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New experiences of the German Federal Railways with tropical hardwood species

presented by Dr. Georg Schulz
Central Office of the German Federal Railways, Minden (Westf.)

1. Introduction

At the 13th International Wood preservation Conference of the German Association for Wood Research in 1974, I had presented a paper titled "Experiences of the German Federal Railways with foreign wood species used for sleepers" (4), which was then published, in 1975 in the journal "Holz als Roh-und Werkstoff". Most of the then made statements are still valid and do not need to be repeated. During the last 10 years there have been a lot of new discoveries which should be explained here.

Apart from small amounts of tropical wooden sleepers, which had to be imported between 1970 - 1974 for research purposes and to overcome the supply bottle neck, the German Federal Railways uses since 1968 only beech (fagus silvatics) for the track sleepers. For switch sleepers the standard species is the European Oak. Since the demand of the German Federal Railways cannot be covered by sleepers of this species at economical prices, large amounts of sleepers made of tropical species had to be purchased since 1970. Experiences with those species and other tropical species which were used for research purposes will be reported here. These *experiences* and also the collaboration with the Institute for Wood Biology and Wood Preservation / Hamburg and their scientific researches have led to new opinions on the natural durability of timber species.

2. Wood Species

In evaluating the suitability of a timber species for sleepers there are various decisive aspects which are economical as well as technical. From the economical point of view, useful life is an important aspect. This aspect is again determined by the mechanical wear and maintenance to which the sleepers are subjected on the line, but also by the strength and durability of the timber species concerned. The*ir* resistance against bio-deterioration depends either on the quality of the preservative treatment or on the natural decay resistance of the wood resulting from the appropriate natural heartwood substances.

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Since the tropical sleepers normally cannot compete with the beech or oak sleepers in regard to the price if they need impregnation, the main concern of the German Federal Railways in purchasing of tropical sleepers was to use only those timber species whose natural durability made the creosote impregnation unnecessary. The knowledge about the natural durability was acquired from the scientific literature or from practical experience. Since such results relate only to the heartwood and not to the sapwood, timber species which do not need any impregnation have to be bought without the easily perishable sapwood.

The necessary strict differentiation between heartwood and sapwood is not usually mentioned in practice reports, and with the exception of the German Federal Railways, no railway administration requires the absolutely sap*wood free* delivery of sleepers which are to be installed without impregnation. For that reason, publications about the useful life of sleepers should be judged with care, since sometimes there is no information whether there has been any impregnation, and if so, which preservatives were used, in what dosage, and applied by what method. During previous years the German Federal Railways were also not insisting on heartwood sleepers, and it is possible that sometimes a sleeper with a proportion of sapwood can be overlooked, since it can only be clearly differentiated on very fresh timber. However, the heart rot and sap rot are always clearly noted down in the research results, even if one rot overlaps with the other.

Now, according to their origin, the different species will be discussed:

<u>Latin American</u>

The condition of the oldest overseas sleepers in the lines of the German Federal Railways, made of red Quebracho (Quebracho Colorado) and installed in 1902, are, 10 years after the last report, still unchanged and the statements made then still valid. The sleepers show on the ends and partly on the surface an insignificant degradation of wood, which has carbon structure and is only limited to the wood surface. The cause could be a long lasting effect of the atmospherilia *(environment?)*, namely a physical cause, or may come from the slow attack of soft rot on the surface. During the latest tests, the red Quebracho wood showed after a service life of 21 years not the slightest degradation of the heartwood, as it is to be observed on the 83 year old sleepers. In the inner part, at some sleepers namely in the pith, there are a few rotten parts which could have already existed on the living tree and were overlooked during the inspection. The appearance of pith rot on the Quebracho Colorado is known. Apparently the natural durability of the inner heartwood diminishes clearly, as it has been observed in other timber species which were classified as very durable species.

As far as there were sap parts on the 21 year old test sleepers, they were rotten so cleanly that one cannot *determine* whether there was any sapwood at all.

The strong corrosion of the screws caused by the high proportion of tannic acid in the wood, is a real problem of Quebracho Colorado. After a few years it was hardly possible to loosen the screws. They broke off although the screw holes have a diameter of 18 mm *(0.709" = 11/16")* like all very hard wood species instead of 16 mm *(0.630" = 5/8")* as normal. Whether galvanized screws would be an effective help cannot be judged yet.

According to the experiences of the German Federal Railways, the Quebracho Colorado (Schinopsis balansae) is one of the few really durable wood species. Among the wood species that can be used for sleepers, this species is perhaps the most resistant one against fungi attack.

Although there were certain experiences on the species Massaranduba (Manilkara species) about which Schmidt had reported in 1966 (2), a new test was carried out with this species. The sleepers were not cut with a saw but prepared with an axe (*or adze?*) which is still a partly used method in South America, and therefore contained sapwood. A great amount of the untreated sleepers showed after a service life of 8 to 10 years more or less strong rot, and a number of them had to be removed. The fungal attack was not restricted only to the sapwood, but had already reached the heartwood. This fact brings us to the conclusion that, contrary to the technical literature which classifies the Massaranduba as durable or very durable, the decay resistance of this timber species has to be classified *as* not more than moderate. For that reason, the German Federal Railways consider the timber species Manilkara as unsuitable for sleepers.

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Africa

According to the general opinion and to technical literature, Bongossi or Azobe or Ekki (Lophira alata) has with regard to its natural durability an outstanding position among the timber species used for sleepers, because this timber is classified, for example, as "absolutely durable in the earth, in water and near water" (1), as unrotable or at least extremely resistant against fungi.

The German Federal Railways had installed the first Bongossi *(Azobe)* test sleepers in 1954, and had been buying certain amounts of switch sleepers since the middle of the fifties every year until a few years ago. Altogether 1.41 million running meters *(4,620,000 linear feet)* of switch sleepers and 174,000 track sleepers made of Bongossi wood were purchased. Most of the sleepers were installed without impregnation. Until 1978 there had been no indication which could create doubt about the legendary decay resistance of the species. Occasional observation of fungus attack were associated with the sapwood, which sometimes occurred in spite of the fact that it had to be non-existent according to the terms of delivery so that even I could not talk about a remarkable fungus attack in the above mentioned report.

In 1978 it was observed for the first time that, in addition to the Bongossi sapwood, also the heartwood was attacked by wood destroying fungi after a useful life of only 8 years. From then on the Bongossi wood was put under systematic observation which proved that Bongossi sleepers showed in many cases more or less fungus attack. Without doubt, this fact could have been known a few years earlier if it had been looked at and researched more accurately. Its reputation for extreme durability prevented such attention. Besides, before the mid-seventies relatively few Bongossi sleepers were dismantled *(removed from track)*, and also the science had no contradictory opinion about Bongossi. As a special phenomenon the Bongossi wood has a light red zone, the so called intermediary wood, between the yellowish sapwood and the dark red heartwood. The question *of* how this intermediary wood should be classified in regard to its durability was answered by the science until a few years ago to the effect that intermediary wood should be accepted and judged as heartwood. As the observations of the German Federal Railways have also proved it, this opinion is in the meantime no longer valid.

The wood destroying fungi attacks first the sapwood but the transition *of the attack* into the intermediary wood and the heartwood occurs then without interruption if the circumstances are favorable for the growth of fungi.

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In the meantime sufficient knowledge has been acquired about the necessary conditions for fungal attack of Bongossi wood. The sufficient moisture which is a requisite condition for the growth of fungi is granted only when the Bongossi wood is fed by water continuously over a long time. Because of the high density of the wood, it takes years until the wood becomes sufficiently moist so that a fungus infection can develop. This condition will be achieved through a badly aerated dirty ballast where up to 2/3 of the height of the sleeper continuously remains moist, where Bongossi wood stays in contact with the humid earth over a long time, or where in some other way *the* wood gets a frequent water inflow which cannot evaporate quickly enough, as in the case of bridge sleepers under cover. Bongossi wood overcomes occasional humid periods with immediate drying without fungus attack or damage. Probably this is the reason why this wood species won the reputation of being extremely durable.

Generally the Bongossi sleepers show no signs of fungal attack on the track or in the switch, because the parts outside the ballast are hard and not attacked. The rotten side faces can only be seen when the surrounding ballast stones are removed. At a very severe damage one can stab easily a knife into the otherwise very hard wood.

In an extreme case, after a useful time *(service life)* of 22 years, switch sleepers were rotten up *to the* middle of the sleeper, but the sleepers seemed to be intact from above.

During time of two years (1982-1984) all of the dismantled switch sleepers were tested for rot, and the rot attack up to a depth of 2 cm *(0.79" = ¾")* was classified as "light rot" and rot attack deeper than that was classified as "severe rot". Sleepers which already had fungus mycelium growth on the side parts or under the sleeper but showed no distinct damage were not evaluated. According to the results of the test, 36.6% of the sleeper *sets* from 101 dismantled switches showed more or less rot. In terms of the number of the sleepers, it was only 14.4%, meaning that only part of the sleepers of a switch were attacked by fungi. Differentiation according to the degree of rot attack showed that 79% of the attacked sleepers had light rot, which had a depth of less than 2 cm, *(0.79" = ¾")* and 21% of the sleepers were severely rotten.

A codification of the rot intensity according to the age of the sleepers can only be made in regard to the severity of the rot (depth of the rot). With the exception of two switches which had a few severely rotten sleepers after a useful life of 10 to 11 years, such an intensive rot could only be seen on 18 to 24 year old sleepers.

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All the switches which were installed in 1960 had rotten sleepers, and 72.2% of the sleepers of these switches showed wood damage and 43.2% of them were classified as severely rotten.

The appearance of rot is very different. Sometimes the whole sleeper is attacked in full length, but often there is zonal *(localized)* damage. The rotten sleepers in a switch are sometimes scattered beside sound sleepers, but occasionally they are also accumulated one after another.

In one case, as all the sleepers near the switch blade showed extremely strong damage, it was suspected that probably de-icing salt was used in winter which could have stimulated the growth of fungi. *(?This logic seems strange. Would not deicing salts kill fungus?)* During the analysis of all the dismantled switches this assumption, however, could not be proven in this regard. Probably the moisture near each sleeper and also its position in the track are important factors. Sleepers in a well aerated and sufficiently dry ballast can be without rot even after 20 years. Consequently, after a service life of 18 years, of the 17 dismantled switch sleeper sets which were installed in 1965, only 4 sets had rotten sleepers, but all of the 90 sleepers (100%) of those sets *with rot* were severely attacked. Expressed in terms of the total amount of 1,122 sleepers, the ratio was only 8%.

According to the tests made by the German Federal Railways and according to the experiences of many years, it can be said that, the Bongossi *(Azobe)* wood does not possess the extraordinary natural durability against wood destroying fungi which is mentioned in the literature. On the contrary, one should take into consideration that Bongossi wood shows rotten parts already after a useful life of only 8 years and that with an increasing useful life also the probability and the intensity of decay increases. After a useful life of 20 years, most of the sleepers of a switch will be attacked by rot.

Since Bongossi wood is extremely hard, difficulties may appear during adzing and drilling and during the tightening of the screws. Although the diameter of the screw holes, normally 16 mm *(0.630" = $^{5}/_{8}$")* on oak and beech was increased to 18 mm *(0.709" = $^{11}/_{16}$")*, it happens often that screws are turned off. But if there are 2 or 3 screws missing in a rail plate because of the fact that they were broken off during tightening, all of the 8 holes have to be bored once again in the track after removing the set screws and changing the position of the sleeper, a procedure which is very expensive and difficult. For that reason, Bongossi sleepers are not favored.

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Another problem is the resistance of a track on the Bongossi sleepers against lateral sliding. Since in the first years the ballast stones cannot press themselves into the bottom of the sleepers, it was feared that the stability of the track could be endangered, especially in the curves, and there were restrictions of use. New tests of the Research Institute of the Federal Railways, however, showed that the higher weight of the Bongossi sleepers and of other similar tropical sleepers was balancing the insufficient contact with the ballast stones so that all the restrictions of use could be abolished.

Other African timber species which are supposed to be resistant against fungi are Bilinga or Badi or Kusia (Sarcocephalus diderrichii), Tali (Erythrophlieum guineense), Dabema or Dahoma (Piptadenia africans) and Iroko (Chlorophore excelsa). All these timber species are being tested by the German Federal Railways as untreated switch sleepers.

Bilinga and Tali were installed for the first time in 1967. Bilinga was laid also in 1972 and 1974. After a service life of 10 years Bilinga sleepers have already shown rot and the first sleeper had to be removed after 13 years because of rotten parts in the heartwood which to all appearances originate in the pith. After 17 years the Bilinga switches as well as Tali switches had to be dismantled. Operationally it was impossible to keep them because of the broken screws and loose rail fastenings. During the analysis of the dismantled sleepers it was seen that, despite relatively clean ballast beds, the sleepers made of both timber species had more or less strong wood destruction on the bottom side by decay which could not be notice earlier because of the ballast. Moreover, within the region of the plate bases and under the base plates there were heartwood damages which could be seen even from above.

A final evaluation of the tests on Bilinga sleepers is not made yet, since sleepers made of these species are still being used. Nevertheless, it can be said that Bilinga and Tali react very similarly, and that both of them cannot be classified as very durable as *they are* in the technical literature. Indeed, they have a certain durability, but not enough to use these species without impregnation.

The species Dabema (Piptadenia africans) is being tested without impregnation since 1976 as switch sleepers. The time is not enough to form and opinion on it, but already after a useful life of 7 years, rot attacks of about 1 cm *(0.39" = 3/8")*, depth were seen on the lower parts of the side faces of the sleepers in the ballast bed, so that this wood species could by no means be classified as decay resistant or very durable, as it is generally pretended in the technical literature. As far as it can be judged, the natural durability of ?
? ?

of the sleeper screws caused by the natural ingredients of the wood is a secondary phenomenon which is harmful.

Switch sleepers mode of Iroko (Chlorophora excelsa) have been used since 1972 as test sleepers without impregnation. Already after a useful life of 12 years single sleepers had to be removed because of strong rot. The remaining sleepers show more or less heavy decay on the side parts. The attacked wood is partly sapwood, but the rot attack clearly reaches deep into the heartwood. A final opinion can be formed only after removing all the sleepers. However, it is clear that this species does not possess the durability which is attributed to it, and in regard of this fact it is likely to be classified on the international scale a half *step* or one step below Bongossi, Bilinga, and Tali.

East Asia

The oldest sleepers made of Keruing (Dipterocarpus species) have been used since 1960 as test sleepers in switches. They were impregnated according to the oak diagram and absorbed 35 to 40 kg/m^3 *(2.2 to 2.5* lb/ft^3*)* of creosote. Although the net absorption was, according to our present knowledge, very low, and the impregnation was irregular, the test sleepers are still in good condition without any visible rot. In order to cover its requirements, the German Railways have bought large amounts of Keruing switch sleepers every year. Until today, a total quantity of 4.31 million meters *(14,100,000 linear feet)* of sleepers have been bought from Malaysia and Indonesia. Eight to 10 different species of Dipterocarpus are being delivered under the trade name Keruing. Most of them do not possess sufficient *natural* durability and need to be impregnated. For this purpose a special diagram (3) has been developed which renders a creosote impregnation of about 100 kg/m^3 *(6.2* lb/ft^3*)* possible provided that *the* relatively well treatable timber is seasoned for at least one year.

According to the large amount of sleepers, it can be said clearly that the Keruing sleepers endured the test, and that no deficiencies have been observed so far. It can already be told in advance that Keruing possess a longer useful life than oak.

In the beginning of the seventies, besides Keruing, track sleepers and switch sleepers made of Kempas (Koompassia malaccensis) were bought for test purposes. Nevertheless, the purchase of them did not continue since the unavoidable appearance of a special tissue, the so called "Phloem stripes" in Kempas wood were considered as a deficiency. If this veinless tissue appears in wide range and especially near the screw holes, it can cause the sleeper to fall apart. Consequently, the necessity to limit the Phloem stripes inevitably caused difficulties during the inspection and untreatable rejects. The test sleepers which were impregnated according to the special diagram (3) with about 130 kg/m^3 *(8.1* lb/ft^3*)* of creosote have shown no deficiency so far.

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They have less splits than oak and Keruing and up to a certain tolerable extent phloem does not show any disadvantage. Kempas is a good and resistant sleeper wood, which can quickly be seasoned and easily impregnated. It is considered that it could be used anew, if a restriction on the phloem stripes could be obtained in the production and through the terms of delivery.

The increasing prices of Keruing sleepers in recent years have led to a larger purchase of the wood species Yellow Balau or Bangkirai (Shorea species), since test switch sleepers have been used since 1975. Until now a total of 842,000 meters *(2,760,000 linear feet)* of Balau switch sleepers have been purchased.

Yellow Balau is considered as very durable also in the countries of origin, Malaysia and Indonesia. However, like Keruing, Balau is not a clearly defined timber species, but 4 to 6 very similar and related Shorea species are covered by this trade name. They are not equally resistant against fungus. However, at purchasing it is completely impossible to make a choice between them and also to differentiate them in the form of sleepers. For that reason, it is possible to obtain varying results from durability tests. Although no rot was seen until now on untreated Balau sleepers, the German Federal Railway has, based on its bad experience with Bongossi sleepers, decided from this year on to impregnate all the Balau sleepers after seasoning. Sapless wood due to its anatomical structure can absorb only about 15 to 30 kg/m^3 *(0.9 to 1.9 lb/ft^3)* of creosote, according to *the amount of* dry crack formation. A final judgment can be formed only after years.

Another Shorea species, Red Balau, which can clearly be differentiated from the Yellow Balau, is also being tested without impregnation as switch sleepers in order to know the difference in durability. There was seen rot damage on 1/3 of the lower side parts already after a useful life of 5 years, so that it can be said that this wood species is unsuitable for sleepers.

Kapur (Drypbalanops species) is another wood species from East Asia which is being tested without impregnation as switch sleepers for the first time since 1979. It is too early for a final judgment. However, a slight rot attack was already seen on the lower side faces.

Chengal (Balanocarpus heimii) is a very suitable wood species for sleepers. Unfortunately it is only available in a limited amount. Also in East Asia it is considered as very durable and the test sleepers which have been used by the German Railway since 1979 have shown no deficiency.

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As Chengal, also Merbau (Intsia species) is considered as very durable in its country of origin. The test switch sleepers installed by the German Railways are in best shape *(excellent condition)*, and have shown not the least rot since 1975. The wood splits very little, but its ingredients cause corrosion on the sleeper screws. Whether galvanized screws would be appropriate or not is unknown.

Australia

The wood species Jarrah (Eucalyptus marginata) has an excellent reputation as a durable species in England. The oldest switch sleepers have been used without impregnation by the German Railway since 1963 and 1965. It is striking that the splitting grows with the increasing age and is stronger than with oak. The resistance of the wood against fungus could not be judged so far. Some of the removed sleepers showed light rot after a useful life of 15 years. In another switch which is still being used, rotten parts are observed in the base plate area after a useful life of 23 years. A final opinion can be formed only in a few years time.

3. Discussion of the results

The research results and experiences of the German Federal Railway with tropical wood species have shown that <u>in regard to the durability there is a large difference between the statements of the scientific literature and the practical results</u>.

When the first alarming rot attacks were seen on Bongossi (Azobe) sleepers, the subject became very urgent. The Institute for Wood Biology and Wood Preservation of the Federal Research Institute for Forestry and Timber Industry has in collaboration with the German Federal Railways made researches to solve this problem. Thereby it has become obvious that more attention has to be paid to the research methodology in the laboratory. This concerns the way of sampling, test methods, test fungus, the duration of the test and the classification of the natural durability of the tested timber according to the research results. It would take very long to mention the probable influences (6) separately. In regard to practice, the way of sampling, the duration of the test and classification are essential.

Whether the sample will be taken from the inner part, middle part or from the outer part of the heartwood, is very important for sampling. The degree of the damage can essentially depend on it.

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This situation reflects itself in the changing formation of the sleeper in regard of its position in the trunk *of the tree.* According to different fungus resistance of the heartwood zones, the rot attack could appear in scattered form. This fact, however, does not explain the different judgments, for example on the Bongossi wood, because the results of the German Federal Railways are based on tests which were carried out on a large number of sleepers.

The key to this problem lies probably in the duration of the laboratory tests, which normally provide a duration of 12 to 16 weeks *of exposure to* the influence of the test fungi. Willeitner (6) has proved that after a long term exposure of the samples to fungus cultures there was an essential loss of substance (8%) from Bongossi wood only after 32 weeks which increased to 21% after an exposure time of 64 weeks and to 40% after 96 weeks. This is directly related to our observations on sleepers, which showed fungal attack only after a useful life of many years in a moist ballast bed. Consequently, when Bongossi wood and other timber species were classified as very durable after laboratory tests, it was mainly due to the too short *a* duration of *exposure to* fungal effect, where no loss of substance could occur.

