



The effects of different manufacturing strategies on the properties of machine stress graded sticks of timber

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ABSTRACT

During machine stress grading, as it is currently carried out in New Zealand, sticks of timber are colour coded with the grade at 150 mm intervals along their lengths. A possible manufacturing strategy is to select higher grade sections of certain sticks and use them in critical areas. Concerns have been expressed that the remainder of the timber would have significantly lower grade characteristics than the original material.

In this paper, the results of Monte Carlo simulations of different manufacturing strategies are presented along with the results of experimental testing carried out to verify the simulations.

The effects of different manufacturing strategies on the properties are shown depend on a numbers of factors, which include removal rate of higher grade material. It is also shown that the only minor differences occur at the lower bounds of strength and stiffness with significant differences occurring at the mean and higher bound levels.

INTRODUCTION

Machine stress grading (MSG) was developed in the United States of America, Australia and South Africa in the late 1950's, early 1960's (Galligan et al, 1977). It was first used commercially in the United States in approximately 1963 and in New Zealand in 1976 (Whiteside et al, 1979).

Problems were experienced in early production of MSG timber. Insufficient dimensional and moisture control resulted in a lack of uniformity of product. With the introduction of proper production quality control procedures and grading standards such as AS/NZS 1748:1996 MSG has become consistent and accurate method of grading timber.

As with all grading techniques, machine stress grading uses predictors to estimate the strength and stiffness properties of the timber. In machine stress grading, the stiffness of a stick or part of a stick of timber is measured and a grade is assigned to the stick based on the results of the stiffness measurement. This stiffness grading technique uses the knowledge there is a relationship between the strength and stiffness of a stick of timber. In visual grading however, the size of defects such as the size of knots and slope of grain are predictors used to assess the grade of timber.

The grade of a length of MSG timber can be assigned in a number of ways. A single grade can be assigned to the stick based on the minimum stiffness measurement made in the length of timber. Alternatively a stick can be continuously marked, usually with coloured paint, to indicate the grade of the stick at the point of measurement. The overall grade of the continuously marked stick of timber is taken as the minimum grade mark on the timber.

The use of the continuous marking system has a number advantages for manufacturers using MSG timber. The manufacturer can select or dock out particular grade material for different end uses. For example, higher grade material can be used for the critical members of trusses. This docking of timber results in changes in the population strength and stiffness characteristics of the original grade of timber from which the docked stick was taken.

In this paper, assessments of the effects of different manufacturing strategies on the population characteristics are determined. To date, only changes to the original population grade have been assessed. Work is currently being undertaken to assess the properties of the higher grade material removed from the stick of timber.

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DERIVATION OF ENGINEERING DESIGN VALUES

In limit state design codes, engineering design values are often termed characteristic values. These characteristic values are estimates of the population values at particular levels. For example, the characteristic bending strength value for a particular grade is often an estimate of the population five percent lower limit bending strength. That is 95 percent of all the boards of a particular grade should have a bending strength higher than or equal to the characteristic value. The characteristic modulus of elasticity value is often taken as an estimate of the population mean modulus of elasticity value. Estimates of the characteristic strength values are usually made with a confidence level of 75 percent.

In Australia and New Zealand, a method of determining the characteristic values for a particular grade of timber is set out in AS/NZS 4063:1992. AS/NZS4063:1992 stipulates that testing should be undertaken on a representative random sample (usually greater than 30 specimens) of the grade of timber. Testing is carried out at a random position along the length of timber and not at the position of worst defect. In random position testing, estimates of the population characteristics for a particular grade are determined from results of tests carried out on sections of sticks containing only high strength and stiffness characteristics as well as sticks containing low strength and stiffness characteristics. Therefore removal of the higher grade material from the sticks will result in changes to the overall population characteristics.

ASSESSMENT OF DIFFERENT MANUFACTURING STRATEGIES

The assessment of different manufacturing strategies on the strength and stiffness characteristics of MSG timber was carried out in two parts:-

- (i) an analytical investigation
- (ii) an experimental investigation.

