REVISION OF AUSTRALIAN MGP STRESS GRADES 2009

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ABSTRACT:
This paper presents the process undertaken to revise a suite of stress grades used for machine-graded softwoods in Australia. The legal framework in which timber is currently produced has highlighted that manufacturers need to have confidence that all published properties are met by the populations of stress-graded products. The paper outlines the development of properties for MoE, bending strength, tension strength, compression strength and shear strength. Two properties, usually bending strength and MoE, are tested in quality control programs, and compliance of all other properties is inferred from these tests. The study investigated the relationships between the tested properties and the inferred properties.

KEYWORDS: Structural grades, properties, MGP, design characteristic values

1 INTRODUCTION

1.1 ORIGINAL MGP GRADES
MGP grades were first incorporated in AS 1720.1\(^1\) in the 1997 edition, though they had been in production for two years prior. AS 1720.1 defined MGP graded timber as seasoned softwood that complied with the mechanically stress-graded timber product standard AS/NZS 1748\(^2\) and was subject to a continuous monitoring program to ensure that the structural properties were maintained. AS 1720.1 also required, via AS/NZS 4490\(^3\), that the grade properties be initially verified by in-grade evaluation and the graded timber be subjected to periodic monitoring – an annual test of bending properties for one size and grade combination.

The MGP grades were based on an extensive nation-wide testing and evaluation program implemented in 1992\(^4\). 12 mills submitted Australian-grown pine that had been stress-graded to AS/NZS 1748 using uniform grade thresholds. Bending, tension, compression and double span bending shear tests were completed and the pooled results were used to derive characteristic values for three grades – MGP10, MGP12 and MGP15. The same test results were used to derive size factors for each property.

1.2 NATION-WIDE CONFIRMATION TESTING
A number of in-grade test programs\(^5\) have been conducted since the commencement of the MGP grades and as a result of those programs, some changes were made:
- Design tension strength of MGP10 was reduced based on both new test data and a re-evaluation of the 1992 tension test data.\(^6\)
- Research\(^7\) on the bending strength of 45mm vs 35 mm thick MGP10 indicated no real difference, contrary to the previously published properties.
- The industry adopted a 75% level of confidence for verification testing of strength properties and a 50% level of confidence for verification testing of MoE.\(^8\)

1.3 OPPORTUNITY TO REVIEW DESIGN PROPERTIES
Revisions of AS1720.1\(^9\) and AS/NZS4063\(^10\) were undertaken in 2008 and 2009 with publication in 2010. A reliability study had shown the need to change many of the capacity factors in AS1720.1 and to address compatibility issues between the two standards. As a result of the changes to AS1720.1, and changes to testing and evaluation procedures in AS/NZS4063, the opportunity became available for a review of the characteristic values for design for all structural timber product grades. A project was implemented in collaboration with the MGP producers to perform this review and the outcomes are presented in this paper.

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The design MoEs for the revised grades were selected based on a careful balance of technical, marketing and legal issues. The existing Elastic Moduli for the three MGP grades were confirmed (see Table 1). Then strength properties were selected to best position the product to meet all of the technical and legal requirements, while at the same time, minimizing the impact on market acceptance of any changes to the established MGP grades.

### 1.4 REVISION OF TESTING AND EVALUATION STANDARDS

The Australian design characteristic values have been based on random position tests on randomly selected structural products. This convention remains in the new standards, but there have been some other changes to the AS/NZS 4063 testing and evaluation procedures:

- The interpretation of bending strength was changed – rather than being measured as the largest stress in the test span, it is now measured as the stress at the defined failure point. This caused a reduction in strength for some random position bending test results.
- A note under shear testing in the previous version of AS/NZS 4063 had permitted the double-span shear tests used on the MGP grades in 1992. This provision was removed.
- The analyses of the 1992 data and the 2003 data had all been undertaken with a 2 parameter Weibull tail fit analysis to determine the 5%ile strength. A number of different analysis methods to obtain the 5%ile value (eg log-normal) are now permitted.
- A normalization process was used on the 1992 data that was intended to give a 'soft' conversion from working stress design values to limit states design values. This normalization was removed.
- New guidelines for evaluation of design characteristic values were presented in AS/NZS4063.

Aside from any changes in resource since the inception of the MGP grades, the changes due to the revision of the test standards caused both increases and decreases in characteristic values. The net effect varied for each property:

- The removal of normalization reduced the characteristic values obtained from the original test data, when analysed using the new methods. The difference was most significant for the higher grades that generally had a lower CoV.
- For bending strength tests, the resulting design characteristic value was reduced because of the change in the method of measurement in the bending test.
- For bending shear strength tests, the single span shear test in the standard gave generally lower results than the two-span test method.
- The characteristic values from log-normal analysis were often a little higher than those from the 2 parameter Weibull analysis, due to the lower sampling correction factor.