Whether the late attack of the wood destroying fungi is only a matter of sufficient moisture *penetration* in*to* the usually very dense timbers or whether the fungus needs *a* long time for the decomposition of the poisonous substances *naturally present in the wood* after an inevitable slow start is so far unknown.

Some of the tropical wood species used be the German Federal Railways are not suitable, because their natural durability is not sufficient. The applied standard is that untreated tropical sleepers must be durable for at least 30 years like treated oak sleepers. Small rot damage areas can be tolerated as long as they do not endanger the function of the whole group of sleepers, and as long as sleeper need not be replaced.

The avoidance of impregnation has first of all economical reasons, as it was explained above. However, it is also a technical question, whether it is reasonable to impregnate tropical species which absorb creosote only up to *a depth of* 2 to 4 mm *(0.08" to 0.16" = $^1/_{16}$" to $^3/_{16}$")* into the outer wood layer and into the sides of the splits. The effectiveness of such impregnation is doubtful. It surely depends on the penetration depth of the preservatives, but also on the proportion of the high boiling components in the creosote, and on the position of the treated parts of the timber, i. e. a larger portion of the creosote will evaporate or will be washed away in the course of time from the upper part of the sleeper.

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The lower part of a sleeper stays in a more or less moist ballast bed, which, however, needs more protection as it was explained before. However, this protection is only valid as long as the attack of the wood destroying fungi comes from the outside. If the rot penetrates through splits or if it comes from the inner part of the timber, the impregnation of the surface can hardly be effective.

Finally, it can be said that in general sleepers which are properly treated with sufficient high quality creosote will have a better protection against biological attacks, and so a longer useful life than the untreated sleepers made of timber species which are considered as durable. This statement is valid first of all for a humid tropical climate where the degradation of the wood through organisms occurs much quicker and more intensively than in a moderate climate.

4. Summary

The knowledge based on tests, observations and the experiences of the German Federal Railways on natural durability of some tropical wood species for sleepers has shown that there was a large discrepancy between the statements of the scientific literature and the actual results. Therefore, it seems to be inevitable to reconsider the test methods for the evaluation and classification of the wood species to apply new standards and correct the former knowledge. Bongossi *(Azobe)* wood provides the best example to what a great extent practice and theory are removed from each other.

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Research and Test Department

An Evaluation of the Properties and Likely Performance of Two Tropical Hardwood Species as Crossties in North America

Report No. R-713

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D. D. Davis, Senior Research Engineer, Association of American Railroads
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13. ABSTRACT

This report describes the tests and results from an analysis of the applicability of two tropical hardwood species as crossties in North America. Tie strength and accelerated aging tests were conducted for the two species, commonly known as Azobe and Yellow Balau. The results were compared with previously tested Red Oak ties as a standard. The tropical hardwoods showed superior capabilities in several areas; thus indicating that superior mechanical performance is possible.

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EXECUTIVE SUMMARY

This report examines the properties of two tropical hardwoods. Their suitability for use as crossties in the North American service environment is considered. The two species, commonly known as Azobe and Yellow Balau are compared to the commonly used creosote treated Red Oak crosstie.

Testing of a small group of specimens includes standard wood strength tests as well as specialized tie plate area tests. In addition to new tie testing, accelerated aging tests are also conducted.

The results indicate that the tropical hardwoods are superior to Red Oak in several key plate area tests. This is especially significant in the aged specimens, as all ties tested lost a significant portion of the values of their initial strength.

Preliminary tests also indicate that the two tropical hardwood species are, as the literature suggests, quite resistant to biological attack. A small scale test showed that both species were significantly better in both decay and termite resistance than Southern Yellow Pine.

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The following personnel have assisted in preparing and testing the ties discussed in the report:

Tim Harp, Research Assistant, Wood Science Department, University of Illinois

Benjamin Midgette, Research Assistant, Wood Science Department, University of Illinois

Brad Stater, Research Assistant, Wood Science Department, University of Illinois

Stephen Henderson, Research Assistant, Wood Science Department, University of Illinois

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1.0 INTRODUCTION

The railroad crosstie market is rapidly changing now and in the near future as railroads and suppliers look to improve the product. Several new and exciting products are being offered, with the prospect of more alternatives on the horizon.

In an effort to keep up with the dazzling array of new products, the AAR has embarked on a major crosstie research effort. The AAR is working on methods to improve crosstie maintenance planning, alternative and supplemental tie treatments, and in-place tie treatment and maintenance. More basic research is also aimed at the causes of tie failure and their prevention. Field tests of tie sizes and spacings and failed tie clustering are also proceeding.

This report examines the properties of two tropical hardwoods and their suitability for use as crossties in the North American service environment. The hardwoods are commonly known as Azobe (Lophira alata) and Yellow Balau (Shorea spp.). Both are currently marketed in North America. In order to provide a common frame of reference a group of Red Oak ties (Quercus rubra), air seasoned and pressure treated with creosote-coal tar was also tested. The tropical hardwood ties were air seasoned but not treated.

More and more frequently in high tonnage, heavy service environments railroads have desired crossties with superior performance characteristics than the typical wooden crosstie cut spike fastener system. Problems areas commonly noted include frequent and excessive gage widening, spike killing, and plate cutting. These problems often occur on lines that have high curvature, gradients, and heavy usage (e.g., high tonnage capacity cars and/or high speed trains). The major problems appear to be related to tie lateral restraint; however, inadequate longitudinal and vertical restraint have also been noted. In the vertical plane, the chronic loss of track surface is growing with the capacity of cars. These and other, non-service related problems with conventional systems have lead the industry to look for improved performance.

1.1 Background

The two species are both tropical hardwoods with physical properties superior to native North American hardwoods. These two products claim to be both decay resistant and pressure treatment resistant. Unlike oak ties which can also be resistant to pressure treatment, these products are recommended for untreated usage.

The Azobe tie has a fairly long history of usage in Europe and Africa. Azobe is a common name for the species Lophira alata. Other common names are Ekki, Bongossi, Esore, and Aba. the species grows in West Africa and the Congo Basin.

The Yellow Balau tie is not as well known around the world. The species is Shorea. Common names include Balau, Guijo, and Membatu. The species grows in Malaya, Indonesia, and the Philippines.

The Red Oak tie is one of the most commonly used species in North America. It has a long history of usage as a crosstie wherever it grows in abundance. The oak family species is Quercus. Common names include: Northern Red Oak, Pin Oak, Black Oak, Southern Red Oak, and Water Oak. In North America, the

Exhibit 1. Species Tree and Lumber Characteristics.

	RED OAK	AZOBE	YELLOW BALAU
TREE:	up to 150'	up to 160' long clear bole to 100'	up to 200' bole straight
Wood: Heartwood	brown with tinge of red	dark red, chocolate brown	light to deep red brown
Sapwood	white 1-2 inches thick	pale pink 2 inches thick	lighter in color
Specific Gravity	0.56-0.69	0.90	0.70
air-dry density (lb./cu. ft.)	45-56	70	53
Shrinkage (green to over dry) radial (%)	4.3	8.4	6.2
tangential (%)	9.5	11.0	11.4
volumetric (%)	14.5	17.0	———
Working Properties	Generally Good for planing, boring and turning	very difficult to work with hand or machine tools; Pre-boring required severe/blunting effect	Difficult to machine; Pre boring required
Durability: Heartwood	non-durable	very durable	variable; non-durable
Sapwood	non-durable	durable	Susceptible to insect attack
Preservation: Heartwood	Slightly resistant	extremely resistant	extremely resistant
Sapwood	permeable	resistant	permeable
Other Uses	Heavy Construction Furniture, Flooring, Pulpwood, Fuelwood	Heavy Construction, Flooring, Harbor work	Heavy Construction, Flooring, Furniture

species range includes the eastern seaboard states and most of the mid-south and Midwestern states, too.

Some of the characteristics of each species and its lumber are listed in Exhibit 1.[1] [2]

2.0 METHODOLOGY

Representative specimens of each species were collected by AAR and forwarded to the University of Illinois for testing and evaluation at the Department of Forestry laboratory in Urbana, Illinois. Two untreated crosstie-size (7" x 9" x 9') pieces of Yellow Balau and three untreated crosstie-size (7" x 9" x 9') pieces of Azobe were supplied by Southern Group, Inc. It is unknown whether the samples supplied are typical or not. However, the samples matched the descriptions and published reference values for the species. It should also be remembered that wood, being a natural product, is more variable in its mechanical properties than most track materials.

Ten treated crosstie-sized (7" x 9" x 8'6") pieces of Red Oak were supplied by Norfolk Southern Corporation in 1986 in conjunction with other tests.[3] The ties were seasoned and treated to NS specifications; they are standard Red Oak ties.

Exhibit 2 lists the physical dimensions of the specimens at the time of the initial tests.

Exhibit 2. Specimen Physical Dimensions.

Group	Weight (lbs)	Cross Section (inches)	Moisture Content (percent)	Density (lb/cu.ft)
Oak	220	7 x 9	30	56.4
Azobe	260	6.79 x 9.00	29.4	68.9
Yellow Balau	267	7.25 x 9.125	34.5	62.6

2.1 Strength Properties Tests

Each species was tested for the strength properties considered important to tie performance in the field. Tests performed on new specimens included:

Static bending tests - maximum load - bending stress - modulus of elasticity	Structural Capacity of tie (Breakage)
Compression Perpendicular to Grain	Structural Capacity of tie (Crushing)
Surface Hardness	Surface, Plate Cutting Lateral Strength
Spike Resistance - drive-in force - lateral resistance - withdrawal force	Lateral Strength, Surface, Spike Holding

These tests were conducted on the new full-size specimens and/or 18" pieces from each specimen. The results of these tests will indicate the relative merits of each species as a potential crosstie material. The static bending tests indicate the structural capacity of the tie. These properties are important for track load capacity, deformation, and surfacing.

The compression perpendicular to grain and surface hardness tests define the strength properties of the wood in the critical plate areas. This is the area of the tie that is prone to failure in severe service environments. A detailed description of all tests were reported in AAR Report R-702.[3]

The spike resistance tests are used to indicate the rail gage and rollover restraint capacity of the tie. Rail gage restraint is an area where railroads are looking for improved performance. In severe loading environments (high tonnage, high curvature) the standard cut spike, wooden tie system has experienced a significant shortening of service life and a decline in performance. These problems will increase as cars and locomotives become larger and more powerful. Thus, improvement in this area is considered to be essential to alternative systems.

2.2 Artificial Aging Tests

In addition to he structural requirements, a crosstie must be durable. It is difficult to assess the durability of new crosstie products due to the unique service environment of the product and its relatively long life. At least two processes are involved in the degradation of the crosstie with time and tonnage. The first is the "aging" of the material. This is the non-bacteriological deterioration of crosstie strength in service. A recent study by AAR has shown that ties may experience a 50 percent strength loss over a period of 20 years in service in typical Mid-West mainline track.[4] The University of Illinois has developed a wooden crosstie artificial aging process for AAR.[3] This process allows accelerated testing of specimens that produces meaningful results in a few days. The process has been calibrated with mainline ties from a major U.S. railroad.

A brief description of the artificial aging process is given in Exhibit 3. The effects of tie aging on strength properties for each species were simulated with ten cycles of the accelerated aging process. Compression Modulus and Surface Hardness tests were conducted on each sample after each cycle of accelerated aging. In addition, the spike resistance tests were conducted on each sample after the final (10th) artificial aging cycle.

The top surface area of each specimen was also measured after each accelerated aging cycle. Losses in surface area, due

Exhibit 3. Crosstie Artifical Aging Schedule.

(6 Cycle Aging schedule)

Condition	Exposure Period
Vacuum (25 inches) in water,	30 minutes
Pressure (170 psi) in water,	30 minutes
Freezing (0^0F),	3 hours
Steaming (250^0F, 15 psi)	30 minute warmup + 10 hours
Oven Drying (220^0F)	9.5 hours
Conditioning (70^0F and 50-60% R.H.)	about 22 hours

to checks and splits, indicate the dimensional stability of the tie. This is important for structural reasons as well as for decay resistance. Checks create moist, exposed locations where decay can invade a crosstie. This is especially important in pressure treated crossties, where the checks can extent below the treated area of the tie; exposing untreated wood.

Splitting can also greatly reduce the bearing capacity of the tie. Bearing capacity is a power function of tie width. Thus, a tie that splits in half would lose half of its bearing capacity. Also, a split passing through one or more line spike(s) can reduce gage restraint significantly.

Another factor critical in crosstie durability is decay resistance. The literature suggests that Azobe crossties do not need preservative treatment.[2] They are naturally decay resistant. However, they are only moderately resistant to termite attack. The Yellow Balau is also somewhat naturally decay resistant.[2] But, it is much more variable, and cannot be considered for use as an untreated crosstie. It also appears to be susceptible to insect attack. The Red Oak is susceptible to both decay and insect attack. Treatment with preservative is considered to be an economic necessity; as it increases service life from 10-15 years to 25-35 years.

3.0 RESULTS

The test results are divided into two categories; the new tie tests and the accelerated aging tests. For both of the tropical hardwood species the average result from all samples is presented. The number of samples varied by the type of test; however all samples were taken from three Azobe and two Yellow Balau ties. The average values from ten treated Red Oak ties are given.

3.1 New Tie Strength

Examination of the specimens revealed that all were within dimensional tolerances. The Azobe crossties with their interlocking grain had very regular seasoning checking patterns. The checks were numerous but very small in size. The Yellow Balau crossties had more conventional checking patterns. One of the two specimens had decay pockets and ring shake defects. Exhibits 4 and 5 show these defects. The higher moisture content in Yellow Balau specimen B is another indicator of its decay problem. See Exhibit 2.

Exhibit 4. Yellow Balau Specimen Defects.

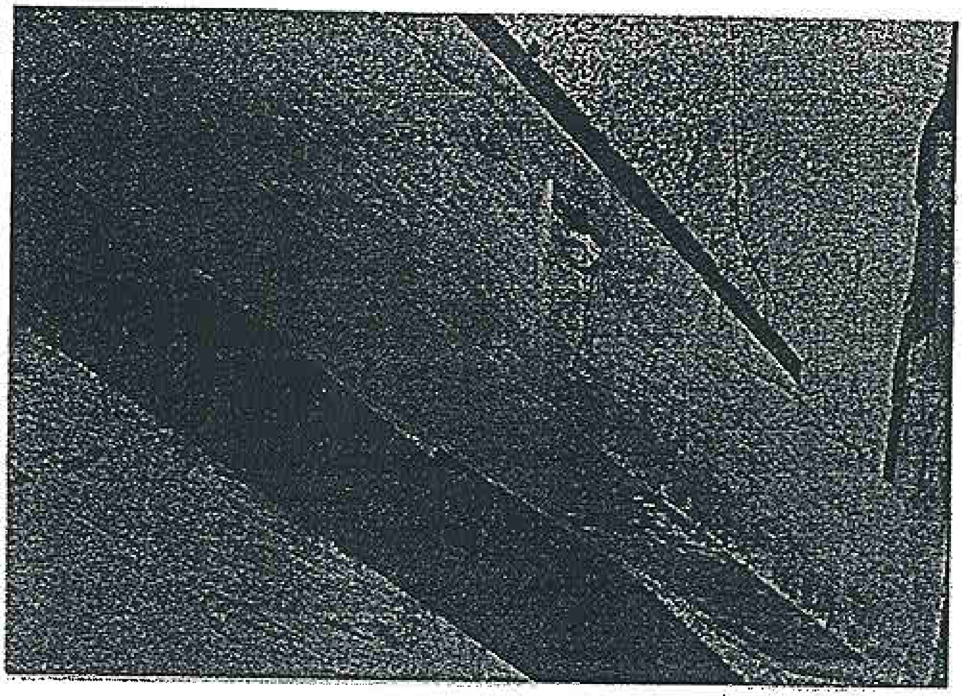
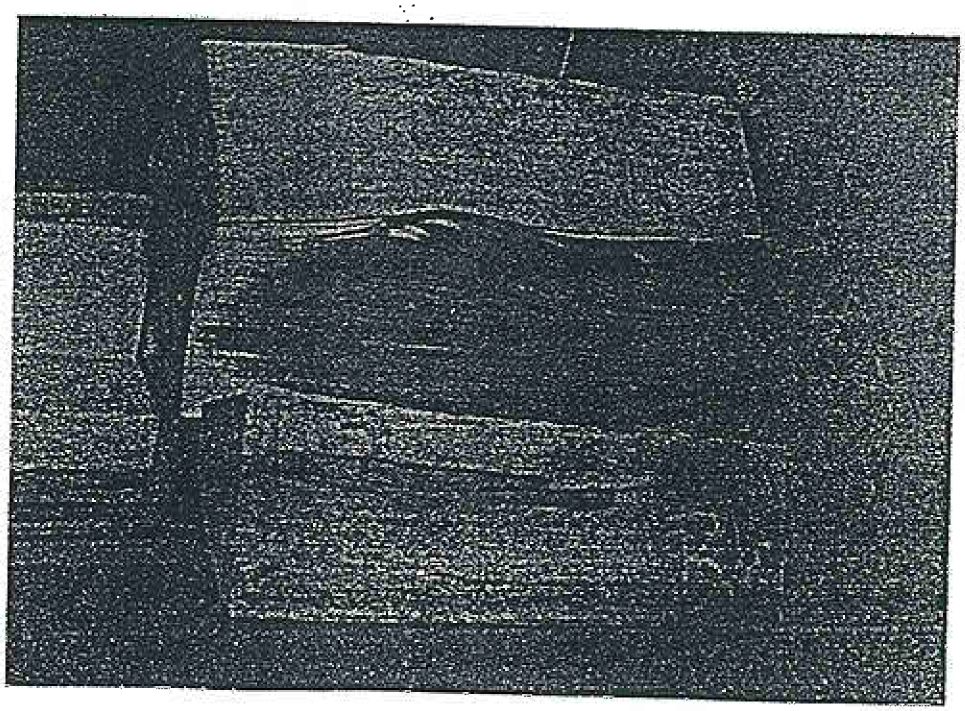


Exhibit 5. Yellow Balau Specimen Defect.



The Azobe specimens were the most dense of the three materials. The Azobe specimens were 22 percent denser than Red Oak, while the Yellow Balau were 11 percent denser.

No attempts to test the decay resistance of these species in revenue service were made. However, the Azobe species have a history of service as untreated crossties in Europe.[5] Service tests are underway in North America. But, the decay resistance of Azobe under North American service conditions is not known.

A preliminary test to determine the decay and termite resistance of these species was conducted at Mississippi State University. Based on the limited data both species are shown to possess good resistance to decay and termite damage. Appendix 6.3 contains the results of a small scale laboratory study of decay resistance conducted for AAR.

The density of these tropical hardwoods and their structure precludes deep or effective pressure treatment. The Azobe is known to be extremely difficult to treat; with the Yellow Balau moderately so.

Among native species, the White Oaks are considered to be difficult to treat. Their structure is largely impenetrable in the heartwood. While the Red Oaks have more open heartwood pores, they can also be difficult to treat. Treatment penetration depths of 2-3 inches are common in 7 x 9 inch Red Oak crossties.

Wood density has traditionally been used as indicator of strength.[1] Its effect varies with strength property.

The results of the tie strength tests on new ties are presented in Exhibit 6. For comparison purposes the test values given for both tropical hardwoods are also expressed as multiples of the creosote treated oak tie values.

One way to assess the likely performance of these products as crossties is to compare them to the standard oak tie. Exhibit 7 and 8 are "Figure of Merit Tables" which show the test results as ratios of the actual value to the new Red Oak tie value.

Exhibit 6. New Tie Test Results.

Test/Property	Red Oak	Azobe	Azobe/Oak	Balau	Balau/Oak
Max. Bending Stress (psi)	7,660	11,660	1.52	12,300	1.60
Static Bending Modulus (psi)	920,000	1,028,590	1.12	987,829	1.07
Compressive Modulus (psi)	39,154	58,840	1.50	60,080	1.53
Surface Hardness (lbs)	6,460	8,562	1.33	5,480	0.85
Spike Insertion Force (lbs)	9,700	22,504	2.32	8,516	0.88
Spike Withdrawal Force (lbs)	8,800	18,048	2.05	10,172	1.16
Spike Lateral Resistance Force (lbs)	3,285	2,812	0.86	3,187	0.97

With these tables one can assess the likely performance of the ties when they are new and when they are older. One can also see how the strength of Red Oak ties decreases with age.