Analytical Investigation

In the analytical investigation, a series of Monte Carlo simulations were undertaken. The grading output from stress grading machines located at saw mills in Australia and New Zealand were downloaded and converted into modulus of elasticity values using the Tadpole quality control and assessment program (Grant (1998)). Moduli of elasticity values were obtained at 150 mm intervals along each stick. Values from a minimum of 4000 sticks of each grade were stored for each stress grading machine. The values from the 4000 sticks were considered as the parent population of the sawmill where the measurements were made.

Simulation Method

The simulation process involved randomly selecting a stick of timber from the parent population. After selection of the stick, the manufacturing modification of stick was then undertaken. These modifications looked at the removal of higher grade material. For example, if the manufacturing modification involved the removal of a 1200 mm length of higher grade timber from one end of the stick of timber then the stick length was shorten by 1200 mm if the condition could be met. A test position was then determined at a random position along the remaining length of timber. A weighted modulus of elasticity value then was calculated for the stick. The weighted bending modulus of elasticity was calculated using the MSG modulus of elasticity values in test span, weighted in accordance corresponding bending moment in the test span. A test span of 18 times the depth of member was used in the simulation process. This test span was determined in accordance with the guidelines given in AS/NZS4063:1992. The selection of sticks was repeated up to 30000 times in order that cumulative frequency distributions could be plotted. To determine the population bending characteristics for each parent population, a simulation was undertaken on the parent population with no modification of the stick of timber.

The simulation routines were written in Fortran. These routines made extensive use of the NAG Fortran Library Routines (NAG Fortran Library Manual, 1990) for generating the random stick numbers and test positions.

Simulation Results

An initial investigation was carried out to determine the effects of removing a 2400 mm length of higher grade material from one end of the stick of timber. Two extreme results are presented in Figures 1 and 2. In each figure, the cumulative frequency is plotted against the relative modulus of elasticity where the relative modulus of elasticity is the actual modulus of elasticity divided by the median modulus of elasticity of the parent population.

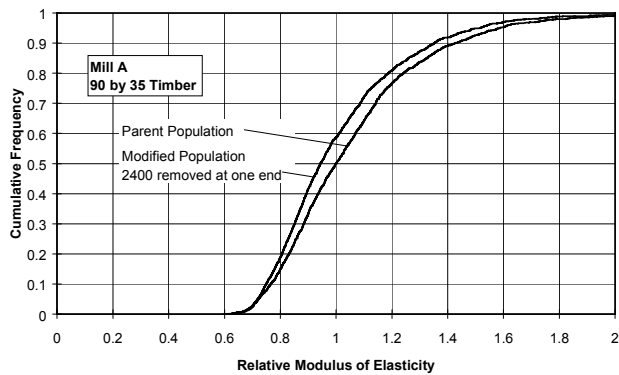


Figure 1

Cumulative Frequency Distributions of Relative Modulus of Elasticity for Mill A's Parent Population and Modified Population (2400 removed from one end)

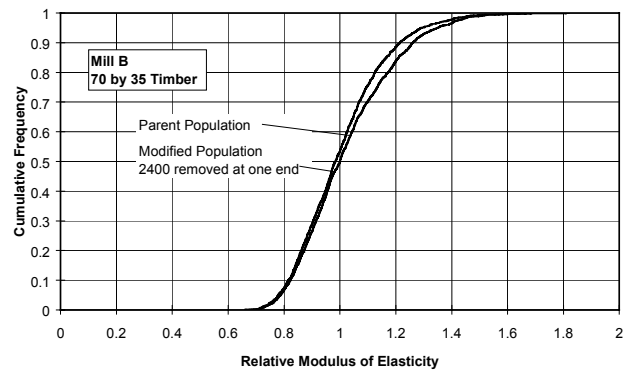


Figure 2

Cumulative Frequency Distributions of Relative Modulus of Elasticity for Mill B's Parent Population and Modified Population (2400 removed from one end)

In Figure 1, the results of the simulation undertaken using the data for 90 by 35 timber processed at Mill A are presented. Approximately 20 percent of the boards selected were able to have a 2400 mm length of higher grade material cut from one end. This manufacturing process made little discernible difference at the five percentile level and the modulus of elasticity of the modified population was only 94 % of the original population value at the fifty percent level. At the ninety-five percentile level the modified value was 95 % of the parent population ninety-five percentile value. A comparison of results for both mills is given in Table 1.

