30	7	20	38
Minimum	325	8	125	588
Maximum	466	43	207	737
Count	40	30	40	30
Confident Level (95.0%)	9	3	8	14

Middle heartwood

	Basic density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	352	14	173	703
Standard Error	4	0	3	4
Standard Deviation	30	3	18	23
Minimum	283	11	126	630
Maximum	441	21	210	735
Count	40	30	40	30
Confident Level (95.0%)	9	1	7	9

Top heartwood

	Basic density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	378	14	159	685
Standard Error	3	1	2	4
Standard Deviation	17	3	9	16
Minimum	332	11	147	644
Maximum	409	24	177	713
Count	40	30	40	30
Confident Level (95.0%)	8	2	5	9

Appendix 8: Descriptive statistics of basic density (kg/m^3), air dried moisture content (%), green moisture content (%) and maximum absorption (l/m^3) variation within *Ficus sur*

Butt sapwood

	Basic density (kg/m^2)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	359	19	173	687
Standard Error	3	1	2	4
Standard Deviation	18	5	11	24
Minimum	331	7	148	643
Maximum	412	29	197	732
Count	40	30	40	30
Confident Level (95.0%)	5	2	4	9

Middle sapwood

	Basic density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	367	16	168	690
Standard Error	4	1	3	6
Standard Deviation	24	6	16	33
Minimum	323	8	138	600
Maximum	419	32	201	740
Count	40	30	40	30
Confident Level (95.0%)	7	2	6	12

Top sapwood

	Basic density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	424	14	286	591
Standard Error	16	0	140	15
Standard Deviation	68	0	541	58
Minimum	342	14	121	500
Maximum	539	15	240	712
Count	40	30	40	30
Confident Level (95.0%)	32	0	300	32

Appendix 8 Descriptive statistics of basic density (kg/m^3), air dried moisture content (%), green moisture content (%) and maximum absorption (l/m^3) variation within *Ficus sur*

Butt

	Basic density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	363	18	172	688
Standard Error	3	1	2	4
Standard Deviation	25	6	16	31
Minimum	325	7	125	588
Maximum	466	43	207	737
Count	80	60	80	60
Confident Level (95.0%)	5	2	4	8

Middle

	Basic density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	360	15	170	696
Standard Error	3	1	2	4
Standard Deviation	28	5	17	29
Minimum	283	8	126	600
Maximum	441	32	210	740
Count	80	60	80	60
Confident Level (95.0%)	6	1	4	7

Top

	Basic density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	407	14	155	638
Standard Error	9	0	4	12
Standard Deviation	68	2	22	64
Minimum	332	11	121	500
Maximum	539	24	224	713
Count	80	60	80	60
Confident Level (95.0%)	18	1	8	24

Appendix 8: Descriptive statistics of basic density (kg/m^3), air dried moisture content (%), green moisture content (%) and maximum absorption (l/m^3) variation within *Ficus sur*

Whole tree

	Basic density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	375	16	168	681
Standard Error	5	0	2	4
Standard Deviation	30	5	19	45
Minimum	283	7	121	500
Maximum	539	43	224	740
Count	240	180	240	180
Confident Level (95.0%)	6	1	3	7

All sapwood

	Basic density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	381	17	167	669
Standard Error	5	1	2	6
Standard Deviation	56	5	19	53
Minimum	323	7	121	500
Maximum	539	32	224	740
Count	120	90	120	90
Confident Level (95.0%)	10	1	4	12

All heartwood

	Basic density (kg/m^3)	Air Dried MC (%)	Green MC (%)	Max absorption (l/m^3)
Mean	365	15	170	694
Standard Error	3	1	2	3
Standard Deviation	29	5	18	29
Minimum	283	8	125	588
Maximum	466	43	210	737
Count	120	90	120	90
Confident Level (95.0%)	5	1	4	7

Appendix 9: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

	600 kPa, 30 mins				600 kPa, 60 mins		
Radial sections	Orientation	rel. absorption	Vol. retention	Radial sections	Orient ation	Rel. absorption	Vol. retention
S	L1	23	130	H	L1	51	295
H	L2	17	95	H	L2	32	185
H	L3	32	185	H	L3	45	260
H	L4	31	180	H	L4	47	267
H	L5	24	138	S	L5	32	184
S	L6	20	115	H	L6	37	213
H	R1	53	306	S	R1	30	170
S	R2	54	310	S	R2	60	342
H	R4	36	207	S	R4	45	257
H	R4	62	357	H	R4	27	153
S	R5	44	252	H	R5	38	216
H	R6	75	429	H	R6	41	236
H	T1	84	484	S	T1	37	215
S	T2	38	220	H	T2	59	336
H	T3	31	176	S	T3	50	287
S	T4	47	268	H	T4	44	250
H	T5	32	184	S	T5	55	317
H	T6	29	167	S	T6	25	146
			233				**241**

Appendix 9: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

	600 kPa, 120 mins				600 kPa, 240 mins		
Radial sections	Orientation	rel. absorption	Vol. retention	Radial sections	Orientation	rel. absorption	Vol. retention
S	L1	20	117	S	L1	16	93
H	L2	43	246	S	L2	35	200
S	L3	51	294	H	L3	74	425
S	L4	52	301	H	L4	24	139
H	L5	44	252	S	L5	45	259
H	L6	60	343	S	L6	28	163
H	R1	67	387	S	R1	104	598
S	R2	65	372	H	R2	66	379
H	R4	77	440	H	R4	85	488
S	R4	52	299	S	R4	73	419
S	R5	37	212	S	R5	71	410
H	R6	81	463	H	R6	79	451
H	T1	52	298	S	T1	33	192
H	T2	51	290	S	T2	86	496
H	T3	64	366	S	T3	64	369
H	T4	59	340	H	T4	78	448
S	T5	74	427	H	T5	75	428
S	T6	68	389	H	T6	90	516
			324				**360**

Appendix 9: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

	800 kPa, 30 mins				800 kPa, 60 mins		
Radial sections	Orient ation	rel. absorption	Vol. retention	Radial sections	Orient ation	rel. absorption	Vol. retention
S	L1	25	146	S	L1	39	223
H	L2	39	225	H	L2	50	284
H	L3	28	161	H	L3	29	164
S	L4	59	338	H	L4	82	469
H	L5	38	216	S	L5	48	273
H	L6	44	253	H	L6	55	314
H	R1	39	221	S	R1	53	303
H	R2	70	402	H	R2	69	399
H	R4	76	437	H	R4	73	417
S	R4	57	327	S	R4	51	294
H	R5	71	406	S	R5	54	308
H	R6	14	83	H	R6	25	145
H	T1	69	394	H	T1	63	363
H	T2	53	306	S	T2	47	268
S	T3	51	293	H	T3	69	398
S	T4	50	285	H	T4	81	463
H	T5	72	410	H	T5	81	467
S	T6	59	338	S	T6	68	392

Appendix 9: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

	800 kPa, 30 mins				800 kPa, 60 mins		
Radial sections	Orientation	rel. absorption	Vol. retention	Radial sections	Orientation	rel. absorption	Vol. retention
S	L1	25	146	S	L1	39	223
H	L2	39	225	H	L2	50	284
H	L3	28	161	H	L3	29	164
S	L4	59	338	H	L4	82	469
H	L5	38	216	S	L5	48	273
H	L6	44	253	H	L6	55	314
H	R1	39	221	S	R1	53	303
H	R2	70	402	H	R2	69	399
H	R4	76	437	H	R4	73	417
S	R4	57	327	S	R4	51	294
H	R5	71	406	S	R5	54	308
H	R6	14	83	H	R6	25	145
H	T1	69	394	H	T1	63	363
H	T2	53	306	S	T2	47	268
S	T3	51	293	H	T3	69	398
S	T4	50	285	H	T4	81	463
H	T5	72	410	H	T5	81	467
S	T6	59	338	S	T6	68	392

Appendix 9: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

	800 kPa, 120 mins				800 kPa, 240 mins		
Radial sections	Orientation	rel. absorption	Vol. retention	Radial sections	Orientation	rel. absorption	Vol. retention
H	L1	83	478	S	L1	52	300
H	L2	52	299	S	L2	36	206
S	L3	48	276	H	L3	51	291
H	L4	53	301	S	L4	80	462
S	L5	62	355	S	L5	45	256
S	L6	58	331	S	L6	70	400
H	R1	62	354	H	R1	89	511
H	R2	86	491	S	R2	81	465
H	R4	61	350	H	R4	59	341
H	R4	72	412	S	R4	85	488
H	R5	79	454	H	R5	81	462
S	R6	42	243	H	R6	81	465
S	T1	48	274	S	T1	74	427
S	T2	60	344	S	T2	83	473
H	T3	46	264	H	T3	46	261
H	T4	59	340	H	T4	98	561
S	T5	63	361	S	T5	98	565
H	T6	68	391	H	T6	89	508

Appendix 9: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

	1000 kPa, 30 mins				1000 kPa, 60 mins		
Radial sections	Orientation	rel. absorption	Vol. retention	Radial sections	Orientation	rel. absorption	Vol. retention
H	L1	59	339	S	L1	69	398
H	L2	30	175	S	L2	65	372
H	L3	35	200	H	L3	65	375
H	L4	69	396	H	L4	49	282
H	L5	25	145	S	L5	61	351
S	L6	38	221	S	L6	82	468
S	R1	81	465	H	R1	79	454
H	R2	44	252	H	R2	59	338
H	R4	69	396	H	R4	77	442
H	R4	51	295	S	R4	68	388
H	R5	65	372	S	R5	32	181
S	R6	55	318	H	R6	76	434
S	T1	61	350	H	T1	74	424
S	T2	57	326	H	T2	59	339
S	T3	23	134	H	T3	50	284
H	T4	79	455	H	T4	64	368
S	T5	65	374	H	T5	45	261
S	T6	52	298	S	T6	44	254

