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HIGH PERFORMANCE EXTERIOR ALKYD WOOD COATING

It is readily apparent that the correct formulation of exterior wood coatings has, over the years, been given scant regard within South Africa

In a country of extremes in Climatic conditions - from the prolonged damp periods of the Southern Cape, through the humid conditions of the Eastern coast to the high UV levels of the Transvaal - one would not expect a simple coating formulation to suffice. Unfortunately, the market is dominated by products such as these.

The standard alkyd coating formulation, although perfectly acceptable for interior finishes, does not meet the exacting demands made of exterior wood finishes. Decorative coatings which are colour retentive, rapid drying and resistant to knocks and scrapes, tend to be hard and consequently have limited flexibility. This flexibility will be reduced further through photo-oxidative degradation experienced during the weathering process. When such a film is applied to a dimensionally unstable substrate such as wood, the inevitable result is checking, cracking, and flaking.

It is the purpose of this paper to describe the requirements of an alkyd coating system that will meet the particular characteristics essential for long term exterior durability.

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HIGH PERFORMANCE EXTERIOR ALKYD WOOD COATINGS

1. INTRODUCTION

Plants gained their first tenuous foothold on dry land during the Silurian Period, some 400 to 440 million years ago. During Devonian times (350-400 million years) plants became widespread in occurrence throughout all the continents. Most of the plants of this period were small although some attained trunk diameters of up to 75cm. However, it was during the upper Carboniferous (310-350 million years)' that the great coal forests of the world were laid down and it is here, for the first time, that we find annual growth rings within the trees indicative of seasonal climatic changes. In these Coal Measures we find the Coniferophyta which include a great variety of living and fossil conifers such as the Pine, Cedar, Sequoia and Cypress. Throughout the intervening eras, plants continued to develop and evolve as necessitated by changes in atmospheric conditions as the world aged.

Since the early beginnings of man, some 1 000 000 years ago wood has been of benefit to man "from cradle to grave". This renewable resource was in great abundance in early times and afforded man many of his necessities, such as implements for hunting and defence, as well as sources of heat and rudimentary shelters through four periods of glaciation.

Today, however, the scenario changes with great areas of forest being decimated by man. Logging and land clearance for agriculture and hydroelectric schemes destroys 15 million hectares of forests annually - an area larger than Austria - with little or no provision made for replanting.

After 400 million years of survival deforestation may see the demise of wood as a common commodity. It is therefore incumbent upon mankind to ensure the optimal usage of this increasingly scarce material.

The decreasing sales of timber for external applications such as fascia boards, cladding and window frames and the inroad of metals is not necessarily due to price considerations but rather the apparent lower maintenance schedules afforded by the latter. Although both materials by and large suffer from degradation by corrosive attack, wood has the added disadvantages of attack by insects, micro-organisms and ultraviolet irradiation.

2. TIMBER

It is impossible to evaluate the performance of coating systems in isolation from the substrate for which it is intended. Wood is a somewhat complex material and those aspects which will dictate its suitability for an application, and the performance of coatings applied to it, are enumerated below:

2.1. WOOD TYPES

Wood may be differentiated into two types namely softwoods.

(Coniferous) and Hardwoods (Broad leaf). This old nomenclature can, however, be misleading as some of the harder softwoods can be harder than the softer varieties of hardwood.

Within each of these wood types two gross features can be distinguished (FIG I):

- (i) Sapwood - the (generally) paler outer circumference of the trunk which is responsible for the movement of nutrients through the tree and
- (ii) Heartwood - the inner centre of the trunk composed of darker, dead wood.

2.2. COMPOSITION

Wood is mainly composed of 3 Polymeric species, Cellulose, accounting for 50% of the composition, lignin (20%) and hemi-cellulose (25%) whilst natural resins and oils make up the remainder. It would appear that the celluloses affect the strength and toughness of the wood whilst the lignin contributes to its hardness. The pH of wood is generally in the region of 3 to 5 whilst those woods with a pH of below 4 promote corrosion of metal fixtures and fastenings.

