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Some Aspects of the Rheological Behaviour of Wood Part IV: Non-Linear Behaviour at High Stresses in Bending and Compression

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Summary

The incidence of non-linearity with stress in the rheological behaviour of wood in bending was shown earlier to occur at an unexpectedly low stress. This has been further confirmed by the study of an additional species, alpine ash.

Tests on hoop pine, one of the species previously studied in bending, have shown that in compression, non-linearity first occurs at stresses which are a much higher fraction of the ultimate stress than in bending, but in approximately the same range of actual stress. This suggests that the cause of non-linearity at such a low stress in bending lies in the fact that the compressive strength is considerably lower than the bending strength. The stress on the compression face of a beam reaches a high percentage of the ultimate compressive strength by the time the bending stress reaches the limit of proportionality in bending and the non-linear effects in a beam are attributable mainly to stresses near the compression face.

A marked effect of temperature on fractional total creep for hoop pine in compression was found even within the range 20 to 50° C, the creep increasing by a factor of about 2.5 in this range.

Introduction

In a study on the behaviour of wood in bending, Kingston and Clarke [1961] showed that a marked non-linearity in deformation with stress is apparent at stresses above 50 to 60% of ultimate load. Softwoods and eucalypt woods did not show appreciable differences in the incidence of non-linearity, either from the point of view of the fractional stress (i.e. the actual stress expressed as a fraction of the ultimate stress) at which it appeared or of the sudden and marked increase in compliance once non-linearity was established.

This work was confirmed by additional tests, and the point of onset of non-linearity again occurred at an unexpectedly low stress, being in the vicinity of the limit of proportionality as determined by means of short-time tests. Failure usually appeared first on the compression face of the beam and as the compressive strength is considerably lower than the bending strength, it was considered that the early appearance of non-linearity was probably due to non-linear behaviour on the compression face. If this were the case, non-linearity should appear in compression tests at a considerably higher fractional stress than in bending.

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It was therefore decided to carry out a series of tests on a number of species in compression to investigate the correctness of this prognosis. The first species to be considered was hoop pine (*Araucaria cunninghamii*), the work on which is reported here.

It was considered desirable also to carry out tests on an additional species in bending, to confirm the results already obtained, especially in view of the marked difference between the compliance-stress relationship for mountain ash of Tasmanian and Victorian origin found by Kingston and Clarke [1961].

Experimental

General

The time to failure of wood at high stresses is relatively short [Armstrong and Kingston, unpublished data], and consequently it was decided that the test duration should be limited to about 100 hours. This rendered it convenient to use a simple lever type testing machine for the compression tests, and the machine was designed in such a way that for temperature and humidity control, the part of the machine containing the specimen could be enclosed in a small sealed chamber to simplify control problems. Dead weight loading was used and the deformation measured by means of electrical resistance strain gauges which had been shown by previous comparison with mechanical gauges to be stable for times of the order of these tests. Gauges were mounted on opposite sides of the specimen and connected in series to correct for the effect of bending stresses, although these were largely avoided by loading through a steel ball, cardboard being used at the upper end of the specimen to minimize local end crushing. Dummy gauges were mounted on identical unloaded specimens placed as near as possible to the loaded specimens in the test chamber.

Bending tests were carried out using the equipment described by Kingston and Clarke [1961] for stresses of 60% of ultimate and above. Below this stress, dead loading was used, a number of beams being loaded at the quarter points in series, as shown in Fig. 1 in a cabinet whose relative humidity was controlled by means of saturated salt solutions with excess of the solid phase.

For tests in bending at higher stresses and in compression, the same method of humidity control was adopted.

Material for bending tests

A sample of alpine ash (*Eucalyptus delegatensis*) from Victoria was used for the tests in bending. Matching of specimens was tangential and longitudinal to ensure that, as far as possible, all the material tested was from the same group of growth rings. These are very definite in this species. Hence it was quite easy to match groups of growth rings in selecting test material.

Material for compression tests

For tests in compression, hoop pine was used, the sample being taken from south Queensland. Here the growth rings are sometimes rather indistinct, but by means of careful cutting it was found possible to match groups of specimens to approximately the same groups of growth rings. However, it was not possible to obtain all specimens from the same group of growth rings from the material available, as a considerable number of specimens was required. A complete replication was therefore selected from each group of growth rings covering a width radially equal to that of the specimens. The specimens forming each replication were allotted randomly to the different treatments used in the experiment.

