Dynamic mechanical analysis of wood

C. BIRKINSHAW, M. BUGGY, G. G. HENN
Department of Materials Engineering and Industrial Chemistry, The National Institute for Higher Education, Limerick, Ireland

Despite its extensive and varied use as a structural material, relatively little work has been directed to establishing the dynamic mechanical behaviour of wood. As it is a composite polymeric system, application of techniques used to characterize simpler polymers may yield useful information. Dynamic mechanical analysis (DMA) is a well established technique for measuring the thermomechanical transitions of polymers. In particular, it is usual to relate the changes in the mechanical response of the material to changes at the molecular or microstructural level. Although a limited amount of work has been reported on the application of DMA to wood and wood products, such work has usually been restricted to a specific property investigation in a single species or type [1–3]. The work reported here is the initial result of a more general and comparative study of the application of the DMA technique to the characterization of woods and wood products. Of particular interest was the resolution of the question whether the dynamic mechanical behaviour could be treated generically or had to be considered as a species specific phenomenon.

Timber species show very considerable differences in both density and microstructural morphology. It is generally recognized that density makes a significant contribution to mechanical behaviour, but the microstructural influence has received little consideration. The species investigated in this work were chosen to represent a wide range of densities and structures and thus included both tropical and temperate hardwoods and softwoods. Table I lists the species and the measured densities and moisture contents prior to testing.

All timbers were from conventional commercial sources and had been subjected to a further two years air drying before testing. DMA test pieces were milled from the bulk material using a vertical milling machine to give finished dimensions of 60 mm × 12 mm × 4.2 mm. These dimensions were determined from experimental optimization trials. The long dimension of the specimen was cut parallel to the grain whereas the width was in the direction of radial growth. Experimental difficulty was initially encountered in obtaining reproducible results from unconditioned specimens. This was ascribed to shrinkage associated with dehydration during testing. Using an air-circulated oven, a heating programme of 1 h at 40° C, followed by a rise of 10° C h^{-1} to 100° C, plus a further 2 h at 100° C was adopted to condition DMA specimens. Mechanical restraint was applied to the specimens to prevent distortion during this conditioning period.

A Du Pont 982 DMA interfaced to a 9900 programmer and data analysis station was used to obtain the shear storage modulus and loss tangent between −100° and 150° C. A heating rate of 5° C min^{-1} was used, and during the test the samples were blanketed in nitrogen to eliminate oxidative degradation. Clamp length was 43.6 mm and oscillation amplitude 0.1 mm. The configuration of the test system was such as to produce shear deformation perpendicular to the grain and tangential to the radial growth direction. Shear storage modulus and loss tangent (tan δ) were calculated using Du Pont programme DMA Modulus 2.0F [4]. Duplicate tests were conducted on each species to confirm reproducibility. The shear storage modulus and tan δ variation with temperature for each species are displayed in Figs 1 and 2, respectively.

TABLE I Properties of timbers before testing

Species	Density ($kg\,m^{-3}$)	Moisture (%)
Ash (*Fraxinus excelsior*)	613	10.7
Brazilian mahogany (*Swietenia macrophyla*)	503	11.2
Iroko (*Chlorophora excelsa*)	589	9.0
Keruing (*Dipterocarpus* spp.)	681	8.0
Kingwood (*Dalbergia cearensis*)	1049	9.0
Obeche (*Triplochiton scleroxylan*)	395	11.5
Parana Pine (*Araucaria augustifolia*)	481	9.2
Pine (*Pinus sylvestris*)	482	9.8
Sapele (*Entandophragma cylindricum*)	607	10.6
Spruce (*Picea abies*)	340	10.0

It is apparent from an examination of the figures that, although there is considerable variation in absolute values, the general forms of the shear storage moduli and tan δ curves are similar for all species examined. In view of the substantial microstructural differences [5] which exist between the selected species such an observation is surprising. In the case of pine and keruing, significant quantities of resin exuded from the sample during test, yet the DMA results show no evidence of associated structural change.

All tan δ curves display two main features, a low temperature transition evident as a maximum around −50° C, and a progressive increase in relative damping evident from 50° C upwards. This latter effect can be ascribed to the increasing thermoplasticity of the proto-lignin [6]. No evidence was found with any species for a transition at 80° C which has been reported for spruce [3]. Because of the consistent pattern of behaviour obtained in this work, the transformation reported for spruce is more probably associated with interaction between wood and moisture, and is not a fundamental transition within the polymer network. The low-temperature transition observed in all species is considered to be associated with the structural polymers which make up the wood.

