RECOVERY OF COLLAPSE IN *EUCALYPTUS DELEGATENSIS* BY USE OF ANHYDROUS AMMONIA AND STEAM

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ABSTRACT

Eucalyptus delegatensis wood dried to 5, 12, and 18% moisture content was treated with steam and anhydrous ammonia to recover collapse. Steam or ammonia gave similar results in terms of the optimum treating moisture content, viz. 12%, but steaming was the more effective at other levels. Ammonia swells collapsed wood considerably, but only part of this "recovery" is permanent. At the lowest moisture content, further shrinkage may occur.

INTRODUCTION

Research into the process variables that govern the reconditioning treatment for recovery of collapse in seasoned timber has yielded few reports over the last three decades which in any way expand or clarify the hypothesis suggested by Greenhill (1938, 1940). Apart from the undoubted complexity of the processes involved, it could also be said that since collapse is recoverable in large measure by the very simple process of holding timber in saturated steam at 100 C for periods dependent principally upon dimensions, this seems to have been reason enough not to investigate the mechanisms involved. Generally accepted theory (Greenhill 1938, 1940) postulates that under the influence of heat the inelastic structural layers of the cell wall are rendered plastic, thus allowing recovery to occur by expansion of elastic layers. That is, the collapsed cell wall can be regarded as a two-element system consisting of an elastic and a nonelastic component both held in compression. When the nonelastic component is made more pliable, e.g. by steam, the energy stored in the elastic component is used to expand it and the nonelastic component to their original shapes. There is little reason to believe that any plasticizing agent would not allow this reaction to take place. Plasticizing by ammonia, both liquid and gaseous, has been described in depth in recent years; and as pointed out by Davidson and Baumgardt (1970), we can view the reaction between wood and ammonia as being analogous to the reaction between wood and water. This study was undertaken to determine first whether collapse recovery could be effected by gaseous ammonia and if so whether the accepted theories of recovery and ammonia plasticizing are compatible.

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EXPERIMENTAL PROCEDURES AND RESULTS

Wood samples used in this study came from a single freshly milled quartersawn 8- by 2-inch board from a green *Eucalyptus delegatensis* log. For collapse and recovery measurements, the dimensions of samples were 7 by 1.75 inches and 0.75 inch along the grain, and for collapse-free shrinkage they were 0.04 inch along the grain. One hundred eight of the former samples were randomly allocated to three groups for drying to 5, 12, or 18% equilibrium moisture content at 60 C dry bulb temperature. Twenty-seven of the latter samples were precision-sawn on a jig with a carbide-tipped saw and were dried at this temperature in twelve steps of decreasing humidity to nearly 0% moisture content.

Dimensional measurements were made

TABLE 1. [illegible]

Moisture Content	Direction of Recovery	Treatment	S_t [a]	S_a [b]	S_r [c]	Recovery [d] %
5	Radial	Steamed	4.84	9.46	5.81	78.9
		Heated	4.84	8.92	[illegible]	0.0
	Tangential	Steamed	9.56	16.94	10.78	83.5
		Heated	9.56	18.50	18.48	0.2
12	Radial	Steamed	3.46	7.20	3.74	92.5
		Heated	3.46	[illegible]	[illegible]	0.6
	Tangential	Steamed	6.80	[illegible]	6.90	97.6
		Heated	6.80	[illegible]	[illegible]	0.5
18	Radial	Steamed	1.90	[illegible]	[illegible]	74.7
		Heated	1.90	6.03	[illegible]	-0.5
	Tangential	Steamed	4.58	11.36	[illegible]	78.3
		Heated	4.58	13.18	[illegible]	1.6

[a] Collapse-free shrinkage

[b] Total shrinkage

[c] Shrinkage after reconditioning

[d] $\frac{S_a - S_r}{S_a - S_t} \times 100$

TABLE 2. [illegible]

Moisture Content	Direction of Recovery	Ammonia Pressure lb/in^2	Final [a] Recovery	Maximum [b] Recovery	Time to [c] Maximum Recovery min.	Gradient of [d] Recovery vs. Time
5	Radial	20	-3.5	63	200	0.91
		50	25.9	114	167	2.75
	Tangential	20	-4.9	71	200	0.83
		50	28.3	112	140	[illegible]
12	Radial	20	78.9	119	115	3.30
		50	79.1	145	85	2.07
	Tangential	20	79.5	135	95	3.56
		50	82.4	160	75	7.24
18	Radial	20	28.5	83	75	6.04
		50	29.2	103	25	16.57
	Tangential	20	35.3	87	75	4.95
		50	38.8	124	45	23.42

[a] Final recovery: measured after re-equilibration at original moisture content conditions.

