New Zealand Journal of Forestry Science Vol. 10 No. 3 (1980): 558-76

EFFECTS OF WOOD AGE ON THE PAPERMAKING PROPERTIES OF RADIATA PINE KRAFT PULPS

J. M. UPRICHARD

Forest Research Institute, New Zealand Forest Service, Private Bag, Rotorua, New Zealand

The effects of wood age (internodes from apex, growth ring number from the pith) on the papermaking properties of kraft pulp from radiata pine are discussed.

In 40-year-old trees the tear strength of pulps from 30th internode material (that which contains 30 growth rings) was almost twice that of 10th internode material. Similarly in 18-year-old thinnings, the 15th internode pulps had higher tear index than the pulps from 10th or 5th internodes. Pulps from all types of material were readily beaten to good burst and tensile strength, the ease of beating decreasing with increase in wood age.

In studies of 5-ring-group material numbered from the pith it was found that the outer wood pulps from mature trees had tear strength 3 times that of pulp from growth rings 1–5; the inner wood pulps formed sheets of higher density than pulps from outer wood, since the fibres were more readily collapsed.

As expected, slabwood pulps gave pulps with highest tear strength. The data on slabwood and those for internodal and ring-group pulps indicate that the strength parameter most affected by wood age is tear index. As tree age increases tear strength of pulps also increases. It is concluded that the use of slabwood pulp to supplement whole-log pulps will be necessary for both export pulp and for certain packaging grades of paper. Empirical procedures for estimating the effects of forest age on the tear index of pulps based on ring-group sampling are described.

INTRODUCTION

The main purpose of this review is to assess the effects of wood age on the papermaking properties of kraft pulps from *Pinus radiata.* The paper also indicates how the wood technologist can largely control the properties of the pulp and paper produced by control of the blend of wood types going to the pulp digester.

WOOD SUPPLY: PRESENT AND FUTURE

The present wood resource yields radiata pine pulps which have good resistance to tear (tear index) if lightly or moderately beaten and which if further beaten have high tensile strength (tensile index), burst resistance (burst index), and tensile energy, although tear strength is correspondingly decreased (Uprichard & Gray 1973).

Much of the kraft pulp currently available arises from a diverse mixture of pulpwood types. The pulpwood mixture consists of slabwood from mature trees, mature but mishapened radiata pine trees unsuitable for sawn timber production, top-logs from mature 40- to 50-year-old trees, and pulpwood thinnings in the 18- to 20-year-old age

Received 10 October 1980; revision 4 December 1980

class. This situation has arisen because much of the wood supply is drawn from radiata pine stands of essentially the same age-class, most of which were planted during the period 1926–1935.

Although there will be several silvicultural regimes in operation in future, virtually all the trees produced will be of a much younger age-class than the present crop. There will be differences in regard to the supply of pulpwood thinnings between State and private company forests. A paper by NZ Forest Products Ltd at the Mount Gambier "Appita Mini-Conference" (Fry *et al.* 1978) makes it clear that this company will "production-thin" its forests, rather than use the "thin-to-waste and heavy-pruning regime" now favoured for the State and some company forests (Sutton & Crowe 1975).

In mills supplied by the State, the proportion of thinnings supplied to the mill will decline, and high quality pruned butt logs will be available. These residues from pruned butt logs, although from only 25-year-old trees, will still have useful attributes.

VARIATION IN WOOD PROPERTIES WITH TREE AGE

Fibre length and wood density

The strength properties of paper are known to depend upon fibre dimensions. Various authors have therefore examined the effects of variation in fibre length and fibre wall thickness in pulpwood species on the strength and optical properties of papers, so that there is now a voluminous literature available on the subject. Papers which discuss both strength and optical properties are those by Giertz (1966), Kibblewhite (1973), and Uprichard (1973); however, the subsequent discussion is mainly confined to strength properties.

In radiata pine, as in other plantation-grown softwoods, wood density and fibre length vary with growth ring number from the pith in a well defined manner (Dadswell *et al.* 1959; Harris 1965; Uprichard 1971; Cown 1975; Cown & McConchie 1980). It is this variation in wood properties with wood age, which is responsible for the observed variation in strength properties of pulps from radiata pine with tree age.

The wood density and fibre length of radiata pine increase over the first 10 or 15 growth rings from the pith (core wood) and in subsequent growth rings (outer wood) fibre length is approximately constant but wood density continues to increase (Harris 1965; Uprichard 1971; Cown & McConchie 1980). Southern pine species show similar behaviour (Zobel 1980). Because radiata pine grows quickly, there is generally an appreciable proportion of "core wood" or inner wood in the old-crop radiata pine being harvested. As forest rotation age is reduced to 25–30 years, then the proportion of the "core wood" or low density inner wood in the crop will be increased.

Variation in wood properties with tree age is a most important concept in pulpwood utilisation, and often receives less attention than it deserves, possibly because the nomenclature involved is confusing (Duff & Nolan 1957). A simplified model of tree growth is shown in Fig. 1. This diagram show schematically the individual growth sheaths of a softwood. Wood age increases in the sequence "growth ring number from the pith" or with "internodes from the apex within a single growth sheath" (Fig. 1). The variation in wood density within a 12-year-old tree of radiata pine, also plotted in Fig. 1, illustrates the wood age effect, which has also been discussed by Cown & McConchie (1980).

