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Shrinkage and collapse in thin sections and blocks of Tasmanian mountain ash regrowth

Part 3: Collapse

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Summary. Total collapse values from the green condition to various equilibrium moisture contents (EMC) were obtained by comparing shrinkage before reconditioning in matched blocks and sections of the wood of *Eucalyptus regnans.* It was shown that while collapse to 17% EMC comprised the largest portion of total collapse, a significant component, apparently caused by drying stress, developed below 17% EMC. Between 5% EMC and 0% moisture content a collapse recovery of some 1% occurred, seemingly because of changes in drying temperature. After reconditioning, collapse recovery was only partial and a high level of residual collapse remained. It was shown that collapse recovery was highest near the sapwood-heartwood boundary, while residual collapse was highest near the heartwood centre. While residual collapse was weakly negatively correlated with specific gravity, this relationship was not significant after adjustment was made for change in shrinkage after reconditioning in sections. All types of collapse were positively correlated with R-ratios calculated for blocks. However, relationships were not as well defined when R-ratios for sections were employed, the exception being for collapse below 17% EMC which was highly negatively correlated with R. The difference between shrinkage before reconditioning and shrinkage after reconditioning in sections, while totalling near zero, was positively correlated with specific gravity. It was demonstrated that this quantity could not constitute collapse in the traditional sense of collapse of the cell lumens. A possible association with moisture content of the material was discussed.

Introduction

Collapse in wood during drying has had an infamous history as a cause of timber degrade in *Eucalyptus*. However, the reconditioning of such material through steaming and redrying can substantially restore lost volume (Kauman 1964). The success of reconditioning, i.e. the extent to which collapse is recovered, is dependant on previous drying history, the steaming temperature during the reconditioning process, and the moisture content of the wood (Greenhill 1938). Therefore, while substantial collapse recovery will occur during reconditioning, total recovery is unlikely and a residual collapse component probably will remain.

Recent examination of the shrinkage-specific ratio in reconditioned wood of *Eucalyptus* has indicated non-compliance with the standard relationship of Stamm (1935, 1952), $S = f\varrho$, where S = volumetric shrinkage, f = the fibre saturation point, and ϱ = specific gravity (Chafe 1986a; Chafe, Ilic 1992a). Although previously not considered as a likely cause (Chafe 1986a), more recent studies suggest that residual collapse may contribute to such shrinkage behaviour (Chafe, Ilic 1992a, 1992b). The current paper describes results obtained with matching blocks and sections of the wood of *Eucalyptus regnans*; this approach allowed calculation of total collapse to various nominal equilibrium moisture contents (EMC), and facilitated comparisons with recovered and residual collapse.

Materials and methods

These are fully described in Chafe and Ilic (1992a). Briefly, blocks 25 mm square and 20 mm along the grain, together with 1 mm-thick matching sections, were prepared along a single radius, taken at breast height, from each of eight trees of 55-year-old Tasmanian mountain ash (*Eucalyptus regnans* F. Muell). All samples were sequentially dried from the green condition in a conditioning chamber progressively calibrated to provide nominal equilibrium moisture contents of 17, 12 and 5%. Drying to 0% moisture content was carried out in a 103 °C drying oven. Samples then were reconditioned for two hours in saturated steam at 100 °C and dried again to 0% moisture content in the drying oven. Weights and volumes of samples were measured at each stage and shrinkage, moisture content and specific gravity (based on basic density) determined.

Total collapse (C_t) was expressed as the difference in volumetric shrinkage before reconditioning between blocks and sections; recovered collapse (C_r) was expressed as the difference between shrinkage before reconditioning and shrinkage after reconditioning in blocks; and residual collapse (C_l) was expressed as the difference between C_t and C_r. Collapse from green to 17% EMC (C_a), from 17% EMC to 0% moisture content (C_b), and from 17% EMC to 5% EMC (C_f) were calculated as the difference in shrinkage before reconditioning between blocks and sections for each of the respective moisture content ranges. All collapse was expressed as a per cent of initial green volume.

For plots of collapse with respect to radial position in the stem, data was sorted by distance from the periphery expressed as a per cent of the radius, and smoothed by an eight-point (to correspond to eight trees) moving average to help gauge overall trends and reduce variation. Linear regression analysis and paired t-tests were carried out on a microcomputer using Statistix, Version 2.1 software, and all graphs were composed using Sigmaplot V 3.10.