Table 1

Comparison of Parent Population and 2400 mm Modified Population Relative Modulus of Elasticities

	Relative Modulus of Elasticity			
	Mill A		Mill B	
	Parent Population	2400 Modified Population	Parent Population	2400 Modified Population
5 % Level	0.72	0.72	0.79	0.78
25% Level	0.86	0.83	0.89	0.88
50 % Level	1.00	0.94	1.00	0.98
75% Level	1.18	1.13	1.13	1.10
95 % Level	1.59	1.51	1.35	1.29
Mean	1.06	1.01	1.02	1.00
Coefficient of Variation	0.28	0.27	0.17	0.16

In Figure 2, the results of the simulation undertaken using the data for 70 by 35 mm timber processed at Mill B are presented. Approximately 7 percent of the boards selected in the second part of the simulation process were able to have a 2400 mm section of higher grade material cut from one end. This manufacturing process made little discernible difference at the five and fifty percentile levels and only minor differences at the higher levels. The results of initial simulations indicated that degree of change to the population characteristics is dependent on the amount boards removed or recovery rate of higher grade material.

A second series of analyses were undertaken to investigate the effects of the manufacturing recovery rate on the properties of the population. Simulations using various manufacturing strategies were undertaken. Strategies investigated included removal of a 600, 1200, 1800, 2400 mm lengths of timber at any position along the length of the stick. Figures 3, 4 and 5 show cumulative frequency distributions for different modified populations. Recovery rates for the various manufacturing strategies are shown in Table 2.

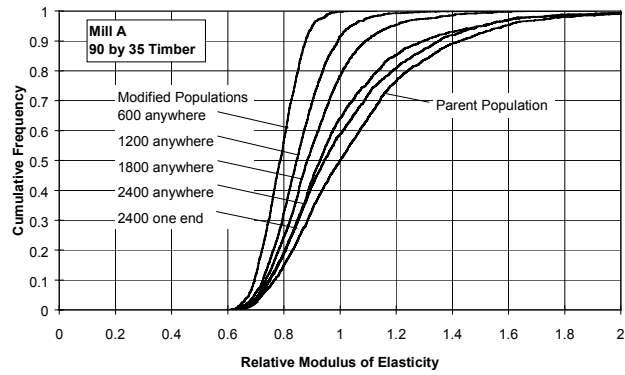


Figure 3
Cumulative Frequency Distributions of Relative Modulus of Elasticity
Effect of Different Manufacturing Strategies for Mill A

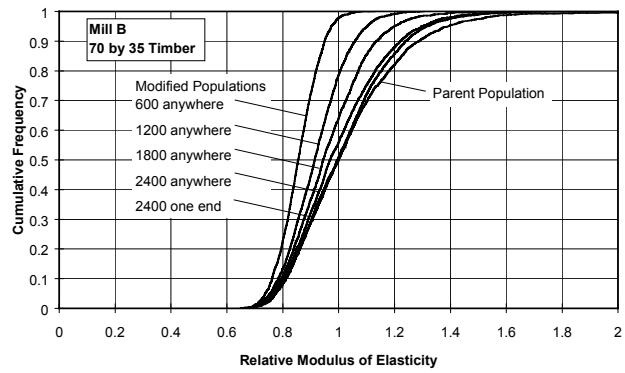


Figure 4
Cumulative Frequency Distributions of Relative Modulus of Elasticity
Effect of Different Manufacturing Strategies for Mill B