These tables indicate the differences in properties among the wood species in the new tie results. The EKKI (AZOBE) tie is significantly stronger than oak in its spike holding, surface

Exhibit 7. Relative Strength Values of Tropical Hardwoods Figure of Merit Table - Modulus Tests.

"AGE"	SPECIES	M.O.E BENDING	M.O.E COMPRESS	SURFACE HARDNESS
NEW	RED OAK	1.00	1.00	1.00
NEW	AZOBE	1.12	1.50	1.33
NEW	BALAU	1.07	1.53	0.85
5 CYCLES	RED OAK	NA	0.45	0.29
5 CYCLES	AZOBE	NA	0.91	0.58
5 CYCLES	BALAU	NA	0.93	0.47
10 CYCLES	RED OAK	NA	NA	NA
10 CYCLES	AZOBE	NA	0.85	0.33
10 CYCLES	BALAU	NA	0.75	0.31

Exhibit 8. Tropical Hardwood Performance Indicators Figure of Merit Table - Spike Tests.

"AGE"	SPECIES	SPIKE IN	SPIKE OUT	SPIKE LATERAL
NEW	RED OAK	1.00	1.00	1.00
NEW	AZOBE	2.32	2.05	0.86
NEW	BALAU	0.88	1.16	0.97
10 CYCLES	RED OAK	0.39	0.24	0.26
10 CYCLES	AZOBE	1.23	1.95	0.47
10 CYCLES	BALAU	0.55	0.64	0.96

hardness, maximum bending stress and compression modulus values. It is moderately stronger in bending modulus. But, it is moderately weaker or equal in lateral spike strength. This is a serious weakness for the Azobe tie in that spike killing and gage restraint are already shortcomings of the conventional wooden tie-cut spike system used today.

The Yellow Balau tie is also significantly stronger than Red Oak in compression modulus, maximum bending stress and spike holding (withdrawal). Surface hardness and spike insertion force are slightly lower than Red Oak results. Bending modulus and lateral spike strength values were similar to Red Oak.

3.2 Artificially Aged Tie Strength

Only in very severe environments do new or relatively new crossties fail. Crossties generally fail after several years of service. The resultant loss of strength due to aging/weathering and decay weakens the tie until a point is reached when mechanical failure can occur.

The artificial aging process allows one to estimate the strength losses of these species over extended periods of time. At five cycles of aging both the Azobe and Yellow Balau crossties have values more than 90 percent of the compressive modulus, and about 50 percent of the surface hardness of those of the new Red Oak crosstie, respectively. The Red Oak crosstie, at five cycles of aging has values of 45 and 29 percent, respectively, for the same tests. Thus, the Red Oak strength at five cycles is about half of that of the other two species.

At five cycles of aging, the equivalent of about twenty years for a Red Oak, the Red Oak specimen have lost more than fifty percent of their strength. The rate of strength loss for all species decreases with the number of cycles or "age" of the specimen.

The compressive modulus values at ten cycles of aging are 85 percent of the new Red Oak value for Azobe and 75 percent of the new Red Oak value for Yellow Balau. The surface hardness values for both species are 33 and 31 percent of new Red Oak strength, respectively.

Lateral and vertical spike tests at the ten cycles aging levels were also conducted. Spike driving forces were 39, 123, and 55 percent of the new Red Oak value for the aged Red Oak, Azobe, and Yellow Balau. Spike withdrawal forces were 24, 195, and 64 percent of the new Red Oak value for the aged Red Oak, Azobe, and Yellow Balau. The lateral forces required to move a spike 0.2 inches laterally were 26, 47, and 96 percent of the new Red Oak value for the aged Red Oak, Azobe, and Yellow Balau crossties.

Thus, for aged specimens, the Azobe and Yellow Balau crossties will have better spike holding and gage restraint capacity than the currently used Red Oak. In some cases, the aged Azobe and Yellow Balau specimens are stronger than the new Red Oak specimens.

The surface-loss measurement results indicate the tendency of a tie sized timber to check and split. The net surface area of the tie plate area was measured after each aging cycle. The results demonstrate the dimensional stability of each species. After ten aging cycles both the Red Oak and Azobe ties had lost about 6 percent of their tie plate contact ares to checks and splits opening. The Yellow Balau performed better; with only a 3 percent loss of surface area after ten cycles.

4.0 SUMMARY

The tropical hardwood species discussed show promise of providing superior performance in the critical tie plate area. These species have superior properties to Red Oak ties; both when new and after artificial aging.

The artificial aging process affects the Azobe (Ekki), Yellow Balau, and Red Oak specimens in the same way. The normalized strength losses are approximately equal; with the tropical hardwoods performing somewhat better after several cycles of accelerated aging.

The effects of biological deterioration on tie performance were not considered in the tests performed. The susceptibility of the tropical hardwoods to decay is low but can be quite variable. Also, the treatability of these species with conventional pressure methods and materials is quite limited.

The economic viability of these products must be considered, also. With the expected cost premium over domestic hardwood ties, applications of the tropical hardwoods would most likely be limited to areas where standard tie life is relatively short or potential derailment costs are extremely high (e.g., turnouts, bridges, and environmentally sensitive areas). The life span of the tie and, thus, the time to recoup the additional investment of the premium tie precludes the universal application of a more expensive tie. However, areas where conventional tie lives of 5 to 10 years are common are candidates for premium ties.

5.0 REFERENCES

1. U. S. Forest Products Laboratory, Wood Handbook: Wood as an Engineering Material, U. S. Department of Agriculture, 1974.

2. Chudnoff, M. L., Tropical Timbers of the World, U. S. Department of Agriculture, 1984.

3. Lewis, S. L., et. al, Durability of Wood Crossties (Phase I), Report R-702, Association of American Railroads, 1987.

4. Davis, D. D. and Chow, P., Tie Condition Inspection - A Case Study of Tie Failure Rate, Modes, and Clustering, Report R-714, Association of American Railroads, 1988.

5. Railway Track and Structures, "Out of Africa: 'Superwood' Tie," July 1987.

6.0 APPENDICES

6.1 Test Results - Tables

SURFACE AREA LOSS (inches^2)

AGING CYCLES	RED OAK AVE	AZOBE AVE	BALAU AVE	AZOBE /OAK	BALAU /OAK	RED OAK % RETAINED	AZOBE % RETAINED	BALAU % RETAINED
0	----	---	---	NA	NA	100.00	100.00	100.00
1	1.10	1.80	0.40	1.64	0.36	98.90	98.20	99.60
2	1.80	2.00	0.57	1.11	0.31	98.20	98.00	99.43
3	2.90	2.50	0.83	0.86	0.29	97.10	97.50	99.17
4	3.90	2.90	1.52	0.74	0.39	96.10	97.10	98.48
5	5.20	3.30	1.78	0.63	0.34	94.80	96.70	98.22
6	5.20	3.50	2.05	0.67	0.39	94.80	96.50	97.95
7	5.20	3.90	2.60	0.75	0.50	94.80	96.10	97.40
8	5.50	4.10	2.83	0.75	0.52	94.50	95.90	97.17
9	6.00	4.40	2.98	0.73	0.50	94.00	95.60	97.02
10	6.00	5.60	3.45	0.93	0.58	94.00	94.40	96.55
11	----	6.00	---	NA	NA	NA	94.00	NA
12	----	6.60	---	NA	NA	NA	93.40	NA
13	----	6.70	---	NA	NA	NA	93.30	NA
14	----	6.80	---	NA	NA	NA	93.20	NA
15	----	6.80	---	NA	NA	NA	93.20	NA

COMPRESSIVE MODULUS OF ELASTICITY (psi)

AGING CYCLES	RED OAK AVE	AZOBE AVE	BALAU AVE	AZOBE /OAK	BALAU /OAK	RED OAK % RETAINED	AZOBE % RETAINED	BALAU % RETAINED
0	39154	58840	60080	1.50	1.53	1.00	1.00	1.00
1	30334	39980	46610	1.32	1.54	0.77	0.68	0.78
2	24752	39445	41820	1.59	1.69	0.63	0.67	0.70
3	21333	38035	39595	1.78	1.86	0.54	0.65	0.66
4	18744	36010	37970	1.92	2.03	0.48	0.61	0.63
5	17777	35490	36595	2.00	2.06	0.45	0.60	0.61
6	18002	30950	35125	1.72	1.95	0.46	0.53	0.58
7	-----	34574	34140	NA	NA	0.00	0.59	0.57
8	-----	34522	31710	NA	NA	0.00	0.59	0.53
9	-----	33320	29715	NA	NA	0.00	0.57	0.49
10	-----	33240	29265	NA	NA	0.00	0.56	0.49
11	-----	34715	---	NA	NA	0.00	0.59	0.00
12	-----	34590	---	NA	NA	0.00	0.59	0.00
13	-----	32705	---	NA	NA	0.00	0.56	0.00
14	-----	32560	---	NA	NA	0.00	0.55	0.00
15	-----	31370	---	NA	NA	0.00	0.53	0.00

HARDNESS (maximum load in lbs)

AGING CYCLES	RED OAK AVE	AZOBE AVE	BALAU AVE	AZOBE /OAK	BALAU /OAK	RED OAK % RETAINED	AZOBE % RETAINED	BALAU % RETAINED
0	6460	8562	5480	1.33	0.85	100.00	100.00	100.00
1	4637	5988	3720	1.29	0.80	71.78	69.94	67.88
2	2943	5235	3550	1.78	1.21	45.56	61.14	64.78
3	2502	4947	2960	1.98	1.18	38.73	57.78	54.01
4	1977	3560	3493	1.80	1.77	30.60	41.58	63.74
5	1884	3743	3040	1.99	1.61	29.16	43.72	55.47
6	1899	3611	3170	1.90	1.67	29.40	42.17	57.85
7	----	2730	2590	NA	NA	NA	31.89	47.26
8	----	2808	2430	NA	NA	NA	32.80	44.34
9	----	2654	2050	NA	NA	NA	31.00	37.41
10	----	2117	1990	NA	NA	NA	24.73	36.31
11	----	2407	---	NA	NA	NA	28.11	NA
12	----	2833	---	NA	NA	NA	33.09	NA
13	----	2415	---	NA	NA	NA	28.21	NA
14	----	1863	---	NA	NA	NA	21.76	NA
15	----	1946	---	NA	NA	NA	22.73	NA

STATIC BENDING MODULUS OF ELASTICITY (psi)

AGING CYCLES	RED OAK AVE	AZOBE AVE	BALAU AVE
0	920100	1028590	987824
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

SPIKE DRIVING FORCE (lbs)

AGING CYCLES	RED OAK AVE	AZOBE AVE	BALAU AVE	AZOBE /OAK	BALAU /OAK	RED OAK % RETAINED	AZOBE % RETAINED	BALAU % RETAINED
0	9700	22504	8516	2.32	0.88	1.00	1.00	1.00
1								
2								
3								
4								
5								
6								
7								
8								
9								
10	3800	11971	5305	3.15	1.40	0.39	0.53	0.62
11								
12								
13								
14								
15								

SPIKE LATERAL STRENGTH (FORCE (lbs) REQUIRED TO PUSH SPIKE 0.2")

AGING CYCLES	RED OAK AVE	AZOBE AVE	BALAU AVE	AZOBE /OAK	BALAU /OAK	RED OAK % RETAINED	AZOBE % RETAINED	BALAU % RETAINED
0	3283	2812	3187	0.86	0.97	1.00	1.00	1.00
1								
2								
3								
4								
5								
6								
7								
8								
9								
10	850	1553	3162	1.83	3.72	0.26	0.55	0.99
11								
12								
13								
14								
15								

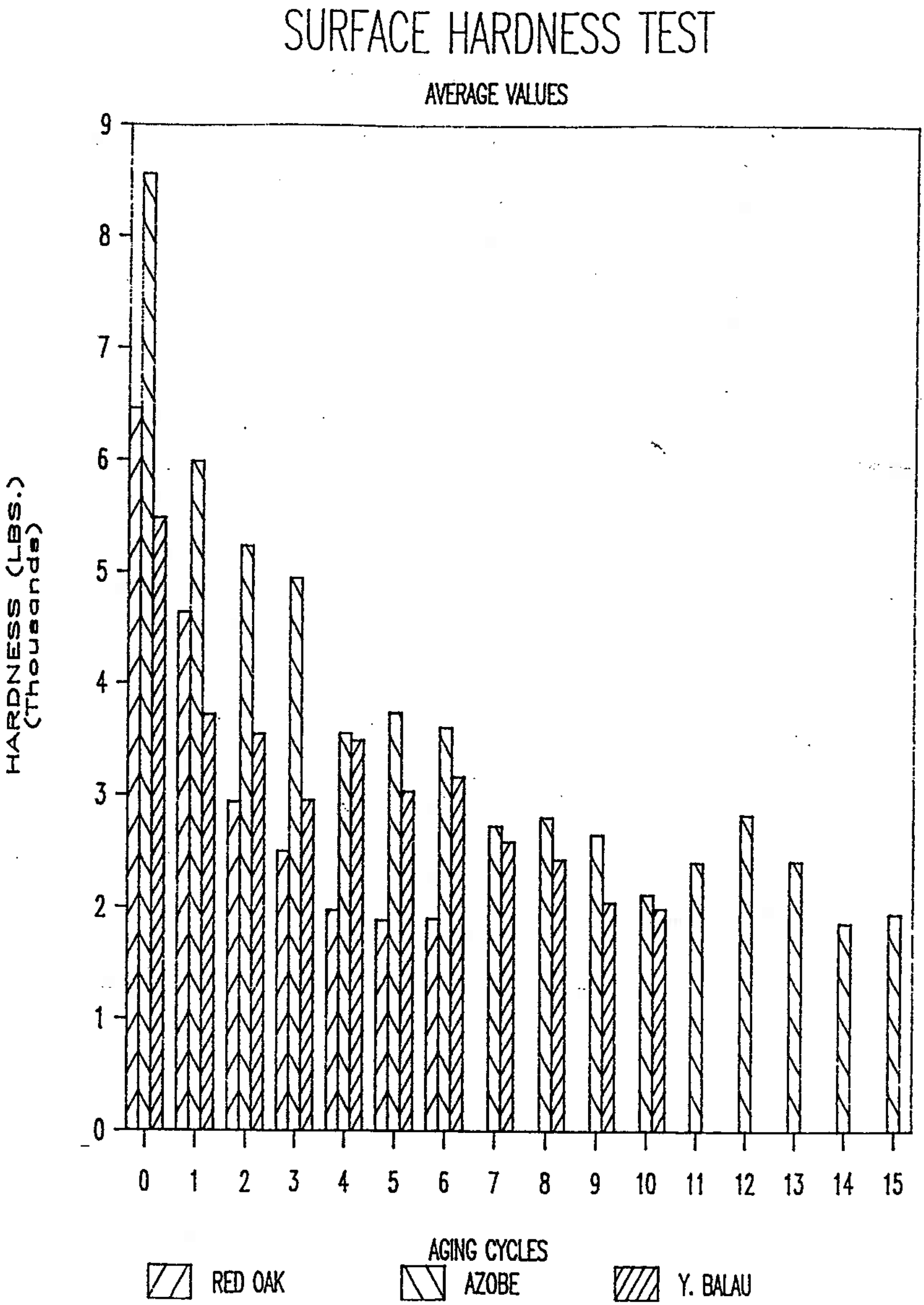
SPIKE WITHDRAWAL FORCE REQUIRED (lbs)

AGING CYCLES	RED OAK AVE	AZOBE AVE	BALAU AVE	AZOBE /OAK	BALAU /OAK	RED OAK % RETAINED	AZOBE % RETAINED	BALAU % RETAINED
0	8800	18048	10172	2.05	1.16	1.00	1.00	1.00
1								
2								
3								
4								
5								
6								
7								
8								
9								
10	2100	17130	5665	8.16	2.70	0.24	0.95	0.56
11								
12								
13								
14								
15								

MAXIMUM BENDING STRESS (psi)

AGING CYCLES	RED OAK AVE	AZOBE AVE	BALAU AVE	AZOBE /OAK	BALAU /OAK	RED OAK % RETAINED	AZOBE % RETAINED	BALAU % RETAINED
0	7658	11650	12294	1.52	1.61	100.00	100.00	100.00
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								