TREE FORMATION

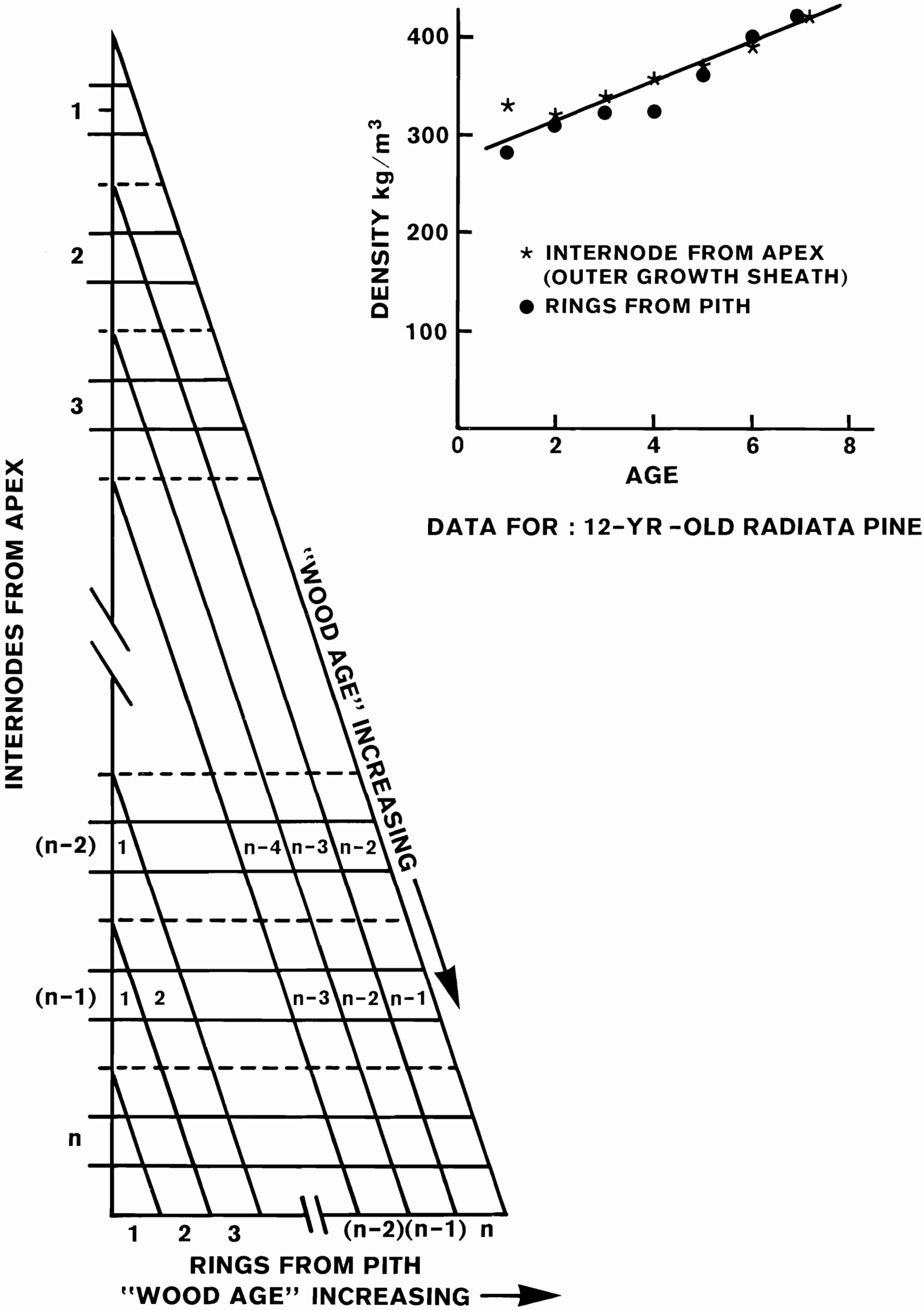

FIG. 1—Tree formation.

Within a given tree of radiata pine, wood properties at the same growth ring number from the pith (or ring group from the pith) are approximately similar at the various "internodal" levels within the stem (the 25th internode wood sample contains 25 growth rings, the 15th internode sample contains 15 growth rings and so on) as is shown in Fig. 2.

Samples formed at the same number of growth rings from the pith have been produced at the same formation stage (or "same cambial age") of tree growth, and may therefore be considered to have approximately the same wood age.

Variation in carbohydrate composition

It has been shown that the chemical composition of radiata pine varies with wood age (Harwood & Uprichard 1969; Uprichard 1971; Harwood 1971). The cellulose and glucomannan content of radiata pine increases over 10 to 15 growth rings from the pith, after which it is approximately constant. On the other hand, glucuronoxylan, the main pentosan present, descreases with growth ring number from the pith. This variation in chemical composition, though well defined, appears to have little effect on pulp yield and has no effect on papermaking properties of pulps (Harwood & Uprichard 1969).

Kraft pulps prepared from earlywood and latewood radiata pine samples from inner wood and outer wood zones were shown by Kibblewhite (1973, 1981) to have very similar chemical compositions, but their papermaking qualities were remarkably different. All the available evidence clearly shows that it is variation in fibre dimensions (fibre length and wall thickness) which chiefly govern papermaking properties, and that variation in chemical composition is of little importance.

WOOD AGE AND PAPERMAKING PROPERTIES OF KRAFT PULPS

Variation in papermaking quality with internodal position

Wood age controls wood properties and hence papermaking properties of pulps. The extent to which wood age controls wood properties and thus the papermaking properties of pulps is clearly shown in Fig. 2, where the properties of pulps from radiata pine samples which contained 10, 20, and 30 growth rings are compared (unpubl. data).

The effects of wood age on pulp quality are well defined. There is a marked increase in tear index of pulps as the number of growth rings in the wood samples increases. The tear strength of the 30th internode pulps is almost twice that of the 10th internode sample. It can also be seen from Fig. 2 that as the proportion of mature wood used for pulp production increases there is a decrease in sheet density, and that as this occurs there are corresponding decreases in tensile strength and burst, pulp properties which are mainly dependent upon bonding between fibres.

Thinnings

The effects of wood quality variation within the stem on papermaking properties of pulps from internodes 5, 10, and 15 from the apex of 18-year-old trees of radiata pine (unpubl. data) are shown in Fig. 3. For all the pulps examined, there was a decrease in the ease of beating as wood age increased, and this was apparent at all levels of beating. The pulps from different internodes are compared after a beating level equivalent to 4000 rev. in the PFI mill.

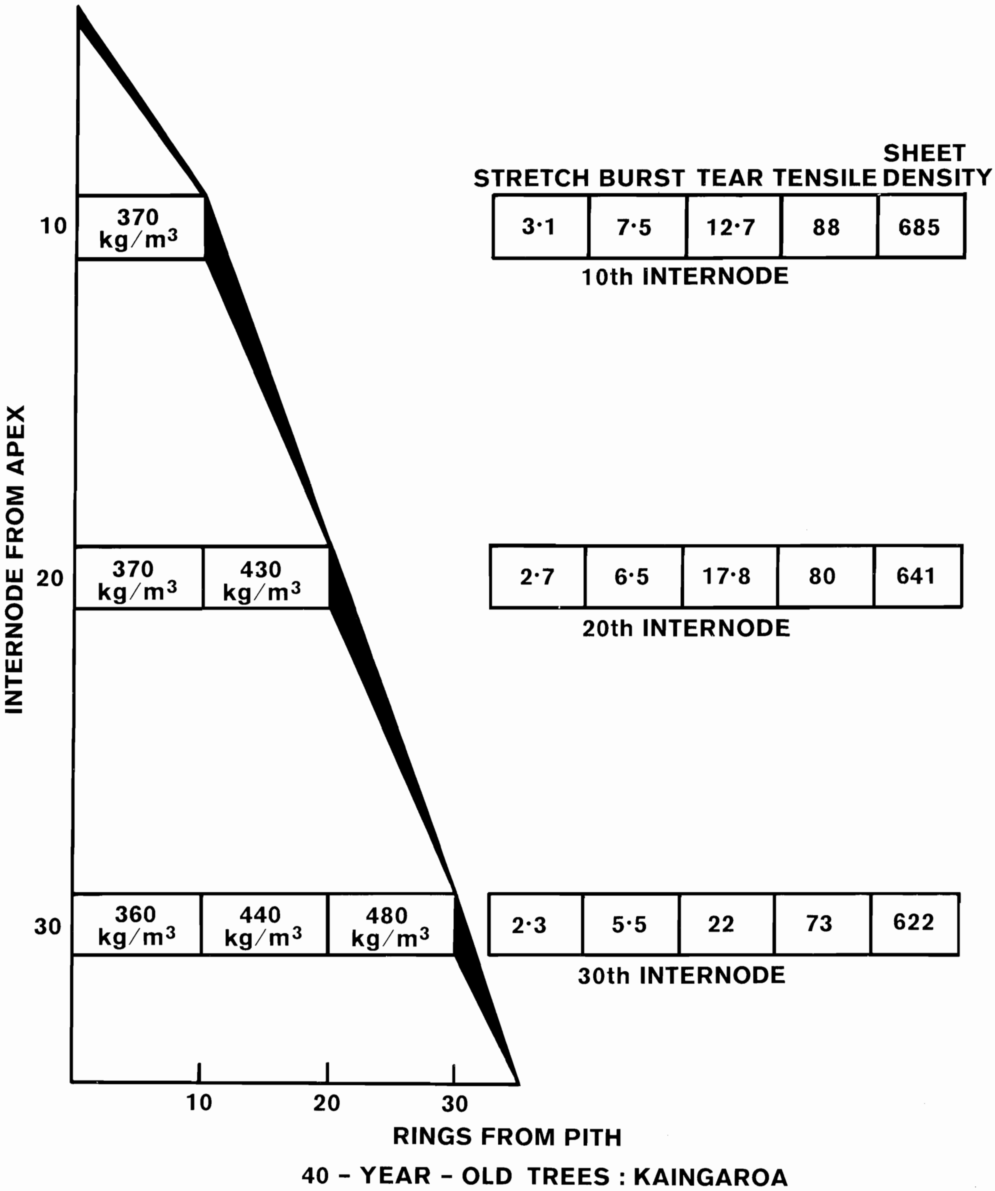

FIG. 2—Wood age and pulp properties 4000 rev. PFI.