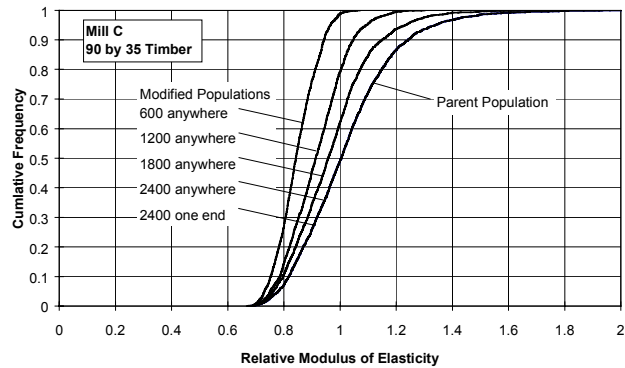


Figure 5
Cumulative Frequency Distributions of Relative Modulus of Elasticity
Effect of Different Manufacturing Strategies for Mill C

Table 2
Effects of Manufacturing Strategy on Recovery Rate

Mill	Recovery Rate				
	2400 mm removed one end	2400 mm removed anywhere	1800 mm removed anywhere	1200 mm removed anywhere	600 mm removed anywhere
Mill A	20 %	25 %	37 %	53 %	78 %
Mill B	7 %	15 %	29 %	47 %	75 %
Mill C	5 %	6 %	27 %	49 %	78 %

The plots of Figures 3 to 5 show that the recovery rate has only a small effect on the population characteristics at the lower modulus of elasticity bounds. However, as the recovery rate increases, the more significant the effect is on the population at higher bounds of modulus of elasticity.

Experimental Investigation

The simulation process was unable to assess the effects of the different manufacturing strategies on the population strength characteristics because of the lack of relevant strength information. In order to assess the effects of a particular manufacturing strategy on strength, a series of two experimental investigations were undertaken. In both investigations, 400 sticks of MGP10 *Pinus radiata* timber were taken from the production runs of two sawmills, one sawmill in New Zealand and the other in Australia.

Each lot of 400 sticks was split into two equal sized samples. One sample from each sawmill was tested in bending in accordance with the requirements of AS/NZS 4063:1992, except each specimen was only loaded to a maximum extreme fibre stress of 30 MPa. These samples were designated the control or undocked groups. Each stick of timber from the second sample from each sawmill was inspected to determine whether a 2400 mm length of MGP12 or higher grade material could be removed from either end of the stick. If higher grade material could be removed then the remaining section of the stick was only considered for testing, or alternatively the entire length was considered for testing.

Approximately 36 % and 40 % of specimens from the second samples from Mills A and D respectively were able to have a 2400 mm length of higher grade material removed from either end of the stick. Figures 6 and 7 show cumulative distributions of relative modulus elasticity, where the relative modulus of elasticity is taken as the actual modulus of elasticity divided by the median modulus of elasticity of the control group. A summary of the relative modulus of elasticity results is presented in Table 3.

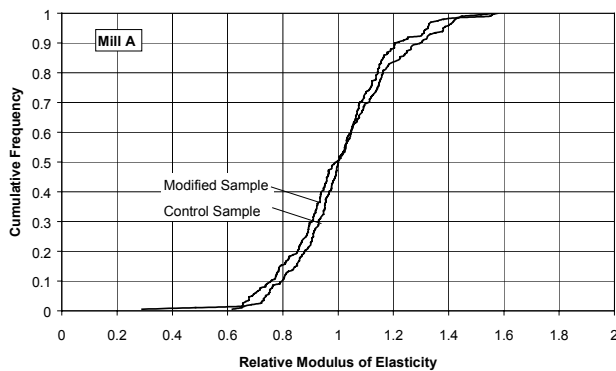


Figure 6
Cumulative Frequency Distributions of Relative Modulus of Elasticity for Mill A's Control Sample and Modified Sample (2400 removed from either end)