[b] Maximum recovery: greatest measurement following ammonia treatment.

[c] Time to maximum recovery: time to attain greatest measurement after ammonia treatment.

[d] Gradient of recovery versus time: rate of recovery in the linear initial stage during ammonia treatment.

with a cathetometer, in the green condition and at each step, in both the tangential and radial directions. The range in radial or tangential shrinkage for these collapse-free samples was less than 1% at any given moisture content. The average shrinkage values were plotted against moisture content, and the "true shrinkage" values, S_t, for the treatment moisture contents were read directly from the graph.

The following measurements and calculations were made on the collapse samples and all percentages were based on green dimensions.

- S_a: Total percentage shrinkage to a given moisture content
- S_t: True percentage shrinkage to a given moisture content (obtained from collapse-free samples)
- S_r: Total percentage shrinkage, after reconditioning and equilibration to a given moisture content.

Collapse: $S_a - S_t$

Recovery, based on collapse: $\frac{S_a - S_r}{S_a - S_t} \times 100$

Individual samples from each group were randomly distributed in duplicate to the three reconditioning treatments as follows:

Steam reconditioning was carried out at 100 C for 15 min in a small chamber. Half the samples were sealed in vapor-proof bags to test for the interaction of heat and moisture. After treatment the samples were replaced in conditioning rooms to regain their original moisture content before dimensional measurements were made. Gaseous ammonia treatments were made at 22 C in a small cylinder at pressures of 20 or 50 psi. Blocks were taken from the cylinder after 5 min and then at 10-min intervals, immediately wrapped in Saran film to prevent ammonia from escaping, and weights and dimensions were measured. The blocks were then unwrapped and replaced in the cylinder, and ammonia was readmitted to the required pressure. This procedure was repeated until no further increases in dimensions were detectable. Finally blocks were equilibrated at their original relative humidity conditions and dimensions were measured again.

Recovery of the steamed blocks is clearly shown in Table 1, those at an initial moisture content of 12% being greatest. Dimensions of blocks heated in vapor-proof bags were practically unchanged, with no apparent influence of initial moisture content. The data of Table 2 show that recovery in ammonia is highest at both pressure levels in those blocks treated at an initial moisture content of 12% and that those tested at 5 or 18% are similar. Two stages of recovery were apparent in all cases: a linear initial

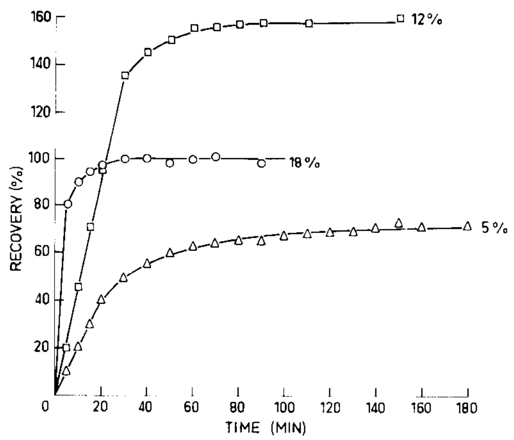

FIG. 1. Selected rate curves showing the development of recovery to the maximum obtained in the radial direction of three individual blocks, one at each moisture content, treated with ammonia at 50 psi.

stage during which most of the maximum recovery was attained, and a slower final stage. This is shown for three typical blocks in Fig. 1. The rate of recovery in the initial stage was highest in blocks treated at 18% moisture content (Table 2). The rate of ammonia uptake was clearly greatest in the wettest blocks because of the affinity of the anhydrous gas for water. Similarly, Davidson and Baumgardt (1970) showed that the required treatment time for ammonia plasticizing as indicated by bending stiffness was inversely related to wood moisture content. Also shown in Table 2 are the times taken for blocks to attain maximum recovery; blocks treated at 12 and 18% required considerably less time than those treated at 5% moisture content.