0261–8028/86 $03.00 + .12

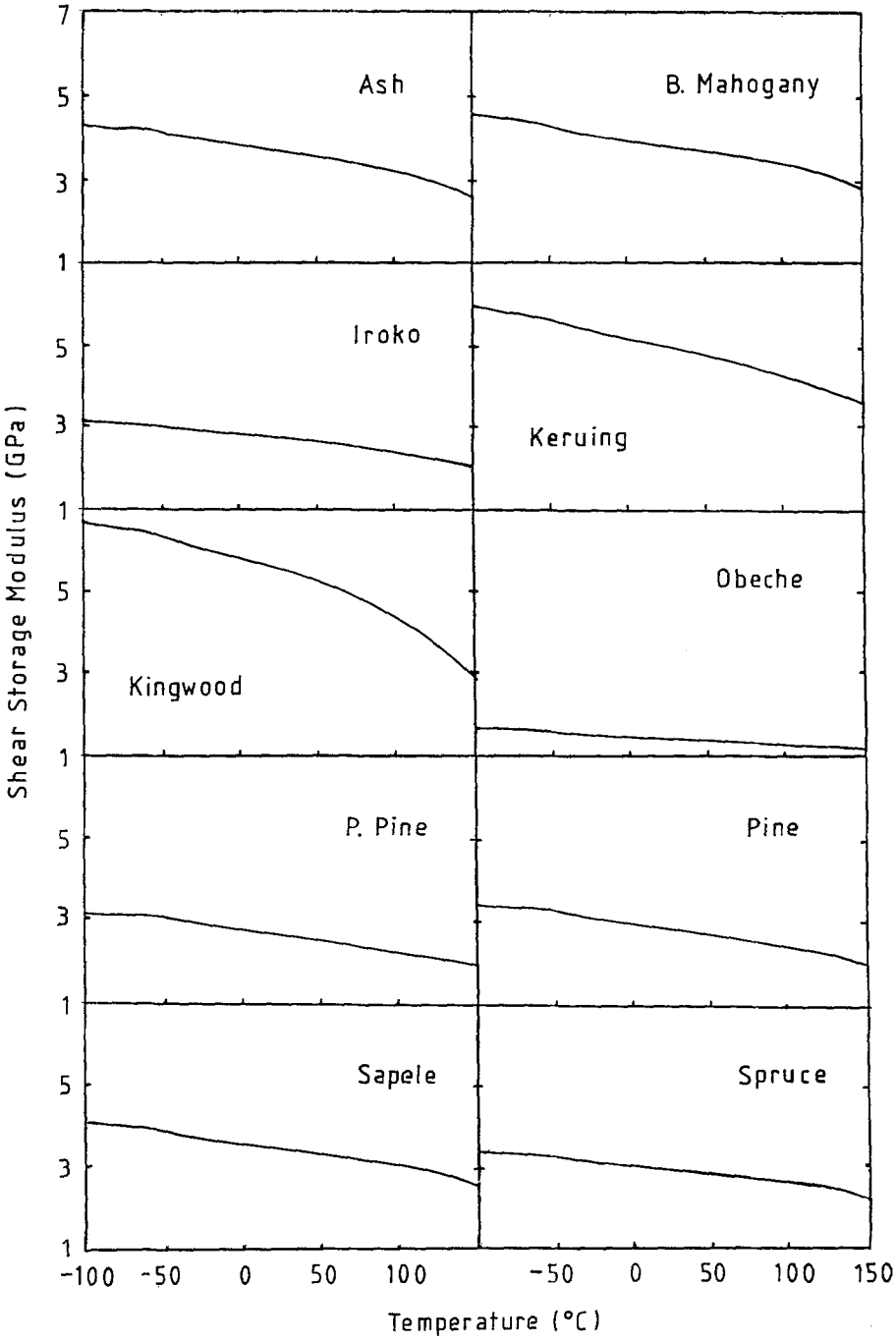

Figure 1 Variation of shear storage modulus with temperature.

The temperature at which this transition occurs and the magnitude of the tan δ change indicates that it is associated with side-chain movement rather than main-chain conformation changes.

In all cases the modulus shows a steady decrease with increasing temperature. Table II lists the specific dynamic shear moduli (shear storage modulus/specific gravity) for all species at three temperatures. The temperatures chosen are $-80°$ C, which is below the observed low-temperature transition, 20° C and 120° C. At this latter temperature the materials are beginning to show significant thermoplasticity. Apart from kingwood the fall-off in specific dynamic modulus over the 200° C range examined is consistent and not dependent upon the absolute value of the property. Comparison of results with available published data [7] for cellulose and lignin contents for the various species does not indicate a clear correlation with the measured dynamic properties.

In general terms the results suggest that the significant microstructural variations which occur from species to species, and indeed from hardwood to softwood, are not important in determining dynamic mechanical behaviour. It is considered that explanations for variations in properties such as dynamic

TABLE II

Species	Specific dynamic moduli (GPa)		
	$-80°$ C	20° C	120° C
Ash	6.79	5.92	4.81
Brazilian mahogany	8.77	7.53	6.42
Iroko	5.13	4.52	3.75
Keruing	8.55	7.42	6.09
Kingwood	6.22	5.29	3.76
Obeche	4.28	3.57	3.09
Parana pine	6.47	5.51	4.35
Pine	6.74	5.58	4.54
Sapele	6.57	5.60	4.68
Spruce	9.82	8.56	7.26