Appendix 9: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

1000 kPa, 120 mins				1000 kPa, 240 mins			
Radial sections	Orientation	rel. absorption	Vol. retention	Radial sections	Orientation	rel. absorption	Vol. retention
H	L1	59	337	H	L1	67	383
H	L2	81	463	H	L2	79	455
S	L3	79	456	H	L3	76	435
H	L4	73	416	S	L4	47	272
H	L5	86	492	S	L5	75	432
H	L6	49	283	S	L6	73	416
S	R1	74	425	H	R1	79	454
H	R2	73	421	S	R2	77	444
H	R4	76	435	H	R4	93	531
H	R4	21	122	S	R4	79	455
S	R5	66	380	S	R5	88	506
S	R6	74	423	H	R6	56	319
S	T1	81	463	H	T1	72	413
H	T2	87	500	H	T2	76	438
H	T3	81	464	S	T3	46	266
S	T4	93	534	S	T4	82	471
S	T5	20	117	S	T5	80	457
H	T6	75	429	S	T6	67	382

Appendix 9: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

	1200 kPa, 30 mins				1200 kPa,60 mins		
Radial sections	Orientation	rel. absorption	Vol. retention	Radial sections	Orientation	rel. absorption	Vol. retention
S	L1	57	325	S	L1	34	196
H	L2	88	505	H	L2	84	480
S	L3	13	74	H	L3	78	447
H	L4	27	156	S	L4	35	203
H	L5	45	256	S	L5	65	373
H	L6	24	139	H	L6	30	170
S	R1	86	495	S	R1	59	340
S	R2	68	392	S	R2	50	284
H	R4	50	286	S	R4	75	429
H	R4	40	231	S	R4	78	445
H	R5	60	344	H	R5	41	237
H	R6	75	432	H	R6	76	438
S	T1	82	468	H	T1	52	298
H	T2	28	159	H	T2	72	415
S	T3	60	347	S	T3	80	459
H	T4	74	423	S	T4	82	473
H	T5	60	344	H	T5	81	464
H	T6	82	470	H	T6	69	397

Appendix 9: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

1200 kPa, 120 mins				1200 kPa,240 mins			
Radial sections	Orientation	rel. absorption	Vol. retention	Radial sections	Orientation	rel. absorption	Vol. retention
H	L1	86	492	H	L1	89	511
H	L2	39	222	H	L2	72	411
S	L3	67	385	S	L3	68	390
H	L4	73	416	H	L4	84	480
H	L5	45	260	S	L5	76	437
S	L6	53	307	S	L6	64	370
H	R1	56	323	S	R1	75	429
H	R2	84	484	S	R2	89	510
H	R3	81	465	S	R3	67	384
S	R4	77	443	H	R4	94	542
H	R5	80	461	S	R5	83	475
H	R6	91	521	H	R6	54	310
H	T1	76	435	S	T1	56	322
H	T2	94	537	H	T2	64	366
S	T3	70	402	S	T3	94	537
H	T4	49	281	H	T4	96	548
S	T5	81	465	H	T5	91	523
S	T6	78	450	S	T6	64	368

Appendix 10: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

600 kPa, 30 mins

Radial sections	Orientation	rel. absorption	Vol. retention
H	L1	24	168
S	L2	41	286
H	L3	56	392
H	L4	63	436
H	L5	23	158
H	L6	67	469
S	R1	84	582
H	R2	42	291
S	R3	39	270
H	R4	66	458
H	R5	41	286
S	R6	71	495
S	T1	81	566
S	T2	41	288
S	T3	20	139
H	T4	79	553
S	T5	59	413
		53	**368**

600 kPa, 60 mins

Radial sections	Orientation	rel. absorption	Vol. retention
S	L1	78	546
S	L2	30	210
S	L3	24	167
H	L4	84	586
H	L5	29	202
S	R1	85	592
H	R2	64	446
H	R3	61	428
H	R4	57	394
H	R5	71	495
S	R6	73	508
H	T1	63	441
S	T2	81	562
H	T3	71	495
H	T4	60	419
H	T5	21	149
S	T6	26	180
		58	**401**

Appendix 10: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

	600 kPa, 120 min				600 kPa, 240 mins		
Radial sections	Orient ation	rel. absorption	Vol. retention	Radial sections	Orient ation	rel. absorption	Vol. retention
H	L1	80	554	S	L1	83	580
H	L2	52	362	H	L2	68	472
H	L3	56	392	H	L3	57	396
H	L4	72	501	H	L4	67	466
S	L5	57	399	H	L5	44	309
S	L6	83	578	S	L6	33	228
S	R1	19	132	S	R1	36	251
H	R2	74	513	H	R2	71	492
S	R3	72	498	H	R3	59	412
H	R4	71	497	H	R4	73	505
S	R5	72	499	H	R5	68	474
H	R6	72	504	S	R6	87	605
S	T1	81	562	S	T1	69	483
H	T2	71	491	H	T2	53	368
S	T3	22	151	S	T3	86	596
S	T4	72	503	S	T4	77	536
H	T5	23	162	S	T5	70	491
H	T6	65	455	H	T6	88	616
		62	**431**			**66**	**460**

Appendix 10: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

800 kPa, 30 min

Radial sections	Orientation	rel. absorption	Vol. retention
S	L1	45	314
S	L2	50	347
S	L3	47	327
H	L4	39	271
H	L5	78	544
H	L6	46	318
S	R1	55	381
H	R2	25	174
H	R3	40	275
H	R4	82	568
H	R5	39	270
H	R6	83	581
H	T1	86	601
H	T2	54	374
S	T3	79	552
H	T4	84	588
S	T5	64	443
		59	**408**

800 kPa, 60 mins

Radial sections	Orientation	rel. absorption	Vol. retention
H	L1	41	287
H	L2	30	211
H	L3	72	500
H	L4	85	594
H	L5	46	317
S	L6	66	462
H	R1	61	427
S	R2	65	451
H	R3	66	461
S	R4	80	554
H	R5	69	481
S	R6	34	239
S	T1	87	607
S	T2	35	241
H	T3	72	501
H	T4	66	461
S	T5	37	260
S	T6	76	528
		61	**421**

Appendix 10: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

800 kPa, 120 mins

Radial sections	Orientation	rel. absorption	Vol. retention
H	L1	71	492
H	L2	70	488
S	L3	54	374
S	L4	51	356
S	L5	75	524
S	R1	65	450
H	R2	78	541
H	R3	70	488
H	R4	69	480
S	R5	60	418
H	R6	68	476
H	T1	67	466
S	T2	73	505
H	T3	66	457
S	T4	73	508
H	T5	61	422
H	T6	71	493
		67	**467**

800 kPa, 240 mins

Radial sections	Orientation	rel. absorption	Vol. retention
S	L1	78	546
H	L2	74	515
S	L3	80	556
H	L4	59	410
H	L5	74	515
S	R1	56	390
H	R2	60	416
H	R3	78	544
H	R4	71	498
S	R5	73	511
S	R6	85	594
H	T1	72	504
S	T2	88	615
S	T3	14	100
S	T4	95	659
H	T5	86	600
H	T6	54	377
		71	**491**

Appendix 10: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

1000 kPa, 30 min				1000 kPa, 60 mins			
Radial sections	Orientation	rel. absorption	Vol. retention	Radial sections	Orientation	rel. absorption	Vol. retention
S	L1	55	381	S	L1	91	632
H	L2	37	254	H	L2	71	493
H	L3	62	434	H	L3	83	581
H	L4	64	448	H	L4	88	614
S	L5	85	590	S	L5	43	301
H	L6	34	237	H	R1	78	544
S	R1	65	454	S	R2	87	609
H	R2	56	389	S	R3	80	556
H	R3	81	562	S	R4	98	683
S	R4	75	519	H	R5	40	282
S	R5	33	232	H	R6	67	468
S	R6	80	560	H	T1	82	571
S	T1	79	551	S	T2	41	287
H	T2	67	469	S	T3	90	626
H	T3	74	515	H	T4	79	550
H	T4	81	564	S	T5	45	316
S	T5	55	382	S	T6	74	513
		64	**444**			**73**	**507**

Appendix 10: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

1000 kPa, 120 mins

Radial sections	Orientation	rel. absorption	Vol. retention
S	L1	70	491
H	L2	93	651
H	L3	60	418
H	L4	92	641
H	L5	97	675
S	L6	60	417
H	R1	70	487
S	R2	61	427
H	R3	58	407
H	R4	90	628
S	R5	69	480
S	T1	73	509
S	T2	95	661
S	T3	59	414
H	T4	59	414
H	T5	69	477
H	T6	72	499
		73	**512**

1000 kPa, 240 mins

Radial sections	Orientation	rel. absorption	Vol. retention
S	L1	89	620
S	L2	64	445
H	L3	87	606
S	L4	85	591
H	L5	90	630
S	L6	54	376
H	R1	89	619
S	R2	96	666
H	R3	68	472
S	R4	54	378
H	R5	68	476
H	R6	74	516
S	T1	52	362
H	T2	69	481
H	T3	87	603
H	T4	65	455
S	T5	90	626
		75	**525**

Appendix 10: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

1200 kPa, 30 mins

Radial sections	Orientation	rel. absorption	Vol. retention
H	L1	33	227
S	L2	72	504
H	L3	87	608
S	L4	71	497
H	L5	80	555
H	R1	63	438
S	R2	81	562
S	R3	69	481
H	R4	82	574
S	R5	61	425
S	R6	75	520
S	T1	83	578
H	T2	75	520
H	T3	40	280
S	T4	81	561
S	T5	66	462
H	T6	72	504
		70	**488**

