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Forestry and Forest Products
NEWSLETTER

Wood Fibres and Plastics

A.J. Michell

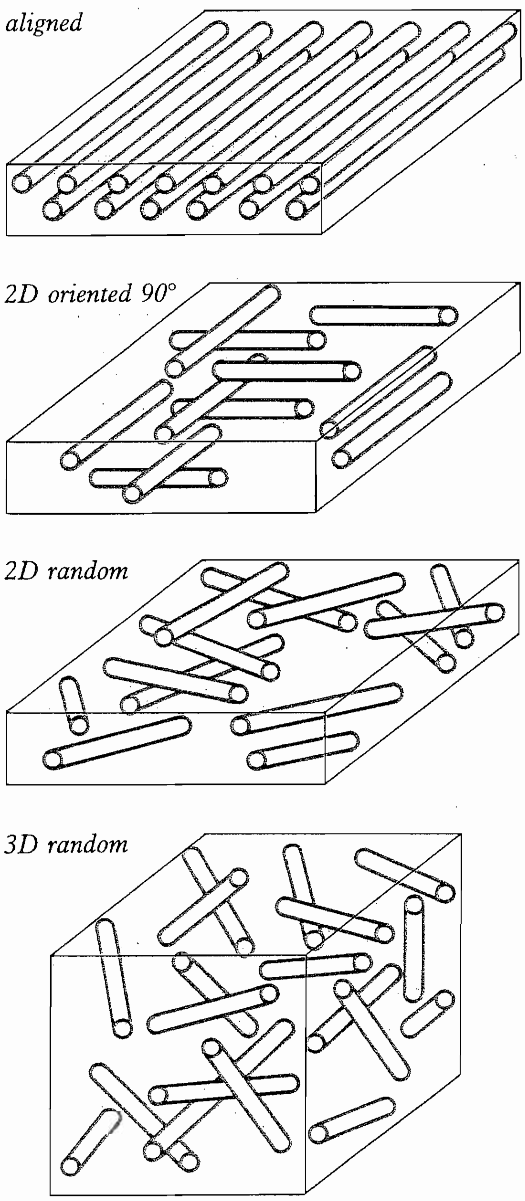

Fig. 1. Fibre distributions in fibrous composites.

Dr A.J. Michell

Introduction

In an earlier edition of the *Forest Products Newsletter* (Vol. 2 No. 1) Dr R.S. Coutts described work in the Division on wood pulp fibre inorganic composites under the heading "Sticks and Stones". In this article we will consider complementary research done on organic polymer composites containing wood pulp fibres.

Composites are materials created by the combination of two or more components — usually a reinforcing agent such as glass and/or a filler such as chalk and a continuous bulk material such as polyester or polypropylene. The fibres can be either short or continuous and can be arranged in any of the ways shown in Figure 1. Each results in a different distribution of properties.

Thus composites are very versatile and can be used to form new materials having balances of properties which

in this issue....

Editor: Susan Lucas
Address for correspondance: CSIRO Division of Forestry and Forest Products, Private Bag 10, Clayton, Vic, 3168
Telephone: (03) 542 2244. Telex: AA 35675. FAX: (03) 543 6613.

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Table1. Properties of organic polymers and of wood pulp fibres

Component	Approx. price.* $/m^3	Tensile modulus (GPa)	Tensile strength (MPa)	Flexural strength (MPa)
Low density polyethylene	1400	0.2	25	125
High density polyethylene	1420	1.2	32	195
Polypropylene	1400	1.2	31	50
Polystyrene	1750	3.1	40	70
PVC (rigid)	2550	2.8	49	95
(plasticised)		0.02	19	n.a.
Polyester	2450	3.5	7	108
Softwood Kraft fibre	780	30	690	n.a
Softwood TMP fibre	405	n.a.	290	n.a.

* $1986

could not be obtained with the separate components.

It is this versatility which has caused fibre-reinforced polymer composites to become one of the most rapidly expanding areas in the field of materials. Hitherto, wood-based fillers, such as wood flour, have captured only a small share of this market compared to mineral or glass fibre reinforcements. The small share is because wood-based fillers have only been used for filling thermosetting polymers — a sector of the market now in relative decline. On the other hand, reinforced thermoplastic polymer composites, which started to compete with metals in 1979, are now achieving a rapidly increasing market share to the point where it has been estimated that plastic composites will replace 65 per cent of other materials in the world by 1995.

Composites and their properties

Bulk materials, often referred to as matrices tend to be weak and easily deformed whereas fibres tend to be strong and resistant to deformation. The properties of composites formed from particular fibres and matrices can be estimated from the properties of the components by the use of Rules of Mixtures. Some properties of organic matrix components and wood pulp fibres and their approximate prices are shown in Table 1.

The tensile modulus is a measure of the resistance of the material to stretching while the tensile and flexural strengths are measures of the strengths of the materials when stretched and bent, respectively.

Since the wood pulp fibres are less expensive than the organic polymers their additions to these polymers would result in reduced materials cost. However, this is feasible only if processing costs are not high and there is no undue deterioration in the component properties. Table 1 shows that adding wood pulp fibres to the matrices can improve both the resistance to deformation and strength of the materials. Toughness, or resistance to fracture, is a factor not included in the table because of difficulties in obtaining appropriate numerical values. However, many organic polymers are very tough and their toughness will be diminished usually by the inclusion of wood pulp fibres.

Composite properties, actually obtained, are often much lower than the properties estimated from the considerations above. This shortfall is due to a combination of factors including poor adhesion at the fibre-matrix interface and attrition of properties during processing.

Comparison of reinforcing fibres

Asbestos and glass are fibres which have been used widely for plastics reinforcement. Their stretching properties are compared with those of wood pulp fibres in Table 2. As you can see the asbestos fibres are the most cost effective for providing resistance to stretching whilst the asbestos and wood pulp fibres are the most cost effective in providing strength.

Fibre-polymer bonding — The two major components of woody fibres are polysaccharides and lignin. Polysaccharides, which are polymers of sugars, are highly oxygenated and have a strong affinity for water. Lignin is an aromatic hydrocarbon polymer which is less oxygenated. It is a general rule of adhesion that like bonds well to like and that dissimilar surfaces do not bond well together. Thus one would not expect a highly oxygenated material such as a polysaccharide to bond well to a non-oxygenated hydrocarbon material such as a polyethylene but a less oxygenated material such as lignin might bond better. In wood pulp-fibres lignin and polysaccharides are organised in layers having differing proportions of each. Thus the composition of the fibre surface and its nature depends on which layer is exposed and on chemical reactions which may have taken place during pulping. X-ray photoelectron spectroscopy provides a means of estimating the relative amounts of the two components at the surface and of the relative proportions of oxygen and carbon atoms in

Table 3. Lignin mass fractions and oxygen-carbon ratios of fibre surfaces

Pulp fibre	Lignin mass ratio	Oxygen/Carbon ratio
Bleached Kraft	0.04	0.55
Chemithermomechanical	0.36	0.52
Thermomechanical	0.37	0.46
Refinermechanical	0.45	0.42
Asplund	0.60	0.38

Table 2. Properties of reinforcing fibres

Fibre	Cost ($/m3)*	Tensile modulus (GPa)	Tensile strength (MPa)	Cost/MN[a] modulus (c)	Cost/MN[a] strength ($)
Glass E	4080	72	1400	5.7	2.9
Asbestos JM5R	1045–1450	164	700	0.6–0.8	1.5–2.1
Softwood Kraft	780	30	690	2.6	1.1
Softwood TMP	405	-	290	-	1.4
Softwood Asplund	185	-	155	-	1.2

* $1986

[a] Based on 1m^3

the surface. Table 3 shows the mass fractions of lignin and the oxygen/carbon ratios obtained by workers, of the CSIRO Division of Forestry and Forest Products and the Division of Coal and Energy Technology, from X-ray photoelectron spectroscopic studies of the surfaces of Pinus radiata fibres separated by different pulping techniques.

The oxygen/carbon ratios show considerable variation and fibres with lignin-containing surfaces might be sufficiently compatible with organic polymers having some oxygen containing groups. However the values obtained do not approach zero as for unoxidised polypropylene. In such cases it is necessary to use a coupling agent to make the dissimilar surfaces of the two components compatible. Such agents contain at least two types of chemical grouping. The first bonds well to the fibre and the second to the organic polymer.

Wood fibres and polymers — Wood pulp fibres can be combined with organic polymers in a number of ways. Two major groups may be distinguished, namely those in which the fibres are first formed into sheets before being combined with the polymers and those formed directly from the fibres and the polymers.

1. Sheets saturated with polymers from organic solvents.
In this case the organic solvents are usually such as do not interfere with the original bonding existing between the fibres in the sheet. Thus the original sheet strength is preserved and the added polymer strengthens it. Decorative laminates are an example of materials made by this type of process. Reels of paper are impregnated with solutions of thermosetting resins and the solvent removed by passing the webs of impregnated paper through a series of ovens. A second stage involves pressing together plies of impregnated paper at elevated temperatures.

