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NATIONAL INSTITUTE FOR FOREST PRODUCTS INNOVATION

Characterising softwood sawn products in Australia

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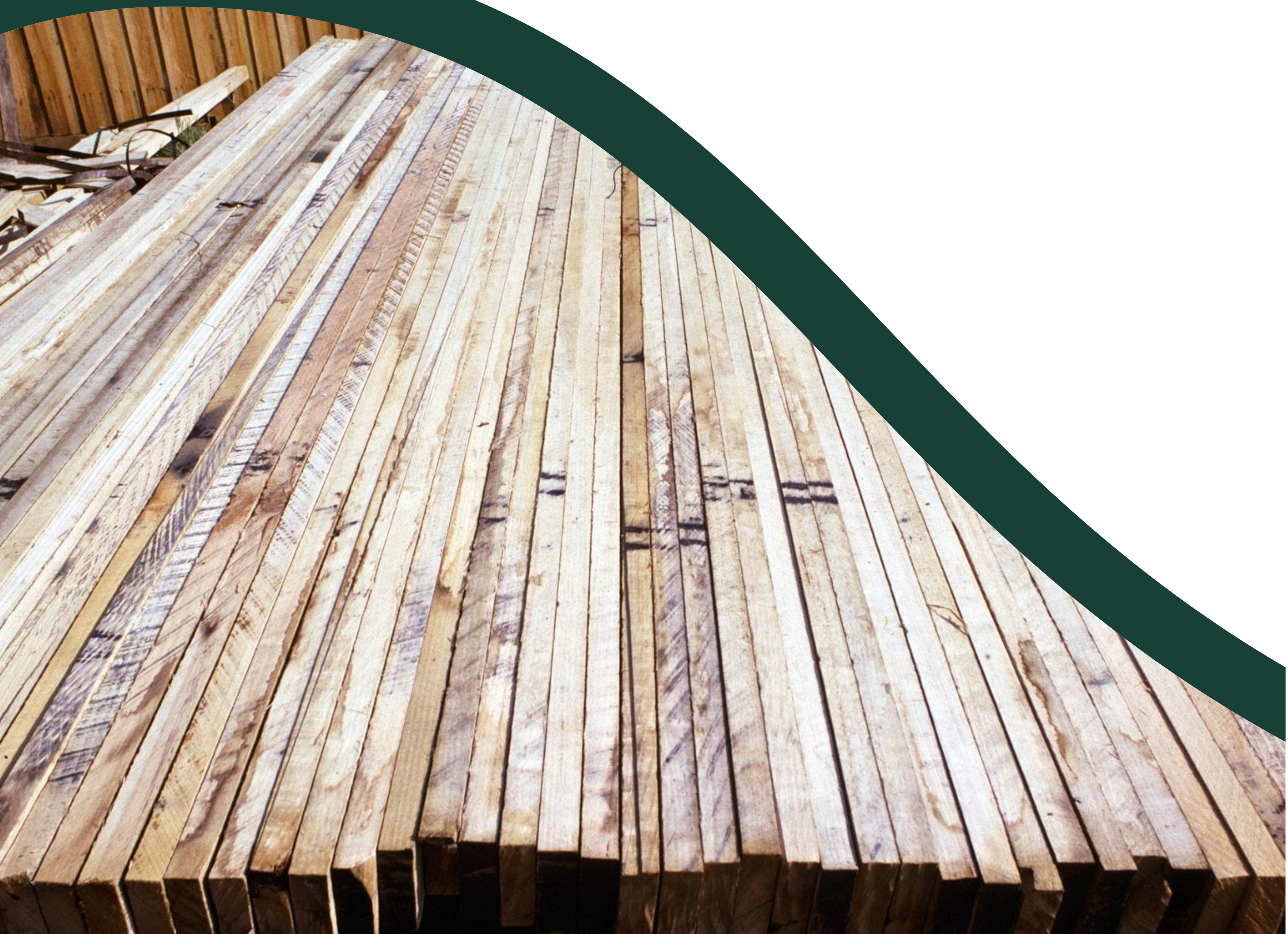

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NATIONAL INSTITUTE FOR
FOREST PRODUCTS INNOVATION
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Characterising softwood sawn products in Australia

Prepared for

National Institute for Forest Products Innovation

Mount Gambier

by

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Executive Summary

The aim of this project was to capture detailed information on the mechanical properties of structural softwood material produced in Australia from across the country predominantly used for timber framed construction. Timber was sampled from 13 mills throughout Australia that cover approximately 90% of machine graded national production. Grading profiles were captured at the time of production allowing for future work on the project dataset; this is an opportunity only possible with modern mill developments in grading and data capture.

Material was tested 'in-grade' as structural sized elements across a range of structural properties including bending strength and stiffness, tension parallel to grain, compression parallel to grain, beam shear, and density. Properties for use in design are presented in AS 1720.1-2010 by grade and size (design values). The national sample covered in this study had characteristic values exceeding the design values across all properties, indicating that mill grading processes within the framework of AS/NZS 1748:2011 are performing as anticipated.

Opportunities for refinement of design values through further research projects have been identified including compression and shear test methods to AS/NZS 4063.1:2010 (commenced at the time of writing). Design characteristic values for density for the existing MGP grades have been proposed along with a relationship between design characteristic values for density and modulus of elasticity.

The legacy dataset from this *2023 In-Grade Study* including test results and grading profiles of the tested boards provides a powerful tool for future MGP grade development work. This project represents a comprehensive, contemporary in-grade study of Australian-grown structural softwood sawn timber.

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Definitions

CFDs	Cumulative frequency diagrams are the graphical representation of the tested populations for quantitative assessment of relative performances.
Count	The number of specimens tested.
JD	Joint design classification groups for seasoned timbers.
MGP	A stress grade with Design Characteristic Values presented in Table H3.1 of AS 1720.1-2010 (Standards Australia, 2010a).
QC	Quality control, the systematic process of ensuring that products or services meet specific standards and requirements.
Sample piece	A manufactured timber piece from the reference population, in its full length.
Stress-graded timber	Timber that has undergone grading to assign a stress grade.
Test piece	A timber segment cut from a sample piece to be tested for a specific mechanical property.
Test span	The loaded portion of a test for a specific mechanical property.

Abbreviations

%ile	=	Percentile, expressed in percentage (%)
b	=	breadth of a rectangular cross-section, expressed in millimetres (mm)
CoV	=	coefficient of variance calculated in accordance with AS/NZS 4063.2:2010
CV	=	characteristic value calculated in accordance with AS/NZS 4063.2:2010
d	=	depth of a rectangular cross-section, expressed in millimetres (mm)
DR	=	design ratio calculated as the ratio of characteristic value and design characteristic value, i.e., *CV/DV*
DV	=	design characteristic value from AS 1720.1-2010, expressed in megapascals (MPa)
E	=	modulus of elasticity parallel to direction of grain, expressed in megapascals (MPa) or gigapascals (GPa)
e	=	displacement of beam, expressed in millimetres (mm)
F	=	applied load, expressed in newtons (N)
f_b	=	bending strength, expressed in megapascals (MPa)
f'_b	=	characteristic bending strength, expressed in megapascals (MPa)
f_c	=	critical (minimum) compression strength among the eight subset compression tests, expressed in megapascals (MPa)
f'_c	=	characteristic compression strength, expressed in megapascals (MPa)
f_t	=	tension strength parallel to grain of the test piece, expressed in megapascals (MPa)
f'_t	=	characteristic tension strength, expressed in megapascals (MPa)
F_{ult}	=	value of the applied ultimate load, expressed in newtons (N)
f_v	=	shear strength, expressed in megapascals (MPa)
f'_v	=	characteristic shear strength, expressed in megapascals (MPa)
k_{ntp}	=	a factor to introduce conservatism appropriate for a 'non tested property'
L	=	length of a test piece, expressed in millimetres (mm)
L_b	=	test span of a bending test piece, calculated as 18 times the depth (18*d*), expressed in millimetres (mm)
L_s	=	length of a sub-set of test piece for compression tests, expressed in millimetres (mm)
L_v	=	horizontal distance from the centre of the test span to the point of failure, expressed in millimetres (mm)
m	=	mass of test piece, expressed in kilograms (kg)
MoE	=	modulus of elasticity parallel to direction of grain, expressed in megapascals (MPa) or gigapascals (GPa)

R^2	=	coefficient of determination, expressed in a decimal number
ρ	=	density, expressed in kilograms per cubic metre (kg/m^3)
ρ_{12}	=	density at 12% moisture content, expressed in kilograms per cubic metre (kg/m^3)
ρ_k	=	characteristic density at 12% moisture content, expressed in kilograms per cubic metre (kg/m^3)
V	=	volume of the test piece, calculated as the product of the measured length, depth and breadth, expressed in cubic meter (m^3)

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1 Introduction

The *Characterising softwood sawn products in Australia* study covered in this report commenced in 2019 and was completed in 2023. It will be referred to in this report as the *'2023 In-Grade Study'*. The study captures the nationally pooled characteristic properties of mechanically stress graded pine produced in Australia over a period from 2020 to 2022. This study characterises the contemporary in-grade performance of Australian grown and produced timber to AS/NZS 1748 series (Standards Australia, 2011a, 2011b), building on previous studies by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (Leicester et al., 1988; Walsh et al., 1993), and *Revision of Australian MGP Stress Grades 2009* (Boughton & Juniper, 2010).

1.1 Participation, roles and responsibilities

The *2023 In-Grade Study* led by the University of South Australia (UniSA) represents a collaboration between participating mills, UniSA, and TimberED Services (TimberED). This project has been funded by the National Institute for Forest Products Innovation (NIFPI) Mt Gambier hub and participating mills. A project steering committee comprising Australian Forest Products Association (AFPA) Solid Wood Processing Technical Subcommittee (SWPTC) representatives, Forest and Wood Products Australia (FWPA), and Engineered Wood Products Association of Australia (EWPAA), was established to provide oversight to the execution of the project. The roles and responsibilities of this project are listed in the Table 1.1. More information on the tasks listed in Table 1.1 is presented throughout this report.

Table 1.1 – Roles and responsibilities in project execution

Tasks	Led by	Support from
Oversight and milestone sign off	Project steering committee	
Development of sampling plan	TimberED	Mill team
Sampling and transport	Mill team	TimberED
Testing and data collection	UniSA	TimberED
Data processing and analysis	TimberED	UniSA
Report generation	TimberED	UniSA

Participating mills represent approximately 90% of domestic pine production graded in accordance with AS/NZS 1748 (Standards Australia, 2011a, 2011b) and cover the geographic spread of radiata pine and Queensland pine (Caribbean/slash pine hybrid) production nationally. Participating mills are listed alphabetically by company name in Table 1.2. This study presents data from material sampled from participating mills as a nationally aggregated dataset; results from individual mills are anonymised within the national dataset. Mill-by-mill sample of product by size, grade or species is not presented in this report.

Table 1.2 – Participating mills

Company	Location
AKD	Caboolture, QLD
AKD	Colac, VIC
AKD	Tumut, NSW
Allied Timber Products (QLD)	Burpengary QLD
Australian Softwoods Bathurst	Bathurst, NSW
Dongwha Australia	Bombala, NSW
Highland Pine Products	Oberon, NSW
Hyne	Tuan, QLD
Hyne	Tumbarumba, NSW
OneFortyOne	Mt Gambier, SA
Timberlink	Bell-Bay, TAS
Timberlink	Tarpeena, SA
Wespine	Dardanup, WA

1.2 Background

Timber is graded in production to allocate each individual piece to a grade with a predetermined set of mechanical properties for use in design. In such a case, the design of timber structures can occur with separation from timber production; linked only through the clear definition of the mechanical properties of the timber grades.

Early studies on timber properties (19th century and early 20th century) used mechanical testing of small clear specimens to characterise the timber in different species. The trend internationally since the 1980s has been towards assessing the performance of the timber as graded in structural sizes ('in-grade') to improve knowledge of the structural performance of graded timber in service.

CSIRO, NSW Forest Commission Research Division (FCRD) and the Radiata Pine Research Institute (RPRI) conducted a study of in-grade evaluation of mill produced radiata pine of 90x35 and 140x45 mm (Leicester et al., 1988) referred to generally as an 'in-grade study'. This was significantly expanded upon by CSIRO in studies assessing the in-grade properties of the national resource of mechanically stress graded "Australian Pine" in 1993 (Walsh et al., 1993) and 1998 (Leicester, 1998) which will be designated generally as the '*1998 In-Grade Study*', for example, in this report.

The *1998 In-Grade Study* (Leicester, 1998) covered mills in SW Western Australia, SE South Australia, Victoria, New South Wales, and SE Queensland. The "Australian Pine" in the study included plantation radiata and Queensland pine (then approx. 2/3 slash and 1/3 Caribbean pine). 7500 specimens were selected for the study in sizes from 70x35 to 290x45 mm. The timber had all been produced using mechanical stress-graders of the time, set with limits prescribed by FCRD to produce F5, F8 and F11. The outcome of the *1998 In-Grade Study* was in-grade design properties for new grades MGP10, MGP12, and MGP15 matching the characteristic properties of the material. The results represented the national picture of in-grade machine-graded pine, reflecting the forest resource, production techniques, grading methods, design standards, and test standards in use at the time in response to markets and construction methods common at the time.

Boughton and Juniper (2010) published a study on MGP properties using in-grade data captured in *1998 In-Grade Study* and bending testing data captured in 2003. This is referred to as the *2010 MGP Properties Study* (Boughton and Juniper 2010). By 2010, AS/NZS 4063 had developed from the 1992 version to one part describing test methods AS/NZS 4063.1:2010 and a second part AS/NZS 4063.2:2010, which included characterisation of properties for Limit States Design directly. In the period from the *1998 In-Grade Study* to the *2010 MGP Properties Study* the industry had seen significant change in grading equipment and its use mill-by-mill, resource change, and utilisation of the machine stress-graded timber in construction. The outcome of the *2010 MGP Properties Study* was revision to bending design values for the MGP grades suitable for Limit States Design. These are the MGP design characteristic values as currently presented in Table H3.1 of AS 1720.1-2010 (Standards Australia, 2010a).

1.3 Current study

The study presented in this report builds on the founding MGP work in 1988 (Leicester et al., 1988), 1993 and *1998 In-Grade Studies* (Walsh et al., 1993; Leicester, 1998), and the *2010 MGP Properties Study*. This *2023 In-Grade Study* captures the contemporary in-grade performance of MGP material from throughout Australia. Many factors have changed that potentially impact in-grade properties since the previous studies:

Forest resource

Forest rotations for Australian Pine targeting sawn boards, such as MGP products, are typically 25-30 years. With each new rotation comes changes to growing stock caused by climatic variations and new planting site locations, changed silvicultural practices and genetics as growers and foresters seek constant improvement. There is continuing interest in the potential to further reduce harvest cycles.

Major bushfires during the sampling period for the project impacted available resource for milling. Several of the contributing mills entered into a period of milling only bushfire affected material. Such material was not sampled for this *2023 In-Grade study.*

Production techniques

Production techniques are continuously developing towards increased quality, recoveries and efficiencies; this development will continue. Changes in production techniques potentially impact the relationships between major and minor properties (indicator and inferred properties in production). Significant production developments since previous in-grade studies include:

- Techniques for log sorting, primary breakdown product mix, and green mill sorting / grading are in constant development, impacting the material that flows to the drymill for grading.
- Kiln schedules and kiln drying processes have developed. There has been increased use of Continuous Drying Kilns (CDKs). Drying processes potentially impact timber quality.
- Mills have been introducing grade optimisation and docking in the production process; longer lengths of timber are docked into shorter boards if a higher grade (more valuable board) can be recovered from the shorter board. Shorter boards offer fewer options for random positioning of test locations and impact the characteristic value for the grade. This is discussed further in Section 2.1 and a parallel study *Developing a technical basis for biased testing structural property verification method of Australian sawn softwood* (Shanks, 2023).