2.3. MOISTURE CONTENT

The moisture of green wood (i.e. timber freshly felled) depends largely on the free volume space within the cell structure. The sapwood of a tree naturally contains higher moisture levels than the heart wood and it is not uncommon for trees to contain as much as 200% moisture over the dry wood mass.

2.4. PESTS

Provided wood is protected from extremes of moisture and insects it can remain unchanged for centuries as evidenced by the excellent condition of wooden artifacts retrieved from the dry Egyptian tombs. However, under more natural conditions trees and timber are susceptible to both fungal attack and insect infestation; with different timbers varying appreciably in their susceptibility. Because of its higher nutrient content, the sapwood is more prone to attack whilst the heartwood often contains infiltrates which are sometimes toxic to fungi and insects.

i) FUNGI

Fungi, and, to a lesser extent, bacteria, thrive in damp and low light conditions. Most fungal growth takes place within the thickness of the wood and remains hidden from the naked eye. Fungal attack not only reduces the strength of the wood but also increases its porosity, favouring the uptake of further moisture and subsequently enhancing the conditions for the proliferation of the fungus.

ii) INSECTS

Some insects tunnel into timber spoiling its appearance, although not necessarily affecting its strength. However, it is the larvae of certain species which are more important. Some larvae can live up to a few years on the substances from which cell walls are made, before turning into a parent, and can totally destroy the wood structure. Within the tropics and sub-tropics termites can cause serious damage to wooden structures and it is important to note that although some timbers have a natural resistance to insect attack, as pointed out previously, no untreated timbers are immune to the subterranean termite.

iii) GENERAL DECAY

Decay of timber is not necessarily due only to fungal or insect attack but can take place in the absence of both. Given a sufficiently high moisture content, especially free surface water and ultra-violet irradiation from direct sunlight, chemical decomposition of the polymeric species of which wood is made can also occur. It is often difficult to distinguish between this type of decay and that due to fungus.

2.5. SHRINKAGE

Once a tree is felled, the biological processes sustaining its life are interrupted. The wood begins to naturally dry out as the transpiration equilibrium can no longer be supported by the root system. As the drying process continues the wood begins to shrink as the moisture content of the wood decreases and internal stresses within the cell walls are generated. The wood fibres which are aligned more or less to the axis of the tree do not shrink to an appreciable extent but shrinkage across the grain can be appreciable with the tangential shrinkage being greater than the radial shrinkage. (Fig 1).

3 WOOD TREATMENTS

As we have seen thus far, wood, or timber freshly hewn from a felled tree is not an ideal material for longevity or dimensional stability. Logs received by the sawmill are not only sawn into useable pieces but are also treated to improve the characteristics of the timber produced. There are numerous treatments to which timber can be subjected to improve its attributes but only two are of direct importance in the context of this paper.

3.1. SEASONING

Seasoning (or drying) of the timber is undertaken to render the timber as stable as possible in its new, unnatural, relationship with the environment. Some of the advantages to be gained by seasoning of the timber are:

- i) To minimise the degree of shrinkage when it is used for structural purposes.
- ii) To improve its resistance to fungal decay and staining as fungi will not actively grow or germinate in wood with a moisture content below 20%.
- iii) To reduce its mass before transportation and improve its handling.
 - iv) To inhibit the corrosion of metal fixing.
 - v) To render suitable for the application of surface coatings.
 - vi) To improve its impregnation by preservative fluids.

Seasoning may be undertaken by one of two methods - air drying or forced drying - although the former is rarely used today due to the prolonged periods required for the moisture

content of the timber to attain equilibrium with the ambient conditions (c.a. 6 to 7 weeks per 25mm thickness vs 2 to 7 days for forced drying).

As has been noted previously, timber shrinks upon drying and allowance is made, by machining oversize, to attain the required final dimensions after the drying process. Softwoods generally shrink less than hardwoods and shrinkage from green to oven dry can be as high as 14% tangentially and 7% radially although the average for most timbers is 8% and 4% respectively.