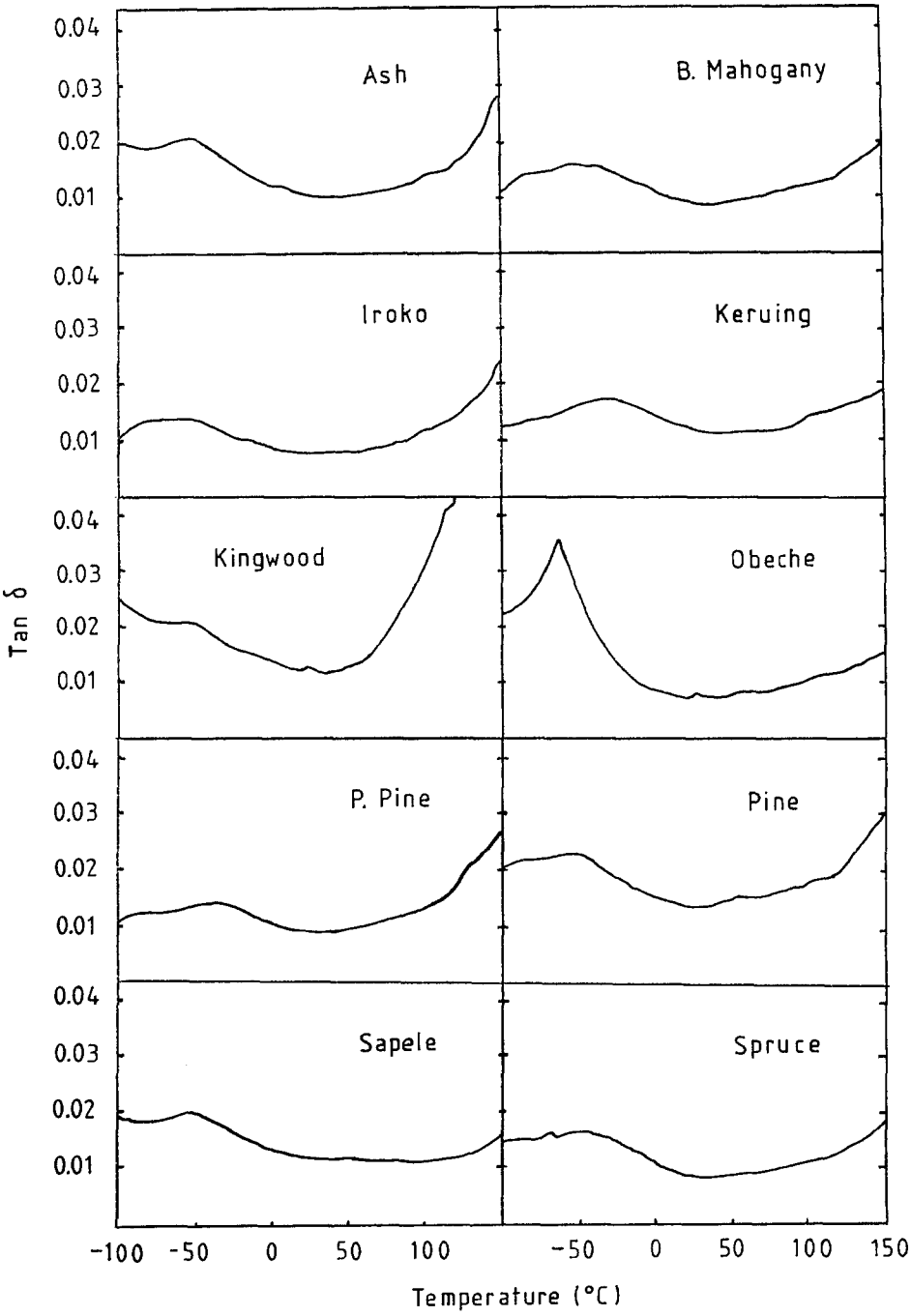

Figure 2 Variation of relative damping (tan δ) with temperature.

specific stiffness should be sought by examination of cellulose content and structure, and in particular the crystal morphology of the structural tracheids.

References

1. R. N. SUBRAMANIAN and R. HOFMANN, *J. Polym. Sci. Lett.* **21** (1983) 105.
2. T. HANDA, S. YOSHIZAWA, M. SUZUKI and M. FUKUOKA, Proceedings of the 22nd Japanese Construction Materials Research Conference, Kyoto, 1978.
3. D. ATACK, *Phil. Mag.* **43A** (1981) 619.
4. Du Pont DMA Calibration Programme PN996227-001 (December 1984).
5. A. MILES, "Photomicrographs of the Worlds Woods" (Building Research Establishment HMSC, 1978).
6. A. J. PANSHIN and C. de ZEEUW, "Textbook of Wood Technology" 4th Edn (McGraw-Hill, 1980).
7. R. M. ROWELL, "The Chemistry of Solid Wood" *Adv. Chem. Ser.* **207** (1984).

Received 17 February
and accepted 14 March 1986