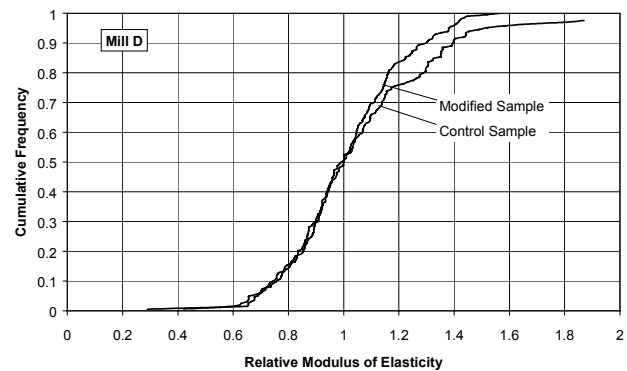


Figure 7
Cumulative Frequency Distributions of Relative Modulus of Elasticity for Mill D's Control Sample and Modified Sample (2400 removed from either end)

Table 3
Comparison of Control Sample and 2400 mm Modified Sample Relative Modulus of Elasticities

	Relative Modulus of Elasticity			
	Mill A		Mill D	
	Control Sample	2400 Modified Sample	Control Sample	2400 Modified Sample
5 % Level	0.73	0.69	0.66	0.71
25% Level	0.91	0.89	0.87	0.89
50 % Level	1.00	1.00	1.00	0.99
75% Level	1.12	1.14	1.16	1.10
95 % Level	1.32	1.36	1.45	1.52
Mean	1.02	1.01	1.03	1.01
Coefficient of Variation	0.17	0.20	0.24	0.21

The results of Figures 6 and 7 and Table 3 show that the removal of 2400 mm length of higher grade material has little measurable change on the sample stiffness characteristics. Mill A's modified modulus of elasticity values are slightly less than control sample values at lower levels, however at higher levels the values are greater than the control sample values. This trend is opposite to the trend predicted by the simulations, where there is little change at the lower levels and at higher levels the modified sample values are less than the control sample values. The results from Mill D followed similar trends to those predicted by the simulations.

Figures 8 and 9 show cumulative frequency distributions of relative strength. The relative strength is taken as the actual strength divided by the 5 percentile lower limit strength of the control sample. Approximately 12 % of Mill A's and 14 % of Mill D's control and modified samples were failed in the testing. Details of the five percentile lower limits of the control and modified samples are given in Table 4. Coefficients of variation values are also given in Table 4. These coefficients of variation were calculated using the tail fit method given in the draft of AS/NZS 4063:1998.

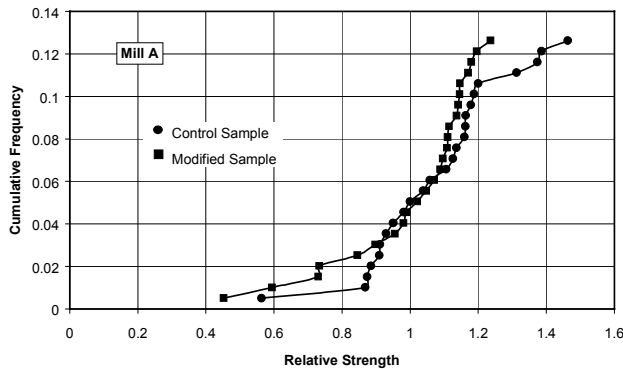


Figure 8
Cumulative Frequency Distributions of Relative Strength for Mill A's Control Sample and Modified Sample (2400 removed from either end)

