AN INVESTIGATION INTO THE SUITABILITY OF SELECTED LESSER UTILISED GHANAIAN HARDWOODS FOR USE AS OUTDOOR FURNITURE AND DECKING

A thesis submitted for the degree of Master of Philosophy

By

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1. ABSTRACT

The potential for using the Ghanaian lesser utilised hardwoods esa (*Celtis mildbraedii*), denya (*Cylicodiscus gabunensis*) and dahoma (*Piptadeniastrum africana*) for garden furniture and decking in the UK is investigated. Specific properties are examined using field and laboratory experiments against reference species; iroko (*Milicia excelsa*), African mahogany (*Khaya ivorensis*), teak (*Tectona grandis*) and European oak (*Quercus robur*). The effectiveness of decking and teak oil coatings at reducing weathering defects is described.

With weathering colours of all species changed over the six month exposure period though the greatest rate of change is seen in iroko and oak. There is an increase in lightness (L* value) and greying (a* and b* values). Oil treatments delay the rate of colour change but do not prevent it. Oil treatments reduce checking during weathering which is worse in oak, esa and denya. Analysis of samples during outdoor exposure using FTIR show a loss in lignin at the surface, with the absorbance peak at $(1505\text{cm})^{-1}$ absent following 1 month for untreated samples and two months for oiled samples. Scanning electron microscopy revealed that teak and deck oil formed thin films on the surfaces of wood but do not coat vessel lumens. Following six months exposure a number of defects were apparent, including raised wood fibres, fungal colonisation and cell wall and pit checking. Defects are observed in coated and uncoated wood.

Natural durability using the method described in BS EN 350-1 show denya to be very durable, dahoma moderately durable and esa not durable. Field exposure shows esa is liable to blue stain in service though no decay is detected in lap joints after nine months exposure.

A market research survey carried out on weathered and unweathered deck boards and furniture show denya and dahoma to be attractive to potential consumers. Respondents prefer oiled decks over untreated decks once weathered since colour change is not as great in these.

2. INTRODUCTION

2.1 Background

Ghanaian forests contain many tree species that are commercially important or have the potential to be commercialized. Timber from these trees is either sold or has the potential to be sold into domestic and export markets.

Upton and Attah (2003) reported some 680 tree species in the forest reserves in Ghana, though only a small number have been used commercially and an even smaller number have been processed for export. Erfurth (1976) calls timber species that have not been used commercially but have the potential for use, lesser used species (LUS). Erfuth stated that, in West and Central Africa, there are 105 commercial wood species and 112 LUS. It is apparent therefore that a large number of species with commercial potential are not used.

The Forestry Commission of Ghana export permit reports for 2002-2005 show 53 species were exported over this period. Of these, 65% are termed preferred species and include African mahogany *Khaya* spp A. chev , iroko *Milicia excelsa* Welwa. C.CBerg,, asanfina *Aningera robusta* A.Chev ,Aubrev. Pellegr., sapele *Entandrophragma cylindricum* Sprague and teak *Tectona grandis* L.f., with the latter plantation grown.

Wagner and Cobbinah reported in 1993 that that the make up of forests in Ghana are changing as a result of logging. They stated that some of the well known tree species will no longer exist in sufficient numbers to be useful commercially. This has resulted from too much selective felling of the preferred species. Berberi (2002) reported that this overexploitation of the preferred species in Ghana has made continuation of profitable logging difficult. Also, sustainable forest management cannot be achieved if this process continues. There is growing pressure to meet the raw material demands of the forest products industries with LUS.

In view of this, the need has arisen for investigations into the promotion and marketing of Ghana’s LUS as a means of reducing the over exploitation and dependence on the preferred species. For these lesser utilised species to be used as substitutes and accepted on the market, it is important to understand their properties and how they perform in service.

There have been a number of grants from the International Tropical Timber Organization (ITTO), and the European Union to help develop Ghana’s forest product industries (e.g. the Woodworking Sector Development Project (WSDP)). The aim of this project was to increase the export of value added wood products especially those manufactured from LUS. As part of this work, three lesser used Ghanaian species namely esa *Celtis mildbraedii* Engl., dahoma *Piptadeniastrum africana* Hook.f., Brenan, and denya *Cylicodiscus gabunensis* Harms, are being studied to see whether they have potential to be used as outdoor furniture and decking in the UK. Since iroko, African mahogany, teak and European oak *Quercus robur* L, are used for these applications already, they are included in the study as references. This allows the performance of the LUS to be compared with these.

Most of the research work conducted to date on the three Ghanaian LUS has concentrated on their basic properties such as durability, strength and working qualities. No work has been carried out to investigate their performance as outdoor furniture or decks, where resistance to weathering is important. Another important factor that is likely to influence whether these LUS are acceptable for use as furniture is their aesthetics. This area of wood science research has received little attention and will be addressed in the study.

2.2 Aim and objectives

2.2.1 Aim

To examine whether denya, esa, and dahoma are suitable for use as outdoor furniture and decks, and are acceptable to the UK consumer.

2.2.2 Objectives

- To investigate the weathering performance of denya, esa, and dahoma when exposed out of doors in the UK.
- To investigate the weathering performance of denya, esa, and dahoma under laboratory conditions using a weatherometer.
- To compare the weathering performance of the LUS with oak, teak, African mahogany and iroko.
- To assess durability of denya, esa, dahoma, teak and beech against white and brown rot fungi likely to decay wood out of doors in the UK.
- To explore the appeal of the LUS for outdoor furniture and decking through market research.
- To examine the influence of deck oil and teak oil on wood weathering and durability.

2.3 Justification for the study.

Large outdoor furniture companies in Ghana such as Mim Scanstyle Ltd, generate about six million Euros in turnover (Forestry Commission Export Report, 2005). This company is dependent on timber species that are overexploited. There is insufficient timber from the species they currently use to meet their demands. This threatens their levels of production and is likely to have serious socioeconomic effects since the company employs about 3000 staff.

One solution to this problem would be to use more LUS.

Donkor, Vloski and Attah (2005) stated that research investigating the performance of LUS in service is required to determine whether they can be used as substitutes for species currently employed.

In order to encourage the use of LUS, two hurdles need to be overcome;

1. A willingness by processors to use LUS.
2. An acceptance of the species by consumers.

If the LUS can be demonstrated to perform as well, or indeed better than species currently selected for particular end uses, then processors may be persuaded to switch species. Data on in service performance is useful when marketing these timbers to the consumer.

Karki (2000) reported that wood species was not the overriding factor influencing outdoor furniture purchases in Germany, indicating consumers may accept products manufactured from LUS. The fact that some outdoor furniture is coated may provide an opportunity for certain LUS to make inroads into this market where wood aesthetics is not an overriding factor.

The present study assesses performance of the three LUS as decks and outdoor furniture.

A market research survey was conducted to measure consumer acceptance of these species against those already sold into furniture and decking markets. Results from this allow Ghanaian wood processors identify whether there is a suitable market for the LUS in the UK.

Weathering experiments outdoors assess how the samples perform as decks and garden furniture. A survey of weathered decking boards by consumers is included in the study. This provides useful data on customer satisfaction with the decks after they have weathered. Since most furniture and decks are treated with oils prior to exposure, the influence of these on weathering and customer satisfaction is investigated.

Wood used outdoors for these applications is at risk from wood decay since it is liable to wetting. For this reason moisture uptake of the LUS was studied. In addition durability tests assess resistance of the LUS to wood decay. The influence of the decking and teak oil on moisture uptake and decay was also determined.

3. LITERATURE REVIEW

3.1 Ghanaian forests and tree specie diversity.

The Ghana Forestry Commission reports Ghana has a land area of 238,000 square kilometres (about 92,000 square miles). Two thirds of this is dry savannah with sparse tree cover, the latter being small and stunted in nature. The Northern, Upper East and Upper West regions of the country are dry savannah (Figure 3.2). The rainforest, which covers about 82,000 square kilometers (31,600 square miles), covers the southern part of the country from the Brong Ahafo region to the Western and Volta regions.

There are 252 legally constituted primary and secondary permanent forest reserves in the rainforest regions, accounting for about 20% of the land area of Ghana (Anon., 2001). These reserves are where the bulk of timber extraction is undertaken. Figure 3.1 shows the map of Africa indicating the position of Ghana. Figure 3.2 shows the various geographical regions of Ghana.

Figure 3.1Map of Africa showing the various countries including Ghana.

Source: Http://www.ghanaweb.com

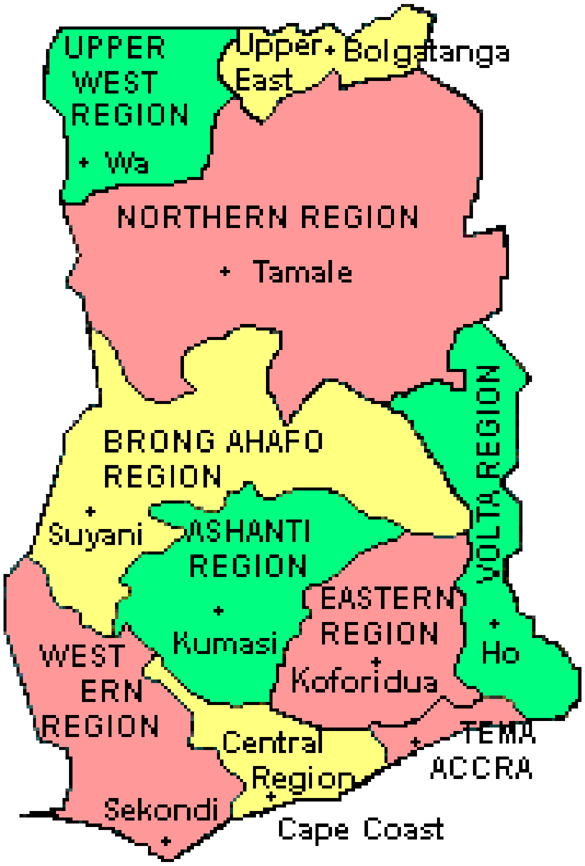


Figure 3.2 Map of Ghana showing the various geographical regions.

Source: Http://www.ghanaweb.com

Natural forest areas can also be found outside the forest reserves, and these are either primary or secondary in nature. Extraction of timber is carried out in these areas too.

Plantation forests are established both within the and outside forest reserves. These plantations are owned by the government, local communities, non governmental institutions, and private individuals. Teak forms a greater percentage of the species grown in these plantations while gmelina *Gmelina arborea* L., cedrella *Cedrella* spp. e.g. *C. odorata* L., and other traditional species like ofram *Terminalia superba* Engl.,Diels and emeri *Terminalia ivorensis* A.Chev., constitute the rest of the plantation species.

3.2 Measures to reduce over-exploitation of traditional species in Ghana

Traditional or preferred species are those commonly sold on international markets and include those listed in Table 3.1.

Kuffour (1998) and Appiah *et al*. (1998) reported the current policy of the Ghanaian Government and the timber industry is to reduce the exploitation of these traditional species by promoting use of LUS.

Previous policies designed to reduce over-exploitation of traditional species in Ghana included;

- A ban on exporting logs of traditional species in the round, introduced in 1994
- Introducing export levies on selected species whenever traditional species were exported in the air dried form.
- The introduction of a total annual allowable cut (AAC) of 1 million m^3 was introduced for all species in 1996. However, the volume of traditional species such as iroko, African mahogany and sapele allowed to be cut was far less than for other species.

These actions were intended to ensure that all timber species could be used sustainably including the traditional species listed in Table 3.1.

Local name for species	Botanical name
Akasaa	*Chrysophylum albidum*
Asanfina	*Aningera robusta*
Avodire	*Turreanthus africana (Welw. ex C. DC.) Pellegr*
Black shedua	*Guibourtia ehie (A. Chev.) J. Leon.*
Candollei	*Entandrophragma candollei Harms*
Ekki/ Kako	*Lophira elata. Banks ex Gaertn.f*
Edinam	*Entandrophragma angolense (Welw.) C. DC.*
African mahogany	*Khaya ivorensis*
Kokrodua/Afromosia	*Pericopsis elata (Harms) van Meeuwen*
Koto	*Pterygota macrocarpa K. Schum*
Makore	*Tieghemella heckelii Pierre ex A. Chev*
Mansonia	*Mansonia altissima A. Chev.*
Niangon	*Heritiera utilis (Sprague)*
Odum/Iroko	*Milicia excelsa*
Ofram	*Terminalia superba*
Papao	*Afzelia africana Smith ex Pers.,*
Sapele	*Entandrophragma cylindricum*
Utile	*Entandrophragma utile (Dawe & Sprague) Sprague*
Walnut	*Lovoa trichilliodes Harms*
Wawa	*Triplochiton scleroxylon K. Schum*

Table 3.1 Some traditional species exported from Ghana.
Source: Ghana Forestry Commission Export Permit Report (2001-2005)

3.3 The status of use of Ghana's LUS

In Ghana lesser utilised species are those timbers that have the potential for commercial utilisation but have not been utilised due to limited information and market acceptability. Table 3, shows some 23 potential LUS identified by the TIDD in Ghana between 2001 and 2005. It is important to note that all Ghanaian timbers other than the traditional species may be termed LUS. However, those listed are usually those considered to have most potential for commercialisation. Amartey *et al*. (2004) stated LUS have commercial potential but have not yet been utilised properly since there is limited information available on their properties and they are not familiar to end users. For this reason, these species are still abundant in Ghanaian forests.

Local name	Botanical name
Aprokuma	*Antrocaryon micraster*
Ayan	*Distemonantus benthamianus Baill*
Bodwe	*Ongokea gori*
Bombax	*Bombax buonopozense P. Beauv.*
Cedrella	*Cedrela odorata L.,*
Ceiba	*Ceiba pentandra (L.)Gaertn.*
Esa	*Celtis mildbraedii*
Chenchen	*Antiaris africana (Engl.) C.C. Berg,*
Dahoma	*Piptadeniastrum Africana*
Danta	*Nesogordonia papaverifera (A. Chev.) Capuron*
Denya	*Cylicodiscus gabunensis*
Entedua	*Copaifera salikounda Heckel*
Esia	*Petersiantus macrocarpus (P. Beauv.) Libend.*
Gmelina	*Gmelina aborea L.*
Hotrohotro	*Hannea Klaineana*
Ohaa	*Sterculia oblonga*
Potrodom	*Erythrophleom spp. A. Chev.,*
Nyamedua	*Alstonia boonei Engl.*
Subaha	*Mitragyina ciliate*
Tetekon	*Gilbertiodendron spp. J. Leon.*
Tweneboa	*Cordia millenii Bak.,*
Wawabima	*Sterculia rhinopetela K. Schum*
Yaya	*Amphimas pterocarpoides Harms*

Table 3.2 Some Lesser Utilised Species of Ghana.

Source: Ghana Forestry Commission Export Permit Reports (2001- 2005)

3.4 Commercialization of LUS in Ghana

Using the Ghana wood products export statistics for the period 1992-2002, Donkor *et al*. (2005) reported that of the 53 hardwoods exported, 28 (53%) were LUS. Indeed, the proportion of LUS in processed wood products increased from 2% in 1992 to 40% in 2002. This was largely a result of the measures introduced to reduce over-exploitation of the more traditional species.

Of the LUS exported over this period, Donkor reported the most important to be ceiba, chenchen , otie, esa, dahoma, danta, cedrela and ogea. The most important of these were ceiba, chenchen, otie, and cedrella.

Early export reports from the period 1999-2002 showed denya, esa, and dahoma only made up a small proportion of exports. More recently, statistics for the period 2002-2005 show these LUS to be exported in greater quantities. Table 3.3 shows export figures for the LUS examined in this study in various product forms between 2002-2005.

Year/ Product 2002	Species					
	Denya		Dahoma		Esa	
	Volume m^3	Value €	Volume m^3	Value €	Volume m^3	Value €
KD Lumber	44	16,900	84	25,700	30	9,500
AD Lumber	923	304,500	810	244,190	11	2,500
Furniture parts	-	-	23	25,700	19	25,300
Mouldings	614	242,700	-	-	1500	635,500
Flooring	-	-	-	-	20	25,300
Sliced veneer	-	-	-	-	*224,500	118,700
Rotary veneer	-	-	-	-	6,600	1,869,000
Plywood	-	-	-	-	1,500	2,520,000
Total	**1,581**	**564,100**	**908**	**295,590**		**5,205,800**

Year/Product	Species					
	Denya		Dahoma		Esa	
	Volume m^3	Value €	Volume m^3	Value €	Volume m3	Value €
2003:						
KD Lumber	40	11,300	281	88,600	170	55,000
AD Lumber	945	282,900	3,200	775,500	207	43,900
Furniture parts	-	-	45	60,300	-	-
Mouldings	1,500	629,600	29	16,700	429	162,900
Flooring	30	14,100	-	-	58	40,700
Sliced veneer	-	-	-	-	*313,700	128,400
Rotary veneer	-	-	-	-	5,300	1,295,000
Plywood	-	-	-	-	1,000	471,700
Broomsticks	-	-	-	-	36	19,500
Total	**2,515**	**937,900**	**3,515**	**941,100**		**2,217,100**

Year/Product	Species					
	Denya		Dahoma		Esa	
	Volume m^3	Value Є	Volume m^3	Value Є	Volume m^3	Value Є
2004:						
KD Lumber	107	39,000	618	200,800	184	44,900
AD Lumber	1,300	445,700	3,400	790,700	27	3,900
Furniture parts	-	-	45	60,300	-	-
Mouldings	1,700	741,700	243	86,200	850	315,500
Flooring	33	8,100	0.601	212	241	151,400
Sliced veneer	-	-	-	-	*634,400	258,500
Rotary veneer	-	-	-	-	3,900	847,800
Plywood	-	-	-	-	88	25,400
Dowels	-	-	-	-	7	3,400
Total	**3,140**	**1,234,500**	**4,306.601**	**1,138,212**		**1,650,800**

Year/Product	Species					
	Denya		Dahoma		Esa	
	Volume m^3	Value €	Volume m^3	Value €	Volume m^3	Value €
2005:						
KD Lumber	81	30,000	1,100	363,600	244	72,200
AD Lumber	1,000	335,500	2,200	539,000	19	5,900
Furniture parts	-	-	38	45,300	-	-
Mouldings	1,200	565,800	260	109,600	504	256,800
Flooring	75	18,300	14	6,000	1,000	75,400
Sliced veneer	-	-	-	-	*378,100	168,700
Rotary veneer	-	-	-	-	3,400	782,400
Plywood	-	-	-	-	113	23,100
Broomsticks	-	-	-	-	51	27,900
Dowels	-	-	-	-	18	8,400
Total	**2,356**	**949,600**	**3,612**	**1,063,500**	**383,449**	**1,420,800**

Table 3.3 Volumes and values of esa, dahoma and denya exported within 2002-2005.

Where *= Area in m^2, AD= Air dried, KD= Kiln dried

From Table 3.3 it may be seen that there was an increase in both volume and value of exports for all LUS under investigation in this study between 2002 -2004. Exports fell back slightly in 2005. This fall can be attributed to the re-introduction of teak log exports, thereby shifting the focus of producers from further processing of the LUS.

Mouldings and flooring in the three species seem to be enjoying market acceptability as volumes and values keep increasing. Denya in the form of mouldings, had the greatest volume exported

Esa has been used in various product forms including veneer and plywood and generated the greatest income over this period. Dahoma was the most exported specie in the air and kiln dried forms.

3.5 A review of the published literature on the LUS and reference species used in the study

Kribbs (1959), Banks and Schoeman (1963), Bolza and Keating (1972), HMSO (1984), ITTO (1986), Petterson (1988) and Keay (1989) all presented data about properties of the African hardwoods studied. Chudnoff (1984) and Woods of the World (2001) reviewed and presented this information. A review of the available information about the three LUS and reference species is provided in the following sections.

3.5.1 Nomenclature

The table below list some of the common trade names used for species under investigation.

TRADITIONALLY PREFERED SPECIES				LUS		
***odum**	***mahogany**	***teak**	***oak**	***denya**	***dahoma**	***esa**
iroko	African. mahogany	Burma teak	encino	akan	dabema	African celtis
abang	Akuk	djati	rable	edum	agboin	ohia
kambala	Bandaro	giathi	rable amarillo	bokaka	atui	esa-fufu
lusanga	Bitchi	tsik		adada	bokungu	asan

Table 3.4 Common trade names of species used in the study

Where * = Common names used in Ghana.

3.5.2 Distribution of species included in the study

The traditional hardwoods (iroko, African mahogany) and lesser-used species (denya, dahoma and esa) grow in West and Central Africa, and some parts of Eastern Africa, particularly Kenya and Zimbabwe. Teak is reported to be indigenous to Myanamar, Thailand, Java and Malaysia, but has been planted extensively throughout the world, especially East and West Africa, the West Indies, Jamaica to Trinidad, and from Panama to Brazil. Oak used in the present study is (*Quercus robur*) and is used for benchmarking as it is Europe's most important native naturally durable timber. Woods of the World (2001)

3.5.3 Uses for species included in the study

The reference species selected were chosen since they are used for the manufacture of outdoor furniture and decks (Timber Export Development Board of Ghana (1994)). Iroko, African mahogany, teak, and oak can be used in the production of veneers: while the only LUS that can perform that function is esa. With the exception of esa, all species are employed in heavy construction activities like ship and boat building, for foundation posts, bridge beams, and wharf construction (Bolza and Keating (1972)). Since the literature indicates the usage of denya and dahoma for outdoor applications like bridge beams and wharf construction then there is the potential for outdoor applications like decking and furniture.

3.5.4 Mechanical Properties for LUS and reference species

Mechanical properties of wood include its strength, stiffness and hardness. These are important properties for end uses such as decks and outdoor furniture, where components are subject to loading and are required to resist wear particularly in the case of decks. For this reason, what is known about relevant mechanical properties for the LUS and reference species are reviewed. Information for the reference species are included so that comparisons may be made.

Property	Units	Traditional Species				Lesser Utilised Species		
		Iroko	A.Mahogany	Teak	Oak	Denya	Dahoma	Esa
Bending Strength	N/mm^2	92	78	100	127	140	108	144
Crushing Strength	N/mm^2	58.67	46.53	54.60	60.10	85.40	58.46	72.90
Stiffness	N/mm^2	10602	8344	10602	12170	16100	11976	15900
Hardness	N	6849	3691	4448	7205	12320	5849	7470
Shearing Strength	N/mm^2	12.29	11.88	14.87	12.70	22.30	10.47	17.70

Table 3.4 Mechanical properties of LUS and reference species in the study.

Sources: Commercial timbers of Ghana (2003); Handbook of hardwoods (1988)

Denya has much better strength characteristics therefore superior to the well known timbers in Table 3. Dahoma is compared to Iroko.

3.5.5 Aesthetics of LUS and reference species

Flaete, Alfredson, and Evans (2006) state one of the principal reasons for the increased interest in using “new” species is that they offer a broader range of aesthetical elements for architecture. For both decking and furniture, aesthetics are considered important. To date, no one has conducted a market research through a choice test on furniture or decking made using these species.

Aesthetics of wood is influenced by colour, grain and texture, figure and knots which are wood species related. Mode of processing may also have significant effects on aesthetics. Aesthetics may also be influenced by weathering and the application of finishes. Factors relating to wood species and mode of processing are reviewed in this section

The sapwood of dahoma, iroko, denya, African mahogany, oak and teak can be easily differentiated from the heartwood since their sapwood is of lighter colour. In the case of esa it was not possible to differentiate heartwood and sapwood through colour as they are similar. Below is a table of the colours of the LUS and reference species used in the study.

SPECIES	**COLOUR**
Esa	Whitish or clear light yellow
Dahoma	Yellowish brown
Denya heartwood	Yellowish to golden brown with a slight tinge
Denya sapwood	Pale pinkish shade
Iroko	Yellowish brown
African mahogany	Pink
European oak	Yellowish brown
Teak	Golden brown

Table 3.5 Colours of LUS and reference species used in the study.

Source: Handbook of Hardwoods (1972).

Grain refers to the orientation of fibres relative to the axis of the longitudinal surface (Patterson, 1988). Grain may be; straight, diagonal, spiral irregular, interlocked or wavy. The grains of all LUS investigated in the study are interlocked. Oak is generally straight, African mahogany sometimes straight but usually interlocked, producing a stripe or roe figure. Iroko is typically interlocked and sometimes irregular. Teak is often straight but sometimes wavy. Desch and Dinwoodie (1981) explain that interlocked grains make milling difficult resulting in more waste. However, interlocked grains give rise to ornamental figures.

Texture relates to the size of the wood cells and their arrangement (Tsoumis, 1991). This is often described as being coarse, fine, even or uneven. Bolza and Keating (1972) report that dahoma and denya are coarse textured and esa even textured.

Figure in wood relates to the ornamental markings produced on the longitudinal surface of wood, as a result of either its inherent structure, or its induced structure, following some external interference.

According to Bolza and Keating, lustre depends on the ability of the cell wall to reflect light. Quarter sawn boards are more lustrous than flat sawn ones.

3.5.6 Durability of the LUS and reference species

EN 350-1 (1994) defines natural durability as the 'inherent resistance of wood to attack by wood destroying organisms'. Wong *et al.* (2005) state that natural durability normally refers to the heartwood of timber species, except for those species with no differentiation between heartwood and sapwood

According to Zabel and Morrel (1992) the three major groups of organisms that deteriorate wood are;

1. fungi and bacteria
2. insects including termites and beetles
3. marine borers

The relative importance of each group of organisms in decaying wood in service is dependent on its use and geographical location. In the case of outdoor furniture and decks in the UK, the wood decay fungi pose the greatest threat (Eriksson *et al.,* 1990; Eaton and Hale, 1993 and Highley *et al.,* 1994). The risk of decay is described for wood in service through hazard classes. These give an indication of the period of time wood for a particular end use will be 'wetted-up' (i.e. have moisture contents above 20%) which is necessary for fungal growth and decay. There are five hazard classes.

Class 1- where wood is enclosed and not in contact with moisture or water e.g. beams for ceiling.

Class 2- wood used in an enclosure but slightly in contact with the atmosphere e.g. flooring in rooms.

Class 3- wood used out of ground contact but exposed to the atmosphere, rain and sunshine. Examples are garden furniture and decking.

Class 4- wood in contact with the ground and river water, e.g. electric poles.

Class 5- wood in contact with sea water e.g. wharf post.

Another standard BS EN 350-1 (1994) describes the required durability class required for timber if it is to be used for these applications untreated.

It is important to note that it is the wood decay fungi that are responsible for degrading the structural wood components and therefore reducing its strength (Blanchette *et al*. 1990). However, another group of fungi mould and stains are able to colonise wood and although they have little influence on the strength properties of wood, they bring about disfigurement (Rayner and Boddy, 1988; Willeiter and Liese, 1992). This is undesirable in wood for furniture and decking applications. Since these fungi utilise primary metabolites and storage compounds normally concentrated in sapwood parenchyma, then this is one reason for sapwood being less durable than heartwood (Basham and Cowling, 1976 and Panshin and de Zeeuw, 1980)

A number of factors are believed to be responsible for the higher durability of heartwood to decay fungi. These include;

- The presence of fungicidal extractives in the heartwood of some species (Oquist, 1988 and Goldstein, 1991)
- Reduced permeability of the heartwood. This results from blocking of flowpaths through pit aspiration, deposition of extractives and formation of tyloses. This reduces penetration of water and therefore wetting up and exchange of gases including oxygen (Eslyn and Highley, 1967; Zabel and Morrel, 1992 and Desch and Dinwoodie, 1996)
- A lower nitrogen content in this region of the stem (Haack and Slansky, 1987; Zabel and Morrel, 1992; Wong and Wilkes 1988; Wong and Singh 1997; and Daniel and Nilsson 1998).

Other factors that have been reported to influence the durability of wood include;

- Lignin content; where timbers with high lignin content have greater durability (Takahashi, 1976 in Syafii *et al.,* 1988 and Yamamoto and Hong, 1994)
- Density; where timbers with a greater density are normally more durable. Denser timbers have reduced void volume which reduces the rate of gaseous diffusion and therefore the rate of decay (Yamamoto and Hong, 1994).

- Mineral deposits; where timbers containing mineral deposits are of greater durability. Higher quantities of mineral deposit in some tropical hardwoods make these less palatable to wood boring invertebrates. They are also believed to reduce water absorption thereby reducing susceptibility to fungal decay (De Silva and Hillis, 1980 in Panshin and de Zeeuw, 1980). Wong and Wilkes (1988) have shown that as mineral contents (notably potassium, phosphorus, calcium and magnesium) increase the decay rate of *Pinus radiata* L. by the white- rot fungus *Perennipori tephropora* decreases.

Natural durability of wood is assessed using the laboratory method detailed in EN 113 (based on mass loss), and the field tests method described in EN 252 (based on visual evaluation, pick or splinter test and mechanical failure). Laboratory tests are useful since resistance to individual agents may be investigated under controlled conditions (Eaton and Hale, 1993) although the European standard for assessment of wood durability (EN 350-1) states that results from field testing are preferred. This is because wood is exposed to a wider range of biodeteriogens which colonise wood sequentially and may act synergistically (Eaton and Hale, 1993). One problem with field testing is the time required to obtain results especially in temperate countries like the UK. EN 113 provides a fast track method to assess natural durability.

Ulrika *et al*., (2005) reviewed the European field test methods used to assess natural durability. European Standard EN 252 assesses performance of wood stakes in ground contact against reference species. Results from this standard are used to assign durability ratings for the test species according to the methods outlined in EN350-1. Other European standards such as the L-joint and lap joint tests were developed to examine the performance of wood out of ground contact for specific types of application. These methods are not used to assign durability ratings. A wide range of other methods have been used to assess weathering performance of wood above ground in temperate and tropical countries.

Anon (1994) classified the natural durabilities of the lesser utilised species investigated in this study. Esa was classified as not durable, dahoma durable and denya very durable The durabilities of these timbers were assessed in ground contact though the test methods were not provided. Handbook of hardwoods (1988) describes iroko as very durable, African mahogany is moderately durable, oak durable and teak very durable.

3.5.7 Treatability of the LUS and reference species

Treatability is defined by Desch and Dinwoodie (1996) as the ease with which wood can be treated. The type, quantity and method of application of wood preservative will depend on the wood species and hazard class in which it is exposed. As the species are to be used above ground contact then they fall within hazard class 3. In this hazard class, timber species that are not durable are usually treated with a wood preservative.

The literature reveals that the heartwood of all species used in the trial are resistant to preservative treatment. Esa, responds moderately to treatment. All the species have their sapwood accepting preservatives to some level (Woods of the World, 2001). Treatability of the species was based on BS EN 351-1.

Other methods used to protect the surface of wood form weathering is through the application of a coating such as paint or varnish (Eaton and Hale, 1993) or through the application of an oil treatment. Coatings are normally applied to surfaces, whereas, some oil treatments are designed to penetrate timber. Teak oil and decking oil may periodically be applied to the surface of outdoor furniture and decks to protect the timber surface from weathering.

Meijer (1999) reports that, the performance of coating on wood during outdoor exposure is controlled by various stressing factors like: photo irradiation, thermal radiations, mechanical impact, the presence of moisture and micro organisms causing different weathering effects like photochemical degradation, loss of surface integrity (cracking, flaking or erosion) and discolouration.

Teak oil according to www.caprinol.co.uk/product/teak-oil-usage.html preserves and beautifies wood. The oil surrounds the wood fibres deep below the surface to lock out moisture, maintaining the woods natural integrity. It also prevents drying out, checking and cracks.

Decking oil according to www.cuprinol.co.uk/products/decking-oil-overview.html is durable scuff resistant oil, which forms a waterproof barrier to protect wood against weathering, warping, swelling, drying and splitting. It resists mould and algae growth and its fade resistant finish, protects wood against UV rays.

3.5.8 Movement in Service

Movement as described by Handbook of Hardwoods (1988) is the dimensional changes that take place when timber which has been dried is subjected to changes in atmospheric conditions.

Tsoumis (1991) explains that movement is assessed by measuring the changes in dimension that occur when a piece of wood that has reached equilibrium moisture content in an atmosphere of 20°C at 90% relative humidity is transferred to and allowed to reach equilibrium in an atmosphere of 20ºC at 60% relative humidity. The dimensional changes that occur in movement are related to diurnal or seasonal changes in relative humidity. Woods of the World (2001) reports that properly seasoned iroko and teak are dimensionally stable and retain shape well after manufacture, and movement in both cases are small. Dahoma, esa, and oak are moderately stable as the wood exhibit medium movement in use. A. mahogany retains the shape well after seasoning and shows small movement in service. There is no information on the movement of denya.

3.6 Use of timber for decking and furniture out of doors

3.6.1 Use of wood for decking in the UK

The deck according to Anon (2006.) developed as an uncovered version of verandas typical of frame houses of the tropics and the Southern states of America. They are an integral feature of open- air living which is such an aspect of the lifestyle of these areas. However, timber decks are now common all over the world, including the UK.