### 2 BASIS FOR ESTABLISHING REVISED MGP PROPERTIES

The opportunity to define new properties required a careful balance of technical, marketing and legal issues. The design MoEs for the revised grades were selected based on an understanding of market acceptance and the character of the national softwood resource. The test results of both the 1992 study and the 2003 study were analysed to determine the log-normal 5%ile of the bending strength data. In order to include the effects of the change in the definition of bending strength, the characteristic bending strength values evaluated from the 1992 and 2003 data were reduced by the representative values above. The results were plotted against the characteristic MoE of the same product from the same mill.

Figure 1 shows the superimposed results of each product from each mill in the two studies, together with the line of best fit for each and the line adopted for the revised MGP grades.

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**Figure 1: Characteristic Bending strength vs Characteristic Bending MoE**
In Figure 1, each point represents the characteristic values for each grade for each mill. It shows that there is a spread of values about the lines of best fit. There appears to be a difference between the two data sets with the 2003 data having generally lower MoE than the 1992 data (the 2003 line is to the left of the 1992 line). The 2003 data also appears to have less scatter than the 1992 data which implies that producers are achieving more uniform properties with improvements in grading technologies and the experience gained in producing MGP grades.

The relationship between the design characteristic bending strength and the design characteristic MoE for the MGP grades was taken as the black line in Figure 1 and is presented in equation (1). Points that are lower than the line, represent mills that tend to be more strength limited in production, and those above the line represent mills that tend to be more stiffness limited in production. The MGP relationship is close to the lower envelope of the 2003 data. This means that most producers' recent production would be stiffness limited. This is appropriate as all grading methods currently used and those planned for implementation in the near future rely on estimates of product stiffness as a primary grading parameter.

\[ f'_{b} = 0.201 \times E^{1.935} \text{ MPa with } E \text{ in GPa} \quad (1) \]

where \( f'_{b} \) = characteristic bending strength, and \( E \) = characteristic Modulus of Elasticity.

The steps to derive this equation were as follows:

- The line of best fit through the adjusted 2003 mill data was found
- The strength values from the relationship were then reduced to ensure that less than 20% of products would be strength limited in production.
- The reduction was greatest for lower strength products with a higher CoV for strength and smallest for higher strength products with a lower CoV for strength.

Equation (1) shows the relationship between the two principal design characteristic values for the three MGP grades. The design characteristic properties for compression, tension and shear were linked to these two properties using test data.

### 2.2 COMPLIANCE OBLIGATIONS

Any of the design characteristic properties may be critical in some applications. Producers must be able to demonstrate, with an appropriate level of confidence, that all batches of MGP structural timber have achieved all of the properties.

Normally compliance is demonstrated by testing two structural properties. The tested properties are the "indicator" properties, and for most operations these are bending strength and bending MoE. This has implications for setting the design characteristic values of tension, compression, and shear strength properties ("inferred" properties).

The derivation of the inferred properties must all incorporate conservatism to account for the variations at any time in the relationship between the inferred and its closest indicator property. The level of conservatism was set to give a 75% confidence level, that each inferred property would comply based on a verification of the indicator properties on a sample size of 30 pieces. Each characteristic value from testing of an inferred property was multiplied by a property modification factor \( k_i \) given in equation (2) in order to develop the design characteristic value.

\[ k_i = 1 - 1.17 \frac{CoV}{\sqrt{n}} \quad (2) \]

where \( k_i \) = property modification factor, \( CoV \) = coefficient of variation of the inferred property, and \( n = 30 \).

Equation (2) is appropriate for the 5%ile of a log-normal distribution.

Each of the inferred properties was related to one of the indicator properties. To determine whether each inferred property was better linked to bending MoE or bending strength, correlations of the test data from the 1992 tests in which all properties were evaluated, were used to derive a line of best fit for the relationship. As small samples were used for the properties of the highest grade (MGP15) sampling error induced much higher scatter into the MGP15 data than is seen in testing that grade with normal sample sizes. Therefore, the comparison of correlations was only performed on the data from testing of MGP10 and MGP12. Each mill’s data was used to derive the characteristic values of each grade, and in Figures 2, 3 and 4, the red points represent this data. Power law relationships were fitted to the data as they are often used to determine the relationship between properties in stress-grades or strength classes. (They represent any non-linearities in the relationship and always pass through zero for both properties). The correlation coefficients for the power law relationships were compared to find the best predictor of the inferred property.