1200 kPa, 60 mins

Radial sections	Orientation	rel. absorption	Vol. retention
H	L1	42	293
H	L2	90	630
S	L3	76	531
H	L4	92	643
S	L5	72	503
H	L6	89	619
H	R1	90	624
S	R2	48	332
S	R3	86	599
H	R4	89	623
H	R5	89	619
H	T1	59	410
H	T2	59	413
S	T3	76	529
S	T4	72	500
H	T5	86	601
S	T6	72	502
		76	**528**

Appendix 10: Raw data of the volumetric retention (kg/m^3) and the relative absorption (%) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of 600 to 1200kPa and duration 30 to 240 mins

1200 kPa, 120 min				1200 kPa, 240 min			
Radial sections	Orientation	rel. absorption	Vol. retention	Radial sections	Orientation	rel. absorption	Vol. retention
S	L1	80	559	S	L1	78	542
H	L2	88	614	S	L2	74	514
S	L3	67	469	H	L3	81	566
S	L4	68	474	H	L4	77	536
H	L5	91	633	H	L5	68	476
H	R1	74	519	H	L6	91	634
H	R2	77	537	H	R1	77	535
H	R3	76	533	H	R2	92	639
S	R4	69	481	S	R3	80	560
H	R5	80	557	S	R4	84	584
H	R6	83	579	S	R5	71	496
S	T1	95	660	H	R6	100	693
H	T2	71	495	H	T1	79	549
H	T3	73	509	H	T2	71	496
S	T4	76	531	S	T3	78	543
S	T5	75	519	H	T4	79	550
H	T6	91	633	S	T5	86	599
		79	**547**			**80**	**560**

Appendix 11: Raw data of the percentage area penetrated (%) and the depth of penetration (mm) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of 600 kPa and duration 30 to 240 mins

	600 kPa, 30 mins				600 kPa 120 mins		
Radial sections	Orientation	% Area penetrated	Depth (mm)	Radial sections	Orientation	% Area penetrated	Depth (mm)
S	R1	15	4	S	L6	76	380
S	R4	20	5	S	R1	40	10
S	L3	10	50	S	R6	40	10
S	T1	10	3	S	T5	35	9
H	R2	15	4	S	T6	7	2
H	R5	20	5	H	L1	84	420
H	T4	25	6	H	R2	75	19
H	T6	50	13	H	R3	20	5
H	L4	44	220	H	T1	10	3
Mean		**23**	**34**	Mean		**43**	**95**

	600,60mins				600, 240mins		
Radial sections	Orientation	% Area penetrated	Depth (mm)	Radial sections	Orientation	% Area penetrated	Depth (mm)
S	L6	95	475	S	L1	90	450
S	R2	10	3	S	R4	60	15
S	R5	20	5	S	T3	10	3
S	T2	15	4	H	L4	63	315
S	T4	20	5	H	L5	80	400
H	L3	90	450	H	L6	84	420
H	R1	15	4	H	R3	40	10
H	R3	20	5	H	T2	5	1
H	T1	10	3	H	T6	30	8
Mean		**33**	**106**	Mean		**51**	**180**

Appendix 11: Raw data of the percentage area penetrated (%) and the depth of penetration (mm) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of 800 kPa and duration 30 to 240 mins

	800 kPa, 30 mins				800 kPa, 120 mins		
Radial sections	Orientation	% Area penetrated	Depth (mm)	Radial sections	Orientation	% Area penetrated	Depth (mm)
S	L1	48	240	S	L1	60	300
S	R3	20	5	S	L5	70	350
S	R4	15	4	S	R5	50	13
S	T2	10	3	S	T4	30	8
H	L4	87	435	S	T6	10	3
H	R1	50	13	H	L4	98	490
H	R6	10	3	H	L6	90	450
H	T4	29	7	H	R4	10	3
H	T5	40	10	H	T5	20	5
Mean		**34**	**80**	Mean		**49**	**180**

	800 kPa, 60 mins				800 kPa, 240 mins		
Radial sections	Orientation	% Area penetrated	Depth (mm)	Radial sections	Orientation	% Area penetrated	Depth (mm)
S	L1	30	150	S	L3	94	470
S	R1	50	13	S	R4	45	11
S	R4	40	10	S	R5	50	13
S	T6	35	9	S	T6	20	5
H	L3	94	470	H	L2	84	420
H	R2	20	5	H	L6	45	225
H	R6	60	15	H	R6	70	18
H	T1	40	10	H	T2	50	13
H	T2	10	2.5	H	T5	50	13
Mean		**42**	**76**	Mean		**56**	**132**

Appendix 11: Raw data of the percentage area penetrated (%) and the depth of penetration (mm) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of 1000 kPa and duration 30 to 240 mins

	1000 kPa, 30 mins				1000 kPa, 120 mins		
Radial sections	Orientation	% Area penetrated	Depth (mm)	Radial sections	Orientation	% Area penetrated	Depth (mm)
S	L1	80	400	S	L5	49	245
S	T2	20	5	S	L6	90	450
S	R4	20	5	S	T2	5	1.25
S	T1	25	6	S	T5	60	15
S	L3	40	200	H	L4	97	485
H	L4	89	445	H	L1	40	200
H	R2	5	1	H	R5	60	15
H	R6	40	10	H	T4	60	15
H	T4	48	12	H	T6	80	20
Mean		**41**	**121**	Mean		**60**	**161**

	1000 kPa, 60mins				1000 kPa, 240mins		
Radial sections	Orientation	% Area penetrated	Depth (mm)	Radial sections	Orientation	% Area penetrated	Depth (mm)
S	L1	45	225	S	L2	76	380
S	L2	50	250	S	L5	60	300
S	L4	72	360	S	R1	82	21
S	R4	25	6	S	T2	5	1
H	L6	86	430	S	T3	54	14
H	R1	65	16	H	L4	92	460
H	R6	30	8	H	L6	70	350
H	T2	30	8	H	R2	70	18
H	T3	95	24	H	T5	80	20
Mean		**55**	**147**	Mean		**65**	**174**

Appendix 11: Raw data of the percentage area penetrated (%) and the depth of penetration (mm) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of 1200 kPa and duration 30 to 240 mins

	1200 kPa, 30 mins		
Radial sections	Orientation	% Area penetrated	Depth (mm)
S	L5	30	150
S	R4	40	10
S	T5	35	9
S	T2	70	18
H	L1	86	430
H	R2	50	13
H	R3	55	14
H	R5	30	8
H	T6	60	15
Mean		**51**	**74**

	1200 kPa, 120 mins		
Radial sections	Orientation	% Area penetrated	Depth (mm)
S	L1	75	375
S	R4	40	10
S	T5	65	16.25
S	T6	50	12.5
H	L3	40	200
H	L4	84	420
H	R2	80	20
H	T2	60	15
H	T4	80	20
Mean		**64**	**121**

	1200kPa, 60 mins		
Radial sections	Orientation	% Area penetrated	Depth (mm)
S	R6	10	2.5
S	L5	89	445
S	R4	12	3
S	T3	90	22.5
H	L1	92	460
H	L4	93	465
H	R5	60	15
H	T4	20	5
H	T1	30	7.5
Mean		**55**	**158**

	1200 kPa, 240 mins		
Radial sections	Orientation	% Area penetrated	Depth (mm)
S	L4	92	460
S	L3	96	480
S	R2	25	6.25
S	T5	30	7.5
H	L1	96	480
H	L6	92	460
H	R4	70	17.5
H	R5	64	16
H	T4	65	16.25
Mean		**70**	**216**

Appendix 12: Raw data of the percentage area penetrated (%) and the depth of penetration (mm) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude of 600 kPa and duration 30 to 240 mins

	600kPa, 30mins		
Radial sections	Orientation	% area penetrated	Depth (mm)
H	L3	40	200
H	L5	30	150
H	R4	30	7.5
H	T6	55	13.75
S	L1	20	100
S	R5	30	7.5
S	R6	54	13.5
S	T2	35	8.75
S	T4	50	12.5
Mean		**38**	**57**

	600kPa, 60mins		
Radial sections	Orientation	% area penetrated	Depth (mm)
H	L3	28	140
H	R1	35	8.75
H	L5	40	200
H	T3	56	14
S	L6	30	150
S	R2	54	13.5
S	R4	50	12.5
S	T1	40	10
S	T2	15	3.75
Mean		**39**	**61**

	600,120mins		
Radial sections	Orientation	% area penetrated	Depth (mm)
H	L3	30	150
H	R5	50	12.5
H	R6	65	16.25
H	T2	50	12.5
H	T4	60	15
S	L5	65	325
S	R1	20	5
S	R4	60	15
S	T1	30	7.5
Mean		**48**	**62**

	600, 240mins		
Radial sections	Orientation	% area penetrated	Depth (mm)
H	L1	65	325
H	L3	76	380
H	R4	40	10
H	R5	20	5
H	T4	60	15
S	L5	80	400
S	T1	50	12.5
S	R6	60	15
S	T2	47	11.75
Mean		**55**	**130**

Appendix 12: Raw data of the percentage area penetrated (%) and the depth of penetration (mm) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of 800kPa and duration 30 to 240 mins

800kPa, 30mins

Radial sections	Orientation	% area penetrated	Depth (mm)
H	L1	50	250
H	R2	40	10
H	R3	25	6
H	T5	49	12
H	T6	54	14
S	L2	10	50
S	R4	49	12
S	T3	60	15
S	T1	20	5
Mean		**40**	**42**

800kPa, 60mins

Radial sections	Orientation	% area penetrated	Depth (mm)
H	L5	60	300
H	R2	30	7.5
H	R4	50	12.5
H	T1	60	15
H	T4	60	15
S	L2	45	225
S	R3	40	10
S	T5	40	10
S	L1	50	250
Mean		**48**	**94**