Anon (1999) reveals, external decking has a long history. Its origins may be traced to its use as mediaeval walkways in the Fens in the UK, to verandas, railway platforms, piers and jetties of the nineteenth century. In the major timber growing areas of the world, such as North America and Scandinavia, wood was used for sidewalks in the cities and lasted for many years before eventually being replaced by paving.

Materials used in the UK decking market are wood, PVC, stone /concrete/other and wood polymer composites AMA Research Ltd (2006).

For many open-air spaces in the UK wood decks are preferred. This is because they are easy and quick to build, require less groundwork than masonry construction, particularly on sloping, or rough sites, and can blend in well with existing landscape features Anon (2006).

According to AMA Research Ltd. (2006), timber decking can aesthetically enhance the appearance of a house, while the installation of a good quality system can also help increase the overall property value. Timber, according to their research accounts for the vast majority of domestic decking installations in UK, with a market share of almost 95%. It was estimated that the UK domestic decking market in 1999 was £18 million, rising to £37 million in 2005. This domestic market excludes decks at hotels, golf courses restaurants and other commercial developments.

The estimated market for both domestic and non domestic decking when including these sectors and retail margins is in the region of 130 million pounds sterling at installed prices, but the year of estimation was not determined. In addition, there are other applications for "decking" materials (marinas, boardwalks etc, which fall outside this definition.

The decking market initially experienced rapid growth following its introduction in 1997. Growth has slowed down in recent years due to certain factors namely;

- The slowdown in the UK economy and falling levels of consumer confidence.
- Uncertainty over the future of UK housing market, leading to consumers postponing the installation of expensive items.

Unfortunately there is no information on the current size of the market, though changes to the legistlation on smoking in UK pubs and resturants will lead to increased requirements for smoking decks in 2007 (Timber Trades Journal, April 2007).

Softwoods accounts for 80% of the total wood used for decking installation and hardwood making up for the 20%. In addition, softwood products can be treated to resemble the appearance of hardwood products while maintaining their cost advantage. Although more expensive, hardwood decking requires less treating in general, negating the need for chemical preservatives.

AMA (2006) reports that many manufacturers operating within the timber decking market have attained Forest Stewardship Council accreditation, promoting responsible and sustainable forestry management and give preference to certified FSC products.

3.6.2 Use of wood for outdoor furniture in the UK

Furniture is defined as movable articles in a room or an establishment that make it fit for living and working. It may be made of wood, metals, plastics, stones, glass, fabrics and related materials.

The Ghana Forestry Commission Export Permit Report for 2001-2005 reveals that the exports in furniture and its parts dropped from 3,399m^3 in volume and €7,994,326 in value in 2001 to 1,769m^3 in volume and €3,531,445 in value during 2005. This may be attributed to the limited availability of the traditional species which were used in the production of furniture during this period. The United Kingdom was the leading importer of Ghana's furniture in 2005.

To increase Ghana's share of the UK outdoor furniture market, and since there are insufficient volumes of traditional wood species, there is the need to promote the use of appropriate alternatives including LUS. Denya and dahoma are durable species that can be used to replace iroko and African mahogany in outdoor application. Although esa is dense, it is susceptible to fungal attack. Aesthetically, these species are appealing.

3.7 Weathering of wood

According to Feist (1983) and Sam (2005) weathering may be defined as the slow degradation of any material exposed to the weather. This degradation is caused by a combination of factors including moisture, sunlight, heat/cold, chemicals, abrasion by windblown materials and biological agents.

Browne and Simonson (1957) and Feist and Mraz 1978 report that because of the limited ability of light to penetrate into wood, the effects of weathering are limited to a depth of 2.5mm and the rate of erosion is slow, 5-12mm per 100years.

Weathering results in a number of changes to the surface of wood which are normally considered deleterious (Miniutti, 1967). These changes are outlined in the following sections.

Bentum and Addo-Ashong (1977) investigated weathering of a wide range of West African timbers. They found during weathering, heavy and hard woods check (e.g. kaku, dahoma and opepe), while light and soft woods were prone to fungal attack and surface erosion over the five year trial.

3.7.1 Changes to wood colour

The aesthetics of wood is considered important for many end uses. Since colour plays an important role in wood aesthetics then any change in wood colour can have a negative impact on wood aesthetics and the perceived value of this material.

Colour as described by the Technical Advisory Services for Images is the way we perceive the interaction of light on substances. The group further explained that, none of the colours we name do exist in reality but they are categories we create in order to describe and control the experience we call “colour”.

The CIE (International Commission on Illumination) developed an L* a* b* model in (1976) for the determination of colours. It had a three dimensional colour gamuts used in assessing colours. Wood colour in this study was assessed using the L*a*b* or (CIELAB) modes.

The L* mode measures lightness, with a shift from a positive to negative value indicating darkening. The maximum +ve value is +100 which records white and the minimum –ve value -100 that is black. The a* mode has red as a positive value and green negative, while the b* mode, records yellow as positive and blue negative (Figure 3.3). Using the L*a*b* values, it is possible to assign a colour to each timber sample.

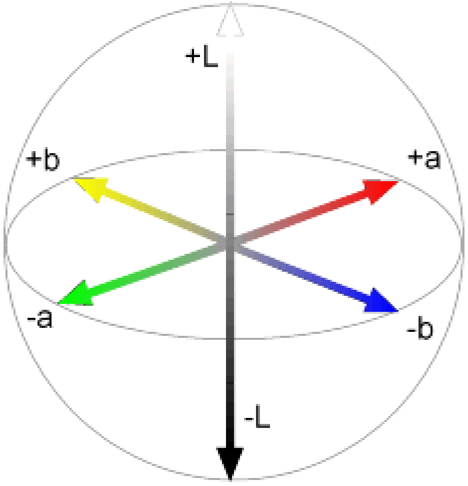


Figure 3.3 Model of CIELAB system of colour measurement.

FRN, (1966) and Sell and Leukens, (1971) describe the colour changes that occur in untreated wood when exposed out of doors (i.e. weathering). Initially wood becomes lighter or darker and eventually silvery grey.

Suppliers of outdoor furniture often advise consumers at the point of purchase that the colour of wood will become ‘silvery grey’. However, to date no study has compared consumer preferences for timber species before and after weathering.

3.7.2 Changes at the microscopic level

Fengel and Wegener (1989) report that wood samples weathered over years showed a slow disintegration of the outer layer of the fibres. The primary walls and secondary walls were often found to be partly flaked off or completely missing on the exposed side of the fibres.

Timar *et al.* (2004) used microscopy to show that the surface discolouration of beech exposed to weathering out of doors resulted from mould fungi.

Microscopy also showed that weathering and UV irradiation caused a contraction of the cell walls, resulting in microchecks along the middle lamella and breakdown of pit membranes in softwoods (Miniuttii, 1967 and Fengel and Wegener, 1989). Pandey and Pitman (2002) reported checking in the cell walls and pit degradation in rubberwood for 125-360 days outdoors in S. India.

3.7.3 Changes at the macroscopic level

As wood weathers, checking may occur in the wood surface, these may merge to form cracks (Evans *et al.* 2003). Decking boards may also cup and warp and pull away from fasteners.

Fowler *et al*. (1990) examined weathering of CCA-treated and untreated southern yellow pine. Results indicated that irrespective of exposure period, checking was more severe in the untreated samples than those that were treated with CCA suggesting that some treatments are able to improve the weathering performance of wood.

Wood surfaces also gather dirt and mildew (mould fungi) which alter surface colour (Sell and Wälchli 1969).

3.7.4 Changes to wood chemistry as a result of weathering

In order to understand the influence of weathering on the chemistry of wood, it is necessary to provide a brief overview of wood chemistry.

A number of researchers have reviewed the effects of weathering on wood chemistry (Fengel and Wegener, 1989).Reviews indicate that weathering is complex and that it differs with the wavelength of light and environmental conditions. Wavelength and wood moisture content were found to be the most important factors influencing weathering.

Studies showed that all structural components were degraded during weathering. However, since UV absorbance was greatest in the lignin fraction, this component showed the greatest degradation. With cellulose and hemicellulose, there is a reduction in the degree of polymerization with weathering. Under normal circumstances weathering breakdown products are washed from the wood (Fengel and Wegener, 1989). Advances in analytical chemistry have made it possible to study weathering of individual structural components over time. One such method is Fourier Transform Infra Red spectroscopy (FT-IR) considered in the next section.

3.7.5 FT-IR spectroscopy as a tool for studying wood weathering

Pandey and Pitman (2004) reported on the usefulness of FT-IR for the study of chemical changes in wood when weathered, since it provides rapid chemical characterization of small quantities of material with little preparation.

FT-IR has previously been used to examine changes in the chemistry of wood on weathered surfaces (Horn et al., and Pandey and Pitman, 2002). The second group of researchers examined the use of different types of metal salts for preventing weathering of rubberwood when exposed out of doors in India. For this tropical exposure site de-lignification started following one day of exposure with complete de-lignification detected following one week.

For FT-IR, specific absorbance bands are characteristic for specific polymers in wood (determined through analysis of isolated components). By comparing the changes in band heights or area over time, it is possible to assess changes in components with weathering. $(1505\text{cm})^{-1}$ is taken as a reference for lignin and peaks at (1740), (1157) and $(890\text{cm})^{-1}$ have been taken as polysaccharide references. Since all structural components are degraded over time, then the intensity of the band at $(895\text{cm})^{-1}$ is used as a reference for studying weathering. This band is assigned to the wagging motion of the hydrogen atom on the C1 position of glucose in cellulose. This absorption band has been shown to be unaffected by weathering.

Horn *et al*., showed an increase in the proportion of carbohydrate relative to lignin following exposure to UV light both with and without water. However, the presence of water greatly enhances degradation. Pandey and Pitman (2002) showed a rapid loss in the $(1505\text{cm})^{-1}$ lignin associated band and the $(1740)^{-1}$ xylan associated band, though lignin was degraded first.

3.7.6 Methods used to examine wood weathering

3.7.6.1 Field test methods used to examine wood weathering

A number of researchers have examined weathering of wood out of doors. This is useful since it exposes wood to a number of abiotic and biotic agents. It is therefore more realistic than laboratory testing.

No standard test method exists to assess weathering performance out of ground contact. However, a number of standards used to assess wood preservative performance out of ground contact may provide useful information (e.g. the lap joint method ENV 12037 (1996)). Normally, weathering tests expose wood samples in such a way that they are wetted by rainfall and exposed to direct sunlight (Bentum and Addo-Ashong (1977).

Evans *et al*. (2003) examined weathering of decking timbers measuring 3.0m (length) by 90.0mm (wide) by 22.5mm (thick). One side of the decking timber had been machined to produce 18 narrow grooves, 1.0mm deep. The timber consisted entirely of sapwood. Samples were treated and the boards fixed with their flat (ungrooved) face uppermost to an underlying frame of Douglasfur at 450mm centres. The ends of the boards were fixed to the frame using 45-mm-long screws inserted into predrilled holes and a similar method was used to fix the boards at points located 900mm from the ends.

Weathering of samples may be assessed visually by examining checking, by chemical analysis of wood at the surface, or by measuring weight loss or loss in hardness.

3.7.6.2 Laboratory tests

A range of laboratory tests have been used to assess weathering performance including devices which produce light of specific wavelengths, together with weatherometers that expose samples to alternate cycles of wetting and UV light.

Artificial weathering methods according to Arnold, Sell, and Feist (1990) are useful tools for studying the weathering of finished and unfinished wood products that will be used outdoors. Such weathering tests are reported to accelerate the effects of natural weathering from 5 to 20 times depending on the exposure conditions chosen. Conditions that are usually created during artificial weathering can be controlled and reproduced at all times. Because all the modes of natural weathering cannot be reproduced, the focus is usually on effects of UV light and moisture when dealing with artificial weathering.

3.8 Market research relating to forest products

Marketing according to Jean Mater *et al.* (1992) is the development and distribution of products and services that create and satisfy customers. Marketing recognises that people do not buy a product or service, but rather buy expectations or solutions to their problems.

Hansen and Weinfurter (1999) reported the largest perception gap between supplier and buyer of softwood concerned lumber aesthetics. Aesthetics is of great importance to decking and furniture manufacturers. Pakarinen (1999) investigated the success factors of wood as a furniture material and showed the four most often mentioned attributes were reliability, environmental friendliness, aesthetics and perceived value. These attributes go a long way in helping buyers gain customers.

Different species have different properties therefore it is important to educate the customer about the benefits of using certain species. This may be done effectively at point of purchase. For example, labels on garden furniture may say that the furniture changes to an attractive silvery grey colour with time (Mater *et al.*, 1992). Sometimes timbers are so familiar to customers that they form a ‘brand’. This can be seen with teak which is synonymous with durability out of doors (Mater *et al.*, 1992). Iroko is a brand in the commercial sector in the UK.

Ozanne and Smith (1996) in their market research investigation also reported how non economic buying criteria, such as the environment influence customers and their purchasing with respect to wood furniture.

The factors outlined above imply that by providing wood that is aesthetically desirable, sustainable, durable and reliable, Ghanaian forest products can achieve success in the market place.

West and Sinclair (1992) report that although marketing efforts are likely to influence competitiveness, good product design, market intelligence, distribution channels, and customer service are also vital. Globalization according to Capen and Glazer (1987) has “neutralised” international boundaries, making information available to firms to compete, and enabling them to compete and be effective. Consumers now have increased access to information and are able to contact many competitors in a short time.

Changes in policies that affect trade have three main effects including changes in production capacity, changes in incentive to produce specific commodities and changes in demand (Collins 1998). For wood products sold on European markets the sustainability of the raw material is becoming increasingly important for the importer/seller and the consumer.

In view of the increasing cost and decreasing availability of timber, global competition, and dramatic changes in the needs and wants of consumers the world over, companies are now shifting from the production of primary processing commodities like lumber, to the manufacture of secondary value added products such as mouldings to attract the market (Syme, 1990). This is also being undertaken in Ghana. However, to sell these value-added products to consumers overseas it is essential to understand their requirements. Jensen and Pompelli (2000) conducted a market research for the Tennessee forest products industries and found conducting market research to be vital for identifying potential buyers for products including those overseas. Swearingen, Hansen, and Reeb (1998) highlighted the importance of recognising the wood attributes their customers prefer.

Market research according to Mater *et al.* (1992) minimises the risk in marketing decisions by systematically gathering, recording, and analysing data to solve marketing problems.

The principles of market research are;

- Identify the marketing objective
- Acquiring existing data such as previously published marketing reports.
- Acquiring primary data through surveys.
- Critically analysing data
- Using information so acquired to achieve the marketing objective.

In the case of this study the objective is to examine whether the Ghanaian LUS have potential to be used for decking and outdoor furniture in the UK. A review of marketing reports has shown that although some data exists this is not specific enough and deals with the whole market rather than hardwoods or specific furniture end-uses.

However, knowledge of the existing timbers used for decking and outdoor furniture assisted with the identification of timber property requirements.

No marketing survey close to the point of sale has previously been undertaken for these timbers in the UK. These types of marketing survey are useful since Sandoh and Nakoto (1987) reveal that the surface properties of wood are still among the least known properties, although they are important, particularly in relation to psychological sensation of users of wood and wood products. For this reason having products for potential customers to handle was beneficial.

4. WEATHERING PERFORMANCE OF LUS AND REFERENCE SPECIES IN THE FIELD

4.1 INTRODUCTION

Wood weathering results from a complex combination of chemical, mechanical and light energy factors. For this reason weathering should ideally be assessed out of doors at the locations where it is to be used.

Chapter 3, reviewed literature on wood weathering. Feist (1983) reported that during weathering outdoors, smooth planed wood surfaces as found in decks and furniture become rough as the grain raises. The wood checks and boards cup and warp and may pull away from their fasteners. The wood surface changes colour and gathers dirt and mildew. Eventually wood loses its surface coherence and becomes friable with fragments being removed. This all leads to wood becoming unsightly and losing value. Defacement of wood also results from colonisation by micro organisms mainly stain fungi.

Since it is proposed to use the selected Ghanaian LUS for garden furniture and decking, then the performance of these species with respect to weathering requires investigation. A review of the literature shows that no study of the weathering of the LUS has previously been conducted

4.2 Materials and Methods

4.2.1 Wood species exposed in the weathering trial

Esa, denya and dahoma were used in the weathering trial along with iroko, African mahogany, teak and European oak (*Quercus robur).* The last four species were included as reference species as they are currently used for the manufacture of decks and/or outdoor furniture. Denya was obtained from the Western region, and the other Ghanaian timbers from the Brong Ahafo region.

4.2.2 Methods used to prepare samples for the field exposure test

Three types of sample were prepared;

1. Decking boards
2. Cross pieces
3. Lap joints

4.2.2.1 Preparation of decking boards

Four decking boards were prepared from the heartwood of iroko, A. mahogany, esa, and dahoma. In addition, four sapwood and heartwood boards were prepared for denya. All boards measured 800 x 100 x 25mm lbh (length, breath and height) and were finished planed. Grooves were machined along the upper and lower faces of each board. Each groove measured 3mm in diameter and was 2mm in depth. The middle portion of each board face was left planed (Figure 4.1). Pairs of holes were drilled into the boards at either end, 25mm from the sides and 50mm from the end. These screw holes were 3mm in diameter. Decking boards were fixed through these four holes for exposure in the field.

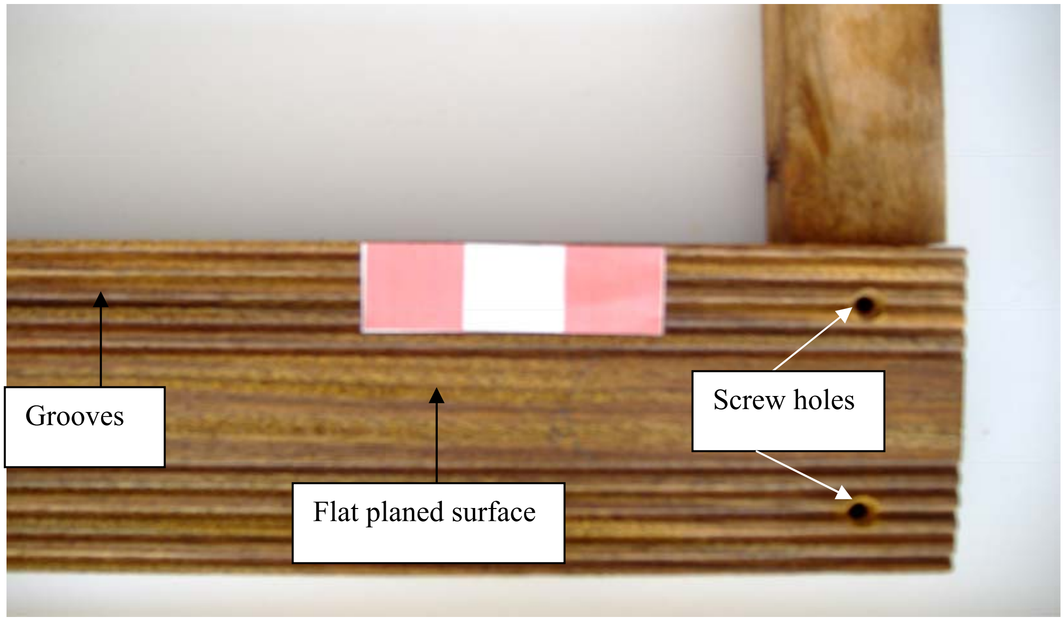


Figure 4.1 Decking board.

Prior to exposure in the field, half of the decking boards of each species were treated with clear decking oil (Liberon Ltd). This was applied to the upper faces of the boards only, at an application rate of 0.25 litres per m^2 using a brush and left for 48 hours to dry at 20°C and 65% relative humidity.

The colour of each board was assessed at three positions on the upper face using a Minolta chromameter and the L* a* b* colour axis system. The boards were marked in such a way that the colour of wood could always be assessed at exactly the same position. Any defects to the board surfaces were recorded. Each deck board was weighed to the nearest 0.01grams and their moisture contents determined using an electrical resistance moisture meter (Brookhuis Ltd).

4.2.2.2 Preparation of cross pieces

The cross pieces are designed to simulate performance of wood in garden furniture, where timber components overlap. The cross pieces measure 200mm x 50mm x 10mm lbh and were planned. Half of the samples were treated with teak oil (Barrettine Products) prior to exposure with the same quantity of oil applied per unit area rate as for the decking samples and allowed to dry for 48 hours. These pieces were laid across each other at 90° prior to exposure (Figure 4.2). Some of the samples were fixed with dowels and others screws. The colours and moisture contents of the cross pieces were measured prior to exposure using the same methods as 3.2.2.1

4.2.2.3 Preparation of lap joint pieces

Lap joint pieces are designed to simulate performance of wood in garden furniture where a number of joints overlap where wood at the lap is prone to have elevated moisture content.

The samples were processed to the following dimensions 300mm x 50mm x 22mm lbh. Samples were then machined to 11mm thickness to 150mm from one end as shown in Figure 4.3. Half of the samples were treated with teak oil with the same quantity of oil applied per unit area as for the decking samples. These samples were fixed in such a way that the thinner portions overlapped (Figure 4.5). The colours and moisture contents were measured prior to exposure as for the decks

Figure 4.2 Denya cross piece.

Figure 4.3 Denya lap joint.

Figure 4.4 Fixed cross piece.

Figure 4.5 Fixed lap joint.

4.2.3 Methods used to expose field test samples

Deck boards were screwed onto 50mm diameter softwood joists with 780mm spans. The cross piece and lap joint samples were initially fixed onto plywood then fixed onto the softwood frame. Figure 3.6 shows the deck boards, cross pieces and lap joints exposed at the field test site.

Figure 4.6 Installed decks, cross pieces and lap joints.

Samples were exposed from 2^{nd} June 2006 at Piggots Farm, North Dean, Buckinghamshire. At intervals of 1, 2, 3 and 6 month intervals, samples were removed from the field test site and returned to FPRC laboratories for assessment.

4.2.4 Methods used to assess field test samples following exposure

Following exposure intervals specified in 3.2.3, oil treated and untreated decking boards and cross pieces were assessed. Moisture contents were determined through weight change and surface defects examined immediately at arrival at the laboratory. This enabled the moisture contents and checks to be examined before the specimens conditioned. Colour change and stain was assessed following 48 hours, once the specimens had conditioned so that wood moisture content did not interfere with the colour measurement.

4.2.4.1 Wood Colour Measurement

Wood colour was assessed using the L*a*b* or (CIELAB) modes. The L* mode measured lightness with a shift from a positive to negative value indicating darkening. The a* mode has red as a positive value and green negative, while the b* mode, records yellow as positive and blue negative. Using the L*a*b* values, it was possible to assign a colour to each timber.

L* a* and b* measurements were taken at three identical positions on each sample prior to exposure and following each exposure period using a Minolta chromameter and recorded. These were used to calculate average L* a* and b* values.

Following each exposure period the overall colour change was determined using the following equation.

$\Delta E = \sqrt{} (L^*i-L^*f)^2 + (a^*i-a^*f)^2 + (b^*i-b^*f)^2$

Where i = initial measurement and f = final measurement

To assess which of the L*a* and b* values were responsible for the overall colour change, then the percentage colour change for the L*a* and b* values were also presented according to the following equation

$\% \text{ change} = ((a-b)/a)*100$

Where a = L* a* or b* value prior to exposure

b = L* a* or b* value post exposure

4.2.4.2 Measurement of checks in wood specimens

Checks were assessed at three pre-determined positions on the upper surface of each decking board. Each position measured 80x 80mm. The number of checks falling within each area was determined. The number of checks within the range 5-20mm, 20-40mm and 40-80mm were recorded.

The number of checks on the surface of the upper cross piece was determined for an area measuring 200 x 50mm. The number of checks measuring 10-80mm, 80-120mm and 120-200mm were recorded.

4.2.4.3 Measurement of stain and decay of specimens exposed in the field

The amount of stain present on the upper faces of the boards and cross pieces were assessed through estimating the percentage surface area stained following each exposure period. Staining was assessed over an area measuring 100mm x 800mm for each deck board , and 50mm x 200mm was for the cross pieces. Additional, assessment of stain was undertaken where the pieces overlapped for the cross pieces, on an area measuring 50mm x 50mm.

Wood decay was assessed in the lap joint samples. The lap joints were separated and the moisture content of the wood comprising the joint was assessed. The wood in this region was assessed for the presence of mycelium and surface softening resulting from decay organisms. Wood decay was assessed by the detection of surface softening using an awl.

Small cubes of wood $0.25cm^3$ were removed from the surface of the weathered specimens. These were mounted on aluminium stubs and gold coated. The surfaces of the samples were examined in an electron microscope using methods provided in Pandey and Pitman (2002).

4.2.4.4 Analysis of surface chemistry using FT-IR

Specimens of denya, dahoma, esa, iroko, A. mahogany, teak, and oak exposed in the field were used in to study changes in surface chemistry. Small samples $2mm^2$ were removed from the surface of each sample following different exposure periods.

FTIR was performed by transmittance using a Perkin Elmer Spectrum One with Universal ATR sampling accessory. Spectra were measured at a spectral resolution of $(4cm)^{-1}$ and good quality spectra were generally obtained according to the smoothness of the baseline. Peak areas were measured at wave numbers known to correspond to functional groups in cellulose, hemicelluloses and lignin. Peak areas were determined using Spectrum software by constructing connecting points either side of the peak.

Ratios of peak areas for wave numbers corresponding to cellulose and lignin were calculated against $(895cm)^{-1}$. The influence of exposure period on the chemistry of structural polymers was compared as was the influence of teak oil and decking oil.

4.2.4.5 Assessment of weathering in the laboratory

Denya, esa, dahoma and teak samples were planed to dimensions of 150 x 75 x 18mm. One sample of each species was treated with deck oil, one with teak oil and the other left untreated. Both oils were brush applied at the same loading as the field exposure samples and allowed to dry for 48 hours in the laboratory. The colours of the surfaces of each sample were recorded at three pre-determined positions. The samples were then transported to Osmose UK, where a QUV Weatherometer was used to test the weathering performance of the species. The weatherometer was adjusted to give alternate UV exposure and wetting cycles with 4 hours for each cycle. Samples were exposed to alternate cycles for a period of two-weeks. After this period surface colour and chemistry were assessed.

4.3 Results

4.3.1 Wood Colour Measurement

4.3.1.1 Initial colour values for LUS and reference species

The initial colour values for of the lesser utilised species and reference species are provided in Figures 4.7 and 4.8.

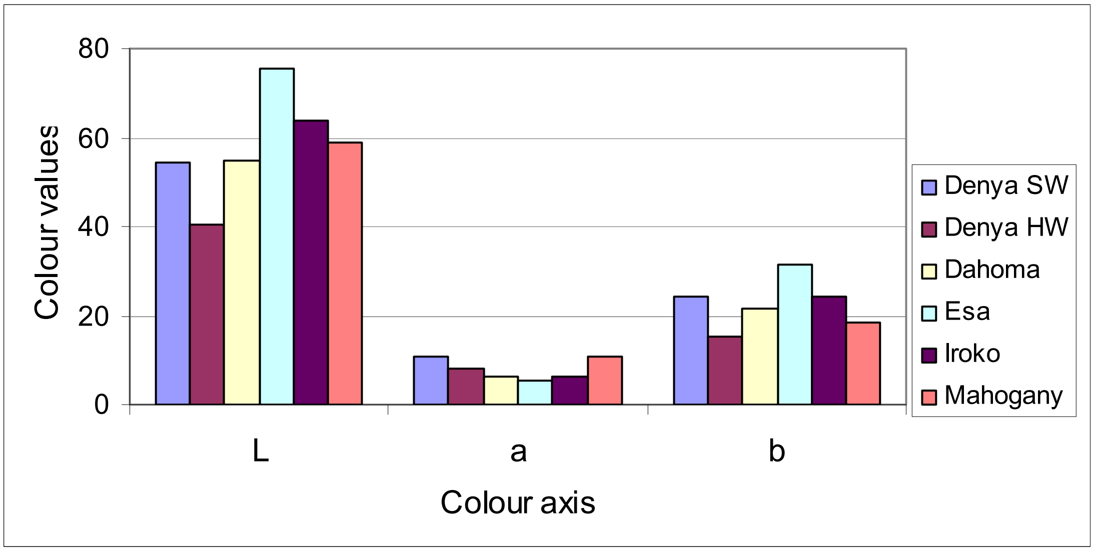


Figure 4.7 Average colour values for untreated planed wood prior to exposure.

Where; HW = Heartwood and SW = Sapwood

Figure 4.7 shows the greatest L* value to be found in esa. This indicates that this was the lightest species at the start of the test. Iroko was next lightest. In contrast, denya heartwood was darkest with the sapwood of this species somewhat lighter.

The a* and b* values describe hue and chroma. The a* values for all species range from 8-10 meaning samples were more red than green. Values for b* show that the samples were more yellow than blue. Esa had the highest b* value.

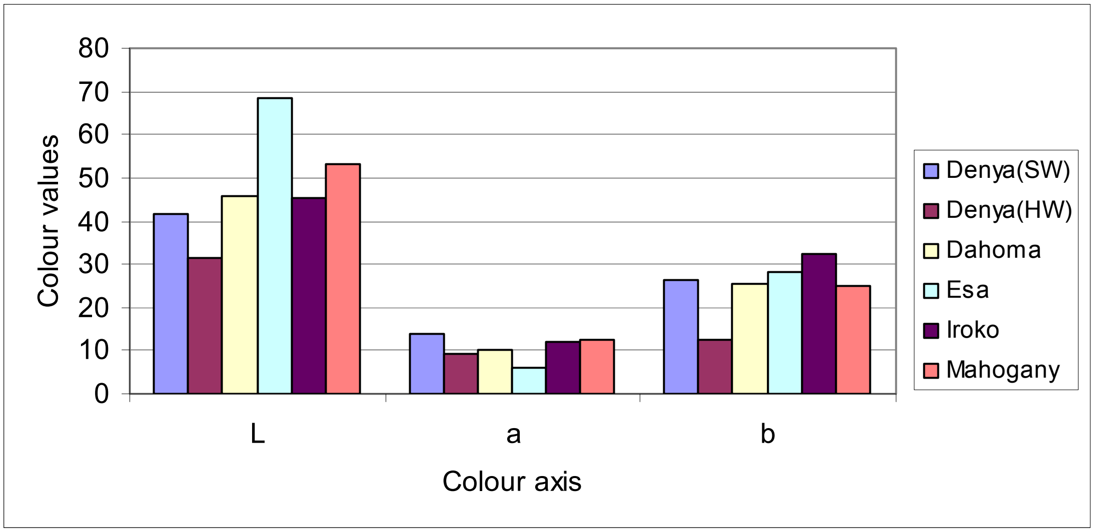


Figure 4.8 Average colour values for wood treated with decking oil prior to exposure.

Where; HW = Heartwood and SW = Sapwood

When the L* values for wood treated with decking oil (Figure 4.8) are compared with those for untreated wood (Figure 4.7). Then in all cases there has been a reduction in the L* value indicating that all species darken following oil treatment. The a* values increased with treatment indicating that wood treated with oil became more red following treatment. For the b* values, then in some cases these increased (e.g. denya heartwood) while in others they decreased following oil treatment (e.g. iroko).

4.3.1.2 Final colour values for LUS and reference species following field exposure

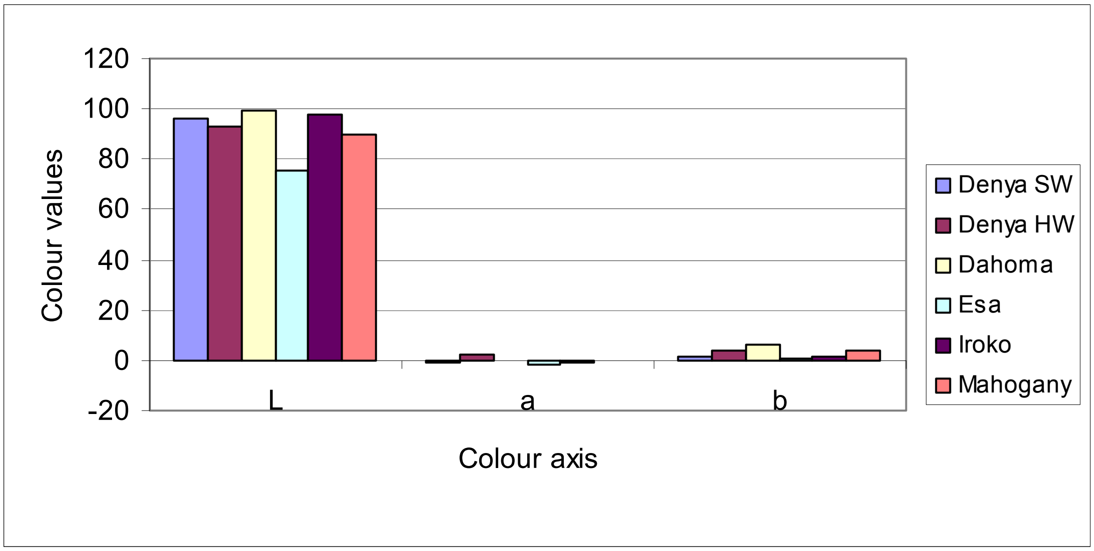


Figure 4.9 Final colours of untreated planed wood decking boards after six months field exposure.