Too rapid drying of the timber generates excessive moisture gradients throughout the depth of the wood resulting in internal stresses which produce dried timber with "cup", "bow" and sometimes "twist" defects.

3.2. WOOD PRESERVATIVES

Seasoning of timber reduces its equilibrium moisture content down to between 10 and 18% under most terrestrial conditions of relative humidity and temperature. However, exposure to surface water, whether due to damp conditions or standing water, can again increase its moisture content to above the 20% level and promote fungal attack. In addition to this, wood of any moisture level is generally susceptible to insect infestation.

In order to effectively prevent attack by fungi and insects most of the timber varieties require the application of preservatives. Although many techniques have been developed over the years, only two of the methods will be pursued here.

3.2.a SURFACE APPLICATION

Application of preservative fluids by brush, spray or dip cannot be construed to be an effective treatment of the timber. Penetration of the preservative is time dependant, and the short duration of fluid contact is not amenable to maximum penetration. However, brush and spray application is the only practicable means of applying preservatives to existing timber built into structures.

3.2.b PRESSURE APPLICATION

Pressure application enables penetration of the preservative fluids to considerable depths into the timber and affords the most effective treatment. In general two types of treatment are used namely the full cell (Bethel) process and empty cell (Rueping and

Loury) process. Both processes are similar and only really differ in the initial stage where either a vacuum (full cell) or pressure (empty cell) is used to promote penetration of the preservative into the timber.

The wood Preservatives used in these processes can be divided into three distinct groups, the tar oils, the solvent soluble and the water soluble varieties.

i) TAR OIL WOOD PRESERVATIVES

This class of wood preservatives is typified by creosote, a complex substance containing up to 200 or so constituents, derived from coal or wood distillates. The toxic compounds in creosote are phenolic entities although it is quite Possible that some of the other constituents may also act in a similar manner. In general, the coal tar distillates are superior to those obtained from wood although many grades, differing in performance, are available. Creosote has been widely used as a preservative for many years and, correctly applied, can afford excellent durability and an attractive finish. Creosote is insoluble in water and therefore resistant to leaching, providing for a highly effective, permanent, preservation of the timber. However, creosote has certain undesirable properties.

- a) It has a strong, somewhat objectional odour, when freshly applied.
- b) It has a propensity to stain articles which come into intimate contact.
- c) It is difficult to coat if one desires an alternative surface finish.

ii) SOLVENT SOLUBLE PRESERVATIVES

The most commonly used solvent soluble wood preservative is pentachlorophenol (PCP) dissolved in a suitable organic solvent such as white spirits. These preservatives are quick drying and the solvents used do not normally have a persistent or objectional odour. In addition, PCP does not corrode metal fastenings, discolour the wood or cause it to swell and distort. Unfortunately, PCP can cause skin irritation and is now being banned worldwide due to its human toxicity.

Tributyl tin oxide (TBTO) is more effective than PCP at equal concentrations, has lower toxicity and skin irritation potential but is very expensive in comparison.

iii) WATER SOLUBLE PRESERVATIVES

Many type of inorganic soluble salts have been used world-wide such as Zinc Chloride, Sodium fluoride and Magnesium Silicofluoride, but only Chrome Copper Arsenate (CCA) is used extensively within South Africa. As CCA is water soluble it would be reasonable to expect it to leach out of the timber in damp conditions. However, the relatively high proportion of chromium used causes the salts to be "fixed" to the cell Walls. Although the neat solution is toxic to humans, the proportion of CCA absorbed into the timber is not considered a health risk. CCA treated timber does not have an unpleasant odour and is readily painted. It must, however, be remembered that timber treated with water soluble salts must be re-dried before being put into service.

The quantity of preservative absorbed by the timber is, of course, critical and depends not only on the type of preservative and timber species but also on the intended application to which the timber is to be subjected. The success and rate of impregnation also varies between timber species and whether the timber is cut from the sapwood or heartwood, the latter being the more impenetrable. The following table is presented as a guide to the relative proportions required.