Grading methods

Timber in the *1998 In-Grade Study* was from three stress grades: F5, F8 and F11, representing MGP10, MGP12 and MGP15 in the contemporary terminology. At the time of the *1998 In-Grade Study* grading modulus thresholds were common across all mills in the production of stress-graded timber, predetermined by the FCRD (Leicester et al., 1998), with mechanical graders of the time. (The grading modulus at the time was the modulus of elasticity assessed in a three-point minor axis bending over a span of around 900 mm.)

Machine stress grading processes have changed significantly since the previous in-grade studies. In most Australian mills, the grading algorithms now use a combination of mechanical grader output and scanner output to determine the grade of structural timber. A visual over-ride required for the ungraded ends of mechanically stress-graded timber are by visual (by person or camera) or X-ray scanning machines. A number of mills in the study use non-contact scanning technologies combined with acoustic MoE measurement as the only method of grading the timber.

In the contemporary context, producers adopt custom arrangements of grading equipment with bespoke thresholds and custom quality control (QC) processes; AS/NZS 1748:2011 series (Standards Australia, 2011b, 2011a) requires individual timber producers to qualify their grading processes. As producers have developed more understanding of their grading processes through customisation, they have greater control over production in response to verification testing (to AS/NZS 4490:2011 (Standards Australia, 2011c)) and are able to seek greater recoveries and quality.

Design standards

The *1998 In-Grade Study* was set in the context of timber design standard AS 1720.1-1997 (Standards Australia, 1997), which at the time represented a 'soft conversion' from Working Stress Design to Limit States Design. AS 1720.1-2010 (Standards Australia, 2010a) adopted limit states design. As such, methods for developing Characteristic Values from tested populations for use in Limit States Design are presented in AS/NZS 4063.2:2010 (Standards Australia, 2010c).

Test standards

The *1998 In-Grade Study* adopted four-point bending, tension, double-span shear, and compression to AS/NZS 4063:1992 (Standards Australia, 1992). AS/NZS 4063.1:2010 (Standards Australia, 2010b) and AS/NZS 4063.2:2010 (Standards Australia, 2010c) were published in 2010 as a revision to AS/NZS 4063:1992. Bending test methods were changed such that the bending strength at failure location was added if failure occurred outside of the middle third, rather than always taking the maximum moment. The length of the 90 mm test span changed from 2700 to 2720 mm for tension tests. The modification of the compression test method involved increased compression specimen length from 30*b* to 8*d*+2000 mm in AS/NZS 4063.1:2010. This is approximately 2.5 times the length for 90x35 mm and 190x45 mm sections. The option for multiple short subset tests was modified accordingly, discussed in Section 3.8. The shear test method changed significantly from a double-span in the *1998 In-Grade Study* to a single-span three-point test in AS/NZS 4063.1:2010 (Standards Australia, 2010b). The *2010 MGP Properties Study* (Boughton & Juniper, 2010) used the source data from the *1998 In-Grade Study* with bending test results from a 2003 study to develop the design characteristic values presented in AS 1720.1-2010 Table H3.1 (Standards Australia, 2010a).

Markets and construction methods

The use of sawn structural softwood timber in engineered structures such as mid-rise buildings is growing because of increased prefabrication in the supply chain and ambitions to decrease the embodied energy in construction. Timber-engineered structures are typically designed with high structural efficiency leading to timber-framed elements loaded potentially near to their design capacities in major and minor properties in new and developing applications. It is crucial in this context that engineering properties of the grades are regularly and comprehensively reviewed through in-grade studies such as this.

This study represents a comprehensive in-grade study of the national MGP resource going to market. It is larger in scale than the *1998 In-grade Study* and undertaken in the contemporary context in which each mill operates uniquely in regard to their qualified grading lines (Standards Australia, 2011b) with their tailored verification processes (Standards Australia, 2011c). This study samples 90x35 mm and 190x45 mm boards to capture the in-grade performance of 'narrows' (≤140 mm) and 'wides' (>140 mm). All structural grades produced by each participating mill are sampled along with the non-structural (NS) material from below the lowest structural grade from each mill. Section 2 discusses the material sampled.

2 Test material

2.1 Introduction

This study sampled timber from mills around Australia to assemble a nationally pooled sample representing the production of seasoned sawn structural softwood manufactured to the requirements of the AS/NZS 1748 series (Standards Australia, 2011b, 2011a). At the completion of the project, confidential reports were prepared for each participating mill. These reported on the results from just that mill. The intention of the nationally pooled data is to represent the properties of the domestically produced material available in the market, representing the way in which material is specified and supplied – independent of region and independent of species. This section provides information on how the sample was drawn, the data collected, and how the contemporary mill processes were accommodated in this study.

2.2 Sampling

A sampling strategy was developed for each participating mill to capture representative material from production across grades and sizes (narrows and wides). The sampling strategy was tailored to suit the drymill processes at each mill site. The target for the overall sample was to capture material through an annual production cycle to represent typically varying resources month-to-month. Project sampling commenced late 2020 and completed late 2022, with sampling periods varying mill-by-mill. Black Summer Bushfires impacted the project sampling period in 2020 and 2021, and the COVID-19 pandemic through 2020 - 2022. (Material was not sampled for this study from three mills during the period in which they were only processing bushfire-affected material for up to 18 months.) The sampled materials were considered representative by the mills. Docking and cut solution optimisation processes vary between the mills. See Section 2.5 for detail on how the docking vs. full length was considered in this study.

2.3 Material size and grade

Characteristic Values for design vary by size for a given grade in Table H3.1 AS 1720.1-2010 (Standards Australia, 2010a). Boards of 140 mm depth or less are grouped as ‘narrows’. Boards greater than 140 mm in depth are grouped as ‘wides’ based on understanding of performance variation with size developed from previous in-grade studies. The aim of this study is to generate an understanding of the national MGP resources for both narrows and wides. Therefore, samples were drawn from

90x35 mm and 190x45 mm representing common narrow and wide sizes. All participating mills produce 90x35 mm boards. Seven mills also produce 190x45 mm boards.

Analysis for this project only included boards that were 4.8 m or longer. AS/NZS 4063.1:2010 (Standards Australia, 2010b) requires random position testing to establish characteristic values. As board length reduces relative to the depth, the relationship between the random position result and the biased position result tends towards 1.0 when the boards are equal to the test length. If boards are too short the characteristic values developed from testing will not be representative of those used in establishing the design characteristic values in AS 1720.1-2010 (Standards Australia, 2010a) which were based on longer boards in an era prior to docking and cut solution optimisation at production (Leicester et al., 1998; Boughton & Juniper, 2010). This is discussed in more detail in Section 5.3.

AS 1720.1-2010 Table H3.1 (Standards Australia, 2010a) presents the design characteristic values of MGP10, MGP12 and MGP15. Not all participating mills produce material across all grades. Mills are only able to produce and supply for this study boards in grades they are qualified to produce (Standards Australia, 2011b). Additionally, some participating mills produce F5 or F7 timber at the same time as they produce the MGP grades. Where produced on a regular basis, F5 or F7 was therefore sampled for this study. Material was additionally sampled from all participating mills from timber that failed to achieve the minimum structural grade at the producing mill, but still satisfied the utility requirements. This material is known in the industry as non-structural / merch / utility. In this study, it is referred to as 'non-structural' (NS). Including non-structural material in this in-grade study allows a complete picture of material through the drymill grading line and helps understand/realise potential future opportunities in recovery into potential structural grades. The processes of primary log-breakdown and greenmill sorting that influence material entering the drymill vary mill-by-mill. However, all of the data was combined into the nationally pooled data presented in this study to represent the nationally available population of Australian-produced sawn softwood structural timber.

Table 2.1 – Sampled material specification

Section Size (mm x mm)	Board Length (mm)	Sample Grade
90 x 35 190 x 45	4800 - 6000	Non-Structural F5 MGP10 MGP12 MGP15

In the case where a particular product (size and grade combination) was represented by only one or two contributing mills, the data were pooled with the adjacent appropriate grade for the purposes of the nationally pooled dataset. The impact of this pooling on the Design Ratios reported in this study was evaluated and found to be minimal.

The sample collected per size, per grade, for each property test from each mill is required to contain sufficient pieces for characterisation. AS/NZS 1748.2 (Standards Australia, 2011b) calls for a minimum sample size of 50 for each property evaluated. However, in this project sample sizes targeted a consistent level of statistical confidence. Sample sizes varied with CoV, targeting 50 specimens for MGP10, fewer specimens for higher grades and more specimens for lower grades. Target sample sizes were derived from Equation 2.1.

$$n = \left(\frac{1.15V_b}{0.073}\right)^2 \tag{2.1}$$

With

1.15 = the sampling factor used in AS/NZS 4063.2 for bending strength evaluated using a fit of the data to the log-normal distribution.

V_b = the CoV of bending strength data.

0.073 = a constant that gives n = 50 for a V_b of 45% (a 'typical' CoV for MGP10)

This equation gives a consistent level of confidence in the characteristic values (75%) and is based on Appendix F in AS/NZS 4490. It is plotted in Figure 2.1 with *2023 In-Grade Study* data presented from an example mill. In this case the orange dots represent the sample size required to achieve a consistent level of confidence per grade based on the 'typical' bending strength CoV by grade. The black crosses are the sample size-to-CoV relationship from the *2023 In-Grade Study* data. All crosses are above the blue line that describes the relationship, and therefore all sample sizes by grade satisfied the required level of confidence. This approach was taken mill-by-mill. The nationally pooled data included many more boards in the samples per grade, per size, per tested property. The sample sizes selected in this project are compatible with the methodology outlined in ISO 12122-1:2014 *Timber structures — Determination of characteristic values — Part 1:Basic requirements* (International Organization for Standardization, 2014).

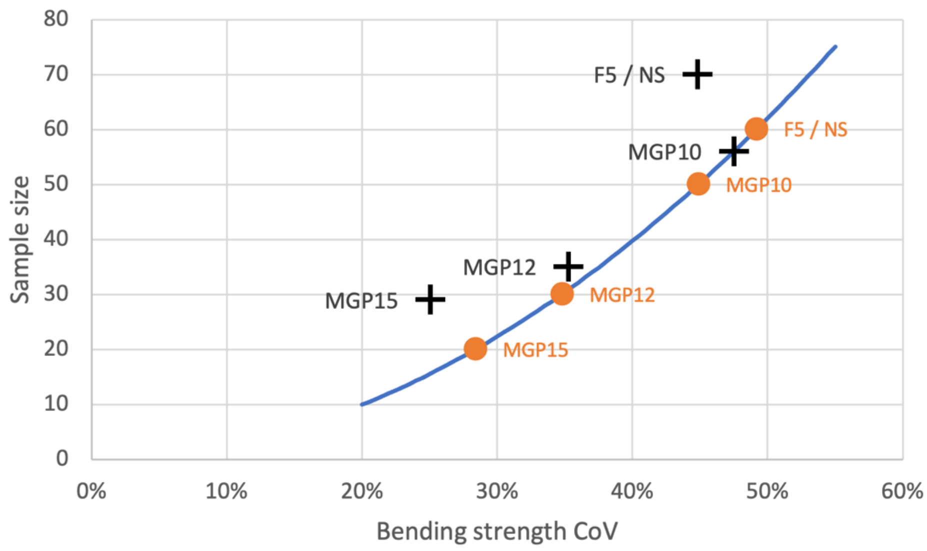


Figure 2.1 – Sample size by bending strength CoV

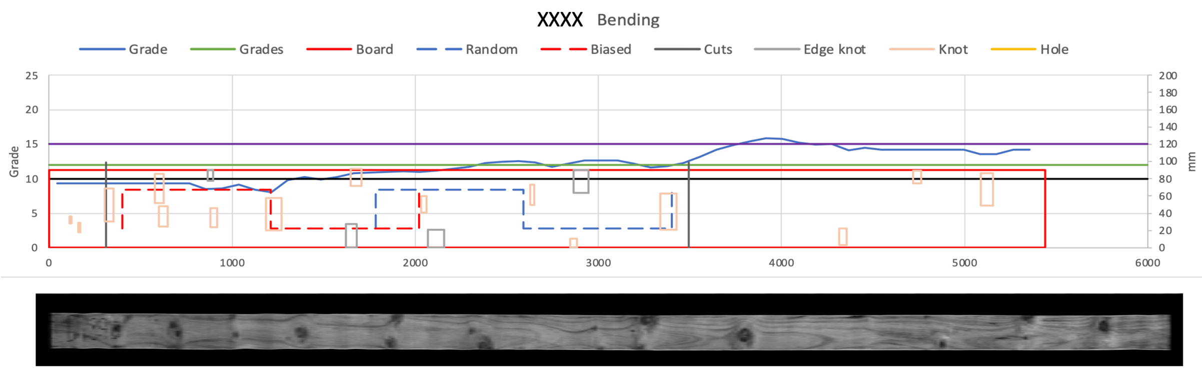
2.4 Procedures for machine stress grading

AS/NZS 1748 series covers *Timber – Solid - Stress-graded for structural purposes* with *Part 1: General requirements*, and *Part 2: Qualification of grading method*. AS/NZS 4490:2011 *Timber – Solid - Stress-graded for structural purposes – Verification of properties* is referenced by AS/NZS 1748 series. Together these standards cover the production of timber sampled for this *2023 In-Grade Study*.

Previous In-grade studies (Walsh et al., 1993; Leicester et al., 1998) sampled materials from participating mills operating machine stress graders using a consistent set of threshold floors referred to as Minimum Grading Modulus that were developed by FCRD for the national production of machine stress graded timber. Since these studies, mills have been required to qualify their grading processes in accordance with AS/NZS 1748.2:2011 (Standards Australia, 2011b), enabling the mills to operate with grading parameter threshold floors to suit their resource (log diet), production processes (grading equipment), product suite, and verification processes. With that in mind there is no single process for machine stress grading adopted through the participating mills, but all mills are required to be producing material in accordance with the AS/NZS 1748.1:2011 requirements (Standards Australia, 2011a), on grading lines qualified in accordance with AS/NZS 1748.2:2011 (Standards Australia, 2011b), with verification processes in accordance with AS/NZS 4490:2011 (Standards Australia, 2011c).

2.5 'Agnostic' grading profiles

The participating mills have a variety of machine stress grading equipment, with tailored operation as discussed in Section 2.4. In production, mills are required to stamp the graded timber with the stress-grade assigned to the piece. In many mills the graded piece in production may be a sub-section of a longer board that has been identified to be docked into smaller, individually graded pieces to maximise value. For this study participating mills were required to provide grading information along the full length of the boards (4.8 m and longer). Available information varied mill-by-mill. The information provided was used to construct an 'agnostic' grading profile along the board length (Figure 2.2). The 'agnostic' grading profile allows legacy storage of the grading data used in this study whilst preserving anonymity of participating mills. The 'agnostic' grading profile also allows for interrogation of the impact of length to depth ratio on random position test results (see Section 5.3).



Specimen	D1898		Test type	Bending	C	Piece min Ag	8.01
			Cut 1	310	mm	Grade limit	Stiffness
			Piece 1	Random and Biased		Random test specimen	
Size	90x35		Cut 2	3492	mm	Minimum Ag	10.9
Grade	F5		Piece 2			Grade limit	Stiffness
Length	5438	mm	Cut 3		mm	Biased test specimen	
Random loca	2592	mm	Piece 3			Minimum Ag	8.01
Bias location	1210.39407	mm	Cut 4		mm	Grade limit	Stiffness

Figure 2.2 – 'Agnostic' grading profile and test data

Figure 2.2 presents an example 'agnostic' grading profile along with a board image captured from the in-line scanner from the participating mill. This information was used in the quality procedures adopted in this study to verify board identification in testing (Section 3).