2. Sheets impregnated with a polymer emulsion in water.
Some of the fibre-fibre bonds in the sheet are broken by water and may be replaced by fibre-polymer-fibre bonds. Again, the properties obtained are largely those of the sheet modified according to the nature of the added polymer.

A variant on both of the above is the addition of polymers in either aqueous solution or solvent to dry-formed networks of cellulose fibres. Here the effect of the addition of polymer is likely to be more marked

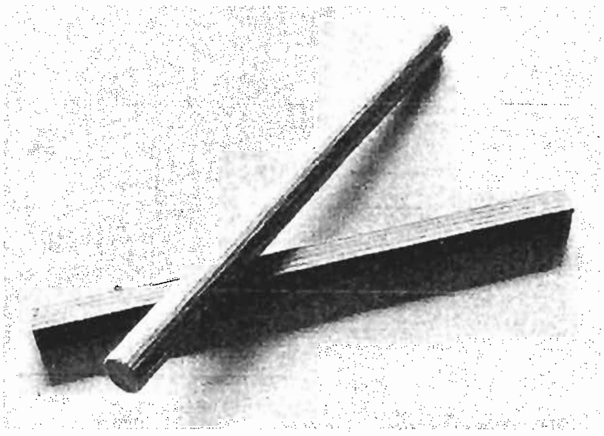

Fig. 3. Composites of pultruded paper, wrapped yarns and polyester.

because the interfibre bonds are weaker and more readily destroyed in dry-formed than in wet-formed sheets. The sheets are also weaker because their fibres have not been subjected to the drying stresses as have those in wet-formed sheets. Products made by this route are normally used in markets requiring properties such as good water absorptivity rather than strength.

3. ***Sheets impregnated with molten polymers.***
Laminates can be prepared by interleaving thermoplastics polymer films and paper sheets off rolls and then hot-pressing.

The method could be practical for producing thin composites but would be too cumbersome for thicker products. A composite produced in this way from paper and low density polyethylene is shown in Figure 2.

The method has proved useful as a laboratory system for examining the effects of various fibre treatments on the properties of composites made by combining fibres with molten thermoplastics.

4. Paper wrapped yarns and polymers.
New composite yarns were developed in the CSIRO Divisions of Forestry and Forest Products and Wool Technology by wrapping paper around multifilament glass or nylon cores. These yarns were then combined with thermosetting polyester resin by drawing the yarns slowly through a bath of the resin into a heated die where the resin was cured. Composites of the type shown in Figure 3 were produced by this means in the laboratory.

They had a number of interesting properties which

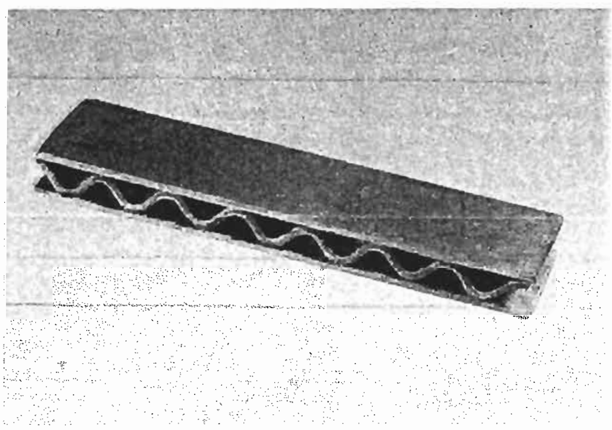

Fig. 2. Composite made from laminated paper and low density polyethylene.

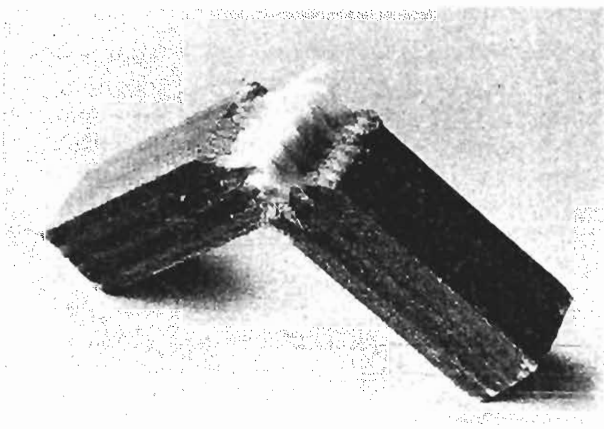

Fig. 4. Fractured pultruded paper, wrapped glass and polyester composite.

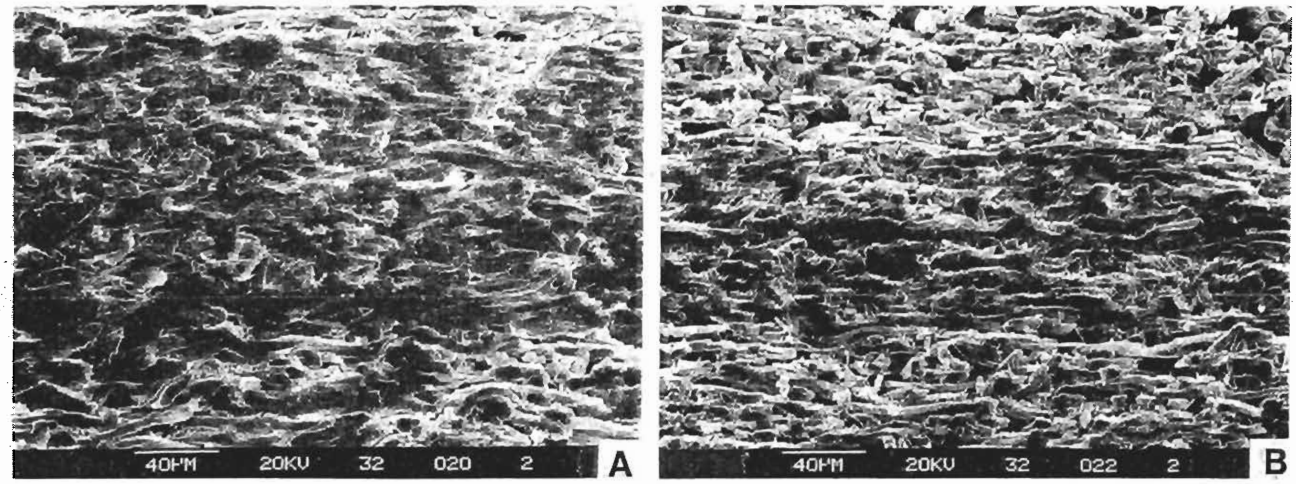

Fig. 5. Cross-sections of laminates of paper and low density polyethylene — (A) Untreated paper; (B) Paper treated with coupling agent.

included specific bending strengths similar to that of mild steel but notch insensitive, and specific impact absorbing energies which increased with sample length and exceeded that of steel or pultruded glass-polyester composites having much higher proportions of glass. Figure 4 shows a sample composite which has been fractured in a bending test but whose two pieces are inseparable until the glass cores have been pulled through them — a highly energy absorbing process.

5. Fibres combined with polymer latices.

The wet-end addition of latex to fibres goes much further than impregnating sheets with aqueous polymer dispersions in establishing fibre-polymer bonds in the final product. The effects are thus much greater and the variables increased since retention of the polymer, its distribution on the fibres and effects on sheet formation and structure become important. The opportunity exists to substitute relatively cheap inorganic filler for some of the pulp fibres in the composite. The composite retains significantly less water resulting in energy saving at the dryer relative to sheets containing higher contents of wood pulp.

6. Fibres combined with molten polymers.

This is the way composites are most commonly produced in the reinforced thermoplastics industry. Industrial composites are produced by mixing the fibres and polymers under conditions of high temperature and shear in mixing equipment such as screw extruders. The fibre/polymer mixes are then cooled and granulated. In the case of successful reinforcement by inorganic fillers such as glass fibre and mica, organosilane coupling agents have been used to make the dissimilar surfaces of the fibres or fillers and polymers compatible. Organosilanes are known not to work well with wood pulp fibres so there is a need for other coupling agents to be discovered. The Division has demonstrated the efficacy of a new coupling agent for wood pulp fibres and molten polymers in such systems.

Some adhesion can be obtained between wood pulp fibres and low molecular weight polyolefins by allowing the surface to become oxidised during melt processing. Photomicrographs of laminates of paper and polyolefins produced in this way showed, however, little penetration of the paper by the polymer. This situation was changed quite markedly when the paper was first coated with a solution of one of a new class of metallo-organic complexes. The effects are shown in Figure 5 where the left picture (A) shows a cross-section of a laminate containing untreated paper and the right (B) shows a cross section of a laminate containing paper treated with the agent.