PRESERVATIVE	EXTERNAL APPLICATION	MARINE APPLICATION
CCA	5.3 kg/m ³	30 kg/m ³
Creosote	80 kg/m ³	160 kg/m ³

4 EXTERIOR WOOD COATINGS

One may be excused for thinking that the various pretreatments given to timber at the sawmill should be sufficient to ensure its durability in external applications. However, this is not always the case for there are four other factors which remain to be considered.

i) NON-PRESERVED TIMBER

Not all timber used for external applications contains preservatives. Where required, regulatory authorities dictate the use of preserved timbers utilized for structural purposes such as roof beams and trusses. However, no such regulations exist for non-load bearing timbers such as doors, window frames and fascia boards. Invariably, preserved timbers cost more and the use of preserved timbers is dictated more by economic consideration than good sense.

ii) JOINERY

During the joinery process, timber is of necessity cut and/or planed to size and shape. As it is impossible to ensure the penetration of preservatives to the centre of thick sections, crosscutting of timber invariably leads to the exposure of untreated end-grain which, being some 200 or so times more absorbent than the surface grain may lead not only to the excessive ingress of moisture but also fungi and insects.

iii) MOVEMENT

As mentioned previously wood expands and contracts with changes in its moisture content, at different rates across the grain than along the grain. This differential movement causes excessive stress on Butt joints which may lead to failure of the adhesive and exposure of the end-grain.

Timber also has a peculiarity known as "Set". When a timber article, such as a door frame, is built into a wall, moisture absorption, whether due to damp brick work, plaster or simply high relative humidity, causes the timber to expand. When this expansion is constrained by an immovable surface, such as brickwork, it becomes compressed and "Set".

Later reduction of the moisture content to a lower level is accompanied by shrinkage to a new, smaller, dimension resulting in the development of cracks between the timber and the immovable surface. These cracks can, and do, allow the ingress of moisture, fungi and insects

to areas of the timber which are inaccessible to later treatment whether by preservatives or surface coatings.

iv) COATINGS

The old, white lead, oil based coatings for timber, were renowned for their effectiveness and formed the basis of exterior wood coatings for many years. Due to toxicological reasons these coatings have now been discontinued and little cognisance would appear to have been taken of the exacting demands placed upon exterior coatings in formulating their replacements. Although exterior coatings may be suitable for application to interior woodwork, the reverse certainly does not hold true.

From the above it becomes apparent that although the timber may have been seasoned and, where necessitated by the species and intended application, preserved, it is still essential to ensure that all newly exposed surfaces, and surfaces which will later be inaccessible, are adequately treated prior to the installation of the wooden product into the structure.

4.1. PRETREATMENT OR TRANSIT STABILIZATION COATINGS

Suffice it to say that pretreatment is a fairly new concept, and it is yet too early to tell precisely what its full effect will be on exterior woodwork longevity. However, the following guidelines for the formulation of coatings suitable as pretreatments are based on several of the points already covered.

i) PRESERVATIVE

For those timbers requiring preservative treatment, a spirit soluble preservative, such as DBTO, may be necessary to impregnate newly exposed surfaces.

ii) LIGHT STABILIZATION

The addition of an ultra-violet light absorber is necessary to not only protect the timber itself from degradation during storage and installation, but it is also known that certain of the timber preservatives can also be destroyed by photo-oxidation induced by ultra-violet irradiation.

iii) CARRIER

The carrier should be composed of a non-drying or slow drying resin dissolved in a suitable solvent to ensure the maximum penetration of ingredients into the wooden substrate and provide some barrier to the excessive ingress of moisture. Although one cannot preclude natural or bodied oils from this context, their tendency to dirt retention would generally limit their usefulness.

Whilst the utilization of a transit stabiliser will no doubt enhance the durability of exterior wood-work, the main factor resulting in the degradation of coatings, namely the ingress of end-grain moisture, will not be adequately circumvented by this approach. Historically the sealing of the end-grain before assembly was accomplished by coating the end grain with a lead based primer. However, this method has now fallen into disuse, although there has lately been renewed emphasis with research aimed at the utilization of epoxy esters for this purpose.