Sensitivity studies of the mill data had shown that for some relationships involving the inferred properties, omitting just one mill's data could change the actual correlation without altering the indicator property that was best correlated with it. So, in establishing the power law relationship between the indicator and inferred properties, the data for all mills was pooled to give a single very large sample for each grade (including MGP15 which had enough pooled data to give meaningful results). The pooled data was then used to derive the power law to relate inferred properties to the relevant indicator property. Sensitivity studies showed that these power laws were not significantly changed by removing any one mill's data.
2.3 TENSION STRENGTH

Figure 2 shows that in the 1992 mill data for MGP10 and MGP12, tension strength correlated better with bending strength than MoE ($R^2$ of 0.82 compared with 0.58). Hence the design characteristic value for tension was derived from the bending strength rather than the MoE for each grade.

The resulting power law is shown in equation (4) and is taken from the pooled data for each grade.

\[ f'_{t} = 0.438 \times f'_{b}^{1.015} \text{ MPa with } f'_{b} \text{ in MPa} \]  \hspace{1cm} (3)

where $f'_{t}$ = characteristic tension strength, and $f'_{b}$ = characteristic bending strength.

The power law relationship derived from the pooled data in Figure 2 and reproduced as equation (3) gives a very similar line to the line of best fit through the mill data in Figure 2. The design characteristic values for tension strength were established using equation (3) and a property modification factor applied to give confidence as it was an inferred property, using equation (2). The process is summarized in Table 1.

2.4 COMPRESSION STRENGTH

Figure 3 shows that in the 1992 mill data, compression strength correlates better with MoE than with bending strength ($R^2$ of 0.62 compared with 0.50). Hence the design characteristic value for compression was derived from the MoE rather than the bending strength for each grade.

The design characteristic value for compression strength was based on equation (4) and subjected to a property modification factor from equation (2) as it was an inferred property.

\[ f'_{c} = 1.551 \times E^{1.098} \text{ MPa with } E \text{ in GPa} \]  \hspace{1cm} (4)

2.5 SHEAR STRENGTH

Figure 4 shows that in the 1992 mill data, shear strength of the data correlates marginally better with MoE than with bending strength ($R^2$ of 0.52 compared with 0.35.) While the correlation with either was not good, the design characteristic value for shear strength was derived from the MoE rather than the bending strength for each grade. The shape of the relationship with MoE was more consistent with expectations of timber properties.

Figure 4 was used to establish that the bending shear strength was better correlated with the MoE of the grade rather than the MoR of the grade. The resulting power law from the two-span shear test is shown in equation (5) and is taken from the pooled data for each grade.
\[ f'_s = 0.323 \times E^{1.145} \text{ MPa with } E \text{ in GPa} \]  

(5)

where \( f'_s \) = characteristic shear strength, and \( E \) = characteristic Modulus of Elasticity.

\[ f'_s = 0.208 \times E^{1.125} \text{ MPa with } E \text{ in GPa} \]  

(6)

where \( f'_s \) = characteristic shear strength, and \( E \) = characteristic Modulus of Elasticity.

Figure 4: Shear strength correlations with indicator properties

However, the data obtained in 1992 and used as the basis of this analysis was based on the two span shear test. A very limited amount of information was available for the single span shear test offered as the only test method in the most recent revision of AS/NZS4063. This data gave a power law shown in equation (6).

\[ f'_s = 0.208 \times E^{1.125} \text{ MPa with } E \text{ in GPa} \]  

(6)

where \( f'_s \) = characteristic shear strength, and \( E \) = characteristic Modulus of Elasticity.

It can be seen that while the exponent in the power laws shown in equations (5) and (6) were similar, the multiplier was significantly lower (around 2/3 the value). In establishing design characteristic values for shear, the industry considered the following factors:

- The comprehensive nationwide test program that led to equation (5) was performed to a non-standard test no longer offered as an alternative in AS/NZS4063.
- It was found that Equation (6) gave shear to MoE ratios similar to softwoods in other parts of the world whereas equation (5) gave values significantly higher than those published elsewhere.
- The very limited data available made it difficult to conduct a technical investigation with the same rigour as for the other properties.
- Published timber framing span tables were unaffected by the lower shear values given in equation (6).
- The need to be able to demonstrate property compliance based on the revised test.

As a conservative interim solution, the design characteristic value for shear strength was based on equation (6) and subjected to a property modification factor from equation (2) as it was an inferred property. The CoV values for shear used in Table 1 were those from the nationwide study using two-span tests.

A research project to refine shear test methods and develop more national test data on bending shear strength of the MGP grades is planned.

### 3 DESIGN CHARACTERISTIC VALUES FOR MGP GRADES

The design characteristic values to be included in AS1720.1:2010 are shown in Table 1. The rounding protocol adopted in AS1720.1 was taken into account in determining the final design characteristic values.