800kPa, 120mins

Radial sections	Orientation	% area penetrated	Depth (mm)
H	L3	80	400
H	L4	48	240
H	R3	64	16
H	T4	38	10
S	L1	70	350
S	R1	56	14
S	R6	50	13
S	T1	70	18
S	T3	30	8
Mean		**56**	**119**

800kPa, 240mins

Radial sections	Orientation	% area penetrated	Depth (mm)
H	L2	67	335
H	R5	54	14
H	R6	65	16
H	T3	60	15
S	L5	70	350
S	L6	50	250
S	R2	30	7.5
S	T1	79	20
S	T5	65	16
Mean		**60**	**114**

Appendix 12: Raw data of the percentage area penetrated (%) and the depth of penetration (mm) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of 1000kPa and duration 30 to 240 mins

1000kPa, 30min

Radial sections	Orientation	% area penetrated	Depth (mm)
H	L3	50	250
H	R1	40	10
H	T2	50	12.5
S	L1	35	175
S	L5	15	75
S	R4	45	11
S	T2	56	14
S	T3	65	16
S	R3	20	5
Mean		**42**	**63**

1000, 60mins

Radial sections	Orientation	% area penetrated	Depth (mm)
S	L2	75	375
S	L5	65	325
S	R2	60	15
S	T1	40	10
S	T4	30	8
H	L4	84	420
H	R1	67	17
H	T3	40	10
H	R6	40	10
Mean		**56**	**132**

1000, 120mins

Radial sections	Orientation	% area penetrated	Depth (mm)
S	L3	74	370
S	L5	76	380
S	R5	20	5
S	T1	54	14
H	L1	80	400
H	L6	98	490
H	R1	50	12.5
H	T2	65	16
H	T5	62	16
Mean		**64**	**189**

1000, 240mins

Radial sections	Orientation	% area penetrated	Depth (mm)
S	L1	64	320
S	L6	50	250
S	R5	84	21
S	T2	56	14
H	L4	90	450
H	R1	53	13
H	R4	70	18
H	T4	82	21
H	T6	49	12
Mean		**66**	**124**

Appendix 12: Raw data of the percentage area penetrated (%) and the depth of penetration (mm) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of at 1200kPa and duration 30 to 240 mins

1200kPa, 30mins				1200kPa, 120mins			
Radial sections	Orientation	% area penetrated	Depth (mm)	Radial sections	Orientation	% area penetrated	Depth (mm)
S	L1	55	275	S	L1	70	350
S	L4	62	310	S	R2	50	13
S	R4	50	12.5	S	R1	89	22
S	T4	50	12.5	S	T3	50	13
S	T5	76	19	H	L2	65	325
H	L3	60	300	H	L5	92	460
H	R1	60	15	H	R4	69	17
H	R6	40	10	H	T1	62	16
H	T1	60	15	H	T2	50	13
Mean		**57**	**108**	Mean		**66**	**136**

1200kPa, 60mins				1200kPa, 240mins			
Radial sections	Orientation	% area penetrated	Depth (mm)	Radial sections	Orientation	% area penetrated	Depth (mm)
H	L4	70	350	S	L1	79	395
H	R4	67	17	S	L4	92	460
H	T1	60	15	S	R4	60	15
H	T3	60	15	S	T1	80	20
S	L3	89	445	H	L3	80	400
S	R3	54	14	H	L2	90	450
S	T4	50	13	H	R2	65	16
S	R2	50	13	H	T2	70	18
S	L2	50	250	H	R5	50	13
Mean		**61**	**126**	Mean		**74**	**198**

Appendix 13: Raw data of the oxide retention (kg/m^3) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of at 600 to 1200kPa and duration 30 to 240 mins

600 kPa, 30 mins

	CRO_3	CUO	AS_2O_5	Total
LH	0.51	0.17	0.36	
TH	0.61	0.23	0.39	
RH	0.96	0.38	0.55	
Mean	0.69	0.26	0.43	**1.39**
RS	0.78	0.30	0.51	
LS	0.47	0.16	0.36	
TS	0.82	0.32	0.52	
Mean	0.69	0.26	0.46	**1.41**

600 kPa, 60 mins

	CRO_3	CUO	AS_2O_5	Total
LH	0.83	0.23	0.45	
TH	0.84	0.31	0.48	
RH	0.71	0.31	0.45	
Mean	0.79	0.28	0.46	**1.54**
RS	0.84	0.34	0.53	
LS	0.52	0.16	0.36	
TS	0.80	0.35	0.54	
Mean	0.72	0.28	0.48	**1.48**

600 kPa, 120 mins

	CRO_3	CUO	AS_2O_5	Total
LH	0.50	0.15	0.35	
TH	1.15	0.42	0.69	
RH	1.10	0.44	0.66	
Mean	0.92	0.34	0.57	**1.82**
RS	0.97	0.37	0.55	
LS	0.60	0.19	0.38	
TS	0.79	0.33	0.49	
Mean	0.79	0.30	0.472	**1.56**

600 kPa, 240 mins

	CRO_3	CUO	AS_2O_5	Total
LH	0.84	0.20	0.48	
TH	1.01	0.37	0.56	
RH	1.13	0.46	0.67	
Mean	0.99	0.34	0.57	**1.91**
RS	0.99	0.42	0.63	
LS	0.60	0.17	0.39	
TS	1.13	0.43	0.64	
Mean	0.91	0.34	0.55	**1.80**

800 kPa, 30mins

	CRO_3	CUO	AS_2O_5	Total
LH	0.42	0.15	0.30	
TH	0.79	0.30	0.45	
RH	0.96	0.39	0.56	
Mean	0.72	0.28	0.44	**1.44**
RS	0.85	0.37	0.53	
LS	0.32	0.14	0.30	
TS	0.98	0.45	0.63	
Mean	0.72	0.32	0.49	**1.52**

800 kPa, 60mins

	CRO_3	CUO	AS_2O_5	Total
LH	0.92	0.27	0.52	
TH	1.29	0.43	0.64	
RH	1.03	0.35	0.55	
Mean	1.08	0.35	0.57	**2.00**
RS	0.74	0.29	0.51	
LS	0.74	0.23	0.45	
TS	0.81	0.39	0.55	
Mean	0.76	0.30	0.50	**1.57**

Appendix 13: Raw data of the oxide retention (kg/m^3) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of at 600 to 1200kPa and duration 30 to 240 mins

			800kPa, 120mins					800kPa, 240mins	
	CRO_3	CUO	AS_2O_5	Total		CRO_3	CUO	AS_2O_5	Total
LH	1.07	0.31	0.57		LH	0.52	0.14	0.33	
TH	1.12	0.43	0.62		TH	1.35	0.52	0.80	
RH	0.95	0.36	0.57		RH	1.31	0.44	0.69	
Mean	1.05	0.37	0.59	**2.00**	Mean	1.06	0.37	0.61	**2.03**
RS	1.14	0.41	0.61		RS	0.97	0.39	0.63	
LS	0.62	0.18	0.41		LS	0.89	0.19	0.47	
TS	1.03	0.38	0.59		TS	1.23	0.46	0.76	
Mean	0.93	0.32	0.54	**1.79**	Mean	1.03	0.35	0.62	**2.00**

			1000kPa, 30mins					1000kPa, 60mins	
	CRO_3	CUO	AS_2O_5	Total		CRO_3	CUO	AS_2O_5	Total
LH	0.44	0.15	0.32		LH	0.93	0.27	0.50	
TH	0.79	0.31	0.49		TH	1.17	0.43	0.67	
RH	1.02	0.45	0.64		RH	1.11	0.44	0.66	
Mean	0.75	0.30	0.48	**1.54**	Mean	1.07	0.38	0.61	**2.06**
RS	0.85	0.36	0.56		RS	0.97	0.36	0.58	
LS	1.18	0.42	0.72		LS	0.81	0.30	0.53	
TS	0.63	0.31	0.45		TS	1.10	0.47	0.68	
Mean	0.89	0.36	0.58	**1.83**	Mean	1.02	0.38	0.60	**2.00**

			1000kPa, 120mins					1000kPa, 240mins	
	CRO_3	CUO	AS_2O_5	Total		CRO_3	CUO	AS_2O_5	Total
LH	1.12	0.26	0.58		LH	1.06	0.30	0.55	
TH	1.23	0.37	0.65		TH	1.17	0.40	0.61	
RH	0.99	0.38	0.61		RH	1.21	0.44	0.64	
Mean	1.11	0.34	0.61	**2.06**	Mean	1.15	0.38	0.60	**2.13**
RS	1.10	0.42	0.61		RS	1.18	0.44	0.68	
LS	1.01	0.37	0.65		LS	1.09	0.23	0.59	
TS	0.94	0.36	0.56		TS	1.01	0.31	0.57	
Mean	1.02	0.38	0.61	**2.01**	Mean	1.09	0.33	0.61	**2.03**

Appendix 13: Raw data of the oxide retention (kg/m^3) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of at 600 to 1200kPa and duration 30 to 240 mins

	1200 kPa, 30mins				1200 kPa, 60mins			
	CRO_3	CUO	AS_2O_5	Total	CRO_3	CUO	AS_2O_5	Total
LH	0.69	0.22	0.45		1.14	0.29	0.58	
TH	1.07	0.54	0.71		0.98	0.39	0.61	
RH	1.10	0.37	0.57		1.33	0.44	0.73	
Mean	0.95	0.38	0.58	**1.91**	1.15	0.37	0.64	**2.16**
RS	1.48	0.44	0.74		1.11	0.39	0.66	
LS	0.47	0.14	0.34		0.83	0.19	0.49	
TS	1.16	0.46	0.74		0.86	0.40	0.60	
Mean	1.04	0.35	0.61	**1.99**	0.93	0.33	0.58	**1.84**