A number of tests had to be culled because of movement of the specimen in the loading gear due mainly to uneven end crushing. For this reason more replications were used than appeared necessary to ensure at least six successful tests under every condition. However, at one stress the number fell below this, but as this stress was within the linear range it did not affect the conclusions.

Conditions and method of test

In the bending tests on alpine ash, creep tests were carried out at 21.5° C over a period of one week.

Loads were adjusted to give constant stresses of 10, 15, 22.5, 35, 45, 63, 75 and 80% of ultimate short-time strength. Specimens at the five lower stresses were loaded in groups of beams in series, by means of dead loads as shown in Fig. 1. At the three higher stresses, specimens were loaded singly in a testing machine, the load being automatically adjusted to a predetermined value. The deformation was in all cases measured by means of electrical resistance strain gauges mounted in pairs on opposite sides of the test specimen. Higher stresses than 80% of ultimate stress could not be used on account of the high incidence of failures, even after only a few days under load.

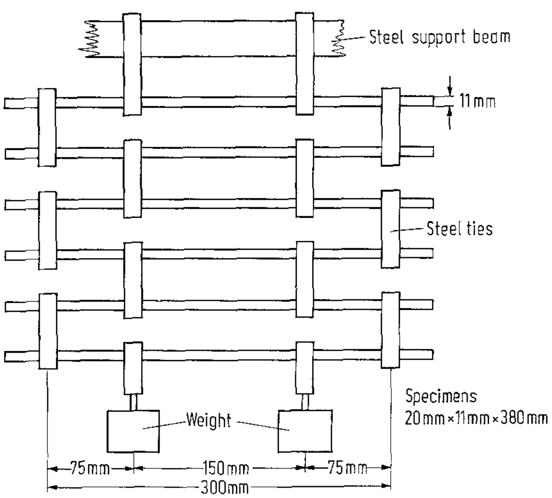

Fig. 1.
Method used for loading beams in series at low stresses

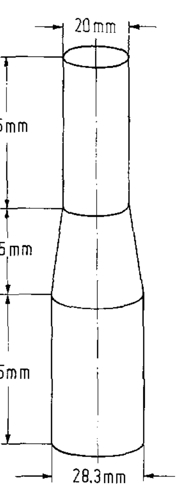

Fig. 2.
Compression specimen

At the end of 4 to 5 days, the beams were then unloaded and recovery measured until the deflection readings became substantially steady, as they did after about four days.

Unlike the method used in earlier tests, the irrecoverable deformation was in these experiments determined from the recovery tests without any assumption as to its form, which proved to be far from linear, even for tests lasting only a few days.

The compression tests on hoop pine again included both creep and recovery tests and were carried out at 21.5° C. In addition, a few tests were carried out at higher temperatures, namely 30°, 40° and 50° C but only for two stresses, one twice the other and both below the limit of non-linearity. In these tests two moisture contents were used, one at 12.5 to 14.5% and the other at 9.0 to 10.0%, control being by means of saturated salt solutions.

The variations in moisture content occurred between tests at different temperatures, tests at the higher temperature being at the lower end of the moisture content ranges and vice versa. This was unavoidable as the salts, for which data was available, did not include any suitable ones with a smaller temperature coefficient than those used. However, at all temperatures, an appreciable difference in equivalent moisture content for the two salts was available, being always over 3% and reaching 4% at 21.5° C.

The bending specimens were of rectangular cross-section 20 mm × 11 mm, and of 380 mm in length and were loaded over a span of 300 mm at the quarter points on the broad radial face. Fig. 2 shows the dimensions of the compression specimens used.

Results and discussion

Variability

The average coefficient of variation of absolute individual values of total creep for alpine ash in bending was 44%. For hoop pine in compression, the average coefficients of variation were 32% for tests at 20° C and at the lower moisture content, and 39% for tests at various temperatures and times under load at stresses of approximately 30 and 60% of ultimate value at both moisture contents.

Bending tests on alpine ash

The results of the creep tests on alpine ash in bending are shown in Fig. 3 where the creep compliance for total creep is compared with results for hoop pine and mountain ash obtained previously.