Results and discussion

Development and recovery during drying

The difference in shrinkage between blocks and sections to each nominal equilibrium moisture content shows the amount of total collapse from the green condition and the development of collapse from 17% EMC to 0% moisture content (Fig. 1). Collapse from green to 17% EMC averaged 5.8% and 6.2% for all data and heartwood respectively (Table 1). This constituted the major collapse component which, in large part, would have been liquid tension collapse formed above the fibre saturation point

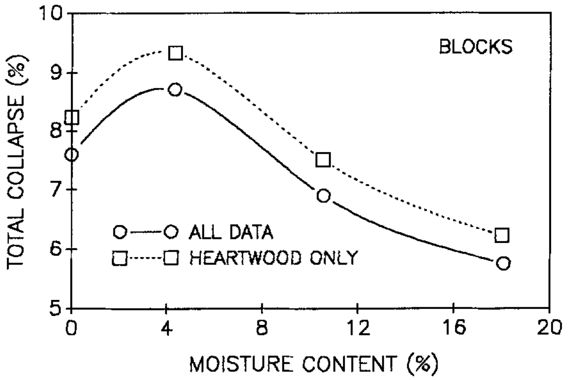

Fig. 1. Average collapse plotted against average measured moisture content showing development during drying from the green condition. All data and heartwood only

Table 1. Average values (%) of collapse for all data and heartwood only

Collapse	All data	Heartwood
C_t	7.59	8.23
C_a	5.75	6.23
C_b	1.84	2.00
C_f	2.96	3.11
C_r	3.82	4.20
C_l	3.78	4.04
C_s	0.05	0.02

C_t = total collapse to 0% M
C_a = total collapse green to 17% EMC
C_b = total collapse 17% EMC to 0% M
C_f = total collapse 17% EMC to 5% EMC
C_r = recovered collapse to 0% M
C_l = residual collapse to 0% M
C_s = recovered 'collapse' to 0% M for sections

(= the intersection point (I_p) as described in Chafe and Ilic (1992a)). However, collapse continued to increase below I_p, and below 17% EMC a further 3.1% was added in the heartwood to 5% EMC. Kauman (1960) considered a portion of collapse to be associated with drying stress and it would seem that this collapse increment was similarly derived (Chafe, Ilic 1992a). The reversal of this trend, i.e. the apparent collapse recovery evident from 5% EMC to 0% moisture content (M) (Fig. 1) parallels similar changes in total shrinkage and cell lumen volume in blocks (Chafe, Ilic 1992a; 1992b).

In looking for causes for such recovery, it may be instructive to consider changes in temperature during drying, that is from 5% EMC (dry bulb = 40 °C) to 0% M (103 °C). Greenhill (1938) has shown how temperature and moisture content affect collapse recovery and provides data on recovery at various moisture contents at 100 °C. If Greenhill's values for tangential and radial collapse are transformed to volumetric, and volumetric collapse recovery is calculated and linearly regressed

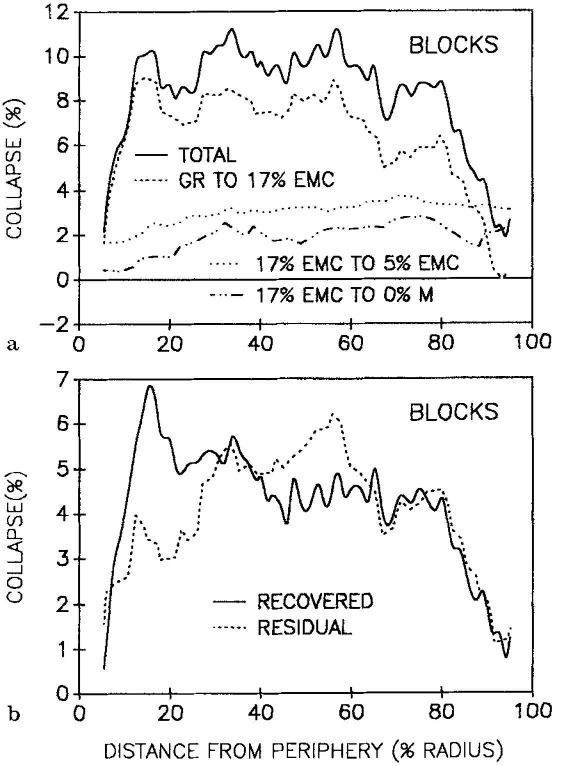

Fig. 2 a and b. Collapse plotted against distance from periphery. **a** Total collapse, collapse from green to 17% EMC, collapse from 17% EMC to 5% EMC, and collapse from 17% EMC to 0% M. **b** Recovered collapse and residual collapse. Lines constructed using an eight-point moving average for collapse and per cent radius data