	1200 kPa, 120 mins				1200 kPa, 240 mins			
	CRO_3	CUO	AS_2O_5	Total	CRO_3	CUO	AS_2O_5	Total
LH	1.08	0.34	0.59		0.78	0.19	0.45	
TH	1.38	0.50	0.71		1.36	0.46	0.69	
RH	1.17	0.45	0.64		1.51	0.61	0.82	
Mean	1.21	0.43	0.65	**2.29**	1.22	0.42	0.65	**2.29**
RS	1.28	0.48	0.73		1.23	0.46	0.70	
LS	1.05	0.37	0.60		0.99	0.28	0.57	
TS	1.09	0.34	0.61		1.29	0.43	0.69	
Mean	1.14	0.40	0.65	**2.18**	1.17	0.39	0.65	**2.21**

Appendix 14: Raw data of the oxide retention (kg/m^3) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of at 600 to 1200kPa and duration 30 to 240 mins

600 kPa, 30 mins

	CRO_3	CUO	AS_2O_5	Total
TS	1.28	0.50	0.69	
LS	0.30	0.12	0.23	
RS	1.35	0.47	0.65	
mean	0.98	0.36	0.52	**1.86**
LH	0.84	0.39	0.57	
RH	0.99	0.45	0.63	
TH	0.84	0.42	0.55	
Mean	0.89	0.42	0.58	**1.89**

600 kPa 60 mins

	CRO_3	CUO	AS_2O_5	Total
TS	1.02	0.36	0.61	
LS	0.73	0.24	0.44	
RS	1.27	0.52	0.74	
Mean	1.01	0.37	0.60	**1.98**
LH	0.85	0.37	0.57	
RH	0.99	0.52	0.68	
TH	0.95	0.54	0.66	
Mean	0.93	0.48	0.64	**2.04**

600 kPa, 120 min

	CRO_3	CUO	AS_2O_5	Total
TS	1.49	0.60	0.83	
LS	0.35	0.11	0.25	
RS	1.27	0.58	0.80	
Mean	1.04	0.43	0.63	**2.09**
RH	0.91	0.39	0.54	
TH	1.42	0.62	0.83	
LH	0.92	0.30	0.50	
Mean	1.08	0.44	0.62	**2.14**

600 kPa, 240 min

	CRO_3	CUO	AS_2O_5	Total
TS	1.21	0.49	0.69	
LS	1.37	0.51	0.79	
RS	1.05	0.43	0.58	
Mean	1.21	0.48	0.69	**2.37**
RH	1.43	0.62	0.74	
TH	1.30	0.51	0.70	
LH	0.83	0.25	0.38	
Mean	1.19	0.46	0.61	**2.2.25**

800 kPa, 30 mins

	CRO_3	CUO	AS_2O_5	Total
RS	0.70	0.32	0.44	
LS	0.86	0.31	0.57	
TS	1.29	0.63	0.77	
Mean	0.95	0.42	0.59	**1.96**
LH	0.70	0.22	0.37	
RH	1.18	0.48	0.64	
TH	1.33	0.49	0.64	
Mean	1.07	0.40	0.55	**2.01**

800 kPa 60 mins

	CRO_3	CUO	AS_2O_5	Total
RS	1.27	0.65	0.80	
LS	0.72	0.19	0.41	
TS	1.19	0.60	0.79	
Mean	1.06	0.48	0.67	**2.20**
LH	0.86	0.36	0.57	
RH	1.08	0.53	0.68	
TH	1.15	0.48	0.63	
Mean	1.03	0.46	0.63	**2.11**

800 kPa, 120 min

	CRO_3	CUO	AS_2O_5	Total
RS	1.43	0.81	0.97	
LS	0.69	0.21	0.38	
TS	1.01	0.53	0.65	
Mean	1.04	0.52	0.67	**2.23**
LH	1.34	0.30	0.64	
RH	1.10	0.51	0.68	
TH	0.98	0.42	0.58	
Mean	1.14	0.41	0.63	**2.18**

800 kPa, 240 min

	CRO_3	CUO	AS_2O_5	Total
RS	1.30	0.54	0.77	
LS	1.12	0.39	0.65	
TS	1.19	0.52	0.74	
Mean	1.20	0.48	0.72	**2.41**
LH	0.97	0.40	0.60	
RH	1.26	0.46	0.74	
TH	1.17	0.55	0.69	
Mean	1.13	0.47	0.68	**2.28**

1000kPa 30 mins

	CRO_3	CUO	AS_2O_5	Total
RS	1.47	0.63	0.87	
LS	0.26	0.11	0.21	
TS	1.42	0.58	0.79	
Mean	1.05	0.44	0.62	**2.11**
RH	1.15	0.51	0.69	
TH	0.89	0.46	0.59	
LH	0.90	0.32	0.55	
Mean	0.98	0.43	0.61	**2.02**

1000kPa 60 mins

	CRO_3	CUO	AS_2O_5	Total
RS	1.05	0.52	0.66	
LS	0.75	0.25	0.45	
TS	1.44	0.61	0.91	
Mean	1.08	0.46	0.67	**2.21**
RH	1.05	0.51	0.66	
TH	1.36	0.50	0.80	
LH	0.79	0.27	0.49	
Mean	1.07	0.43	0.65	**2.14**

1000 kPa 120 mins

	CRO_3	CUO	AS_2O_5	Total
RS	1.30	0.52	0.77	
LS	1.07	0.32	0.61	
TS	1.13	0.48	0.66	
Mean	1.17	0.44	0.68	**2.29**
RH	1.20	0.59	0.70	
TH	1.35	0.56	0.77	
LH	1.04	0.33	0.58	
Mean	1.20	0.49	0.68	**2.37**

1000 kPa 240 mins

	CRO_3	CUO	AS_2O_5	Total
RS	2.05	0.87	1.06	
LS	0.49	0.18	0.30	
TS	1.21	0.62	0.75	
Mean	1.25	0.56	0.70	**2.51**
RH	1.48	0.58	0.87	
TH	1.32	0.55	0.80	
LH	0.88	0.33	0.57	
Mean	1.23	0.49	0.75	**2.46**

			1200,30					1200, 60	
	CRO_3	CUO	AS_2O_5	Total		CRO_3	CUO	AS_2O_5	Total
RS	1.07	0.60	0.75		RS	1.14	0.50	0.74	
LS	0.87	0.29	0.51		LS	1.13	0.34	0.62	
TS	1.21	0.56	0.74		TS	1.32	0.56	0.83	
Mean	1.05	0.48	0.67	**2.20**	Mean	1.20	0.47	0.73	**2.39**
RH	1.11	0.49	0.70		RH	1.05	0.63	0.77	
TH	1.09	0.62	0.75		TH	1.00	0.55	0.73	
LH	0.82	0.30	0.51		LH	0.84	0.31	0.56	
Mean	1.00	0.47	0.65	**2.13**	Mean	0.96	0.50	0.69	**2.15**

			1200, 120					1200, 240	
	CRO_3	CUO	AS_2O_5	Total		CRO_3	CUO	AS_2O_5	Total
RS	1.43	0.63	0.92		RS	1.68	0.76	0.98	
LS	1.20	0.47	0.72		LS	1.29	0.33	0.59	
TS	1.51	0.75	0.93		TS	2.05	0.80	1.15	
Mean	1.38	0.62	0.86	**2.85**	Mean	1.67	0.63	0.91	**3.21**
RH	1.82	0.79	1.11		RH	1.58	0.62	0.91	
TH	1.09	0.49	0.66		TH	1.77	0.82	1.06	
LH	1.19	0.45	0.72		LH	1.43	0.50	0.87	
Mean	1.37	0.58	0.83	**2.77**	Mean	1.59	0.65	0.95	**3.19**

Appendix 15: Raw data of the preservative oxide balance (%) in the treated wood of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of at 600 to 1200kPa and duration 30 to 240 mins

		600 kPa, 30 mins					600 kPa, 60 mins		
	CRO_3	CUO	AS_2O_5	Total		CRO_3	CUO	AS_2O_5	Total
RS	51.3	19.4	29.2	99.9	RS	48.9	19.8	31.3	100.0
RH	50.1	20.4	29.5	100.0	RH	48.6	21.0	30.4	100.0
TS	49.0	20.5	30.5	100.0	TS	47.4	20.6	32.0	100.0
TH	51.2	19.5	29.3	100.0	TH	51.7	18.9	29.4	100.0
LS	51.3	15.9	32.8	100.0	LS	50.1	15.5	34.3	99.9
LH	47.7	17.5	34.9	100.0	LH	55.0	15.3	29.7	100.0
Mean	50.1	18.9	31.0	**100.0**	Mean	50.3	18.5	31.2	**100.0**

600 kPa 120 min

	CRO_3	CUO	AS_2O_5	Total
RS	48.5	21.0	30.4	99.9
RH	49.9	20.4	29.7	100.0
TS	47.5	21.8	30.7	100.0
TH	51.9	19.3	28.8	100.0
LS	42.3	18.8	38.9	100.0
LH	55.2	13.3	31.5	100.0
Mean	49.2	19.1	31.7	**100.0**

600 kPa 240 mins

	CRO_3	CUO	AS_2O_5	Total
RS	48.5	20.8	30.7	100.0
RH	50.1	20.0	29.9	100.0
TS	51.3	19.5	29.2	100.0
TH	50.8	18.8	30.4	100.0
LS	51.7	14.5	33.9	100.0
LH	49.9	15.4	34.7	100.0
Mean	50.4	18.2	31.5	**100.0**

800 kPa,
30 mins

	CRO_3	CUO	AS_2O_5	Total
RS	51.7	19.6	28.7	100.0
RH	50.8	20.1	29.1	100.0
TS	50.6	19.4	30.0	100.0
TH	49.9	18.4	31.7	100.0
LS	49.6	18.3	32.1	100.0
LH	49.0	16.6	34.5	100.0
Mean	50.3	18.7	31.0	**100.0**