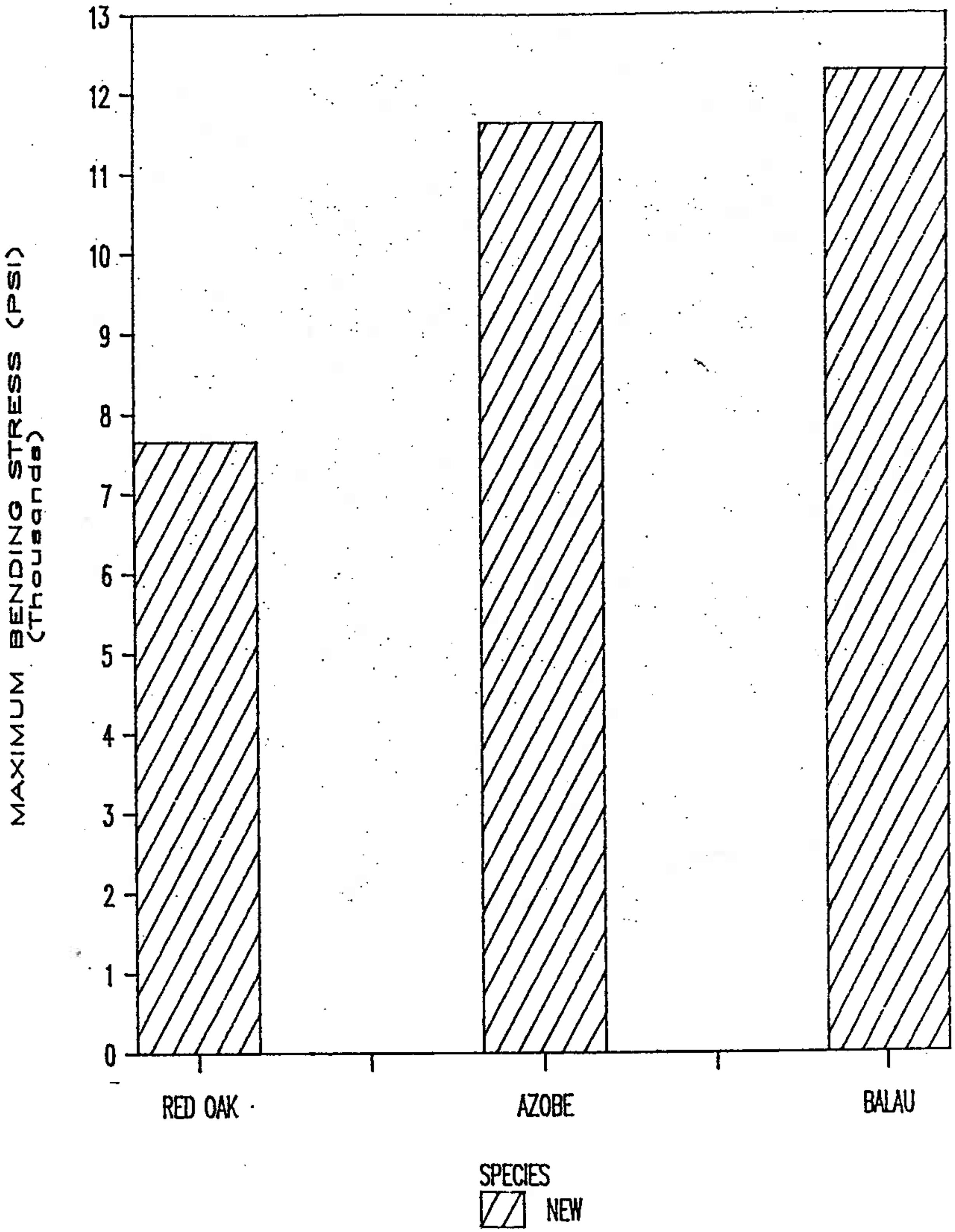
6.2 Test Results - Figures

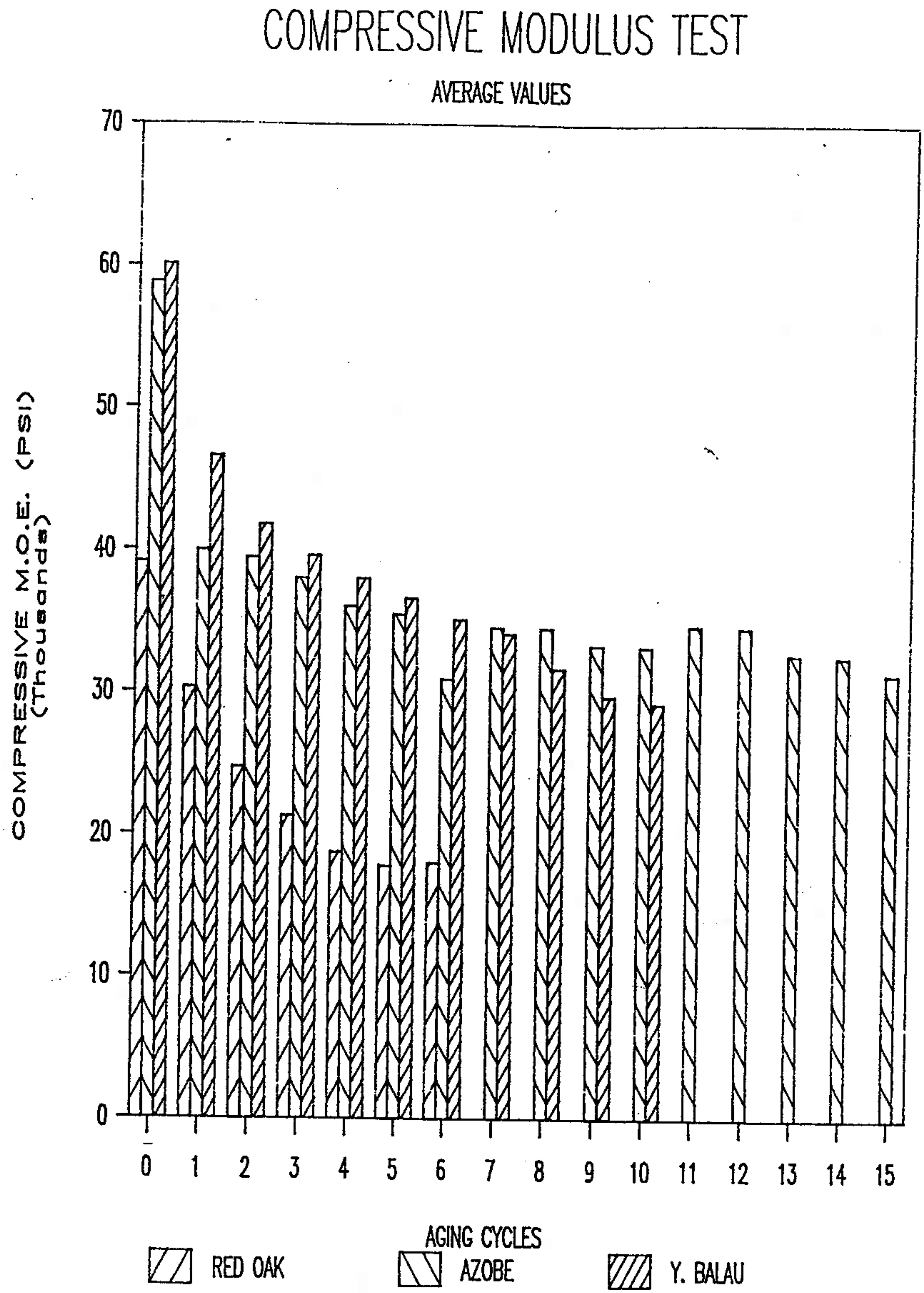


SURFACE HARDNESS TEST
AVERAGE VALUES
HARDNESS (LBS.) (Thousands)
0
1
2
3
4
5
6
7
8
9
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
AGING CYCLES
RED OAK
AZOBE
Y. BALAU

STATIC BENDING TEST

THREE POINT LOADING; 60 INCH SPAN




COMPRESSIVE MODULUS TEST
AVERAGE VALUES
COMPRESSIVE M.O.E. (PSI)
(Thousands)
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
AGING CYCLES
RED OAK
AZOBE
Y. BALAU

6.3 Decay and Termite Resistance Test Results

The Azobe and Yellow Balau species were subjected to a limited test of decay and termite resistance. Specimens blocks cut from one Azobe tie and two Yellow Balau boards were exposed to brown rot and white rot fungus for twelve weeks. Sample blocks were also exposed to Subterranean termites for four weeks. The blocks were untreated. Red Oak Specimens (also untreated) were tested for white rot resistance. Untreated Southern Yellow Pine blocks were used as the control group.

The Azobe and Yellow Balau specimens fared well, in both the exposure to fungus and termites, when compared to the untreated control and Red Oak specimens. Decay losses were one to two percent by weight; and losses due to termites were virtually nil for the tropical hardwoods. (Exhibit 9)

The results, although by no means conclusive, indicate that the tropical hardwoods are much less susceptible to biological degradation than untreated pine or oak. The study suggests that untreated ties of these species may be viable in North American climates. However, extensive testing of each species will be required to prove the viability of these species.

Exhibit 9. Decay and Termite Resistance Test Results.

Summary of the average percent weight loss of untreated blocks (received from AFRICA) due to exposure to brown rot fungus (<u>Gloeophyllum trabeum</u>) and white rot fungus (<u>Polyporus versicolor</u>) for 12 weeks and exposure to Subterranean termites for 4 weeks.

SPECIES	COND.	G. TERABEUM AVG. % WT. LOSS & STD. DEV.	P. VERSICOLOR AVG. % WT. LOSS & STD. DEV.	TERMITES AVG. % WT. LOSS & STD. DEV.	TERMITES BLOCKS RATINGS
SYP-CONTROL	NL	44.36 +/- 8.54	-------------	15.99 +/- 1.33	3.2
	L	44.29 +/- 7.78	-------------	-------------	----
RED OAK	NL	-------------	24.52 +/- 5.24	-------------	----
	L	-------------	30.41 +/- 9.59	-------------	----
AZOBE	NL	0.67 +/- 0.75	1.37 +/- 0.83	1.04 +/- 0.77	10.0
	L	1.11 +/- 0.65	1.55 +/- 0.41	-------------	----
BOARD-1	NL	1.12 +/- 0.22	1.54 +/- 0.10	1.60 +/- 0.68	10.0
YELLOW BALAU	L	3.35 +/- 0.20	2.81 +/- 0.19	-------------	----
BOARD-2	NL	1.97 +/- 0.50	1.62 +/- 0.29	1.61 +/- 0.20	10.0
YELLOW BALAU	L	3.11 +/- 0.43	3.02 +/- 0.52	-------------	----

NL: NON LEACHED
L: LEACHED

SYP: SOUTHERN YELLOW PINE WOOD BLOCKS

BLOCKS RATINGS: 10 IS SOUND, SURFACE NIBBLES PERMITTED.
9 IS LIGHT ATTACK.
7 IS MODERATE ATTACK.
4 IS HEAVY ATTACK.
0 IS FAILURE.

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AZOBE Literature

Post Office Box 2534, Farmington Hills, Michigan 48333, USA • Phone 313-477-0843 • Mobile 313-320-0345 • FAX 313-477-4469

CONTENTS

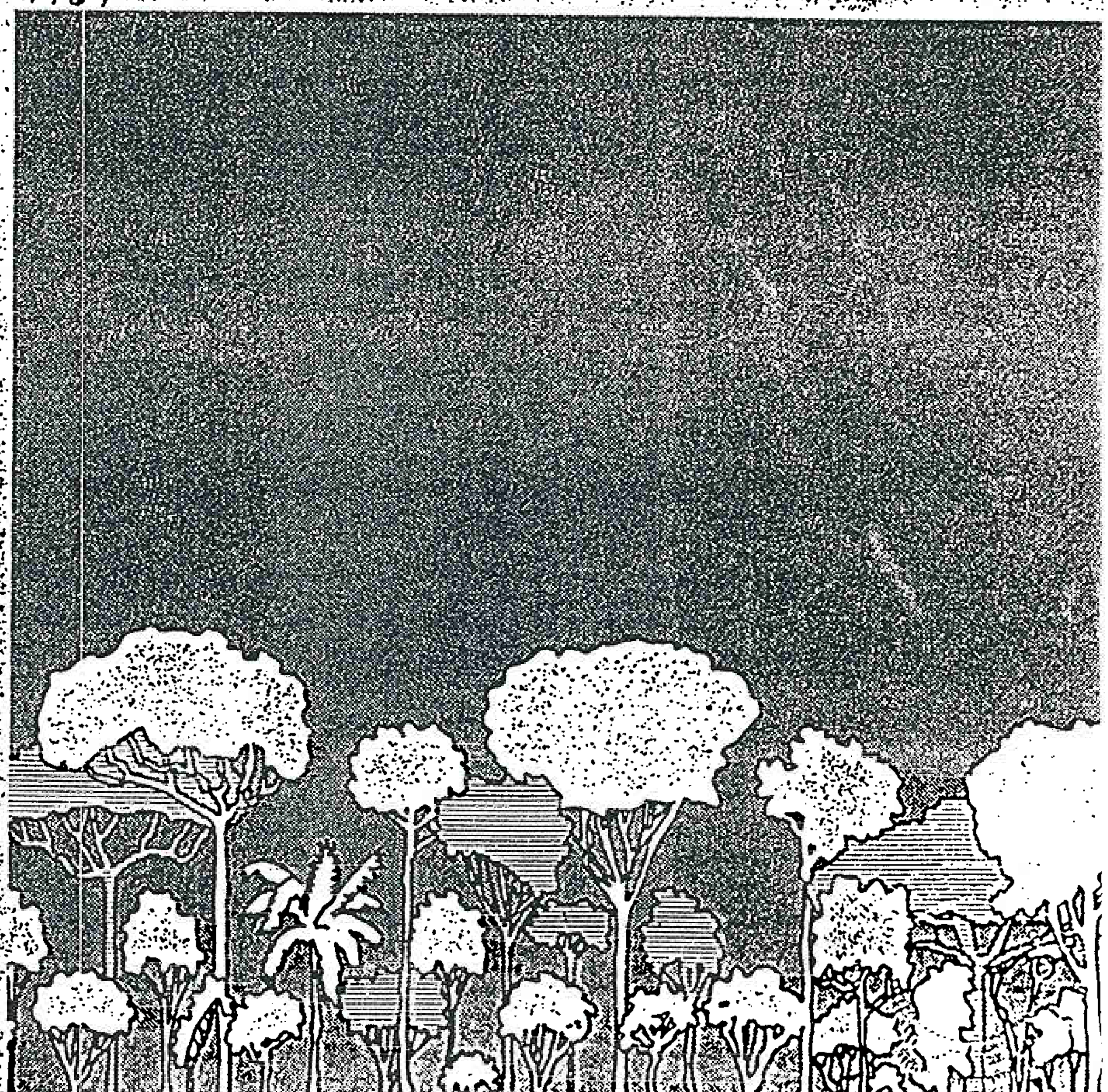
United States
Department of
Agriculture

Forest Service

Agriculture
Handbook
Number 607

1984

Tropical Timbers of the World



Lophira alata

Ekki
Azobé

Family: Ochnaceae

Other Common Names: Bongossi, Bakundu (Cameroon), Kaku (Ghana), Esore (Ivory Coast), Aba (Nigeria), Endwi (Sierra Leone).

Distribution: West Africa and extending into the Congo Basin; occurs in evergreen and moist deciduous forests, in freshwater swamp forests, and close to riverbanks.

The Tree

May attain a height of 160 ft with a long clear bole to 100 ft; trunk diameters 5 to 6 ft; without buttresses but lower portion of the bole sometimes swollen.

The Wood

General Characteristics: Heartwood dark red, chocolate brown, or purple brown with conspicuous white deposits in the vessels; sapwood up to 2 in. wide, pale pink, well defined. Texture coarse; grain usually interlocked; luster low; without characteristic odor or taste.

Weight: Basic specific gravity (ovendry weight/green volume) about 0.90; air-dry density 70 pcf.

Mechanical Properties: (2-cm standard)

Moisture content	Bending strength	Modulus of elasticity	Maximum crushing strength
	Psi	*1,000 psi*	*Psi*
Green (*9*)	17,800	2,010	9,920
12%	25,800	2,450	13,120
12% (*47*)	33,200	3,180	15,200

Janka side hardness 2,900 lb for green material and 3,350 lb for dry. Amsler toughness 625 in.-lb at 12% moisture content (2-cm specimen).

Drying and Shrinkage: Very difficult to season without excessive degrade, particularly surface and end checking; dries slowly. Kiln schedule T2–C2 is suggested for 4/4 stock and T2–C1 for 8/4. Shrinkage green to ovendry: radial 8.4%; tangential 11.0%; volumetric 17.0%. Movement in service is rated as medium.

Working Properties: Very difficult to work with hand and machine tools; severe blunting effect if machined when dry; can be dressed to a smooth finish; gluing properties usually good.

Durability: Heartwood is rated as very durable but only moderately resistant to termite attack. Resistant to acids. Good weathering properties: Resistant to teredo attack.

Preservation: Heartwood is rated as extremely resistant to preservative treatments and the sapwood resistant.

Uses: Heavy durable construction work, harbor work, heavy-duty flooring, parquet flooring, railroad crossties.

Additional Reading

(*3*), (*6*), (*9*), (*47*)

Lophira alata

Index No. 422

AZOBE (common name)

Description : Sapwood is a pale pink colour up to 2 inches (50mm) wide, well defined from the heartwood which is a purple-brown or deep chocolate brown. Texture is variable and the grain interlocked. Occasional figure and gum veins. Tree may occur as one of small stature and twisted bole but in areas of Ghana, Nigeria and Cameroon it may reach large heights with boles up to 100 feet (30 meters). Species occurs in evergreen and moist deciduous forests, in freshwater swamp forests and close to riverbanks.

Characteristics : Very difficult to season without excessive degrade, particularly surface checking and end splitting. However, some reports have been favorable. Because of its hardness and high density the timber is very difficult to work with hand tools and has a severe blunting effect on cutting edges. Hard to screw or nail. Saws comparatively well. Very strong and resilient. Resistant to, but not immune from termites and pinhole borers. Resistant to teredo marine borers. Heartwood impermeable, sapwood resistant to impregnation. Gluing properties variable but usually good. Good wearing and weathering properties. Fairly stable. Resistant to damage by acids. Steam bending properties poor.

References : 1,4,11a,11b,13,18,30,33,40,43,55,72,73,82,107,108,120,123, 126,135..

TREE		PROPERTIES						USES
Height ft (m)	Diameter ft (m)	Origin of data	Density	Strength Group	Shrinkage	Durability	Lyctus attack	
160 (48)	5 (1.5)	6,7,16, 21,48,	10	S1	5	1	N	1,3,5,6,7,10, 11,16,17,20, 21,23,26,27, 28.
		18	10	S2				

Shrinkage code 5 = Tangential- Green to 12% moisture: more than 7%
Radial " " " " : " " 4%
Lyctus attack: N = non-susceptible.

From: African Timbers - The Properties Uses and Characteristics of 700 Species. Eleanor ? and W. Keating. Division of Building Research, Commonwealth Scientific, Industrial Research Organization. Melbourne, Australia, 1972.

hald their original thickness ("strength"); but from above there ties looked completely intact.

For a two-year period (1982-4) all switch ties that had been removed were checked for rot, and that damage was classified into "slight rot" (up to 2 cm depth) and "severe rot" (deeper). Ties showing fungus mycelial growth on the bottom or sides were not counted if they showed no clear wood damage. The result of the evaluation was that 36.6% of the 101 tie switch sets reoved in these years showed more or less severe rot, but only 14.4% of the individual ties: i.e. only some of the ties in a switch were affected. As to the extent of the damage, 79% of the attacked ties showed slight damage, i.e. less than 2 cm deep, and 21% showed severe damage. Analysis of the intensity of the damage by age of the ties is possible only regarding the amount of rot (depth). Except for two switches used to 10 or 11 yesrs, which had individual ties with severe rot, this amount of damage was observed only in ties 18 to 24 years old. All switches laid in 1960 showed rotten ties, 72.3% of the ties in these switches showing wood damage, of which 43.2% had to be rated in the severe category with rot depths of more than 2 cm.

The form of rot was quite varied. Sometimes the whole tie was attacked over its whole length, but often the damage was limited to certain areas. In a given switch, rotten ties were sometimes scattered among intact ones, but sometimes they were adjacent to each other. In one case, where all the ties in the area of the points of a switch showed extreme wood damage, we suspected that thawing salts had been applied here in the winter and had encouraged fungus growth. However, after examination of all the switches which had been removed, this suspicion could not be confirmed. It is probably that the moisture in the area of each individual tie plays a significant role. Ties with a well ventilated, sufficiently dry bedding may be free of rot even after 20 years. Thus of the 17 switches laid in 1965 and removed after 18 years' use, only four (23.5%) had ties affected by rot. The 90 ties of these switches were all (100%) severely damaged. But calculated as a percentage of the total of 1,122 ties, it was only 8%.

On the basis of the studies initiated by the Deutsche Bundesbahn and on the basis of many years' experience we can state that bongossi wood does not possess the extraordinary natural fungus resistance claimed in the literature. Rather, we must expect that bongossi ties may exhibit rot after only eight years' use and that the severity and frequency of rot will increase with longer use. After about 20 years' use, the majority of ties in a set may already be attacked by severe rot.

SInce bongossi wood is extremely hard, there are problems in shaping it and in installing the tie bolts. Although the bore hold diameter was enlarged to 18 mm, compared to the 16 mm used for oak or beech, it repeatedly happened that bolts sheared off. If two or three bolts in one tie-rail contact point sheer off when tightened, then the ties must be undone, all 8 old holes filled [??] and new ones bored, which is very expensive and difficult. For this reason bongossi wood is not much favored in actual use.

Another problem is the lateral displacement resistance of tracks laid on bongossi ties. Since in the early years roadbed gravel does not press into the bottom of the ties, it was feared that the stability of the track might be affected, especially on curves, and there were restrictions on their use. But new studies of the Bundesbahn Testing Institute have shown that the higher weight of bongossi ties and other tropical ties compensates for the poor grip on the gravel, so that it was possible to remove all restrictions on their use.

weather resistant or very weather resistant. The wood variety Manilkara was thus regarded by the Bundesbahn as unsuitable for tiees.

Africa

Among African tie wood types, in the general view and in the technical literature Bongossi wood (or azobé or ekki; Lophira alata)occupies a prominent position in regard to natural durability, since this wood is regarded as "absolutely durable in the ground, in water, and near water" (1), as rotproof or at least extraordinarily rot-resistant.

The Bundesbahn laid the forst Bongossi test ties in 1954, and since the mid-50's it had until recently always bought a certain number of switch ties. All in all, 1.41 million running meters switch ties and 174,000 track ties made of Bongossi wood were purchased. Most ties were laid without impregnation. Until 1978 there was nothing to cast doutb on the legendary fungus resistance. Occasional fungus attack was attributed to sapwood, which was excluded under the terms of the purchase agreement but was present anyway, so that in my earlier talk I said there was no significant fungus attack.

In 1978 we found for the first time that beside the sapwood, Bongossi heartwood was also attacked by wood-destroying fungi, and that after only 8 years' use. From then on Bongossi wood was subjected to systematic observation, which showed that in many instances Bongossi ties showed more or less severe fungus atack. Doubtless this fact would have been noticed years earlier if there had been more careful observation and investigation. The reputation for extreme durability had prevented this, especially since before the mid-70's relatively few Bongossi ties had been dug up, and scientists had not formed a different opinion about Bongossi.

A peculiarity of Bongossi is that between the yellowish sapwood and the dark read heartwood there is a bright red area of so-called intermediary wood. The question of how this intermediary wood should be regarded for durability was answered by saying that the intermediary wood should be regarded and rated as heartwood. This view is no longer valid, as the experience of the Bundesbahn also shows. Thus the sapwood is always first attacked by wood-destroying fungi, but the transition to the intermediary wood and the heartwood than proceeds steadily if the conditions for fungi growth are favorable.

In the meantime much information has been collected on the necessary conditions for fungi to attack bongossi wood. This shows that the moisture necessary for fungus growth is found only when bongossi wood gets a continuous supply of water over a long period. Because of the extreme density of the wood it takes years before the wood is moist enough for a fungus-infection to develop. This situation exists in poorly ventilated, dirty track beds where the tie is kept constantly moist two-thirds of the way up, where bongossi wood is in long-term contact with moist soil, or where the wood is frequently supplied with water that then cannot evaporate fast enough, e.g. in covered bridge ties. Bongossi wood withstands occasional moist periods with subsequent drying without fungus attacks or damage. This is probably the reason why this wood type has the reputation for extreme durability.

When laid in tracks and switches, fungus attacks on bongossi wood are invisible, because the parts extending above the gravel are not attacked and are hard. Only when the surrounding gravel is removed do we see the side surfaces attacked by rot. When the damage is severe, one can stick a knife into the wood that is normally as hard as iron. In one extreme case, switch ties after 22 years were rotted away to about

Performance of South African Grown and Imported Timber Species as Railway Sleepers

6

***G.S. Vermaak and P. Quinn**

SYNOPSIS

Results of various service tests into the suitability of locally grown and imported timbers as sleepers, mainly the *Pinus* and *Eucalyptus* species, are discussed and the main findings are reported in this paper.