The focus of this report is random position testing in accordance with AS/NZS 4063.1:2010 (Standards Australia, 2010b) in characterising a population of timber. Random test positions were identified along with the agnostic grading profiles, as shown in Figure 2.2. Biased position testing was also conducted on viable 90x35 mm bending specimens for an associated FWPA funded project *Developing a technical basis for a biased testing structural property verification method for Australian sawn softwood*

(Shanks, 2023), and to generate Phase II test data to support qualification of participating mills to AS/NZS 1748.2:2011 (Standards Australia, 2011b), covered in the individual, confidential mill reports.

Figure 2.2 presents example data relating to test position presented as 'Random location' and 'Bias location'. These represent the middle of the test specimens to be cut from the board. The 'Cut x' dimensions in Figure 2.2 relate to the cuts to be made in the board from the reference end to obtain the test specimen. The length between the cuts produced a test specimen of length required by the relevant test in AS/NZS 4063.1-2010. In the case of tension testing this included the length required for the clamping jaws. In the case of bending tests for 90x35 mm boards this included a random and biased position test specimen. Depending on the separation of the random and biased test positions this may have been two separate test specimens (where test locations were >20d apart), two coincident tests (<6d apart), or two test specimens joined that produced a random result and may also have produced a biased result.

3 Test procedures

3.1 Introduction

Testing of the sampled boards was undertaken at the timber laboratory of UniSA STEM. The test protocols followed AS/NZS 4063.1:2010 *Characterisation of structural timber, Part 1: test methods* (Standards Australia, 2010b). Mechanical testing was conducted to characterise the following properties: bending (bending strength and apparent modulus of elasticity), beam shear strength, compression parallel to grain, and tension parallel to grain. Each individual board was sampled for one type of testing. The sampling strategy is covered in Section 2.2.

The sampled boards were visually verified prior to cutting into test pieces by comparing the appearance of the board (i.e., location of knots, mill-assigned grade, and visual character) against the associated board photo (when photos were provided) and agnostic grading information provided from the mills (as shown in Figure 2.2). Additionally, a process was implemented whereby test pieces that failed below their anticipated 5th percentile strength or above their anticipated 99th percentile strength were retained for post-failure examination.

Measurement tools (i.e., digital scale, callipers, thermometer and moisture meter) and testing machines (tension, compression, shear, and bending machines) were calibrated by Abstec Pty Ltd. Photos of the testing facilities are shown in Figure 3.1 to Figure 3.4. Essential details of the test configurations are presented from Section 3.2 to 3.8 and schematically illustrated in Figure 3.9 to Figure 3.32.

Results output from the test machines were manually input into a cloud-based data collection platform 'RedCap' and stored on UniSA Research Data Storage. Data were extracted from RedCap for analysis throughout testing and at completion of the testing. Failure modes were recorded for each test type and discussed in more detail in Section 5 as appropriate.

Figure 3.1 – Photo of the tension testing machine (Metriguard Tension Proof Tester, Model 403)

Figure 3.2 – Photo of the compression testing machine (CONTROLS Compression Tester, Model PILOT SMART-Line)

Figure 3.3 – Photo of the shear testing machine (CONTROLS Flexure Tester, Model AUTOMAX SMART-Line)

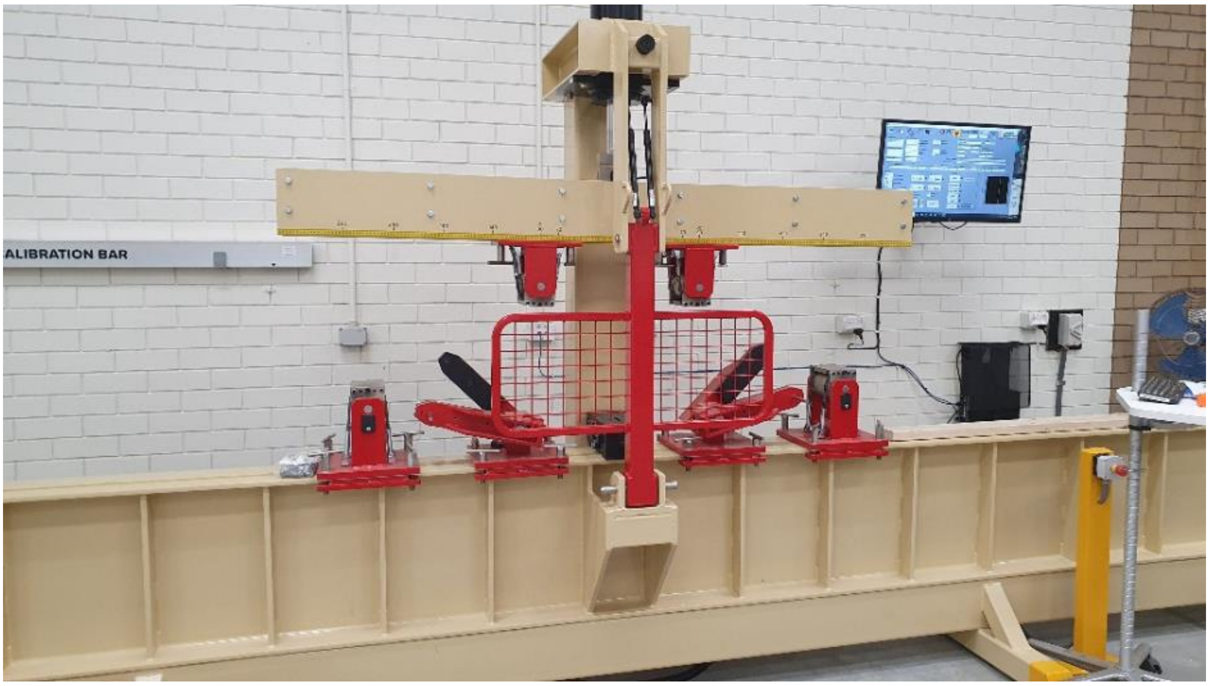


Figure 3.4 – Photo of the bending testing machine (CALIBRE EQUIPMENT Bending Tester, Model STFE20™)

3.2 Test piece location

Random positions were located and presented in the agnostic profile information. Where appropriate, biased position test locations were similarly identified (Shanks, 2023). Refer to Section 2.4 for the information on test location. Test pieces were cut from the sampled boards by using a LEDA radial arm saw (as shown in Figure 3.5).

Figure 3.5 – Photo of the radial arm saw

3.3 Test procedure to determine moisture content

The moisture content of the test pieces were measured within one hour before the mechanical testing by following Clause 5 of AS/NZS 1080.1:2012 (Standards Australia, 2012) using an electrical resistance meter with a hammer electrode (model: Delmhorst RDM-3, serial 15104). The pins on the hammer electrode were inserted into the test piece near the middle of the wide face, aligned parallel to grain, and driven to a penetration of approx. 1/3 breadth. The measurements were taken at 400 mm from the ends of the test pieces (or at the middle of the 4th sub-set test piece in case of the compression tests). Knots and resin pockets were avoided.

Figure 3.6 – Photo of the electrical resistance meter(model: Delmhorst RDM-3, serial 15104)

Oven-dry weight measurement tests were conducted for 5% of the samples by employing Steridium DG-160 (shown in Figure 3.7) in accordance with Clause 4 of AS/NZS 1080.1:2012 (Standards Australia, 2012) to calibrate and verify the electrical resistance meter test results. Oven dry specimens were sampled from bending and shear test specimens with 'zero' at the end of the identifying number. The oven-dry weight measurements were taken twice a day at 9 am and 1 pm and repeated until a stable weight was obtained. Analysis of the moisture content results are presented in Section 4.9.

Figure 3.7 – Photo of the oven (model: Steridium DG-160)

3.4 Test procedure to determine temperature

The surface temperature of the test pieces was measured within one hour before the mechanical testing by using a single laser infrared thermometer (model: FLUKE-62-MAX, as shown in Figure 3.8) with an accuracy of ± 0.1 Celsius.

Figure 3.8 – Photo of the thermometer (model: FLUKE-62-MAX)

In order to fulfil the temperature requirement by Clause 2.2 of AS/NZS 4063.1:2010 (Standards Australia, 2010b), the test pieces were conditioned using two heaters (model: HEATSTRIP THY2200W) located 1700 mm – 2400 mm above the test pieces such that the piece temperature was not lower than 15°C in winter. In summer the test pieces were conditioned by continuously blowing cold air onto the surface using a portable air conditioner (model: WELTEM WPH-3500) such that the piece temperature was not greater than 35°C at the time of testing.

3.5 Test procedure to determine density

Measured board dimensions of the cut test specimens (as opposed to nominal) were used for density calculations, i.e., $\rho = \frac{m}{V}$, where the mass (m) was weighed using a digital balance with an accuracy of ± 0.005 kg, and the volume (V) was calculated as the product of measured length, depth and breadth, i.e., $V = L \times d \times b$.

The depth and breadth were measured using a digital calliper with an accuracy of ± 0.1 mm, while the length was measured using a tape measure with an accuracy of ± 1 mm. The density of the test piece was recorded within one hour before testing.

It should be noted that the compression tests were performed following the alternative procedure (Clause 2.6 of Standard AS/NSZ 4063.1 (Standards Australia, 2010b)). The overall density of the compression specimen was calculated by taking the sum of the lengths and masses of the eight shorter-length test pieces. The depth and breadth was measured at the middle of the fourth subset.

3.6 Test procedure to determine bending strength and apparent modulus of elasticity

The bending tests were performed following Clause 2.4 of AS/NZS 4063.1:2010 (Standards Australia, 2010b) by using a bending testing machine (model: CALIBRE STFE20 (Calibre Equipment Ltd., 2012)). CALIBRE bending test machines are used by most mills throughout Australia for quality control testing to AS/NZS 4063.1:2010 (Standards Australia, 2010b). The loading and supporting plates of the CALIBRE STFE20 used in this project are configured with roller supports and sliding bearing plates for articulation to achieve near simply supported beam conditions.

The four-point bending test setup is shown in Figure 3.9 to Figure 3.11. The CALIBRE STFE20's in-built load cell has a capacity of around 89 kN and an accuracy of ± 2%. The in-built laser displacement measurement tool has a measurement range of 200 mm and an accuracy of ± 0.015 mm.

The overall lengths of the bending test pieces were 20*d*, approximately 1800 mm and 3800 mm for 90x35 and 190x45 mm specimens, respectively. The bending load was applied at a rate to generate a failure of the test specimen typically within 2-5 min. The test was terminated when the load dropped by 20% after reaching the peak. The modulus of elasticity, modulus of rupture, failure mode and failure location were recorded as the results of the bending tests.

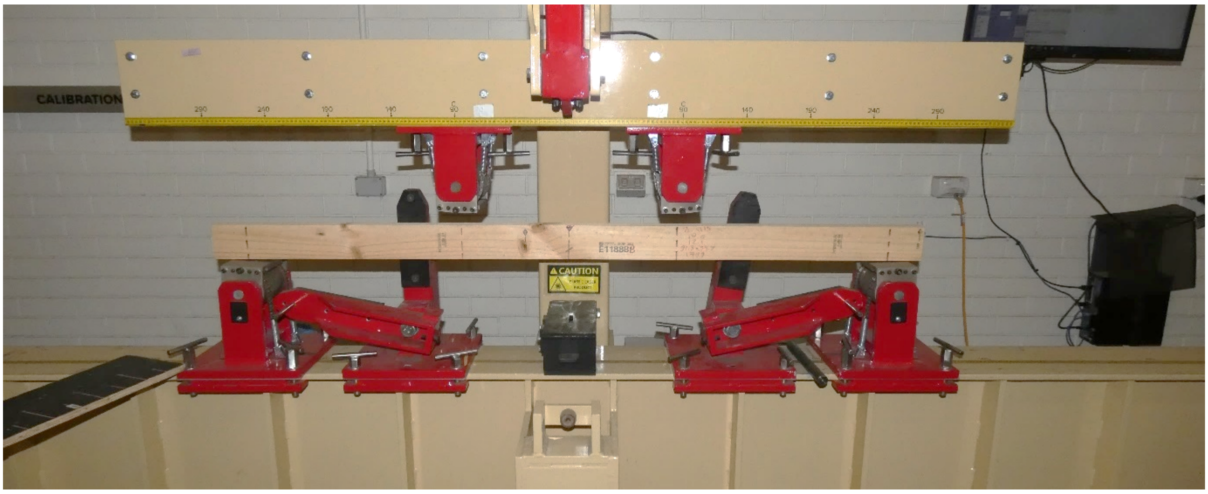


Figure 3.9 – Test set-up for measuring the apparent modulus of elasticity and the bending strength (90x35 mm specimen)

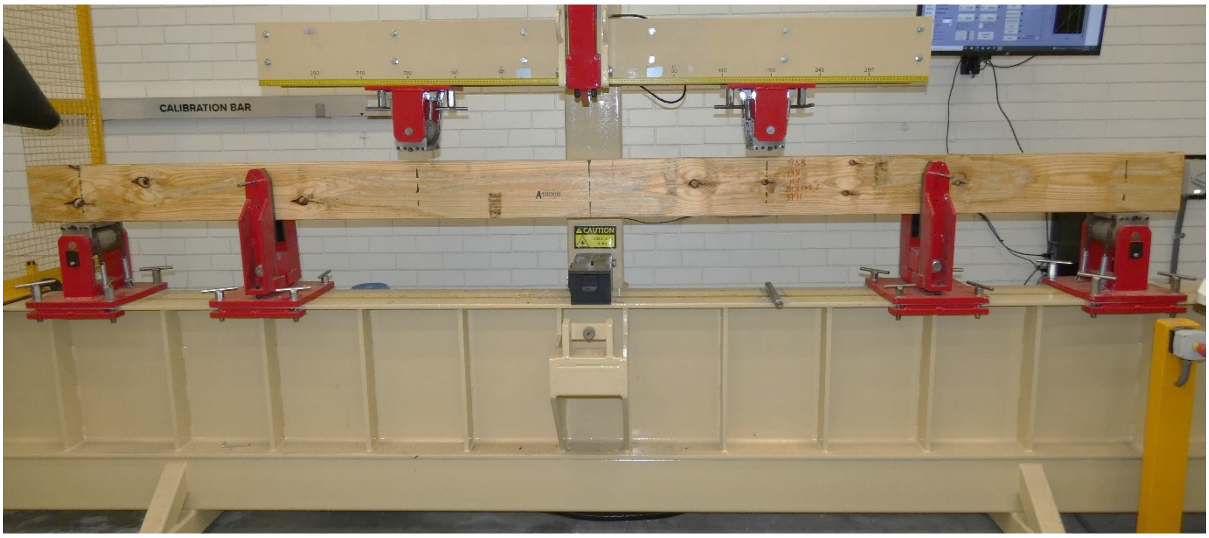


Figure 3.10 – Test set-up for measuring the apparent modulus of elasticity and the bending strength (190x45 mm specimen)

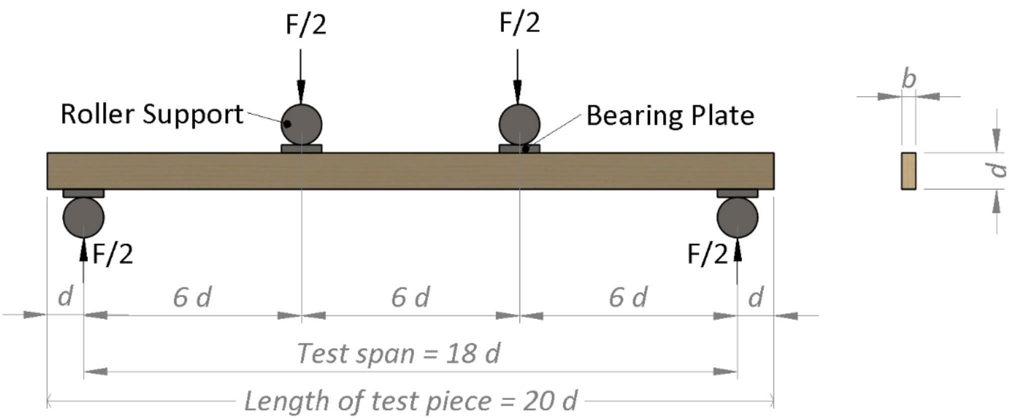


Figure 3.11 – Schematic drawing of the bending test setup

The apparent modulus of elasticity in bending (E) was calculated from the applied bending load (F) and the resultant vertical displacement (e) as following Equation (3.1), where $\frac{\Delta F}{\Delta e}$ was the linear elastic slope of the load-displacement graph, $L_b = 18d$ was the test span, b was the nominal breadth of the test piece, and d was the nominal depth of the test piece.

$$E = \frac{23}{108}\left(\frac{L_b}{d}\right)^3\left(\frac{\Delta F}{\Delta e}\right)\frac{1}{b} \tag{3.1}$$

The method for calculating the bending strength (f_b) of the test pieces depends on the location of the failure. The failure location was measured by using a tape measure and recorded to the nearest millimetre as the distance from the zero end of the test setup to the first and last crack location, i.e. the measurement considered the end of the crack nearest to the centre of the test specimen.