4.2. EXTERIOR WOOD FINISHING COATS

In order to understand the requirements of coatings applied to exterior wooden substrates it is instructive to consider where conventional coatings normally fail. Other than creosote coatings, traditionally three types of finishes have been applied to exterior timber, namely Paints, Varnishes and Emulsion coatings.

i) PAINTS

Paints, or enamels, applied to a properly prepared substrate should theoretically last for periods up to 5 years. Both the resin and substrate are protected against photochemical breakdown to a large extent by the presence of the pigment. Some pigments such as carbon black and the Iron oxides are particularly effective in this respect and pigmented paints based on these have a longer life span than those based on titanium dioxide, even though the film temperature of the darker colours in sunlight is considerably higher than white or pastel shades. The performance of these coatings is thus dependent upon the relative ultraviolet light absorption of the pigment.

However, enamels not only obliterate the natural finish of the wood but also completely seal the wood providing an almost impenetrable barrier to moisture diffusion. Any ingress of

moisture at uncoated sites will cause the inevitable blistering, cracking, and flaking of the coating.

ii) VARNISHES

Varnishes and varnish stains are the only choice for enhancing and protecting the natural appearance of the wood, although they are no more permeable than their enamel counter parts, and also tend to have a short lifespan.

Photooxidation of the coating promotes its embrittlement to a point where it will no longer cope with the dimensional changes of the wooden substrate brought about by the continuous changes in the timber moisture content. In addition, these coatings afford no protection to the timber from the harmful effects of ultraviolet light leading to the degradation of the wood and subsequent loss of adhesion of the coating.

iii) EMULSION COATINGS

Emulsion coatings do not penetrate the wood to any appreciable degree, due to their large molecular particle size, resulting in poor adhesion. In addition, the plasticisation of these coatings, whether internal or external, to achieve the pre-requisite minimum film forming temperature for particle coalescence, tends to render the film susceptible to dirt retention and blocking. Recent studies also indicate that water borne coatings can lead to grain lifting on the timber surface.

5. PRACTICAL CONSIDERATIONS FOR THE FORMULATION OF ALKYD EXTERIOR WOOD COATINGS

Despite the inherent disadvantages of alkyds when exposed to exterior conditions, such as hardening and embrittlement with age, and the potential for hydrolysis of the ester linkages, they can still form the basis for acceptable coatings. To ensure the longevity of films based on alkyds, however, cognisance must be taken of a number of key factors.

5.1. COATING MEDIA

The protection of the wooden substrate from the rigours of the environment and the prevention of the ingress of water can only be assured if the coating retains its integrity over its projected life span. The single most important factor which would impinge on film integrity is whether or not the film will withstand the expansion and contraction of the wooden substrate.

A unit shrinkage or expansion coefficient for wood of 0.2% per 1% moisture change is fairly typical for radial and tangential sections, and, if one assumes a moisture variation of 1.0% from the equilibrium moisture content, this would lead to an expansion or contraction of 0.2% of the wooden substrate which must be coped with by the coating to ensure its integrity. Recent Work indicates that conventional alkyd coatings, exposed at 45 degrees South at Florida, exhibit a drop in flexibility from around 30% to 0.5% over a 12 month period. On prolonged exposure it can safely be assumed that a conventional alkyd will continue to embrittle, due to auto-oxidation, until the film fails through checking and cracking, at around 2 years. Conversely a correctly formulated flexible alkyd exhibits a drop to only 1.5% over the same period giving a projected lifespan in excess of 5 years. (FIG. II)

An added advantage of alkyds with a long lifespan is that they decompose by erosion, rather than flaking and peeling, resulting in easier and less costly maintenance schedules.

5.2. PERMEABILITY

All coatings are permeable to a degree and the crucial property to aim for is controlled vapour permeability. Too permeable a film - a problem often encountered with water based systems results in excessive moisture absorption through the film causing dimensional changes of the timber and the possibility of wood rotting and decay.