Dimension measurements made at regular time intervals after the end of ammonia treatments indicated that in many cases the recovery was to a large extent only temporary. In general, as ammonia evaporated and escaped from the wood, the blocks shrank. In Table 2 comparison is made between maximum and final recovery; the latter represents three days after treatment when each block had been equilibrated to its original moisture content. Those blocks treated at 12% recovered more than all others. Only the 5% blocks treated at 20 lb/in^2 differed significantly in that a negative final recovery or further shrinkage was apparent. In all cases most loss of recovery or re-shrinkage occurred within one hour of removal from ammonia.

DISCUSSION

Shrinkage of dry wood blocks with concomitant density increase after gaseous ammonia treatment has been reported by Pentoney (1966) and others since. The mechanisms reported here involve plastic recovery of collapse so it is likely that any shrinkage following ammonia plasticizing was more than offset by the recovery obtained. However, it appears that in the 5% moisture content blocks treated at 20 lb/in^2 the opposite was true and ammonia shrinkage was greater than ammonia-induced plastic recovery.

Both ammonia and steam gave best recovery in blocks treated at 12% moisture content. That both should have shown their optimum effect at the same moisture content suggests that the controlling factors in collapse recovery lie in the condition of the wood at the time of treatment and not in the plasticizing methods involved. The observed exception to this is that heat alone at any moisture content was ineffective in allowing recovery. There are no known properties of wood that lead one to conclude that 12% is the best wood moisture content for collapse recovery. There are, however, reasons that the alternatives tested might be less than optimum and possibly quite unfavorable.

Kubler (1970) indicated that red oak plugs conditioned to a range of moisture contents and then heated in vapor-proof tubes expanded radially and tangentially to an extent that was far in excess of that due to thermal expansion and was assumed to be a result of collapse recovery. Maximum tangential recovery was reported to be in plugs that had been conditioned within the range of 11 to 15% moisture content.

Collapsed eucalypt timber dried to around 5% moisture content can be shown to be relatively resistant to conventional reconditioning. Greenhill (1938) suggests that at moisture contents lower than 12 to 15%, wood is not pliable enough to recover fully. In addition, it is likely that at 5% the presence of excessive drying stresses would accentuate this factor. During the steaming process, therefore, satisfactory recovery cannot be obtained until the moisture content of the wood is raised considerably.

The same timber dried to 18% moisture content has been shown to recover better than that dried to 5% (Greenhill 1940), and this is the approximate upper limit of the range that has been suggested to kiln-operators in Australia (Anon. 1963). However, reconditioning at this moisture content has been reported, e.g., from industrial sources, to give inconsistent results, and the reasons for this could be similar to those that explain the results found in the present study. If some cells in the wood are completely sap-filled at the time of reconditioning, then capillary tensions and collapse will occur during subsequent redrying to a given moisture content. Although some collapse may be recovered in those cells that are empty of sap, capillary tensions present in partially dried cells would impede their recovery. This situation could arise in both steaming and ammonia treatments. Hart (1970) demonstrated that in white oak heartwood, a slow-drying wood liable to collapse on drying, water-filled lumens persisted during drying even below 20% moisture content. It is suggested that this condition, which has also been observed in *Eucalyptus delegatensis* (Mackay, unpubl.), causes incomplete recovery at 18% moisture content. In timber dried to 12%, however, all lumens are probably empty of sap, and recovery can proceed under the influence of a plasticizing agent. The effect of steaming in raising the moisture content of wood is of some interest. It is well known that during commercial reconditioning treatments, the average moisture content of timber can be raised 3 to 4%, mostly in the surface layers, and further drying may be necessary. Steam treatment of 5% moisture content blocks allowed some recovery to occur, but ammonia treatment of these blocks even at 50 lb/in^2 had considerably less effect (Table 2, Final Recovery).

Wood dried to 12% moisture content therefore presents a balanced situation where the moisture content is low enough that no sap-filled lumens remain yet is not so low that plasticizing is ineffective and is hampered by excessive drying stresses. Steam and ammonia play a similar role in collapse recovery in a number of respects. Although it has been demonstrated that shrinkage following ammonia treatment is greatest in the radial direction (Parham et al. 1972), contrary to normal or collapse shrinkage, the results reported here suggest that recovery in ammonia as in conventional steam reconditioning may be greatest in the tangential direction. In both systems 12% was shown to be the optimum moisture content, although wood at a slightly lower level could still be expected to recover during steaming because of moisture pickup.

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