As for bending modes of failure that occurred within the zone of the constant bending moment, the bending strength f_b was calculated by using Equation (3.2), where F_{ult} was the ultimate bending load. As for bending modes of failure that was within the outer segments of the span (between the loading point and the support), the bending strength f_b was calculated from Equation (3.3), where L_v was the horizontal distance from the centre of the test span to the point of failure ($L_v \geq \frac{L_b}{6}$).

$$f_b = \frac{F_{ult}L_b}{bd^2} \tag{3.2}$$

$$f_b = \frac{3F_{ult}(L_b - 2L_v)}{2bd^2} \tag{3.3}$$

The bending failure mode considered five categories:

a) Failure through knot or hole (Figure 3.12), where the failure occurred as splitting through a knot or hole, or close to a knot or hole through sloping grain associated with the knot or hole.
b) Failure through clear wood (Figure 3.13), where failure occurred as pure tensile fibre failure through clear wood.
c) Failure at general slope of grain (Figure 3.14), where failure occurred as a failure of fibres splitting perpendicular to grain associated with the grain sloping off the edge of the piece. The surface of the split would be longer and look smoother than the tensile fibre failure of "failure through clear wood".
d) Shear failure (Figure 3.15), where the failure occurred as horizontal cracking at or near the support associated with shear failure and may also include staggering of the support markings or piece end. No fibre failure through the bottom in the middle third of the span.

e) Compression failure (Figure 3.16), where the failure occurred as compressive fibre buckling failure in the middle third of the span on the topside of the piece.

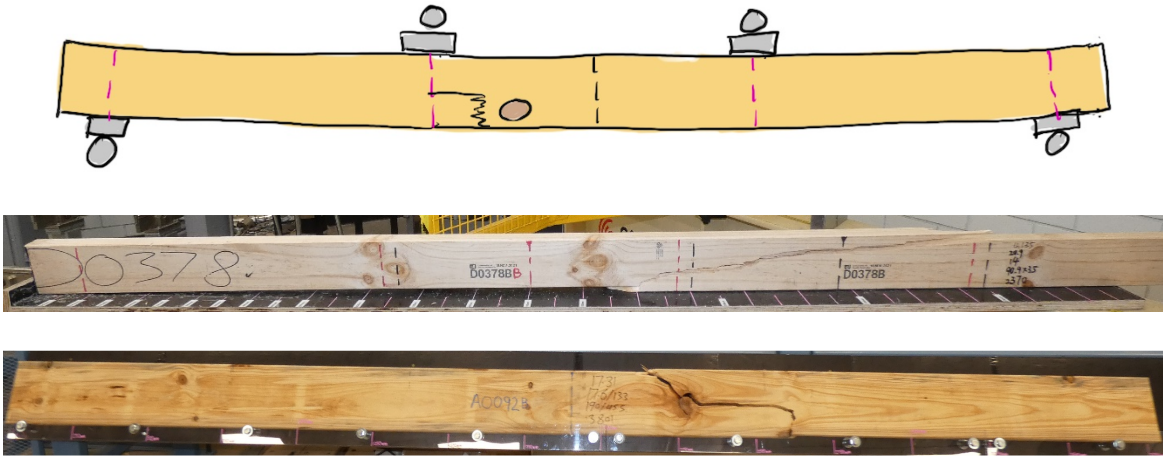


Figure 3.12 – Bending failure through knot or hole

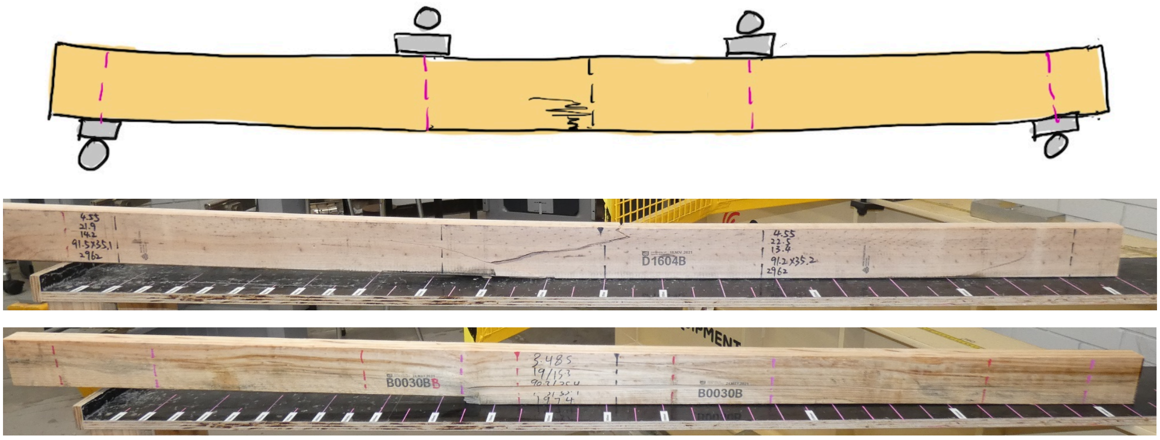


Figure 3.13 – Bending failure through clear wood

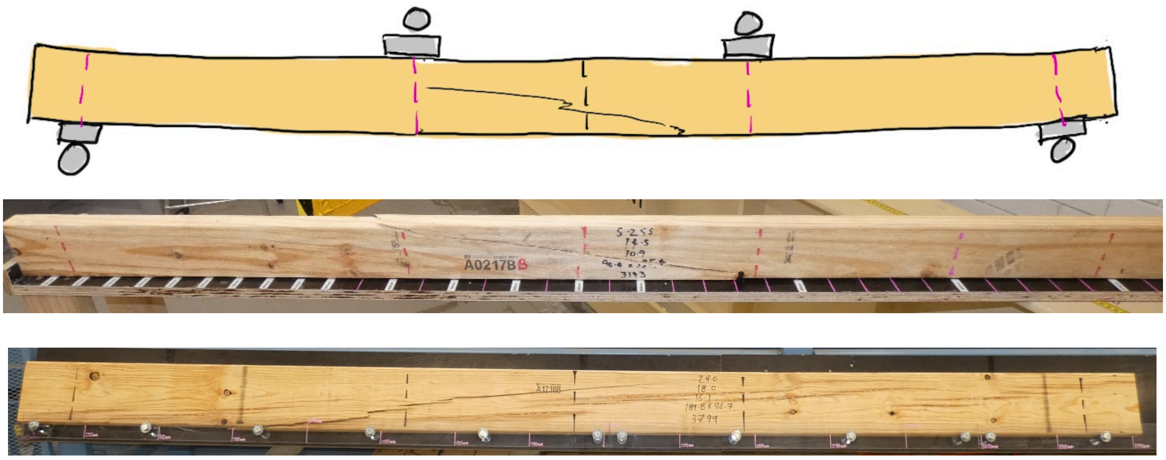


Figure 3.14 – Bending failure in general slope of grain

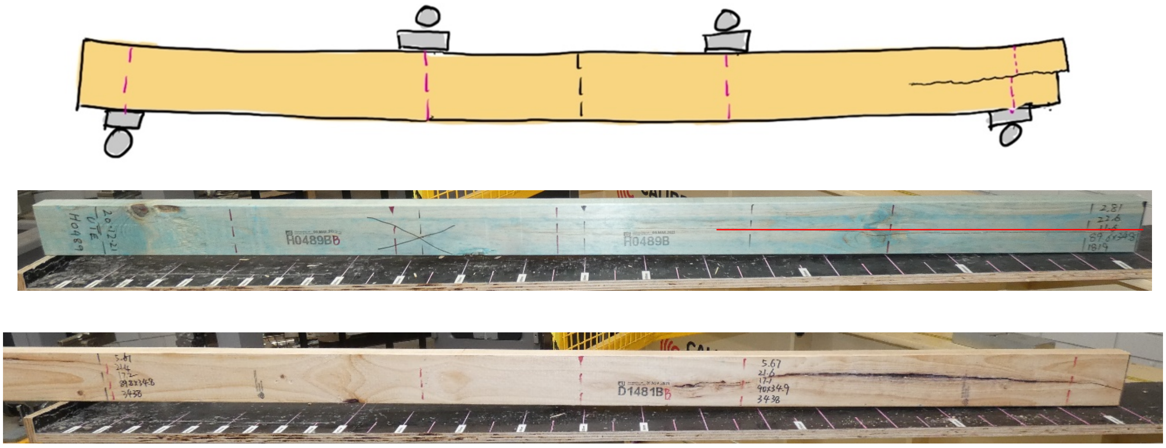


Figure 3.15 – Bending test with shear failure mode

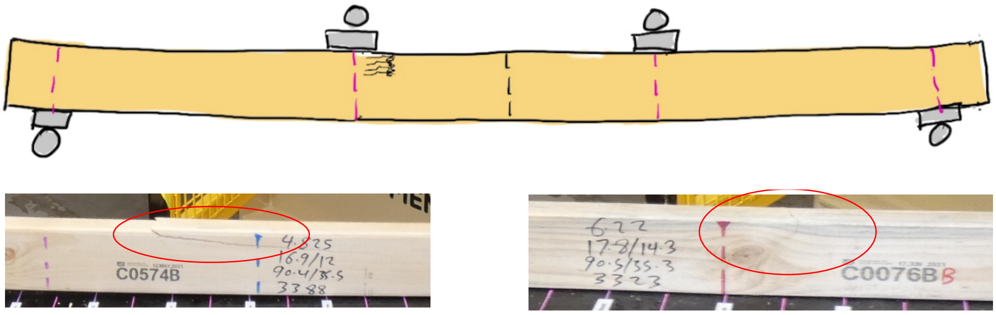


Figure 3.16 – Bending test with compression failure mode

3.7 Test procedure to determine tension strength parallel to grain

The tension tests were performed following Clause 2.5 of AS/NZS 4063.1:2010 (Standards Australia, 2010b) by employing a tension tester (model: Metriguard 403 (Metriguard Inc., 2017)), as the setup shown in Figure 3.17 to Figure 3.19. The Metriguard 403 was equipped with a load capacity of 445 kN and an accuracy of ± 1%.

The overall lengths of the test pieces were approximately 4250 mm and 4850 mm for test pieces with rectangular sections ($d \times b$) of 90x35 mm and 190x45 mm respectively, giving a clear span between test jaws of *8d+2000 mm*, approximately 2720 mm and 3520 mm.

The tension load was applied at a rate to generate a failure of the test specimen typically within 2-5 min. The failure was reached when the test piece was pulled apart, the tensile force dropped to near zero with an obvious tension crack presented in the test piece. The peak tension force and failure mode were recorded as the results of the tension tests.

Figure 3.17 – Test set-up for measuring the tension strength parallel to grain (90x35 mm specimen)

Figure 3.18 – Test set-up for measuring the tension strength parallel to grain (190x45 mm specimen)

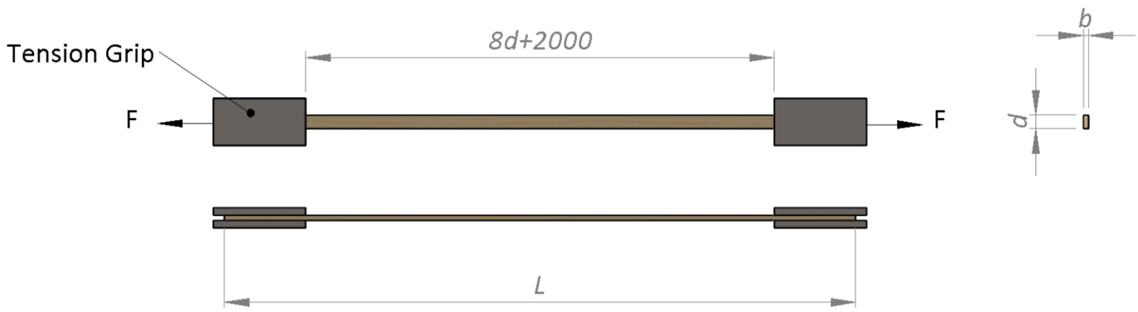


Figure 3.19 – Schematic drawing of the tensile test setup

The tension failure type considered three categories:

a) Failure through knot or hole (Figure 3.20), where the failure occurred through a defect or next to a defect, induced by the grain around it.

b) Failure through clear wood (Figure 3.21), where the failure occurred through clear wood away from the defects or the influence of defects.

c) Specimen did not fail (Figure 3.22), where the specimen was loaded to machine capacity without showing any failure.

Figure 3.20 – Tension failure through knot or hole

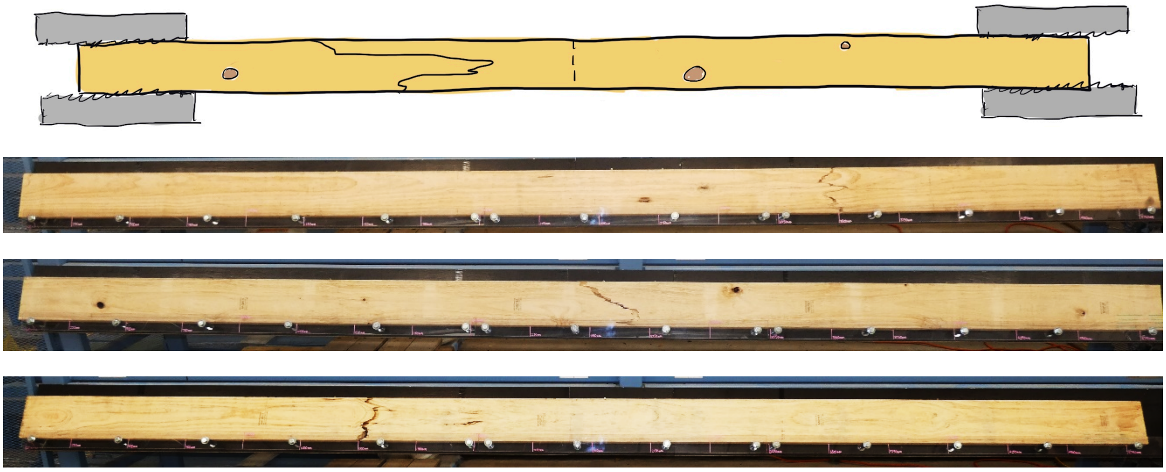


Figure 3.21 – Tension failure through clear wood

Figure 3.22 – No failure in tension test on high strength test pieces that exceeded the machine load capacity

The tension strength (f_t) parallel to grain of the test pieces was calculated following Equation (3.4), where F_{ult} was the maximum force of the test and $b \times d$ was the nominal cross-sectional area of the test piece.

$$f_t = \frac{F_{ult}}{b \times d} \qquad (3.4)$$

3.8 Test procedure to determine compression strength parallel to grain

The compression tests were performed following the alternative procedure (sub-set method) as given in Clause 2.6 of AS/NZS 4063.1:2010 (Standards Australia, 2010b). The specimens were prepared by cutting the original test pieces with span of 8*d*+2000 mm into eight sub-sets, i.e., sub-set lengths of 340 mm and 440 mm for the test pieces with rectangular sections $(d \times b)$ of 90x35 mm and 190x45 mm, respectively. The compressive strengths of each sub-sets were tested, and the minimum result was taken as the compressive strength of the original test piece.