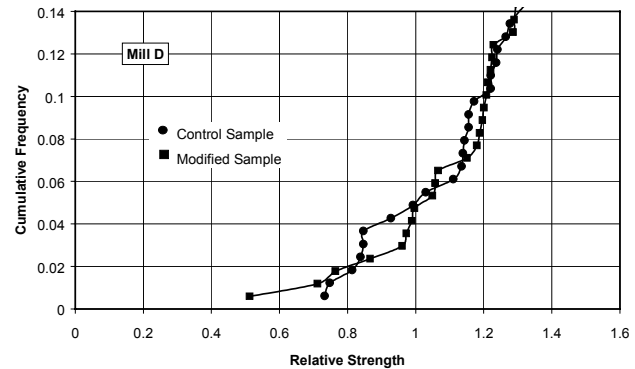


Figure 9
Cumulative Frequency Distributions of Relative Strength for Mill D's Control Sample and Modified Sample (2400 removed from either end)

Table 4
Comparison of Control Sample and 2400 mm Modified Sample Relative Strengths

	Relative Strength			
	Mill A		Mill D	
	Control Sample	2400 Modified Sample	Control Sample	2400 Modified Sample
5 % Level	1.00	1.02	1.00	1.02
Coefficient of Variation	0.21	0.24	0.28	0.24

The strength results for both mills are similar, with there being very little change in the five percentile lower limit strength. In fact, when the higher grade material was removed, there was a 2 percent increase in the lower five percentile value of the remaining material. This highlights the difficulty of measuring the effects of changes in the population characteristics, especially when the effects of the change are very small.

ASSESSMENT OF THE VARIABILITY OF THE TEST METHOD

The experimental investigations showed that removing higher grade material made little difference to the strength or stiffness characteristics. At the five percentile level, the strength of the sample actually increased when the higher grade material was removed. To assess the possible variations resulting from the testing procedure, a series of simulations were undertaken using Mill A's control sample stress grader modulus of elasticity values. In the simulations, a random test position was chosen for each stick of timber and a weighted modulus of elasticity was calculated at the test position. This process was repeated 255 times and cumulative frequency distributions were drawn.

Figure 10 shows range of the cumulative frequency distributions of relative modulus of elasticity and Table 5 gives the range at various levels.

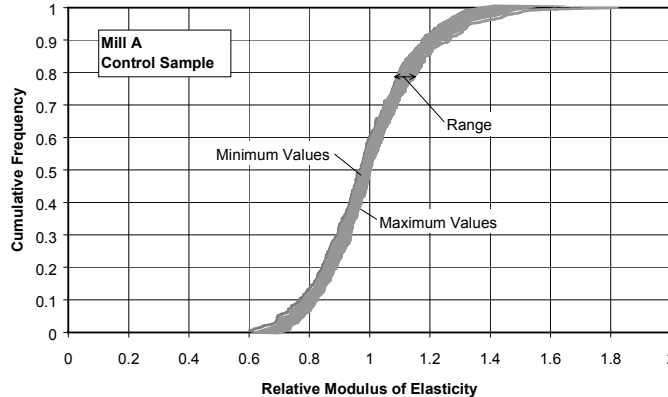


Figure 10
Cumulative Frequency Distributions of Relative Modulus of Elasticity
Effect of Random Position

Table 5
Comparison of Control Sample and 2400 mm Modified Sample Relative Modulus of Elasticities

	Relative Modulus of Elasticity	
	Minimum	Maximum
5 % Level	0.70	0.78
25% Level	0.86	0.91
50 % Level	0.96	1.00
75% Level	1.07	1.17
95 % Level	1.24	1.33

Table 5 shows that up to a 10 % range in values can be expected. Note that the modified sample test values of Table 3 falls in the range of simulation values given in Table 5.

CONCLUSIONS

The results of the analytical investigations indicate that there are only minor changes to the lower bounds of the population stiffness characteristics when higher grade material is removed. However, significant changes are made at the upper bounds of the population when the higher grade is removed. The amount of the change at the upper level is dependent on the amount of higher grade material removed (recovery rate).

The experimental investigations confirmed that only minor changes in the strength and stiffness characteristics occurred at the lower bounds. The experimental investigation also highlighted the difficulty of experimentally measuring the amount of the change especially when the change is small.

Further work is required to assess the properties of the higher grade timber that has been removed.

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