Clearly the polymer has penetrated the paper treated with the coupling agent to a much greater degree than in the case of the control. The use of such coupling agents in the case of molten polymers has a further advantage in that the agents often act to reduce the viscosity of the molten polymer.

Wood pulp fibres have an innate advantage for melt processing as they are more flexible and less damaged in shear flow than are carbon or glass fibres.

What is the optimum combination?

Is there an optimum way of combining wood pulp fibres and plastics, and, if so, what is it? This would seem to depend, at least to some extent, on the properties desired. If one starts with sheets of paper the result of combining them with polymers will be a product having properties similar to those of the combined sheets but modified to a greater or lesser degree according to the extent to which fibre-fibre bonds have been supplanted by polymer-fibre bonds. If one adds polymers to fibres in aqueous solution and then forms a sheet which can later be heat-treated then one is in the realm of papermaking technology. This form of processing is highly advantageous to and well developed for wood pulp fibres but is necessarily a larger scale operation than melt-processing. Nonetheless, the process has a great advantage in that it is a continuous process and products can be stamped out of the sheets with great rapidity. On the other hand, melt processing of fibres and polymers is in the realm of conventional plastics technology and is operated in smaller units at the production level. However, it suffers from the disadvantages of needing to expose both fibre and polymer to high temperatures to reduce the polymer viscosity and high shear fields to obtain adequate mixing. This can cause degradation in the component properties.

A wide number of choices are available to one seeking to devise new products by combining wood pulp fibres and polymers. The challenge is to discover those combinations which will result in new product opportunities in the market-place for Australian manufacturing industry.

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RELATING FIBRE AND PAPER PROPERTIES

A.W. McKenzie

Mr A. W. McKenzie

Although present forest management policies and procedures are designed to maximise the production of sawlogs, consideration must also be given to the suitability of the wood not converted into sawn timber for other purposes. Pulpwood is probably the most appropriate end use for sawmill residues and thinnings and therefore the likely quality of the pulpwood component of the forest resource becomes an important factor in planning the production forests of the future. Any efforts to improve the quality of our forests must include an assessment of the impact of choice of species or provenance and of silvicultural practise on pulpwood quality.

Unfortunately, pulpwood quality is sometimes a rather nebulous concept. Clearly, anything which provides a cost benefit is desirable, whether such benefit is the result of reduced costs of chips at the digester, reduced processing costs or a higher yield of pulp per tonne of wood. However, the end uses of paper and paperboard are so diverse that it is impossible to provide a generalised description of the properties of a universal "best possible" pulp. The best one can hope for is to identify those pulp and fibre properties which are necessary for a specific product and to use this information to provide guidelines for foresters and tree breeders.

Market pressures can also have a strong influence on the perception of pulp quality and this can be reflected in the fibre requirements. This is particularly evident when all or part of the product from a pulp mill is to be sold on the open market. In an integrated pulp and paper mill, especially one making a limited range of paper types, certain paper properties imparted by the fibre may be quite irrelevant to the quality of the product. Thus, lower levels of these irrelevant properties can be tolerated. However, different criteria apply to a market pulp. Properties which were unimportant in the products from our integrated mill may be quite necessary in a different application and lower levels of such properties could present a genuine problem. Alternatively, the lower property levels may not be any more important to the purchaser of the market pulp, but could nevertheless be siezed upon by the purchaser as a bargaining point in price negotiations. Thus, any wood or fibre characteristics which affect quality assume greater importance when the pulp produced is to be sold as market pulp.

Future developments in the Australian pulp and paper industry are likely to include the establishment of pulp mills which will produce market pulp as some part of their output. For such pulp to be competitive on the world market, it will be necessary to ensure that the quality is satisfactory in all respects. In order to maintain the required quality level, it will be necessary to ensure that the wood supply is satisfactory, both immediately and in the future. This means that the pulp properties required by the market (which may not be the same as those really needed by the purchaser) must be defined. Steps must then be taken to ensure that the wood resource is adequate to provide these properties.

Pulpwood quality and pulp quality

In the *1980 Division of Chemical Technology Research Review*, Balodis emphasised that the assessment of pulpwood quality involves both economic and technical factors. Indeed, it is not uncommon to find that in a woodchip quality appraisal the technical aspects are virtually ignored. It is considered sufficient to establish that the quality of the pulp obtained is adequate for the intended end use. Nevertheless, there are times when more specific information on the quality of pulp obtainable from a given wood resource, and on the wood and fibre properties which influence the quality, would be desirable. The real task is to determine the effect of wood and fibre characteristics on pulp property levels and, in particular, on the combination of properties obtainable under various conditions.

A better understanding of the relationships between fibre and paper properties is not merely of academic interest, but is essential for the systematic assessment and improvement of pulpwood quality. The present method of determining the suitability of a given wood sample as a source of pulp, which involves the preparation of pulp and from this the making and testing of handsheets, is tedious and time consuming. With a clearer understanding of fibre requirements, it should be possible to develop a rapid screening procedure whereby only the most promising samples would need to be subjected to a detailed evaluation. Such a technique would be valuable for developing the plantation forests of the future. It is becoming increasingly evident that many opportunities exist for upgrading the quality of pulpwood from plantations. Selection of new tree species and the improvement of species already in use by the selection of superior provenances offer significant benefits, while the possibility of upgrading any species by genetic manipulation should not be dismissed. Furthermore, changes in forest management practices are occurring with the aim of increasing the productivity of the forest — but without any information on the effects of such practices on pulpwood quality. Despite its urgency, it is

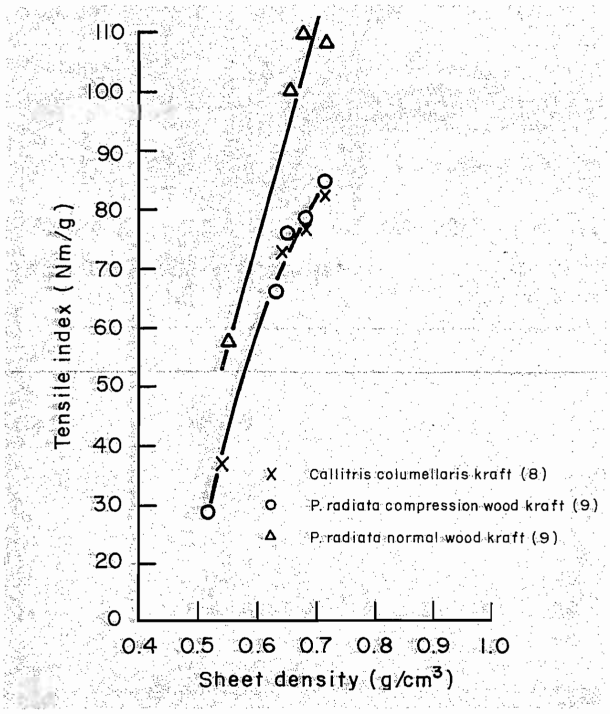

Fig. 1. Effect of fibre strength on sheet density/tensile index relationship.

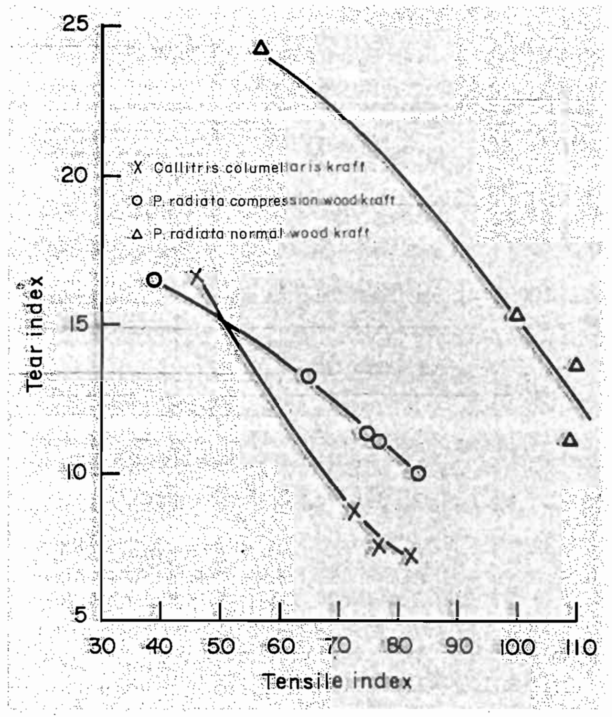

Fig. 2. Effect of fibre strength on tear/tensile curve.

unlikely that resources will be available for this sort of developmental work unless the procedures used can be simplified significantly. A more detailed knowledge of fibre/paper relationships would provide one step in such a simplification.

Within the pulp and paper mill itself, a knowledge of fibre/paper relationships can be used for diagnostic purposes. The effect of changes in the wood supply can be predicted or alternatively changes in product quality can be traced back to their source — either the wood supply or process variables within the mill. Such a system can represent a considerable advance on the problem-solving techniques currently available.