through the origin against moisture content and solved for 4.33%, the average measured moisture content at nominal 5% EMC for blocks in the current study, then the predicted collapse recovery is 17.3%. If, on the other hand, data for blocks and sections are regressed against respective measured moisture contents (Fig. 3, Chafe, Ilic 1992a)) and solved for 0% M, then the difference gives an estimate of total average collapse assuming no divergence in the linear shrinkage – moisture content alignment near zero (Chafe, Ilic 1992a). This value was calculated as 9.2% which, when compared with 7.6%, the figure for total average measured collapse (Table 1), represents a recovery of 17.4%, a value almost identical to the extrapolated value of 17.3% found for Greenhill's data.

Given the approximations used in this exercise, the closeness of the figures is probably coincidental. Nevertheless, they do suggest that temperature changes may have been instrumental in effecting the collapse recovery observed. As noted earlier (Chafe, Ilic 1992b), this effect may contribute to the sometime observed divergence from linearity of shrinkage near 0% moisture content.

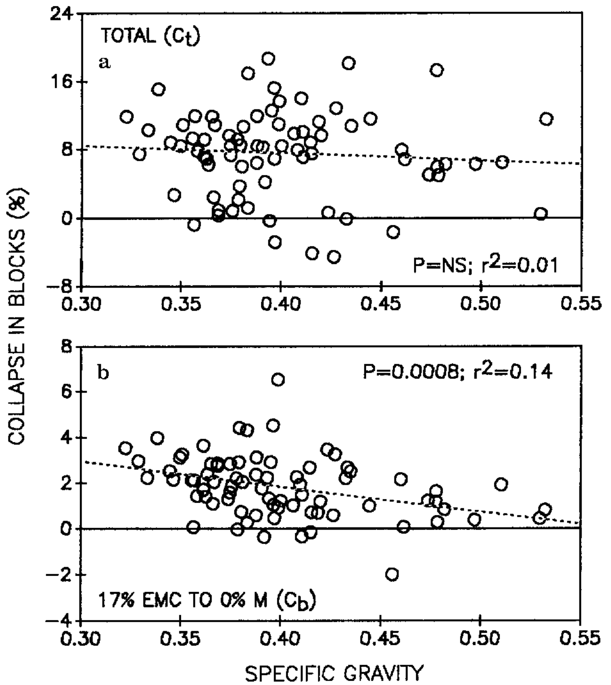

Fig. 3 a and b. Collapse plotted against specific gravity. **a** Total collapse. **b** Collapse from 17% EMC to 0% M. Dashed lines represent simple linear regressions. P = significance

Radial distribution and relationships with specific gravity

When total collapse was plotted with respect to distance from the periphery, a distribution generally similar to that previously reported for recovered collapse was observed (Fig. 2a), namely low collapse in the sapwood and heartwood near the pith, but relatively high elsewhere (Chafe 1986b). Collapse from green to 17% EMC (C_a) generally paralleled total collapse (C_t), but collapse from 17% EMC to each of 5% EMC (C_f) and 0% M (C_b) showed a significant increase towards the pith (Fig. 2a). When plotted and regressed against specific gravity, neither C_t nor C_a were significantly related (Fig. 3a). However, both C_b and C_f were negatively significant (Fig. 3b), a result in accordance with their origin through drying stress. Thus, wood with low specific gravity would tend to have cells with thinner walls less able to resist compressive stress associated with drying (Chafe, Ilic 1992a).

For all data, recovered collapse (C_r), in agreement with C_t and C_a, showed no correlation with specific gravity, although for heartwood-minus-pith data a positive relationship was indicated. This contrasts with previous work on Victorian mountain ash where a negative relationship was observed (Chafe 1985, 1986a). However, residual the particular collapse component recovered during the reconditioning process was somewhat variable. However, when C_l was adjusted for change in shrinkage after reconditioning in sections (see below), i.e. $C_{lc} = C_t - (C_r - C_s)$ where C_{lc} = corrected residual collapse and C_s = 'collapse' in sections, the relationship was not significant.