800 kPa,
60 mins

	CRO_3	CUO	AS_2O_5	Total
RS	47.9	18.8	33.3	100.0
RH	53.3	18.0	28.8	100.0
TS	46.3	22.3	31.4	100.0
TH	54.6	18.2	27.2	100.0
LS	51.8	16.6	31.6	100.0
LH	54.1	15.6	30.3	100.0
Mean	51.3	18.3	30.4	**100.0**

800 kPa,
120 mins

	CRO_3	CUO	AS_2O_5	Total
RS	49.0	18.8	32.2	100.0
RH	52.7	19.4	27.9	100.0
TS	49.4	19.2	31.4	100.0
TH	53.7	18.5	27.8	100.0
LS	47.5	16.4	36.0	99.9
LH	55.6	15.5	28.8	99.9
Mean	51.3	18.0	30.7	**100.0**

800 kPa
240 mins

	CRO_3	CUO	AS_2O_5	Total
RS	51.4	19.1	29.5	100.0
RH	53.6	18.1	28.3	100.0
TS	53.3	16.6	30.2	100.0
TH	50.6	19.5	30.0	100.0
LS	57.0	11.9	31.1	100.0
LH	52.4	14.4	33.2	100.0
Mean	53.1	16.6	30.4	**100.0**

1000kPa
30 mins

	CRO_3	CUO	AS_2O_5	Total
RS	52.8	19.0	28.2	100.0
RH	53.9	18.1	28.0	100.0
TS	51.6	18.8	29.6	100.0
TH	46.1	23.2	30.6	99.9
LS	51.5	14.9	33.6	100.0
LH	50.5	16.2	33.3	100.0
Mean	51.1	18.4	30.6	**100.0**

1000kPa,
60 mins

	CRO_3	CUO	AS_2O_5	Total
RS	48.1	20.2	31.7	100.0
RH	51.6	20.1	28.4	100.0
TS	45.1	22.2	32.7	100.0
TH	53.2	19.3	27.4	99.9
LS	51.0	18.0	31.1	100.0
LH	53.8	16.9	29.3	100.0
Mean	50.5	19.5	30.1	**100.0**

1000 kPa
120 mins

	CRO_3	CUO	AS_2O_5	Total
RS	51.4	19.4	29.2	100.0
RH	53.3	17.4	29.9	100.6
TS	53.5	16.6	29.9	100.0
TH	49.7	19.5	30.8	100.0
LS	52.0	18.3	29.7	100.0
LH	56.6	14.6	28.8	100.0
Mean	52.8	17.6	29.7	**100.1**

1000 kPa,
240 mins

	CRO_3	CUO	AS_2O_5	Total
RS	51.4	17.9	30.6	99.9
RH	51.3	20.8	27.9	100.0
TS	46.3	21.4	32.4	100.1
TH	54.1	18.5	27.4	100.0
LS	54.9	12.8	32.4	100.1
LH	55.0	13.6	31.4	100.0
Mean	52.2	17.5	30.4	**100.0**

1200 kPa
30 mins

	CRO_3	CUO	AS_2O_5	Total
RS	51.2	19.3	29.3	99.8
RH	48.4	21.4	30.2	100.0
TS	53.5	17.7	28.8	100.0
TH	49.9	19.4	30.8	100.0
LS	53.8	15.5	30.8	100.0
LH	48.9	16.4	34.8	100.0
Mean	51.0	18.3	30.8	**100.0**

1200 kPa
60 mins

	CRO_3	CUO	AS_2O_5	Total
RS	55.7	16.6	27.7	100.0
RH	50.3	19.8	29.9	100.0
TS	49.2	19.6	31.3	100.0
TH	51.6	19.0	29.4	100.0
LS	49.2	15.1	35.7	100.0
LH	54.7	15.7	29.6	100.0
Mean	51.8	17.6	30.6	**100.0**

	1200 kPa, 120 mins					1200 kPa, 240 mins			
	CRO_3	CUO	AS_2O_5	Total		CRO_3	CUO	AS_2O_5	Total
RS	50.7	18.8	30.4	99.9	RS	50.9	18.9	30.1	99.9
RH	50.5	19.1	30.5	100.0	RH	50.0	19.0	31.0	100.0
TS	49.0	20.9	30.2	100.0	TS	50.3	18.9	30.8	100.0
TH	51.4	19.8	28.8	100.0	TH	54.7	16.5	28.8	100.0
LS	49.3	18.4	32.3	100.0	LS	57.2	12.4	30.4	100.0
LH	54.8	15.9	29.2	99.9	LH	57.2	13	29.8	100.0
Mean	51.0	18.8	30.2	**100.0**	Mean	53.4	16.5	30.2	**100.0**

Appendix 16: Raw data of the preservative oxide balance (%) in the treated wood of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of at 600 to 1200kPa and duration 30 to 240 mins

	600 kPa, 30 min					600 kPa, 60 mins			
	CRO_3	CUO	AS_2O_5	Total		CRO_3	CUO	AS_2O_5	Total
RS	54.5	19.1	26.4	100.0	RS	49.1	22.3	28.7	100.0
RH	51.1	20.9	28	100.0	RH	48.2	23.6	28.1	99.9
TS	51.9	20.3	27.8	100.0	TS	51.2	20.0	28.8	100.0
TH	54.1	19.9	26	100.0	TH	50.6	20.8	28.6	100.0
LS	47.0	17.8	35.2	100.0	LS	58.6	14.9	26.6	100.0
LH	54.3	17.0	28.7	100.0	LH	53.3	170	29.7	100.0
Mean	52.2	19.2	28.7	**100.0**	Mean	51.8	19.8	28.4	**100.0**

	600kPa 120min					600kPa, 240mins			
	CRO_3	CUO	AS_2O_5	Total		CRO_3	CUO	AS_2O_5	Total
RS	44.2	24.9	30.9	100.0	RS	48.0	21.1	30.9	100.0
RH	49.1	21.5	29.4	100.0	RH	48.1	22.3	29.6	100.0
TS	48.1	22.5	29.5	100.0	TS	47.3	23.5	29.2	100.0
TH	46	23.8	30.2	100.0	TH	49.7	21.0	29.2	99.9
LS	51.9	17.5	30.7	100.0	LS	50.2	19.7	30.1	100.0
LH	50.7	18.1	31.1	99.9	LH	58.9	13.1	28.0	100.0
Mean	48.3	21.4	30.3	**100.0**	Mean	50.4	20.1	29.5	**100.0**

		800kPa 30min		
	CRO_3	CUO	AS_2O_5	Total
RS	51.5	22	26.5	100.0
RH	49.6	21.2	29.2	100.0
TS	46.9	24.0	29.1	100.0
TH	49.5	21.7	28.8	100.0
LS	50.3	18.5	31.2	100.0
LH	53.4	17.5	29.1	100.0
Mean	50.2	20.8	29.0	**100.0**

		800kPa, 60mins		
	CRO_3	CUO	AS_2O_5	Total
RS	50.2	20.2	29.7	100.0
RH	47.2	23.1	29.7	100.0
TS	49.6	21.3	29.0	99.9
TH	50.8	21.1	28.1	100.0
LS	53.4	15.9	30.6	99.9
LH	47.9	20.3	31.8	100.0
Mean	49.9	20.3	29.8	**100.0**

		800kPa 120min		
	CRO_3	CUO	AS_2O_5	Total
RS	47.9	21.9	30.2	100.0
RH	48.1	21.4	30.5	100.0
TS	47.9	23.6	28.5	100.0
TH	44.2	25.1	30.7	100.0
LS	49.4	18.0	32.6	100.0
LH	50.4	18.2	31.4	100.0
Mean	48.0	21.4	30.7	**100.0**

		800kPa, 240min		
	CRO_3	CUO	AS_2O_5	Total
RS	48.1	20.9	31.1	100.0
RH	45.2	23.9	30.9	100.0
TS	48.8	20.7	30.6	100.0
TH	44.3	25.2	30.5	100.0
LS	54.2	16.2	29.6	100.0
LH	47.7	20.6	31.8	100.0
Mean	48.1	21.3	30.8	**100.0**

		1000kPa, 30 min		
	CRO_3	CUO	AS_2O_5	Total
RS	51.0	20.7	28.3	100.0
RH	51.2	22.1	26.7	100.0
TS	50.7	20.4	28.9	100.0
TH	51.7	20.5	27.8	100.0
LS	51.3	19.0	29.7	100.0
LH	57.0	16.8	26.2	100.0
Mean	52.2	19.9	27.9	**100.0**

		1000kPa, 60 mins		
	CRO_3	CUO	AS_2O_5	Total
RS	46.7	23.9	29.4	100.0
RH	49.0	21.2	29.9	100.0
TS	46.1	23.3	30.7	100.0
TH	48.5	21.8	29.7	100.0
LS	54.7	14.1	31.2	100.0
LH	50.2	19.2	30.5	99.9
Mean	49.2	20.6	30.2	**100.0**

		1000 kPa, 120 mins		
	CRO_3	CUO	AS_2O_5	Total
RS	47.0	23.4	29.6	100.0
RH	51.2	18.7	30	99.9
TS	48.6	20.6	30.8	100.0
TH	48.6	23.0	28.5	100.0
LS	51.5	17.3	31.2	100.0
LH	49.0	20.5	30.5	100.0
Mean	49.3	20.6	30.1	**100.0**

		1000 kPa, 240 mins		
	CRO_3	CUO	AS_2O_5	Total
RS	47.9	22	30.1	100
RH	47.1	23	29.9	100
TS	51.1	20.6	28.3	100
TH	51.2	18.8	30	100
LS	48.9	15.7	35.4	100
LH	51.1	17.4	31.6	100
Mean	49.6	19.6	30.9	**100**