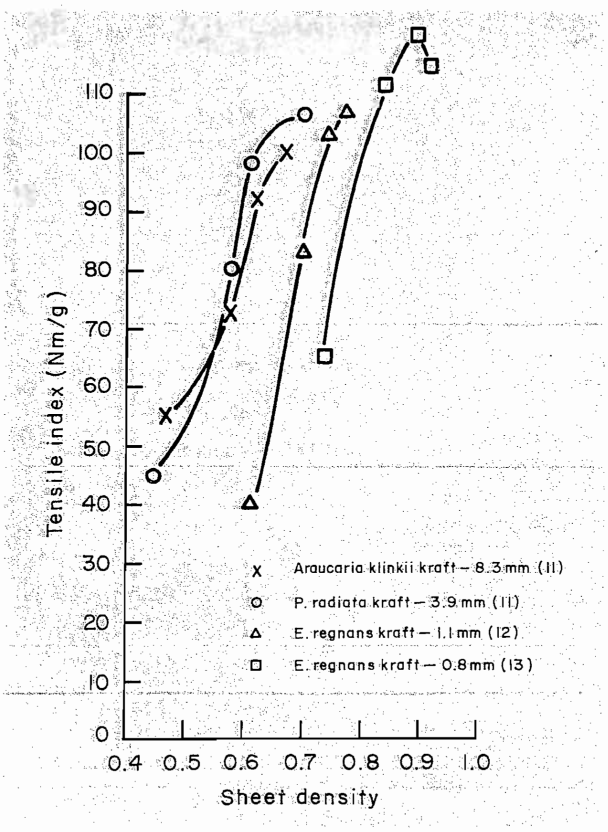

Fig. 3. Fibre length and tensile strength.

Effects of Fibre Properties

Fibre strength

Figures 1 and 2 show the consequences of poor fibre strength arising from natural causes.

The fibre strength of the Callitris kraft, as measured by zero-span tensile strength was some 30 per cent lower than that of a typical pine kraft, while compression wood fibres are known to be considerably weaker than fibres from normal wood. In either case, the weaker fibres are incapable of giving as strong a pulp (at the same sheet density) as their stronger counterparts. This is particularly evident at higher sheet densities, where fibre strength becomes a limiting factor in the development of tensile strength. The pattern shown in Figure 1 is typical of that observed whenever marked fibre weakness occurs, whether the weakness is natural or induced by processing conditions. Acid hydrolysis, as in the sulphite pulping process, or oxidative degradation caused by over-bleaching can both induce such an effect.

Tearing resistance is even more sensitive to fibre strength than is tensile strength. This is clear in Figure 2, which shows that the weaker fibres can not achieve the same level of tear index at a given tensile strength. Indeed, changes in the tear/tensile relationship have been found in cases where the reduction in fibre strength has been insufficient to have any detectable influence on tensile strength.

Fibre length

Maximum tensile strength is obtained when failure occurs as a result of fibre fracture rather than interfibre bond rupture. Fibre length is one of the factors which influences the failure mode. The number of fibre crossings for an individual fibre increases with fibre length. Therefore, other things being equal, the area of each individual contact required to provide a total restraining force large enough to cause fibre fracture is reduced.

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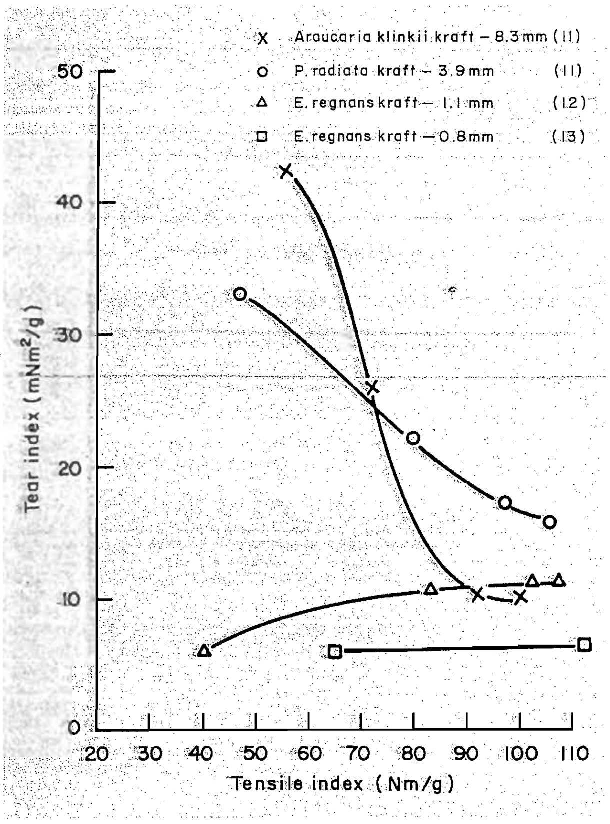

Fig. 4. Fibre length and tearing resistance.

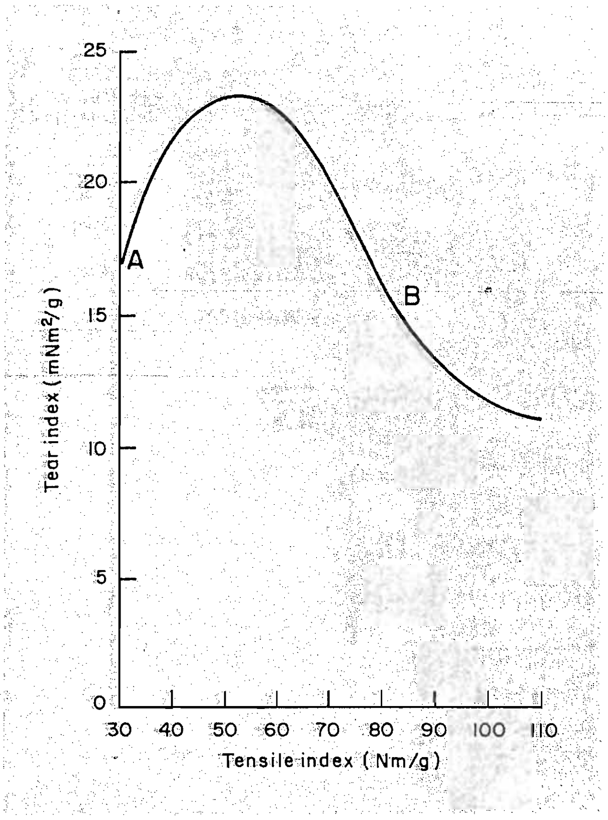

Fig. 5. A hypothetical tear/tensile curve for a "typical" softwood.

From Figure 3, it can be seen that the shorter eucalypt fibres do not necessarily form a weaker paper, but that a higher sheet density — usually an indication of a larger bonded area — is required. There is relatively little difference between the pine and Araucaria pulps, despite the large difference in fibre length.

Figure 4 demonstrates how dependent tear index is on fibre length, and also the difference between softwood and hardwood pulps. Again, the test result depends on the relative proportion of fibres fractured or pulled out of the sheet after bond rupture, with the limiting value being reached when bonding is sufficient to ensure that all fibres are fractured. It must be emphasised that although tear index is quoted in force units, it is actually a measure of work done in tearing the sheet. The work done in breaking fibres is not affected by fibre length. Thus in a well bonded sheet, tear index itself is similar, no matter what the nature of the fibre, unless the fibre is weak or so short that sufficient bonding can not be achieved. The latter situation is apparent in the case of the 0.8 mm eucalypt fibres in Figure 4. The limiting value is usually 10–12 mN m^2/g. The work done in pulling fibres out depends on fibre length and may be greater or less than the work done in breaking them. As a general rule, the work done in pulling out a hardwood fibre is less than that to break the fibre and therefore the more fibres that break, the higher is the tear index. A softwood fibre requires more work to pull it out than to break it and thus tear index decreases to the limiting value.

Fibre cross-section

There is considerable confusion about the relationship between fibre cross-sectional dimensions and paper strength. The strength of each individual fibre is closely related to the cross-sectional area of the cell wall, i.e. to fibre coarseness. To a first approximation, the total bonded area required to ensure fibre fracture rather than bond failure will be the same for all fibres of the same coarseness, no matter whether the fibres are of small diameter with thick walls or of large diameter with thin walls. It is easier to obtain the required bonded area with large diameter, thin-walled fibres. The ratio of surface area to cross-section area is greater and therefore the proportion of the total area which needs to be part of a bond (relative bonded area, RBA) is less. Also the thin-walled fibres have a greater tendency to collapse to ribbon-like structures, giving a higher RBA. It follows that a thin-walled fibre will require less beating to reach the necessary tensile strength.