Where; HW = Heartwood, SW = Sapwood

Figure 4.9 shows the L* a* and b* values for the surfaces of untreated timbers following six months of exposure in the field.

Following six months exposure, the L* values for most species increased indicating they have lightened over the exposure period. Interestingly, the L* value for esa had not increased probably since this timber is already light in colour (Figure 4.9). For other species such as dahoma, there was a large increase in L* value.

With respect to the a* value, then for all species there has been a shift from red towards green with the value being low. This is an indication of the wood greying during weathering. For some species the value is assigned a negative.

In the case of the b* value, then there has also been a shift for all species from yellow towards blue chroma following exposure. Again the chroma value is low indicating the substrate is greying

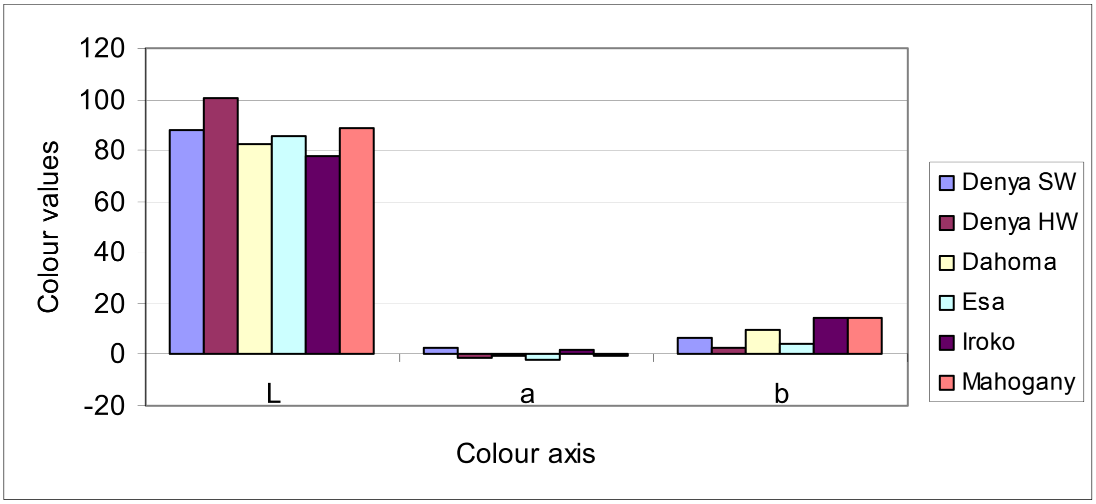


Figure 4.10 Final colour values for wood treated with decking oil and exposed in the field.

Where; HW = Heartwood, SW = Sapwood

Figure 4.10 shows that the exposed faces of all samples lightened with exposure (i.e. the L* value increased). Denya heartwood has the highest L* value followed by denya sapwood and A. mahogany, esa, dahoma and iroko in that order. However, when the L* values for wood surfaces treated with decking oil are compared with those that are untreated, then there is a trend for the L* value to increase less for treated surfaces.

With respect to the a* value, then all species moved from dark red towards green. Although in all the samples in the b* axis moved from yellow towards blue, the values obtained were higher than those in the planned samples.

4.3.1.3 Overall colour changes

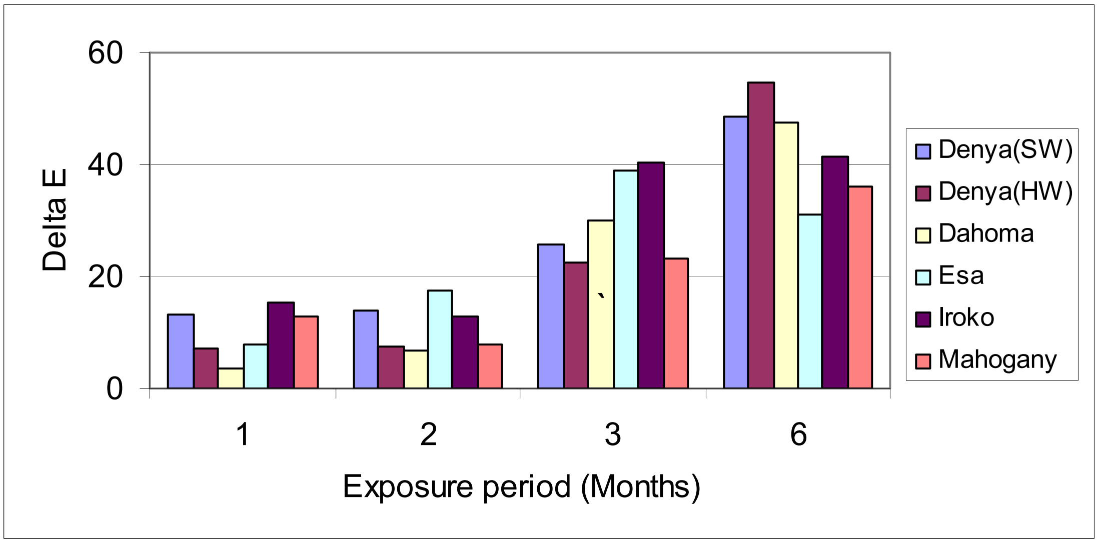


Figure 4.11 Overall colour changes in planed and weathered decking board samples.

The ΔE value provides a measure of overall colour change to the weathered surface of each species. The average ΔE values following each exposure period are presented in Figure 4.11. It can be seen that the value increases for each species with continuing exposure period. This suggests that surface colour will continue to change with exposure.

For individual species, then after the first month of exposure the greatest shift in ΔE value was seen in iroko. Interestingly the increase in value between 3 and 6 months of exposure was slight. This suggests that iroko is the least colour stable species and its colour changes quickly early on in exposure. In contrast, dahoma and denya heartwood have relatively little colour change following one and two months of exposure but show the greatest overall colour change following six months.

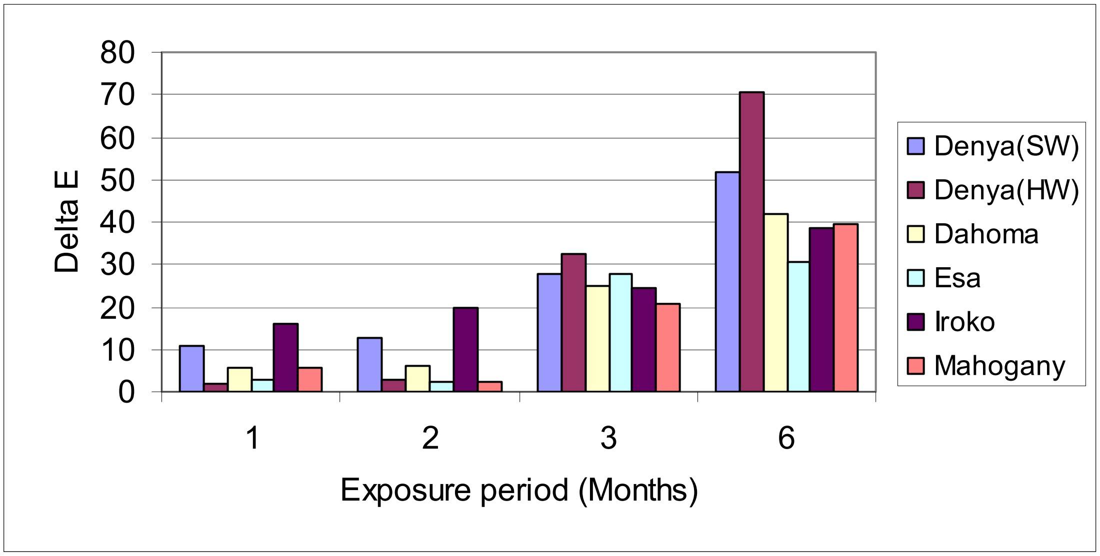


Figure 4.12 Overall colour changes in decking boards treated with decking oil and exposed out of doors for six months.

Figure 4.12 shows that as for the untreated boards, none of the timbers treated with decking oil were photostable. That means that the colours of all samples changed with time. However, for most species the rate of colour change (as indicated by ΔE) was lower over the first two months of exposure

Figures 4.13 to 4.26 show the surfaces of the decking boards untreated or treated with decking oil prior to exposure and following exposure for six months.

Figure 4.13 Iroko decking board untreated prior to exposure.

Figure 4.14 Iroko decking board untreated exposed to weathering for six months.

Figure 4.15 Iroko treated with deck oil unexposed.

Figure 4.16 Iroko treated with deck oil and exposed out of doors for six months.

Figure 4.17 Esa treated with deck oil unexposed.

Figure 4.18 Esa treated with deck oil and exposed for six months out of doors.

Figure 4.19 Denya heartwood planned unexposed.

Figure 4.20 Denya heartwood planned exposed out of doors for six months.

Figure 4.21 Denya heartwood treated with decking oil unexposed.

Figure 4.22 Denya heartwood treated with decking oil weathered out of doors for six months.

Figure 4.23 Untreated denya sapwood unexposed.

Figure 4.24 Untreated denya sapwood exposed out of doors for six months.

Figure 4.25 Denya sapwood treated with decking oil unexposed.

Figure 4.26 Denya sapwood treated with decking oil exposed out of doors for six months.

4.3.1.4 Colour changes in cross pieces

Colour changes were assessed in the cross pieces as these were treated with teak oil. Results are presented diagrammatically below

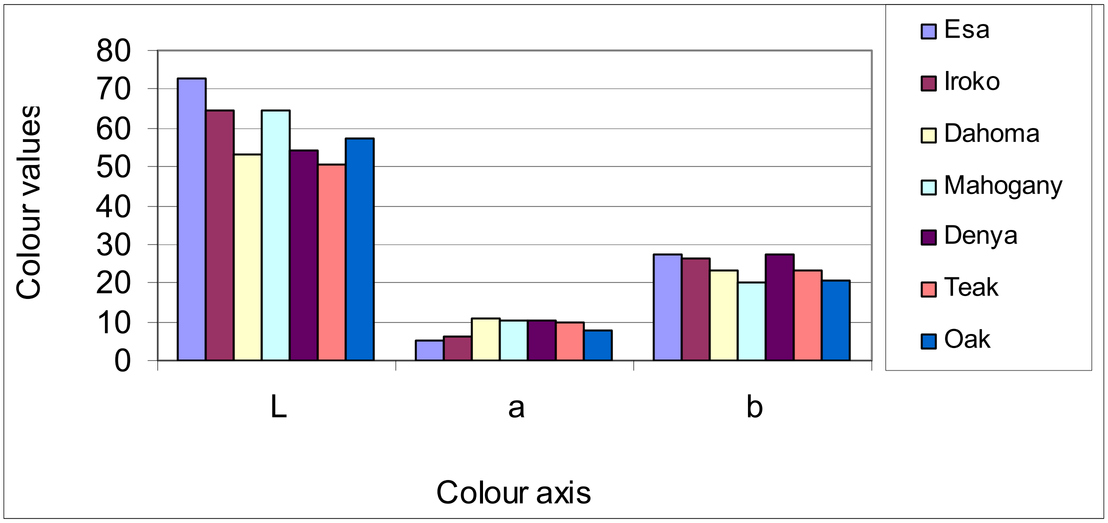


Figure 4.27 L* a* and b* values for untreated, unexposed cross pieces.

All the species were lighter before exposure with esa being lighter than the others on the L* axis. Teak had the least colour in terms of lightness.

On the a* axis all the species recorded a dark red colouration with esa, iroko and oak recording slightly lower values than the others.

The b* axis had all the species being yellow as shown in Figure 4.27. Oak had the least value in terms of yellowing.

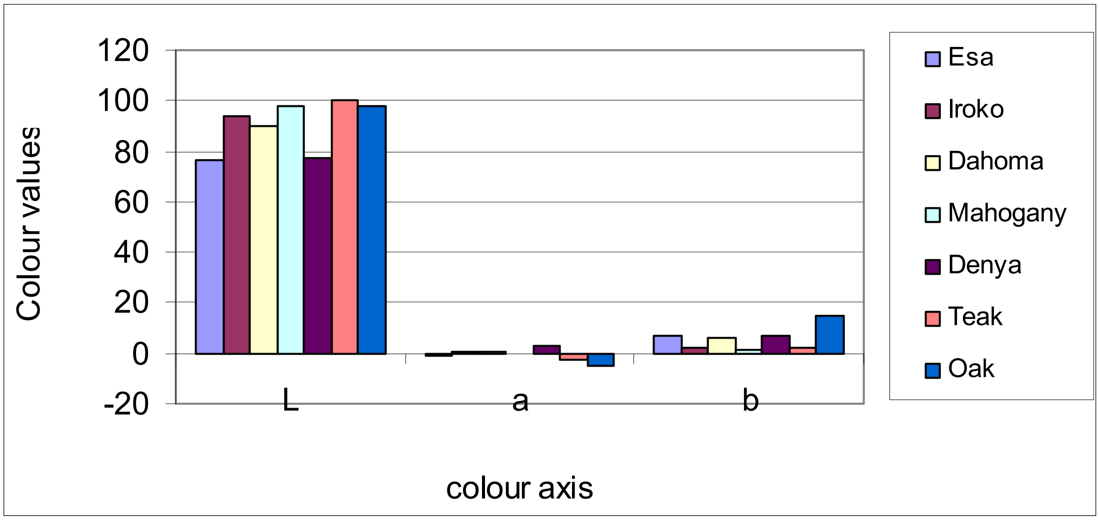


Figure 4.28 L* a* and b* values for untreated, exposed cross pieces weathered for six months.

Figure 4.28 shows the L* values for the surfaces of the cross pieces following six months exposure. All values increased. Teak had the highest value following exposure with esa and denya the lowest. This indicate teak had lightened most and esa and denya the least.

On a*axis all the species moved from red towards green at the end of the exposure period.

The b* axis recorded a movement of all the species from yellow towards blue. The least change was recorded in Oak.

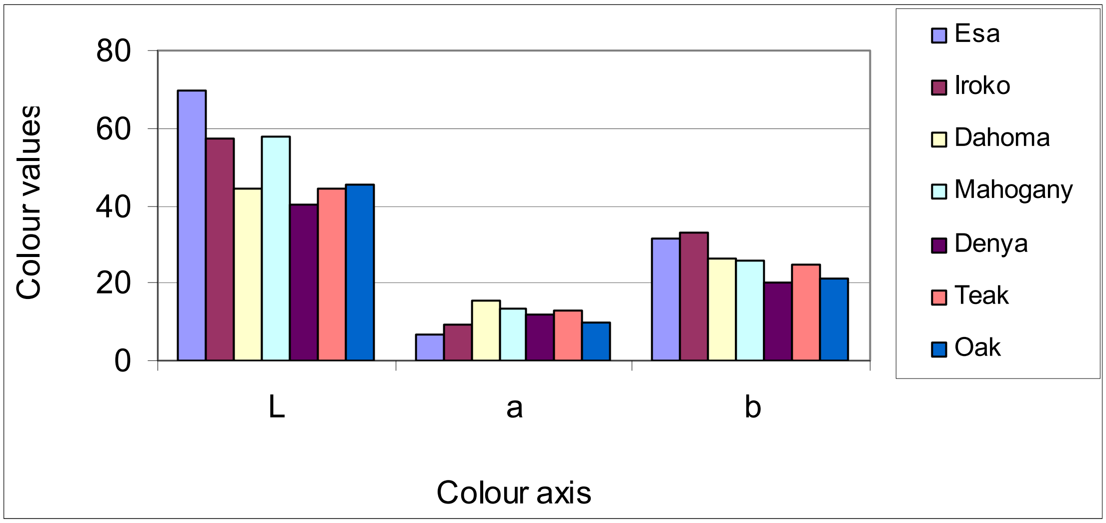


Figure 4.29 L*a* and b* values for cross pieces treated with teak oil prior to exposure.

The L* values in Figure 4.29 reveal that all the species were lighter with esa achieving the highest value and denya the lowest.

Values achieved in a* indicate all the species were dark red with dahoma having the highest value. The least value was in esa.

The b* values reveal all species being yellow with iroko making the highest and denya the least.

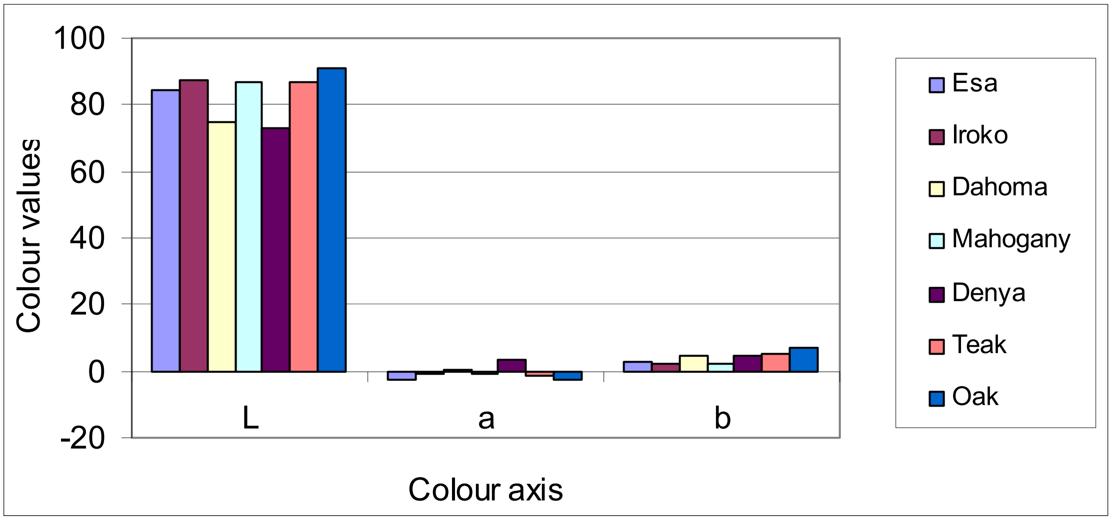


Figure 4.30 Cross pieces treated with teak oil and exposed for six months.

The L* values indicated all the species turned lighter after exposure with Oak having the highest value and denya the lowest.

Values for a* reveal all species moving from dark red towards green.

On the b* axis all species moved from yellow towards blue with oak having the least movement.

4.3.1.5 Overall colour changes in cross pieces

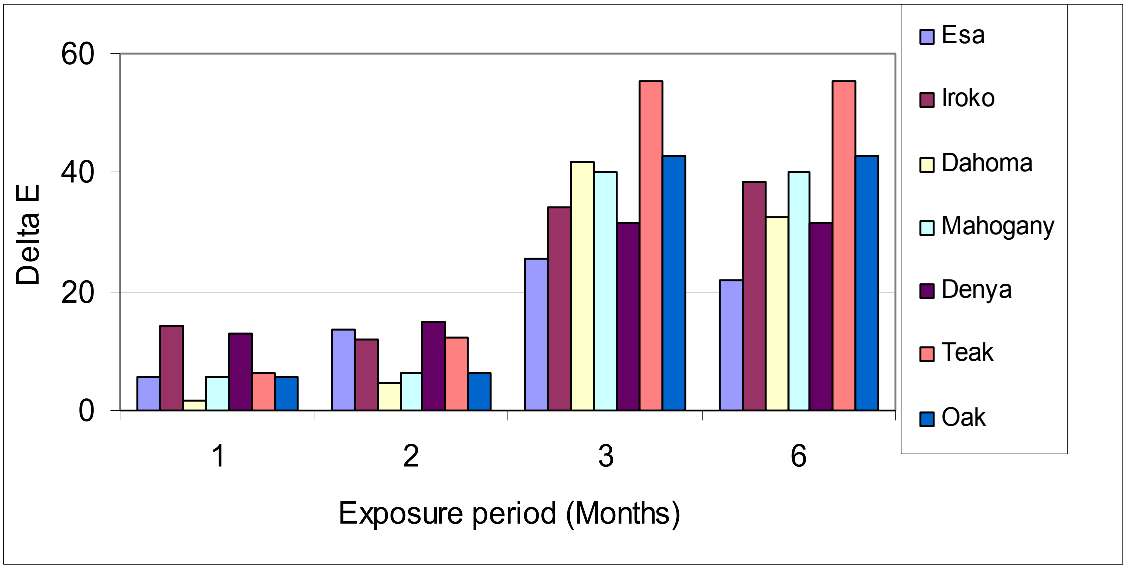


Figure 4.31 Overall colour changes in untreated cross pieces weathered for six months.

There is a trend for the ΔE value to increase across the exposure period, with the exception of esa and dahoma that increased until the third month but decreased by the sixth month. Teak had the greatest change over the period with esa achieving the lowest. Interestingly, mahogany, teak and oak showed no further change in ΔE value between 3 months and 6 months exposure suggesting that their colours had become stable. As for the decking the species that showed the greatest colour change following one month of exposure was iroko that indicates that this species is likely to show the greatest change in colour early on following exposure.

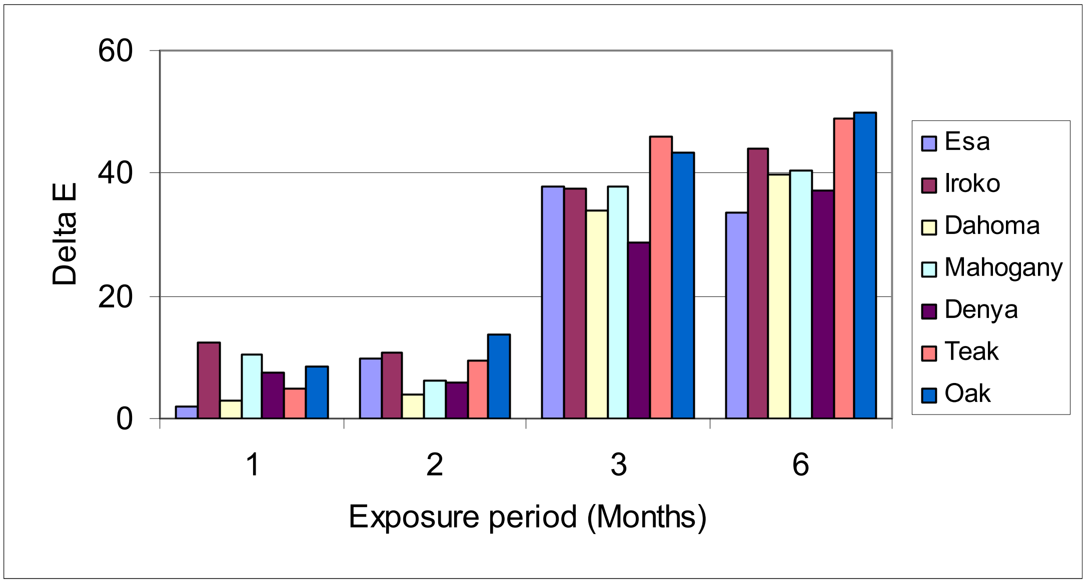


Figure 4.32 Overall colour changes in cross pieces treated with teak oil and exposed for six months.

Results obtained for teak-oiled samples show that with the exception of esa the ΔE value increases with exposure. The teak oil does appear to reduce the colour change for some species, with a lower value being recorded in teak following six months exposure when it had been treated with oil. However, for oak it has increased. This possibly results from the colour values for this species being lower in teak-oiled samples at the start of the test.

4.3.1.6 Percentage colour changes

Although the ΔE value provides us with an understanding of the overall colour change to the surfaces of the wood specimens during weathering, it provides no information on changes in the individual L* a* or b* values.

4.3.1.6.1 Percentage colour changes of decking boards

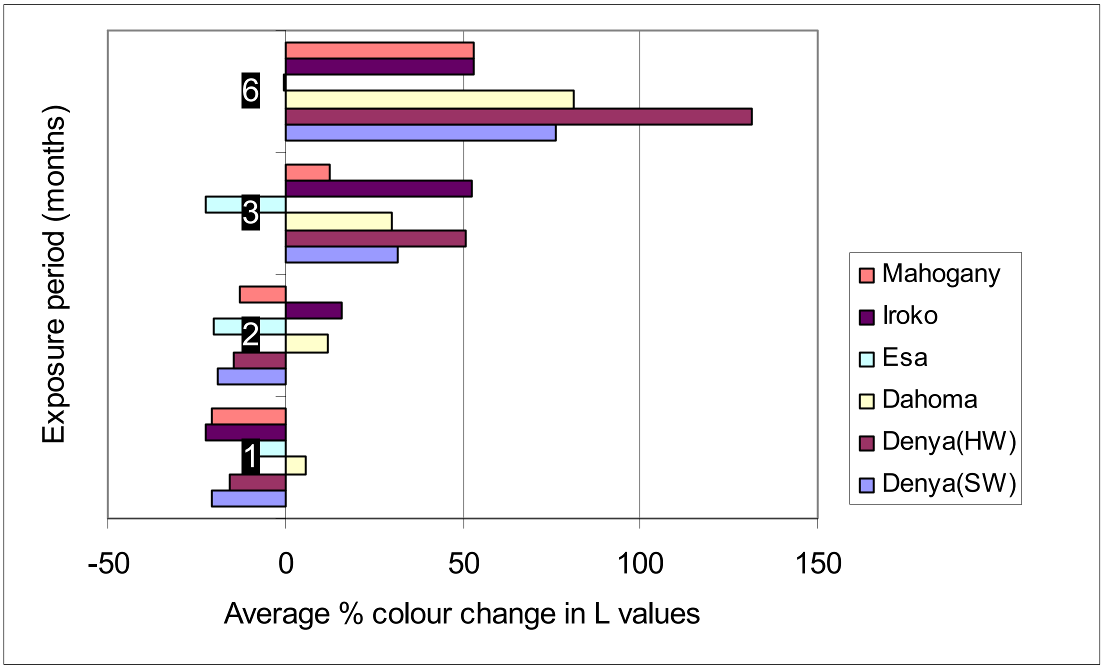


Figure 4.33 Average percentage change in L* values for untreated decking boards over the exposure period.

Figure 4.33 shows a reduction in L* value for all the species in the first month with the exception of dahoma. After two months of exposure, dahoma and iroko increased in lightness, while there was a reduction in lightness for all other species. With the exception of esa all species increased in lightness following 3 and 6 months of exposure. The greatest change in lightness occurred in iroko.

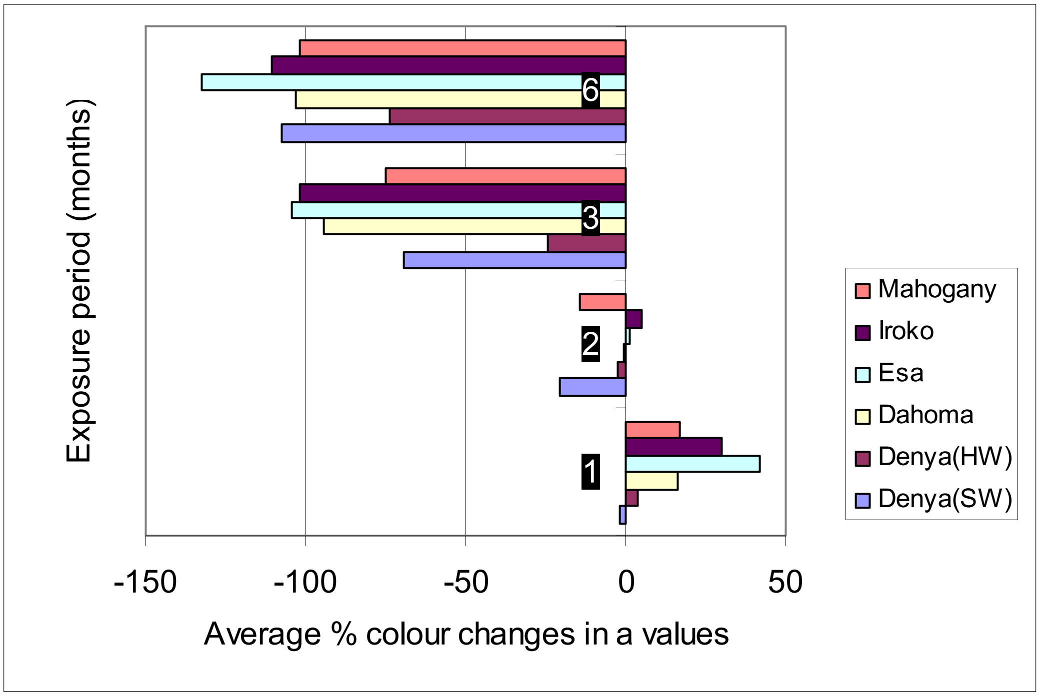


Figure 4.34 Average percentage change in a* values for untreated decking boards over the exposure period.

All species changed positively with the exception of denya sapwood the first month in the a* values. Although all the species moved in the negative direction during the second month onwards, iroko and esa had less positive change during the second month and changed negatively onwards.

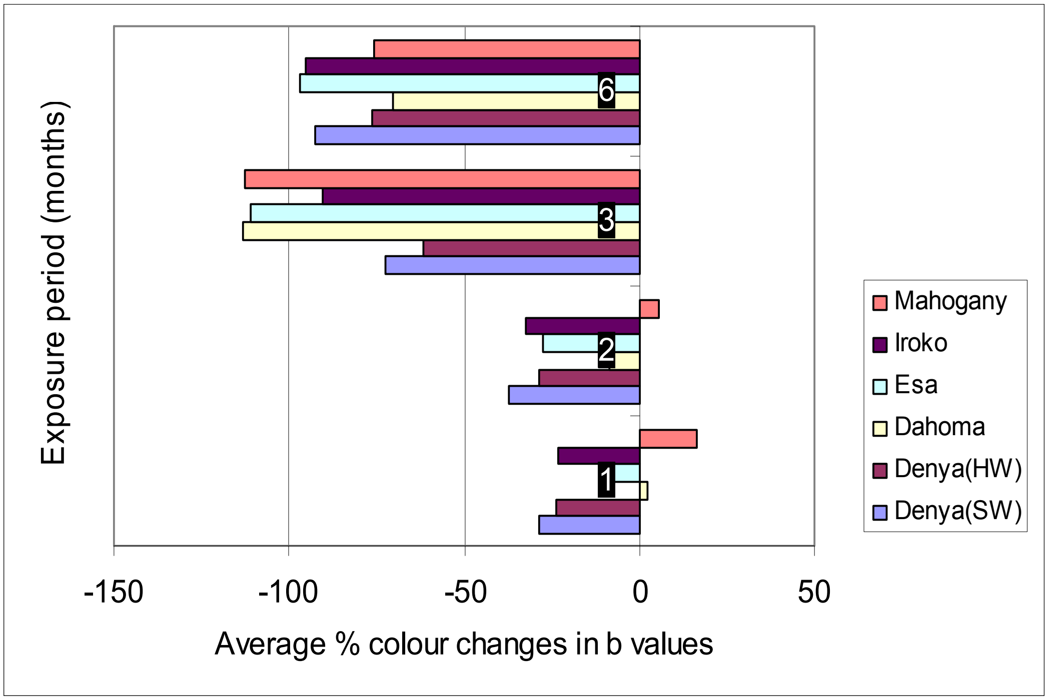


Figure 4.35 Average percentage change in b* values for untreated decking boards over the exposure period.

Figure 4.35 shows A. mahogany and dahoma changed positively the first month, with only A. mahogany changing positively the second month. All other species changed negatively throughout the exposure period.