Since 1910 various service tests have been carried out by the research branch of the Department of Forestry (now the Directorate of Forestry of the Department of Enviornment Affairs) and by the South African Railways (S.A.R.). In the early years a number of water-soluble preservatives were used, i.e. sodium fluoride, Powell salt (copper chrome arsenate), zinc chloride and ASCU Falkamasam (C.C.A.) and creosote and creosote-fuel oil mixtures.

In addition to the service tests the mechanical properties of the species tested which relate to their use as sleepers and their amenability to impregnation with preservatives were also determined. For the non-durable species the volume of preservatives absorbed was a very important factor determining their service life.

INTRODUCTION

The Republic of South Africa is poorly endowed with natural forests, which cover an area of approximately 300 000 ha, i.e. only 0,25 % of the total land area. Although the S.A.R. obtained wooden sleepers from these forests until as late as the 1930's, the forests could not meet the demand and large quantities of sleepers had to be imported.

Afforestation with exotic pine and eucalypt species, already started in the previous century, was considerably accelerated after 1902 and especially during the depression years in the 1920's, with the result that increasing quantities of locally produced timber became available.

Research into the suitability of locally grown timber for sleepers started as early as 1913 and is still continuing. The main findings of this research are reported in this paper. The periodical scarcity of timber forced the S.A.R. to look for alternative materials for railway sleepers, which led to the development of concrete sleepers, and at present three concrete sleepers are used to every wooden sleeper. However, for certain applications, e.g. at switches and bridges, wooden sleepers are preferred to concrete sleepers and for this reason the results of research into the use of wooden sleepers are still of importance.

MATERIALS

Over the years many species have been included in the various service tests for wooden sleepers carried out by the research branch of the Department of Forestry (now the Directorate of Forestry of the Department of Environment Affairs) and by the S.A.R. Both locally produced and imported wooden sleepers were tested and in the case of non-durable timber species they were tested both as untreated and preservative-treated sleepers.

Full details of the species tested are presented in *Tables 3* and *4*.

METHODS

All tests were carried out under normal service conditions in the main tracks of the S.A.R. Periodical inspections were carried out on the sleepers, followed by a final assessment after their removal from the tracks.

INSPECTION CRITERIA

Inspections followed the methods described by Dale (1962) with some modifications:

End-splitting

The condition of a sleeper with regard to end-splitting was recorded as follows:

- Nil to slight — splits absent from both ends or not reaching the rail seat.
- Split at one end — a single split reaching the rail seat.
- Splits at both ends — a single split at each end reaching the rail seat.
- Shattered — unserviceable because of numerous checks and splits.

Surface condition

Surface condition was recorded as good, fair or poor

**The authors carried out this research whilst employed by the South African Forestry Research Institute. They are at present on the staff of the National Timber Research Institute of the Council for Scientific and Industrial Research, Pretoria, South Africa.*

depending on the amount of surface checking, decay (which was minimal) and weathering.

Chair cut

Three grades of chair cut were recorded, namely less than 2 mm, 2 mm to 5 mm and deeper than 5 mm, and were assessed on the worst rail seat of each sleeper.

In addition to the service tests, the mechanical properties of the species tested which relate to their use as sleepers and their amenability to impregnation with preservatives were also determined.

The latter characteristic is especially important in the case of naturally non-durable timber species and indicates the improvement in resistance to fungal decay and wood-boring insects and physical factors. These factors include such destructive forces as weathering, abrasion and fire, which are all encountered in the service life of sleepers.

RESULTS

The results of the various service tests will be discussed in chronological order of their initiation.

The 1913 *Pinus pinaster test*

In 1913 70 *Pinus pinaster* sleepers made of 40-year-old trees were divided into two groups and treated to average retentions of 270 and 390 kg/m^3, respectively, with creosote complying with the American Wood Preservers Association's standards.

Ten sleepers were placed at each centre in tracks at Bloemfontein, Cape Town, Durban, East London, Johannesburg, Port Elizabeth and Waterval-Boven. Ten years after the installation of the sleepers at Cape Town, Ross (1926) remarked as follows in an inspection report: "The sleepers are perfectly sound as regards decay, and the mechanical wear is practically nil; certainly every bit as good, if not better than the imported ,arrah sleepers. Being in main lines, they have to bear the heaviest types of traffic". Unfortunately no further results have been received since.

The 1922 *Pinus radiata test*

Fifteen *Pinus radiata* sleepers were treated with AWPA creosote at Mossel Bay and were placed in a track near Braamfontein (Johannesburg) in 1922. An inspection during March 1931 indicated that the sleepers were in sound condition. As with the 1913 test, no further results could be traced.

The 1928 service test including pine and eucalypt species

In 1928 service tests using 82 *Pinus pinaster*, 73 *Pinus radiata*, 30 *Eucalyptus diversicolor*, 4 *Eucalyptus globulus* and 11 *Eucalyptus grandis* sleepers were initiated in the Northern Transvaal at Pietersburg and in the Eastern Transvaal at Barberton, Lydenburg and Schoemans- dal. These sleepers were mainly found in Sabie in direct contact with the ground. The main causes of failure were rot and termite attack.

The preservatives used, average retentions and average years of service life are given in *Table 1*.

The 1933 comprehensive service test including *Acacia*, pine and eucalypt species

A comprehensive service test was started during 1933 using 684 sleepers of 10 species, namely *Acacia mearnsii, Eucalyptus blakelyi, E. camaldulensis, E. diversicolor, E. globulus, E. longifolia, E. grandis, Pinus pinaster, P. radiata* and *P. roxburghii*. These were installed at Langlaagte and Volksrust. All sleepers were treated with 40:60 creosote/fuel mixture at the South African Forestry Research Institute and were inspected periodically after installation. The sleepers in service after 32 years were returned to the South African Forestry Research Institute for a final assessment. The results are presented in *Table 2*.

The 1947 *Pinus radiata* test

During 1947 windfalls occurred in an experimental *Pinus radiata* stand near Harrismith in the Orange Free State and logs were sent to the State Sawmill, Pretoria.

Two thousand seven hundred sleepers were cut, incised and treated with F.P.I. Creosote (60 % high temperature creosote and 40 % tar prime) at the South African Forestry Research Institute. One hundred and seventeen 2,1 m sleepers were selected and installed in the main line between Pretoria and Germiston as a service test.

Because the trees were never pruned, large knots occurred in some of the sleepers. After more than 30 years of service 81 sleepers are still in the track and are in a fairly good condition.

The 1949 *Pinus radiata* test

Eighty-eight of the *P. radiata* windfall crossing timbers, similarly treated to those in the Pretoria - Germiston line, were installed in the Northern Transvaal at Waterpoort Station. In the past wooden sleepers in that vicinity had to be replaced almost every year owing to severe termite damage. After 22 years of service the crossing timbers were removed and returned to the South African Forestry Research Institute for a final inspection. Most of them were still in fairly good condition. See *Table 2*.

The 1951 *Brachystegia* spp. test

Large quantities of sleepers made of *Brachystegia* species were imported from neighbouring countries such as Angola, Moçambique, Zambia and Zimbabwe. The wood is non-durable, but is amenable to preservative treatment. In 1951 24 sleepers each of *Brachystegia edulus, B. stipulata* and *B. spiciformis* were creosoted and in-

TABLE 1. *Performance of sleepers treated with different preservatives placed at Pietersburg, Barberton, Lydenburg and Schoemansdal*

Botanical name	Number inserted	Preservative	Retention Average (kg/m³)	Av. service life (years)
Eucalyptus diversicolor	4	Creosote	40,4	9
	7	Creosote + fuel oil	25,8	14
	1	Fuel oil	57,6	22
	4	4,65 % $ZnCl_2$	2,0	
		Fuel oil	30,0	14
	3	4,65 % $ZnCl_2$	1,9	8
	6	4 % $ZnCl_2$ ± 0,54 % As_2O_3	3,2	10
	4	2 % Na_2HAsO_4	1,4	15
	1	Untreated	-	2
Eucalyptus globulus	2	4,6 % $ZnCl_2$	2,1	
		Fuel oil	28,0	12
	1	4,62 % $ZnCl_2$	3,5	12
	1	2 % Na_2HAsO_4	1,5	12
Eucalyptus grandis	1	Fuel oil	41,6	18
	3	4,61 % $ZnCl_2$	2,3	
		Fuel oil	34,7	13
	2	4,61 % $ZnCl_2$	2,1	12
	2	2 % Na_2HAsO_4	1,2	9
	2	4,3 % $ZnCl_2$ ± 0,54 % As_2O_3	2,8	7
	1	Untreated	-	2
Pinus pinaster	2	Creosote	96,0	19
	14	Creosote + fuel oil	98,5	25
	4	Fuel oil	107,2	22
	10	5,11 % $ZnCl_2$	11,3	
		Fuel oil	110,6	25
	9	5,18 % $ZnCl_2$	12,1	9
	12	2 % Na_2HAsO_4	6,5	
		Fuel oil	132,2	26
	14	2 % Na_2HAsO_4	6,6	13
	1	0,47 % As_2O_3	7,4	15
	12	4 % $ZnCl_2$ + 0,46 % As_2O_3	9,9	11
	1	4,08 % $ZnCl_2$ + 2 % Na_2HAsO_4	17,8	9
	3	Untreated	-	3
Pinus radiata	3	Creosote	102,4	19
	14	Creosote + fuel oil	85,7	24
	8	Fuel oil	85,2	28
	12	5,12 % $ZnCl_2$	13,9	
		Fuel oil	135,3	23
	11	5,19 % $ZnCl_2$	11,6	10
	8	2 % Na_2HAsO_4	3,7	
		Fuel oil	80,9	26
	14	2 % Na_2HAsO_4	6,0	14
		2,01 % $ZnCl_2$ + 0,46 % As_2O_3	11,0	12
	3	Untreated	-	4

TABLE 2. *Condition of sleepers tested by SAFRI in S.A.R. tracks*

Botanical name	No. of sleepers placed	No. of sleepers returned	Years in track	Incised & creosoted (I & C); creosoted (C); untreated (U)	End splitting (%)				Surface condition			Chair cut (%)			Creosote retention (kg/m³)		Av. service life (years)
					Nil to slight	One end	Both ends	Shattered	Good	Fair	Poor	0-2 mm	3-5 mm	5 mm	AVE.	SD	
Acacia mearnsii (Volksrust)	16	4	32	C	0	31	56	13	0	6	94	6	31	63	61	14	24
Afzelia quanzensis	20	18	19	I & C	100	0	0	0	89	11	0	83	17	0	55	22	-
	20	18	19	C	83	11	6	0	77	23	0	61	39	0	27	8	-
	16	10	19	U	-	-	-	-	-	-	-	-	-	-	-	-	15
Allenblackia stuhlmannii	3	3	14	I & C	67	33	0	0	33	67	0	100	0	0	163	88	-
	4	3	14	C	34	33	0	33	67	33	0	100	0	0	231	61	-
	4	0	8	U	-	-	-	-	-	-	-	-	-	-	-	-	8
Amblygonocarpus andongensis	58	46	10	C	74	11	4	11	19	70	11	100	0	0	31	10	-
	30	3	10	U	67	0	0	33	34	33	33	100	0	0	-	-	7

quebracho	30	30	9	C	100	0	0	0	100	0	0	100	0	0	177	58	-
Brachystegia divers *b	53	38	17	I + C	89	6	5	0	74	26	0	82	18	0	117	72	-
	30	23	17	C	91	9	0	0	61	39	0	91	9	0	143	70	-
	32	0	12	U	-	-	-	-	-	-	-	-	-	-	-	-	8
Brachystegia spiciformis *a,b	24	21	28	C	58	21	17	4	58	29	13	100	0	0	96	45	-
	47	44	24	AWPA-C	15	40	45	0	2	40	58	100	0	0	57	37	-
	41	38	24	F.P.I.-C	24	46	22	8	10	37	53	22	61	17	39	20	-
	10	10	24	F.P.I.-I&C	40	0	60	0	0	40	60	40	50	10	51	23	-
	40	39	24	(Creo+ fuel)-C	18	45	37	0	8	30	62	80	15	5	60	46	-
	10	9	24	(Oil 80:20)-I&C	40	40	20	0	10	60	30	90	0	10	103	60	-
	55	0	21	U	-	-	-	-	-	-	-	-	-	-	-	-	9
Brachystegia spiciformis *a,b (Zambia, Zimbabwe)	24	21	28	C	62	21	17	0	21	67	12	100	0	0	134	53	-
Brachystegia sp. *b	57	51	17	I & C	96	4	0	0	96	4	0	88	12	0	132	86	-
	21	0	11	U	-	-	-	-	-	-	-	-	-	-	-	-	5
Brachystegia stipulata *a,b	24	18	28	C	37	17	46	0	29	63	8	100	0	0	101	67	-
Breonadia microcephala	31	24	14	C	79	13	8	0	67	33	0	100	0	0	69	17	-
	13	2	14	U	100	0	0	0	0	50	50	100	0	0	-	-	9
Chlorophora excelsa	18	12	19	I & C	75	17	8	0	0	92	8	58	42	0	54	22	-
	17	8	19	C	100	0	0	0	13	75	13	38	50	12	20	15	-
	16	0	14	U	-	-	-	-	-	-	-	-	-	-	-	-	5
Cistanthera leplaei	42	39	17	I & C	87	8	2	3	59	33	8	95	5	0	78	38	-
	55	44	17	C	57	23	7	13	32	50	18	90	5	5	51	31	-
	35	0	11	U	-	-	-	-	-	-	-	-	-	-	-	-	11
Dialium engleranum *b	15	15	10	I & C	87	13	0	0	27	73	0	100	0	0	-	-	-
	93	62	10	C	60	11	13	16	24	66	10	100	0	0	48	18	-
	32	0	4	U	-	-	-	-	-	-	-	-	-	-	-	-	4
Dipterocarpus sp.	18	14	19	I & C	86	0	14	0	14	72	14	72	14	14	136	28	-
	16	12	19	C	40	40	20	0	0	100	0	80	0	20	166	49	-
	16	0	14	U	-	-	-	-	-	-	-	-	-	-	-	-	13
Eucalyptus blakelyi (Volksrust)	7	2	32	C	0	14	57	29	0	0	100	29	0	71	73	17	22
Eucalyptus camaldulensis (Volksrust)	81	55	32	C	15	32	43	10	1	15	84	32	27	41	73	24	28
Eucalyptus diversicolor *b (Langlaagte)	12	9	19	C	42	12	44	0	-	-	-	-	-	-	42	11	-
Eucalyptus diversicolor (Volksrust)	20	6	32	C	5	25	55	15	5	0	95	25	40	35	43	7	29
Eucalyptus globulus (Volksrust)	4	2	29	C	0	0	100	0	0	0	100	50	40	0	61	6	26
Eucalyptus longifolia (Volksrust)	6	5	32	C	50	17	33	0	0	33	67	50	17	33	63	8	30
Eucalyptus marginata	144	114	12	I & C	51	27	11	11	25	52	23	74	24	2	153	107	-
	258	196	12	C	55	26	10	7	15	60	25	79	19	2	75	80	-
	29	0	10	U	-	-	-	-	-	-	-	-	-	-	-	-	9
Eucalyptus microcorys	44	24	14	I & C	38	0	0	62	8	58	34	63	37	0	32	14	-
	44	19	14	C	11	0	0	89	5	58	37	79	21	0	25	10	-
	39	0	11	U	-	-	-	-	-	-	-	-	-	-	-	-	11
Eucalyptus moluccana	15	0	11	I & C	-	-	-	-	-	-	-	-	-	-	-	-	8
	15	5	11	C	0	0	20	80	0	0	100	0	100	0	-	-	9
	16	0	7	U	-	-	-	-	-	-	-	-	-	-	-	-	7
Eucalyptus muellerana	29	20	17	I & C	35	45	5	15	0	20	80	55	25	20	50	8	-
	22	8	17	C	25	25	0	50	0	0	100	63	37	0	44	19	-
	16	0	11	U	-	-	-	-	-	-	-	-	-	-	-	-	10
Eucalyptus paniculata	29	0	8	I & C	-	-	-	-	-	-	-	-	-	-	33	11	8
	29	0	8	C	-	-	-	-	-	-	-	-	-	-	30	11	8
	21	0	8	U	-	-	-	-	-	-	-	-	-	-	-	-	8
Eucalyptus grandis (Volksrust)	10	5	32	C	20	10	60	10	20	0	80	40	20	40	87	19	-
Fagara macrophylla *a	15	12	14	I & C	100	0	0	0	92	8	0	92	8	0	94	43	-
	16	12	14	C	83	17	0	0	83	17	0	100	0	0	102	75	-
	14	0	8	U	-	-	-	-	-	-	-	-	-	-	-	-	8

Guibourtia	21	19	17	I & C	74	16	10	0	37	63	0	95	5	0	130	63	-
arnoldiana	16	16	17	C	63	6	6	25	12	69	19	100	0	0	91	60	-
	16	1	17	U	-	-	-	-	-	-	-	-	-	-	-	-	6
Guibourtia	373	347	17	I & C	66	22	11	1	45	48	7	60	37	3	36	11	-
coleosperma	56	36	17	C	86	14	0	0	44	53	3	86	14	0	24	10	-
	45	29	17	U	70	20	10	0	45	50	0	50	50	0	-	-	10
Guibourtia	29	29	9	I & C	100	0	0	0	100	0	0	100	0	0	35	10	-
coleosperma *a	30	29	9	C	62	14	17	7	97	3	0	100	0	0	28	8	-
	27	27	9	U	37	15	26	22	0	100	0	100	0	0	-	-	9
Humbertia	58	49	14	C	71	0	0	29	16	78	6	98	2	0	12	6	-
madagascariensis *a,b	28	17	14	U	71	0	0	29	12	47	41	94	6	0	-	-	12
Julbernardia	46	36	17	I & C	86	10	4	0	69	25	6	92	8	0	123	36	-
angolensis	39	30	17	C	73	17	0	10	43	47	10	90	10	0	102	35	-
	33	0	12	U	-	-	-	-	-	-	-	-	-	-	-	-	33
Mimusops sp.	51	32	17	I & C	91	3	0	6	25	62	13	84	16	0	50	19	-
	49	33	17	C	76	9	0	15	22	48	30	91	6	3	42	17	-
	33	0	11	U	-	-	-	-	-	-	-	-	-	-	-	-	8
Morus mesozygia	16	15	19	I & C	93	7	0	0	20	80	0	93	7	0	44	46	-
	15	10	19	U	30	30	0	40	0	40	60	50	40	10	-	-	15
Newtonia	54	39	19	I & C	97	3	0	0	64	33	3	77	23	0	132	59	-
buchananii	52	32	19	C	85	9	0	6	31	63	6	66	34	0	144	91	-
	32	0	12	U	-	-	-	-	-	-	-	-	-	-	-	-	6
Parinari excelsa	29	21	14	I & C	62	9	0	29	47	29	24	95	5	0	186	88	-
	30	25	14	C	84	0	0	16	28	68	4	88	12	0	235	98	-
	29	0	8	U	-	-	-	-	-	-	-	-	-	-	-	-	7
Pinus caraniensis *a	30	0	15	C	60	27	13	0	63	37	0	100	0	0	194	27	-
Pinus pinaster *d (Langlaagte)	152	104	34	C	83	17	0	0	80	13	7	-	-	-	109	39	-
Pinus pinaster (Volksrust)	69	55	32	C	29	32	30	9	7	25	68	26	26	48	140	86	-
Pinus radiata *d (Langlaagte)	203	139	34	C	84	16	0	0	75	20	5	-	-	-	91	24	-
Pinus radiata (Volksrust)	72	65	32	C	67	10	21	2	30	31	39	33	31	36	108	25	32
Pinus radiata	229	215	19	I & C	60	31	8	1	48	47	5	56	36	8	147	22	-
(New Zealand)	37	30	19	C	60	27	10	3	13	80	7	50	40	10	142	19	-
	63	0	9	U	-	-	-	-	-	-	-	-	-	-	-	-	3
Pinus radiata ex Harrismith (Waterpoort) *c	88	64	22	I & C	72	19	0	9	23	31	46	80	17	3	193	49	-
Pinus radiata ex Harrismith (Germiston — Pretoria) *c	117	81	29	I & C	81	16	3	0	1	86	13	84	10	6	193	49	-
Pinus roxburghii *d (Langlaagte)	14	13	34	c	46	54	0	0	92	0	8	-	-	-	94	21	-
Pinus roxburghii (Volksrust)	8	8	32	C	50	13	25	12	25	50	25	60	40	0	116	17	-
Piptadeniastrum	17	16	19	I & C	100	0	0	0	6	38	56	62	38	0	121	32	-
africanum	17	16	19	C	94	6	0	0	0	25	75	56	38	6	100	25	-
	15	0	13	U	-	-	-	-	-	-	-	-	-	-	-	-	10
Sarcocephalus	28	19	19	I & C	79	21	0	0	89	11	0	58	42	0	237	64	-
diderrichii	28	25	19	C	76	20	4	0	80	20	0	88	12	0	165	80	-
	23	0	14	U	-	-	-	-	-	-	-	-	-	-	-	-	14
Schinopsis sp.	-	161	12	I & C	87	11	1	1	91	8	1	90	10	0	-	-	-
	-	128	12	C	85	13	2	0	96	3	1	70	27	3	27	14	-
Staudtia	42	35	17	I & C	65	23	3	9	40	60	0	91	6	3	87	34	-
gabonensis	44	42	17	C	38	36	7	19	45	50	5	88	12	0	79	49	-
	30	7	17	U	0	0	14	86	0	43	57	57	43	0	-	-	13
Swartzia	29	29	9	I & C	93	7	0	0	100	0	0	100	0	0	52	12	-
madagascariensis	30	30	9	C	87	10	3	0	100	0	0	100	0	0	44	12	-
*a	27	26	9	U	50	27	19	4	62	38	0	100	0	0	-	-	-
Syzygium	13	11	14	I & C	19	9	0	0	55	36	9	100	0	0	139	105	-
guineense	26	20	14	C	80	5	0	15	75	25	0	100	0	0	141	93	-
	14	2	14	U	100	0	0	0	50	50	0	100	0	0	-	-	10
Tieghemella	17	8	19	I & C	88	0	0	12	0	88	12	75	25	0	42	45	-
heckelii	12	5	19	C	40	40	20	0	0	60	40	80	20	0	40	13	-
	12	0	13	U	-	-	-	-	-	-	-	-	-	-	-	-	13

*a = Still in the track

*b = Tends to develop ring-shakes

*c = Placed in ballast consisting of ash and stone. Most sleepers were burnt and termite attack was reported.