The total creep compliance of alpine ash fluctuates at low stresses above and below a mean value, but only a possible small increase occurs until a stress of around 60% of ultimate stress is reached, after which there is at first, a gradually and later a more rapidly increasing value of compliance similar to that occurring for hoop pine. The curve steepens rapidly to its final slope above a stress of about 70%, for stresses above 75% reaching values four to six times that at low stresses.

This behaviour is similar qualitatively to that found previously for other species, and the values reached at stresses of 80% of ultimate, the highest stress feasible without a high proportion of failures occurring during test, were of the same order as those for hoop pine and Tasmanian mountain ash and much higher than that for Victorian mountain ash, as can be seen from the figure.

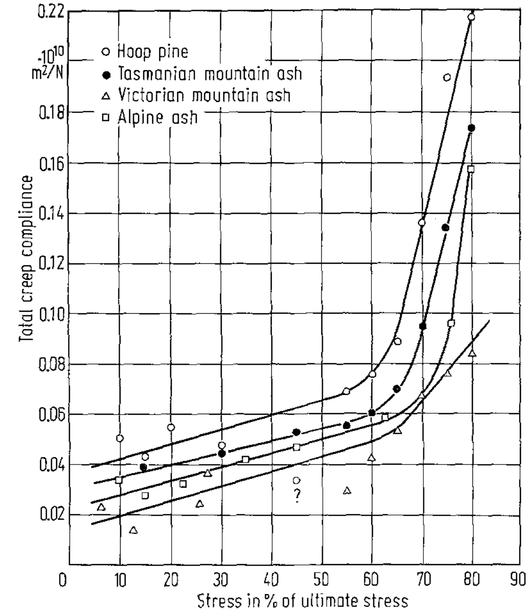

Fig. 3. Total creep compliance for alpine ash, mountain ash and hoop pine in bending v. stress as percentage of ultimate for 20 hrs. under load

The incidence of increasing non-linearity for various species tested occurs at stresses around 55 or 65% of the ultimate short-time load, and occurs at a fairly definite value and appears to depart gradually from linearity in all species except possibly Victorian mountain ash.

The figure shows the behaviour after 20 hours under load, but in general the behaviour is similar for other durations of loading.

The results were rather variable, but although high coefficients of variation were found, the magnitude of the increase in compliance when marked non-linearities appeared was so great that there is no doubt concerning its reality.

Compression tests on hoop pine

The occurrence of non-linearities for hoop pine in compression is shown in Fig. 4 where the curves of compliance against stress as a percentage of ultimate stress at short-time load are given for this species both in compression and bending.

Non-linearities appear in compression between 70% and 80% of ultimate stress, the value at 70% being of the same order as for lower stresses, but a very marked increase, to about seven times its value at lower stresses, occurring at 80%. This is considerably higher than in bending, where increasing non-linearity is apparent at about 55%.

This tends to confirm the opinion that the presence of non-linearities in bending at 50 to 60% of the short-time ultimate stress is due to the direct stresses in the compression face of the beam by this time reaching about 80 to 95% of the compressive strength of the species.

The maximum crushing strength of hoop pine is 64% of its modulus of rupture in 4-point static bending. This is about the same percentage as is the point of

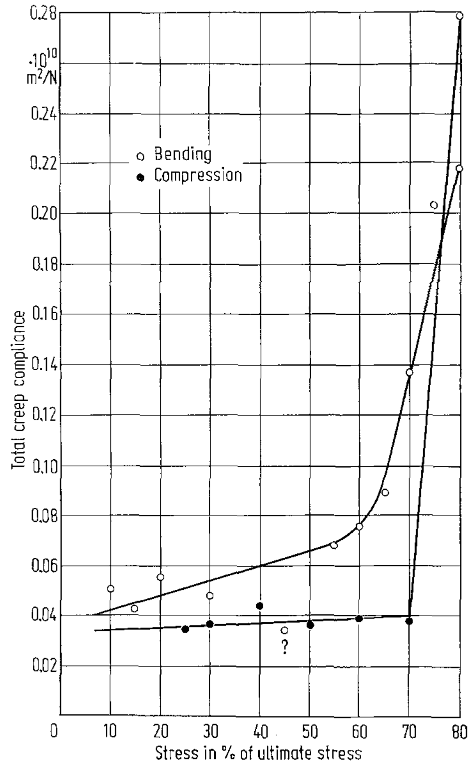

Fig. 4. Total creep compliance for hoop pine in bending and compression v. stress as percentage of ultimate for 20 hrs. under load

incidence of non-linearity in bending of that in compression. Thus non-linearity occurs in bending somewhat below the limit of proportionality for short-time tests which is approximately 70% of the modulus of rupture.