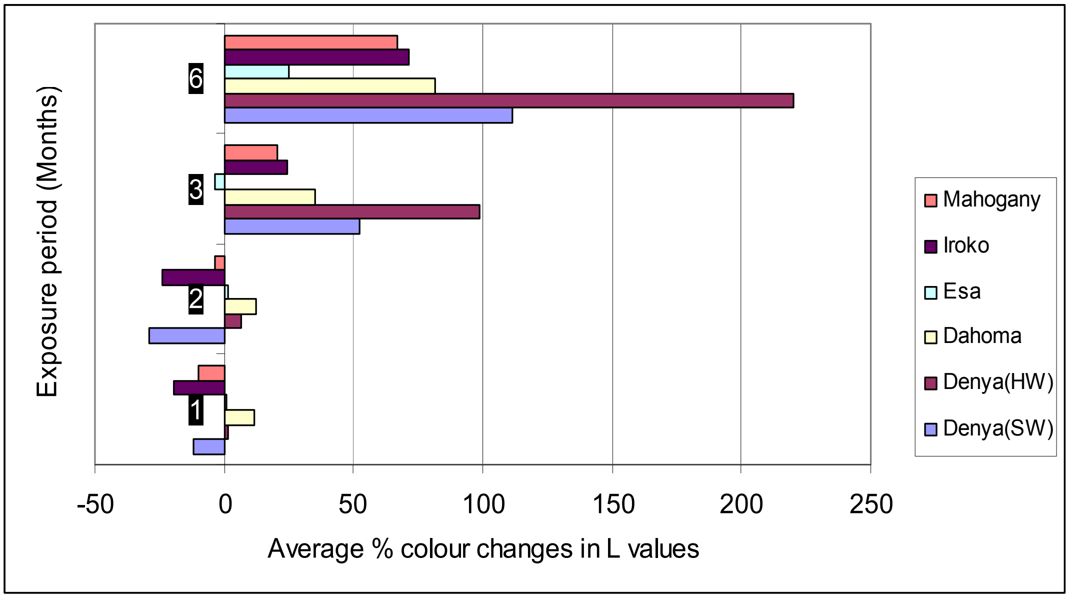


Figure 4.36 Average percentage change in L* values for treated decking boards over the exposure period.

When the change in L* value for the decking boards coated with decking oil was compared with those exposed untreated then the reduction in lightness only occurred in three species, though to a lesser degree than for untreated boards. Interestingly, the L* value increased after one months exposure for esa and denya heartwood as well as dahoma.

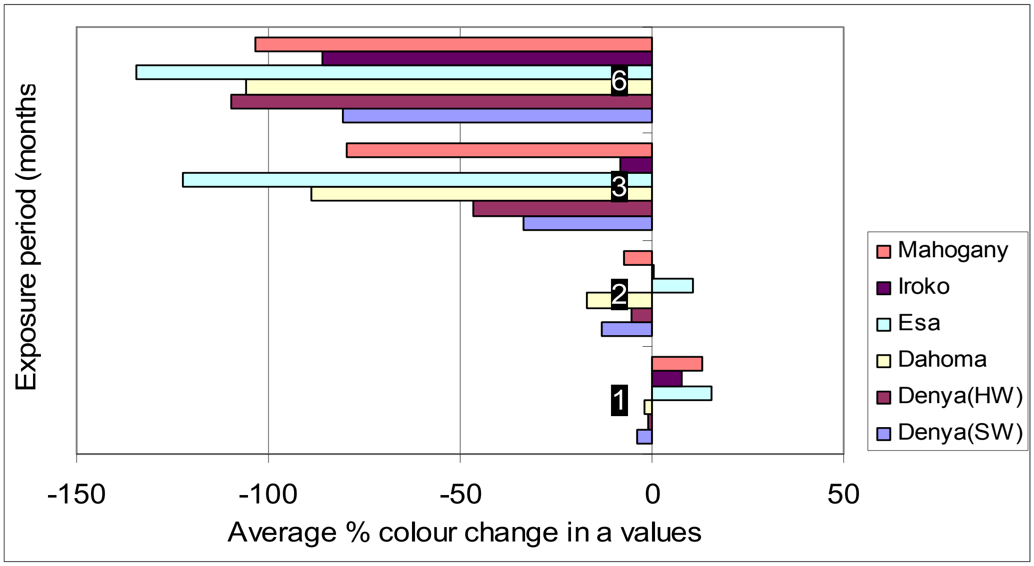


Figure 4.37 Average percentage change in a* values for treated decking boards over the exposure period.

Figure 4.37 shows A. mahogany, esa and iroko changing positively the first month with only esa changing positively the second month. All the other species changed negatively throughout the period.

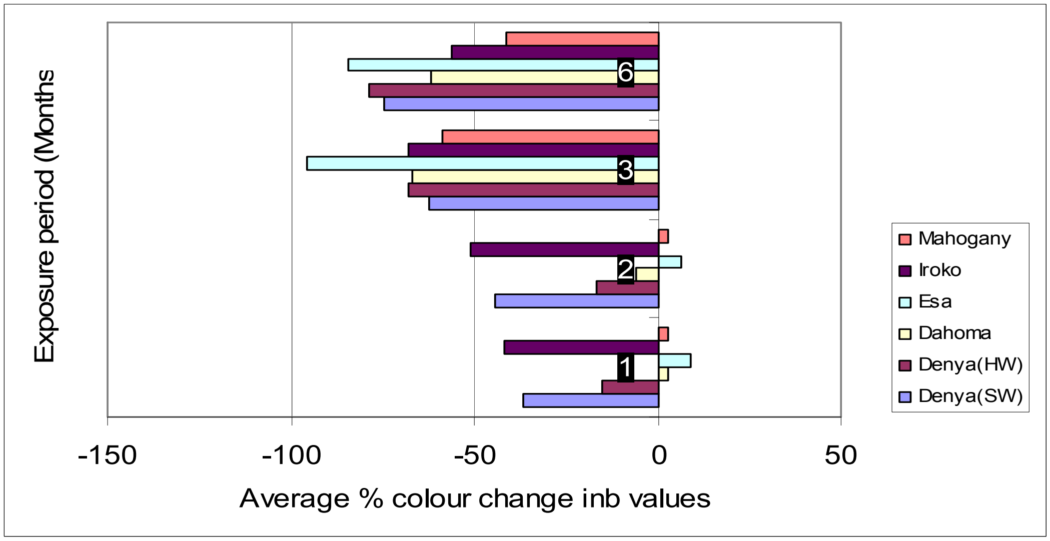


Figure 4.38 Average percentage change in b* values for treated decking boards over the exposure period.

A. mahogany and esa changed positively the first two months whiles dahoma only changed positively the first month. All the other species changed negatively throughout the period. Esa, had the highest negative change.

4.3.1.7 Percentage colour change for untreated cross pieces

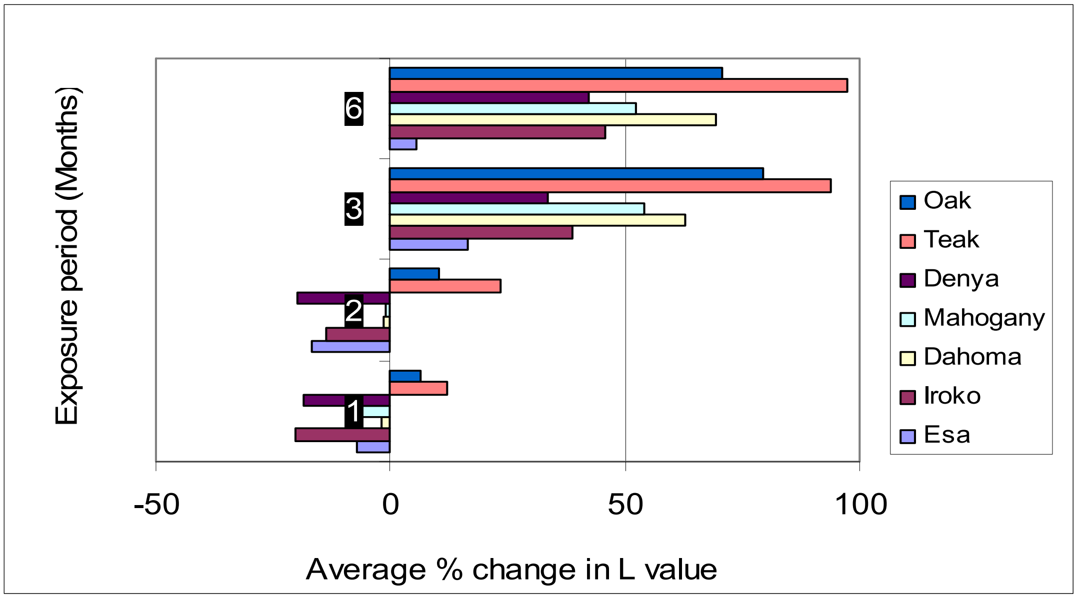


Figure 4.39 Average percentage change in L* values for untreated cross pieces over the exposure period.

Figure 4.39 indicates that with the exception of teak and oak, all the other species had negative changes during the first and second months i.e. darkened, with increased lightness subsequently. Teak and oak increased in lightness throughout. The greatest change was in oak, while esa had the least change.

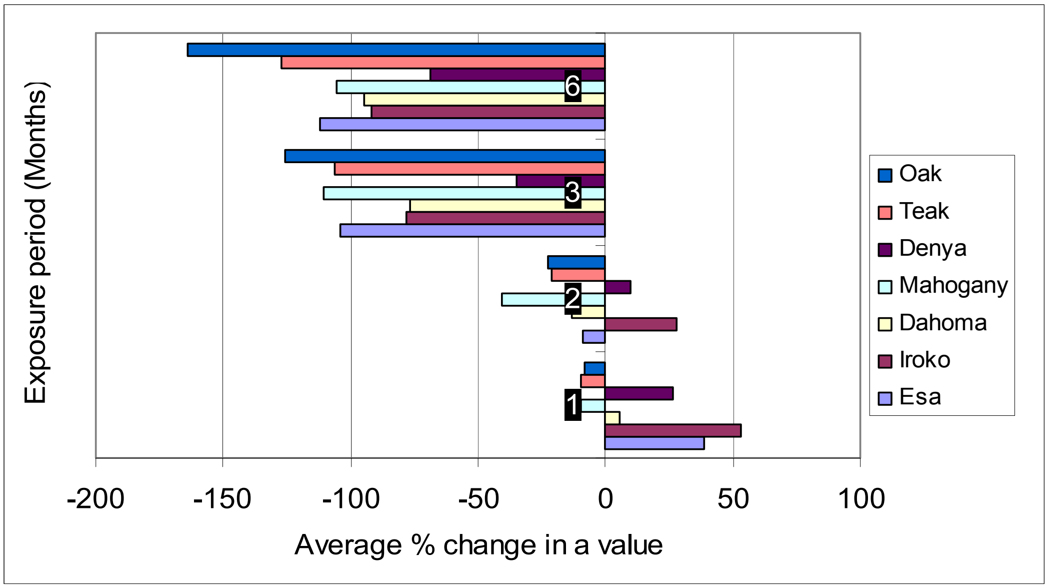


Figure 4.40 Average percentage change in a* values for untreated cross pieces over the exposure period.

The a* values showed a negative change for all the species throughout the exposure period with the exception of iroko and denya which positively changed for two months, and then changed negatively throughout. Esa only changed positively in the first month and negatively changed till the end of exposure. Oak had the highest change with the least change in denya.

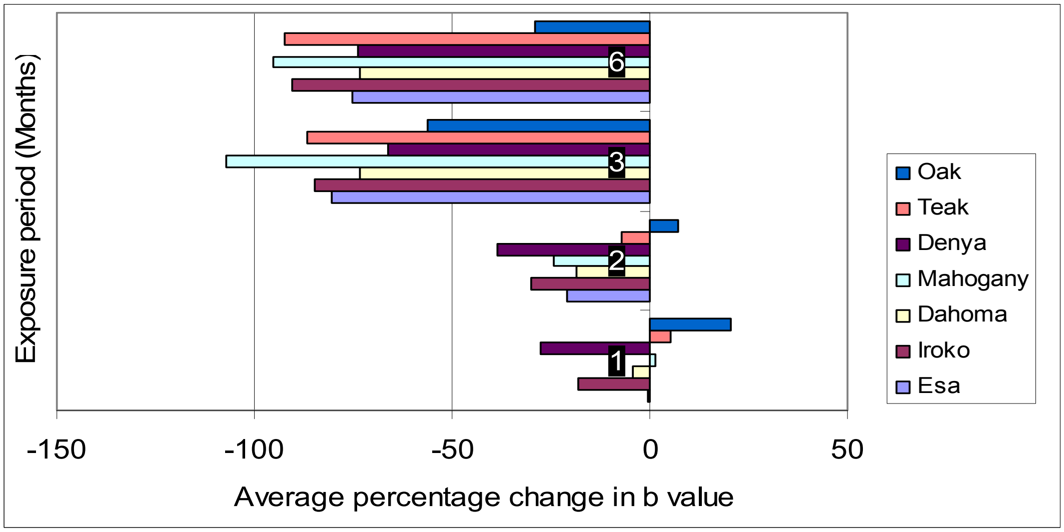


Figure 4.41 Average percentage change in b* values for planned cross pieces over the exposure period.

Figure 4.41 indicates a total negative change for all the species with the exception of oak and teak. Oak changed in the positive direction for two months and then changed negatively, while teak only changed positively for only one month and changed negatively till the end of exposure. The highest change was in African mahogany and the least change was in oak.

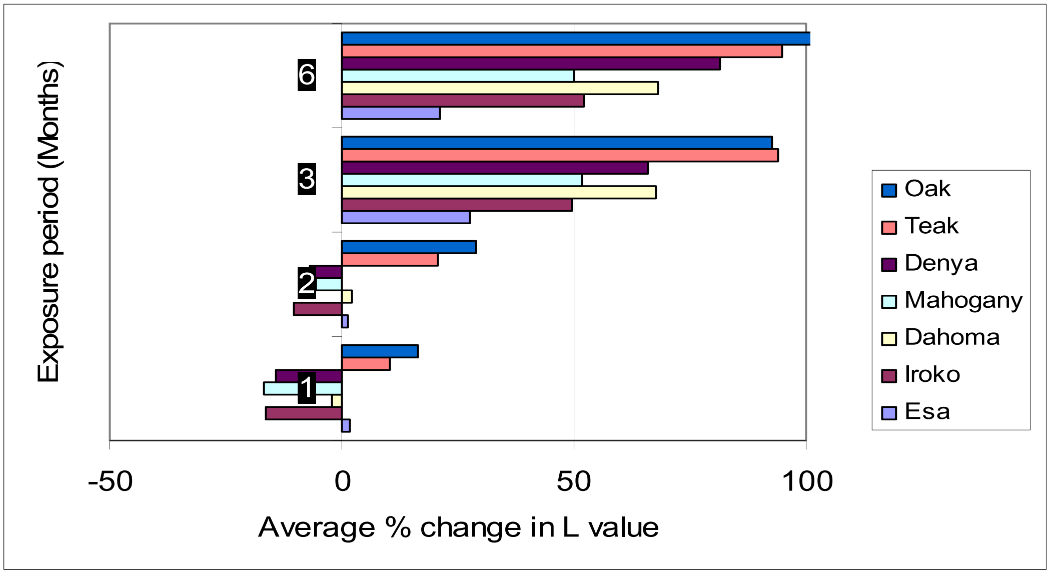


Figure 4.42 Average percentage change in L* values for cross pieces treated with teak oil over exposure period.

In figure 4.42, iroko, A. mahogany and denya changed negatively for two months and changed positively till the end of exposure. Dahoma changed negatively for one month and changed positively the subsequent months. All the other species changed positively till the end of exposure period. Oak had the highest change and esa the least change.

Untreated cross pieces changed more positively than the treated ones. Values obtained for treated cross pieces were higher in the negative than the planned ones.

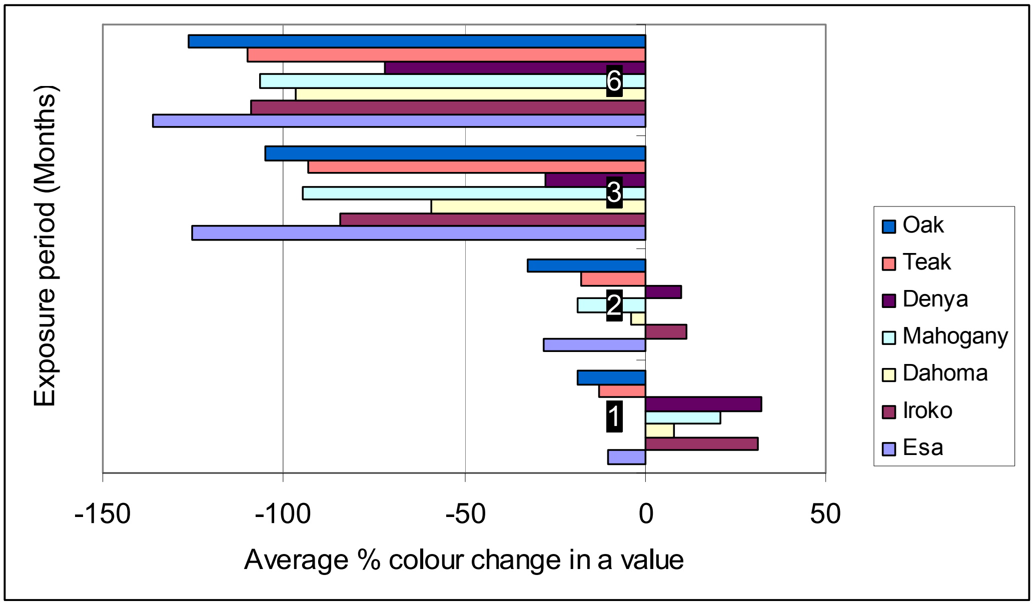


Figure 4.43 Average percentage change in a* values for cross pieces treated with teak oil over the exposure period.

Iroko and denya changed positively for two months and moved in the negative direction till end of exposure period. African mahogany changed positively for a month and moved negatively till end of exposure. All the other species changed positively till end of exposure. Esa had the highest change and denya the least change.

The untreated cross pieces are having values that are higher in both the positive and negative than the treated cross pieces.

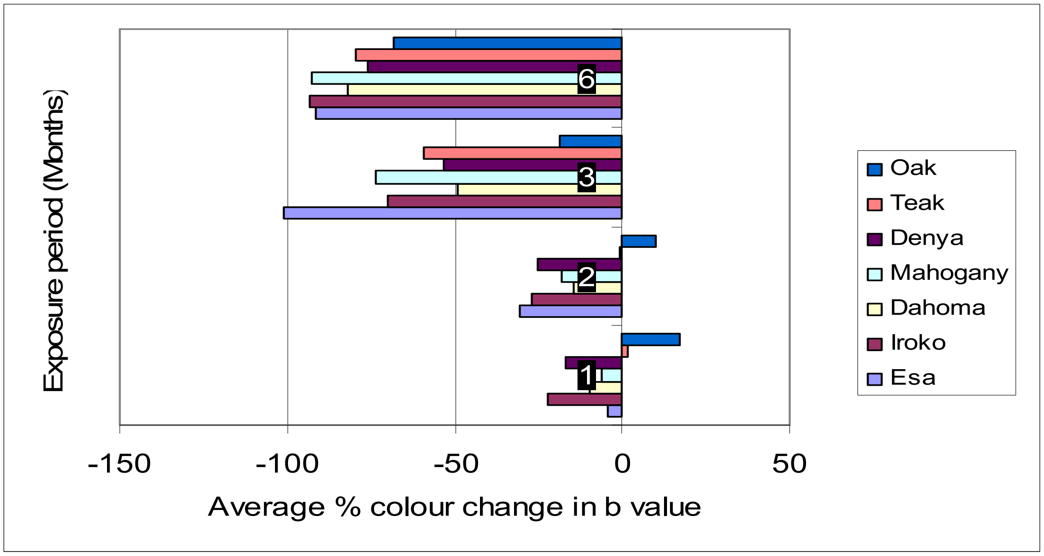


Figure 4.44 Average percentage change in b* values for cross pieces treated with teak oil over exposure period.

Figure 4.44 indicates oak changed in the positive for two months and changed negatively throughout. Teak changed positively for a month and negatively changed throughout the exposure period. Esa had the highest change and denya the least change.

A comparison of untreated cross pieces and treated ones reveal that the untreated samples changed more in the negative direction than the treated ones.

4.3.2 Assessment of checking

4.3.2.1 Checking in decking boards

Results for checking in decking boards exposed between June and September and examined in September 2006 are presented in Table 4.1.

Species	Treatment	Average % moisture content	Length of check (mm)		
			40-80	20-40	5-20
Denya HW	Untreated	15	0	3	8
Denya HW	Decking oil	14	2	2	6
Denya SW	Untreated	17	10	20	15
Denya SW	Decking oil	17	0	0	0
Iroko HW	Untreated	20	0	0	0
Iroko HW	Decking oil	19	0	1	2
A. mahogany HW	Untreated	22	0	0	8
A. mahogany HW	Decking oil	18	0	0	0
Dahoma HW	Untreated	14	1	0	3
Dahoma HW	Decking oil	13	0	0	0
Esa HW	Untreated	13	12	15	20
Esa HW	Decking oil	14	6	3	8

Table 4.1 Numbers and length ranges of checks in decking boards exposed in the weathering trial and examined in September, 2006 together with moisture contents

Where HW= Heartwood and SW= Sapwood

Table 3.1 shows that the greatest numbers and lengths of checks were present in the surface of untreated denya heartwood and esa heartwood. With the exception of denya heartwood, those boards that had been treated with decking oil prior to exposure had fewer checks. The moisture contents of most of the decking boards treated with the decking oil was lower than untreated boards.

Figure 4.45 shows the surfaces of a denya decking board with checks in September 2006.

Table 4.2 reveals results of decking boards exposed from June to December and examined in December for checks over the period.

Species	Treatment	Average % moisture content	Length of check (mm)		
			40-80	20-40	5-20
Denya HW	Untreated	26	3	6	6
Denya HW	Decking oil	25	6	4	8
Denya SW	Untreated	23	12	8	14
Denya SW	Decking oil	26	0	0	1
Iroko HW	Untreated	35	0	0	0
Iroko HW	Decking oil	26	0	0	0
A. mahogany HW	Untreated	35	0	0	0
A. mahogany HW	Decking oil	27	0	0	0
Dahoma HW	Untreated	42	0	0	0
Dahoma HW	Decking oil	39	0	0	0
Esa	Untreated	48	2	6	12
Esa	Decking oil	51	2	3	8

Table 4.2 Numbers and length ranges of checks in decking boards exposed from June to December in the weathering trial and examined in December 2006 together with moisture contents.

Table 4.2 shows checks were present in two species when an assessment was made in December 2006. Untreated denya sapwood had the most checks. The number of checks on samples treated with decking oil was less. There was less checking in the surface of decking boards in December than September. The moisture contents of all species were higher in boards in December than September and for most the moisture contents of those treated with decking oil was lower.

Figure 4.46 Exposed face of a denya sapwood board with checks in December 2006

4.3.2.2 Checking in cross pieces

The table below shows results of cross pieces exposed from June to September for checks and examined in September 2006.

Species	Treatment	Average % moisture content	Length of check (mm)		
			120-200	80-120	10-80
Denya	Untreated	18	0	0	15
Denya	Teak oil	18	0	0	6
Iroko	Untreated	18	1	0	0
Iroko	Teak oil	15	0	0	0
Dahoma	Untreated	18	0	2	0
Dahoma	Teak oil	19	0	0	0
Esa	Untreated	26	3	2	5
Esa	Teak oil	22	0	1	1
Oak	Untreated	50	2	20	25
Oak	Teak oil	50	0	0	20
African mahogany	Untreated	14	0	0	0
African mahogany	Teak oil	14	0	0	0
Teak	Untreated	13	0	0	0
Teak	Teak oil	13	0	0	0

Table 4.3 Numbers and length ranges of checks in cross pieces exposed in the weathering trial and examined in September 2006 together with moisture contents.

Table 4.3 shows that oak had the greatest number of checks on its surface when examined in September. Teak oiled specimens of all species had fewer checks. Also species with the greatest numbers of checks had the highest moisture contents.

Figure 4.47 Checking on the surface of an untreated oak cross-piece in September 2006.

Species	Treatment	Average % moisture content	Length of check (mm)		
			120-200	80-120	10-80
Denya	Untreated	31	4	8	0
Denya	Teak oil	30	0	2	0
Iroko	Untreated	38	1	0	1
Iroko	Teak oil	35	0	0	0
Dahoma	Untreated	38	0	0	0
Dahoma	Teak oil	37	0	0	0
Esa	Untreated	54	0	0	1
Esa	Teak oil	51	0	0	0
Oak	Untreated	69	0	6	20
Oak	Teak oil	70	0	4	18
African mahogany	Untreated	34	0	0	0
African mahogany	Teak oil	31	0	0	0
Teak	Untreated	26	0	0	0
Teak	Teak oil	25	0	0	0

Table 4.4 Numbers and length ranges of checks in cross pieces exposed in the weathering trial from June to December and examined in December 2006 together with moisture contents.

Table 4.4 shows oak still had the greatest number of checks on its surface, though less than were recorded in September. Untreated samples had a higher degree of checking than those treated with teak oil. In all cases those cross pieces treated with teak oil had lower moisture content than those untreated.

Figure 4.48 Checking on the surface of an untreated oak cross-piece in December 2006.

4.3.3 Assessment of stain and decay

4.3.3.1 Stain in decking boards

After six months of field exposure staining was only observed on the surfaces of esa and dahoma decking boards (Table 4.5)

Species	Treatment	% surface area stained	Colour of stain
Esa	Untreated	75	Dark
Esa	Decking oil	50	Dark
Dahoma	Untreated	15	Light

Table 4.5 Extent of staining in decking boards assessed in December 2006.

Table 4.5 shows that staining only occurred in esa (treated and untreated) and to a lesser extent in dahoma following six months of exposure.

Figure 4.49 Stain on the surface of an untreated esa decking board.

4.3.3.2 Stain in cross pieces

Results obtained for cross pieces are tabulated below.

Species	Treatment	% surface area stained	Colour of stain
Esa	Untreated	80	Dark
Esa	Teak oil	60	Dark
Dahoma	Teak oil	5	Light
Oak	Teak oil	15	Dark

Table 4.6 Extent of staining in cross pieces assessed in December 2006.

As for the decks, table 4.6 showed untreated esa to have the highest percentage of staining. Although stain was also observed in the dahoma and oak the percentage of their surface area covered with stain was lower.

Figure 4.50 Stain on the surfaces of untreated esa cross pieces.

4.3.3.3 Analysis for wood decay in lap joints

Analysis of the inner surfaces of the laps (i.e. where the pieces overlapped) showed no decay to be present in any of the samples.

Mycelium was detected in two of the esa lap joint assemblies that is an early indication of colonisation by a wood decay fungus. In addition, esa stained where the timber had overlapped again indicating that substrate conditions support growth and development of fungi.

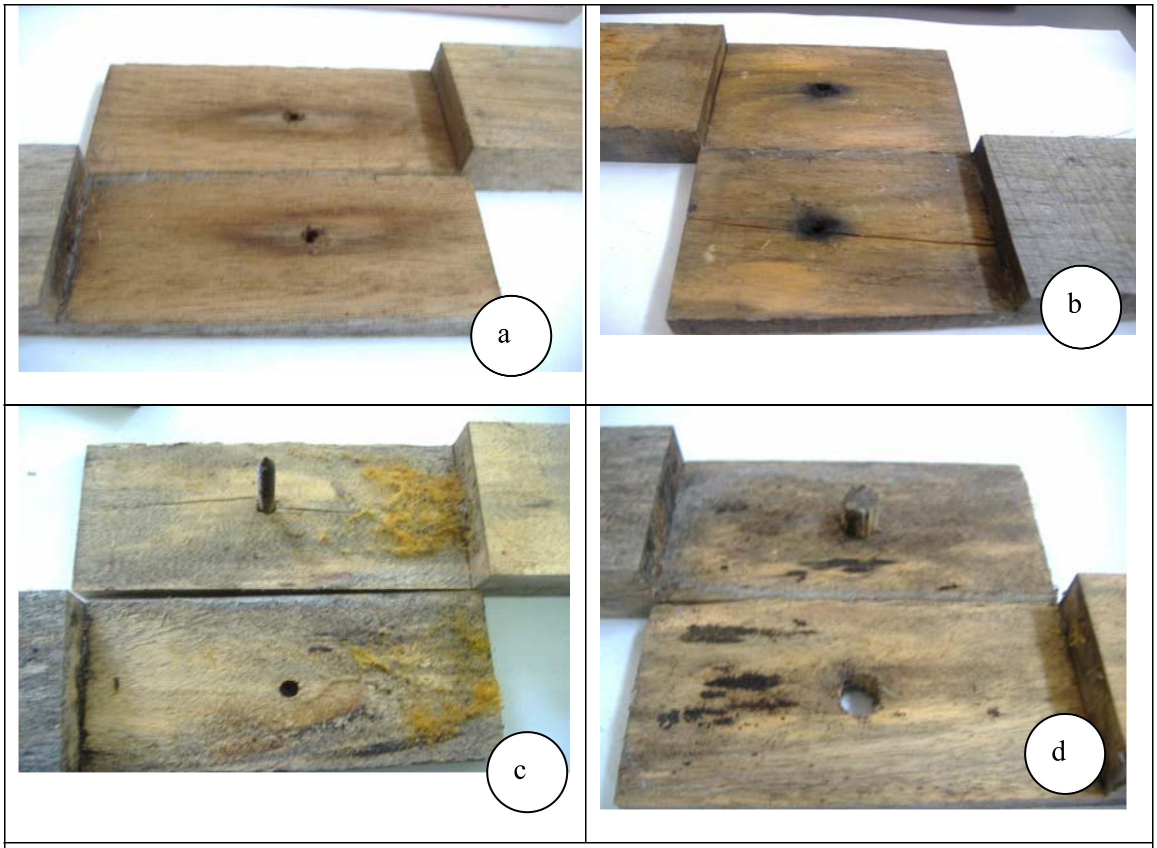


Figure 4.51 Inner faces of lap joints following nine months exposure in the field.

a = inner faces of dahoma showing discolouration around the joint. No mycelium was visible

b = iron stain around the screw fixing in oak

c = fungal mycelium on the inner surface of the esa lap joint

d = dark stain on the inner faces of esa

4.3.3.4 Microscopic examination of weathered wood samples

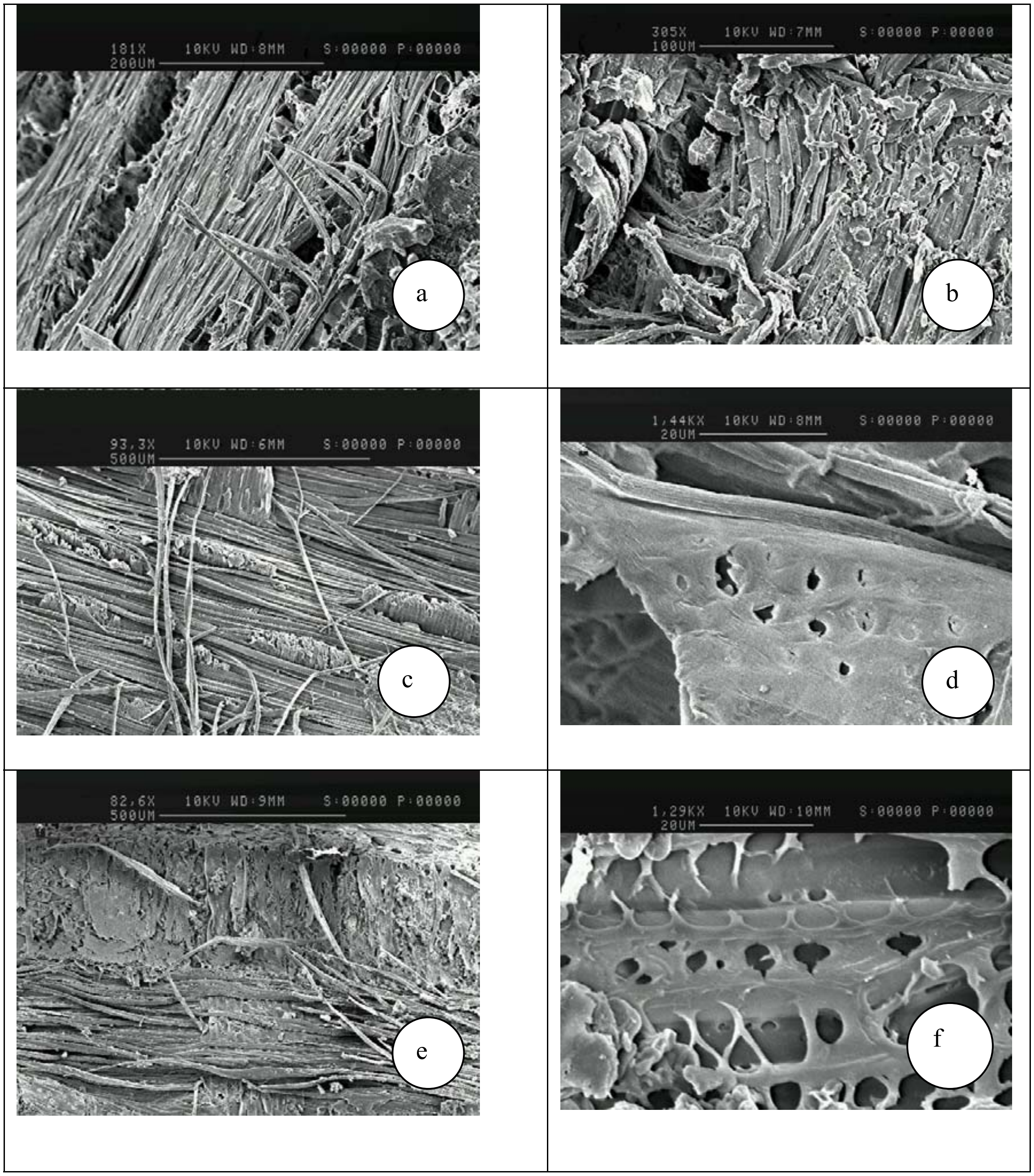


Figure 4.52 Surface weathering of untreated wood following six months exposure out of doors.
a = African mahogany TLS showing degrade of rays and raised fibres
b= African mahogany showing separation of the fibres
c = Dahoma showing fibres separating from the wood surface
d = Dahoma showing checking in the pits
e = Teak showing separation of fibres on the wood surface
f = Denya showing checks in pits

Micrographs a-f show features typical of weathering in hardwoods including degrade of the pit borders, and separation of the fibres resulting from breakdown of lignin rich middle lamellas. The microscopy preparation method would not have caused the formation of the drying cracks.