Conversely, coatings of low permeability (a feature of thick film coatings) can allow moisture levels within the wood to approach the fibre saturation point (22-30% by mass), during prolonged wet spells, if moisture ingress through the end-grain and uncoated areas is not prevented. This will inevitably lead to micro-cracking or, in severe cases, blistering of the coating. (FIG III).

5.3. WATER REPELLANCY

A complicating factor to the utilization of a permeable coating is the possibility of absorption of liquid water through the coating into the substrate making it essential that a water repellent be included in the formulation. Hydrocarbon waxes provide the simplest solution but must be used at a concentration sufficient to provide water repellancy yet not provoke adhesion failure of the film, nor cause recoating difficulties. Paraffin wax is the cheapest route to improved water repellancy although micronized polypropylene or polyethylene waxes are more effective.

5.4. ULTRAVIOLET LIGHT STABILISERS

To prevent darkening of the wooden substrate and both the degradation of the wood and coating, the absorption of incident ultra-violet light is necessary. This can be achieved in two ways, either by the incorporation of proprietary U.V. absorbers or by the incorporation of Iron oxide pigments.

Iron oxide pigments have the unique combination of transparency in the visible regions of the spectrum whilst being opaque to U.V. irradiation. Ultra fine particle size synthetic iron oxide pigments should be used in preference to the traditional variety as they may be more easily dispersed throughout the media whereas the traditional iron oxides tend to form clusters.

Although the ultrafine particle Iron Oxide pigments have a much higher oil absorption than most other pigments and are difficult to disperse, they are only required at concentrations of around the 2% mark to promote adequate colour and U.V. protection. However, the iron oxide pigments are susceptible to in-can settlement on storage, so it is advisable to incorporate a thixotropic agent to maintain the consistency of the product.

The preparation of clear wood coatings requires recourse to the proprietary U.V. absorbers. Recommended levels and combinations differ from manufacturer to manufacturer but in general concentrations of around 1 to 2% will normally suffice. Some of the proprietary U.V. absorbers will not only also protect any preservatives within the coating but have a certain degree of preservative activity in their own right.

5.5. PRESERVATIVES

The addition of micro-biocides to the coating has a two-fold effect - they protect the coating itself from fungal colonisation and replenish the preservative level of the wood surface which may have been depleted by U.V. irradiation, machining or may be absent in the first instance.

Many preservatives are available and differ not only in their activity but also in their effectiveness against various pests and fungi. Care must be taken, however, to ensure that the particular micro-biocide chosen will not actively affect the drying of the coating or cause its discolouration.

5.6. FLATTING AGENTS

Where a matt or satin gloss finish is desirable the use of fine silica matting agents is recommended even though their hydrophilic nature contributes to a loss of water repellancy.

The water repellent additives themselves, such as the micronized polypropylene waxes, contribute in part to a reduction in the gloss of the coating and it is therefore normally only necessary to utilize small quantities of fine silica to obtain the desired sheen.

5.7. PENETRATION

Timber that has not had a transit stabiliser pre-treatment requires a coating with a higher degree of penetration ability than would otherwise be the case. The choice of the correct media here is somewhat of a conundrum as the alkyd should have as low a molecular mass as possible to ensure a slow viscosity increase during drying, hence promoting penetration, whilst still being high enough to ensure film durability. Suffice it to say that a compromise must be reached although stronger and slower evaporating solvents may be utilised to achieve similar results with a somewhat higher molecular mass alkyd.

Appendix A

GENERAL REFERENCES:

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3. Timber - Properties and uses by W.P.K. Findley. (Granada Publishing ISBN 0258969210).