The marked increase in steepness in the creep compliance v. stress curve is probably related to the development of incipient failure. No attempt has been made to study this aspect here but a microscopic study of the test specimens for incidence of failure in experiments such as these at the higher stresses should be rewarding. The limited range of stresses in which it would be necessary to work would necessitate the use of small specimens in order to achieve very close matching.

The relation between compliance for hoop pine in compression and the applied stress as a percentage of ultimate short-time stress, which was discussed above for total creep, follows a similar relationship for both recoverable and irrecoverable creep as is shown in Fig. 5, the type of relationship being similar for 40 and 60 hours.

The increase in compliance for total, recoverable and irrecoverable creep is roughly proportional to the value before the non-linear range is reached, and the compliance at 80% of ultimate short-time stress increases somewhat with time in all cases.

Compliance and fractional creep (i.e. the creep deformation expressed as a fraction of the instantaneous elastic deformation at the same applied load)

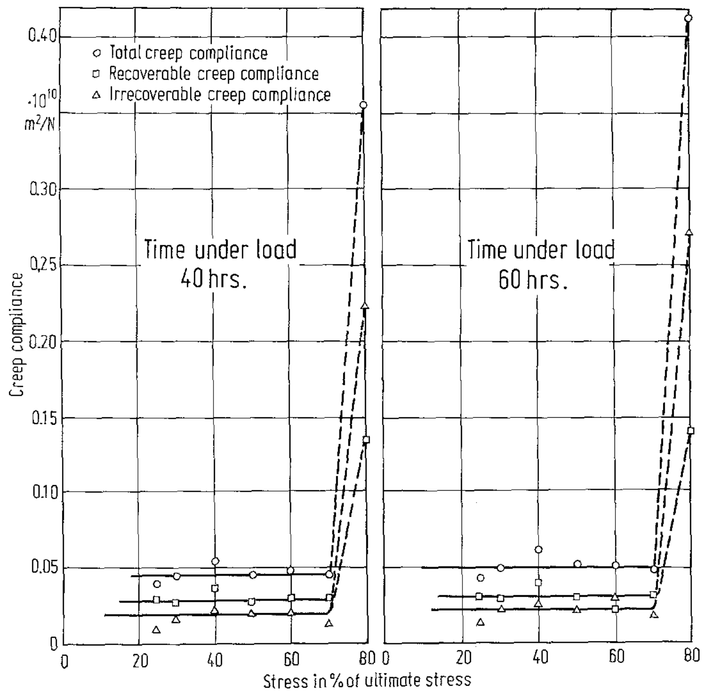

Fig. 5. Total, recoverable and irrecoverable creep compliance v. stress as percentage of ultimate for hoop pine in compression

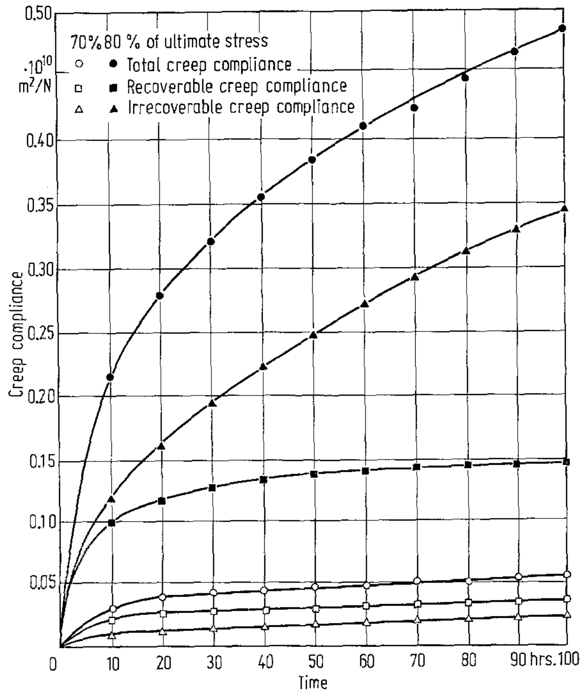

Fig. 6. Total, recoverable and irrecoverable creep compliance for hoop pine in compression