**Table 1: Design Characteristic Properties of MGP grades**

<table>
<thead>
<tr>
<th>Property</th>
<th>MGP10</th>
<th>MGP12</th>
<th>MGP15</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoE (GPa)</td>
<td>10.0</td>
<td>12.7</td>
<td>15.2</td>
</tr>
<tr>
<td>Bending Strength (MPa)</td>
<td>17</td>
<td>28</td>
<td>39</td>
</tr>
<tr>
<td>( f'_b = 0.201E^{1.935} )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension strength (MPa)</td>
<td>CoV 42%</td>
<td>CoV 37%</td>
<td>CoV 30%</td>
</tr>
<tr>
<td>CoV and ( k_s )</td>
<td>( k_s = k_s = k_s )</td>
<td>0.92</td>
<td>0.93</td>
</tr>
<tr>
<td>Based on bending</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f'_t = k_s \times 0.438f'_b^{1.035} )</td>
<td>(7.7)</td>
<td>(12.5)</td>
<td>(18.2)</td>
</tr>
<tr>
<td></td>
<td>7.7</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>Compression strength (MPa)</td>
<td>CoV 3%</td>
<td>CoV 19%</td>
<td>CoV 16%</td>
</tr>
<tr>
<td>CoV and ( k_s )</td>
<td>( k_s = k_s = k_s )</td>
<td>0.95</td>
<td>0.96</td>
</tr>
<tr>
<td>Based on MoE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f'_c = k_s \times 1.551E^{1.098} )</td>
<td>(18.5)</td>
<td>(24.2)</td>
<td>(29.8)</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>Shear strength (MPa)</td>
<td>CoV 23%</td>
<td>CoV 19%</td>
<td>CoV 16%</td>
</tr>
<tr>
<td>CoV and ( k_s )</td>
<td>( k_s = k_s = k_s )</td>
<td>0.95</td>
<td>0.96</td>
</tr>
<tr>
<td>Based on MoE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( f'_s = k_s \times 0.208E^{1.125} )</td>
<td>(2.6)</td>
<td>(3.5)</td>
<td>(4.3)</td>
</tr>
<tr>
<td></td>
<td>2.6</td>
<td>3.5</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Note: Figures in brackets represent the design characteristic values before rounding.

The power law relationships used to derive the inferred properties were developed from test results on Australian pine. The \( k_s \) factor was applied to tension,
compression and shear properties to give a 75% confidence that if the indicator property was found to comply, then the related inferred property would also comply.

Table 2 shows the comparison of the new design characteristic values for the MGP grades and the corresponding values that they supersede.

**Table 2: Comparison of Design Characteristic Properties of MGP grades**

<table>
<thead>
<tr>
<th>Property</th>
<th>Date</th>
<th>MGP10</th>
<th>MGP12</th>
<th>MGP15</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoE (GPa)</td>
<td>1997</td>
<td>10</td>
<td>12.7</td>
<td>15.2</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>10</td>
<td>12.7</td>
<td>15.2</td>
</tr>
<tr>
<td>Bending strength</td>
<td>1997</td>
<td>16 (19)*</td>
<td>28</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>17</td>
<td>28</td>
<td>39</td>
</tr>
<tr>
<td>Tension strength</td>
<td>1997</td>
<td>8</td>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>7.7</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>Compression strength</td>
<td>1997</td>
<td>24</td>
<td>29</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>18</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>Shear strength</td>
<td>1997</td>
<td>5.0</td>
<td>6.5</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>2.6</td>
<td>3.5</td>
<td>4.3</td>
</tr>
</tbody>
</table>

All properties in MPa unless otherwise marked.

* In the 1997 properties, MGP10 35 mm thick sections had a bending strength of 16 MPa and 45 mm thick sections had a bending strength of 19 MPa.

In both Table 1 and Table 2, the properties apply to cross-sections of 140 mm depth or less. Larger sizes incorporate reductions for size effects consistent with previously derived values.

Table 2 shows that the bending properties have changed little, but that the revision has significantly reduced properties for tension and compression, while the shear properties have been reduced to around half their previous values.

4. CONCLUSIONS

In response to an opportunity to revise the design characteristic values of MGP structural timber, the Australian softwood industry used the draft AS/NZS 4063 testing and evaluation standard to reanalyze all available test data. The new design characteristic values reflect the relationships between the properties derived from the most recent test data. As bending tests are commonly used in QC programs in Australian mills, producers are able to have confidence that their product complies with bending strength and MoE properties. For all other properties, compliance is inferred from these tests. The design characteristic values for the inferred properties were derived by modeling the uncertainties associated with relationships between tested and inferred properties. Together with the resulting property modification factors, this means the industry can now have a higher level of confidence of compliance for the properties that are not regularly tested in Quality Control.

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