*d = Locally grown sleepers installed where locomotives discharge ash, which covers sleepers, causing severe decay. 48 *Pinus pinaster*, 64 *P. radiata*, *P. roxburghii* and *Eucalyptus diversicolor* were also burnt.

stalled next to the *Pinus radiata* sleepers from Harrismith in the Pretoria - Germiston main line. After 30 years these sleepers are still in service and in excellent condition.

The 1954 test of 38 species

During 1954 an additional test for imported wooden sleepers consisting of 38 species was planned by the South African Forestry Research Institute and the S.A.R. The majority of these species were non-durable hardwoods from tropical Africa. Twelve sleepers of each species were used for standard mechanical and coach-screw vertical withdrawal tests. The results were reported by Banks and Schoeman (1963) and are summarised in *Table 3.* The remaining sleepers were divided into three groups. The first group was incised and creosoted, the second creosoted only and the third left untreated to serve as controls. See *Table 2.*

During 1957 these sleepers were installed in the main line between Pretoria and Germiston, a line which carries 8 000 000 t/a. The rainfall in this area varies from 700 to 800 mm/a.

From 1976 to 1978 3 700 sleepers of these 38 species were removed from the track for reasons other than 11
failure, e.g. alterations and modifications to the track. Each of these sleepers and those remaining in the track was inspected for end-splitting, surface condition and chair cut. "Years in the track" refers to the period which sleepers of the different species remained in the track and does not necessarily reflect the average service life obtained. The "average service life" is obtained when all the sleepers of a species have been removed from the track owing to failure.

The S.A.R. service tests

Records were kept by the S.A.R. on the performance of 57 species used as sleepers. With their permission, this information is summarised in *Table 4* and it may be used as a guide-line to indicate the suitability of a species for sleeper production and use. The "plus years average service life" indicates that the sleepers were removed for reasons other than failure.

TABLE 3. Mechanical properties of the sleeper timbers tested at 12 % moisture content

Botanical name	Common name	Origin of sleepers tested	Av. density (kg/m³)	Av. modulus of rupture (mPa)	Av. side grain hardness (N)	Av. coachscrew vertical withdrawal load (N)
Acacia galpinii	Monkey thorn	South Africa	825	114	9 007	92 478
Acacia mearnsii	Black wattle	South Africa	756	119	7 632	-
Acacia nigrescens	Knob-thorn	East Africa	1 159	115	18 292	-
Afzelia quanzensis	Chamfuti, pod mahogany	Mocambique	775	98	7 072	66 501
Albizia sp.	Tainakanga	Malagasy	803	112	7 073	65 077
Allenblackia stuhlmannii	—	Tanzania	771	98	5 601	51 599
Amblygonocarpus andongensis	Banga-Wanga, Scotman's rattle	Mocambique	1 044	114	14 055	98 167
Anadenanthera macrocarpa	Curupay	South America	990	158	14 499	104 680
Androstachys johnsonii	Mercrusse, Lebombo ironwood	East Africa	910	80	12 118	96 139
Apodytes dimidiata	White pear	South Africa	807	134	9 042	-
Aspidosperma peroba	—	South America	-	-	-	-
Aspidosperma quebracho	White quebracho	Brazil	924	100	11 222	118 166
Baikiaea plurijuga	Rhodesian teak	Central Africa	914	88	12 839	-
Brachystegia stipulata	—	East Africa	840	-	-	-
Brachystegia spiciformis	Msassa, okwen	Zambia and Zimbabwe	680	81	6 227	67 034
Brachystegia spiciformis	Msassa, okwen	Mocambique	-	-	-	-
Brachystegia spiciformis	Msassa, okwen	Zambia and Zimbabwe	768	84	6 491	67 390
Brachystegia sp.	Msassa, okwen	Zaire and Mocambique	744	103	6 348	64 054
Brachystegia stipulata	Msassa, okwen	Zambia and Zimbabwe	789	95	6 599	62 275
Breonadia microcephala	Matumi, mingerhout	Mocambique	932	114	8 481	87 229
Callophyllum elatum	Poonah	Asia	-	-	-	-
Chlorophora excelsa	Iroko	Tropical Africa	610	72	4 650	45 639
Cistanthera leplaei	Kissinhungo	Angola	835	132	7 745	84 739
Cordyla madagascariensis	Anakaraka	Malagasy	954	132	9 364	86 784
Cynometra alexandrii	Muhimbi	Uganda	916	127	11 848	95 058
Dacrydium cupressinum	Rimu	New Zealand	-	-	-	-
Dalbergia sp.	Manary	Malagasy	982	170	13 374	99 595
Dialium engleranum	N'Tiele	Angola	929	122	11 746	102 353
Dipterocarpus sp.	Keruing	Malaysia	772	113	5 241	50 799
Dipterocarpus tuberculatus	Pluang	Asia	-	-	-	-
Dryobalanops sp.	Kapor	Asia	770	122	-	-
Eucalyptus acmenioides	White mahogany	Australia	966	145	9 962	-
Eucalyptus blakelyi	Blakely's red gum	Australia	-	-	-	-
Eucalyptus camaldulensis	Red River gum	South Africa	961	117	9 440	-

Eucalyptus diversicolor	Karri	South Africa and Australia	882	145	8 075	-
Eucalyptus globulus	Blue gum	South Africa	956	153	9 901	-
Eucalyptus grandis	Flooded gum	South Africa	695	108	5 108	-
Eucalyptus gummifera	Red bloodwood	Australia	647	98	4 432	-
Eucalyptus longifolia	Woolybutt	South Africa	1 006	137	10 957	-
Eucalyptus marginata	Jarrah	Australia	731	99	6 694	69 290
Eucalyptus microcorys	Tallowwood	South Africa	924	139	7 870	53 022
Eucalyptus moluccana	Grey box	Australia	1 097	157	10 347	-
Eucalyptus muellerana	Yellow stringybark	Australia	810	124	6 631	65 211
Eucalyptus obliqua	Messmate stringybark	Australia	781	132	6 948	-
Eucalyptus paniculata	Grey ironbark	South Africa and Australia	1 076	178	13 449	96 601
Eucalyptus pilularis	Blackbutt	Australia	823	135	7 081	-
Eucalyptus punctata	Grey gum	Australia	1 057	163	12 276	-
Eucalyptus resinifera	Red mahogany	Australia	890	137	8 478	-
Eucalyptus grandis	Sydney blue gum	South Africa	850	128	7 416	-
Eucalyptus sideroxylon	Black ironbark	Australia	1 014	134	10 449	-
Eucalyptus wandoo	Wandoo	Australia	-	-	-	-
Eusideroxylon zwageri	Iron wood	East India	-	-	-	-
Fagara macrophylla	Olon	Tanzania	554	86	3 657	55 291
Fagraea fragrans	Kolaka	East India	-	-	-	-
Gilbertiodendron dewevrei	Limbali	West Africa	805	119	6 601	67 390
Glutha renghas	Anga	East India	-	-	-	-
Guibourtia arnoldiana	Benge	Angola	772	141	8 406	86 696
Guibourtia coleosperma	Rhodesian copalwood, bastard mopane	Zimbabwe	820	90	8 775	90 121
Heywoodia lucens	Cape ebony	South Africa	876	124	9 996	-
Humbertia madagascariensis	Endra endra	Malagasy	1 225	161	24 052	113 785
Intsia ambionensis	Merban	Asia	831	114	8 092	-
Julbernardia angolensis	-	Zimbabwe	811	112	7 701	63 788
Koompassia malaccensis	Kempas	Asia	855	138	7 890	60 571
Lithocarpus glaber	Japanese oak	Japan	-	-	-	-
→ *Lophira alata* var. *procera*	Ekki, bongossi	West Africa	1 054	161	14 744	-
Maranthes corymbosa	Kolaki	Asia	-	-	-	-
Marquesia macroura	Mavuca	West Africa	854	125	8 720	75 015
Messiboma sp.	Messiboma	Central Africa	-	-	-	-
Mimusops sp.	-	Angola	830	97	8 097	89 809
Mora excelsa	Mora	Guianas	1 007	142	9 575	86 696
Morus mesozygia	Mecodze, African mulberry	Mocambique	799	91	9 347	75 798
Newtonia buchananii	Mkufi	Angola	666	98	5 269	74 107
Nuxia floribunda	Forest elder	South Africa	745	103	7 221	-
Olea capensis subsp. *macrocarpa*	Black ironwood	South Africa	1 009	156	13 756	-
Parinari excelsa	Mbula	Tanzania	813	111	8 643	70 015
Pinus canariensis	Canary pine	South Africa	700	104	5 731	-
Pinus pinaster	Cluster pine	South Africa	637	107	4 291	-
Pinus radiata	Monterey pine	New Zealand	435	58	2 254	37 276
Pinus radiata	Monterey pine	South Africa	611	101	4 170	-
Pinus roxburghii	Chir pine	South Africa	533	85	3 321	-
Pinus sylvestris	Scots pine	Europe	499	66	2 570	-
Piptadeniastrum africanum	Dahoma	Ghana	689	103	5 864	54 758
Platylophus trifoliatus	Witels	South Africa	534	66	3 047	-
Pseudotsuga menziesii	Douglas fir, Oregon pine	North America	550	83	2 966	42 925
Quelimane sp.	-	East Africa	-	-	-	-
Quercus alba	American white oak	North America	782	88	5 911	77 977
Quercus robur	English oak	Siberia	745	106	5 851	53 868
Rhizophora racemosa	-	West Africa	-	-	-	-
Sarcocephalus diderrichii	Opepe	Angola	729	88	6 211	60 896
Schinopsis sp.	Red quebracho	South America	1 140	125	19 274	116 232
Scolopia mundii	Red pear	South Africa	900	127	9 827	-
Sequoia sempervirens	Californian redwood	South Africa and North America	448	69	2 448	-
Shorea sp.	Red meranti	East India	912	151	8 372	-
Staudtia gabonensis	Niove	Angola	870	136	9 121	72 773
Strychnos decussata	Cape teak	South Africa	950	97	9 955	-
Swartzia madagascariensis	Snake bean	Malagasy	1 024	132	11 908	95 899
Syncarpia glomulifera	Turpentine tree	South Africa and Australia	747	116	-	6 498
Syzygium guineense	Water pear	Tanzania	793	100	5 233	51 021
Tectona grandis	Teak	Burma	670	92	4 454	-
Tieghemella heckelii	Makaré	Ghana	594	88	4 375	51 510
Xylia dolabriformis	Pynikado	Burma	980	145	-	-
Xymalos monospora	Lemonwood	South Africa	594	76	3 697	-

TABLE 4. Performance of sleepers tested by the South African Railways

Botanical name	Number inserted	Treatment	Date inserted	Av. service life (years)
Acacia galpinii	245	Untreated	1919	4
Acacia nigrescens	154	Untreated	1924	11
Albizia sp.	153	Untreated	1959	10
Anadenanthera macrocarpa	855	Untreated	1928	12
Androstachys johnsonii	200	Incised and creosoted	1956	+10
Androstachys johnsonii	15 120	Untreated	1928	24
Apodytes dimidiata	130	Untreated	1919-1920	6
Aspidosperma peroba	15	Untreated	1922	15
Baikiaea plurijuga	8 920	Untreated	1917, 1926	26
Callophyllum elatum	12	Untreated	1919	9
Cordyla madagascariensis	90	Incised and creosoted	1962	+20
Cynometia alexandrii	150	Creosoted	1957, 1962	+18
Cynimetia alexandrii	11	Incised and creosoted	1962	+18
Dacrydium cupressinum	10	Untreated	1913	1
Dalbergia sp.	78	Untreated	1959	7
Dipterocarpus tuberculatis	12	Untreated	1921	13
Dryobalanops sp.	12	Untreated	1931	14
Eucalyptus acemioides	152	Creosoted	1957	12
Eucalyptus diversicolor	956	Fluoride	1927	18
Eucalyptus diversicolor	11 033	Powellised	1914 - 1921	17
Eucalyptus diversicolor	30	Untreated	1919	10
Eucalyptus globulus	20	Zinc chloride	1923	12
Eucalyptus globulus	1 000	Creosote and fuel oil	1915	15
Eucalyptus gummifera	188	Untreated	1957	12
Eucalyptus obliqua	247	Untreated	1932	12
Eucalyptus paniculata	78	Creosoted	1957	12
Eucalyptus pilularis	400	Untreated	1932, 1957	12
Eucalyptus punctata	52	Creosoted	1957	12
Eucalyptus resinifera	237	Untreated	1932	13
Eucalyptus grandis	44	Incised and creosoted	1964	14
Eucalyptus grandis	66	Creosoted	1957	11
Eucalyptus sideroxylon	116	Creosoted	1957	11
Eucalyptus sideroxylon	83	Untreated	1957	10
Eucalyptus wandoo	1 101	Untreated	1927	20
Eusideroxylon zwageri	47	Untreated	1917, 1920, 1937	10
Fagraea fragrans	10	Untreated	1937	16
Gibertiodendron dewevrei	484	Untreated	1941, 1960	8
Glutha renghas	10	Untreated	1937	13
Heywoodia lucens	14	Untreated	1929	2
Intsia amboinensis	10	Untreated	1937	16
Koompassia malaccensis	2 462	ASCU (Falkamasam)	1941	20
Lithocarpus glaber	769	Untreated	1912, 1913	3
Lophira alata ⟵	2 298	Untreated	1944-1957	+20
Maranthes corymbosa	10	Untreated	1937	16
Messiboma sp.	372	Untreated	1947	7
Mora excelsa	4 374	Untreated	1923-1928	8
Nuxia floribunda	200	Untreated	1919-1920	4
Olea capensis subsp. *macrocarpa*	4 916	Creosoted	1923-1924	12
Olea capensis subsp. *macrocarpa*	7 452	Untreated	1917-1924	5
Pinus sylvestris	48 878	Creosoted	1914-1915	10
Pinus sylvestris	10	ASCU (Falkamasam)	1947	10
Plytylophus trifoliatus	1 000	Untreated	1919	2
Pseudotsuga menziesii	153	Creosoted	1915-1925	17
Quelimane sp.	20	Untreated	1916	14
Quercus alba	100	Untreated	1915, 1933	6
Quercus robur	82	Untreated	1913-1921	3
Rhizophora racemosa	216	Untreated	1916	3
Scolopia mundii	229	Untreated	1920	5
Sequoia sempervirens	120	Untreated	1914, 1929	7
Shorea sp.	2 378	Untreated	1940-1945	27
Strychnos decussata	73	Untreated	1928	3
Tectona grandis	50	Untreated	1909, 1910	15
Xylia dolabriformis	594	Untreated	1958	11
Xymalos monospora	82	Untreated	1918	5

DISCUSSIONS AND CONCLUSIONS

therefore recommended for the treatment of sleepers.

Pinus species

Pinus radiata imported from New Zealand and tested on the Pretoria - Germiston main line had an average density of 435 kg/m³ at 12 % moisture content, i.e. 200 kg/m³ less than that of locally produced timber of the same species. The weathering properties of the treated sleepers were very good and the chair cut after 19 years of service was acceptable. Preservative penetration into the heartwood of the imported sleepers was almost complete, whereas the much heavier South African grown *P. radiata* is difficult to impregnate with preservatives. In spite of this and bearing in mind that most sleepers had large surface knots, very good results were obtained with locally grown *P. radiata*, which gave approximately 30 years of service.

Regarding the other *Pinus* species such as *P. canariensis*, *P. pinaster* and *P. roxburghii*, excellent results can be expected as these species usually have more sapwood, which allows deeper penetration than in the case of *P. radiata*.

Under South African conditions, the use of locally grown solid sleepers of *Pinus* species is a feasible proposition and is substantiated by their inclusion in the revised S.A.R. specification.

Eucalyptus species

The weathering properties of treated *Eucalyptus* species are generally poor in comparison with those of treated *Pinus* species. This can be ascribed to the extreme weathering conditions encountered on the South African tracks and to the large proportion of untreatable heartwood. However, incised and creosoted *Eucalyptus marginata* gave better results than the other *Eucalyptus* species tested, but still not as good as the *Pinus* species.

Other species

Of all the species tested, *Brachystegia* species had the longest service life. This can be attributed largely to the amenability to preservative treatment of this species. Supplies are still available from neighbouring countries and these species can therefore compete with our locally grown *Pinus* species.

PRESERVATIVE ABSORPTION

In all the sleepers tested, the volume of preservative absorbed was a very important factor in determining their service life. High retentions of creosotes and oils resulted in an excellent performance by preventing surface deterioration of the sleepers even after 15 years or more. The 1928 test with different preservatives (see *Table 1*) showed that sleepers treated with a heavy fuel oil performed well. The use of waxy oil, obtained from the synthol process, in combination with creosote was

INCISING

Results from experiments conducted at the South African Forestry Research Institute indicated that incising while the timber is still green could be advantageous. The stresses set up near the surface in drying are partially relieved and a reduction in the amount of checking can be obtained. Although no penetration of preservative in refractory heartwood is possible except for small quantities in exposed end-grain, incising increases the area of exposed end-grain and when incisions are filled with preservative it should add more years to the service life of sleepers.