There is one situation where thin-walled fibres are a definite disadvantage. No matter how long the fibres may be, it is impossible to produce a pulp with high tearing resistance from a thin-walled fibre. Figure 5 shows a hypothetical 'tear-tensile' plot for a softwood pulp. Most pulps of the same fibre length will have the same tear-tensile relationship. Thick-walled fibres will initially be poorly bonded, and the curve in Figure 5, starting at point A, demonstrates the effect of increased bonding brought about by beating. However, thin-walled fibres already have considerable bonding capacity, even in the unbeaten state, because of their inherent ability to collapse. Thus, the unbeaten point on the beating curve could be closer to point B and beating will further decrease the tear index, making it impossible to attain a tear index above 15 mN m^2/g. It has also been noted that the tear index at a given tensile index increases with wood basic density. This has important ramifications for the forester. For example, it has been reported that *Pinus taeda* for the manufacture of sack kraft must have a minimum basic density of 450 kg/m^3 in order to obtain the necessary combination of tear and tensile strength. A rotation age of 30 years was required to obtain this density, but it was estimated that

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by breeding for high density, the rotation age could be reduced to 17 years.

Future Prospects

The current lack of detailed information on wood/fibre/paper property relationship limits progress towards several objectives. A better understanding of these relationships will benefit studies aimed at improving the pulpwood quality of the forest resource and also provide a valuable means of identifying the cause of problems affecting pulp quality.

Immediate attention should be given to the effects of fibre length and fibre length distribution and to those factors which are covered by the general description "cross-sectional dimensions". With this information available, it would be possible to give a direction to plans for the breeding of superior trees and to develop a screening technique which would reduce the work required to identify potentially superior species by culling out those with inadequate fibre properties. Such a technique could also provide a rapid preliminary indication of the potential quality of a pulpwood resource and could be used by a pulp mill to monitor the quality and control the uniformity of the incoming wood supply.

Division of Forestry and Forest Products — NEW PUBLICATIONS

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  June 1990, 125 pp, illust., paperback ISBN 0 643 05058 2 $50
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  1984, 704 pp, illust., paperback ISBN 0 17 006264 3 $79.95
- Trees for Rural Australia
  K. W. Cremer (Ed.)
  Late 1990, 432 pp, illust., hardback ISBN 0 909605 65 3 NYP
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Forestry and Forest Products NEWSLETTER

Levels of Insect Defoliation in Forests: Patterns and Concepts

J. Landsberg and C. Ohmart*

* former scientists of the CSIRO Division of Forestry and Forest Products, Canberra, ACT 2600 Australia. now at CSIRO Division of Wildlife and Ecology, Canberra and Scientific Methods Inc. California USA

in this issue....

Are some forest types more prone to defoliation by insects than others?

Recent research has attempted to answer this question empirically, by comparing levels of defoliation recorded in a range of forest types, and theoretically, by making predictions from current herbivory theory.

Despite a proliferation of information on forest herbivory [1–3], comparable data about defoliation levels in different forest types are still relatively few. This partly explains why recent attempts to compare levels of insect defoliation in Eucalyptus forests in Australia with levels in temperate forests in North America and Europe have led to controversy [4–6], however a compilation of the relevant empirical data cited in support of this claim and comparable data from other studies indicates otherwise (see Table 1).

Both temporal and spatial variability are illustrated by the extremes of the range of background levels tabulated, but neither very low nor very high levels are uniquely associated with any particular forest type.

Table 1 shows that the herbivory levels reported in most studies are surprisingly uniform. The bulk of the values of proportional leaf area missing fall between 3% and 17%, with a mean value of 8.8%±5.0% (n=38). A

TABLE 1 Levels of defoliation in temperate Australian and Euro-American forests [a]

	Percentage of leaf area missing								
Forest type	0-3%	3-5%	5-7%	7-9%	9-11%	11-13%	13-15%	15-17%	>17%
North America and Europe									
Mesophytic (Decid.ang.)[b]	7,8,9,9	10,11,5[c]	10,5[c],5[c] 5[c],5[c],12 13,14	7,8,5[c],5[c] 5[c],14,14,14 15,15	11,14,15	15	14,16	14	14,14,17,17
Xeric (Decid. ang.)				5[c]		5[c],5[c]			
Australia									
Mesophytic (Evergreen euc.)[b]		18,18,5[c]				5[c]			4,5[c]
Xeric (Evergreen euc.)						4,4	4		

Note: Numbers refer to references at the end of the article
a Compiled from studies in which the percentage of leaf area missing from mature leaves was assessed during periods in which herbivore activity was perceived to be normal (i.e. no herbivore species appeared to be in outbreak phase). Multiple citations refer to different locations and/or years recorded in the same study. Where more than one value per location per year was measured in a study. Only the most comparable value is tabulated (e.g. middle or upper canopy, end of growing season, no experimental treatment).
b Decid. ang.— forest dominated by deciduous angiosperms; Evergreen euc.— forest dominated by evergreen eucalypts.
c For original citations, see Table 1 in Ohmart 1984.

Editor: Susan Lucas
Address for correspondance: CSIRO Division of Forestry and Forest Products, Private Bag 10, Clayton, Vic, 3168
Telephone: (03) 542 2244. Telex: AA 35675. FAX: (03) 543 6613. ISSN 1032-4232

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TABLE 2 Levels of defoliation in rain forests and mangrove forests *

	Percentage of leaf area missing								
Forest type	**0-3%**	**3-5%**	**5-7%**	**7-9%**	**9-11%**	**11-13%**	**13-15%**	**15-17%**	**>17%**
Tropical rain forest			37,38,39 40	39,39	41,42	39,43,43	40,43		
Subtropical rain forest				44					
Temperate rain forest			44			44			
Tropical mangrove		45	45,46	46,46		45	45,45		
Temperate mangrove	45		45						

* Data presented as in Table 1.

similar compilation of data collected from rain forests and mangrove forests (Table 2), the only other extensively studied systems, revealed a similar uniformity (ranging from 3% to 15% with a mean value of 8.8%±3.5%).

Methodological limitations

Recent research[19,20] has highlighted problems of precision and ecological interpretation of proportional leaf area missing as a measure of herbivory. Practical problems of access to forest canopies as illustrated in Figure 1 restrict many forest herbivory studies to those leaves that can be collected from the ground.

Many herbivores preferentially feed on young leaves[21] (Figure 2). Because of subsequent loss, expansion or distortion of damaged young leaves, the percentage of leaf area missing from mature leaves may not provide accurate estimates of the percentage of leaf area consumed from different tree species[19].

In addition, although the damage caused by phloem-feeding and tip-feeding insects can also be substantial, it has seldom been quantified; even where measurements have been made, they are not usually directly comparable to absolute loss of leaf area[8].

Until a greater number of studies addressing such methodological limitations are undertaken, comparisons of empirical defoliation levels are likely to yield only broad generalisations about patterns of herbivory.

Fig. 1. Access to forest canopies imposes methodological limitations on studies of harbivory.

Predictions from herbivory theory: earlier models

The suitability of plants as food is central to much of the current theory regarding patterns of herbivory[2,3], although early models were more concerned with exploring patterns in the defensive characteristics of plants, rather than in levels of defoliation. Plants were thought to possess different defensive traits depending on their apparency[22] or their predictability[23], thus an assumption that plants can only afford to lose a certain amount of leaf area to herbivores and that background defoliation levels may therefore be rather uniform appears to be implicit in this approach.

This assumption was explored more explicitly in the cost-benefit approach to analysing allocation of resources by plants[24]; if investment in plant defences largely reflects a trade-off between plant growth and potential losses to herbivores, the net result should be a fairly uniform level of defoliation among many plant species. However, none of these models addressed the question of how much leaf area plants can afford to lose, or whether this may vary for different plants and different environments.

Recent theoretical developments: the resource-availability model

The resource-availability model of plant anti-herbivore defence[25,26] predicts that levels of herbivory will vary in environments in which resources are differentially

Fig. 2. Insect herbivores and food plants — Parposis aegrota, *a chrysomelid beetle, on* Eucalyptus nitens.

available. According to this model, levels of herbivory are likely to be relatively high on fast-growing plants in resource-rich habitats and to be relatively low on slow-growing well defended plants in resource-limited habitats. Thus, plant traits associated with resource-limited environments, such as sclerophylly and ever-greenness, are also likely to be associated with relatively low levels of herbivory. However, many aspects of the biology and ecology of eucalypts are in poor agreement with this model. Australian soils are, by world standards, generally infertile[29], and the evergreenness and sclerophylly that typify Australia's woody flora are typical of plants adapted to nutrient-poor and relatively xeric environments. Therefore, according to the resource-availability model, selection in eucalypts should favour characteristics associated with slow growth rates and high levels of anti-herbivore defense, since they have evolved in an environment that is generally poor in resources; consequently, levels of herbivory on eucalypts should generally be low. Eucalypt foliage certainly does contain high levels of putative defensive compounds such as tannins and volatile oils[30]. However, many species of eucalypts also show many of the characteristics that the model associates with resource-rich habitats; they have high maximum rates of growth, they respond rapidly to pulses in resources, they appear to have a high tolerance of defoliation, and, at least in some situations, they sustain high levels of defoliation by insects[31] (Table 1).