		1200kPa 30 min		
	CRO_3	CUO	AS_2O_5	Total
RS	49.7	20.8	29.5	100.0
RH	50.9	19.8	29.3	100.0
TS	48.4	21.4	30.2	100.0
TH	48.4	22.6	29	100.0
LS	52.0	18.1	29.9	100.0
LH	51.1	18.0	30.9	100.0
Mean	50.1	20.1	29.8	**100.0**

		1200kPa, 60min		
	CRO_3	CUO	AS_2O_5	Total
RS	50.2	20.4	29.3	99.9
RH	50.5	19.9	29.6	100.0
TS	51.3	18.0	30.7	100.0
TH	49.3	20.8	29.9	100.0
LS	51.8	16.9	31.3	100.0
LH	49.5	18.4	32.1	100.0
Mean	50.4	19.1	30.5	**100.0**

		1200 kPa, 120 min		Total
	CRO_3	CUO	AS_2O_5	Sum
RS	44.5	25.2	30.3	100.0
RH	42.9	25.8	31.3	100.0
TS	46.1	24.3	29.6	100.0
TH	43.8	24	32.2	100.0
LS	53.9	16.3	29.8	100.0
LH	49.5	17.9	32.6	100.0
Mean	46.8	22.3	31.0	**100.0**

		1200 kPa, 240 min		
	CRO_3	CUO	AS_2O_5	Total
RS	49.6	21.1	29.3	100.0
RH	47.8	21.6	30.6	100.0
TS	50.8	20.9	28.4	100.0
TH	46.3	23.3	30.4	100.0
LS	44.8	19.2	36.0	100.0
LH	46.6	21.5	31.9	100.0
Mean	47.7	21.3	31.1	**100.0**

Appendix 17: Raw data of the oxide retention (kg/m^3) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of at 600 to 1200kPa and duration 30 to 240 mins

		600 kPa, 30 mins		Total
	CRO3	CUO	AS205	
LH	0.84	0.39	0.57	
LS	0.30	0.12	0.23	
Mean	**0.57**	**0.26**	**0.40**	**1.23**
RH	0.99	0.45	0.63	
RS	1.35	0.47	0.65	
Mean	**1.17**	**0.46**	**0.64**	**2.27**
TH	0.84	0.42	0.55	
TS	1.28	0.50	0.69	
Mean	**1.06**	**0.46**	**0.62**	**2.14**

		600 kPa, 60 mins		
	CRO3	CUO	AS205	Total
LH	0.85	0.37	0.57	
LS	0.73	0.24	0.44	
Mean	**0.79**	**0.31**	**0.51**	**1.60**
RH	0.99	0.52	0.68	
RS	1.27	0.52	0.74	
Mean	**1.13**	**0.52**	**0.71**	**2.36**
TH	0.95	0.54	0.66	
TS	1.02	0.36	0.61	
Mean	**0.99**	**0.45**	**0.64**	**2.07**

		600 kPa, 120 mins		
	CRO3	CUO	AS205	Total
LH	0.92	0.30	0.50	
LS	0.35	0.11	0.25	
Mean	**0.64**	**0.21**	**0.38**	**1.22**
RH	0.91	0.39	0.54	
RS	1.27	0.58	0.80	
Mean	**1.09**	**0.49**	**0.67**	**2.25**
TH	1.42	0.62	0.83	
TS	1.49	0.60	0.83	
Mean	**1.46**	**0.61**	**0.83**	**2.90**

		600 kPa, 240 mins		
	CRO3	CUO	AS205	Total
LH	0.83	0.25	0.38	
LS	1.37	0.51	0.79	
Mean	**1.10**	**0.38**	**0.59**	**2.07**
RH	1.43	0.62	0.74	
RS	1.05	0.43	0.58	
Mean	**1.24**	**0.53**	**0.66**	**2.43**
TH	1.30	0.51	0.70	
TS	1.21	0.49	0.69	
Mean	**1.26**	**0.50**	**0.70**	**2.45**

		800 kPa, 30 mins		
	CRO3	CUO	AS205	Total
LH	0.70	0.22	0.37	
LS	0.86	0.31	0.57	
Mean	**0.78**	**0.27**	**0.47**	**1.52**
RH	1.18	0.48	0.64	
RS	0.70	0.32	0.44	
Mean	**0.94**	**0.40**	**0.54**	**1.88**
TH	1.33	0.49	0.64	
TS	1.29	0.63	0.77	
Mean	**1.31**	**0.56**	**0.71**	**2.58**

		800 kPa, 60 mins		
	CRO3	CUO	AS205	total
LH	0.86	0.36	0.57	
LS	0.72	0.19	0.41	
Mean	**0.79**	**0.28**	**0.49**	**1.56**
RH	1.08	0.53	0.68	
RS	1.27	0.65	0.80	
Mean	**1.18**	**0.59**	**0.74**	**2.51**
TH	1.15	0.48	0.63	
TS	1.19	0.60	0.79	
Mean	**1.17**	**0.54**	**0.71**	**2.42**

Appendix 17: Raw data of the oxide retention (kg/m^3) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of at 600 to 1200kPa and duration 30 to 240 mins

	800 kPa, 120 mins			
	CRO3	CUO	AS205	Total
LH	1.34	0.30	0.64	
LS	0.69	0.21	0.38	
Mean	**1.02**	**0.26**	**0.51**	**1.78**
RH	1.10	0.51	0.68	
RS	1.43	0.81	0.97	
Mean	**1.27**	**0.66**	**0.83**	**2.75**
TH	0.98	0.42	0.58	
TS	1.01	0.53	0.65	
Mean	**1.00**	**0.48**	**0.62**	**2.09**

	800 kPa, 240 mins			
	CRO3	CUO	AS205	Total
LH	0.97	0.40	0.60	
LS	1.12	0.39	0.65	
Mean	**1.05**	**0.40**	**0.63**	**2.07**
RH	1.26	0.46	0.74	
RS	1.30	0.54	0.77	
Mean	**1.28**	**0.50**	**0.76**	**2.54**
TH	1.17	0.55	0.69	
TS	1.19	0.52	0.74	
Mean	**1.18**	**0.54**	**0.72**	**2.43**

	1000 kPa,30 mins			
	CRO3	CUO	AS205	Total
LH	0.90	0.32	0.55	
LS	0.26	0.11	0.21	
Mean	**0.58**	**0.22**	**0.38**	**1.18**
RH	1.15	0.51	0.69	
RS	1.47	0.63	0.87	
Mean	**1.31**	**0.57**	**0.78**	**2.66**
TH	0.89	0.46	0.59	
TS	1.42	0.58	0.79	
Mean	**1.16**	**0.52**	**0.69**	**2.37**

	1000 kPa, 60 mins			
	CRO3	CUO	AS205	Total
LH	0.79	0.27	0.49	
LS	0.75	0.25	0.45	
Mean	**0.77**	**0.26**	**0.47**	**1.50**
RH	1.05	0.51	0.66	
RS	1.05	0.52	0.66	
Mean	**1.05**	**0.52**	**0.66**	**2.23**
TH	1.36	0.50	0.80	
TS	1.44	0.61	0.91	
Mean	**1.40**	**0.56**	**0.86**	**2.81**

	1000 kPa, 120 mins			
	CRO3	CUO	AS205	Total
LH	1.04	0.33	0.58	
LS	1.07	0.32	0.61	
Mean	**1.06**	**0.33**	**0.60**	**1.98**
RH	1.20	0.59	0.70	
RS	1.30	0.52	0.77	
Mean	**1.25**	**0.56**	**0.74**	**2.54**
TH	1.35	0.56	0.77	
TS	1.13	0.48	0.66	
Mean	**1.24**	**0.52**	**0.72**	**2.48**

	1000 kPa, 240 mins			
	CRO3	CUO	AS205	Total
LH	0.88	0.33	0.57	
LS	0.49	0.18	0.30	
Mean	**0.69**	**0.26**	**0.44**	**1.38**
RH	1.48	0.58	0.87	
RS	2.05	0.87	1.06	
Mean	**1.77**	**0.73**	**0.97**	**3.46**
TH	1.32	0.55	0.80	
TS	1.21	0.62	0.75	
Mean	**1.27**	**0.59**	**0.78**	**2.63**

Appendix 17: Raw data of the oxide retention (kg/m^3) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Ficus sur* at pressure magnitude range of at 600 to 1200kPa and duration 30 to 240 mins

1200 kPa, 30 mins

	CRO3	CUO	AS205	Total
LH	0.82	0.30	0.51	
LS	0.87	0.29	0.51	
Mean	**0.85**	**0.30**	**0.51**	**1.65**
RH	1.11	0.49	0.70	
RS	1.07	0.60	0.75	
Mean	**1.09**	**0.55**	**0.73**	**2.36**
TH	1.09	0.62	0.75	
TS	1.21	0.56	0.74	
Mean	**1.15**	**0.59**	**0.75**	**2.49**

1200 kPa, 60 mins

	CRO3	CUO	AS205	Total
LH	0.84	0.31	0.56	
LS	1.13	0.34	0.62	
Mean	**0.99**	**0.33**	**0.59**	**1.90**
RH	1.05	0.63	0.77	
RS	1.14	0.50	0.74	
Mean	**1.10**	**0.57**	**0.76**	**2.42**
TH	1.00	0.55	0.73	
TS	1.32	0.56	0.83	
Mean	**1.16**	**0.56**	**0.78**	**2.50**

1200 kPa, 120 mins

	CRO_3	CUO	AS_20_5	Total
LH	1.19	0.45	0.72	
LS	1.20	0.47	0.72	
Mean	**1.20**	**0.46**	**0.72**	**2.38**
RH	1.82	0.79	1.11	
RS	1.43	0.63	0.92	
Mean	**1.63**	**0.71**	**1.02**	**3.35**
TH	1.09	0.49	0.66	
TS	1.51	0.75	0.93	
Mean	**1.30**	**0.62**	**0.80**	**2.72**