MALPRACTICES

In tests where sleepers were placed incorrectly, namely with the concave side of the growth-rings facing up-

TABLE 5. Absorptions that can be obtained with pressure impregnation and rating of some species as sleepers

Botanical name	Impregnation creosote retention kg/m³	Performance*
Acacia mearnsii	61-90	-
Afzelia quanzensis	31-60	xxxxx
Allenblackia stuhlmannii	+120	xxxx
Amblygonocarpus andongensis	31-60	xxx
Androstachys johnsonii	-	xxx
Aspidosperma quebracho	+120	xxxx
Baikiaea plurijuga	-	xxxx
Brachystegia divers	+120	xxxxx
Brachystegia spiciformis	91-120	xxxxx
Brachystegia sp.	+120	xxxxx
Brachystegia stipulata	91-120	xxxxx
Breonadia microcephala	61-90	xxx
Chlorophora excelsa	31-60	xxxx
Cistanthera lepaei	61-90	xxxx
Cordyla madagascariensis	-	xxx
Cynometra alexandrii	-	xxx
Dialium engleranum	31-60	xxx
Dipterocarpus sp.	+120	xxxx
Eucalyptus blakeleyi	61-90	-
Eucalyptus camaldulensis	61-90	xxx
Eucalyptus diversicolor	31-60	-
Eucalyptus globulus	61-90	-
Eucalyptus grandis	61-90	xx
Eucalyptus longifolia	61-90	-
Eucalyptus marginata	91-120	xxx
Eucalyptus microcorys	0-30	xx
Eucalyptus moluccana	-	x
Eucalyptus muellerana	31-60	xx
Eucalyptus paniculata	0-30	xx
Fagara macrophylla	91-120	xxxx
Guibourtia arnoldiana	91-120	xxxx
Guibourtia coleosperma	0-30	xxx
Humbertia madagascariensis	0-30	xx
Julbernadia angolensis	91-120	xxxx
Koompassia malaccensis	-	xxx
Lophira alata var. *procera*	-	xxx
Mimusops sp.	31-60	xxx
Morus mesozygia	31-60	xxxx
Newtonia buchananii	+120	xxxx

Parinari excelsa	+120	xxxx
Pinus canariensis	+120	xxxxx
Pinus pinaster	+120	xxxx
Pinus radiata (S.A.)	+120	xxxx
Pinus radiata ex New Zealand	+120	xxxx
Pinus radiata ex Harrismith (S.A.)	+120	xxxx
Pinus roxburghii	+120	xxxx
Piptadeniastrum africanum	91-120	xxx
Psudotsuga menziesii	-	xx
Sarcocephalus diderrichii	+120	xxxxx
Schinopsis sp.	0-30	xxxx
Shorea sp.	-	xxx
Staudtia gabonensis	61-90	xxx
Swartzia madagascariensis	31-60	xxxx
Syzygium guineense	+120	xxxx
Tieghemella heckelii	31-60	xxx

*The criteria used for the classification of the species are based on years of expected service life of creosoted sleepers in the track and is divided as follows:

-	=	Cannot make an estimate on data available
x	=	0-12 years
xx	=	13-19 years
xxx	=	20-29 years
xxxx	=	30-39 years
xxxxx	=	+40 years

wards, only about half the service life was obtained owing to the accelerated weathering. A reduction in service life was also evident where coachscrew holes were not treated or old holes were left unplugged, resulting in rapid decay in these areas.

It may be concluded finally that preference should be given to the South African grown pine species as a source of sleeper material. Commercially available pine species such as *Pinus radiata* and *Pinus pinaster* have desirable properties required in sleeper production and use, such as densities in the order of 600 kg/m^3 and higher and moduli of rupture of 100 Mpa. These timbers are easy to impregnate with preservatives, retentions of 200 kg/m^3 or more being attained.

Sleepers produced from these species are able to yield an average service life of well over 30 years when treated with preservatives to the required retentions. The *Eucalyptus* species have proved not to give such a good performance as the pine sleepers mainly because their service life is greatly reduced as a result of their impermeable heartwood.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the work done by Mr P.M.D. Krogh, former head of the Wood Preservation Section of the South African Forestry Research Institute and numerous employees of the South African Railways.

Appreciation is also expressed to the National Timber Research Institute of the Council for Scientific and Industrial Research for processing of data and preparation of this report.

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United States Department of Agriculture

Forest Service

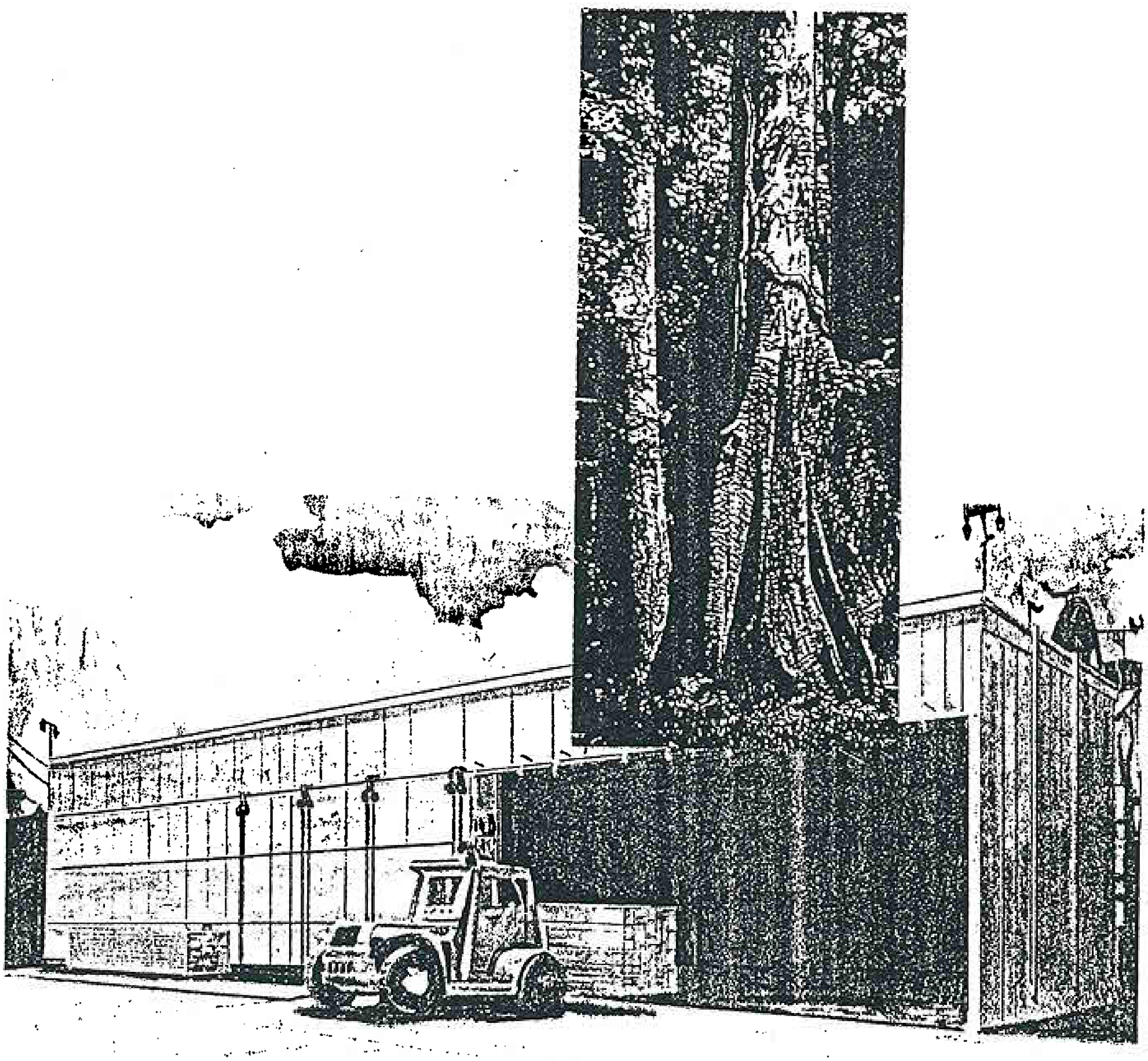
Forest Products Laboratory

General Technical Report FPL-GTR-71

Relative Drying Times of 650 Tropical Woods

Estimation by Green Moisture Content, Specific Gravity, and Green Weight Density

William T. Simpson
John A. Sagoe



Relative Drying Times of 650 Tropical Woods

Estimation by Green Moisture Content, Specific Gravity, and Green Weight Density

William T. Simpson, Research Forest Products Technologist
Forest Products Laboratory, Madison, Wisconsin

John A. Sagoe, Timber Industry Analyst
Timber Export Development Board, Takoradi, Ghana

Introduction

The lumber of tropical species can be kiln-dried most efficiently in species groups because of the large number of species, their diffuse occurrence in the forest, and the difficulty of singling out species for harvesting and drying. However, the many species present a wide variety of drying properties, which complicates the drying of mixtures of species. In a previous report (Simpson and Baah 1989), a mathematical model was described for grouping species by similar estimated drying times. The goal was to develop a grouping model so that all species in a group would emerge from the same kiln at the same time, within set limits of moisture content, and with minimum drying defects. The model, which utilizes experimental drying rate data collected in previously reported research, incorporates specific gravity and initial moisture content as criteria for grouping species on the basis of estimated drying time.

One limitation of the model is the availability of green moisture content data for species. This information is not always collected in studies on the characteristic properties of species nor is it always easily available to interested users. The general objective of our study was to eliminate the need for green moisture content data when such data are not available for estimating drying time.

This report presents data collected from the literature on green moisture content and green weight density (for calculating green shipping weight of tropical species), establishes a relationship between green moisture content and specific gravity, and presents an estimated drying time index for the species listed.

Mathematical Model

Estimation of Drying Time

The method for grouping species is based on a mathematical model that estimates drying time in relationship to specific gravity, initial moisture content, temperature, relative humidity, and board thickness (Simpson and Baah 1989).[1] The final equation of the model is

$$t = \frac{-L^{1.52} b_{T1}}{b_s b_{T2}} \ln\left(\frac{W_a - W_e}{W_0 - W_e}\right) \qquad (1)$$

where

- t is time (days),
- L board thickness (mm),
- b_s empirical specific gravity coefficient (mm$^{1.52}$/day),
- b_{T1} empirical temperature coefficient for $T_1 = 49°C$,
- b_{T2} empirical temperature coefficient for $T_2 = 38°C$ to $82°C$,
- W_a average moisture content of board (percent) at time t,
- W_e equilibrium moisture content (EMC) in kiln (percent), and
- W_0 initial moisture content of board (percent).

Determination of the coefficients was described in Tschernitz and Simpson (1977). In that experiment,

[1] Note: The vertical axis units for b_s in Figure 1 of the Simpson and Baah report are incorrect. These units are inch$^{1.52}$ (136.6 mm$^{1.52}$)/day.

a total of 729 data entries (approximately 650 species). Tropical Asia, Africa, and Latin America were all represented. In some cases species were repeated, but in these cases the repeated data constituted independent data sets.

The results of the literature search are listed in Appendix A alphabetically by scientific name. Common name, geographical region, and literature source are also given. Both the basic specific gravity (ovendry weight/green volume) and specific gravity at 12 percent moisture content (ovendry weight/volume at 12 percent moisture content) are listed, as well as shrinkage data. Green weight density is also listed.

Several references did not provide data on green moisture content or either basic specific gravity or specific gravity at 12 percent moisture content; these values were estimated (see Appendix B). The equations used to calculate green weight density are also presented in Appendix B.

Green Moisture Content and Specific Gravity

The green moisture content–basic specific gravity data in Appendix A were fitted by regression analysis to Equation (6). The values of the regression coefficients A and B are −4.79 and 4.13, respectively. The raw data, regression curve, and maximum moisture content curve are shown in Figure 2. Green moisture content ranged from >200 percent at $G_b \leq 0.3$ to $\leq$30 percent at $G_b \cong 1.0$. Most data were clustered between green moisture content of 50 to 100 percent and G_b of 0.4 to 0.8.

One problem was lack of information on the experimental methods used to collect data on green moisture content. The references did not describe how green moisture content specimens were handled from the time they were cut until the green weight was determined. Freshly cut green specimens can easily lose moisture, resulting in calculation errors in moisture content if the specimens are not either weighed immediately after cutting or wrapped in vapor-resistant wrapping until weighed. Therefore, in general we might expect some reported green moisture content values to be lower than the true values. Figure 2 suggests this because many data points fall well below the maximum moisture content curve.

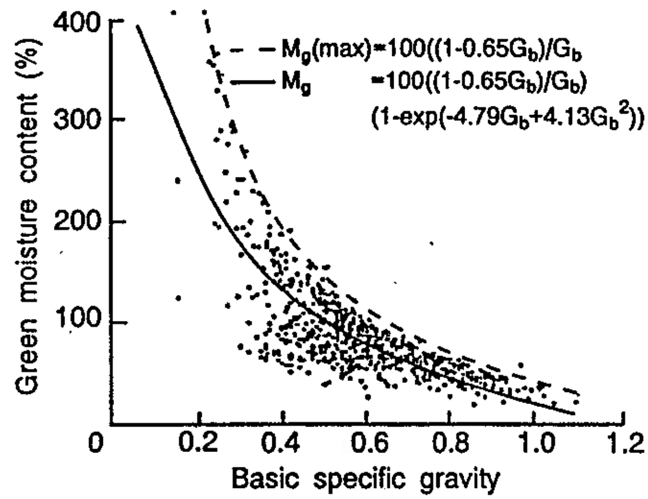


Figure 2—Relationship between basic specific gravity (G_b) and green moisture content (M_g) of tropical hardwoods. Figure shows actual data points, regression curve (solid line), and maximum moisture content curve (broken line).

Table 1—Kiln schedule for calculating drying time index

Moisture content (percent)	Dry bulb temperature (°C)	Relative humidity (percent)	Equilibrium moisture content (percent)
Green–25	40	70	12.2
25–20	50	50	8.1
20–15	60	40	6.3
15–10	70	30	4.6

Drying Time Index

The species listed in Appendix A can be categorized by a drying time index that reflects their relative drying time and thus gives a first approximation for grouping. The base for the index is somewhat arbitrary; we chose the base as the drying time of 29-mm-thick lumber at $G_b = 0.500$. The average green moisture content of the data in Appendix A is 97.5 percent at this specific gravity. The drying time index is thus defined as the ratio of the drying time estimated by Equation (1) at any $G_b - W_0$ combination to the drying time at the 0.500–97.5-percent combination. The index is also slightly dependent on kiln schedule because drying temperature and EMC have a nonlinear effect on drying time. Therefore, we chose a simple conservative schedule that could be applied safely to many species (Table 1). To illustrate the sensitivity of drying time index to drying time, a change in drying time index of 0.065 is equivalent to a change in drying time of 1 day at the drying conditions listed in Table 1. If we were to choose a drying time of 2 days as an interval for grouping, then our grouping criterion would be drying time index ±0.065.

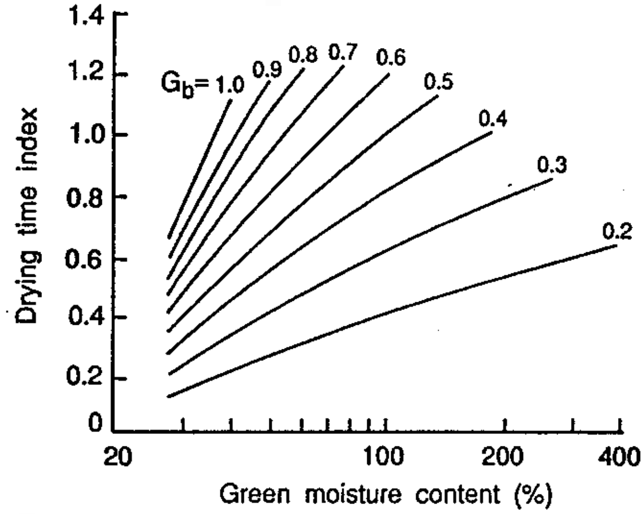


Figure 3—Dependence of drying time index on green moisture content and basic specific gravity of tropical hardwoods.

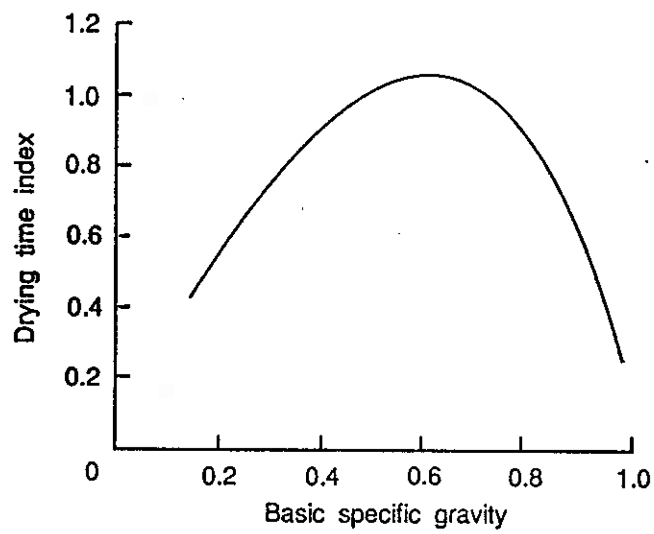


Figure 4—Dependence of drying time index on basic specific gravity of tropical hardwoods, assuming the Equation (2) relationship between basic specific gravity and green moisture content.

The drying time index for each species is included in Appendix A and illustrated in Figures 3 and 4. Figure 3 shows the relationship between drying time index and green moisture content at several levels of basic specific gravity. However, if green moisture content is not known, Figure 3 cannot be used to determine drying time index. In that case, the drying time index–basic specific gravity relationship shown in Figure 4 applies.

The drying time index can also be empirically related to green weight density (Fig. 5). The relationship shown suggests that green weight density alone might offer a good basis for a grouping system. Basic

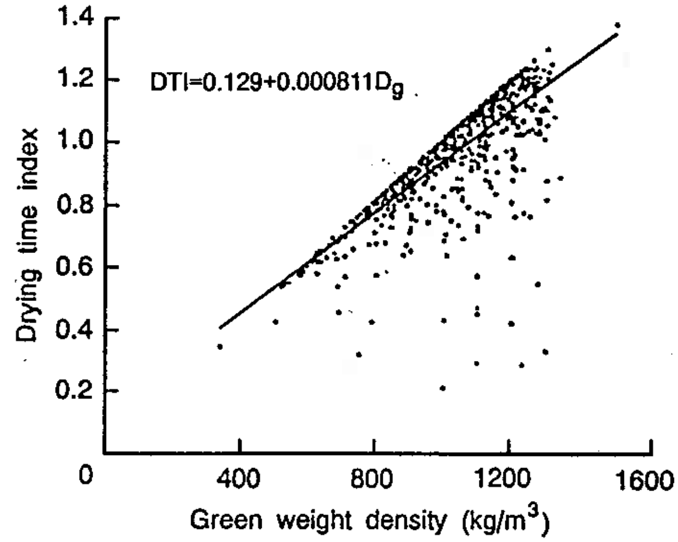


Figure 5—Dependence of drying time index (DTI) on green weight density (D_g). Correlation coefficient is 0.756.

specific gravity and initial moisture content both require an oven to determine ovendry weights. Green weight density requires only calipers (for measuring dimensions) and a balance, and eliminates the need for an oven and the time required for determining ovendry weight. Green weight density is thus easier to determine and could offer a more practical grouping system than do specific gravity and green moisture content. The sensitivity of drying time to green weight density is the equivalency of 1 day of drying to 80 kg/m^3 green weight density. A 2-day drying time interval for grouping could then be stated in terms of green weight density ±80 kg/m^3.

Concluding Remarks

Data on green moisture content of tropical hardwoods have been reported in the literature, but the data are in many different sources, not all of which are easily accessible to potential users. This report brings together some of these data and uses this expanded data base to confirm a previously developed relationship between basic specific gravity and green moisture content. This relationship makes possible a first approximation at grouping tropical hardwoods by similar estimated drying times given only basic specific gravity or green weight density.