Pulps prepared from the lower portion of the stem (internode 15) have highest tear strength, have lowest sheet density, and have low tensile and burst strength compared with those of pulps from the 5th internode sample. It is clear that the high tear index of 15th internode pulps corresponds to the high wood density of the pulpwood sample,

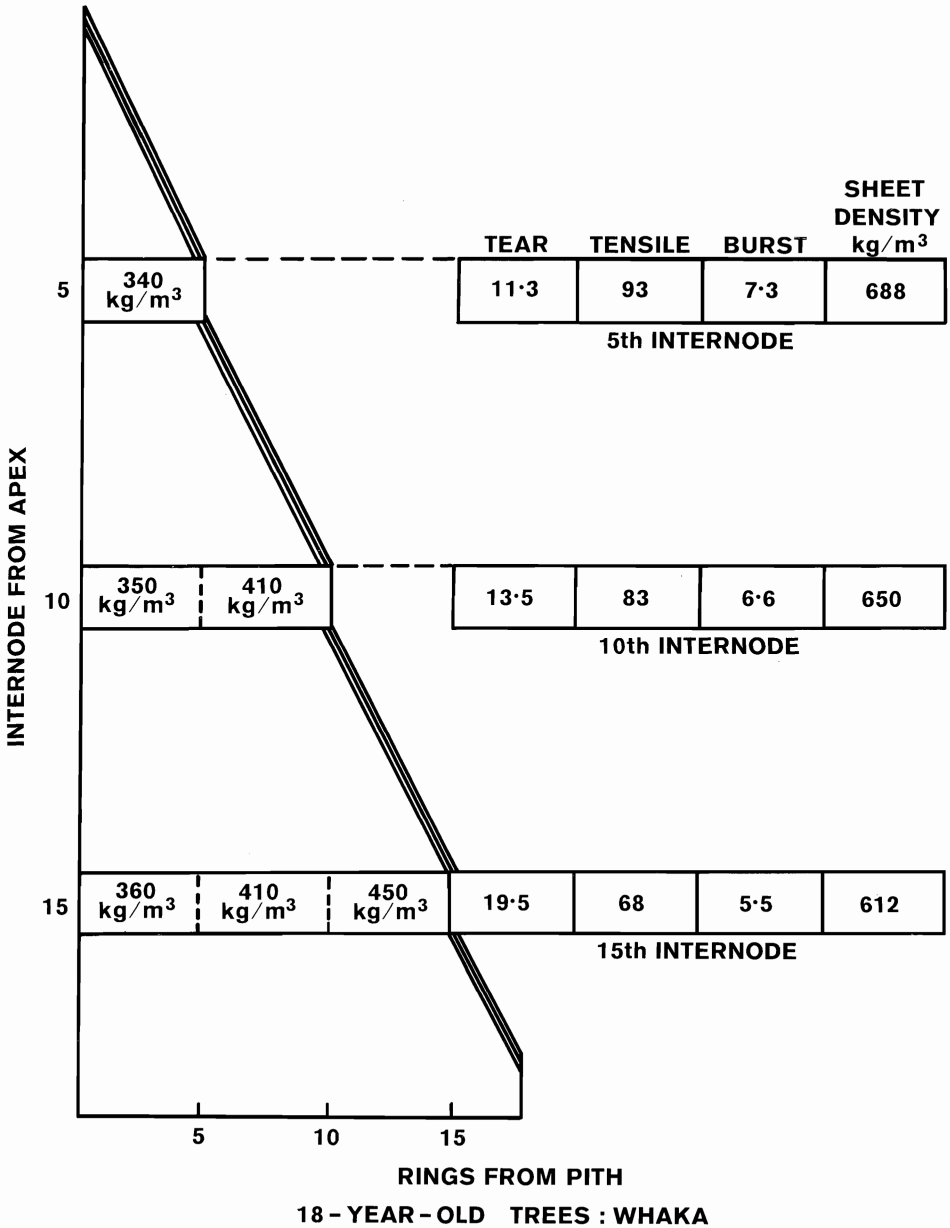

FIG. 3—Wood age and pulp properties 4000 rev. PFI.

although it is recognised that the increase in fibre length in the sample sequence, 5th to 15th internode, will also contribute to the good tear characteristics of pulp from the 15th internode sample.

These data also show that tear index is the property most influenced by wood age.

Beating

The general response of internodal samples to beating is shown in Fig. 4 where the properties of 15th and 25th internode pulps are compared with those of slabwood pulp from radiata pine. The data clearly show that tear index increases with wood age, and also that slabwood pulps have highest tear index. It was earlier shown in a comparison of New Zealand softwoods (Uprichard & Gray 1973) that although radiata pine slabwood pulps have high tear index, they rapidly lose tear strength when beaten. The slabwood pulps are less readily beaten to high burst and tensile index, as might be expected, because the fibres of outer wood have thicker walls and are less readily consolidated than those of inner wood (Kibblewhite 1973).

Pulps from earlywood and latewood samples

Studies by Kibblewhite (1973, 1974) on the handsheet properties of radiata pine kraft pulps prepared from earlywood and latewood samples of young wood (rings 1–10 from pith) and of mature wood (rings 20–30 from pith) are relevant to the previously described data on pulps from different internodes in the stem, and also to data on pulps from 5-ring-group wood samples which are to be given later.

There is generally more earlywood in core wood than in mature wood. Kibblewhite (1973, 1974) showed that for a given amount of beating the ease of sheet consolidation increases in the sequence mature latewood, mature earlywood, young latewood, and finally young earlywood. He found that the inner wood (composite of young earlywood and young latewood) was more easily beaten than the corresponding outerwood composite. It was concluded that the better tensile characteristics of mature wood pulps were related to their greater fibre length compared to core wood pulps.

Latewood fibres from young wood gave pulps of greater tear strength than corresponding earlywood, and similarly the tear strength of mature latewood pulps was more than that of corresponding earlywood, when the pulps were compared at the same level of either beating rev. or sheet density. As would be expected the mature wood composite sample gave pulps with higher tear strength than the core wood pulps.

Overall, these studies clearly show that tear index is, in composite samples, correlated with the amount of latewood present and fully support the general conclusion that as wood density (and fibre length) increase there is a concomitant increase in the tear index of radiata pine kraft pulps. Tear index increases with wood density and with wood age.

Pulps from individual ring-groups

This section of the paper summarises the papermaking quality of pulps prepared from 5-ring-group samples of radiata pine discs, taken in the pith to bark sequence. The combined effect of variation in wood density and fibre length on the papermaking properties of kraft pulps from a low density tree are shown in Table 1, where pulps from individual ring-groups are compared at the same level of beating in the PFI mill. There is a marked increase in tear index in the pith-to-bark sequence, the tear index of outer wood pulp being 3 times that of pulp from the inner 5 growth rings. This inner wood pulp gives sheets with higher stretch than the outer wood pulp. Analogous data for a tree of high wood density are shown in Table 2, and have been previously