1200 kPa, 240 mins

	CRO_3	CUO	AS_2O_5	Total
LH	1.43	0.50	0.87	
LS	1.29	0.33	0.59	
Mean	**1.36**	**0.42**	**0.73**	**2.51**
RH	1.58	0.62	0.91	
RS	1.68	0.76	0.98	
Mean	**1.63**	**0.69**	**0.95**	**3.27**
TH	1.77	0.82	1.06	
TS	2.05	0.80	1.15	
Mean	**1.91**	**0.81**	**1.11**	**3.83**

Appendix 18: Raw data of the oxide retention (kg/m^3) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* (C) at pressure magnitude range of at 600 to 1200kPa and duration 30 to 240 mins

600 kPa, 30 mins

	CRO3	CUO	AS205	Total
CLH	0.51	0.17	0.36	
CLS	0.47	0.16	0.36	
Mean	**0.49**	**0.17**	**0.36**	**1.02**
CRH	0.96	0.38	0.55	
CRS	0.78	0.30	0.51	
Mean	**0.87**	**0.34**	**0.53**	**1.74**
CTH	0.61	0.23	0.39	
CTS	0.82	0.32	0.52	
Mean	**0.72**	**0.28**	**0.46**	**1.45**

600 kPa, 60 mins

	CRO3	CUO	AS205	Total
CLH	0.83	0.23	0.45	
CLS	0.52	0.16	0.36	
Mean	**0.68**	**0.20**	**0.41**	**1.28**
CRH	0.71	0.31	0.45	
CRS	0.84	0.34	0.53	
Mean	**0.78**	**0.33**	**0.49**	**1.59**
CTH	0.84	0.31	0.48	
CTS	0.80	0.35	0.54	
Mean	**0.82**	**0.33**	**0.51**	**1.66**

600 kPa, 120 mins

	CRO3	CUO	AS205	Total
CLH	0.50	0.15	0.35	
CLS	0.60	0.19	0.38	
Mean	**0.55**	**0.17**	**0.37**	**1.09**
CRH	1.10	0.44	0.66	
CRS	0.97	0.37	0.55	
Mean	**1.04**	**0.41**	**0.61**	**2.05**
CTH	1.15	0.42	0.69	
CTS	0.79	0.33	0.49	
Mean	**0.97**	**0.38**	**0.59**	**1.94**

600 kPa, 240 mins

	CRO3	CUO	AS205	Total
CLH	0.84	0.20	0.48	
CLS	0.60	0.17	0.39	
Mean	**0.72**	**0.19**	**0.44**	**1.34**
CRH	1.13	0.46	0.67	
CRS	0.99	0.42	0.63	
Mean	**1.06**	**0.44**	**0.65**	**2.15**
CTH	1.01	0.37	0.56	
CTS	1.13	0.43	0.64	
Mean	**1.07**	**0.40**	**0.60**	**2.07**

800 kPa, 30 mins

	CRO3	CUO	AS205	Total
CLH	0.42	0.15	0.30	
CLS	0.32	0.14	0.30	
Mean	**0.37**	**0.15**	**0.30**	**0.82**
CRH	0.96	0.39	0.56	
CRS	0.85	0.37	0.53	
Mean	**0.91**	**0.38**	**0.55**	**1.83**
CTH	0.79	0.30	0.45	
CTS	0.98	0.45	0.63	
Mean	**0.89**	**0.38**	**0.54**	**1.80**

800 kPa, 60 mins

	CRO3	CUO	AS205	Total
CLH	0.92	0.27	0.52	
CLS	0.74	0.23	0.45	
Mean	**0.83**	**0.25**	**0.49**	**1.57**
CRH	1.03	0.35	0.55	
CRS	0.74	0.29	0.51	
Mean	**0.89**	**0.32**	**0.53**	**1.74**
CTH	1.29	0.43	0.64	
CTS	0.81	0.39	0.55	
Mean	**1.05**	**0.41**	**0.60**	**2.06**

Appendix 18: Raw data of the oxide retention (kg/m^3) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of at 600 to 1200kPa and duration 30 to 240 mins

800 kPa, 120 mins

	CRO3	CUO	AS205	Total
CLH	1.07	0.31	0.57	
CLS	0.62	0.18	0.41	
Mean	**0.85**	**0.25**	**0.49**	**1.58**
CRH	0.95	0.36	0.57	
CRS	1.14	0.41	0.61	
Mean	**1.05**	**0.39**	**0.59**	**2.02**
CTH	1.12	0.43	0.62	
CTS	1.03	0.38	0.59	
Mean	**1.08**	**0.41**	**0.61**	**2.09**

800 kPa, 240 mins

	CRO3	CUO	AS205	Total
CLH	0.52	0.14	0.33	
CLS	0.89	0.19	0.47	
Mean	**0.71**	**0.17**	**0.40**	**1.27**
CRH	1.31	0.44	0.69	
CRS	0.97	0.39	0.63	
Mean	**1.14**	**0.42**	**0.66**	**2.22**
CTH	1.35	0.52	0.80	
CTS	1.23	0.46	0.76	
Mean	**1.29**	**0.49**	**0.78**	**2.56**

1000 kPa, 30 mins

	CRO3	CUO	AS205	Total
CLH	0.44	0.15	0.32	
CLS	1.18	0.42	0.72	
Mean	**0.81**	**0.29**	**0.52**	**1.62**
CRH	1.02	0.45	0.64	
CRS	0.85	0.36	0.56	
Mean	**0.94**	**0.41**	**0.60**	**1.94**
CTH	0.79	0.31	0.49	
CTS	0.63	0.31	0.45	
Mean	**0.71**	**0.31**	**0.47**	**1.49**

1000 kPa, 60 mins

	CRO3	CUO	AS205	Total
CLH	0.93	0.27	0.50	
CLS	0.81	0.30	0.53	
Mean	**0.87**	**0.29**	**0.52**	**1.67**
CRH	1.11	0.44	0.66	
CRS	0.97	0.36	0.58	
Mean	**1.04**	**0.40**	**0.62**	**2.06**
CTH	1.17	0.43	0.67	
CTS	1.10	0.47	0.68	
Mean	**1.14**	**0.45**	**0.68**	**2.26**

1000 kPa, 120 mins

	CRO3	CUO	AS205	Total
CLH	1.12	0.26	0.58	
CLS	1.01	0.37	0.65	
Mean	**1.07**	**0.32**	**0.62**	**2.00**
CRH	0.99	0.38	0.61	
CRS	1.10	0.42	0.61	
Mean	**1.05**	**0.40**	**0.61**	**2.06**
CTH	1.23	0.37	0.65	
CTS	0.94	0.36	0.56	
Mean	**1.09**	**0.37**	**0.61**	**2.06**

1000 kPa, 240 mins

	CRO3	CUO	AS205	Total
CLH	1.06	0.30	0.55	
CLS	1.09	0.23	0.59	
Mean	**1.08**	**0.27**	**0.57**	**1.91**
CRH	1.21	0.44	0.64	
CRS	1.18	0.44	0.68	
Mean	**1.20**	**0.44**	**0.66**	**2.30**
CTH	1.17	0.40	0.61	
CTS	1.01	0.31	0.57	
Mean	**1.09**	**0.36**	**0.59**	**2.04**

Appendix 18: Raw data of the oxide retention (kg/m^3) of radial sections [sapwood (S) and heartwood (H)] and orientations [longitudinal (L), radial (R) and tangential (T)] of *Cola gigantea* at pressure magnitude range of at 600 to 1200kPa and duration 30 to 240 mins

		1200 kPa, 30 mins					1200 kPa, 60 mins		
	CRO3	CUO	AS205	Total		CRO3	CUO	AS205	Total
CLH	0.69	0.22	0.45		CLH	1.14	0.29	0.58	
CLS	0.47	0.14	0.34		CLS	0.83	0.19	0.49	
Mean	**0.58**	**0.18**	**0.40**	**1.16**	Mean	**0.99**	**0.24**	**0.54**	**1.76**
CRH	1.10	0.37	0.57		CRH	1.33	0.44	0.73	
CRS	1.48	0.44	0.74		CRS	1.11	0.39	0.66	
Mean	**1.29**	**0.41**	**0.66**	**2.35**	Mean	**1.22**	**0.42**	**0.70**	**2.33**
CTH	1.07	0.54	0.71		CTH	0.98	0.39	0.61	
CTS	1.16	0.46	0.74		CTS	0.86	0.40	0.60	
Mean	**1.12**	**0.50**	**0.73**	**2.34**	Mean	**0.92**	**0.40**	**0.61**	**1.92**

		1200 kPa, 120 mins					1200 kPa, 240 mins		
	CRO3	CUO	AS205	Total		CRO3	CUO	AS205	Total
CLH	1.08	0.34	0.59		CLH	0.78	0.19	0.45	
CLS	1.05	0.37	0.60		CLS	0.99	0.28	0.57	
Mean	**1.07**	**0.36**	**0.60**	**2.02**	Mean	**0.89**	**0.24**	**0.51**	**1.63**
CRH	1.17	0.45	0.64		CRH	1.51	0.61	0.82	
CRS	1.28	0.48	0.73		CRS	1.23	0.46	0.70	
Mean	**1.23**	**0.47**	**0.69**	**2.38**	Mean	**1.37**	**0.54**	**0.76**	**2.67**
CTH	1.38	0.50	0.71		CTH	1.36	0.46	0.69	
CTS	1.09	0.34	0.61		CTS	1.29	0.43	0.69	
Mean	**1.24**	**0.42**	**0.66**	**2.32**	Mean	**1.33**	**0.45**	**0.69**	**2.46**