The compression tests were carried out by using a compression machine (model: Controls 50-C10D02 (CONTROLS, 2018)), which was calibrated to load of 1000 kN with an accuracy of ± 0.8 kN. The photos of the test setup and the schematic drawings are given in Figure 3.23 to Figure 3.25. An axial load was applied from the bottom compression plate, while the top loading plate was free to rotate but not able to translate (i.e., displacement degree of freedom was fixed).

The compression tests for the 90x35 mm specimens were terminated when the load dropped by 23 kN after reaching the peak load. The compression tests for the 190x45 mm specimens were terminated when the load dropped by 45 kN after reaching the peak load. The peak load and failure mode were recorded as the results of the compression tests.

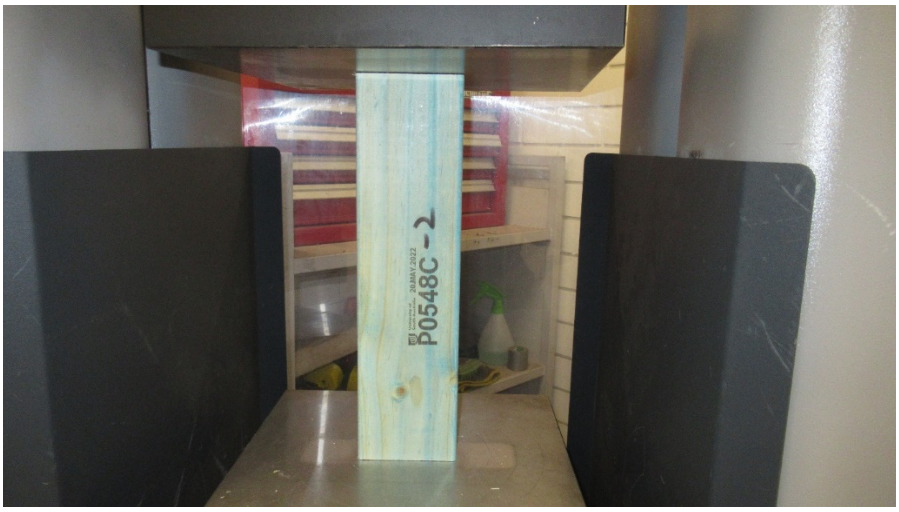


Figure 3.23 – Test setup for measuring compression strength parallel to grain (90x35 mm specimen)

Figure 3.24 – Test setup for measuring compression strength parallel to grain (190x45 mm specimen)

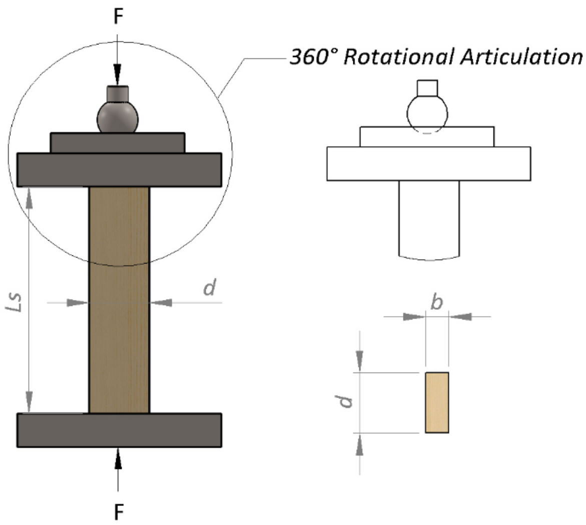


Figure 3.25 – Schematic drawing of the compression test setup

The compression failure type considered four categories:

a) Crushing around knot or hole (Figure 3.26), where the failure occurred as local fibre buckling around a knot or hole. There may also be a vertical tension crack extending from the knot or hole.

b) Crushing in clear wood (Figure 3.27), where the failure occurred as fibre buckling failure. May be seen in vertical fibre buckling or kinks, or as a crease across a portion of the piece.

c) Rotation of specimen (Figure 3.28), where the failure caused by non-uniform material stiffness in the cross-section, or by poor placement in the machine or un-square end cuts.

d) Buckling or flexural failure (Figure 3.29), where failure occurred as bending, often as a result of buckling, which leads to compression on one face and may lead to a tension crack across the grain on the other face.

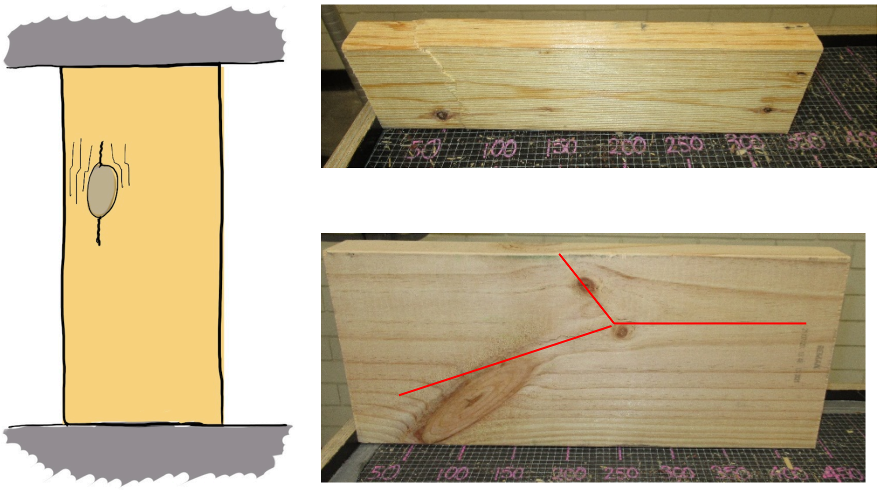


Figure 3.26 – Compression test failure by crushing around knot or hole

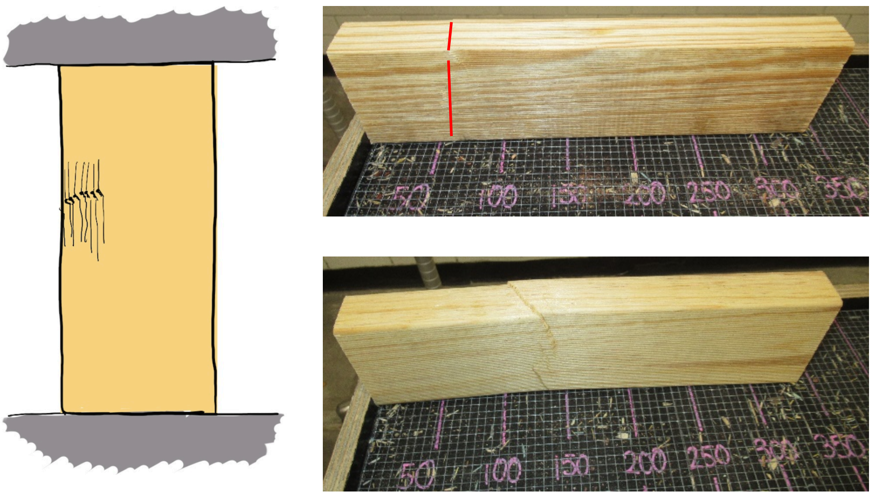


Figure 3.27 – Compression test failure by crushing in clear wood

Figure 3.28 – Compression test failure by rotation of specimen

Figure 3.29 – Compression test failure by buckling or flexural failure of the specimen

The compression strength (f_c) was the critical (minimum) compression strength among the eight subset specimens, calculated following Equation (3.5), where F_{ult} was the failure force of the compression test, and $b \times d$ was the nominal cross-sectional area of the subset test piece.

$$f_c = \frac{F_{ult}}{b \times d} \tag{3.5}$$

3.9 Test procedure to determine beam shear strength

The beam shear tests were performed following Clause 2.7 of AS/NZS 4063.1:2010 (Standards Australia, 2010b) by employing a jig on a shear testing machine (model: CONTROLS AUTOMAX SMART-Line (CONTROLS, 2012)) to articulate the 'pin' support at one end and 'roller' support at the other end, as shown in Figure 3.30 to Figure 3.32. The 'pin' support had fixed displacement and free rotation. The 'roller' support had free rotation and free sliding in the beam longitudinal axis direction.

The shear testing machine was calibrated to load of 200 kN with and accuracy of ± 0.4%. The overall length of the test piece was *8d*, approximately 720 mm and 1520 mm for 90x35 and 190x45 mm specimens, respectively. The shear load was applied at a rate of 80 N/s and 120 N/s for the 90x35 and 190x45 mm specimens, respectively.

The 90x35 mm specimen test was terminated when the load dropped by 5.9 kN after reaching the peak load. The 190x45 mm specimen test was terminated when the load dropped by 13.45 kN after reaching the peak load. The failure mode and peak force were recorded as the results.

Figure 3.30 – Test setup for measuring shear strength (90x35 specimen)

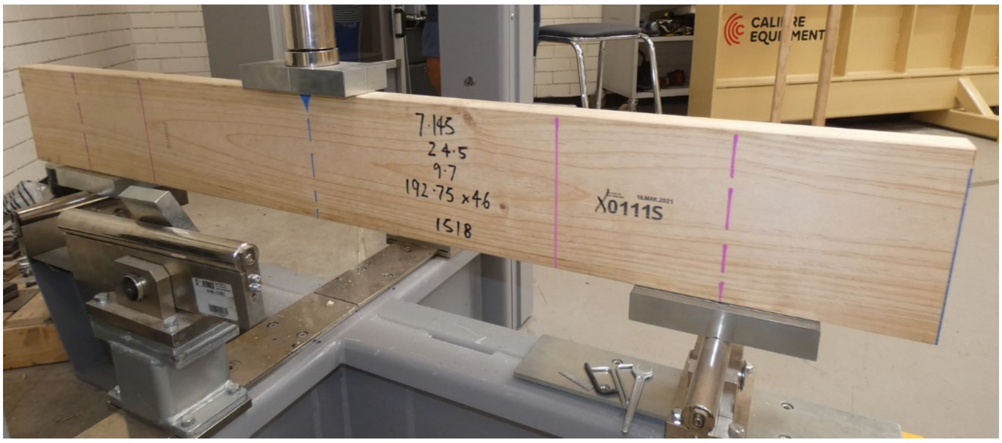


Figure 3.31 – Test setup for measuring shear strength (190x45 specimen)

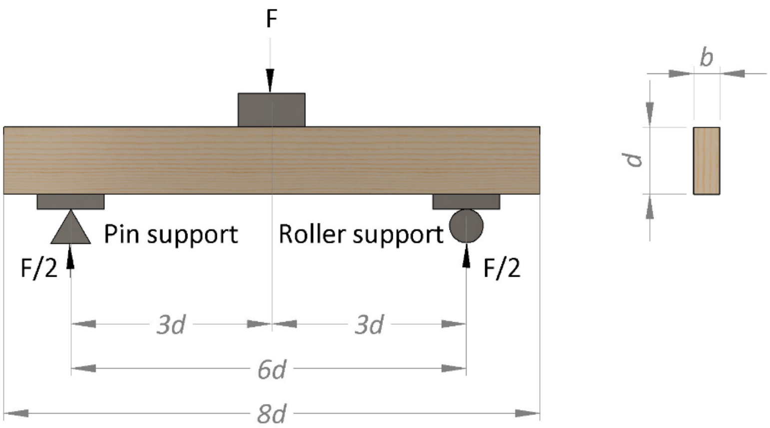


Figure 3.32 – Schematic drawing of the shear test setup

The shear failure type embraced four categories:

a) Shear failure through clear wood (Figure 3.33), where the failure occurred as a horizontal split starting near the centre near mid-depth. The length of the horizontal split varied. If it extended to the end, there may be a staggering of the vertical lines drawn on the piece or a discontinuity in the end of the piece. The shear failure surface does not pass through the bottom of the piece.

b) Shear failure at a defect (Figure 3.34), where the failure is similar to the shear failure through clear wood, but with the split affected by some defect, such as diverting around a knot, passing through a hole, or interacting with a split that was already present.

c) Bending failure through clear wood (Figure 3.35), where the failure occurred at or near the centre point with tensile fibre failure through the bottom of the section, or compressive fibre buckling at the top.

d) Bending failure through a defect (Figure 3.36), where the failure is similar to the failure through clear wood, but with the failure split originating at a defect. This may be directly through a knot or hole, or through a patch of sloping grain associated with a knot or hole.