Many of these characteristics are related to the variety of ways in which eucalypts can produce leafy shoots. Following severe or repeated defoliation they are able to produce abundant leaf growth from numerous epicormic buds in the bark of branches and stems. This coppice foliage is juvenile in form and often appears to be more heavily damaged by insects than adult-form foliage[4,31].

The resource-regulation model and repeated exploitation of coppice foliage

This pattern of herbivore response to coppice regrowth is not restricted to eucalypts. For example, Webb and Moran[32] reported that population levels of a psyllid were very much higher on the coppice foliage of pruned acacia trees in southern Africa than on normal trees, and Washburn and Cornell[33] suggested that local extinctions of a cynipid gall wasp were partly caused by maturation of 'sucker' growth on their host trees. Craig *et al*,[34] found that not only were shoots of the arroyo willow, *Salix lasiolepis*, much more susceptible to infestation by a stem-galling sawfly during their juvenile growth stage, but that heavy galling by the sawfly maintained the host tree in this highly susceptible juvenile stage. They coined the term 'resource-regulation' to describe this pattern, whereby a herbivore maintains or increases the availability of high-quality resources that favour subsequent generations of the same herbivore species on the same individual plant.

Chronic defoliation of woodland eucalypts in pastoral regions of Australia follows a similar pattern, except that a variable suite of locally common species of insects maintains relatively high defoliation of epicormic foliage, thereby 'repeatedly exploiting'[31] rather than 'regulating' a favourable food resource.

The resource-availability model predicts that, in resource-rich environments, selective pressures favour plant species with strong competitive characteristics. However, selection may also favour plants with strong competitive characteristics (such as rapid coppicing) in normally resource-poor environments subject to irregular sub-lethal disturbances that provide pulses of resources. For example, arroyo willows grow in flood-prone canyons[34] and fire has been a dominant selective force in the evolution of eucalypts in Australia[35]. Following both flash-flooding and fire, plants that can rapidly replace lost and damaged stems and foliage by coppicing are likely to be advantaged in the competitive post-disturbance environment. In the examples reviewed, the selective pressure is likely to be very strong because the disturbances result in a pulse of increased availability of resources in environments that are otherwise resource-limited[34,35].

The role of insect-plant interactions in explaining patterns of defoliation

Two major assumptions are central to much of the current theory relating to herbivory patterns; the assumption that damage caused by herbivorous insects is a dominant selective influence on plant evolution, and the counter assumption that food quality has a dominant influence on the abundance of insects and the damage they cause. However, in the development of current theory the fundamental asymmetry in this interaction has sometimes been overlooked: plants generally have much more impact on the dynamics of insect herbivores than the herbivores have on the plants[2]. Coevolutionary models such as resource availability may not be appropriate in very asymetrical systems where strong abiotic selective influences favour plant characteristics that are only inadvertently related to herbivory, in that they may be susceptible to opportunistic exploitation by insect herbivores. Rapid coppicing may be one such plant characteristic[34].

There have also been recent calls for a re-emphasis on the roles of natural enemies and weather in herbivore ecology, to balance a perceived current bias towards food quality as the major determinant of patterns of herbivory[36]. For example in one study of leaf miners on deciduous and evergreen oaks[28], predation, parasitism and abiotic factors appeared to overwhelm any influence that food quality may have had in determining the relative abundance of the insects.

Are some forest types more prone to defoliation than others?

Our review of the available data suggests that at the ecosystem level the answer may be a qualified no: levels of background defoliation, measured as the proportion of leaf area missing from sampled foliage, appear to be rather uniform, tending toward 9%. However, recent research has indicated problems with the more traditional methods of measuring defoliation, and comparable data controlling for methodological variation are too few to determine how universal any generalisations may be. In addition, apparent uniformity in defoliation at ecosystem level masks considerable temporal and spatial variation within forest communities, populations and individuals. No single theory of herbivory is consistent with all the patterns in this variation.

Much of the current theory about patterns of herbivory assumes that observed levels of defoliation predominantly reflect the outcome of narrow insect-plant coevolution. However, this assumption may not be appropriate for systems in which the evolutionary interactions are one-sided, or in which patterns of herbivore distribution are ecologically labile. A better understanding of patterns of defoliation in forests will be achieved by further testing of the insect-plant interaction models, and hypotheses derived from them, in a context broadened to include the often neglected challenges posed by climate and predation.

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Conferences ...

All Australian Timber Congress
11–14 November 1990
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Following the enforced cancellation of the Congress last year due to the pilots' strike, these new dates have been set for the All Australian Timber Congress. Further information on the Congress can be obtained by contacting Cam Kneen tel: (09) 322 2088 or Erica Evans tel: (09) 332 5980.

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Sludges, Spots, Stickies...

A.J. Michell

Unwanted solid residues are the bane of many industrial processes. Examples which come readily to mind in the forest products industry include: sludges in preservation liquors or in adhesives, spots in paperboards from contaminants in recycled pulps, deposits on papermaking machinery and in paper from insolubilised extraneous wood components, deposits on wood surfaces from the migration of extractives. The first step in overcoming these problems is often to determine the nature of the deposit.

One technique which is very useful for this is infrared spectroscopy since a substance's infrared spectrum has the same distinctiveness as a fingerprint. Moreover, unlike many other techniques, it works well with insoluble solid samples. Where the deposit is a mixture of substances the resultant spectrum will be the sum of the spectra of the individual components. The usefulness of the spectrum in enabling the components to be identified will depend on the degree of overlap of bands in the component spectra.

Infrared spectroscopy is not a new technique but its previous major disadvantage, its lack of sensitivity, which now been overcome by the combined application of interferometry and Fourier transform techniques using digital computers.

The purpose of this short article is to show the method's wide application through examples of work taken from recent projects in our laboratory.

Where the solid can be separated the best spectrum is usually obtained by mixing with finely powdered potassium bromide and then pressing the mix into an optically clear disk. If the solid cannot easily be removed from a surface then it can be studied *in situ* by using reflectance techniques such as diffuse reflectance or internal reflectance. These techniques sometimes yield distorted spectra but usually still give sufficient information to identify the solid.

Examples from wood preservation

Green sludges occur in aged and used preservative compositions of the copper-chrome-arsenic type. Their formation is of interest because they represent material inactivated in the preservation process and a problem for disposal. The infrared spectra of sludges from the Tanalith CP treatment of A.–pine and B–hardwoods are compared in Figure 1. The spectra are very similar showing that the sludging is independent of the type of wood being treated. The observed frequencies do not correspond with those expected for ions of any of the components, potassium dichromate, copper sulphate or arsenic pentoxide. The 845cm^{-1} band probably arises, from some sort of Cr–O linkage but not as found in either $(Cr_2O_7)^=$ or $(CrO_4)^=$.

During exposure trials of radiata pine treated with a petroleum oil-based CCA emulsion some white and green deposits were found to develop on the surface. The spectra of these deposits are shown in Figures 2A and 2B respectively. They are clearly different, with the spectrum of the green deposit showing weaker bands near 1694 and 1240cm^{-1} and stronger bands near 1060cm^{-1}. The spectrum of a resin acid, abietic acid is shown in Figure 2C. The strong similarity between the spectra in Figures 2B and 2C suggest that the white deposit is of the resin acid type. The greater intensity of bands near 2925 and 2870cm^{-1} in Figure 2B probably arises from a little of the petroleum oil being absorbed into the deposit. The green deposit then consists of some resin acid, some wood substance and some oil.