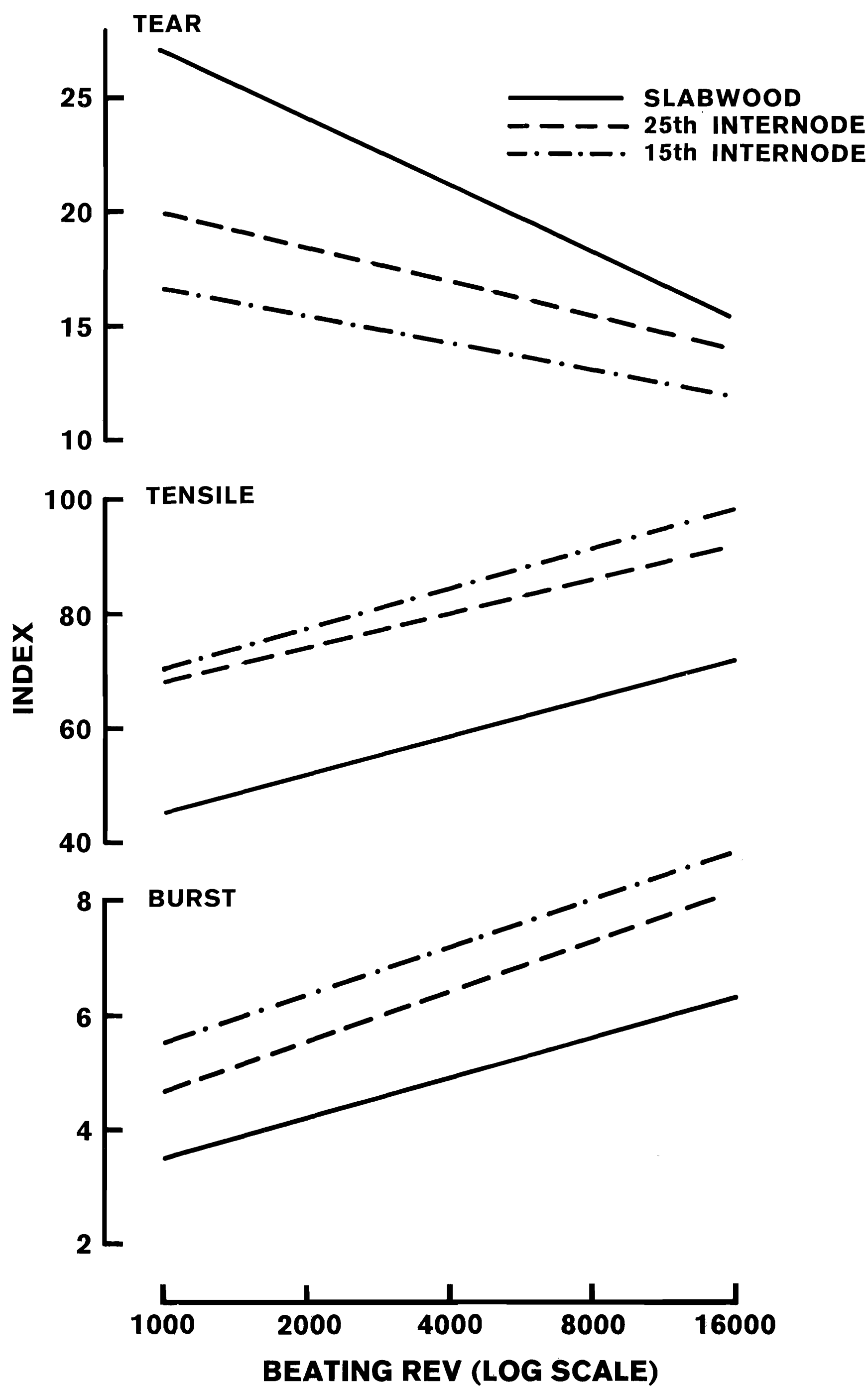

FIG. 4—Internodal values.

TABLE 1—Variation in kraft pulp properties with wood age

Variation in wood or pulp property	Rings from pith			
	1–5	6–10	16–25	26–35
Wood property				
Wood density (kg/m^3)	329	353	379	397
Fibre length (mm)	2.3	3.2	3.7	4.2
Pulp beaten for 4000 rev. in PFI mill				
Tear index	9	14	19	28
Tensile index	102	92	88	82
Stretch (%)	4.0	3.5	3.3	2.9
Burst index	92	88	77	73
Tensile energy (J/kg)	2630	1950	1790	1480
Sheet density (kg/m^3)	727	656	624	602

Data for a radiata pine tree of low wood density

reported (Uprichard 1973). The trends in pulp properties with wood age are generally similar for both types of material. The inner wood pulps form sheets of higher density than those of outer wood when compared at the same degree of beating, since the thin-walled fibres of inner wood are more flexible and are therefore more easily collapsed and consolidated in the papermaking process than those of outer wood.

The general effects of beating on pulps from individual ring-group samples are shown in Figs 5 and 6. As shown in Fig. 5, where sheet density is plotted against beating rev. (log scale), the inner wood pulps are much more easily beaten to high sheet density than outer wood samples; pulps from wood samples in the pith-to-bark sequence are progressively more difficult to beat to high sheet density. Paper properties dependent on bonding between fibres, notably tensile strength and burst, are linearly related to sheet density, up to a sheet density level of about 700 kg/m^3 after which tensile strength is approximately constant (Kibblewhite 1973).

For pulps from the tree of low density (Table 1), there is a general decrease in the tensile and burst strengths of pulps taken in the pith-to-bark sequence, which is largely related to differences in sheet consolidation.

TABLE 2—Variation in kraft pulp properties with wood age

Variation in wood or pulp property	Rings from pith				
	1–5	6–10	11–15	16–25	26–30
Wood property					
Wood density (kg/m^3)	357	401	413	453	491
Latewood (%)	9	22	32	41	43
Fibre length (mm)	2.9	3.7	3.7	4.1	—
Pulp beaten for 4000 rev. in PFI mill					
Tear index	12	19	29	29	39
Tensile index	76	75	69	79	61
Stretch (%)	4.7	3.2	2.8	2.8	2.5
Burst index	7.0	6.8	5.5	5.4	4.8
Sheet density (kg/m^3)	730	648	602	599	575