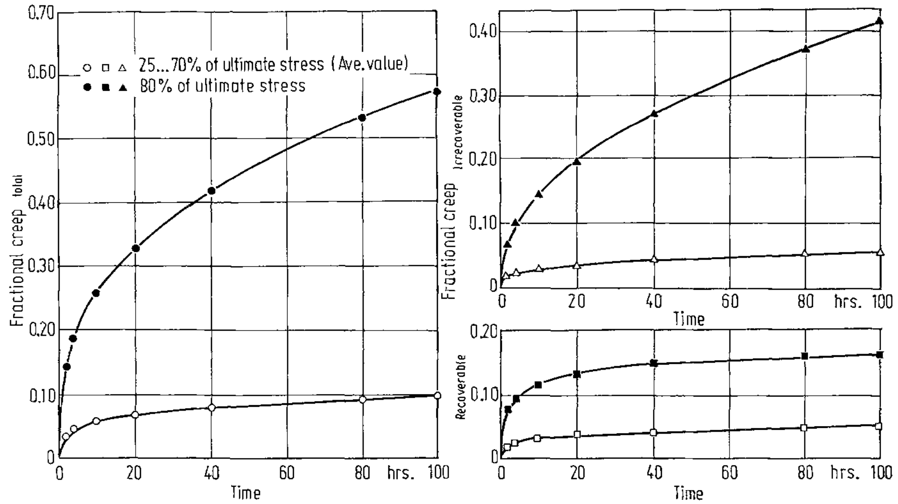

Fig. 7. Fractional, total, recoverable and irrecoverable creep for hoop pine in compression at various stresses

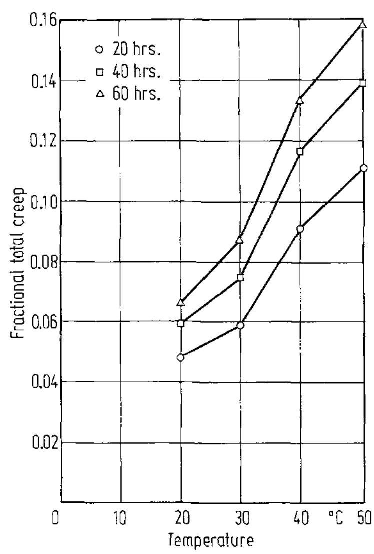

Fig. 8. Fractional total creep v. temperature for hoop pine for 20, 40 and 60 hrs. under load. (Average values for both stress levels and moisture contents)

respectively are shown for total, recoverable and irrecoverable creep in Figs. 6 and 7 where it is seen that the curves for irrecoverable creep are generally similar in form to those for recoverable creep, thus showing that the assumption sometimes used for other materials that irrecoverable creep is linear with time does not hold for wood even for relatively short times. Curves for total, recoverable, and irrecoverable creep for specimens previously at stresses from 25 to 70% of ultimate do not differ significantly.

The effect of temperature on the creep of hoop pine in compression is shown in Fig. 8 where fractional total creep is plotted against temperature. Results for the two moisture contents and stresses of test have been averaged and only the averages plotted. The three lines are for times under load of 20, 40, and 60 hours.

This effect is plotted only for stresses below 70% of ultimate short-time value, as at higher stresses the incidence of failure, even for times up to 100 hrs., becomes very frequent. It will be seen that the creep increases by a factor of about 2.5 with temperature, even in such a small range.

Conclusion

The tests reported here show clearly that with hoop pine, non-linearities in behaviour, apart from possible, slight and unimportant effects in bending, occur at roughly the same stress in bending and compression, although this stress is much nearer the ultimate stress in compression than in bending and that the non-linearity once established is very marked.

The previous work of Kingston and Clarke [1961] has also shown that this non-linearity in behaviour is similar for different species of wood in bending, and this has been further confirmed here for an additional species.

However, although it seems likely that this is also true in compression, only one species has as yet been studied, and it seems desirable that this should be confirmed by further tests. At least one eucalypt should be tested in compression and possibly a rain forest species which is used for structural purposes, such as taun (*Pometia* spp.), kwila (*Intsia* spp.) or calophyllum (*Calophyllum* spp.).

References

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