Glueing and glues

Problems were experienced with glueing veneers from a high density eucalypt species. It was noted that a deposit seemed to be always present on the surface of the veneer before glueing. The infrared spectrum of this deposit was obtained by using a diffuse reflection technique and is shown in Figure 3A. The veneer was then extracted with hot water, the water was removed and a spectrum obtained of the dry powder (Figure 3B). The spectra are very similar but not identical. However, it is probable that the differences arise from mixed

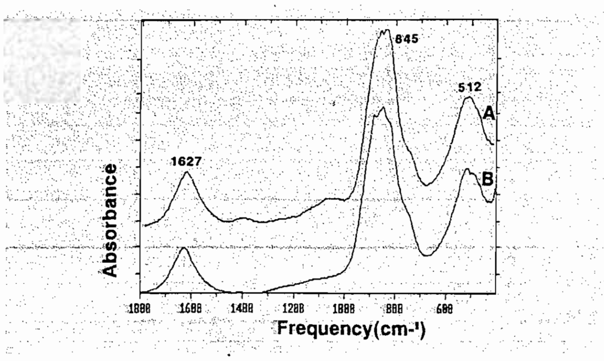

Fig. 1. FTIR transmission spectra of sludges from the Tanalith CP treatment of A. Pine; B. Hardwoods

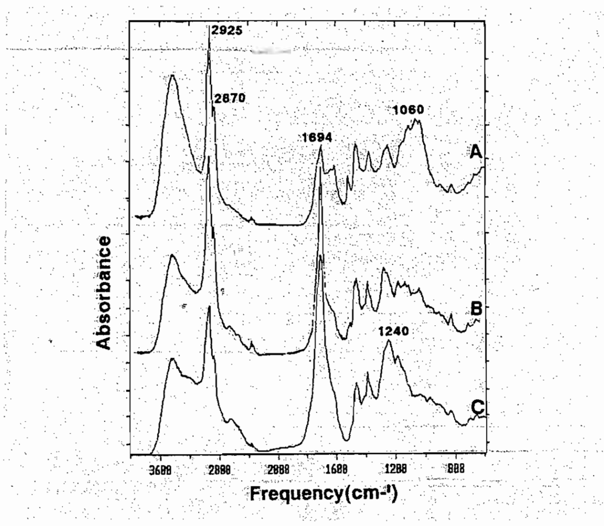

Fig. 2. FTIR transmission spectra of A. Green deposit on preserved pine; B. White deposit on preserved pine; C. Resin acid (abietic)

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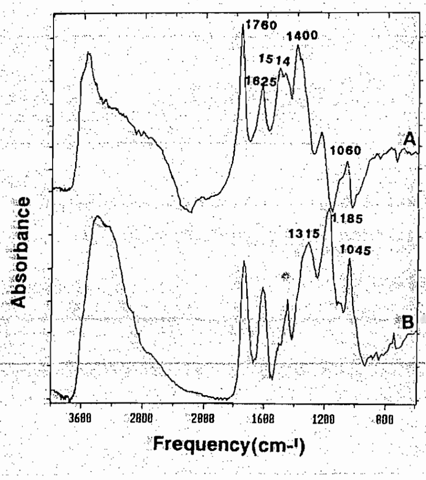

Fig. 3 A. Diffuse reflectance IR spectrum of deposit on surface of high density eucalypt veneer B. FTIR transmission spectrum of hot water extract of the veneer.

modes of reflectance off the extractive containing wood surface. The conclusion was that the substance on the surface of the veneer was the same chemically as the hot water extractives and of such a nature as to interfere with the glueing chemistry.

Another sludge problem occurred during the preparation of foamed wattle tannin urea formaldehyde resin with Teric® X10. The sludge was gummy in nature and insoluble in water. The relevant spectra are shown in Figure 4. The spectra of the resin sludge, wattle tannin and polyethylene oxide were obtained in potassium bromide disks and of the Teric X10 as a thin film. The Teric X10 is composed of an n-octylphenol moiety and an ethoxylate moiety modelled here by polyethylene oxide. Bands in the spectrum of the sludge appear to be a sum of the bands in the spectra of the tannin and the Teric. Bands near 1512 and 1246cm^{-1} from the n-octylphenol moiety of the Teric are present in the spectrum of the sludge as are bands near 1352, 951 and 833cm^{-1} from the ethoxylate moiety. This shows that the sludge formed included the Teric surfactant as a whole rather than being the result of a breakdown of the Teric. The probable explanation of the sludging is that the hydroxyl groups of the tannin have entered into a strong association with the oxygens of the ethoxylate and micelles have formed with the n-octyl chains directed outwards as a hydrophobic layer.

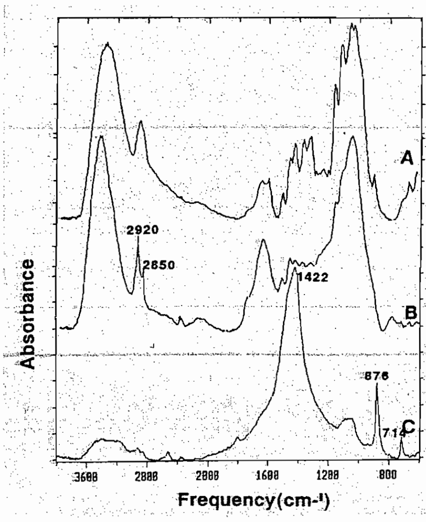

Fig. 5 FTIR transmission spectra of A. Kraft pulp B. Resin filled vessel elements from kraft pulp of tropical hardwoods. C. Crystals ex depressions in kraft paper from tropical hardwoods.

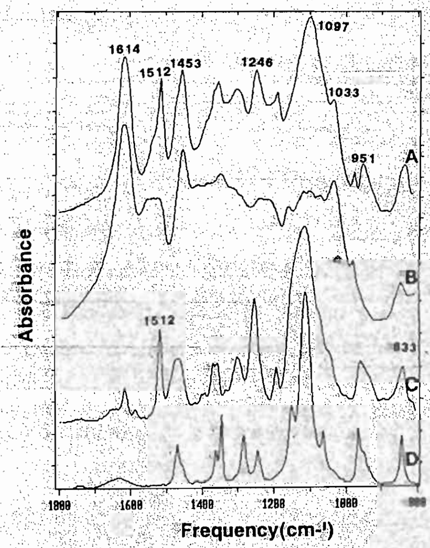

Fig. 4 FTIR transmission spectra of A. Sludge from foamed wattle tannin B. Wattle tannin C. Teric X10. D. Polyethylene glycol.

Paper and paperboard

Spots can often occur in paper and paperboard produced from exotic wood species or recycled furnishes.

In papers made from kraft pulps of certain tropical woods a number of dark spots have been found. Some of these were resin-filled vessels or ray cells. Another surface defect which was evident on some sheets was that of granular deposits located in depressions throughout the sheet. These could be seen under the microscope to be vessels filled with crystals. The crystals could be removed from the sheets with a needle and made into micro potassium bromide disks. The spectra of kraft pulp, resin-filled vessels and vessels filled with

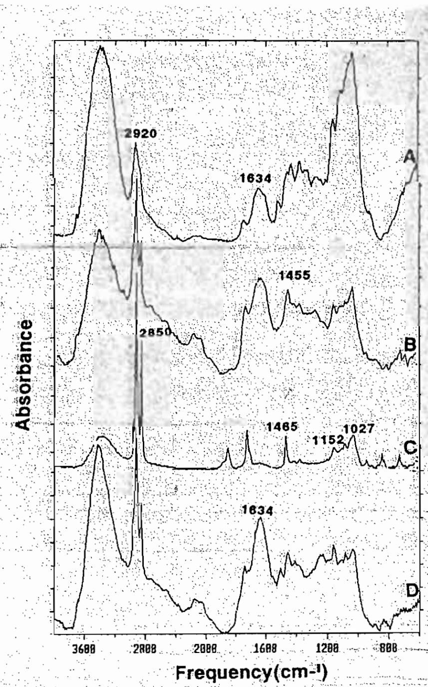

Fig. 6 FTIR transmission spectra of A. Paperboard B. Streaks on paperboard C. Alkyl ketene dimer D. White specks on paperboard.

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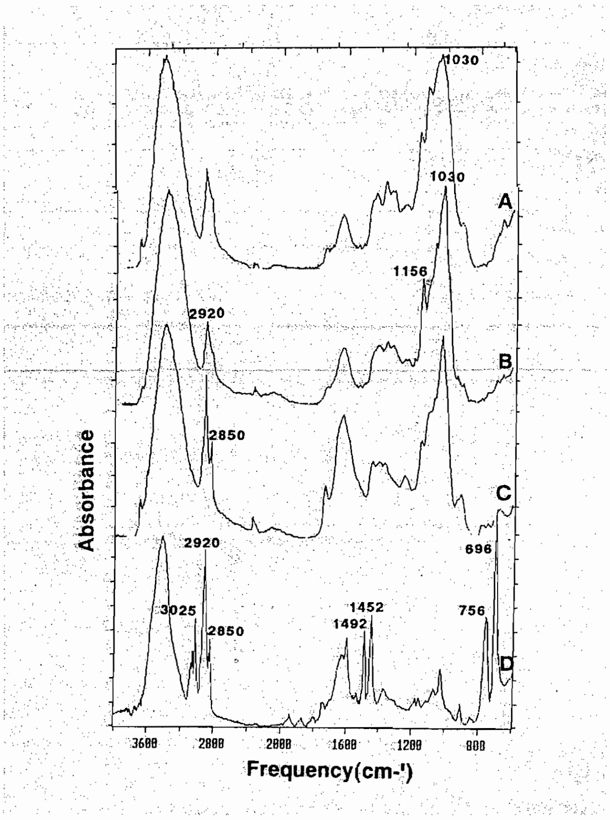

Fig. 7 FTIR transmission spectra of A. Pulp moulding B. Red spots on pulp moulding C. White flecks on pulp moulding D. Polystyrene foam packaging.

crystals are shown in Figure 5. The spectra are quite distinct with the bands at 1422, 876 and 714cm^{-1} identifying the crystals as calcium carbonate.