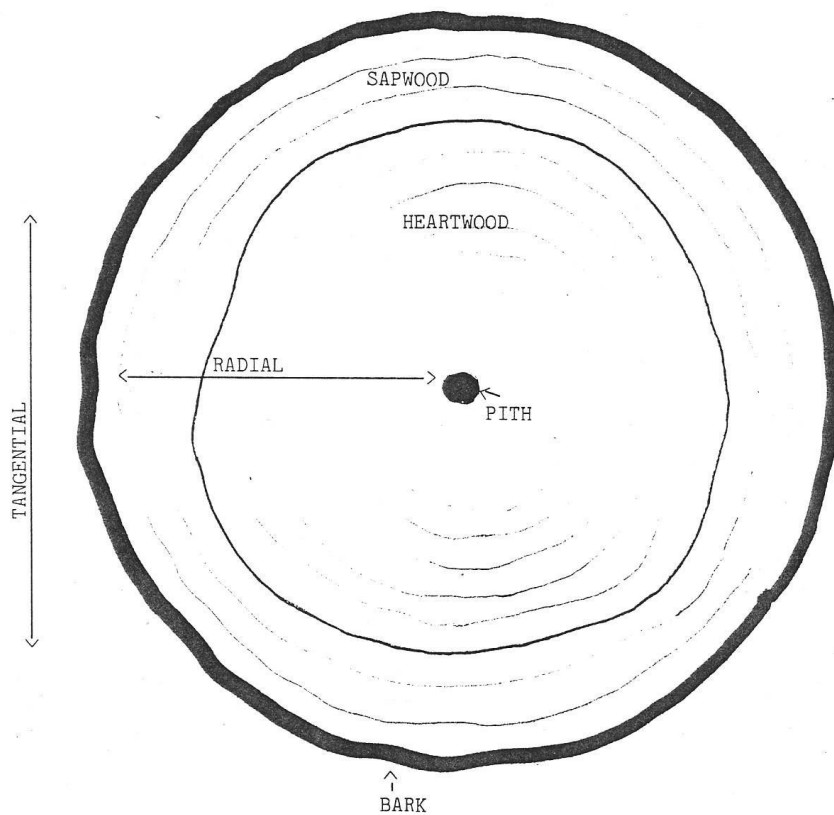
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5. Research on Surface Coatings at the Forestry Research Institute by D. Plackett (NZ Journal of timber construction, volume 3 No. 4).
6. Protection of Mildewcides and Fungicides from Ultra-violet light induced Photo-oxidation by P.D. Gabriele & R.M. Iannucci (Journal of Coatings Technology Vol. 56, No. 712 May 1984).
7. Moisture and Painted wood by B. Lindberg (JOCCA 1986(6)).
8. Timber Preservation - D.A. Jackson (Richards Bay Symposium on Laminated Timber as a Structural Material).