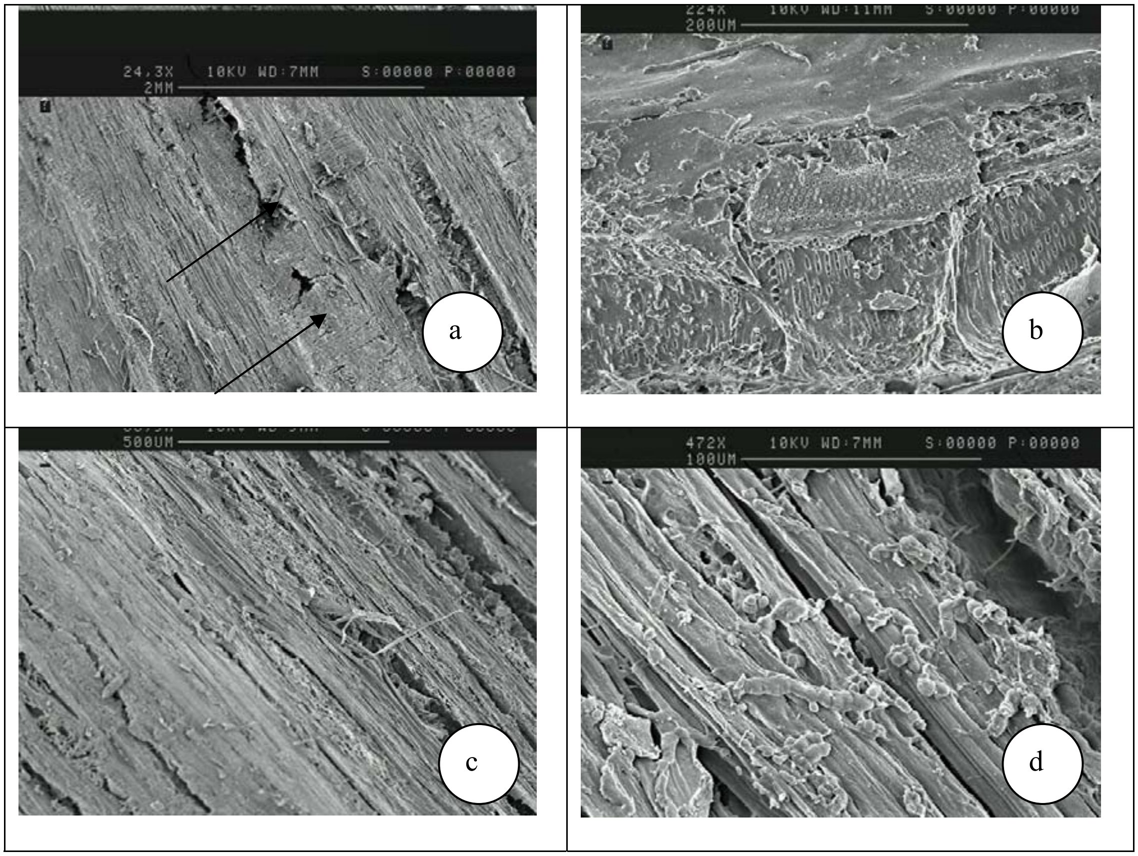


Figure 4.53 Surface weathering of treated wood following six months exposure out of doors.

a = Teak coated with decking oil; note the absence of oil coating the vessels in the bottom right of the micrograph. The coating appears to have failed in places (arrowed).

b= Iroko coated with decking oil again showing only a partial coating of the vessel lumen.

c = Esa coated with decking oil showed raised fibres following weathering.

d = Esa coated with decking oil showing fungal colonisation.

Figure 4.53 shows the wood surfaces pre-treated with decking oil after exposure to weathering for six months. In some cases the decking oil appears not to have coated the vessel lumens e.g. a and b. In other cases rising of fibres and fungal colonisation could be seen (e.g. c and d respectively). It was observed in the control specimens that, there were no cracks on the sample surfaces. This showed the cracks in the exposed specimen were due to weathering.

4.3.4 Analysis of surface chemistry

Figures 4.54-4.56 show the absorbance spectra for iroko untreated and treated with teak oil and decking oil and exposed for different periods of time. The y-axis is represented by (A) and it indicates the absorbence bands. The absorbent bands have no units as they represent ratios. It must be stated that the different lines of absorbence are separated vertically for clarity, to avoid overlapping, e.g.

IrokoUEnooil = Iroko unexposed with no oil

Iroko1monthnooil = Iroko exposed outdoors for one month with no oil, as in Figure 4.54.

IrokoTreatedDO = Iroko treated with decking oil but unexposed.

IrokoTreatedDO1month = Iroko treated with decking oil and exposed for one month, as in Figure 4.55.

IrokoTreatedTO = Iroko treated with teak oil but unexposed.

IrokoTreatedTO1month = Iroko treated with teak oil and exposed for one month.

The relative heights of the peaks are significant, rather than the absolute values.

The x-axis is represented by the wavelength, e.g. (1505cm) $^{-1}$.

Comparatively, the lignin peak of the untreated, teak and deck oiled samples revealed that, lignin diminishes faster in the untreated samples than the teak and deck oiled samples following months of exposure.

6 months.

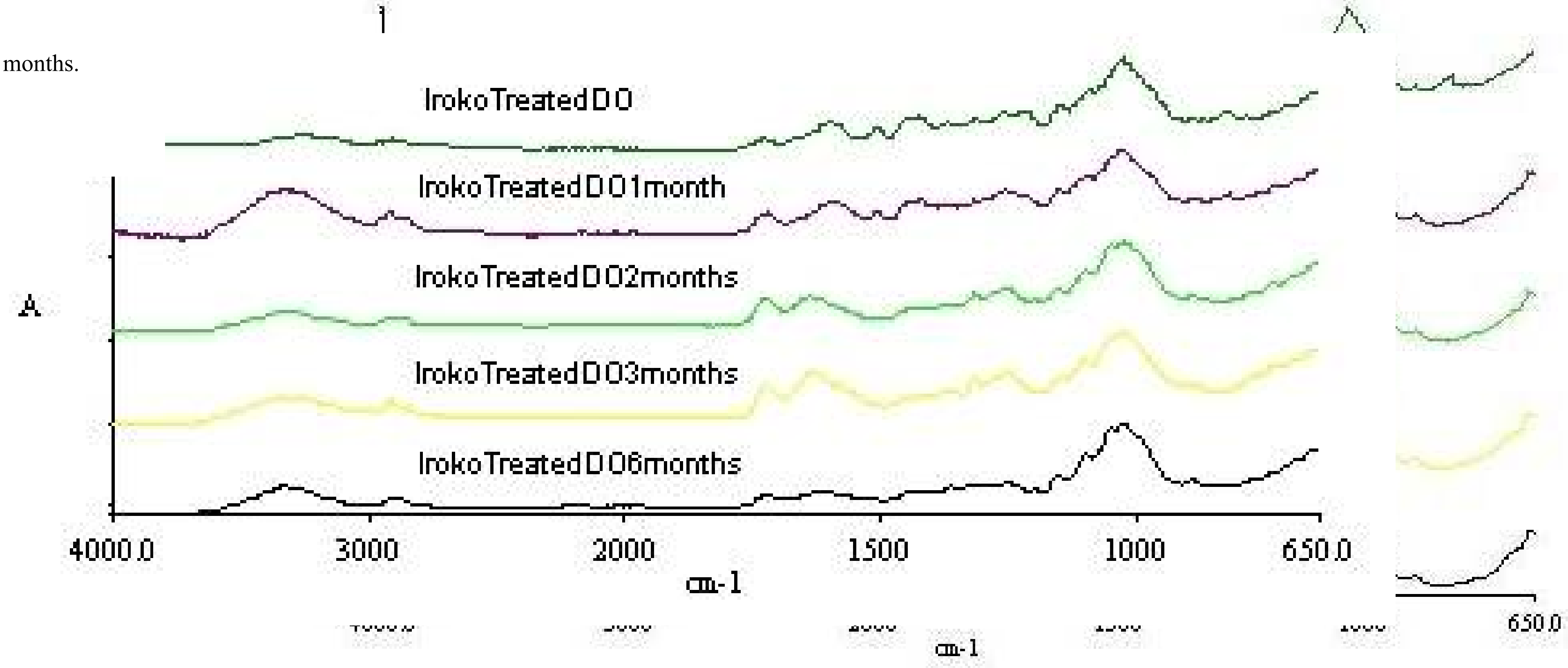


Figure 4.54   FTIR spectra for untreated iroko unexposed (top) and exposed outdoors for 1-6 months.

A= represents absorbence at initial and subsequent months.   X-axis is the wavelengths.

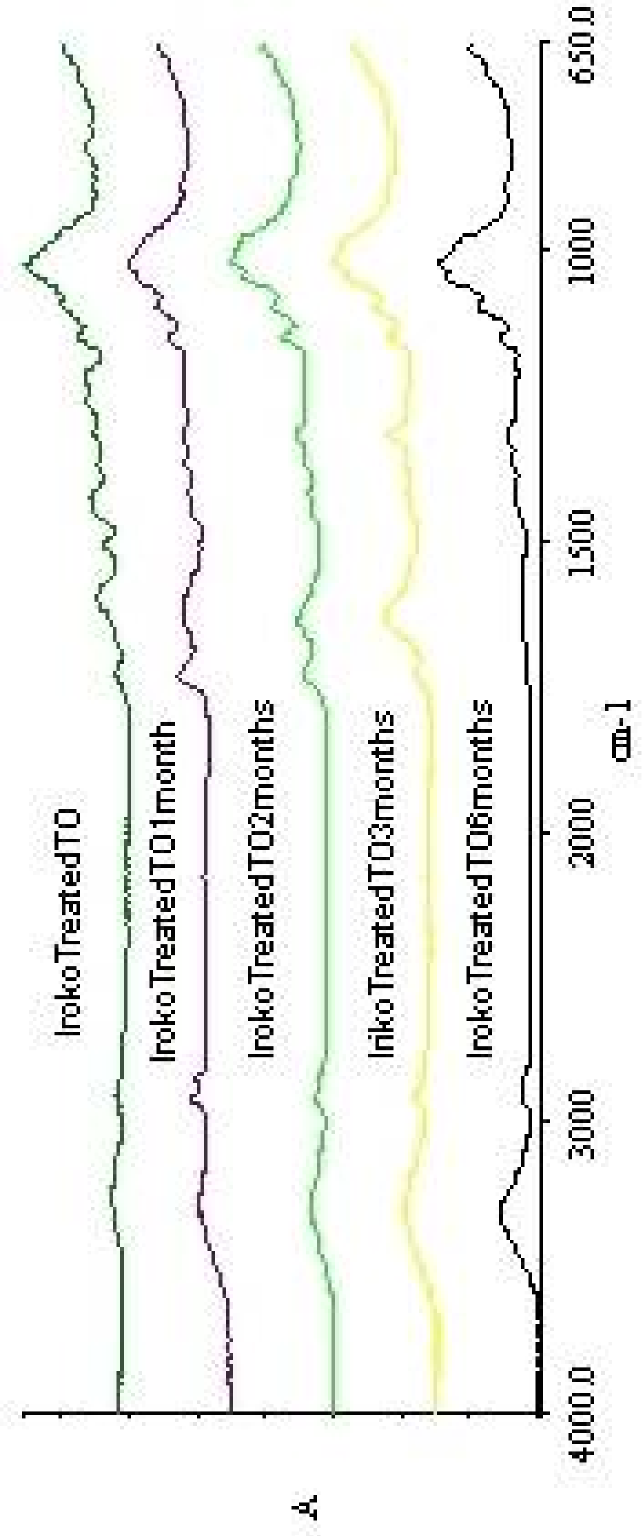

IrokoTreatedTO
IrokoTreatedTO1month
IrokoTreatedTO2months
IrokoTreatedTO3months
IrokoTreatedTO6months
A
4000.0
3000
2000
1500
1000
650.0
cm-1

Figure 4.56 FTIR spectra for iroko treated with teak oil unexposed (top) and exposed outdoors for 1-6 months.

A= represents absorbence at initial and subsequent months. X-axis is the wavelengths.

The spectra show a number of distinct changes to absorbance bands following exposure. Each of the figures presented show the absorbence bands for wood surfaces at wavelengths for different exposure periods. The peak at around $(1505cm)^{-1}$ for example is unexposed wood corresponds with lignin. For the untreated iroko then there is a distinct peak for lignin at $(1505cm)^{-1}$ prior to exposure though this is absent when the surface of this timber is exposed for one month. This was also true of iroko treated with teak oil. For iroko treated with decking oil then a peak for lignin could still be detected following two months.

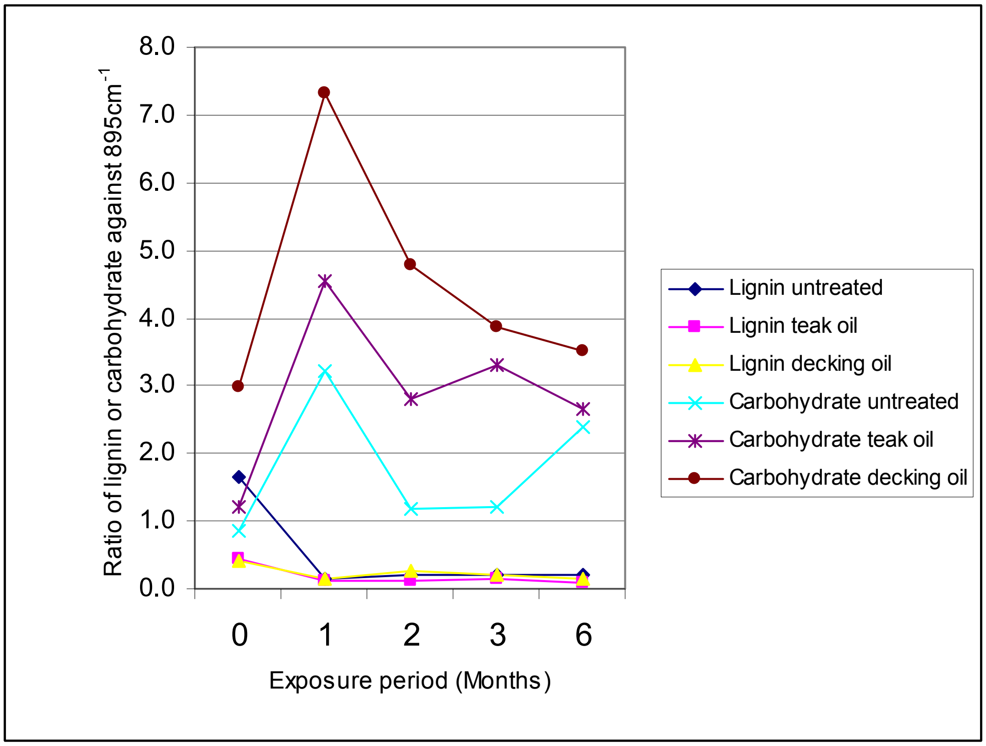


Figure 4.57 Ratios of lignin and carbohydrate against wave number $(895cm)^{-1}$ for untreated and treated esa.

Figure 4.57 shows the ratio of lignin and carbohydrate absorption bands against $(895cm)^{-1}$ in esa. This shows a rapid reduction in the proportion of lignin in the surface of the wood that occurs within the first month of exposure. The proportion of lignin in the oiled esa prior to exposure appears reduced that may result from masking. In contrast the carbohydrate content relative to lignin increases in the first month of exposure before decreasing as weathering progresses. Similar trends were observed with other species.

4.4 Discussion

This study monitored checks in the same decking boards and cross pieces over time. This showed that the numbers of checks recorded during inspections in September were greater than December. This probably relates to the lower moisture contents of the wood surfaces during September. This would lead to shrinkage of the wood at the surface relative to the core of the specimens which results in checking. Conversely, in December the moisture contents at the wood surfaces were higher (all above fibre saturation point) resulting in wood swelling and closure of some of the checks. Chapter 5 deals with moisture contents of wood species in the field and laboratory in more detail.

In general, the application of decking oil and teak oil to the surfaces of the specimens reduced their moisture content and the number of checks. Treu *et al.* (2001) also showed that treatment of wood using linseed oil reduced moisture uptake and checking when exposed out of doors.

Checks in timber allow the ingress of moisture and micro-organisms and lead to potential decay of wood out of ground contact outdoors.

Stain results from fungi colonising wood cells. Although stain fungi do not normally result in changes to the mechanical properties of timber since they do not degrade the structural components of the wood cell wall, they result in defacement and reduce value (Eaton and Hale, 1993). Esa decking boards and cross pieces had stained heavily following six months of exposure. This indicates that the cells of this species contain storage sugars that support development of stain fungi which are unable to breakdown structural polysaccharides.

Although the teak oil and decking oil reduced the percentage of the area stained, it did not prevent staining. This indicates that for applications where the aesthetics of the wood in service out of doors is an issue that pre-treatment using a fungicide is required.

No decay was detected in any of the timber species examined. The lap joint test was included in the field study since moisture accumulates in the joint. This test arrangement provides the substrate with a moisture content that is likely to support wood decay over a longer period of time. The lap joints were also exposed for a period of nine months prior to examination. Examination of the faces abutting the joint showed no surface softening. However, stain and mycelium on the esa samples indicates that the moisture content of the wood in the joint is sufficiently high to support fungal colonisation.

When FTIR was used to assess weathering of the wood surfaces, then in line with other studies there was a rapid degrade in the lignin component resulting in the loss of the absorbance peak at $(1505\text{cm})^{-1}$ by the second month of exposure. The polysaccharide content also decreased over time though initially the proportion of polysaccharide increases relative to the lignin content. The rapid loss of lignin was also reported by other researchers investigating the weathering of hardwood out of doors (Pandey and Pitman 2002). It did appear that decking oil conferred some protection to the wood surface until two months of exposure (see iroko treated with decking oil). This is supported by the findings relating to colour change which was also found to be reduced through the application of decking oil.

Microscopic examination of the weathered wood surfaces following six months of field exposure indicates lignin has degraded. This results in the raising of fibres in a number of species that probably results from breakdown of the lignin rich middle lamella leading to separation of these wood cells. The microscopic degradation of the hardwood cells seen in this study (e.g. checking in the pits and cell walls) is typical of that observed by other researchers (Pandey and Pitman, 2002).

Microscopic examination of the wood surfaces treated with decking oil and teak oil indicated that the brush application had failed to fully coat all wood surfaces, particularly inner faces of vessels. Both oils were applied with care under laboratory conditions according to manufacturer specifications. This suggests that for these timber species that a second coat of oil should be applied.

Following six months of weathering some failures of the coatings were observed and some fibre separation was seen, indicating wood is not fully protected from weathering.

5 THE NATURAL DURABILITY OF THE LESSER USED GHANAIAN SPECIES

5.1 Introduction

This chapter describes methods used to assess the natural durability of the lesser utilised species against wood decay fungi using a laboratory test. A laboratory test was conducted since it provided information about durability within a relatively short time frame.

A standard method BSEN350-1 Durability of wood and wood based products-natural durability of solid wood was used. This enabled the durability's of the Ghanaian LUS to be directly compared against other timbers normally employed for decking and outdoor furniture applications. The fungi used in the tests were those obligatory for the standard. The results for the durability trials are presented for individual LUS for planed blocks and for planed blocks treated with decking oil and teak oil, since decks and outdoor furniture are normally treated with these prior to exposure. The durability of each of the LUS was determined according to methods outlined in BSEN350-1.

5.2 Materials and methods

Esa, dahoma and denya, were tested together with the reference species beech. Wood was taken from the heartwood of trees. In the case of denya, sapwood was also included. Specimens were cut to dimensions of 50mmx25mmx15mm, were free of knots and plane finished. Sixty three specimens each of esa, dahoma and denya were prepared in this way and eight of the beech reference.

All specimens were conditioned at 20ºC and 65% relative humidity. The moisture content of each specimen type was then determined using the oven dry method (Desch, 1989).

LUS specimens were then treated in three ways;

Seven specimens of each were left untreated and are referred to as planed.

Seven specimens of each were treated with decking oil. This was brush applied at a rate of 0.25 litres per m^2 to the top face and the four edges only. The decking oil was left to dry for 48hours. After this period the blocks were re-weighed

Seven specimens of each were treated with teak oil. This was brush applied at a rate of 0.25 litres per m^2 to the top face and the four edges only. The teak oil was left to dry for 48hours. After this period the blocks were re-weighed

Beech reference blocks were left untreated.

The corrected oven dry weights of all specimens were determined according to EN 350-1 using;

Corrected oven dry weight = 100 *Conditioned mass/ (100 + % moisture content)

Sets of specimens were placed in self seal polythene bags and sterilised through ionizing irradiation between 25kGy and 50kGy using a radioisotope according to BSEN113. Bags were only opened immediately prior to the test.

The test fungi employed were the white rot *Coriolus versicolor* CTB863A and the brown rot *Coniophora puteana* BAM Ebw.15. Fungi were grown on 2% malt extract agar for a period of one week prior to the test in 100 diameter Petri dishes.

Culture vessels were 500cm^3 Beason jars containing 2% malt extract agar to a depth of 3mm in each jar. The lids of the jars contained a hole plugged with sterile non-absorbent cotton wool (Figure 5.1). Jars were centrally inoculated with one of the fungi and incubated for fourteen days at 22± 2ºC and 70± 5% rh., until the mycelium covered the agar. Three specimens of each species were placed in each container and incubated for sixteen weeks. After this period, specimens were removed from their chambers and adhering mycelia was removed from their surfaces. Specimens were oven-dried at 105ºC to constant weight then reweighed. The percentage loss in oven dry mass was calculated for each specimen using the following equation;

$$\text{\% Loss in O.D. weight} = 100 * \frac{(\text{Initial O.D. wt} - \text{Final O.D. wt})}{\text{Final O.D. wt}}$$

The average percentage loss in weight for each species and each treatment was determined.

The durability ratings for the Ghanaian lesser utilised species were determined using the following equation and the Table 5.1. The durability ratings were determined on the planed specimens only

$$\text{X value} = \frac{\text{Average corrected mass loss of test specimens}}{\text{Average corrected mass loss of beech specimens}}$$

Table 5.1 Classes of natural durability of wood to fungal attack based on EN113.

Durability Class	Description	Results of lab test expressed as X
1	Very durable	$X \leq 0.15$
2	Durable	$X > 0.15$ but ≤ 0.30
3	Moderately durable	$X > 0.30$ but ≤ 0.60
4	Slightly durable	$X > 0.60$ but ≤ 0.90
5	Not durable	$X > 0.90$

Figure 5.1 Beason jar with cotton wool plug

Figure 5.2 Mycelium covering wood specimen

5.3 Results

Figures 5.3-5.9 and Table 4.2 show the average percentage weight losses of the LUS and beech reference blocks when exposed to *C. puteana* and *C. versicolor.* Blocks referred to in the legends as planned are those that have not been treated. Decking oiled and teak oiled blocks have had these oils applied to five of their faces.

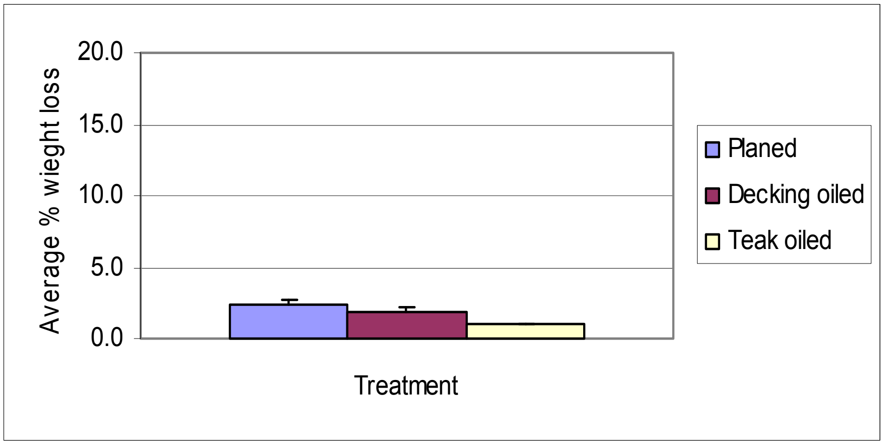


Figure 5.3 Average percentage weight losses of dahoma untreated and treated with decking and teak oil when exposed to *C. puteana.*

Error bars = Indicate standard deviation of values from the average. The longer the bars, the farther it is from the average and the shorter the bars the closer the values to the average.

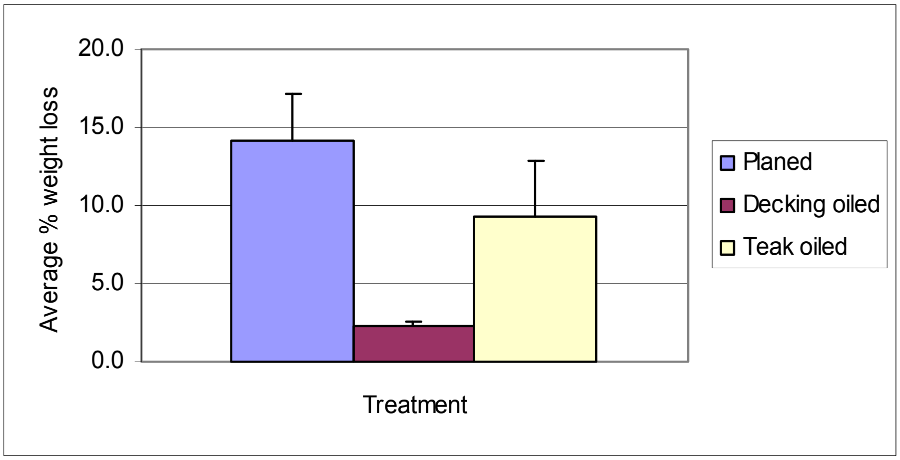


Figure 5.4 Average percentage weight losses of dahoma untreated and treated with decking and teak oil when exposed to *C. versicolor.*

Error bars = Indicate standard deviation of values from the average. The longer the bars, the farther it is from the average and the shorter the bars the closer the values to the average.

For dahoma, the greatest average percentage weight loss was observed in the planned (untreated) blocks exposed to *C. versicolor.* Figures 4.1. and 4.2 show that the application of either decking oil or teak oil reduce the level of decay in this species.

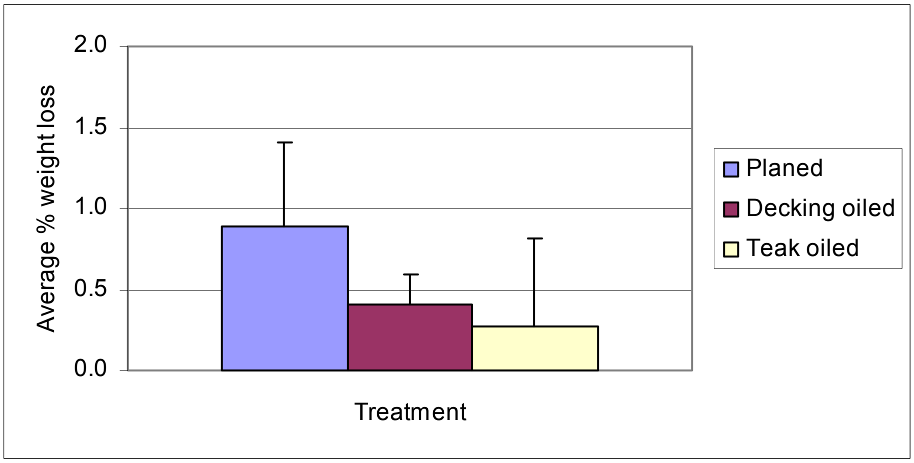


Figure 5.5 Average percentage weight losses of denya sapwood untreated and treated with decking and teak oil when exposed to *C. puteana.*

Error bars = Indicate standard deviation of values from the average. The longer the bars, the farther it is from the average and the shorter the bars the closer the values to the average.

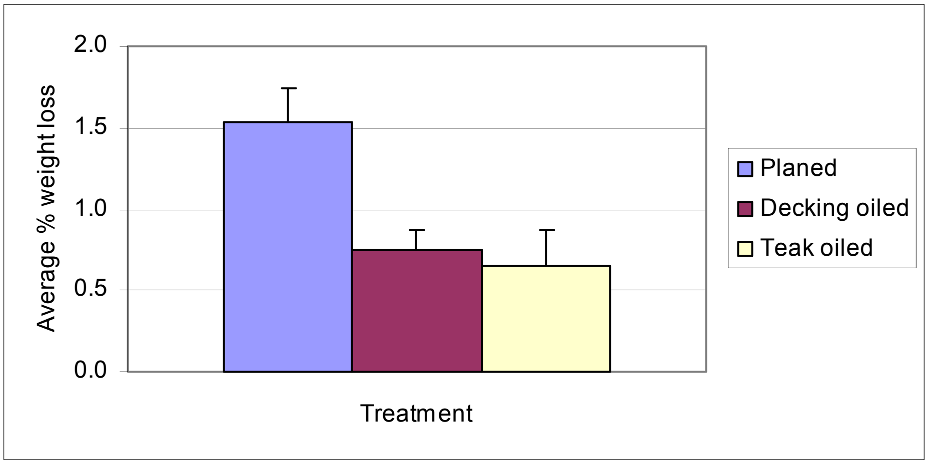


Figure 5.6 Average percentage weight losses of denya sapwood untreated and treated with decking and teak oil when exposed to *C. versicolor.*

Error bars = Indicate standard deviation of values from the average. The longer the bars, the farther it is from the average and the shorter the bars the closer the values to the average.

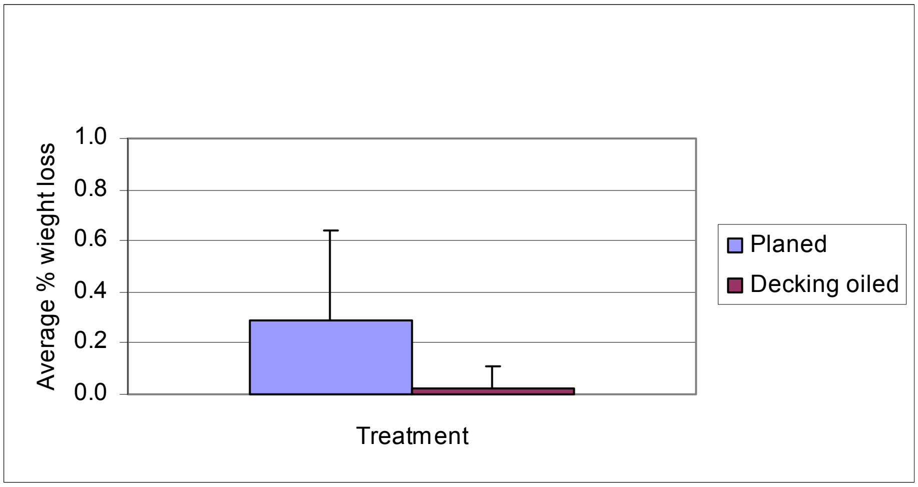


Figure 5.7 Average percentage weight losses of denya heartwood untreated and treated with decking oil when exposed to *C. versicolor.*

Error bars = Indicate standard deviation of values from the average. The longer the bars, the farther it is from the average and the shorter the bars the closer the values to the average.

Figures 5.5 and 5.6 show average percentage weight losses of denya sapwood exposed to *C. puteana* and *C. versicolor* respectively. The greatest weight losses were seen in planed specimens exposed to the white rot *C. versicolor* ≈1.5%. Treatment of the sapwood specimens with decking and teak oil reduced decay in specimens exposed to both types of fungi.