Data for a radiata pine tree of high wood density

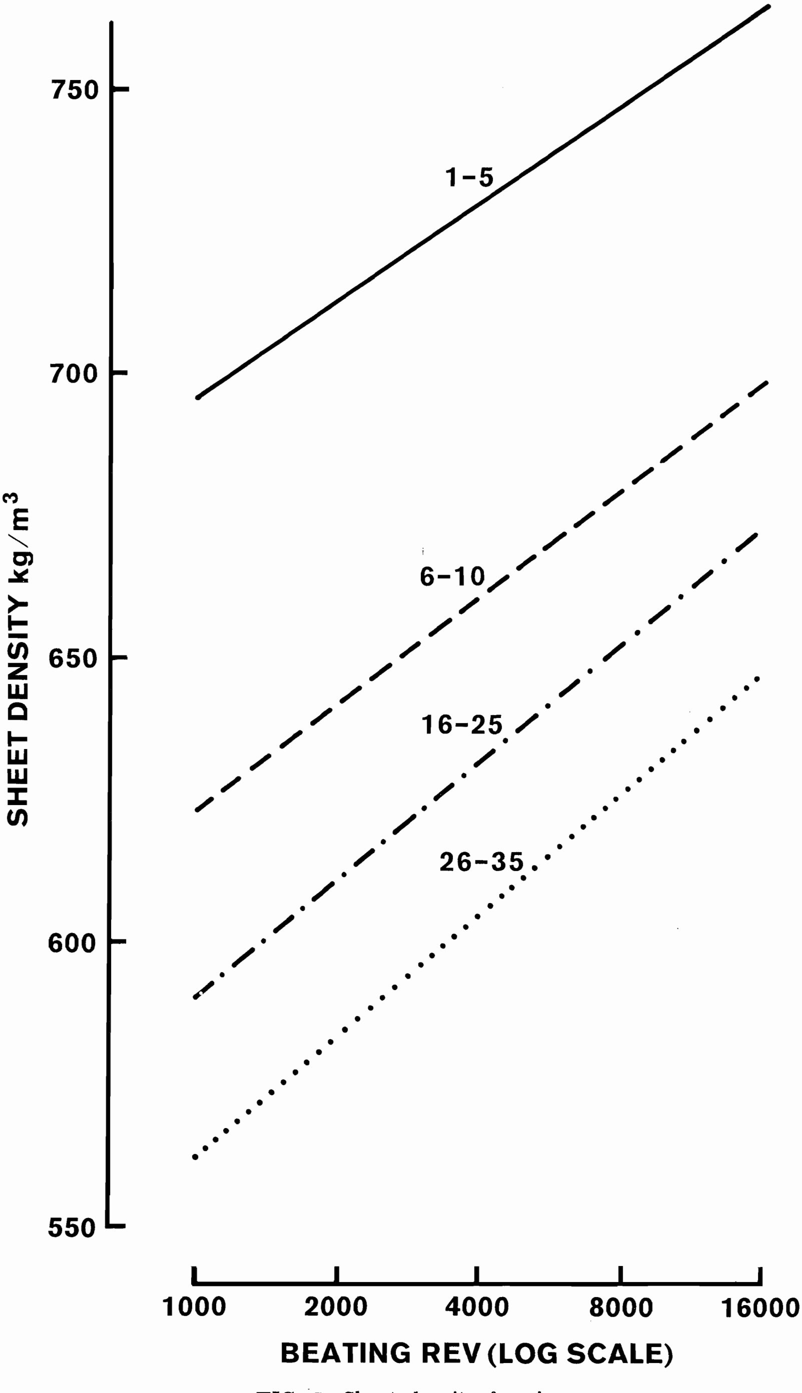

FIG. 5—Sheet density for ring groups.

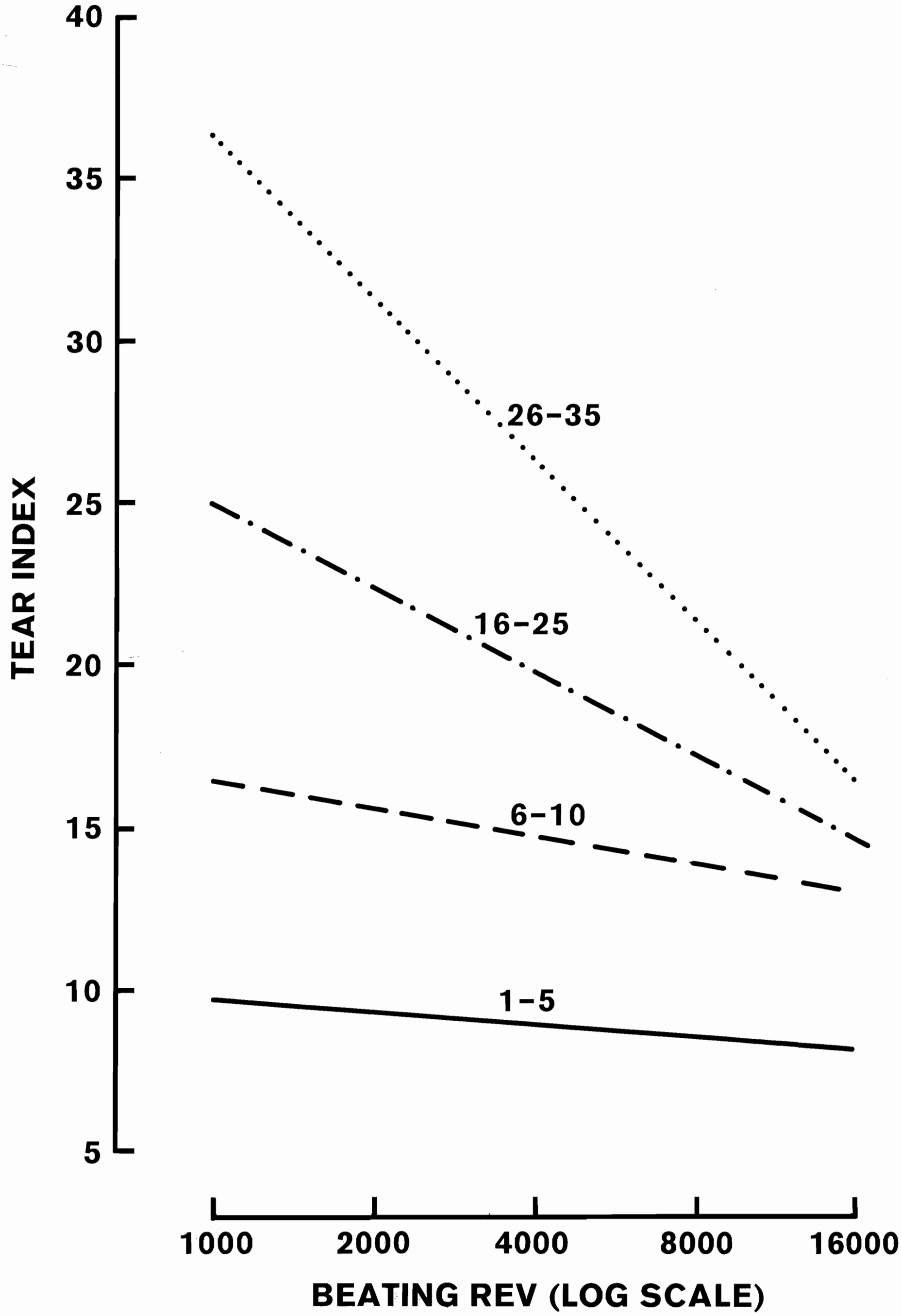

FIG. 6—Tear Index for ring groups.

Tear index is plotted against beating rev. (log scale) for pulps from the samples with different wood age (Fig. 6) and the diagram shows clearly the marked rise in tear strength of pulps which occurs when wood age (or growth ring number from the pith) increases.

In Fig. 7, tear index, tensile and burst index of some individual ring-group pulp samples are plotted against beating rev. (log scale). The data show that although wood age has a pronounced effect on tear index, which increases with wood age, wood age appears to have rather less effect in burst and tensile characteristics — although inner wood samples are more readily beaten.

In Fig. 8, the tear index of pulps from individual ring-groups is plotted against burst index. At a given level of burst the pulps from outerwood have a much higher tear index than innerwood pulps. The data, indirectly, emphasise once again the high tear strength of pulps from slabwood.

Slabwood for pulp production

The effects of beating on the tear index of pulps from slabwood are shown in Fig. 4 (Uprichard & Gray 1973) which compares also the tear strength of pulps from different internodal samples at various levels of beating. It is quite evident from the diagram that the inclusion of slabwood from mature logs will assist in maintaining pulp tear strength.

Pulps from whole-log material will have good tear-strength provided the content of mature wood is high enough. It is therefore clear that if wood age is to be reduced, and a pulpwood rotation of, say, 15–20 years eventuates, then the need for slabwood material from sawlogs becomes greater than ever. It is not obligatory to produce pulps with high tear strength exactly equivalent to the output of today, but it is surely desirable to have slabwood material available to improve the pulp quality obtainable from young age material.

DISCUSSION

Papermaking characterstics of radiata pine pulps

There is generally an initial increase in tear strength of the radiata pine kraft pulps on beating, but on further beating (beyond, say, 1000–2000 rev. in the PFI mill) tear index rapidly declines. Therefore, the general effect of beating is to decrease tear strength, particularly if the papermaker wishes, as he generally does, to develop reasonable tensile strength in the pulps used for papermaking. For many types of paper the pulps must be beaten to lower freeness levels, so as to reduce their drainage rate on the papermachine and so improve sheet formation.

A characteristic feature of radiata pine pulps is that all of them, including those from mature slabwood, develop adequate burst and tensile strengths after only moderate beating. This is advantageous to the papermaker, since beating requires energy. Since tear index is controlled chiefly by wood quality and age, and in the general sense cannot be developed by beating, it follows that tear strength is essentially an intrinsic feature of the raw material, whereas burst and tensile strength, both of which are readily developed by beating and within the papermaker's control, may be regarded as extrinsic factors of the raw material. This rather extreme view is particularly applicable to an easy-beating species like radiata pine.