Although similar in average values (Table 1), when recovered and residual collapse were plotted against distance from the periphery (Fig. 2b), it was apparent that their radial distribution differed. While recovered collapse was greater near the sapwood-hartwood boundary, residual collapse was highest in the central heartwood region. Both recovered and residual collapse were lowest in sapwood and pith areas. Adjustment for C_s did not significantly alter these distributions.

In calculations of total collapse carried out here, seven negative values were observed (Fig. 3a). Although at first this may seem improbable, it should be noted that Greenhill (1936) found that initial shrinkage in thin sections was greater than shrinkage after reconditioning in $1 \times 1 \times 4$ inch samples for a number of different species. The negative values observed here were from either the sapwood or pith regions where collapse was lowest, i.e. where differences between shrinkage before and after reconditioning were least (Fig. 2a). Thus, the presence of negative values in these areas perhaps should not be regarded as surprising. In any event, the omission of such values from analyses did not materially affect relationships observed.

Relationship with the R-ratio

It was shown for the current data by Chafe and Ilic (1992b) that the R-ratio (the change in external volume per change in associated volume of water below fibre saturation (Chafe 1986a)) was negatively related to specific gravity. Since R gives an indication of changes in lumen volume (Chafe 1987; Chafe, Ilic 1992b), and since values greater than unity suggest lumen contraction during shrinkage, high R values might be expected to show the severity of collapse, where that phenomenon itself is defined by collapse of the cell and diminution of the lumen. This proposition is substantiated by Fig. 4a.

When C_t, C_a and C_b each were plotted and regressed against their corresponding R-ratios for blocks, all were highly positively significant (Figs. 4a). This is in accordance with the positive relationship found previously between recovered collapse and the R-ratio (Chafe 1986a) which also applied here. Residual collapse was similarly related. However, when collapse (C_t, C_a, C_r or C_l) was plotted against the R-ratio calculated for sections, themselves characterized largely by expanding cell lumens, and thus low R values (Chafe, Ilic 1992b), less defined relationships were observed. The exception, however, was for collapse from 17% EMC to 5% EMC or to 0% M (C_f, C_b) which were highly negatively correlated with the R-ratio (Fig. 4b). Since, in sections, R was not significantly related to specific gravity (Chafe, Ilic 1992b), but C_b and C_f were negatively related (to specific gravity) (Fig. 3b), the negative relationship between each of C_b and C_f and R is consistent.

Collapse in sections

As shown in Table 1, the difference between shrinkage before and after reconditioning in sections (C_s) was near zero and not significant when assessed by a paired t-test analysis. However, as reported by Chafe and Ilic (1992a, 1992b), the relationship between shrinkage before reconditioning and specific gravity changed from being

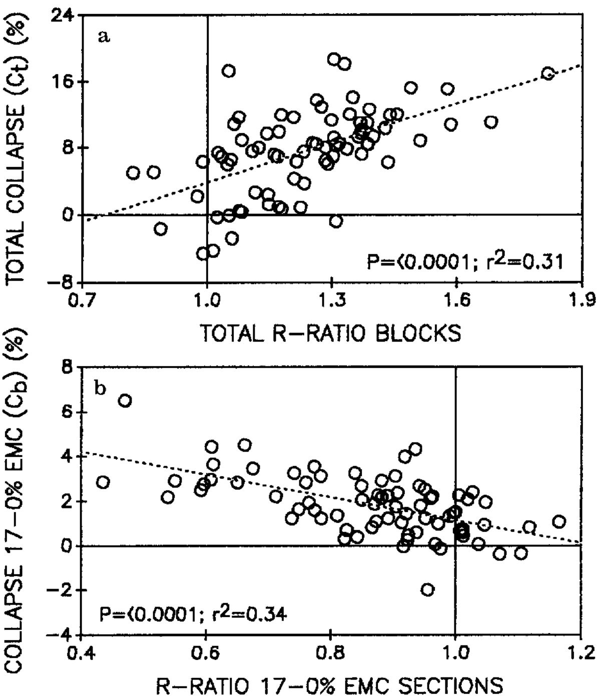

Fig. 4. **a** Total collapse plotted against the R-ratio for blocks. **b** Collapse from 17% EMC to 0% M plotted against the R-ratio for sections