In contrast with sapwood, average percentage weight losses of denya heartwood specimens were less. The highest percentage weight loss was recorded in specimens exposed to *C. versicolor* ≈0.3% (Figure 5.7). Treatment of these specimens with decking oil was also shown to reduce decay. The results for denya heartwood exposed to *C. puteana* have not been presented graphically since none of the specimens lost weight following exposure.

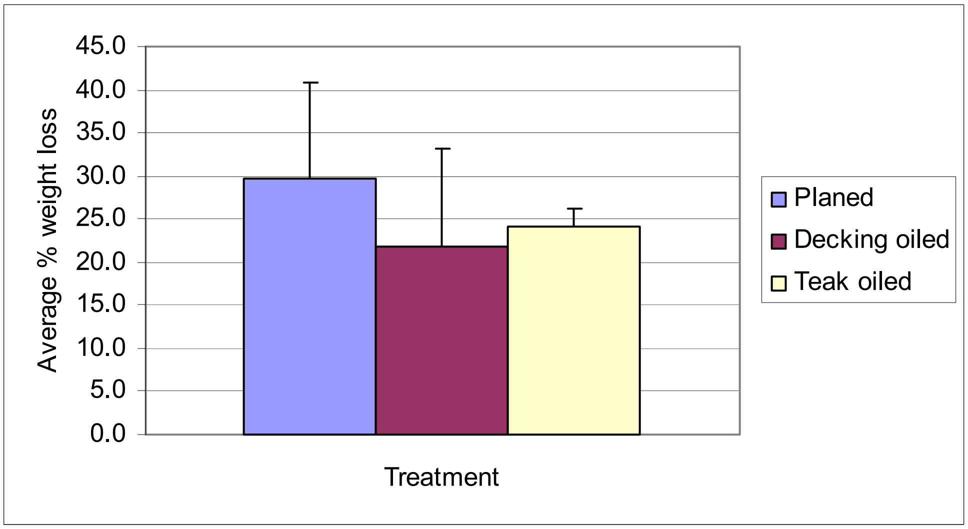


Figure 5.8 Average percentage weight losses of esa heartwood untreated and treated with decking and teak oil when exposed to *C. puteana.*

Error bars = Indicate standard deviation of values from the average. The longer the bars, the farther it is from the average and the shorter the bars the closer the values to the average.

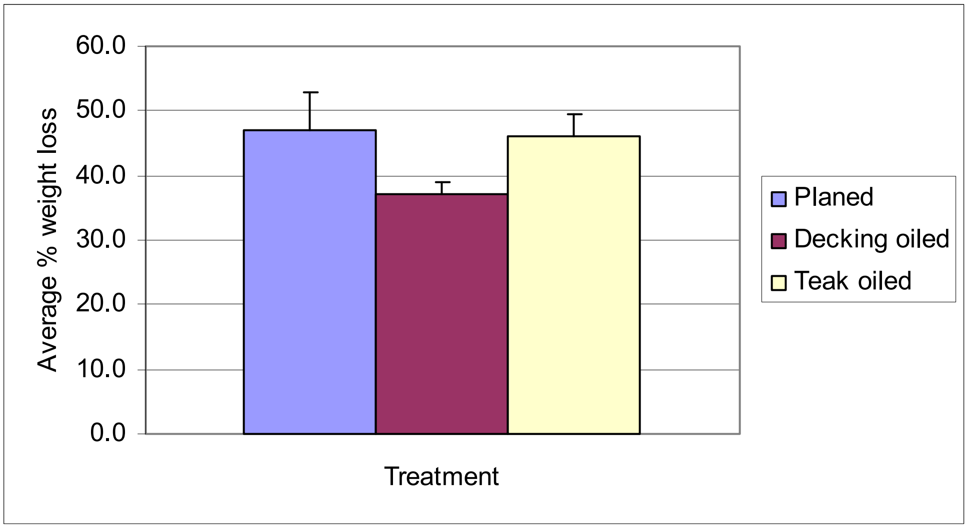


Figure 5.9 Average percentage weight losses of esa heartwood untreated and treated with decking and teak oil when exposed to *C.versicolor.*

Error bars = Indicate standard deviation of values from the average. The longer the bars, the farther it is from the average and the shorter the bars the closer the values to the average.

Figures 5.8 and 5.9 show the average percentage weight losses for esa heartwood following exposure. Greatest weight losses were observed in the untreated specimens exposed to *C.versicolor*. Treating the specimens with teak oil and decking oil appeared to confer some protection. Decking oil appeared to confer more protection to this species than the teak oil.

For the planned beech specimens, their average percentage weight loss was determined as 43% (S.D. = 2.6).

Using the average percentage weight losses for the beech reference specimens and the LUS, then durability classes were assigned to the Ghanaian LUS. Since the percentage weight losses of the LUS specimens were greater when exposed to *C.versicolor,* and then these values were used to calculate the X value.

Table 5.2 Calculated X-values and durability classes for the Ghanaian LUS.

Ghanaian LUS	X value	Durability class
Dahoma	0.33	Moderately durable
denya (sapwood)	0.03	Very durable
denya (heartwood)	0.006	Very durable
Esa	1.1	Not durable

5.4 Discussion

Using weight loss as a measure of wood decay, then for all Ghanaian LUS, greater weight losses were recorded in specimens exposed to the white rot fungus *C. versicolor* than the brown rot *C. puteana*. Other researchers have also reported white rots as being better decayers of hardwoods than brown rots (Pitman, 1999 and Pohleven and Petric, 1997). It is for this reason that *C. versicolor* data was used to calculate the durability rankings for the LUS. Results from the laboratory test show that both the sapwood and heartwood of denya may be classified as very durable (durability class 1), dahoma heartwood moderately durable (durability class 3) and esa heartwood not durable (durability class 5).

The results also showed that treating the blocks with decking and teak oil prior to exposure conferred some resistance to wood decay. This may be a result of the reduced wetting up of the blocks (see water absorption Chapter 5), or blocking of flow paths used by the fungal hyphae to access the timber for decay. There may also be some fungicidal activity in the case of the decking oil.

Due to time restrictions natural durability could only be determined using a laboratory test. Although this provides a useful insight into performance, EN350-1 states only a provisional classification of natural durability can be made using laboratory data and field test data from a temperate climate is preferred.

No decay was detected in any of the timber specimens exposed out of doors in the field trial after seven and nine months of exposure respectively. This applied to the lap joints (exposed for nine months) and decking boards (exposed for seven months). It would be useful to continue running the field trial for longer to assess species performance.

Natural durability in the field is assessed in ground contact, since this provides the greatest decay hazard (Raberg *et al.*, 2005). As yet there are no specific standards for testing the performance of wood in decks or outdoor furniture. However, since the design of decks and outdoor furniture includes horizontal timbers that are joined by screws or dowels, this provides an opportunity for water to collect. The use of lap joint tests and fixed cross pieces was therefore a useful inclusion in this study. That the moisture content of the substrate surfaces and joints were above 20% and therefore support decay may be seen in the growth of stain fungi for some wood species

EN 460-1 gives guidance on the use of wood in various hazard classes. For wood exposed in hazard class 3, then timbers with natural durability classes 1 and 2 no treatment is required, whereas for durability classes 3-5 preservative treatment may be necessary. For this reason denya requires no preservative treatment for decking and outdoor furniture applications, whereas dahoma and esa do. For the UK market it is common practice to preservative treat softwood decking and garden furniture.

When the durabilities of reference species are compared against the lesser utilised species, then; teak falls into durability class 1, iroko 1-2 and oak 2 (EN 350-2). This study indicates that denya performs as well as teak and iroko and better than European oak which are already used for these applications.

6 WATER ABSORPTION BY SPECIMENS IN THE LABORATORY AND FIELD

6.1 Introduction

Since the rate at which the species examined absorbed and desorbed water will have an influence on their performance as outdoor furniture and decking, this was invest

Wood is comprised of wood cells. The structural components of the wood cell wall are remarkably uniform across species (Fengel and Wegener, 1989). Structural components are composed of polymers with hydroxyl and other oxygen-containing groups, making wood hygroscopic. These groups are capable of hydrogen bonding with water (Fengel and Wegener, 1989). As seasoned ('dried') wood is exposed to water, this fluid flows through the wood structure and binds with the structural components in the wood cell wall resulting in an increase in wood volume (Stamm,1964).

This increase in volume or swelling occurs until the wood cell wall is saturated with water. This point is known as the fibre saturation point (FSP), and ranges from 20 to 50% of the O.D. weight of wood (Feist and Tarkow 1967). As further water is added it does so as free water in the void structure mainly the cell lumens and does not contribute to further swelling. This process is reversible, and wood shrinks as it loses moisture below the FSP.

The moisture content of wood has some important effects on its strength properties (Desch and Dinwoodie, 1996), its liability to decay (Eaton and Hale, 1993) and importantly movement. The later is important since movement of wood in joints in the case of furniture, or fixings in the case of decking may lead to failures of joints or checking around fixings such as screws or nails. Movement values for timbers are therefore important for furniture and decking producers. Some timbers such as teak are prized for their low movement. This means as the wood cell wall takes up or loses water there will be little dimensional change.

Since the anatomy of wood and the extractives it contains will influence the ease with which water penetrates the wood structure, then this will influence the rate of water uptake. Also any treatment that reduces penetration of water into the wood structure will influence its rate of dimensional change. Such treatments include modification of the water binding sites (e.g.

chemical modification, heat treatment), impregnation with oils or the application of surface coatings (e.g. paints and varnishes). Through retarding or preventing water uptake, treatments have been shown to reduce damage associated with wood movement together with decay (Treu *et al.* 2001, Eckeveld *et al.,* 2001)

6.2 Materials and methods

6.2.1 Laboratory test to compare water absorption of LUS and reference species

Denya, esa , dahoma and teak heartwood specimens together with denya sapwood were cut to dimensions 50mmx25mmx15mm. All specimens were free of knots and finished planed.

Twenty one specimens of each species were included in the test. Seven specimens were untreated, another seven treated with teak oil and seven treated with decking oil. Oil was applied to specimens using a brush at a rate of 0.25 litres per m^2, on the upper surfaces and the four edges of each specimen and left to dry for 48 hours.

The conditioned weights of all specimens were measured. The oven dry weight of each species was determined according to the methods presented in Desch and Dinwoodie (1996). The corrected oven dry weights for all specimens belonging to each species were then determined using the equation provided in 6.2.2.

Wood samples were then immersed in distilled water. At specific time intervals, samples were removed, blotted to remove excess water and reweighed to determine their percentage moisture contents using the equations provided in 6.2.2.

6.2.2 Field tests to compare moisture contents of decking boards and lap joints

Initial moisture contents of deck boards and lap joints were taken using a moisture meter (Brookhuis). These moisture content values were used to calculate the oven dry weight of each sample at the start of the test using;

Oven dry weight = Wet weight*(100/ (100+ % MC))

Following each exposure period the percentage moisture contents of individual decking boards and cross pieces were determined using the following equation;

Percentage moisture content = (Wet weight – Oven dry wt/Oven dry wt)*100

Moisture contents of lap joints were determined following 11 months exposure using a moisture meter, at five positions where the laps overlapped together with five positions on their upper surfaces.

6.3 Results

6.3.1 Laboratory tests to investigate water uptake

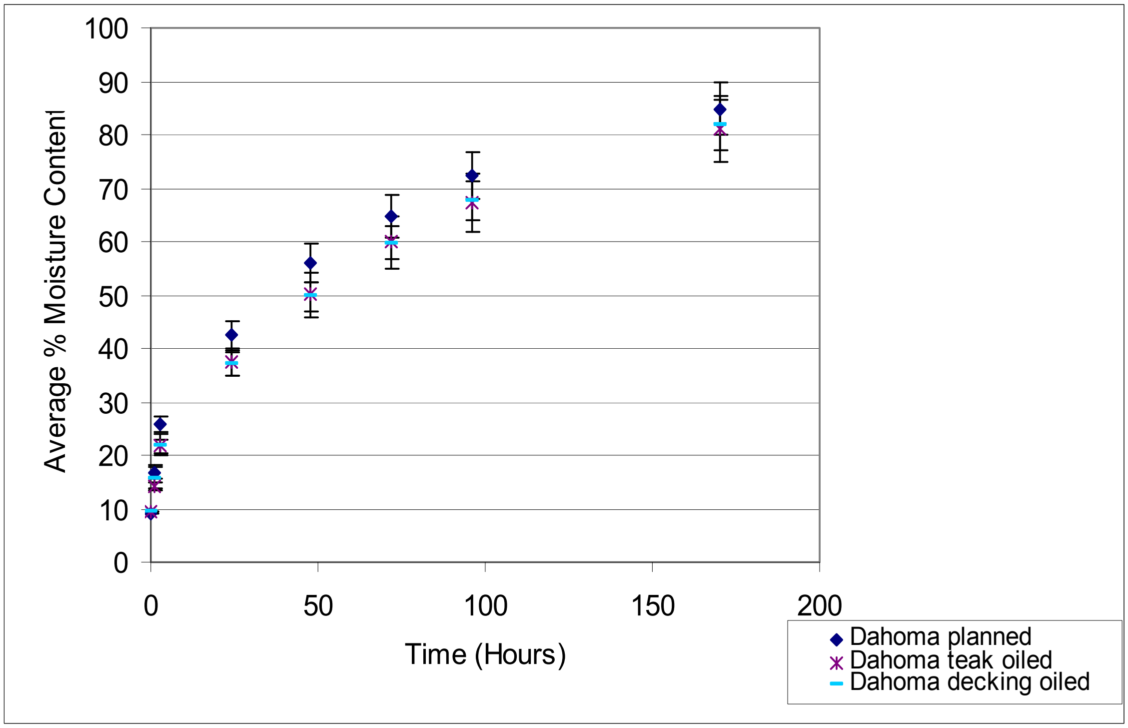


Figure 6.1 Absorption of water by treated and untreated dahoma.

Error bars= Indicate the standard deviation of values obtained. The longer the bars, the farther the results are from the average and the shorter they are, the closer the values to the average.

Results presented in Figure 6.1 shows that over the entire exposure period the untreated dahoma absorbed more water than specimens treated with either teak oil and decking oil. Specimens treated with decking oil absorbed least water. Untreated dahoma attained a moisture content of 85% following 170 hours of immersion, whereas denya treated with decking oil reached 81% moisture content.

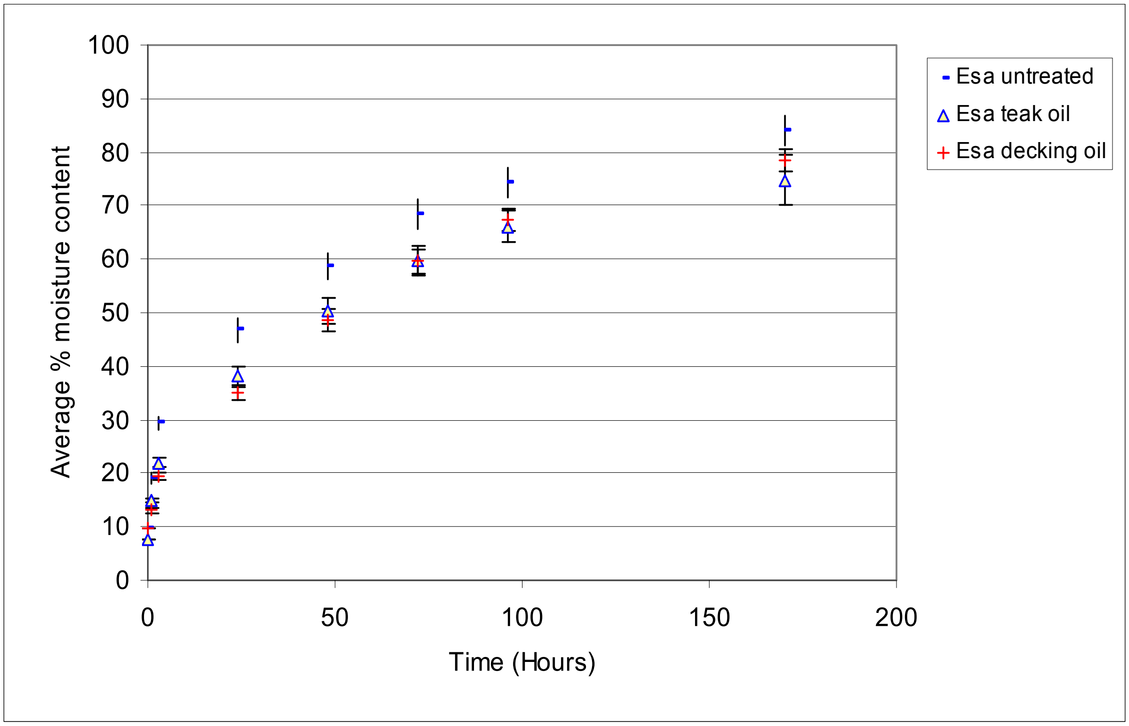


Figure 6.2 Absorption of water by treated and untreated esa.

Error bars = Indicate standard deviation of values from the average. The longer the bars, the farther it is from the average and the shorter the bars the closer the values to the average.

Esa followed a similar trend to dahoma with respect to water uptake, but the untreated samples absorbed around 84%. At the 100th hour onwards esa decking oil absorbed more moisture than the teak oiled ones.

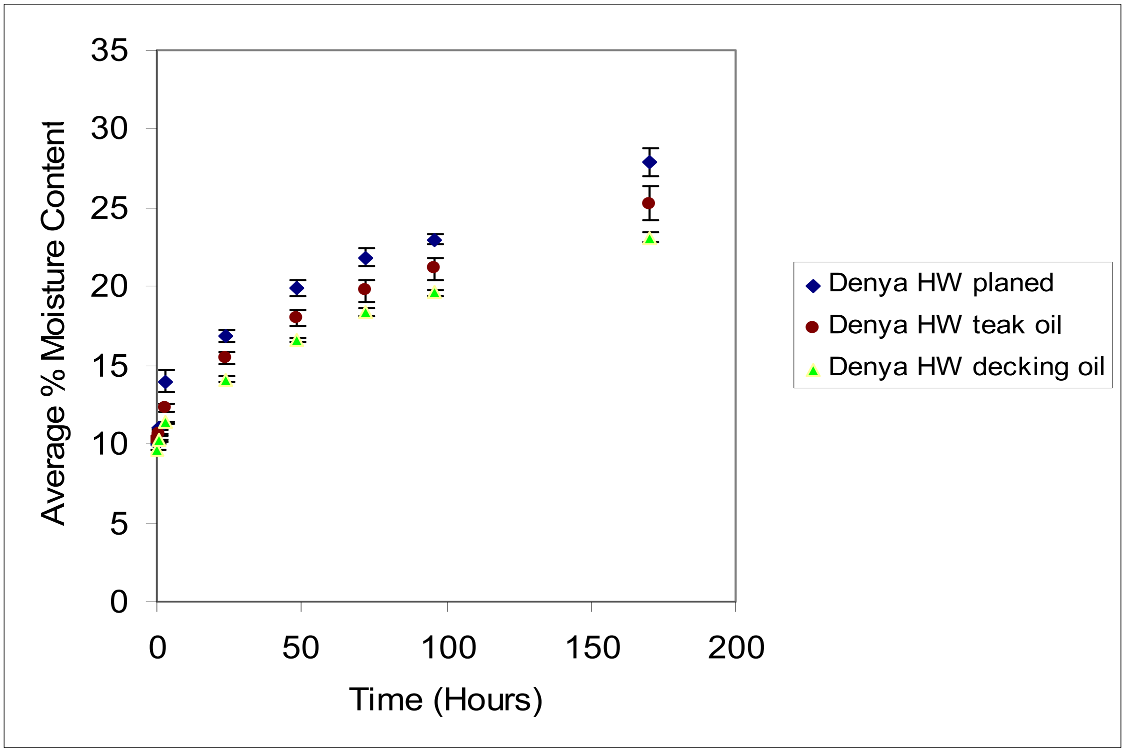


Figure 6.3 Absorption of water by treated and untreated denya heartwood.

Error bars = Indicate standard deviation of values from the average. The longer the bars, the farther it is from the average and the shorter the bars the closer the values to the average.

Figure 6.3 shows water uptake by denya heartwood follows the same trend as the other species, with the untreated denya HW samples absorbing more moisture than the oil treated samples. Denya HW brushed with decking oil absorbed least with an average final moisture content of 23%.

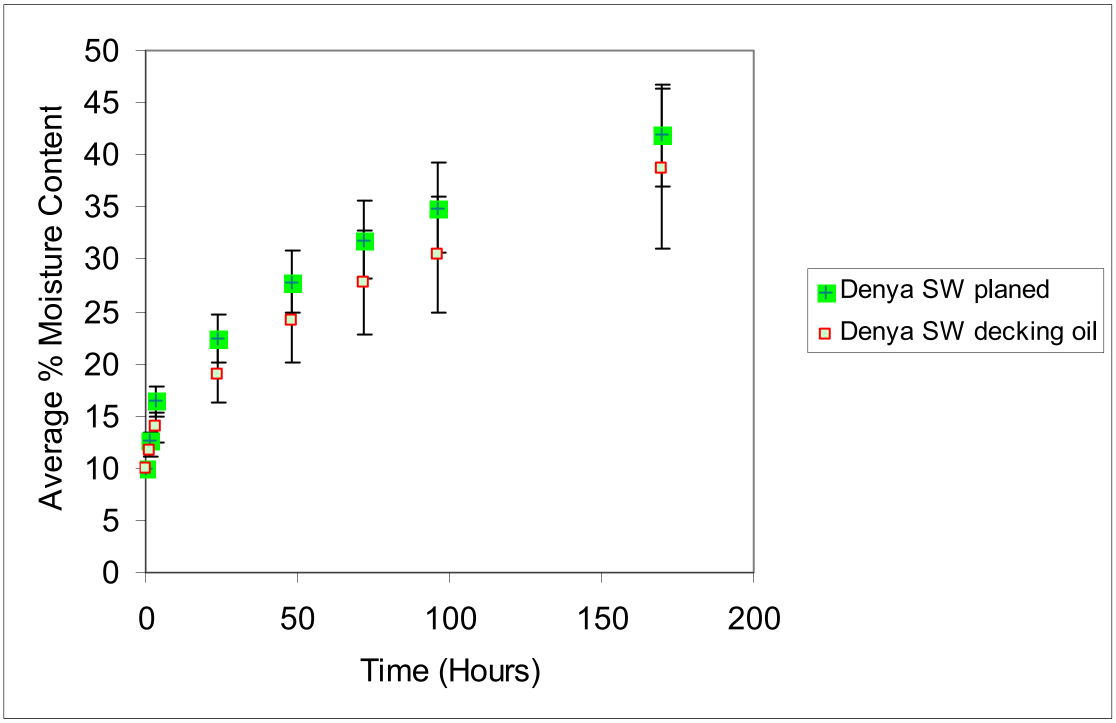


Figure 6.4 Absorption of water by treated and untreated denya sapwood.

Error bars = Indicate standard deviation of values from the average. The longer the bars, the farther it is from the average and the shorter the bars the closer the values to the average.

Water uptake by denya SW followed the same trend as other species including denya HW. Denya SW untreated attained moisture content of 42%, while denya SW treated with decking oil had a final moisture content of 37%.

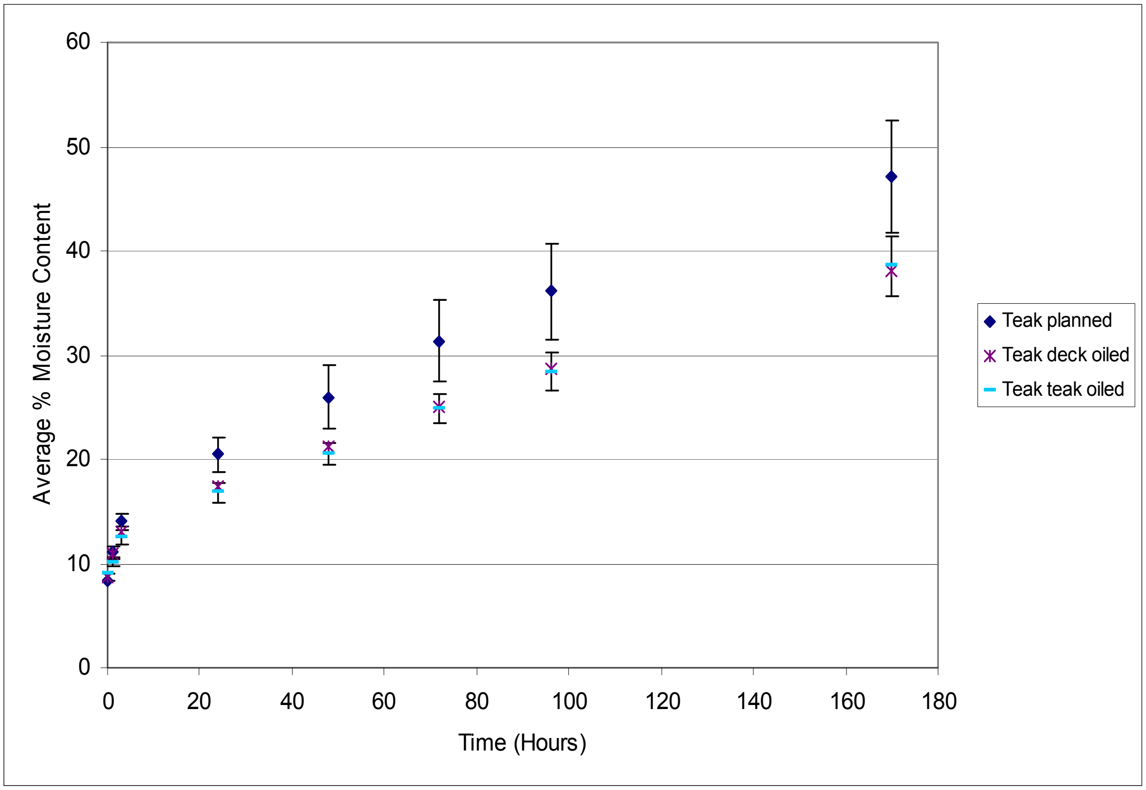


Figure 6.5 Absorption of water by treated and untreated teak.

Error bars = Indicate standard deviation of values from the average. The longer the bars, the farther it is from the average and the shorter the bars the closer the values to the average.

Teak absorption followed the trend shown by other species. Untreated teak absorbed more than that treated with decking oil or teak oil.

6.3.2 Field tests to investigate water uptake

6.3.2.1 Moisture content changes in untreated deck boards exposed in the field

Figure 6.6 shows the moisture contents of decking boards prior to exposure (2/6/06) and at intervals over the six month exposure period. It can be observed that all boards absorb moisture during the first month of exposure and the e.m.c's of all samples remained below 20% until 2/9/06. At 19/12/06 the highest moisture contents were in A. mahogany, dahoma and esa.

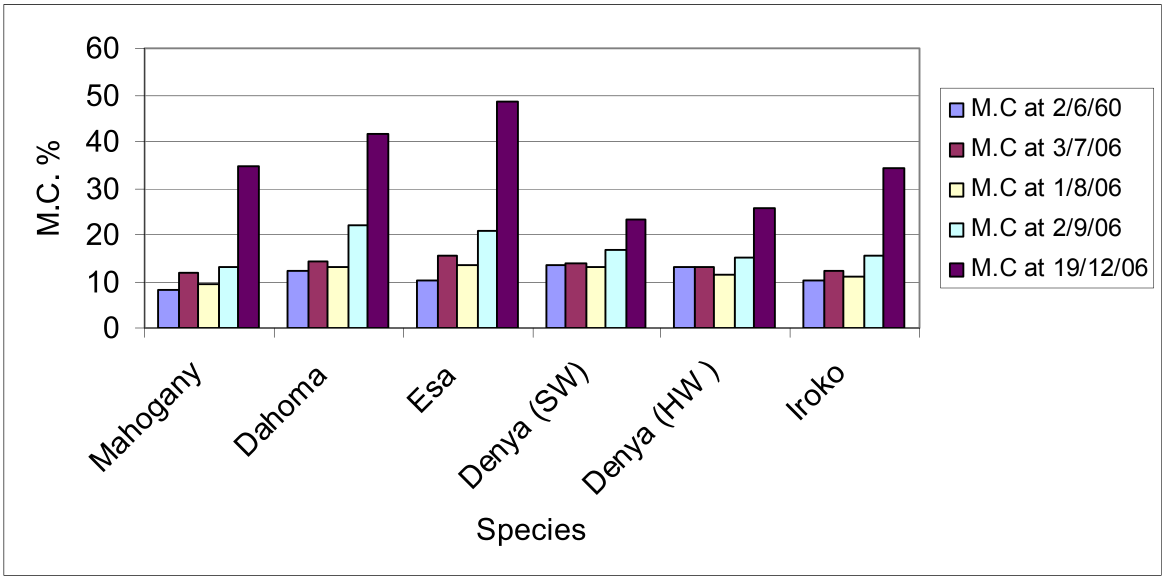


Figure 6.6 Average moisture contents in untreated deck boards between 02/06/2006 to 19/12/2006.

Where, SW= Sapwood and HW= Heartwood.

6.3.2.2 Moisture content changes in treated deck boards exposed in the field

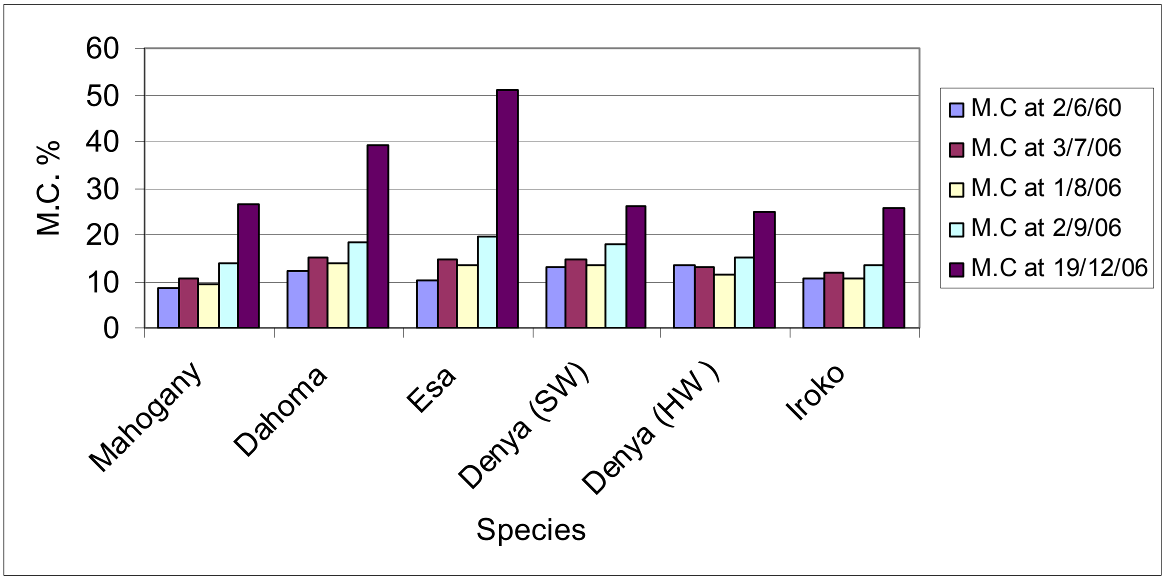


Figure 6.7 Average moisture content change in decks treated with decking oil between 02/06/2006 to 19/12/2006.

Where, SW= Sapwood and HW= Heartwood

Figure 6.7 shows that the moisture contents of the oiled decking boards over the exposure period followed a similar trend to the untreated boards. The application of teak oil had little influence on the uptake of moisture content.

6.3.2.3 Moisture content s of untreated cross pieces exposed in the field

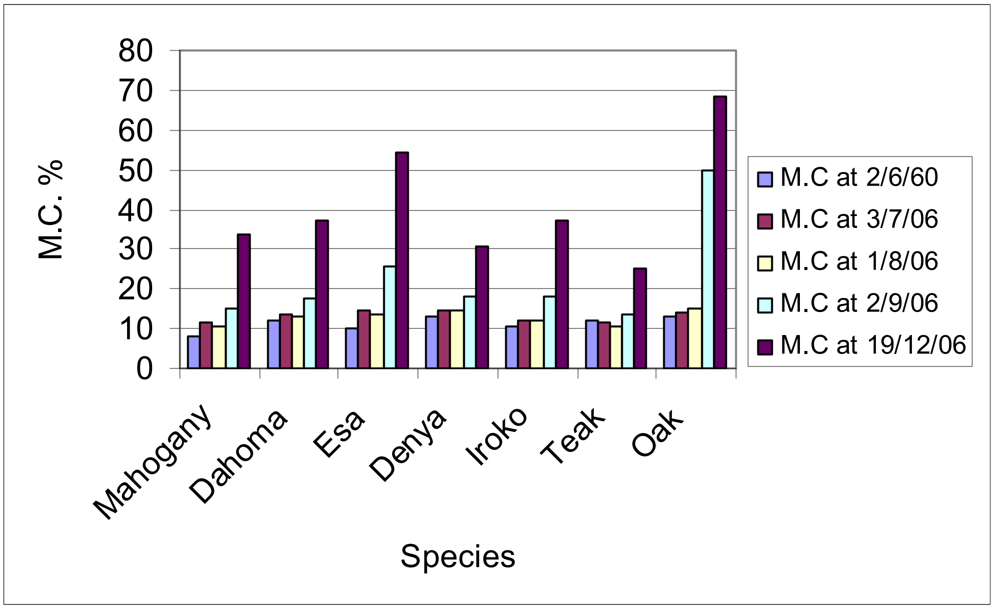


Figure 6.8 Average moisture contents of untreated cross pieces exposed in the field between 20/06/2006 to 19/12/2006.