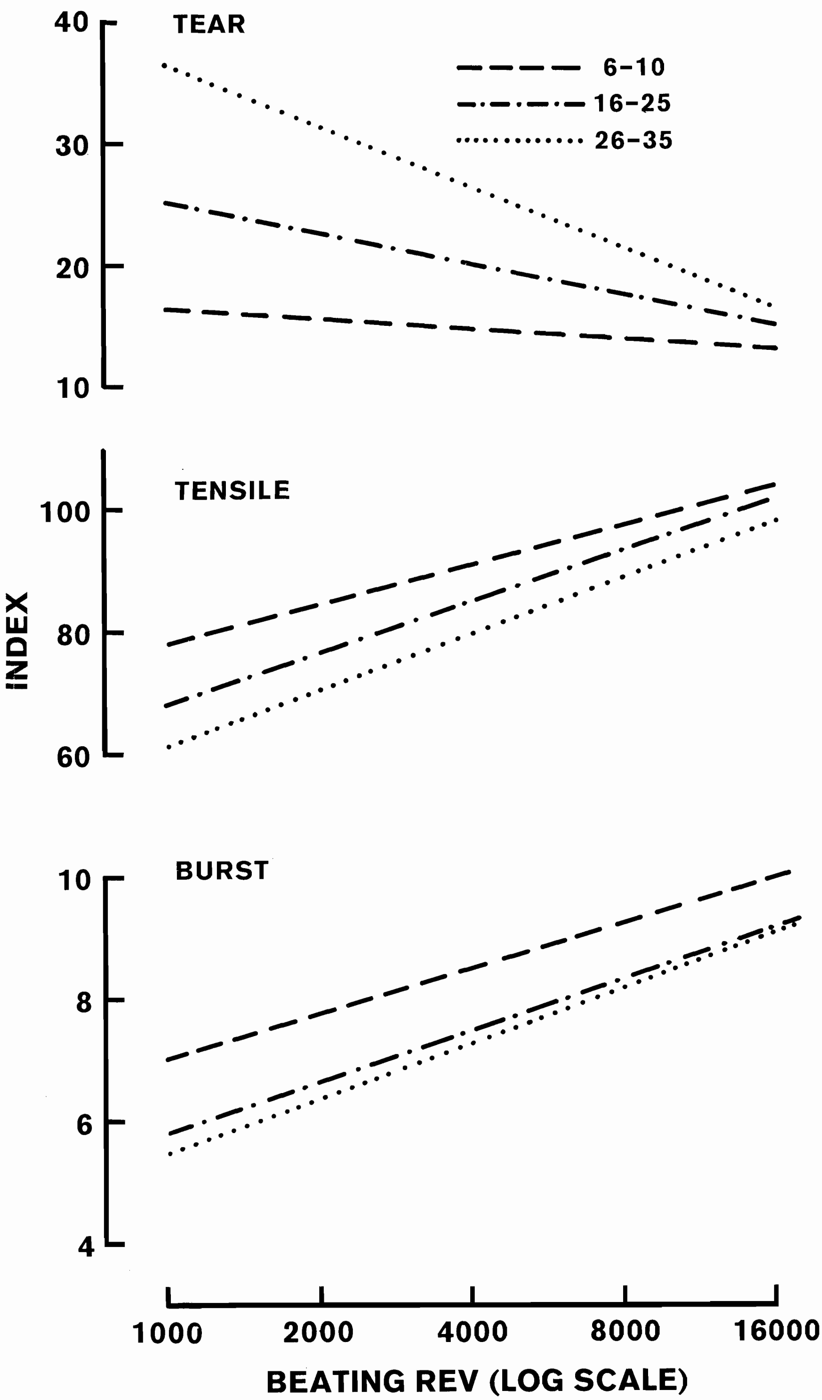

FIG. 7—Index for ring groups.

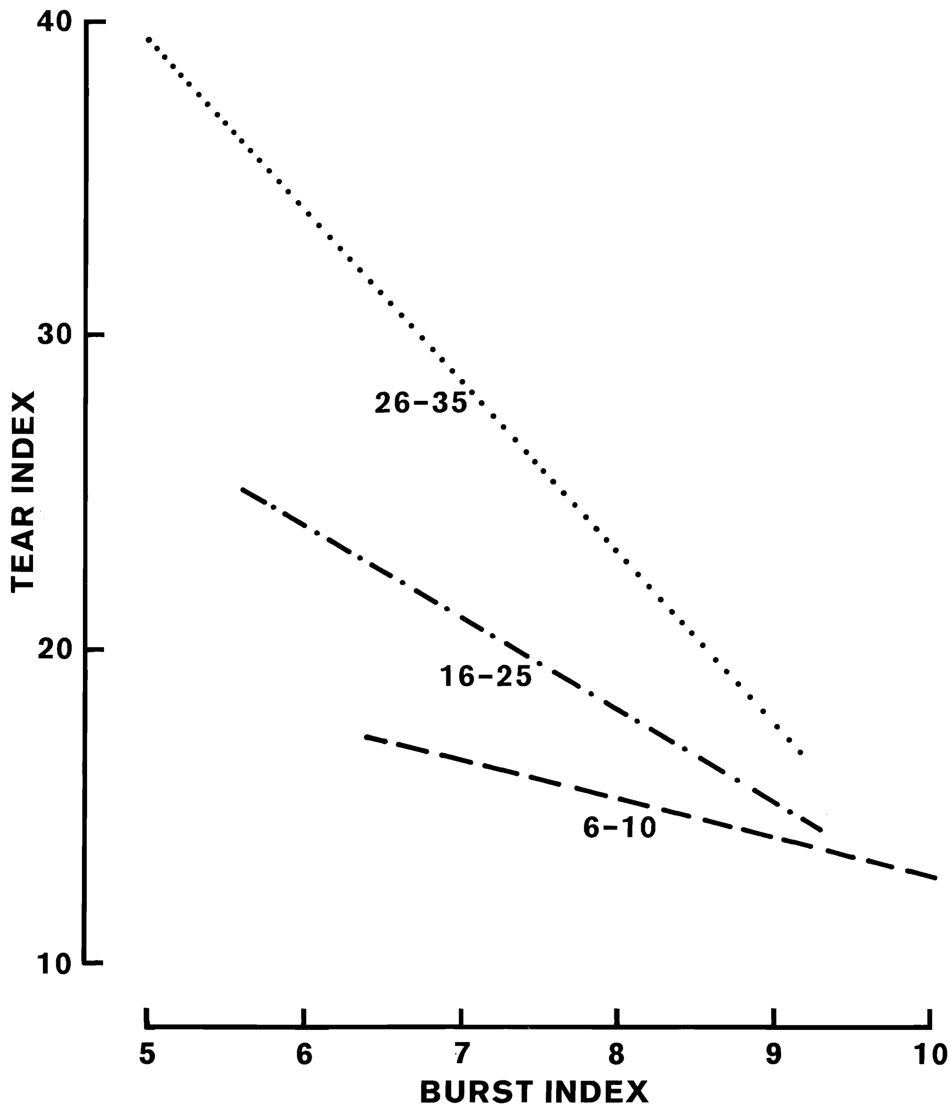

FIG. 8—Tear Index for ring groups.

It is also necessary to point out that most purchasers of softwood kraft pulps expect a reasonable level of tear strength in the product. Tear strength is required in wrapping, bag, and sack papers. Many hardwoods afford kraft pulps with good tensile strength and burst characteristics, but these pulps have low tear (tear index of about 10) compared to those from softwoods. Kraft pulps from radiata pine, if they are to succeed in the export market, must therefore have substantially higher tear index than is obtainable from hardwood pulps, and preferably should be comparable in tear strength to other commercially available softwood kraft pulps.