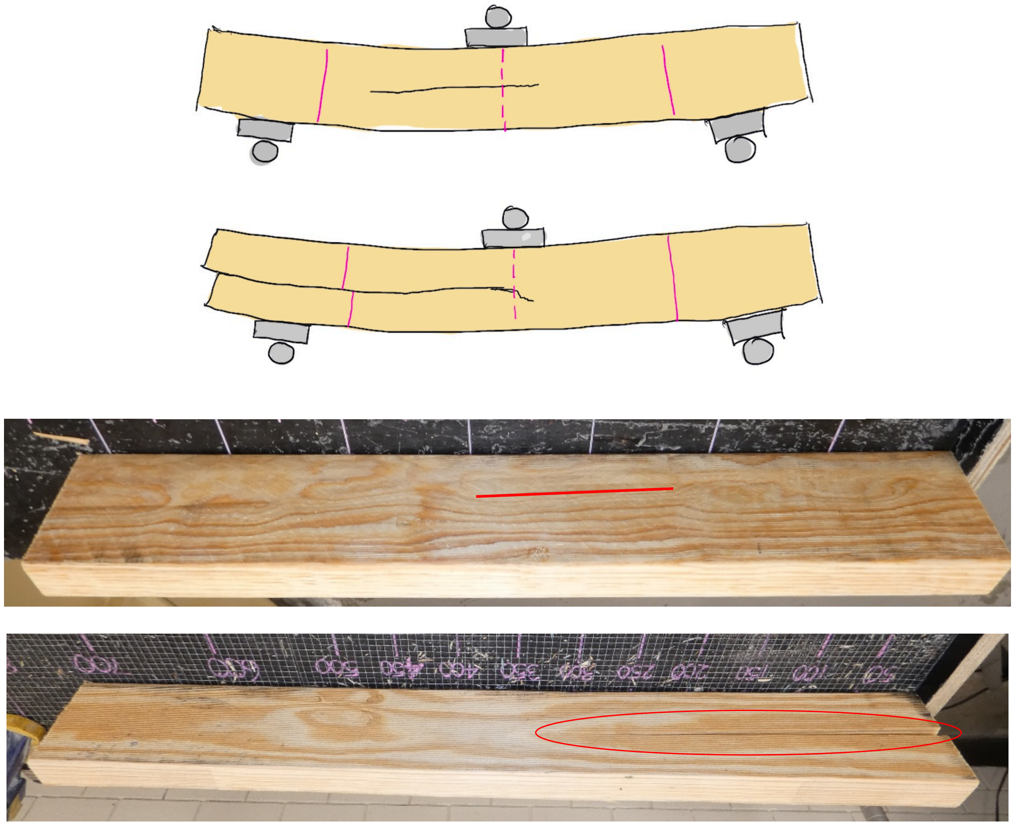


Figure 3.33 – Shear test failure by shear through clear wood

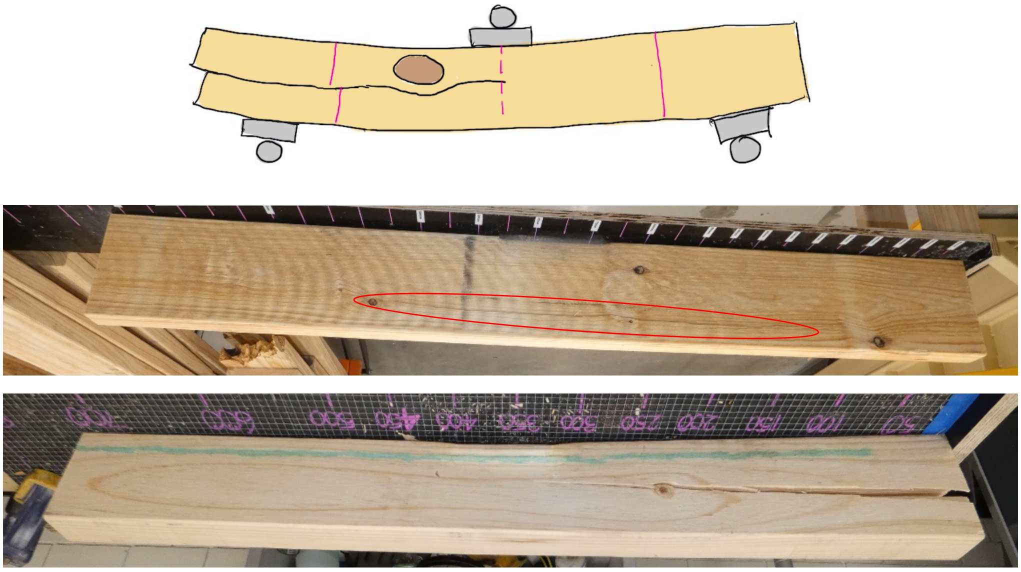


Figure 3.34 – Shear test failure by shear through defect

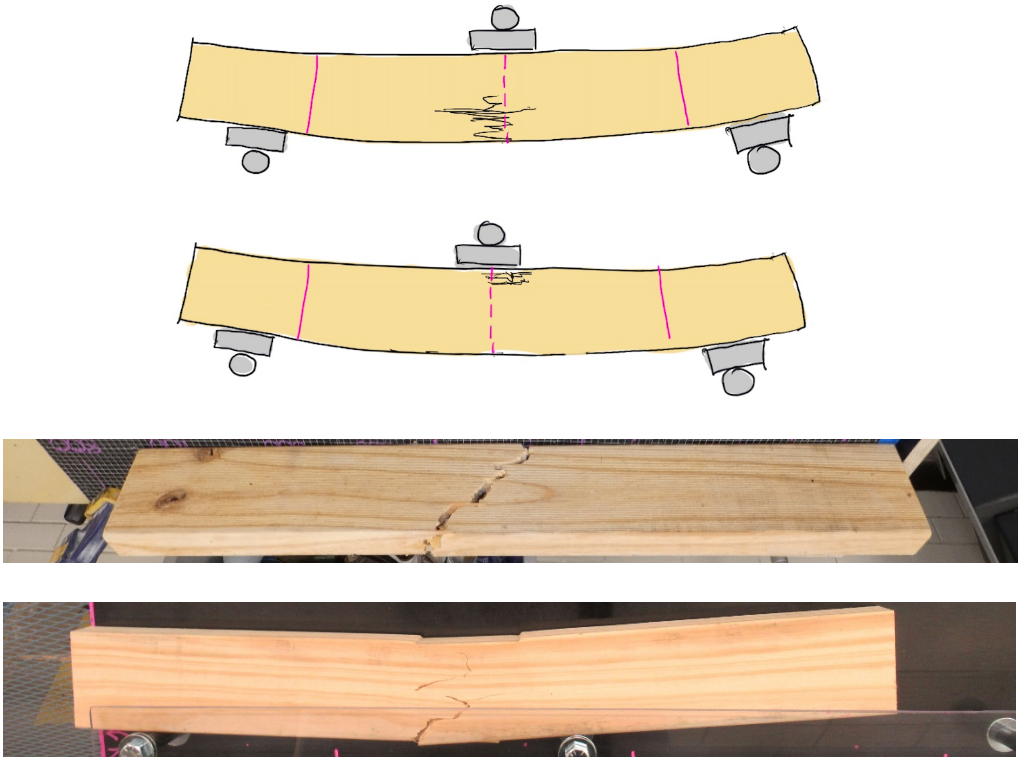


Figure 3.35 – Shear test failure by bending through clear wood

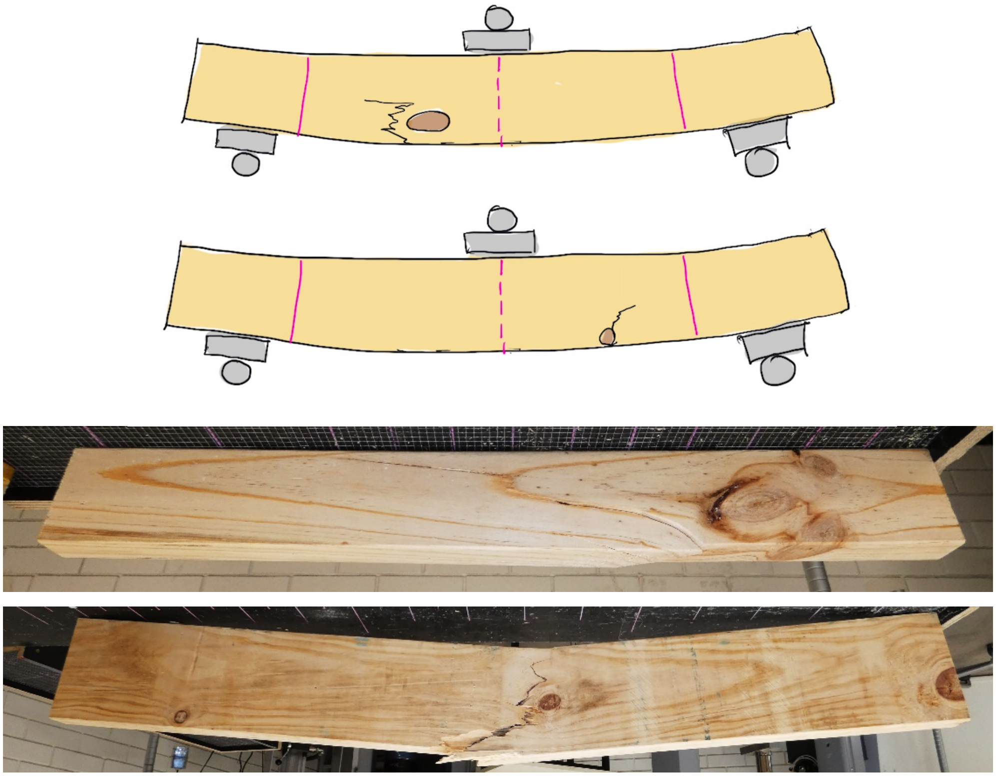


Figure 3.36 – Shear test failure by bending through a defect

Shear strength (f_v) was calculated by using Equation (3.6), where F_{ult} was the peak force and $b \times d$ was the cross-sectional area of the test pieces.

$$f_v = \frac{0.75F_{ult}}{b \times d} \tag{3.6}$$

4 Test data

4.1 Introduction

The following section presents results from the nationally pooled test data. Results are presented by property, by size and grade. Discussion of the results is presented in Section 5. Data in this section are presented in two formats:

Tabulated information is presented typically including; *Count* – the number of specimens tested, *CV* – characteristic value calculated to AS/NZS 4063.2:2010 (Standards Australia, 2010b), *CoV* – coefficient of variation to AS/NZS 4063.2:2010 (Standards Australia, 2010c), *DV* – design characteristic value from AS 1720.1-2010 (Standards Australia, 2010a), and *DR* – design ratio calculated as *CV/DR*. Table 4.1 for density includes an *Avg* (average) and does not include a design characteristic value as AS 1720.1-2010 (Standards Australia, 2010a) does not currently include *DVs* for density. This is discussed further in Section 5.

Cumulative frequency diagrams (*CFDs*) across grades are presented for each property by size. As a graphical representation of the tested populations, *CFDs* provide a tool for qualitative assessment of relative performances discussed further in Section 5. Figure 4.1 presents an example CFD with key features illustrated.

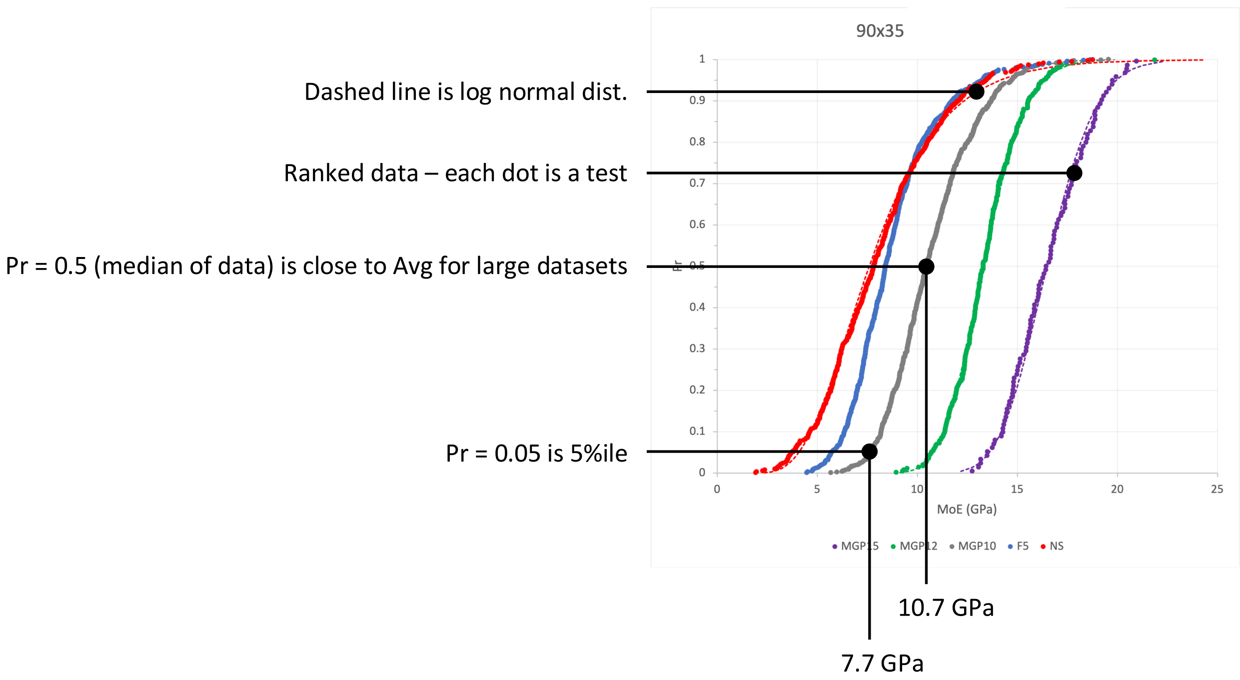


Figure 4.1 – Example CFD with key features highlighted

4.2 Statistical procedures

Analysis was performed using log-normal distributions for all properties and the method presented in AS/NZS 4063.2:2010 (Standards Australia, 2010c) Appendix B3 for MoE, Appendix B2.2 for strength properties and for density.

4.3 Density

Density data was captured on all test specimens. Characteristic values for density in this *2023 In-Grade Study* are calculated using AS/NZS 4063.2:2010 Appendix B2.2 typically adopted for strength properties assuming log-normal distributions. This method differs from that presented in AS/NZS 4063.2:2010 B6 *Characteristic Values for Density* which is based on a mean density. The use of B2.2 for fifth percentile density characteristic values in this study is appropriate given that characteristic density values are presented to inform future development work on connection design (see Section 5.2.5). Table 4.1, Figure 4.2, and Figure 4.3 present density results corrected to 12% moisture content in accordance with AS/NZS 1080.3:2000 (Standards Australia, 2000).

Table 4.1 – Density results

Density *(ρ)* at 12% MC					
Size (mm)	**Grade**	**Count**	**CV (kg/m^3)**	**CoV**	**Avg (kg/m^3)**
90x35	**NS**	1950	397.8	11.8%	487.6
90x35	**F5**	2185	386.4	12.6%	480.6
90x35	**MGP10**	2960	426.3	9.8%	504.3
90x35	**MGP12**	1302	472.0	8.5%	546.4
90x35	**MGP15**	428	537.5	8.2%	619.8
190x45	**NS**	1891	405.1	12.2%	500.1
190x45	**F5**	-	-	-	-
190x45	**MGP10**	1715	433.4	9.3%	508.2
190x45	**MGP12**	760	483.2	8.3%	557.4
190x45	**MGP15**	-	-	-	-

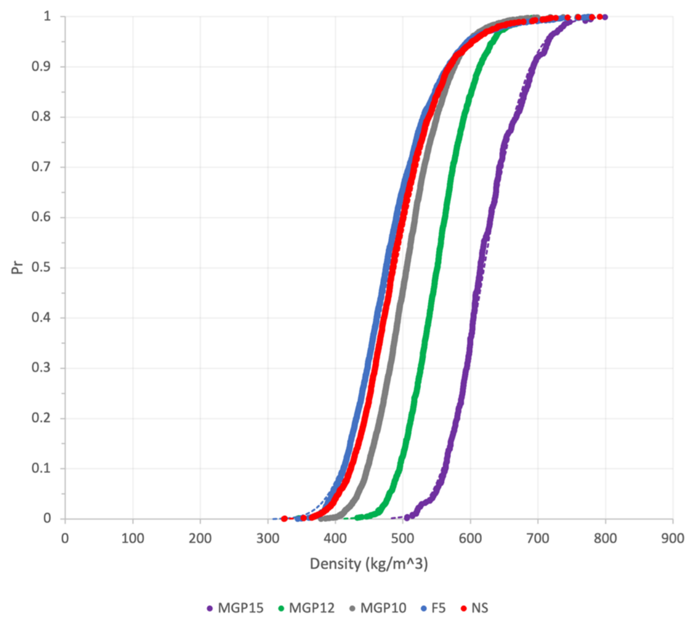


Figure 4.2 – Cumulative frequency diagram – 90x35 mm – Density

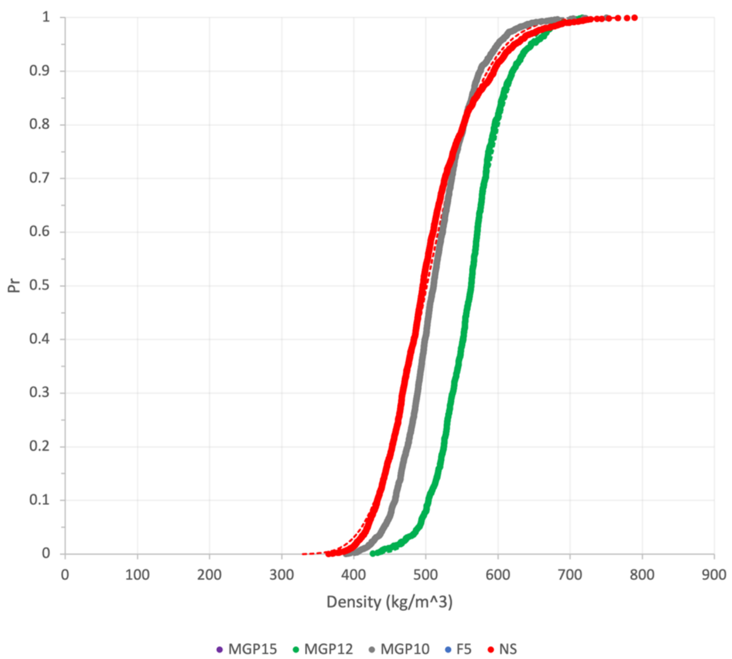


Figure 4.3 – Cumulative frequency diagram – 190x45 mm – Density

Summary observations:

- Log-normal distributions represent a good fit for the data.
- CoV is ~10%, which is as anticipated for a fibre-limited property.
- CoV decreases as grade increases which is as anticipated.
- Non-structural density CV is slightly higher than F5, but the NS will have included some high-density product deemed NS from utility (wane) in the mix. This can be seen on the CFDs (Figure 4.3 and Figure 4.4) where the red line crossed the top of the higher graded material distributions.