Paperboards made from recycled furnishes may also contain streaks or spots from extraneous components which have evaded the cleaning system or precipitated in the white water. The spectra of two examples are shown in Figures 6B and 6D. These samples were separated from the board under a microscope. Figure 6A shows the spectrum of the recycled pulp and Figure 6C the spectrum of alkylketene dimer with a little starch which is used in the system as a sizing agent. The spectrum (Figure 6B) of the streaks show strong absorptions at 2920 and 2850cm^{-1} and at 1455, 1152 and 1033cm^{-1}. These are similar to absorptions in the spectrum of Aquapel (Figure 6C) with the absorptions near 1152 and 1033cm^{-1} arising from starch. There is also a broadness in the region 2600–2800cm^{-1} of the spectra in both Figures 6B and 6D indicating the presence of carboxyl groups. Indeed the spectrum (Figure 6D) of the white spots is fairly similar to that of the streaks (Figure 6B) and unlike the spectrum of styrene foam (Figure 7D) which the white spots resemble visually.

In Figure 7 are shown the spectra of a pulp moulding (Figure 7A) and of some spots in it removed by dissection. Also shown is the spectrum of a styrene based foam — a possible contaminant. The region 1156–1030cm^{-1} of the spectrum in Figure 7B suggests that this deposit which was dyed red was largely starch. The spectrum of the white flecks (Figure 7C) also seems to be polysaccharidic in nature and is quite unlike the spectrum of styrene-based foam packaging (Figure 7D).

Conclusions

Infrared spectroscopy is capable of giving useful information about the nature of a wide variety of unwanted solid deposits occurring in forest product processing. The Division is well equipped in this area and willing to analyse industry samples by arrangement.

Drying Rates of Refractory Hardwoods

J. Ilic and A. Rozsa

Introduction

Drying rate information on regrowth of new species is often requested by industry and to date, no reliable data is at hand to provide the answers.

This report proposes a methodology for collecting information on the drying rates of various commercial timber species. It is hoped that the work will establish the effect of several important variables on drying rates and lead to the formation of a national database. The database will form a reference for the nature of the changing resource over time. It will also enable the collection of data for the purpose of formulating an analytical model for estimating drying times to determine the economics of existing dryers and new systems of dryers.

To provide an effective data base we need a relatively simple reproducible standard procedure that could be carried out in any forest products laboratory on larger mill with minimum investment in time and equipment. To make it worthwhile the information must be standardised nationwide; the problems particularly for regrowth species and short rotation crops seem to be common. The project should be looked on as a long term longitudinal study however the results will also produce short term benefits. The method used needs to be simple, easily reproduced and be of a scale to reflect "real world" drying.

Method

It is proposed to make an initial investigation of the parameters that affect drying rate and determine the the sampling strategy and effect of major variables to minimise the labour component. Some data on drying rates of hardwoods has been collated from experimental work of the former Division of Forest Products and will be used as a preliminary indicator of important factors to be assessed. As there is already an urgent need to establish some drying figures for Victorian regrowth ash species, it is proposed to declare some interim guidelines for a standardised procedure, commence drying specimens and invite comment from interested parties for any proposed modification to the standard procedure.

Main parameters for investigation:

1. Effect of board thickness
2. Effect of sample length

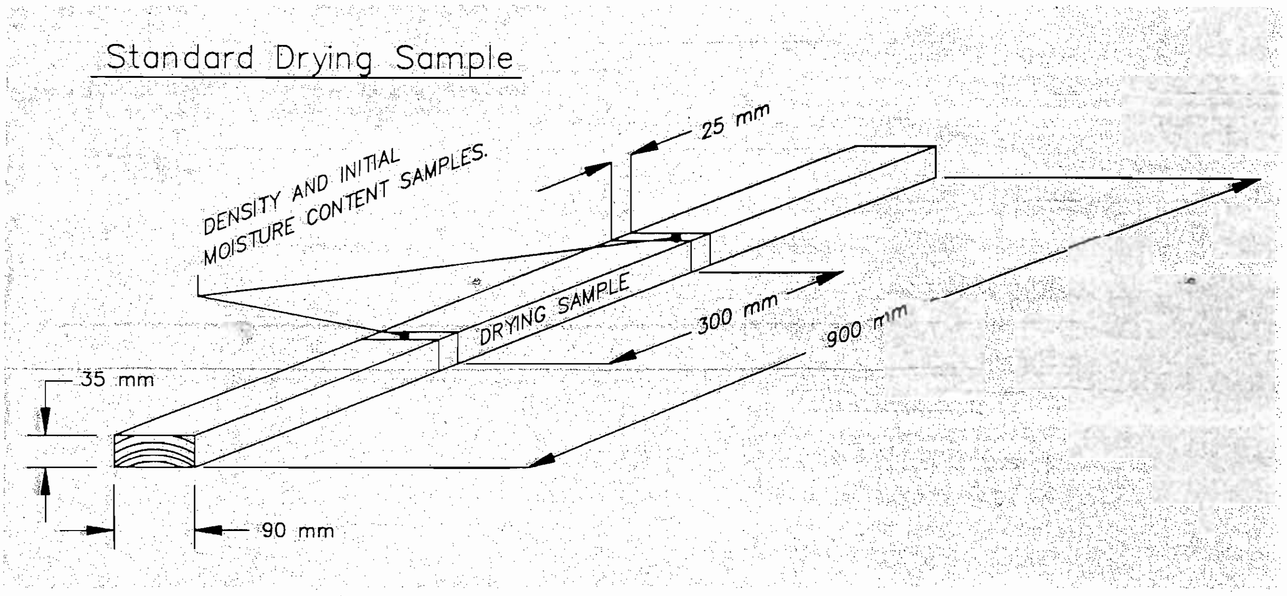

Fig. 1. Typical wood sample used for drying rate studies.

3. Effect of board width
4. Effect of proportions of different face (backsawn and quartersawn)
5. Effect of sloping grain
6. The magnitude of shrinkage, collapse and recovery

Other parameters for investigation:

1. Effect of permeability (gaseous axial and transverse)
2. Effects of pretreatment
   a) cold room storage
   b) prefreezing
   c) presteaming
   d) predressing
   e) other treatments

Proposed interim standard conditions and measurements:

1. *Standard Sample* (see Figure 1)
   a) as green as possible cut to 300mm length from minimum 900mm delivered sample.
   b) dressed to 90mm x 35 Backsawn
   c) ends sealed with silicone/foil
2. *Drying Conditions*
   a) 40°C dry bulb
   b) 35°C wet bulb
   c) air speed 1.5 $m.sec^{-1}$ (19mm stickers at ends)
3. *Parameters for measurement*
   a) average initial moisture content
   b) basic density (from ends)
   c) cross section (L x W) in centre of sample (green)
   d) loss in weight each 24 hours (± 0.5g) for the first 5 days. Then approximately every second day for 2 weeks. Then once weekly to e.m.c.
   e) total recoverable collapse and shrinkage by measuring: cross-section before and after 4hr reconditioning when the wood has reached e.m.c.
   f) incidence of internal checks (measured with image processor).

Discussion

There is an urgent need to collect drying rate information for many of the Australian hardwood timber species in use today. In many parts of Australia timber species that have previously only been air dried and have been used for relatively low value applications are now being dried by different drying techniques. Some of these include air and kiln drying, or drying from green in different types of kilns. Air drying is a protracted process, but its capital costs are low. On the other hand, inventory costs and degrade of large volumes of high cost timber stored in uncontrolled conditions, has led to the use of at least some control of the environment in many drying situations. The use of drying sheds, predryers, dehumidifiers and various designs of heat transfer kilns, has meant a large increase in capital investments in drying equipment, and a limitation on the volume of timber that can be put through the drying system without increasing capacity. Any information that gives more precision to the length of time it takes to dry timber, especially where there has been limited experience with that particular resource, or the conversion parameters of the wood are changing, (such as the increasing proportion of backsawn boards from small logs) will enable the optimisation of turnover times of kiln charges and help in the design of best drying capacity for a given throughput mix.

The proposed work has value to the entire industry as a reference to suggest guidelines for drying. The standard procedures suggested here are open for discussion, and correspondence with the authors is invited from interested parties. We would be particularly interested in any other body willing to carry out some of this work on their own indigineous species, or who would like to arrange for their samples to be tested.

Future work planned along these lines would also include investigating the effect of position in the tree and source of material on drying rate using the standardised procedure. The next step will consider the effects of temperature, relative humidity and air velocity. Ultimately when all these effects are understood, the assessment of varying the drying conditions can be ascertained.

It is hoped that this approach will in the short term provide a comparative analytical method for predicting how quickly wood can be dried, and in the longer term combined with other basic research lead to a predictive model which will provide a rapid method of estimating optimal drying parameters which are currently relatively poorly understood.