Appendix B

APPENDIX B

FIG. I TYPICAL TRUNK CROSS SECTION



WEATHERED ALKYD EXTENSIBILITIES

30 micron dry film

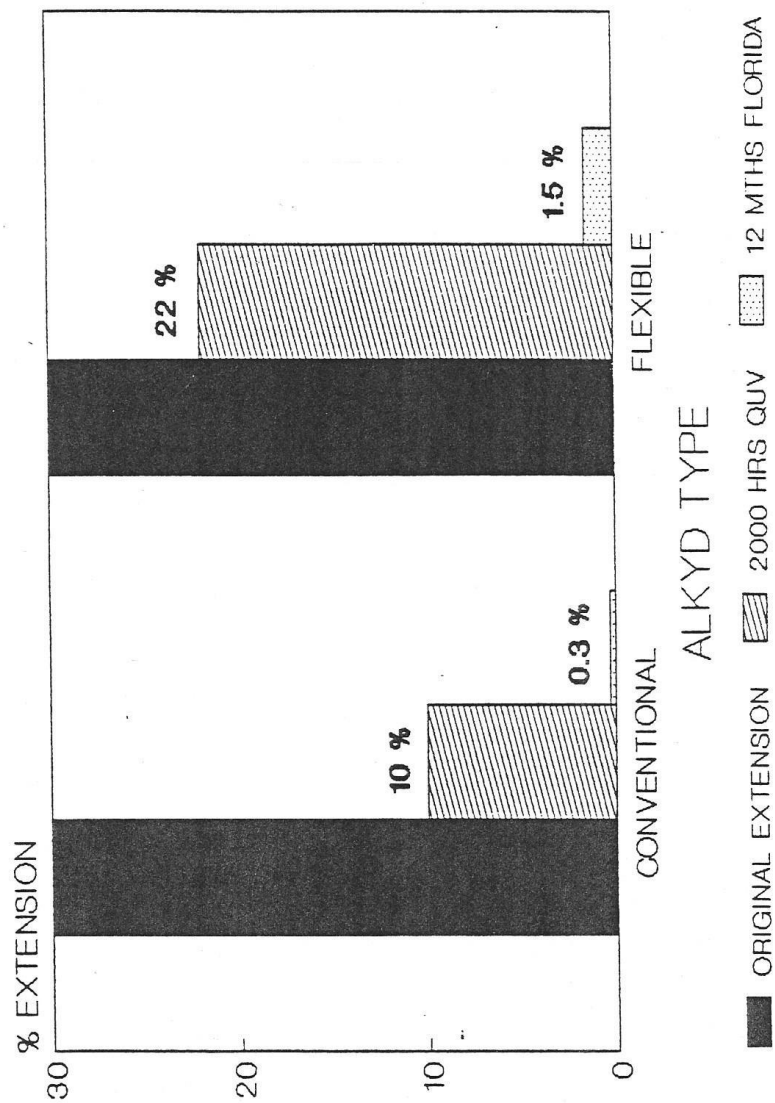


FIG. II

SPECIFIC PERMEABILITY (gm/m²/day) 25 MICRON DRY FILM THICKNESS

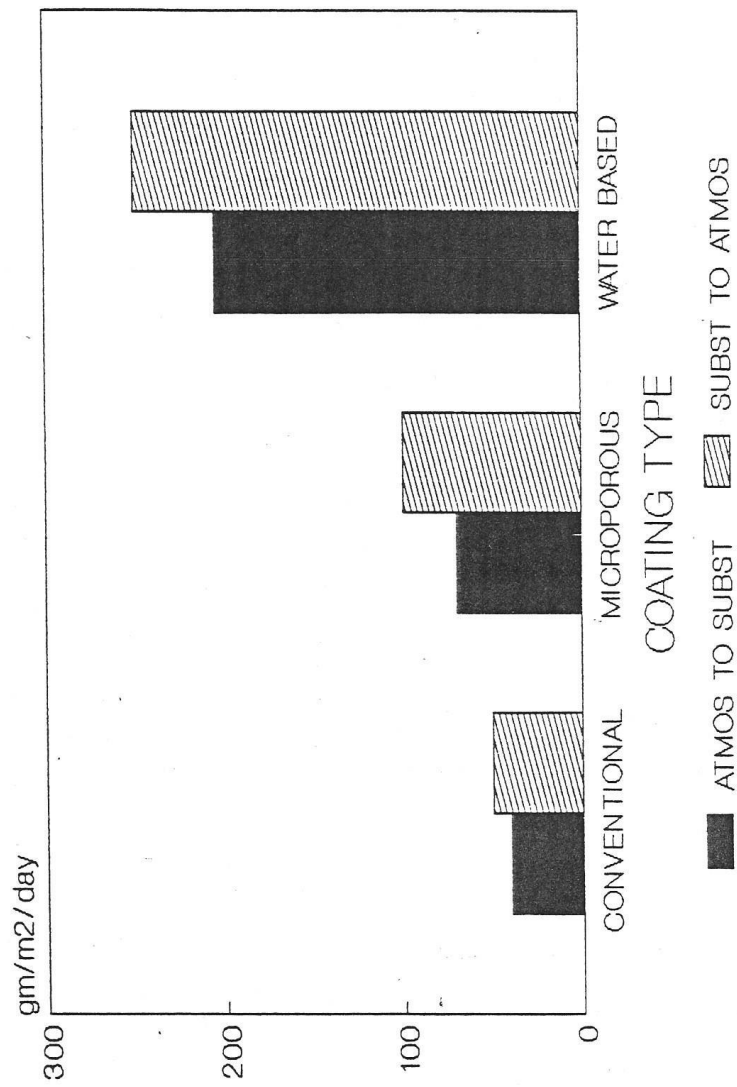


FIG. III