Appendix A. Drying properties of tropical hardwoods[a]–Continued

Scientific name	Common name	Region[b]	Ref.	M_g (%)	G_b	G_{12}	S_v (%)	S_t (%)	S_r (%)	DTI	W_g (kg/m³)
Kleinhovia hospita	Tan-ag	AS	11	176.5	0.364	0.387				0.920	1,006
Koompassia excelsa	Manggis	AS	11	79.0	0.668	0.749				1.195	1,196
Koordersiodendron pinnatum	Amugis	AS	11	86.2	0.639	0.713				1.196	1,190
Koordersiodendron pinnatum	Ranggu	AS	9	53.0	0.720					1.016	1,102
Laetia spp.	Alcarreto	LA	17	78.0	0.590	0.648	14.9	11.3	4.2	1.055	1,050
Lafoensia punicifolia	Amarillo pepita	LA	17	44.0	0.720	0.779	12.7	8.6	4.0	0.881	1,037
Lagerstroemia piriformis	Batitinan	AS	11	121.1	0.487	0.529				1.066	1,077
Lagerstroemia speciosa	Banaba	AS	11	114.9	0.534	0.585				1.141	1,148
Lannea coromandelica	Jhingen	AS	13	130.0	0.497	0.523	8.4	5.4	3.0	1.117	1,143
Lecythis paraensis	Sapucaia	LA	20	45.9	0.880	0.957	13.4	7.6	6.0	1.102	1,284
Lecythis pisonis	Sapucaia	LA	2	48.8	0.840	0.980	13.9	8.0	5.6	1.107	1,250
Lecythis spp.	Sapucaia	LA	5	27.6	0.940	1.020	13.0	7.9	5.1	0.627	1,200
Lecythis tuyrana	Coco	LA	17	95.0	0.610	0.668	14.4	10.3	4.5	1.196	1,190
Leucaena leucocephala	Ipil-ipil	AS	11	78.5	0.728	0.825				1.293	1,299
Licania arborea	Paragua	LA	17	73.0	0.630	0.694	15.4	10.1	5.8	1.086	1,090
Licania buxifolia	Marishiballi	LA	20	37.3	0.880	0.981	17.2	11.7	7.5	0.909	1,208
Licania hypoleuca	Rasca	LA	17	42.0	0.830	0.934	18.5	10.9	7.4	0.967	1,179
Licania macrophylla	Anauera	LA	20	49.8	0.760	0.842	16.2	9.9	6.1	1.023	1,138
Licania octandra	Caraipe	LA	2	62.3	0.770	0.940	17.4	11.9	6.1	1.201	1,250
Licania platypus	Sapote	LA	17	80.0	0.620	0.684	15.5	10.2	5.6	1.121	1,116
Licania spp.	Carbonero/tuquesa	LA	17	80.0	0.650	0.709	13.8	9.2	4.7	1.172	1,170
Licaria cayennensis	Kaneelhart	LA	20	30.4	0.960	1.038	12.5	7.9	5.4	0.758	1,252
Licaria rigida	Louro amarelo/louro	LA	2	52.1	0.730	0.850	13.5	9.1	5.3	1.017	1,110
Licaria spp.	Sigue canelo	LA	17	65.0	0.420	0.452	11.7	8.4	3.3	0.690	693
Litchi philippinensis	Alupag-amo	AS	11	49.3	0.872	1.015				1.155	1,302
Lithocarpus soleriana	Manaring	AS	11	81.0	0.630	0.702				1.145	1,140
Litsea garciae	Bangulo	AS	11	172.2	0.344	0.364				0.864	936
Litsea perrottetii	Marang	AS	11	103.6	0.486	0.528				0.998	989
Livistona rotundifolia	Anahau	AS	11	60.7	0.787	0.902				1.207	1,265
Lonchocarpus castilloi	Black cabbage bark	LA	9	61.0	0.780					1.201	1,256
Lophira alata	Ekki	AF	9	43.0	0.860					1.021	1,230
Lophopetalum fimbriatum	Raktan	AS	1	101.0	0.530					1.074	1,065
Lovoa trichilloides	Walnut, African	AF	9	61.0	0.450					0.710	725
Loxopterygium sagotii	Hububalli	LA	19	98.0	0.560	0.600	11.1	7.2	3.4	1.117	1,109
Lueheopsis duckeana	Acoita cavalo	LA	2	83.9	0.620	0.710	13.3	9.5	4.6	1.147	1,140

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ANDERS E. LUND, INC.

A FIELD EVALUATION OF AZOBE (*Lophira alata*) FOR DECAY AND TERMITE RESISTANCE

A Proposal for the
Railway Tie Association

Anders E. Lund - Roy D. Adams

Post Office Box 2534, Farmington Hills, Michigan 48333, USA • Phone 313-477-0843 • Mobile 313-320-0345 • FAX 313-477-4469

A Field Evaluation of Azobe (*Lophira alata*) for Decay and Termite Resistance

Anders E. Lund and Roy D. Adams
Anders E. Lund inc., Farmington Hills, MI 48333

Part I of this study consists of the determination of decay and termite resistance of azobe in a tropical environment using 3/4 x 3/4 x 18-inch long stakes implanted 9 inches into the ground.

After the azobe is air dried, the stakes will be cut and machined with photographs taken showing the 4 sides and ends of each stake. One hundred and two stakes will be selected for the following use:

90 to be field tested in Panama at the Chiva Chiva site
12 to be retained for controls--references.

Appropriate measurements will be made of each stake, e.g. actual size, moisture content, gross characteristics, etc.

One-half of the 102 stakes will be preservative treated with creosote at a commercial facility. Retentions and other data as needed will be recorded.

As planned, 1/3 of the stakes will be all heartwood, 1/3 all sapwood, and 1/3 mixed.

Field testing will be conducted in Panama at the Chiva Chiva test site as shown in Figures 1 and 2. Site management, administration and financial responsibility are covered under an agreement between Anders E. Lund, inc. and the U.S. Army Test and Evaluation Command, Aberdeen, MD and the Dugway Proving Grounds, UT which includes the Tropic Test Sites in Panama. Test sites include wet and dry terrestrial conditions with and without overstory canopy (partial or complete), ocean salt spray sites and high humidity locations. Marine exposure sites are covered under a separate agreement with the U.S. Navy, Rodman Naval Base, Republic of Panama.

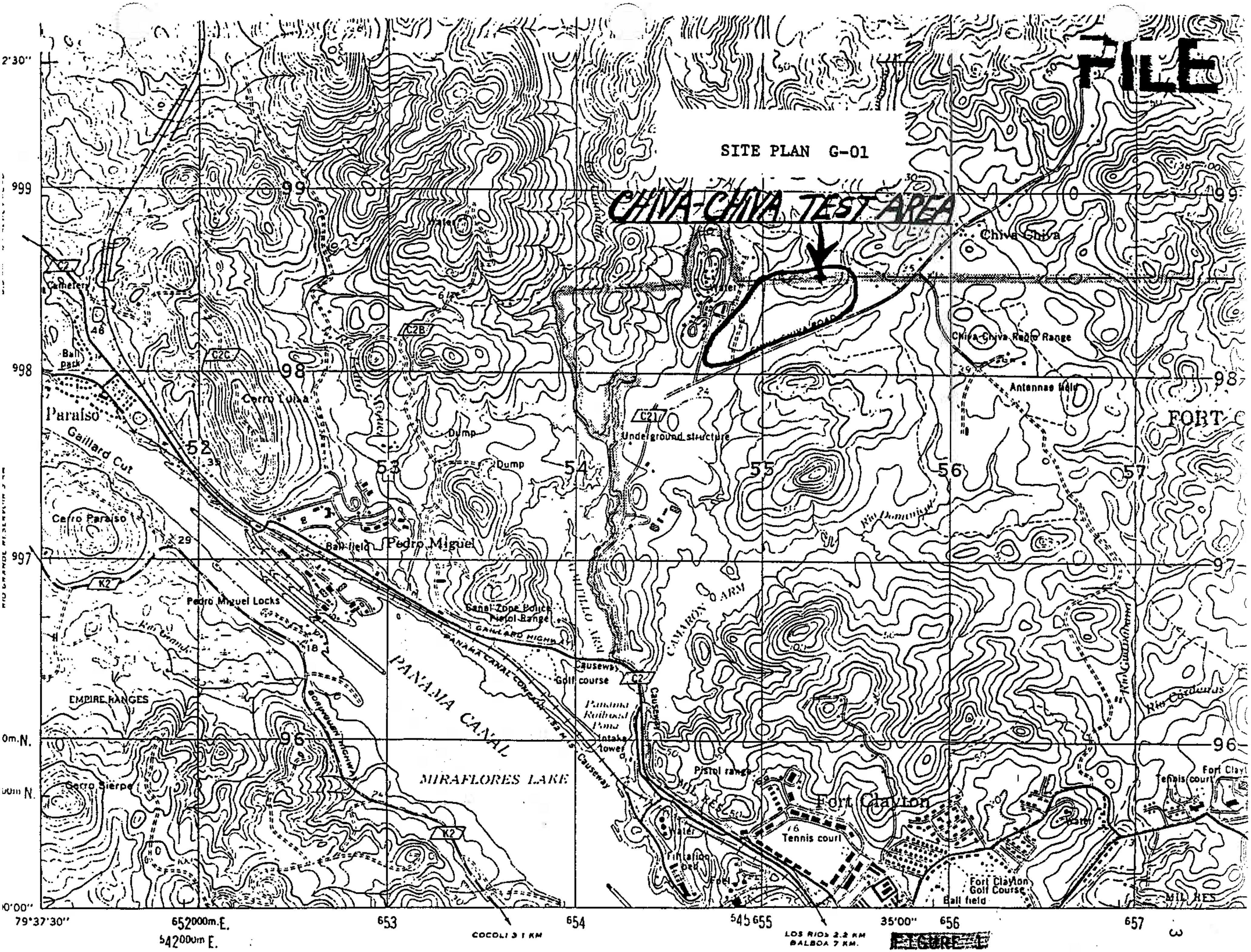
The Chiva Chiva test site has contained over 10,000 samples. The most recent installation was in February, 1991. The next installation will be in March, 1992. Photos 1 through 6 show some general scenes of parts of the test site.

Table 1 gives a brief outline of the test protocol.

An anticipated 3-5 year test duration is planned, dependent on fungal/termite activity. An initial installation report and subsequent annual reports will be supplied to the contractor.

Part II of this study consists of a dimensional stability evaluation of azobe. A number (90) of azobe 2 x 4 x 18-inch samples will be placed horizontally in contact with the ground after removal of all ground surface vegatation and debris. Samples will be exposed in an area with no vegatative overstory. Splits, checks, etc. will be recorded and shown photographically.

It is assumed that the azobe wood will be supplied and preservative treated at no cost. The total project cost is, therefore, estimated at $1,500.00.


FILE
SITE PLAN G-01
CHIVA-CHIVA TEST AREA
Chiva Chiva
Chiva-Chiva Radio Range
Antennae field
FORT C
Underground structure
Paraiso
Gaillard Cut
Cerro Paraiso
Cerro Luisa
Ball park
Cemetery
Dump
Dump
Pedro Miguel
Ball field
Pedro Miguel Locks
Canal Zone Police Pistol Range
GAILLARD HIGHWAY
PANAMA CANAL
MIRAFLORES LAKE
CAMARON ARM
Causeway
Golf course
Panama Railroad Pond
Intake tower
Pistol range
Fort Clayton
Tennis court
Fort Clayton Golf Course
Ball field
EMPIRE RANGES
Cerro Sierpe
BORINQUEN HIGHWAY
C2
C2B
C2C
C21
K2
52
53
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57
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99
999
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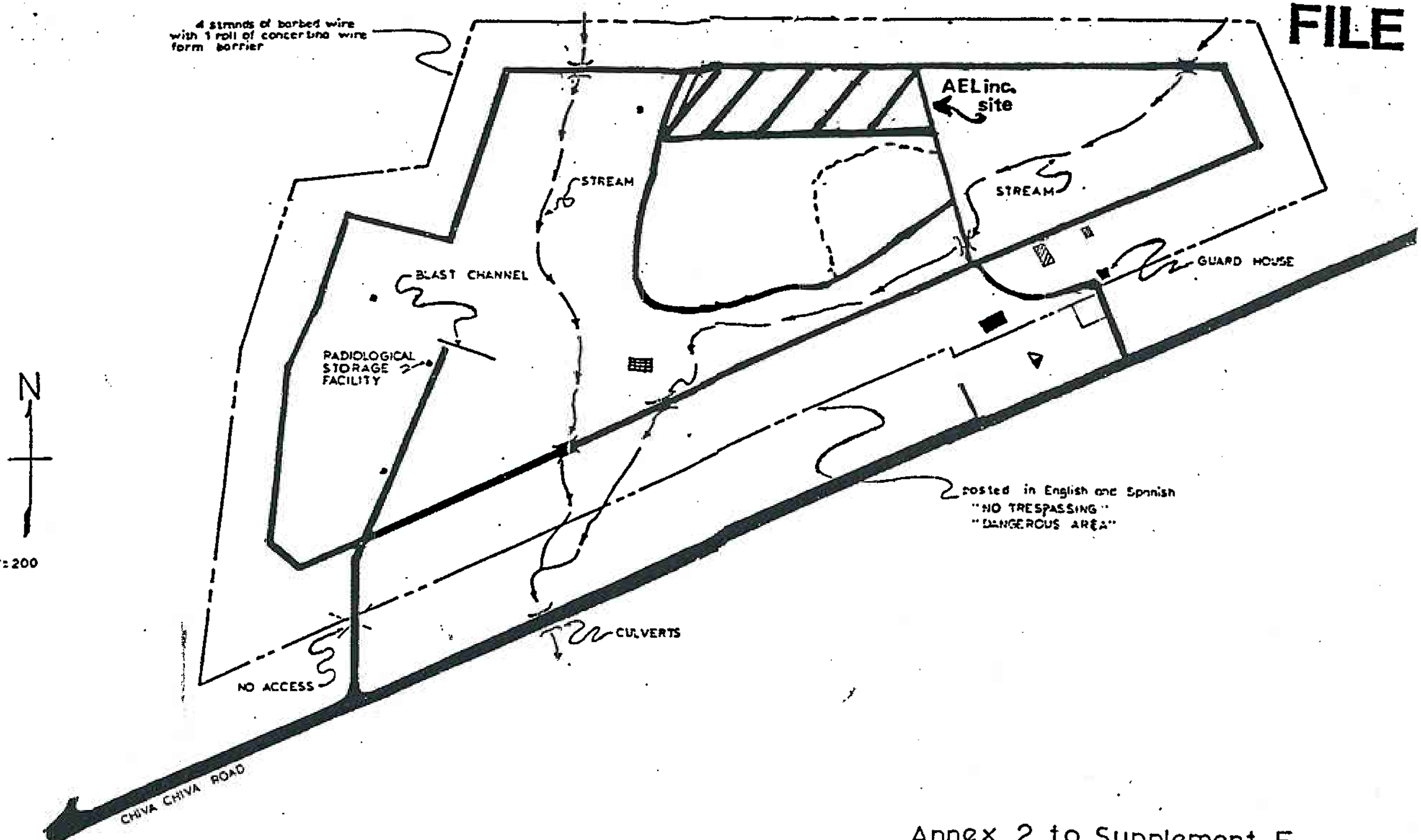
997
79°37'30"
652000m.E.
542000m E.
653
654
545 655
35'00"
656
657
COCOLI 3.1 KM
LOS RIOS 2.2 KM
BALBOA 7 KM.

FIGURE 1

3

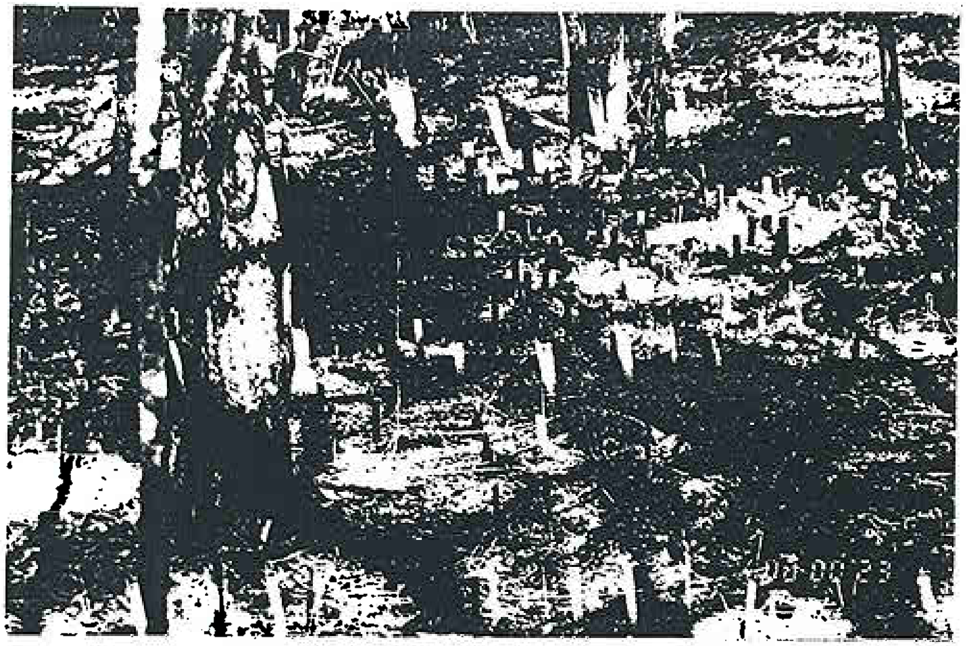
FILE

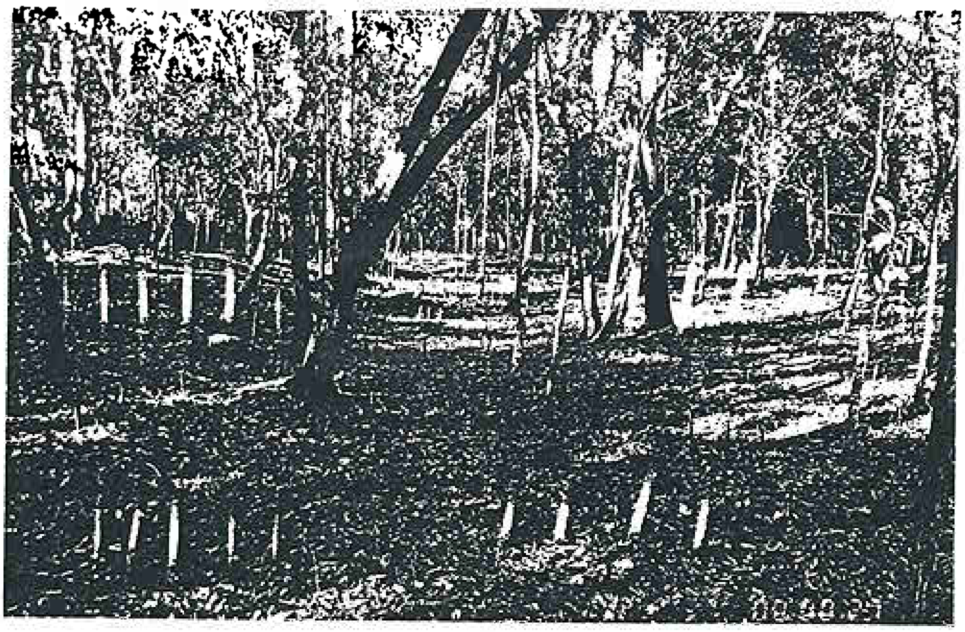


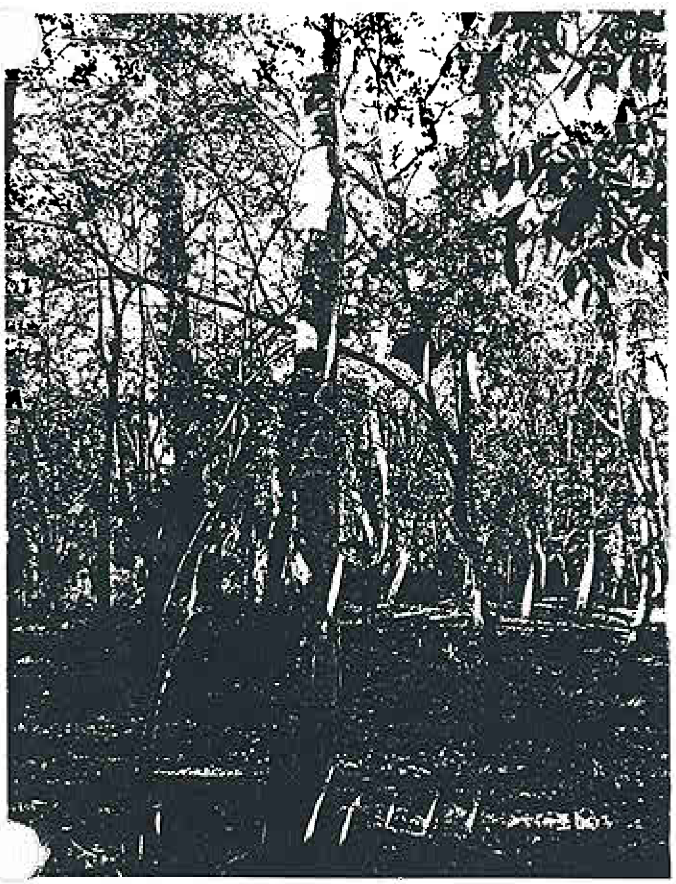
Annex 2 to Supplement E

CHIVA CHIVA TEST FACILITY

[redacted]







Arboreal Nesting Termites

Table 1

Test Protocol for Azobe Evaluation

1. Material: Azobe heartwood, sapwood and mixed.
2. Size: 3/4 x 3/4 x 18-inch stakes and 2 x 4 x 18-inch samples.
3. Quantity: 102 stakes, and a number of 2 x 4 x 18-inch samples
4. Field location: Republic of Panama.
5. Exposure length: 3-5 years, dependent on deterioration.
6. Stake assignments:

<u>air dried - field tested</u>

45	treated-heartwood	15	45	untreated-heartwood	15
	-sapwood	15		-sapwood	15
	-mixed	15		-mixed	15
		45			45

<u>air dried - not field tested</u>

6	treated-heartwood	2	6	untreated-heartwood	2
	-sapwood	2		-sapwood	2
	-mixed	2		-mixed	2
		6			6

7. Sample (2 x 4 x 18) assigments:

<u>air dried - field tested</u>

treated-heartwood	15	untreated-heartwood	15
-sapwood	15	-sapwood	15
-mixed	15	-mixed	15
	45		45