4.4 Apparent Modulus of Elasticity

Random position *Apparent modulus of elasticity* testing was completed in accordance with AS/NZS 4063.1:2010. Characteristic values were calculated to AS/NZS 4063.2:2010 Appendix B3. These are compared with the *Average MoE parallel to grain* design characteristic values presented in AS 1720.1-2010 table H3.1 to estimate design ratios (DRs). Table 4.2, Figure 4.4, and Figure 4.5 present *Average modulus of elasticity* results established from *Apparent modulus of elasticity* testing.

Table 4.2 – Average MoE parallel to grain results

Average MoE parallel to grain *(E)*						
Size (mm)	**Stress Grade**	**Count**	**CV (GPa)**	**CoV**	**DV (GPa)**	***DR***
90x35	**NS**	487	5.8	39.2%	N/A	*N/A*
90x35	**F5**	554	8.1	24.8%	6.9	*1.2*
90x35	**MGP10**	726	10.7	20.0%	10.0	*1.1*
90x35	**MGP12**	326	13.3	12.7%	12.7	*1.1*
90x35	**MGP15**	107	16.5	11.7%	15.2	*1.1*
190x45	**NS**	472	6.6	35.0%	N/A	*N/A*
190x45	**F5**	-	-	-	-	-
190x45	**MGP10**	427	10.7	19.2%	10.0	*1.1*
190x45	**MGP12**	187	13.7	11.9%	12.7	*1.1*
190x45	**MGP15**	-	-	-	-	-

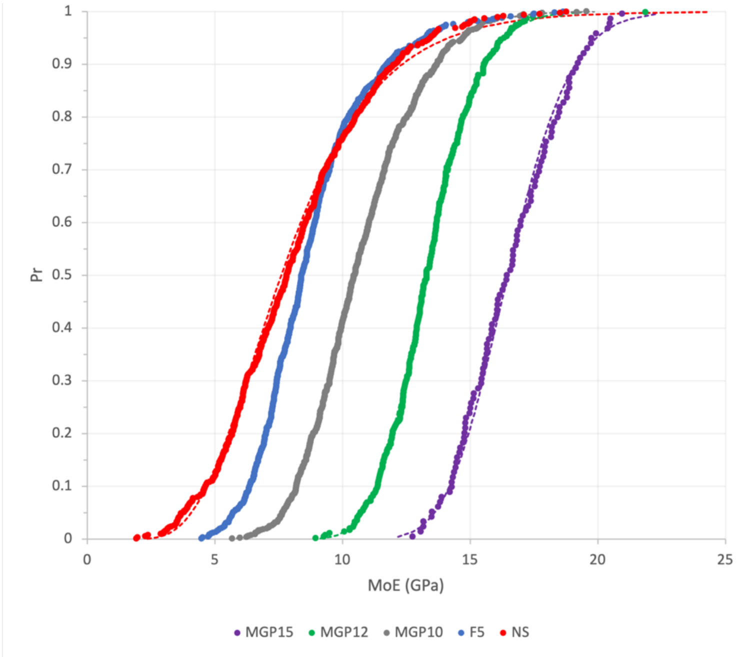


Figure 4.4 – Cumulative frequency diagram –90x35 mm – Average MoE parallel to grain

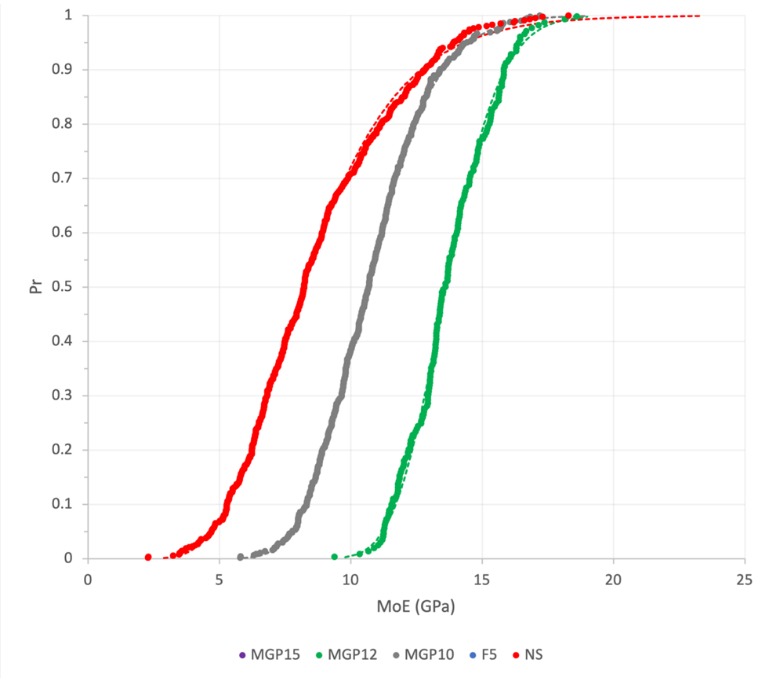


Figure 4.5 – Cumulative frequency diagram –190x45 mm – Average MoE parallel to grain

Summary observations:

- Log-normal distributions represent a good fit for the data.
- The separation between structural grades is well defined.
- Non-structural MoE distribution crosses with the top of higher structural grades as shown with the red line crossing the grade distributions on Figure 4.4 and Figure 4.5; the NS will have included some higher stiffness product deemed NS from having exceeded the utility limits.

4.5 Bending strength

Random position *bending strength* testing was completed in accordance with AS/NZS 4063.1:2010. Characteristic values were calculated to AS/NZS 4063.2:2010 Appendix B2.2. These are compared with the *Bending* design characteristic values presented in AS 1720.1-2010 table H3.1 to estimate design ratios (DRs). Table 4.3, Figure 4.6, and Figure 4.7 present *bending strength* results.

Table 4.3 – Bending strength results

			Bending (f'_b)			
Size (mm)	**Stress Grade**	**Count**	**CV (MPa)**	**CoV**	**DV (MPa)**	***DR***
90x35	**NS**	487	11.4	60.1%	N/A	*N/A*
90x35	**F5**	554	17.1	44.4%	14.0	*1.2*
90x35	**MGP10**	726	22.7	40.7%	17.0	*1.3*
90x35	**MGP12**	326	37.1	29.0%	28.0	*1.3*
90x35	**MGP15**	107	52.6	22.5%	39.0	*1.3*
190x45	**NS**	472	10.2	54.7%	N/A	*N/A*
190x45	**F5**	-	-	-	-	-
190x45	**MGP10**	427	22.3	34.7%	16.0	*1.4*
190x45	**MGP12**	187	32.8	27.2%	25.0	*1.3*
190x45	**MGP15**	-	-	-	-	-

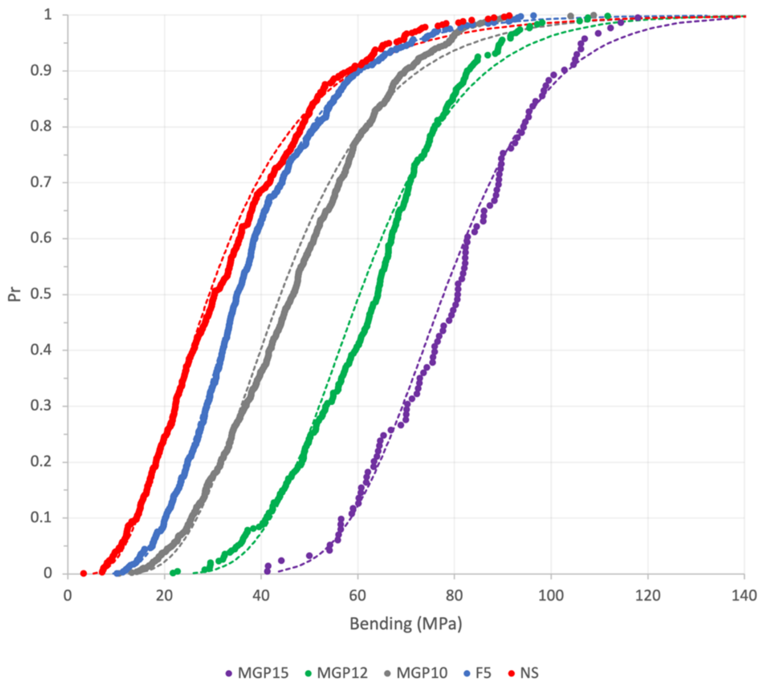


Figure 4.6 – Cumulative frequency diagram –90x35 mm – Bending strength

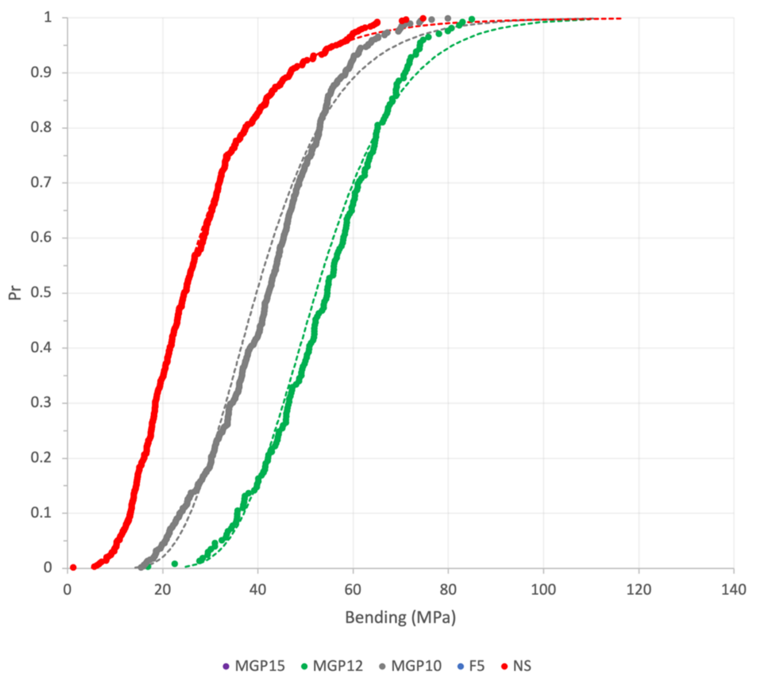


Figure 4.7 – Cumulative frequency diagram –190x45 mm – Bending strength

Summary observations:

- Log-normal distributions represent a good fit for the data.
- Characteristic values vary between the narrows and wides. The DRs are similar, suggesting that the current size effect reflected in the DVs is appropriate.

4.6 Tension strength parallel to grain

Random position *tension strength parallel to grain* testing was completed in accordance with AS/NZS 4063.1:2010. Characteristic values were calculated to AS/NZS 4063.2:2010 Appendix B2.2. These are compared with the *tension parallel to grain* design characteristic values presented in AS 1720.1-2010 table H3.1 to estimate design ratios (DRs). Thirteen tested 190x45 mm boards could not be tested to failure, limited by machine capacity. These are omitted from the top end of Figure 4.9. A log-normal distribution was fitted to the truncated data for the purpose of calculating the CVs. Table 4.4, Figure 4.8, and Figure 4.9 present *tension parallel to grain* results.

Table 4.4 – Tension parallel to grain results

Tension parallel to grain (f'_t)						
Size (mm)	**Grade**	**Count**	**CV (MPa)**	**CoV**	**DV (MPa)**	***DR***
90x35	**NS**	485	4.2	57.0%	N/A	*N/A*
90x35	**F5**	533	7.8	40.1%	7.3	*1.1*
90x35	**MGP10**	746	10.7	39.3%	7.7	*1.4*
90x35	**MGP12**	323	17.8	32.6%	12.0	*1.5*
90x35	**MGP15**	106	23.9	28.7%	18.0	*1.3*
190x45	**NS**	471	5.0	59.3%	N/A	*N/A*
190x45	**F5**	-	-	-	-	-
190x45	**MGP10**	422	10.5	43.7%	7.1	*1.5*
190x45	**MGP12**	174	19.2	31.1%	12.0	*1.6*
190x45	**MGP15**	-	-	-	-	-

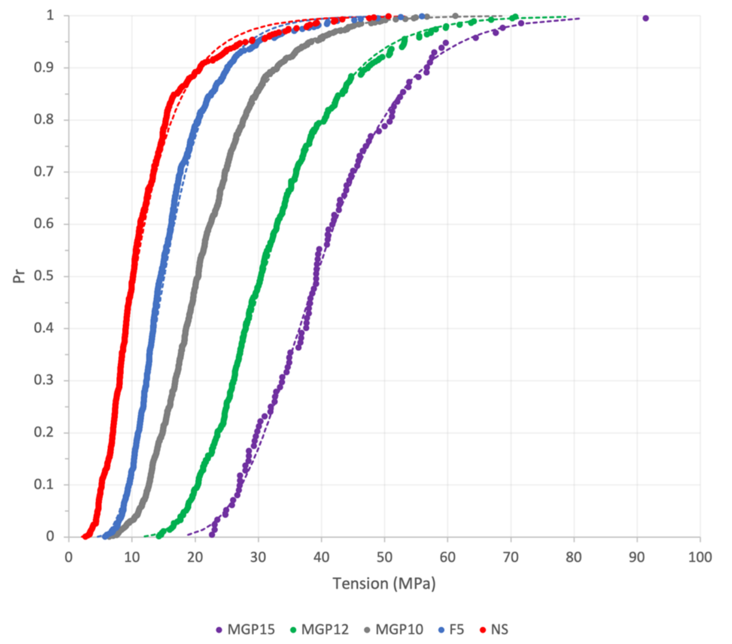


Figure 4.8 – Cumulative frequency diagram –90x35 mm – Tension parallel to grain

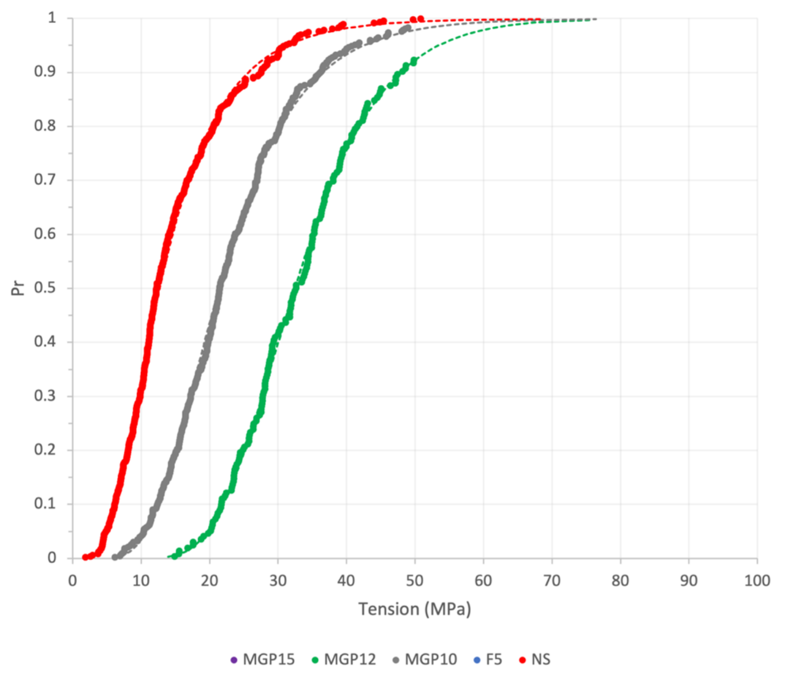


Figure 4.9 – Cumulative frequency diagram –190x45 mm – Tension parallel to grain

Summary observations:

- Log-normal distributions represent a good fit for the data (including the truncated dataset).
- The lower end of the distributions, including the 5th%ile values, are generally well separated. However, MGP10 is close to F5 which is appropriate given that MGP10 and F5 DVs are very close (7.7 and 7.3 MPa respectively).