Moisture content changes in untreated cross pieces exposed in the field followed a similar trend to the decking boards. The moisture contents of most cross pieces increased during the first month. Moisture contents of samples remained low over the summer months until September. The lowest moisture contents during the winter months were recorded in teak and denya and the highest in oak sapwood.

6.3.2.4 Moisture content of treated cross pieces exposed in the field

Figure 6.9 shows the moisture content changes in cross pieces that have been treated with teak oil.

All the species followed the trend of absorbing, losing and further absorbing moisture till the end of the period with the exception of esa and oak. Esa and oak continued to absorb moisture throughout the period.

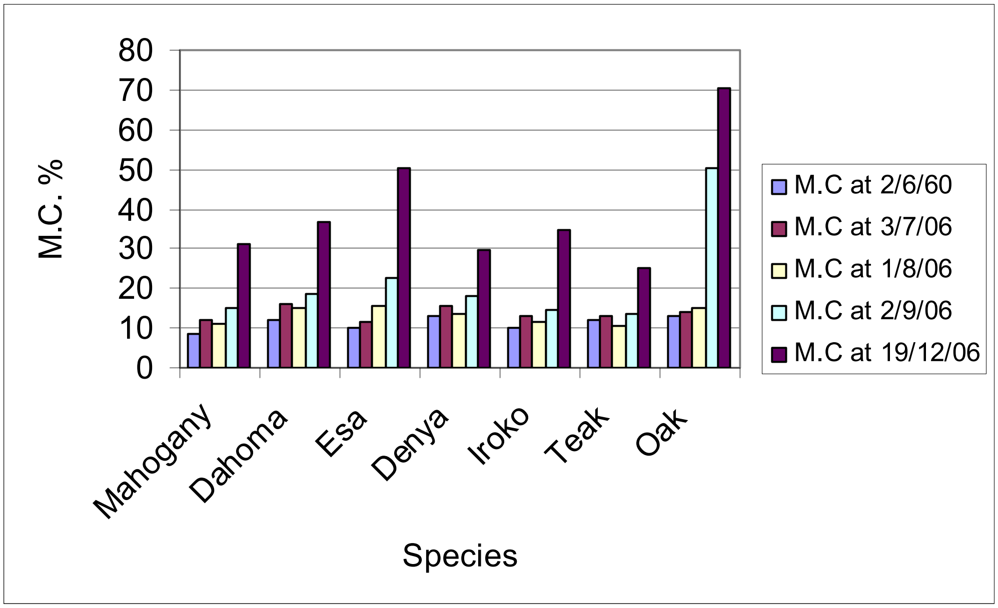


Figure 6.9 Average moisture content changes in cross pieces treated with teak oil between 02/06/2006 and 19/12/2006.

6.3.2.5 Moisture contents of treated and untreated lap joints in the field

Table 6.1 shows the moisture contents of wood in the lap joint specimens assessed in March 2007. The moisture content values are averages of five readings for each specimen code. In nearly all cases the moisture contents of wood at the lap is greater than that at the top of the jointed specimen.

Treatment of the surface of the specimens with teak oil had little influence on moisture contents of the specimens.

The greatest difference in moisture contents were seen between species. Oak had the greatest moisture content. The moisture content of esa was also high. African mahogany had the lowest moisture content while that of denya was similar to iroko.

Species	Code	Treatment	Top M.C	Lap M.C
Esa	CE6	Untreated	19.40	22.60
Esa	CE5	Untreated	20.20	23.40
Esa	CE4	Teak oil	20.60	21.50
Esa	CE3	Teak oil	21.00	22.70
Denya	DA1	Untreated	17.10	17.90
Denya	DA3	Untreated	19.00	22.30
Denya	DA4	Teak oil	18.80	19.20
Dahoma	PP2	Untreated	21.10	27.30
Dahoma	PP7	Untreated	19.6	24.80
Dahoma	PP5	Teak oil	19.30	23.20
A. mahogany	MM1	Untreated	14.30	16.70
A.mahogany	MM5	Untreated	14.80	18.10
A. mahogany	MM6	Teak oil	15.20	17.10
Iroko	001	Untreated	17.00	21.00
Iroko	007	Untreated	20.70	23.80
Iroko	005	Teak oil	15.30	16.40
Oak	OK1	Untreated	18.40	26.50

Table 6.1 Moisture contents of treated and untreated lap joints assessed after nine months exposure.

6.4 Discussion

Results from the laboratory tests show that the untreated samples of all species tested absorb more water than those treated with either decking oil or teak oil. This indicates that application of oils prior to immersion reduced the rate of water absorption and the final moisture content when the test was terminated following 170 hours. It is important to indicate that although the moisture content of the oiled specimens was reduced, this reduction was not sufficient to reduce movement or wood decay. That oil applied by brushing only serves to slow the rate of water uptake may in part result from it not being applied to all faces.

Comparison of the final moisture contents of the untreated specimens show distinct differences between the amounts of water absorbed by the species at the end of the test. Dahoma absorbed most water, then esa. In contrast both denya heartwood and sapwood absorb much less water with the heatwood of this species absorbing about 40% less water than the sapwood. Interestingly, denya heartwood was found to absorb less water than teak heartwood included as a reference.

That denya heartwood absorbs less water than the sapwood results from the reduced permeability of this stem region. Less permeable heartwoods have been reported in other species (Eaton and Hale, 1993). Interestingly, denya heartwood absorbs less water than teak. Teak is considered by many to provide good resistance to water uptake as a result of its oily nature. This study clearly shows that denya outperforms this species in the laboratory test.

The rate of water uptake is important since it is likely to influence wood deterioration and movement in service. Since wood decay and disfigurement fungi require wood to have a moisture content in excess of 20% in order to grow, then the ability of wood to wet up is important. In addition the removal of breakdown products from weathering would be expected to be greater in more permeable wood species. Water uptake is also likely to have an important influence on the development of checks in wood in service, which results from shrinkage or swelling of wood at the surface relative to the core of the timber.

This study did not examine desorption of water from the different species as a result of drying. This is important for decks and outdoor furniture since the risk of wood decay will be dependant on the length of time that wood moisture remains above the 20% threshold necessary to support microbial colonisation.

In general the field tests followed a similar trend to those conducted in the laboratory. For the decking boards, then moisture contents were determined for whole boards by examination of weight change so it was not possible to examine for any moisture content profile across the boards. Understandably the moisture contents of all boards were low when assessed between June and September 2006 since this was a period of low rainfall in the UK. The highest moisture contents of the decking boards were recorded in December.

There were some distinct differences between the moisture contents of boards manufactured from different species when examined in December 2006. The highest moisture contents were recorded in esa and dahoma and the lowest in denya. This study shows that brush application of decking oil prior to exposure under laboratory conditions had little influence on the uptake of water by the decking boards. Other researchers have examined the influence of impregnating wood with oil on water uptake. Wood impregnated with these oils take up significantly less water when exposed outdoors (Treu *et al*., 2006). However, this study clearly shows a brush application has little effect.

Moisture uptake was also examined periodically in the cross pieces. Cross pieces included two additional species oak and teak. The study clearly showed that the uptake of water was greater for oak and lowest for teak. Also treatment with teak oil had little influence on uptake.

A lap joint test was included since the horizontal joint is designed to retain water following wetting and therefore provide conditions suitable for decay. In this case moisture contents were only examined at the surface of the timber to a depth of approximately 2mm using moisture content. The study clearly shows that the moisture content of timber in the joint was higher than on the surface. This probably related to improved drying at the surface compared with the joint.

7 MARKETING RESEARCH FOR DECKING AND OUTDOOR FURNITURE

7.1 Introduction

An initial survey of retailers of wood products was carried out in High Wycombe town to familiarise myself with the various types of furniture products on the market. Figures 7.1-7.3 represent some of the furniture samples on display.

Figure 7.1 Aluminium chairs and tables on display.

Figure 7.2 Wooden chair on display.

!

Figure 7.3 Plastic chairs and table on display.

Market research is a means of minimising risk in marketing. It involves systematically gathering, recording, and analysing data to solve marketing problems. In market research one needs to acquire primary and secondary data for analysis to reach decisions. Primary data acquisition involves observation, surveys, experimentation and simulation (computer technique). Secondary data refers to previously published broad- based data..

The following section describes the methods used to conduct consumer preference surveys for decking and outdoor furniture including that manufactured from selected Ghanaian LUS. The survey was designed not only to ascertain choice based on aesthetics but to determine other factors influencing choice. The results of the survey are presented and the significance of the findings discussed.

7.2 Materials and Methods

The survey was conducted in two phases. In the first phase, a preference survey for outdoor furniture was conducted on the 14th of December 2006 during the final presentation exhibition of the MA in Furniture Design (2006 group) at BCUC. The second phase survey for both furniture and decking was conducted on staff and students from BCUC. An E-mail was sent out inviting participants to visit the Forest Products Research Centre on the 19th of March 2007, to participate in this survey.

All participants were issued with a copy of the relevant questionnaire and allowed to examine the furniture and decking samples.

7.2.1 Decking survey

Iroko, denya, dahoma, African mahogany and esa were employed in the decking survey. Three sets of samples were included;

1. An untreated board of each species (Figure 7.4.)

2. An untreated board of each species weathered for seven months between June and December 2006 (Figure 7.6).

3. A board of each species that had been treated with decking oil and weathered between June and December 2006 (Figure 7.6).

All decking boards were marked up with a lettering system that did not allow participants to identify samples which may otherwise have influenced choice. Participants were presented with a decking questionnaire (Figure 7.5) for completion. At the end of the survey, results from all participants were compiled for analysis.

Figure 7.4 Untreated and unexposed decking boards included in the survey.
Where A= iroko, B= denya, C= A. mahogany, D= Dahoma and E= Esa

Decking Survey Questionnaire

Have you used a deck before? ☐Yes ☐ No

Has a deck been installed for you before? ☐Yes ☐ No

Please indicate your age group ☐18-30 ☐ 30-40 ☐ 40+

Please rank samples A-E for use as a deck boards, with 1 being your favourite and 5 your least-favourite.
☐ A ☐ B ☐ C ☐ D ☐ E ☐ F

What did you like about your favourite deck board?
☐ Colour ☐ Smell ☐ The good look ☐?Any other comment

Please rank samples A-J for use as a deck boards, with 1 being your favourite and 10 your least favourite
☐ A ☐ B ☐ C ☐ D ☐ E ☐ F ☐ G ☐ H ☐ I ☐ J

What did you like about your favourite deck board?
☐ Colour ☐ Smell ☐ The good look ☐ Any other comment?

Do you prefer wood decks to be treated? ☐Yes ☐ No

Why do you think wood should be treated?
☐ Beautification ☐ To prolong service life ☐ To reduce attack by wood destroying organisms.

Which properties of wood do you think are good for decks?
☐ Durability ☐ Strength ☐ Resistance to wear ☐ Ability to withstand weather

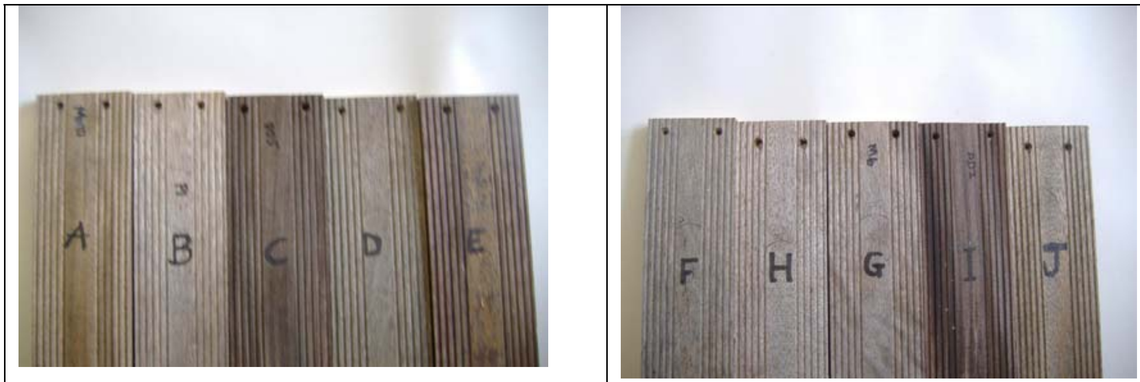
Which would you prefer?
☐ Wood that lasts longer ☐ Wood that looks good.

Do you think wooden decks are good for the environment? ☐ Yes ☐ No

13. If you thought a deck was produced from wood sourced from a well managed forest, would it influence your purchase? ☐ Yes ☐ No

Figure 7.5 Decking survey questionnaires.

Respondents were also asked to select in order of preference from untreated boards and boards treated with decking oil that had been weathered. Figure 7.6 shows these boards.



7.6a A= A. mahogany decking oil
B= dahoma untreated
C= denya decking oil
D= esa decking oil
E= iroko decking oil

7.6b F= esa untreated
G= A. mahogany untreated
H= iroko untreated
I= denya untreated
J= dahoma decking oil

Figure 7.6 Decking boards untreated and treated with decking oil then weathered for seven months.

7.2.2 Garden furniture survey

Participants were asked to choose their favourite timber in the form of garden chairs. To assess which timbers were favoured, prototype garden chairs were manufactured from the five species and participants were asked to complete a questionnaire and select their favourite chair in a choice test. A prototype garden chair is shown in Figure 7.7.

Figure 7.7 A Denya garden chair used in the preference survey.

Furniture Survey Questionnaire

1. Have you bought wooden garden furniture before? ☐ Yes ☐ No

2. Please indicate your age group ☐ 18-30 ☐ 30-40 ☐ 40+

3. Please rank chairs A-E in order of preference, with 1 being your favourite.
☐ A ☐ B ☐ C ☐ D ☐ E

4. Do you think the furniture design should be changed or improved? ☐Yes ☐ No

5. What type of outdoor furniture do you prefer?
☐ Tables ☐ Swinging chairs ☐ Static chairs ☐ Folding chairs

6. Do you prefer the wood to be treated? ☐Yes ☐ No

7. If your answer for question 6 is yes, why should wood be treated?
☐ Beautification ☐ Prolong service life ☐ Change its color

8. Do you prefer your garden furniture ☐ Pre-assembled or ☐ Flat-packed for home assembly?

9. Which properties of wood would you prefer to know? ☐ Durability ☐ Strength
☐ Service life ☐ Other

10. As an outdoor product which materials do you like wood to be blended with?
☐ Steel ☐ Plastic ☐ Aluminium ☐ Only wood

11. Do you think wooden garden furniture is good for the environment? ☐Yes ☐ No

12. If you thought your garden furniture was from a well managed forest, would it influence your purchasing? ☐Yes ☐ No

Figure 7.8 Garden furniture survey questionnaires.

7.3 Results

7.3.1 Decking

A total of 30 questionnaires were completed for the decking, 58% by students and 42% by staff.

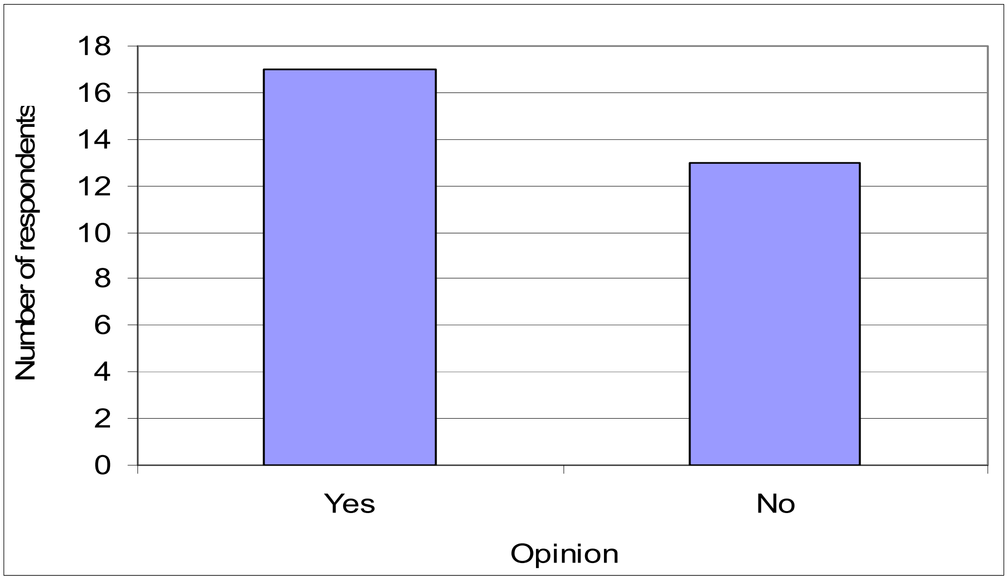


Figure 7.9 Usage of decks by respondents.

In response to *Have you used a deck before*? 17 respondents (56%) stated they had used a deck before, 13 respondents (44%) had not.

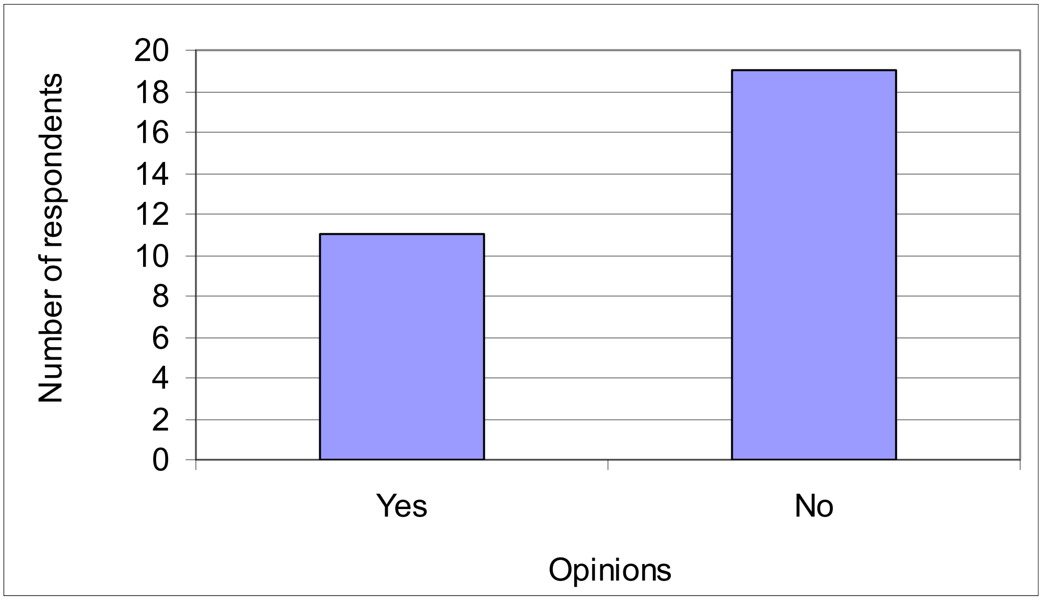


Figure 7.10 Number of participants having purchased a deck.

In response to Have a deck been installed for you before? 11 participants (36%) had previously purchased a deck and 19 (64%) had not. Results indicate that the majority of participants do not own decks.

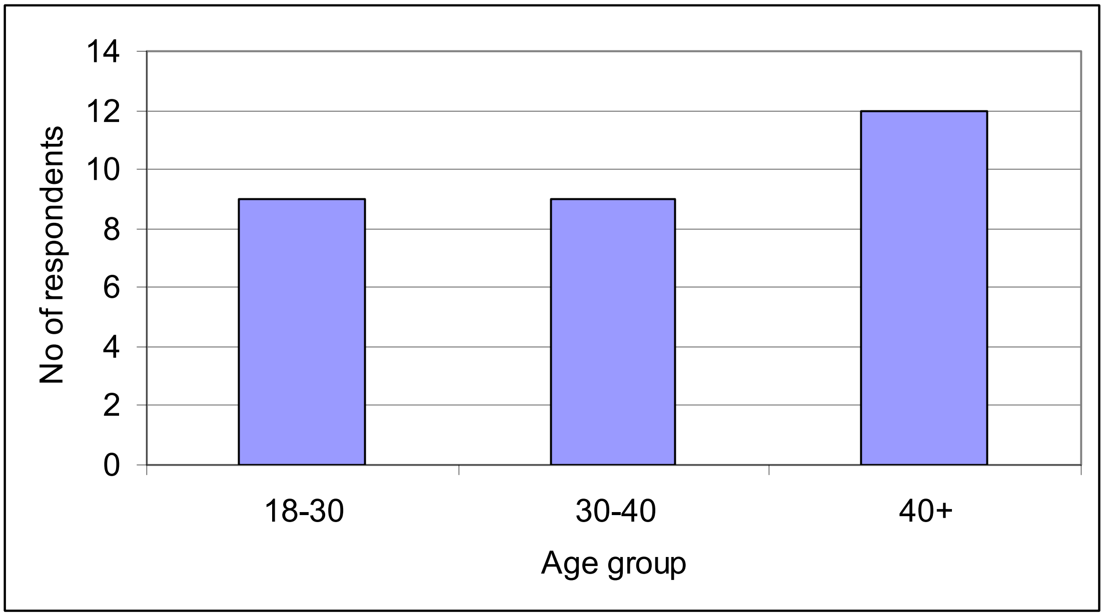


Figure 7.11 Age ranges of respondents in decking survey.

When participants were asked *Please indicate your age group*? An equal number were within the ranges 18-30 (30%) and 30-40 (30%). Majority of the participants were over 40 years (40%).

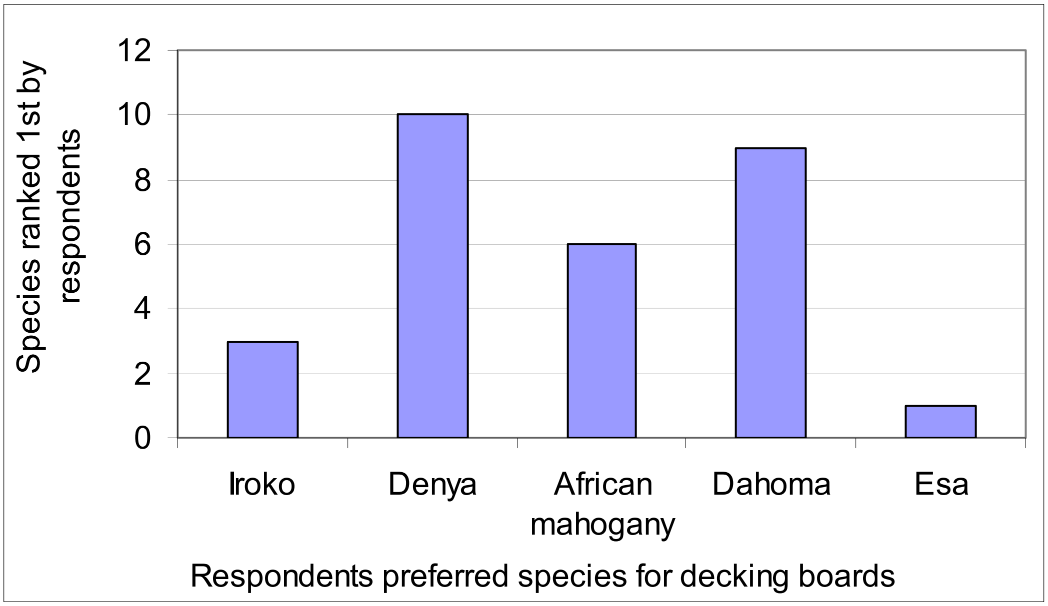


Figure 7.4 Respondents most preferred decking board prior to exposure.

Figure 7.4 shows that denya was the most preferred species being ranked 1st by 34% of participants. Dahoma was preferred by 31% of respondents. In the eyes of respondents, denya was the most appealing and esa the least.

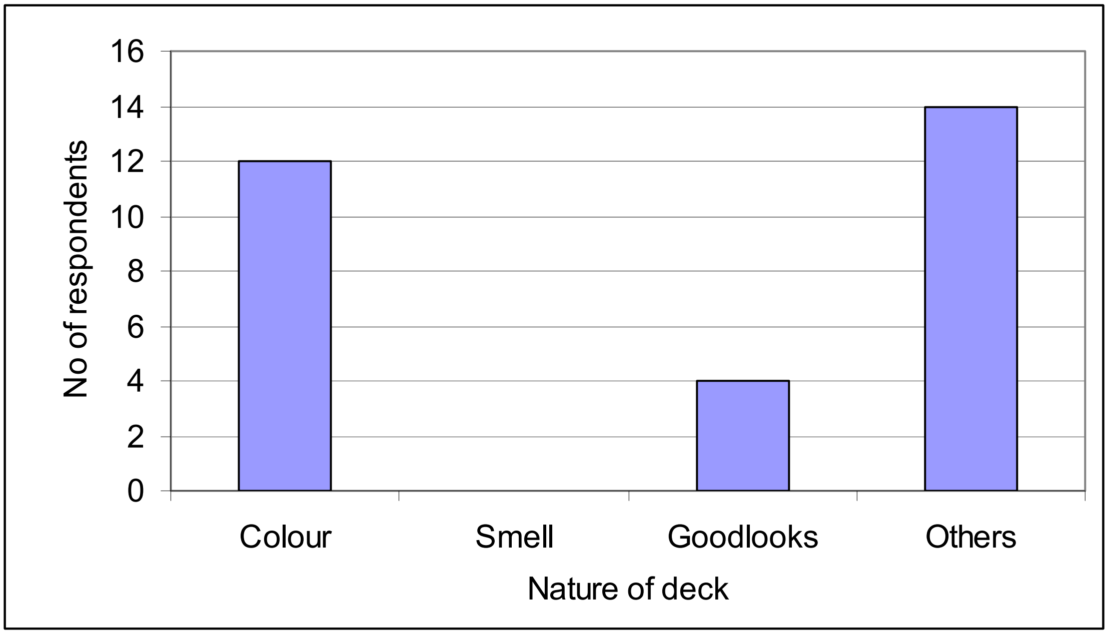


Figure 7.5 Factors influencing choice of decking board prior to exposure.

When respondents were asked *What did you like about your favourite deck board*? the majority of respondents reported factors other than colour and good looks influenced their choice. However, colour was also an important factor to 40% of respondents. None of the respondents reported smell to be a factor influencing their choice.

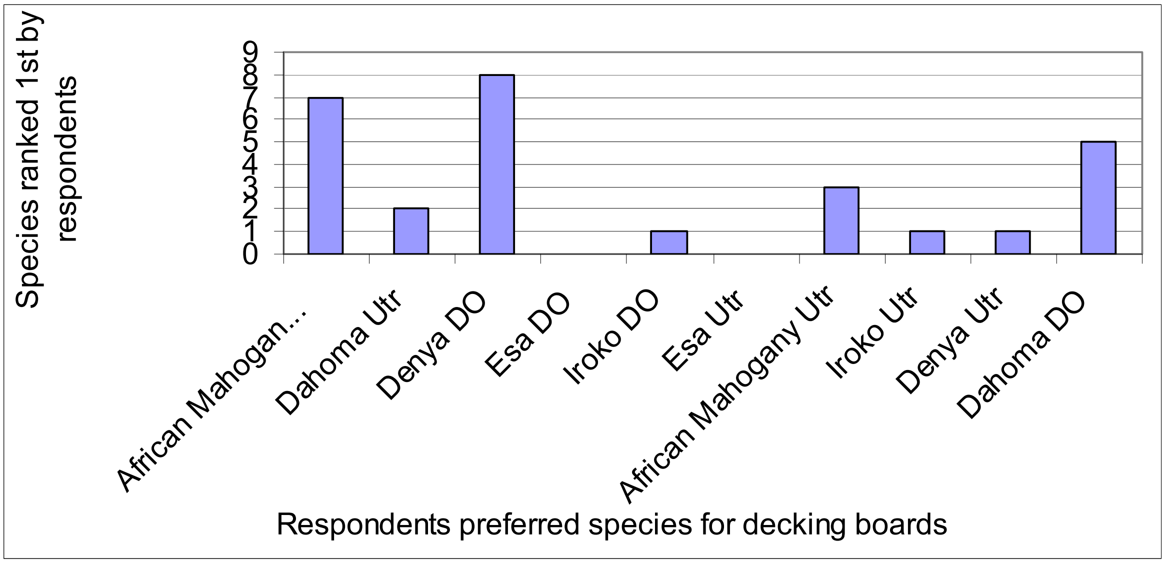


Figure 7.6 Ranking of species untreated, treated and weathered.

Figure 7.6 shows the samples ranked first choice by the respondents. From the figure, the most favoured decking board following weathering was Denya that had been oiled followed by African mahogany that has been oiled. Denya oiled had 29% whiles African mahogany oiled achieved 25%. This indicates that pre-treatment using decking oil seems to have a positive effect on choice of decking once weathered.

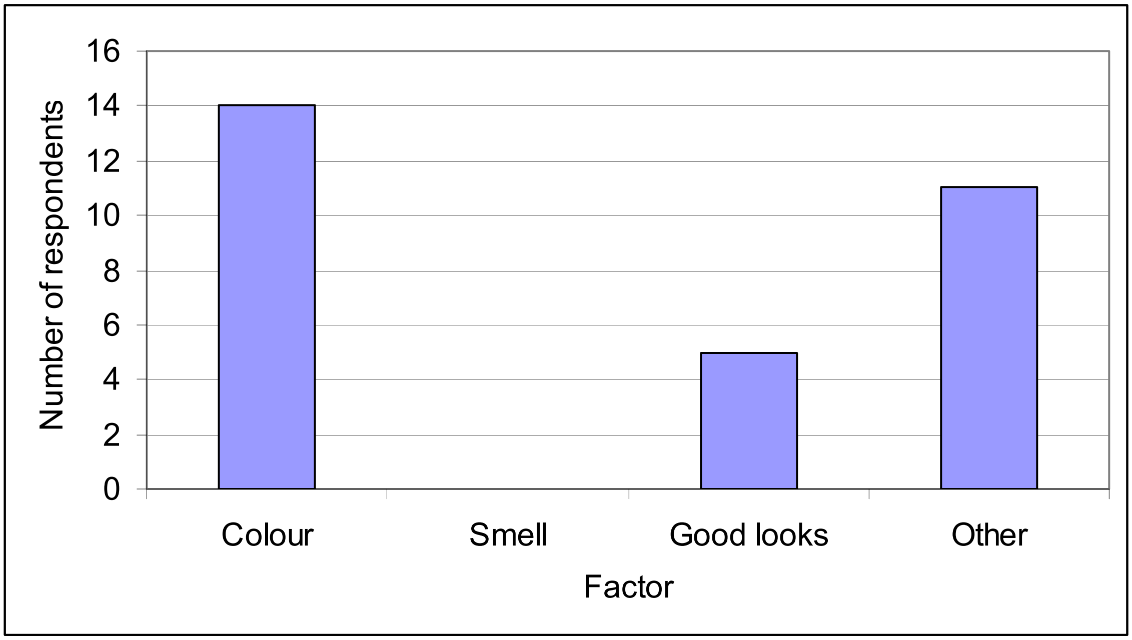


Figure 7.7 Factors influencing the selection of preferred decking boards when weathered.

When respondents were asked *What did you like about your favourite decking board*? The majority of respondents stated that colour was the factor on which they based their choice. Colour as the main factor recorded 46%, followed by Other considerations 36% and Good looks 17%. Maintenance of the colour of boards was important to respondents.