Most of the preceding data support the following important conclusion:

Tear strength is the papermaking property most influenced by wood age and therefore the parameter of most concern when considering the effects of changes in forest rotation age on the quality of kraft pulp available for export.

From the standpoint of wood utilisation, rather than the cost of growing wood itself, the most effective means of controlling pulp quality would be to have a raw material supply consisting of essentially one age-class which could be as low as 15–20 years, and an adequate supply of slabwood from mature trees (25-year-old trees). Such raw material could be mixed for specific end-uses, as required, so that medium and high tear strength pulps could be prepared.

Pulp blending

Most paper grades are prepared by judicious blending of the requisite component pulps which will have been beaten to the particular levels required. In doing this it is generally assumed that the qualities of beaten pulps are roughly additive. In Fig. 9 tear index data for individual earlywood and latewood pulps of radiata pine were used to calculate the experimentally determined tear index data for "young wood" and "mature wood" composite pulps from the measured earlywood and latewood contents of the wood samples used for pulp preparation (Kibblewhite 1973). The calculated tear index data are in reasonable agreement with the experimental values, confirming that tear index data are additive properties (Fig. 9).

Based on the preceding section it is clear that if paper grades with high tear strength grades are required for special purposes, then it will be desirable to increase the proportion of slabwood pulp in the mix of whole log and slabwood pulps. The amount of slabwood required will obviously depend upon the age of the trees actually employed, and also upon the quality of the slabwood pulp itself — and this will depend on the age of the trees harvested (wood age) and the nature of the forest site, since mature wood density (i.e., allowing for the effects of tree age) is environmentally and genetically controlled.

Pulp quality and tree age

Under mill conditions, it would be useful if the papermaking quality of pulps from trees of known age could be predicted. This can be done approximately by using data obtained from pulping studies on internodal material, and determining the weighted mean average of a particular pulp property at a given level of beating for trees of a particular age class. The technique is demonstrated for data obtained on some 50-year-old trees from Kaingaroa Forest. Tear index data (4000 rev.) for individual 5-ring-groups were used, and the mean tear index for internode 5, for internode 5 plus 15 (as weighted means) and so on were then calculated. Output data are shown in Fig. 10, which contains data plots for tear index (at beating rev. 4000 PFI) with respect to tree age which were obtained using the 5-ring-group pulp evaluation data. By composite sampling techniques (on 30 trees or more) this procedure could be used to estimate pulp quality from trees on a given site.

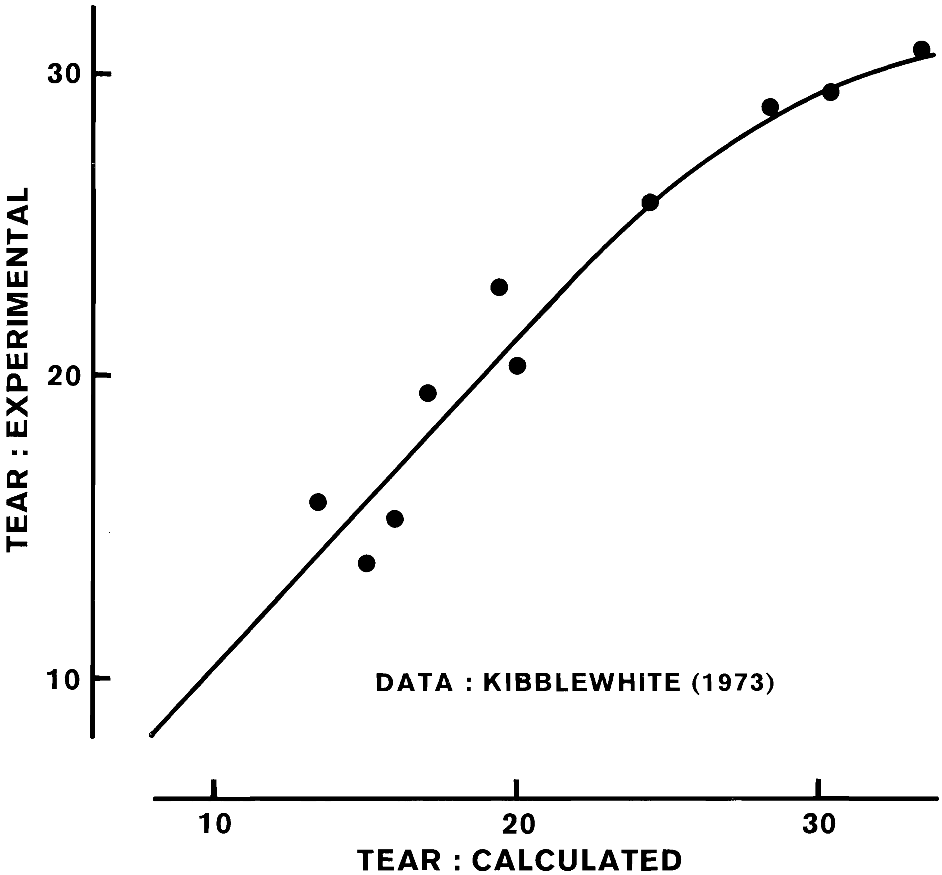

FIG. 9—Effects of fibre blending.

Fig. 10 also shows the effects of adding slabwood pulp (nominal value tear index 21, at 4000 rev. PFI) to pulps from trees of different age classes, using slabwood pulp addition of 20 and 40% respectively. At the lower level of slabwood pulp addition, pulp of tear index 18 can be obtained from 25-year-old trees; using 40% slabwood pulp addition, pulp with tear index 18 can be obtained from 20-year-old trees (Fig. 10).

The data in Fig. 10 emphasise the important role that the slabwood from mature trees will play in future. The industry will be able to cope with the wood coming on stream in future only if it rations its supply of mature logs. In this respect there is a need to ensure that sufficient mature sawlogs are available so that slabwood pulp of the requisite quality will be available to blend with the pulpwood crop becoming available. On this basis, the industry would do better to export its younger trees for log export capital and retain its mature sawlogs for the next decade. Overall it seems likely that there will be enough slabwood pulp available in future. This needs to be ensured.