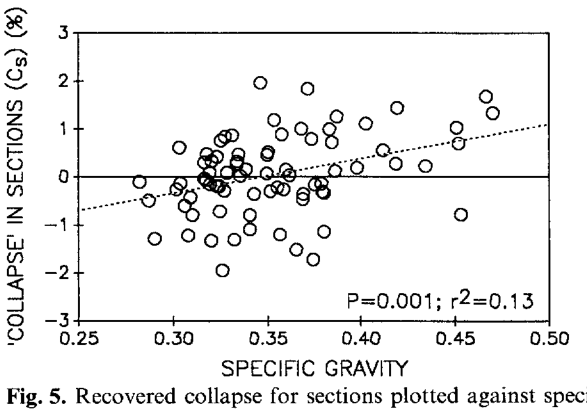

Fig. 5. Recovered collapse for sections plotted against specific gravity

positively significant to being not significant after reconditioning. Thus, when C_s was plotted against specific gravity, a significant positive relationship was evident (Fig. 5). Reconditioning, therefore, had the effect of tending to reduce shrinkage in higher density material and of increasing shrinkage in lower density material. Expressed another way, oven dry volume increased in higher density material and decreased in lower density material.

It would seem unlikely that C_s bears any real similarity to the typical cell lumen collapse found in blocks. Firstly, nominal thickness of sections was only 1 mm along the grain, a dimension likely sufficient to obviate the development of liquid tension collapse. Actual thicknesses of all sections were less than that at which Greenhill (1936) found an increase in shrinkage (due to collapse) in *E. regnans*, viz. 0.053 inches (1.35 mm). Furthermore, when C_s was plotted and regressed against section thickness measured here, no significant relationship was observed.

Secondly, collapse associated with drying stress would not appear a likely candidate, as this was shown to be negatively, not positively, correlated with specific gravity (Fig. 3b). Thirdly, there was no suggestion of a 'collapse recovery' in sections from 5% EMC to 0% M since, by contrast with blocks, there was no similar divergence from linearity in the shrinkage – moisture content curve near 0% M (Chafe, Ilic 1992a, Fig. 3).

While the reasons for the relationship between C_s and specific gravity remain obscure, a final point may be made with respect to moisture content of the material. It is possible that moisture absorptive capacity and/or composition of the cell wall may vary with density, a point suggested by Chafe (1991) in reporting a relationship between measured moisture content, at various equilibrium moisture contents, and specific gravity. Moisture content following reconditioning was not measured in the current study, but it can be shown from data employed in previous experiments on *E. regnans* (Chafe 1990) that a significant negative relationship exists between moisture content following reconditioning and specific gravity. If that relationship also applied here, it could be suggested that cell walls of higher density samples were less absorptive than those of lower density. However, that may also indicate that higher density sections should 'recover' less and such a conclusion would be at odds with the relationship shown in Fig. 5a. Alternatively, if moisture content after reconditioning (from Chafe 1990) is expressed as a proportion (P_I) of maximum cell wall saturation, i.e. the fibre saturation (intersection) point, then P_I can be shown to be positively significant with respect to density. Thus, if it were the case that the degree of 'recovery' were contingent on the level of cell wall saturation, agreement would be suggested with respect to results obtained here (Fig. 5).

Conclusions

Measurements of shrinkage on collapse-prone blocks and matching, collapse-free sections of *E. regnans*, to various equilibrium moisture contents, allowed the development of total collapse to the monitored during various stages of drying. It was evident that while the major collapse component occurred above 17% EMC, a significant increment was added through drying stress below 17% EMC; this collapse was somewhat reduced through a recovery apparently based on temperature changes in the final stages of drying.

Reconditioning did not recover total collapse and a large proportion remained in the material as residual collapse. As judged by radial distribution, recovered collapse peaks near the sapwood-heartwood boundary and residual collapse near the heartwood centre.

It was demonstrated that the apparent 'collapse' in sections, which was significantly related to specific gravity, could not be properly described as such, i.e. as collapse of the cell lumen, but might, nevertheless, have an association with the moisture content of the material.

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