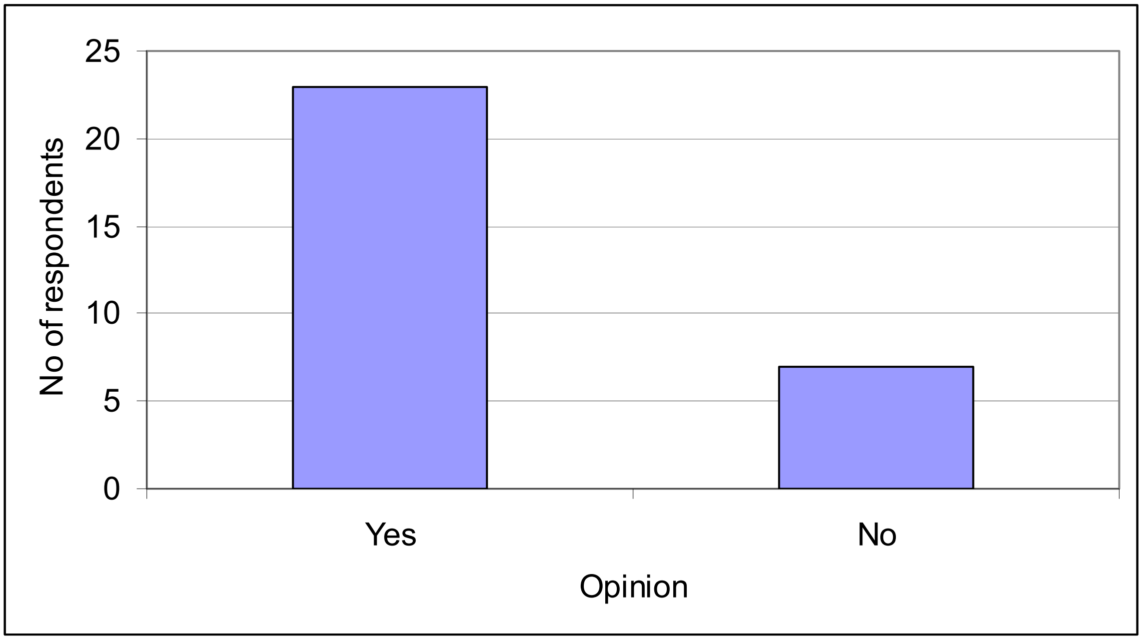


Figure 7.8 Requirement for wood decks to be treated.

In response to *Do you prefer wood decks to be treated*? The majority (73 %) stated Yes, as evidenced in Figure 7.8

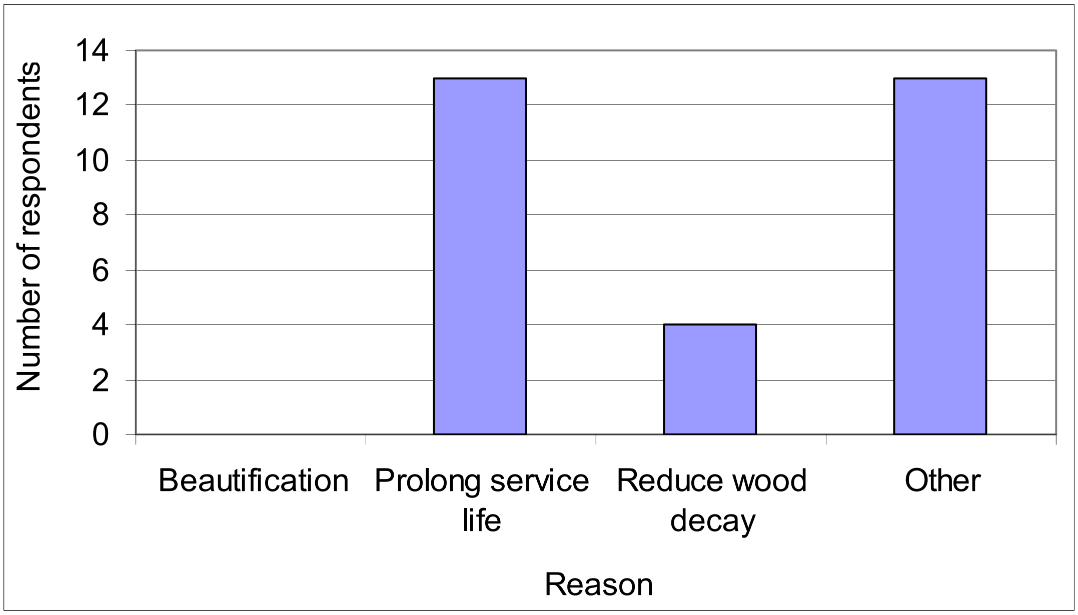


Figure 7.9 Perceived importance of treating decking boards.

Figure 7.9 shows the most important perceived reason for treating decking is to prolong the service life and other reasons. They recorded 43% each.

In response to the question of *Which properties of wood do you think are good for decks*? Although there were only four factors, respondents considered a combination of more than one factor to be important with the most important being durability and resistance to weathering. Others preferred all the four properties i.e. durability, strength, resistance to wear, and resistance to weathering.

When respondents were asked whether they preferred wood that lasts longer or looks good for decks, majority (65%) preferred decks that last longer.

On environmental issues 78% felt wood was good for the environment.

In response to whether your purchase would be influenced if a decking was sourced from a well managed forest, 95% of respondents said that they would prefer to buy decking from a sustainable source.

7.3.2 Garden furniture results

There were sixty two respondents to the furniture questionnaires in all. The initial questionnaire distributed to the MA furniture design 2006 group at the conference room had thirty two respondents. The remaining thirty completed their questionnaires in 2007.

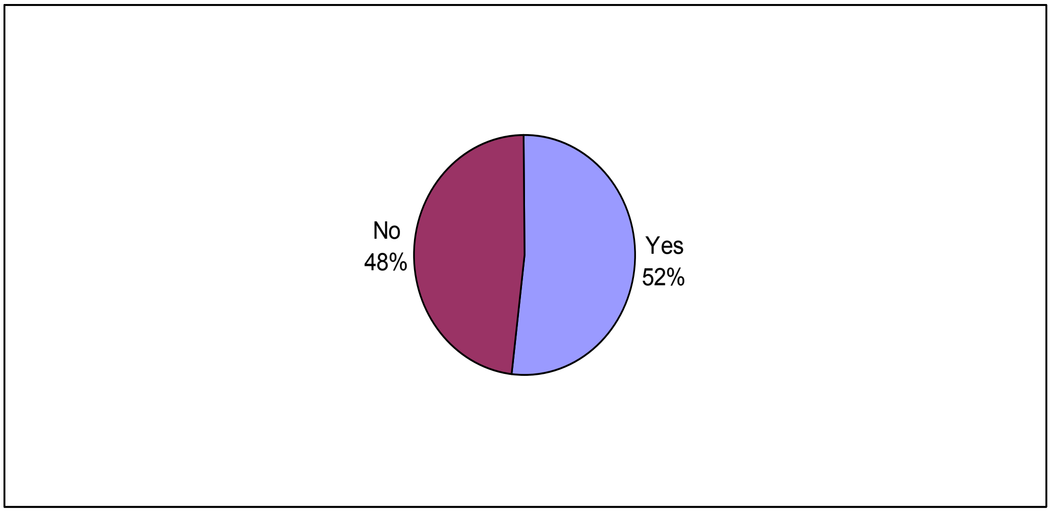


Figure 7.10 Percentages of participants having purchased wood garden furniture.

When participants were asked whether they had bought wooden garden furniture previously, 52% stated yes.

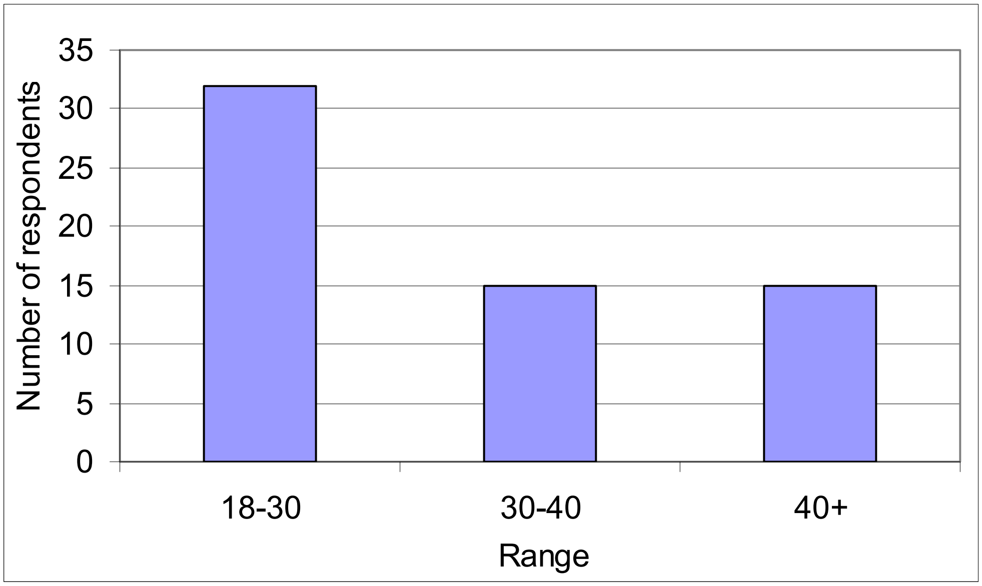


Figure 7.11 Age ranges of respondents in furniture survey.

Results obtained indicate that there were 32 (52%) of the lower age group than the other age groups which had 15 (24%) each.

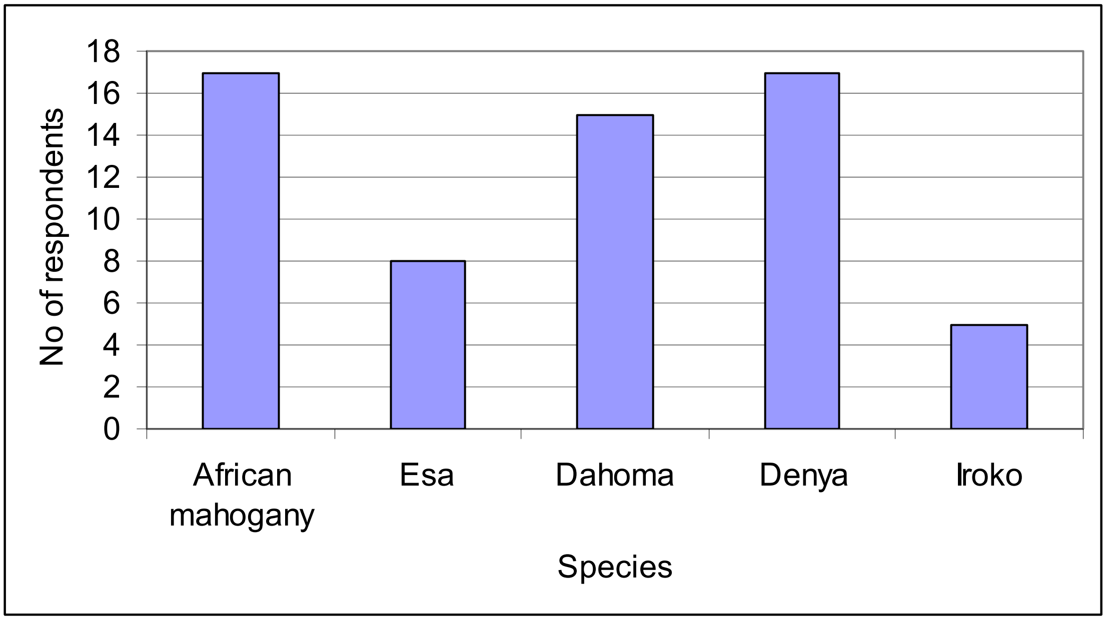


Figure 7.12 Preferred species used to manufacture furniture from the survey.

When participants in both surveys were asked to rank furniture according to preference, African mahogany and denya were the most popular with iroko least.

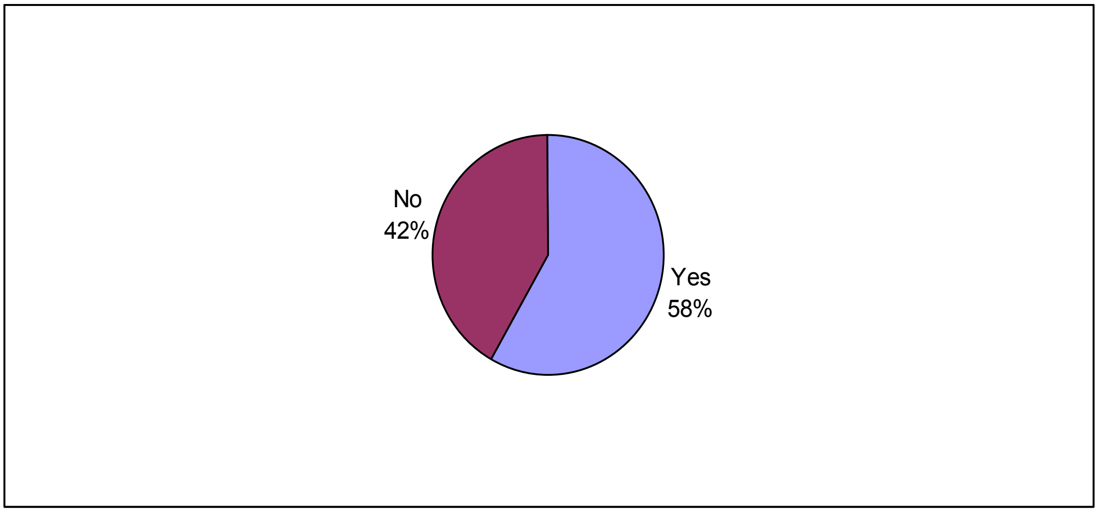


Figure 7.13 Appropriateness of the design of garden chairs.

In response to the question *Do you think furniture design should be changed*? 58% of participants responded Yes.

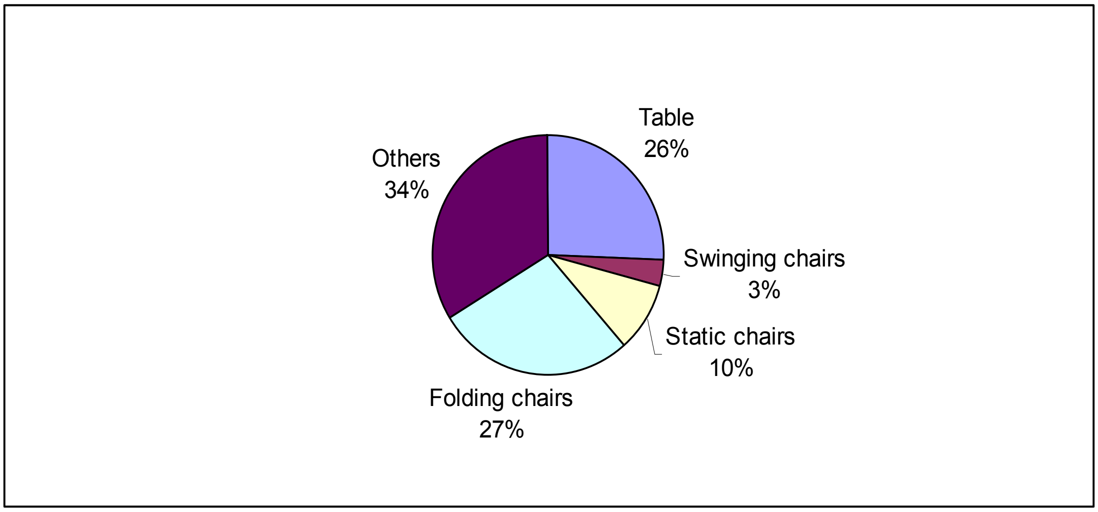


Figure 7.14 Types of outdoor furniture preferred by survey participants**.**

Results indicate that survey participants preferred other forms of furniture to the choices provided. Of the choices provided, folding chairs were most popular.

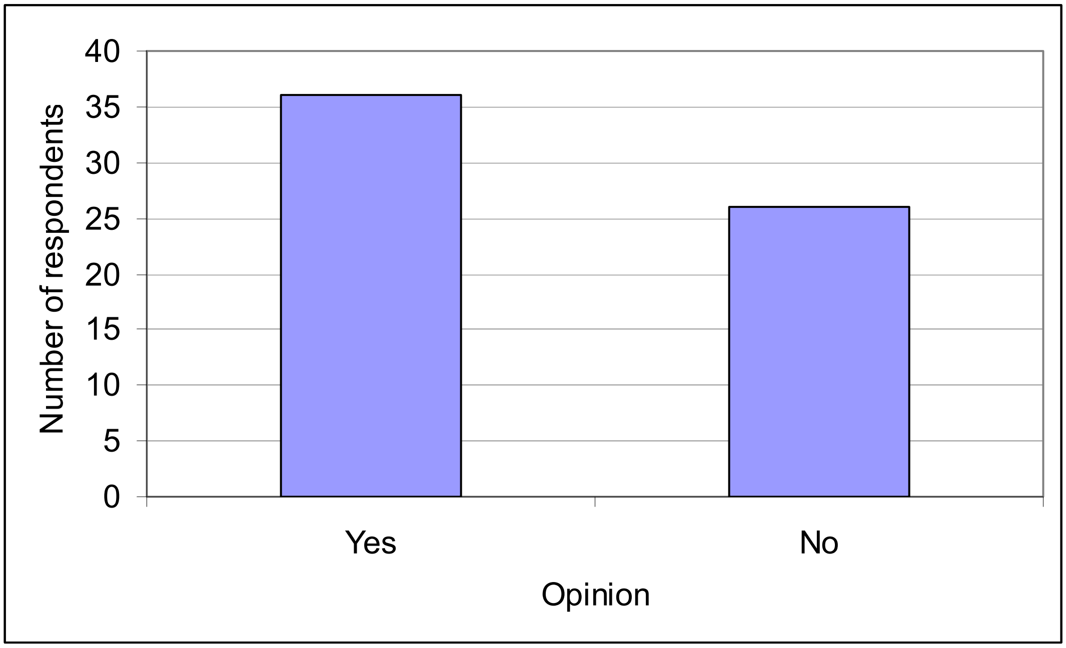


Figure 7.15 Requirements for wood garden furniture to be treated.

In response to preferring wood garden furniture to be treated, 58% of respondents stated yes.

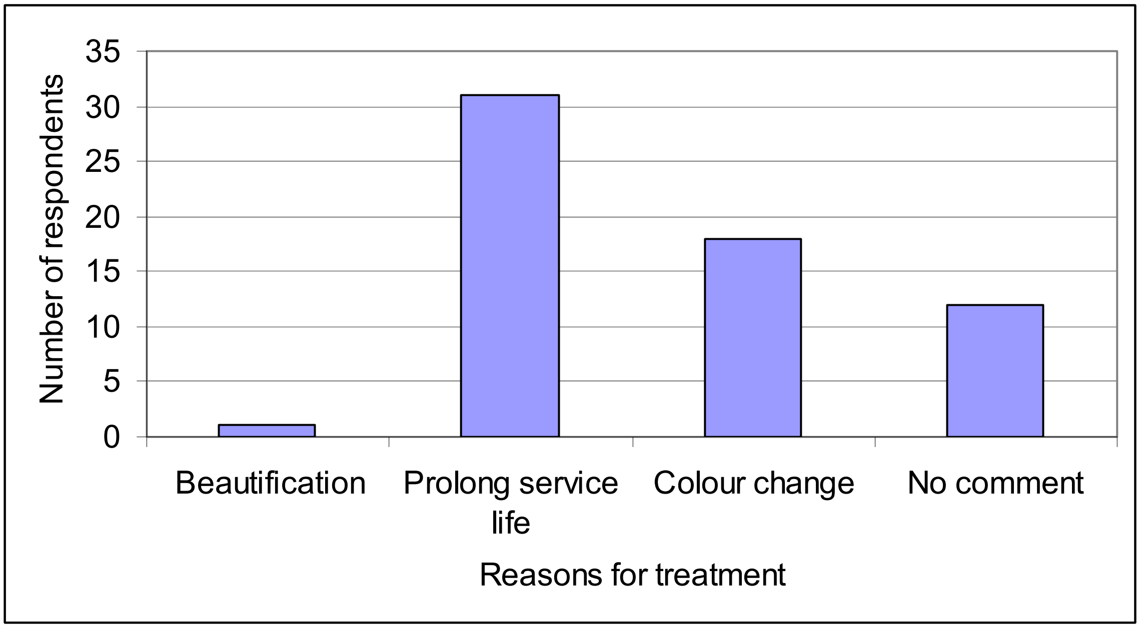


Figure 7.16 Reasons for treating wood garden furniture.

When asked what the function of treatment was, the majority of respondents believed it was to prolong the service life as portrayed in Figure 7.16.

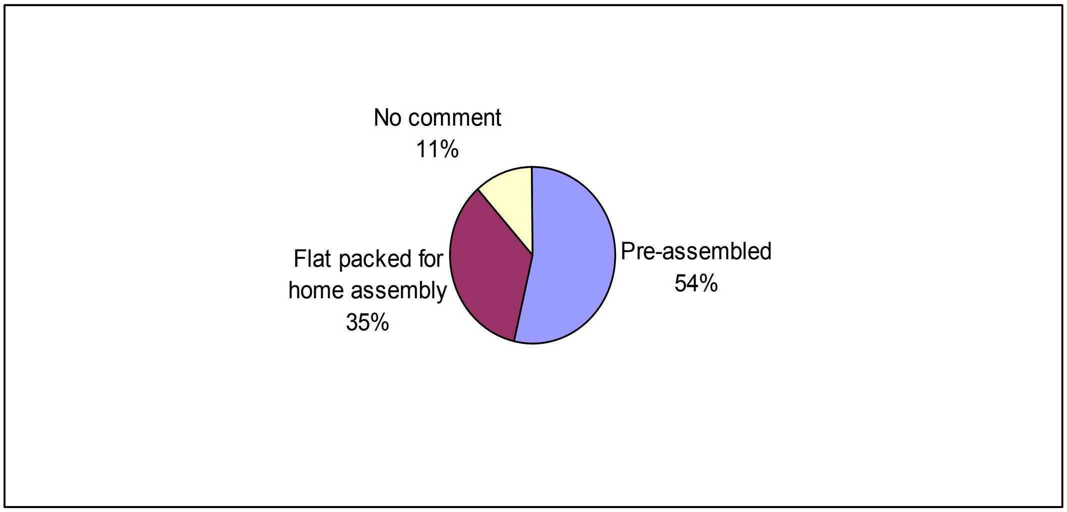


Figure 7.17 Type of garden furniture assembly preferred.

In response to the question of *Do you prefer your garden furniture pre assembled or flat packed for home assembly*? Furniture pre-assembled had the highest scoring; indicating participants will not like to worry about assembling the product.

The desired properties of wood furniture were durability and a prolonged service life of the product. Strength was the least important property.

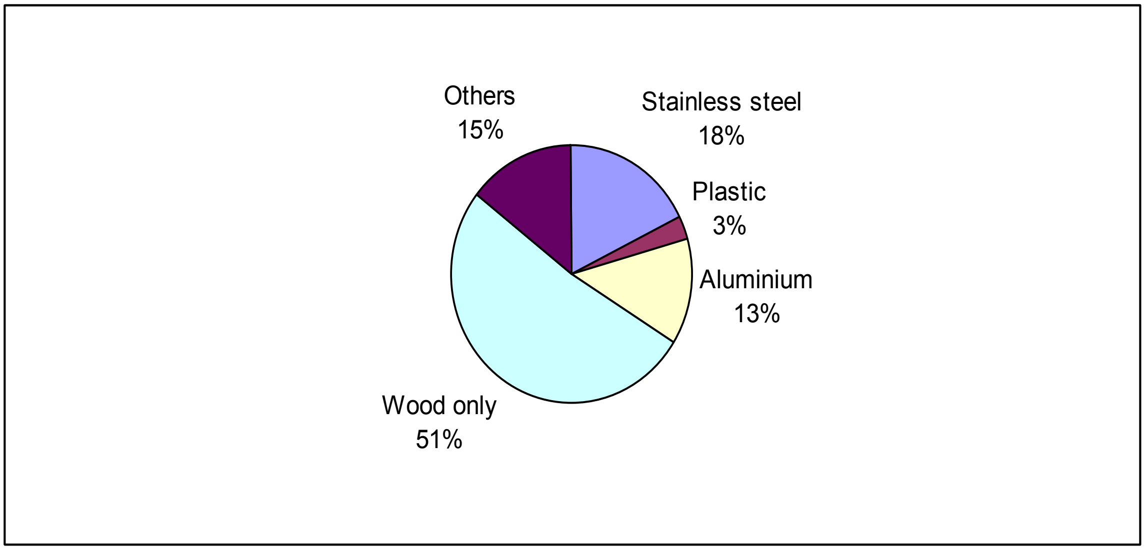


Figure 7.18 Types of material to be blended with wood in the manufacture of outdoor furniture.

The majority of participants preferred outdoor furniture to be manufactured from wood alone. Plastic was the least preferred.

When respondents were asked if wood garden furniture is good for the environment, the majority 71% responded yes.

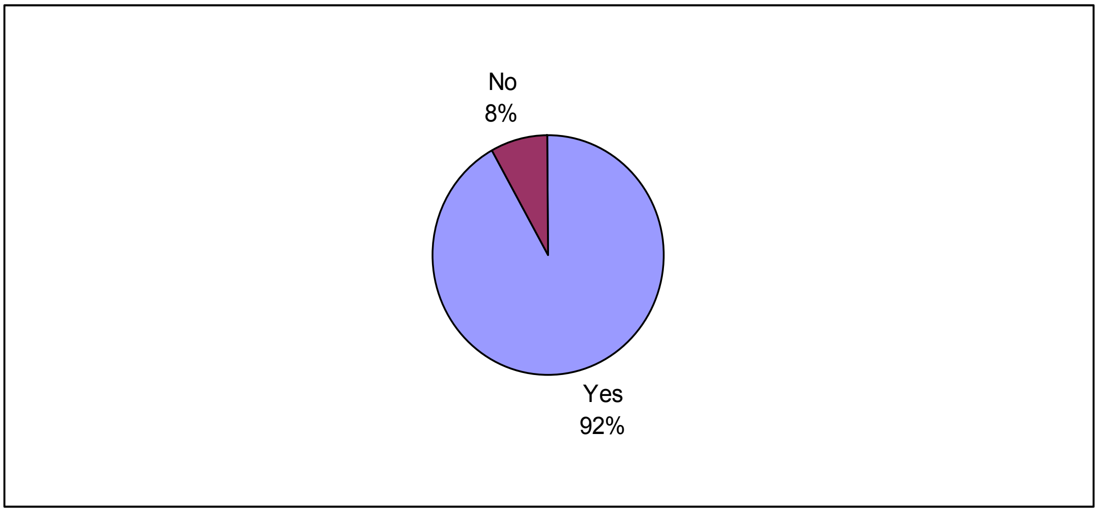


Figure 7.19 Influence of sustainable sourcing of timber on purchasing.

In response to if you thought your garden furniture was from a well managed forest would influence your purchasing, 92% responded Yes.

7.4 Discussion

Considering the decking results, most of the respondents have used decks before which indicates most participants are familiar with decks, although relatively few own decks. A slightly greater percentage of respondents were above the age of forty years. There was a fair spread of ages, in the survey.

When respondents were asked to select their favorite decking board prior to weathering, denya was most preferred species then dahoma. A. mahogany and iroko were less popular with esa being the least favoured. Importantly, denya and dahoma were more attractive than iroko and A. mahogany, which are already imported for decking by the UK market. Provided that other properties of these species are acceptable (e.g. durability), it is likely that they would be accepted on the UK market.

It is useful for the suppliers of decking to understand the factors that influence an individual's choice at point of purchase. The questionnaire was designed to ascertain what made an individual select their preferred species. Discussions with participants indicated these factors to be the feel of wood and its figure. Colour was also important when selecting a deck.

In ranking species untreated and treated with decking oil that have been weathered, then the first ranked (1) taken to be the participants favourite. In this case, denya, A. mahogany, and dahoma treated with decking oil were selected as favourites by respondents. This clearly shows that following seven months of weathering, wood pre-treated with decking oil is preferred over untreated weathered wood. One exception was iroko. In this case, it was less preferred when treated with decking oil since this peeled off during exposure which was unattractive according to survey participants.

Colour was the main factor influencing the selection of weathered decking. Some species performed poorly in the survey when untreated and unexposed. But, because these species were able to maintain their colour on weathering they were preferred. A typical example of this was A. mahogany. A flaw was detected in the survey experimental design by not including boards that have been decking oiled and unweathered, but it was felt that, as the finish was transparent, it could not have had much influence on selection.

This study clearly showed that a long service life was most important for decking and any treatment that extends its service life is important. This suggests that wood durability or treatability is likely to have an important influence on its suitability for decking. Durability was investigated in Chapter 4 of this thesis using methods appropriate for the UK market.

It is also clear that respondents prefer wood decking to be sourced from well managed forests. In view of this, producers from Ghana should ensure that, all species including denya and dahoma that are showing signs of acceptance in the UK, are sourced from well managed and certified forests.

If we consider the results from the furniture survey, a total of 62 participants were involved with students making up 65% of the participants. This is reflected in the age profiles of the participants with the age group 18-30 constituting more than 50% of total respondents.

Analysis of rankings showed that for outdoor chairs, A. mahogany and denya were the preferred species, each receiving 27% of the responses. Dahoma was considered attractive by 25% of the participants, with to iroko and esa found attractive by 13% and 8% of participants respectively This clearly indicated that denya and dahoma will be acceptable to the UK market. Interestingly, iroko was the least favoured species, though this is widely used for the manufacture of outdoor furniture for the UK market (e.g. outdoor furniture manufactured by Alexander Rose http://www.worldofalexanderrose.co.uk). Since all chairs were identical in design, then it is only the aesthetics of the wood material that influences choice. Participants were not questioned about the factors influencing their choice of furniture. However, the dimensions of the pieces and lack of figure means that colour is likely to be most important factor influencing their choice. African mahogany is as desirable as denya when used in the manufacture of furniture. Interestingly, when one considers the decking survey denya achieved 38% whereas only 24% preferred African mahogany.

The survey also provided other useful marketing information for manufacturers. It is clear that wood is the preferred material for manufacturing garden furniture, that people prefer this furniture delivered pre-assembled and to be treated to prolong its service life. The general opinion was that, wood for both decking and garden furniture should be sourced from sustainable well managed forests.

It would be beneficial for future market surveys to include buyers and retailers of decking and garden furniture.

8 GENERAL DISCUSSION

The Ghanaian timber trade faces the problem of being short of primary/preferred species. Only a limited number of species are currently being exported and these are currently over exploited. One solution to this problem is to use species that are presently abundant e.g. LUS. To sell these species onto the international market, studies must be undertaken to investigate their properties so that they can be correctly specified. It is also important to understand the desires of the customer.

This study investigated the potential for three Ghanaian LUS to be used for decking and outdoor furniture through investigations of their performance in service in the UK. A market survey of potential consumers was conducted to determine the acceptability of the species by the UK market.

From the market survey, then denya and dahoma have appeal to the consumer both in furniture and decking. Indeed as new (unexposed) products they are more desirable than some species already sold onto the market (e.g. iroko).

In terms of weathering performance, then with respect to colour change, denya and dahoma had better colour permanence than iroko, oak and A. mahogany already sold onto the UK market. This is a good marketing feature for these LUS.

Durability is important for timbers used for applications in Hazard Class 3. Using a recognised European standard, denya heartwood and sapwood were rated as very durable and dahoma moderately durable. This indicates that denya and dahoma are as durable as teak and iroko presently used. Esa would require pre-treatment prior to use for decks and outdoor furniture. Although denya was rated as very durable, more checking was observed in this species when weathered than iroko or teak references. This checking suggests that this species may have greater movement though this was not investigated.

Moisture uptake has a number of important influences on wood performance. Of the three LUS, esa has the greatest rate of water uptake in both the laboratory and field tests. This probably supported the heavy staining of this species. Interestingly, denya showed low uptakes suggesting its anatomy does not support moisture access. Its resistance to moisture uptake may partly explain the durability of this species.

The study clearly showed that the brush application of teak and decking oil had little long term influence on water uptake or colour change. For some species the decking oil coating failed and led to deleterious aesthetics.

In addition to the market research on decking prior to exposure, a preference survey was conducted on decking boards weathered for six months. The survey showed a clear preference for the denya and dahoma LUS over iroko and A. mahogany already sold onto the market. This gives assurance that these species will be acceptable to consumers as decks.

The market research survey highlighted the importance of sourcing certified wood products for the UK market. There is the assumption that most tropical wood is being sourced illegally resulting in deforestation therefore making it unattractive to the European markets. This in a way has become a hindrance to the promotion of tropical hardwoods. There is therefore the need for the Ghana Forestry Commission to expedite action on the certification of Ghana’s wood products to ensure its share of the world timber trade. This includes potential decking and furniture products for the UK market.

9 FURTHER RESEARCH

Further research should be carried out in the use of other lesser utilised species in different product forms, to measure their strength and mechanical properties using European standards as most of these species are being promoted in Europe.

A market research in other European countries to assess the performance of the lesser utilised species in outdoor application must be given a second thought.

Research work needs to be conducted into the use of certain preservatives that are accepted in Europe on most of the LUS to assess their performance after a longer period of time.

The culture of keeping research findings on the shelves should be a thing of the past, and rather ensure that recommendations are implemented to achieve the best out of research findings.

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