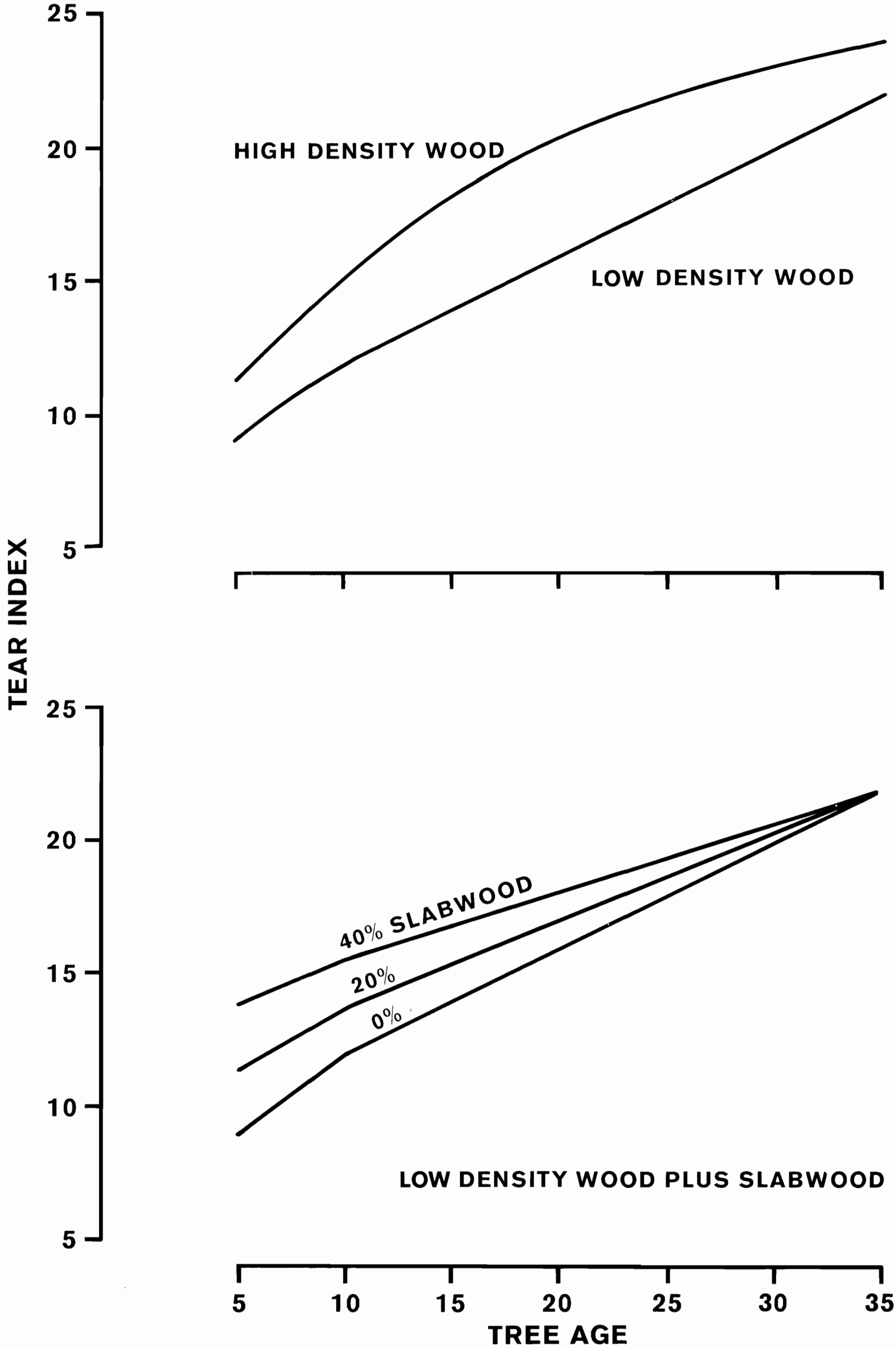

FIG. 10—Tear Index for pulps beaten 4000 rev. PFI.

Valuable paper products from young trees

Although most of this discussion has concentrated on methods for increasing tear index in pulps, it is fully recognised that for certain products, such as high density papers or papers in which smoothness is an important parameter, wood pulps from young trees are required. Although pulps from young trees have low tear, if processing within the mill is kept to a minimum, and the pulps only receive light beating, they will have good strength properties. Overall these core wood pulps are very readily beaten to high burst and tensile strength, but have poor tear index. There are grades in which they will be acceptable in terms of strength, but their ease of beating means that their propensity to form well consolidated sheets (Uprichard 1973; Kibblewhite 1973) means that papers of lower opacity are formed, so that they require more fillers than pulp from more mature wood. These core wood pulps can, however, be used successfully in many products and can be used for the manufacture of high value products, e.g., high density papers and low basis weight products. They form smoother sheets than mature wood pulps. It is likely that the range of products obtainable from pulps from young trees will increase in future (Hamilton 1980; Jackson 1980).

CONCLUSIONS

(1) Tear strength is the papermaking property most influenced by wood age and therefore the parameter of most concern when considering the effects of reduction in forest rotation age on the quality of kraft pulps available for export.

(2) Slabwood from mature trees gives pulps with high tear strength.

(3) The use of wood from a young forest (15–20 years old) will give pulps with lower tear strength than is obtainable from more mature trees; however, such pulps are required for high density paper products, or where paper smoothness is required.

(4) The combination of wood from young trees with a proportion of slabwood (20–40%) will give pulps with good tear strength, and with good burst and tensile strength.

(5) There is a need to ensure that mature sawlogs are available over the next decade, so that an adequate supply of slabwood pulp is available for blending with pulps from young trees.

ACKNOWLEDGMENTS

This paper is based on laboratory records, reports, and papers. The author wishes to thank Mr J. T. Gray for his valuable assistance in processing much of the data available.

REFERENCES

COWN, D. J. 1975: Variation in tracheid dimensions in the stem of a 26-year-old radiata pine tree. **Appita 28:** 237.

COWN, D. J.; McCONCHIE, D. J. 1980: Wood property variations in an old-crop stand of radiata pine. **New Zealand Journal of Forestry Science 10:**

DADSWELL, H. E.; WATSON, A. J.; NICHOLLS, J. W. 1959: What are the wood properties required by the paper industry in the trees of the future. **Tappi 42:** 521.

DUFF, G. H.; NOLAN, H. J. 1957: Growth and morphogenesis in the Canadian forest species. II. Specific increments and their relation to the quantity and activity of growth in **Pinus resinosa** Ait. **Canadian Journal of Botany 35:** 527.

FRY, G.; GRAYBURN, A. W.; SEWELL, W. D. 1978: Management options for wood production in New Zealand. Appita Mini-conference, Mount Gambier, S. Australia, November 1978.

GIERTZ, H. W. 1966: Consolidation of the Paper Web, P. 928 **In** "Transactions of the Cambridge Symposium 1965", published by Technical Section of the British Paper and Board Makers' Association (Inc.), London.

HARRIS, J. M. 1965: A survey of the wood density, tracheid length and latewood characteristics of radiata pine grown in New Zealand. **New Zealand Forest Service, Forest Research Institute, Technical Paper No. 47.**

HARWOOD, V. D. 1971: Variation in carbohydrate analyses in relation to wood age in **Pinus radiata. Holzforschung 25:** 73.

HARWOOD, V. D.; UPRICHARD, J. M. 1969: Pulp quality and chemical composition of **Pinus radiata** pulps. **Appita 22:** 153.

KIBBLEWHITE, R. P. 1973: Effects of beating and wood quality on radiata pine kraft paper properties. **New Zealand Journal of Forestry Science 3:** 220.

——— 1974: Effects of beating on radiata pine kraft properties: effects of beaters. **Appita 27:** 418.

——— 1980: Radiata pine corewood and mature wood and their interrelations with pulp and handsheet properties. **New Zealand Journal of Forestry Science 10:**

——— 1981: The qualities of radiata pine papermaking fibres. Paper presented at the 35th Appita General Conference, Rotorua, New Zealand. 6–10 April 1981.

NEW ZEALAND FOREST SERVICE 1978: Statistics of the forests and forest industries of New Zealand to 1977, Table 32, p. 44. New Zealand Forest Service, Wellington, New Zealand.

RICHARDSON, S. D. 1961: A biological basis for sampling in studies of wood properties. **Tappi 44:** 170.

SUTTON, W. R. J.; CROWE, J. B. 1975: Selective pruning of radiata pine. **New Zealand Journal of Forestry Science 5:** 171.

UPRICHARD, J. M. 1971: Cellulose and lignin content in **Pinus radiata** D. Don. Within-tree variation in chemical composition, density, and tracheid length. **Holzforschung 25:** 97.

——— 1973: Effects of wood age on optical and strength properties of softwood kraft pulps. **Appita 27:** 179.

UPRICHARD, J. M.; GRAY, J. T. 1973: Papermaking properties of kraft pulps from New Zealand grown softwoods. **Appita 27:** 185.

ZOBEL, B. J. 1980: Inherent differences affecting wood quality in fast-grown plantations. P. 169, Proceedings of the Division 5 Conference of the International Union of Forestry Research Organisations. Oxford, U.K.