4.7 Compression strength parallel to grain

Random position testing followed the 'alternative procedure' to AS/NZS 4063.1:2010 for *compression strength parallel to grain* using short sub-sections of the overall test specimen. The lowest strength sub-section defined the compression strength in each test specimen. Characteristic values were calculated to AS/NZS 4063.2:2010 Appendix B2.2. These are compared with the *compression parallel to grain* design characteristic values presented in AS 1720.1-2010 table H3.1 to estimate design ratios (DRs). Table 4.5, Figure 4.10, and Figure 4.11 present *compression parallel to grain* results.

Table 4.5 – Compression parallel to grain results

Compression parallel to grain (f'_c)						
Size (mm)	**Grade**	**Count**	**CV (MPa)**	**CoV**	**DV (MPa)**	***DR***
90x35	**NS**	493	11.1	36.6%	N/A	*N/A*
90x35	**F5**	551	16.7	24.0%	11.0	*1.5*
90x35	**MGP10**	749	19.1	23.1%	18.0	*1.1*
90x35	**MGP12**	327	24.8	18.8%	24.0	*1.0*
90x35	**MGP15**	109	33.0	16.3%	30.0	*1.1*
190x45	**NS**	473	11.1	39.2%	N/A	*N/A*
190x45	**F5**	-	-	-	-	-
190x45	**MGP10**	431	18.6	23.0%	18.0	*1.0*
190x45	**MGP12**	192	28.9	15.3%	23.0	*1.3*
190x45	**MGP15**	-	-	-	-	-

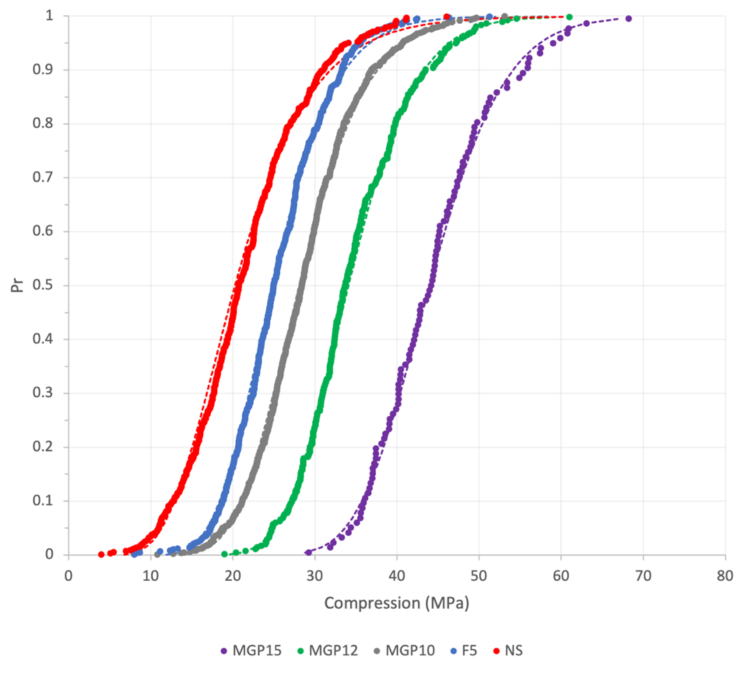


Figure 4.10 – Cumulative frequency diagram –90x35 mm – Compression parallel to grain

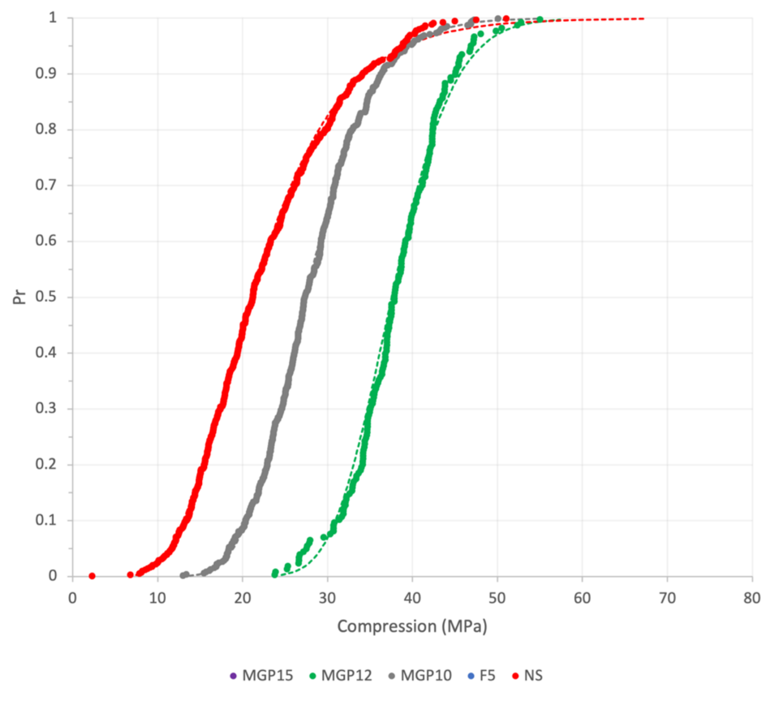


Figure 4.11 – Cumulative frequency diagram –190x45 mm – Compression parallel to grain

Summary observations:

- Log-normal distributions represent a good fit for the data.
- Design ratios are lower than anticipated. This is discussed further in Section 5.2.3.

4.8 Beam shear strength

Random position *beam shear strength* testing was completed in accordance with AS/NZS 4063.1:2010. Characteristic values were calculated to AS/NZS 4063.2:2010 Appendix B2.2. These are compared with the *shear in beams* design characteristic values presented in AS 1720.1-2010 table H3.1 to estimate design ratios (DRs). Table 4.6, Figure 4.12, and Figure 4.13 present *shear in beams* results established from *beam shear strength* testing.

Table 4.6 – Shear in beams results

Shear in beams (f'_v)						
Size (mm)	**Grade**	**Count**	**CV (MPa)**	**CoV**	**DV (MPa)**	***DR***
90x35	**NS**	480	2.3	38.0%	N/A	*N/A*
90x35	**F5**	547	2.8	31.4%	1.6	*1.7*
90x35	**MGP10**	739	3.4	27.5%	2.6	*1.3*
90x35	**MGP12**	326	4.5	21.6%	3.5	*1.3*
90x35	**MGP15**	106	5.4	20.4%	4.3	*1.3*
190x45	**NS**	473	1.8	40.9%	N/A	*N/A*
190x45	**F5**	-	-	-	-	-
190x45	**MGP10**	429	2.9	25.9%	2.5	*1.1*
190x45	**MGP12**	194	3.9	19.2%	3.3	*1.2*
190x45	**MGP15**	-	-	-	-	-

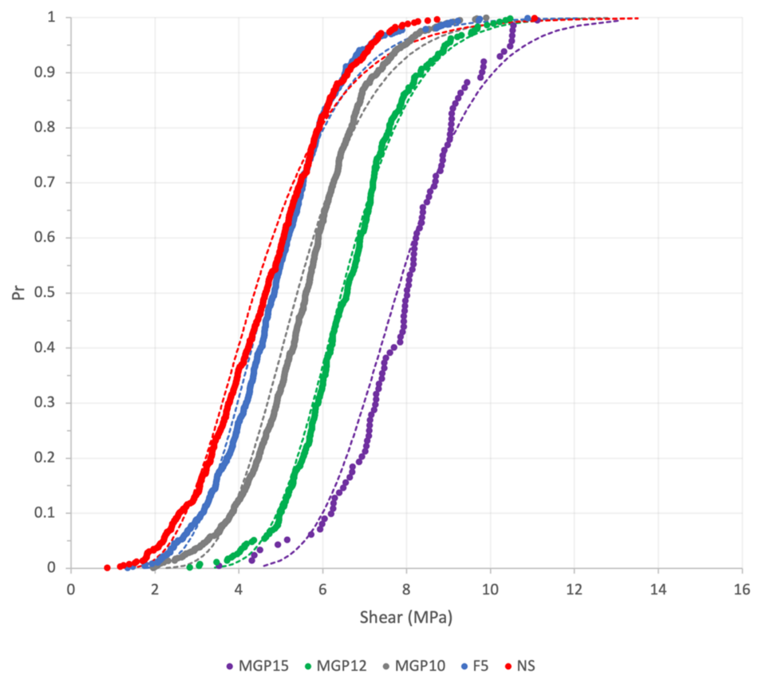


Figure 4.12 – Cumulative frequency diagram –90x35 mm – Beam shear strength

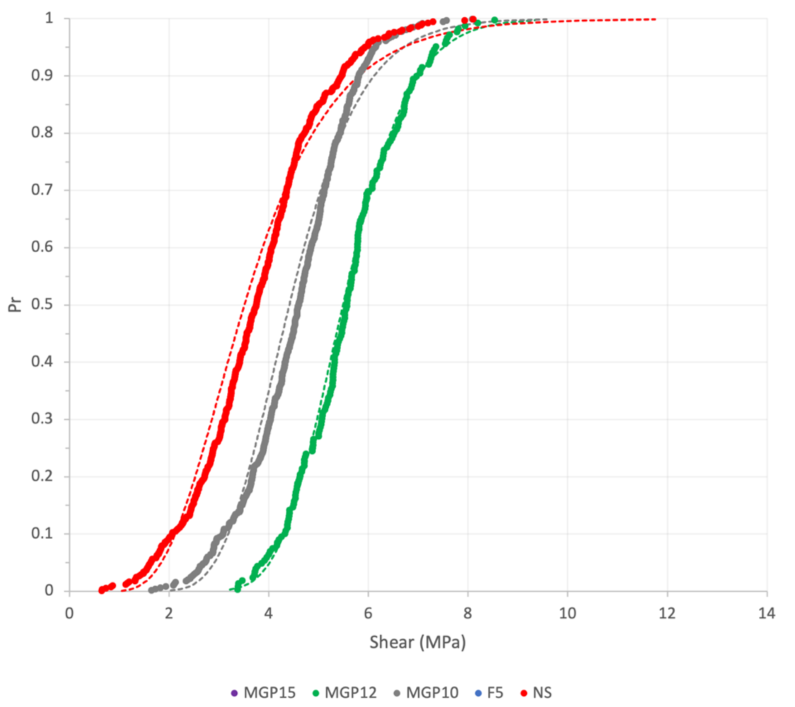


Figure 4.13 – Cumulative frequency diagram –190x45 mm – Beam shear strength

Summary observations:

- Log-normal distributions represent a good fit for the data.
- The size effect presented in the DVs from AS 1720.1-2010 does not reflect the CVs for the wides compared to the narrows. This is discussed more in Section 5.2.4

4.9 Moisture content

Moisture content measurement is described in Section 3.3. Data were captured using two pin electrical resistance meter on all specimens used in accordance with manufacturers guidelines and oven dry moisture content was also established on 5% of specimens (Standards Australia, 2012). Results from the two methods are compared in Figure 4.14. The black line represents the 1:1 line of identical measurements. Table 4.7 presents values capturing the range of moisture contents measured. There is reasonable agreement between the two methods over the typical range of moisture content anticipated.

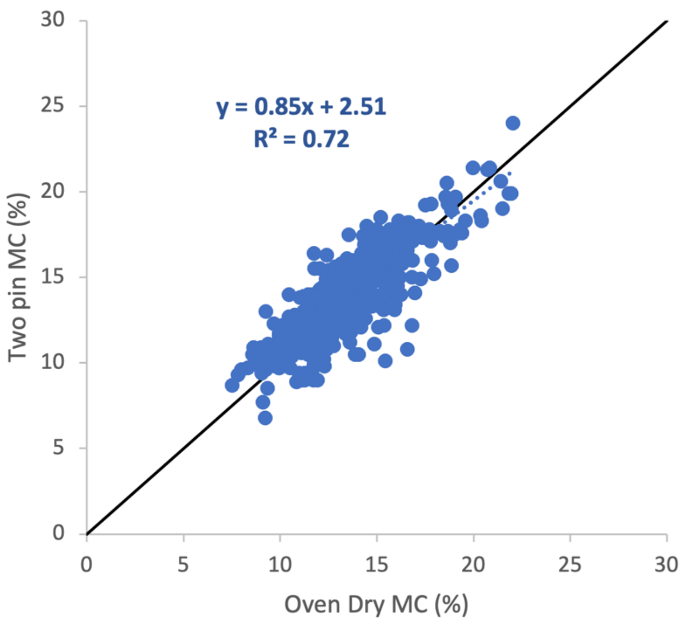


Figure 4.14 – Moisture content two pin vs oven dry

AS/NZS 1748.1:2011 (Standards Australia, 2011a) specifies the moisture content requirement (for Australian end-use) as not greater than 15% average and no piece exceeding 21% at the time of manufacture. The 613 comparative boards on which both moisture content measurement methods were used are presented in Table 4.7. Average moisture content was ~13%, below the 15% requirement. The 99%ile is less than the required 21%. Two boards (of 613) exceeded 21% moisture content. However, these moisture content measurements were taken at the time of testing, and not the time of manufacture; some of the supplied boards were in storage for several months, during which time their moisture content would have been impacted. The moisture content range presented in Table 4.7 is such that the moisture content of the boards tested in this *2023 In-Grade Study* can be considered representative.

Table 4.7 – Moisture content (excluding non-structural boards)

MC (%)	Oven Dry	Two pin
Count	613	613
1%ile	8.9	9.0
Average	13.1	13.7
99%ile	19.9	19.7

4.10 Measured dimensions

AS/NZS 1748.1:2011 Appendix A (Standards Australia, 2011a) presents requirements for dimensional tolerance for dressed timber as +2, -0 mm on the breadth and depth at the time of manufacture. Table 4.8 presents measured board dimensions. Average dimensions are in agreement with the tolerance requirement from AS/NZS 1748.1:2011 (Standards Australia, 2011a). At the time of testing, 2% of boards measured were over tolerance (too large), 9% were under tolerance (too small) on breadth (35 or 45 mm), and 30% under tolerance on depth (90 or 190 mm). This relates to dimensions measured at the time of testing which will differ from dimensions at the time of manufacture, as moisture content changes. The strength and stiffness of each piece is calculated on the nominal dimensions of the pieces, so is not biased by changes in the cross-sectional dimensions since the time of manufacture.

Table 4.8 – Measured (actual) board dimensions (excluding non-structural boards)

Dimension (mm)	90	35	190	45
Count	8902	8902	2720	2720
1%ile	88.5	34.4	186.6	44.1
Average	90.4	35.4	190.3	45.4
99%ile	91.9	36.4	192.8	46.8

4.11 Summary tables

Table 4.9 and Table 4.10 present a summary of the information presented in Sections 4.4 to 4.8 for easy reference.

Table 4.9 – Characteristic value summary table

Size (mm)	Stress Grade	Bending (MPa)	Tension parallel to grain (MPa)	Compression parallel to grain (MPa)	Shear in beams (MPa)	Average MoE parallel to grain (GPa)
90x35	**NS**	11.4	4.2	11.1	2.3	5.8
90x35	**F5**	17.1	7.8	16.7	2.8	8.1
90x35	**MGP10**	22.7	10.7	19.1	3.4	10.7
90x35	**MGP12**	37.1	17.8	24.8	4.5	13.3
90x35	**MGP15**	52.6	23.9	33.0	5.4	16.5
190x45	**NS**	10.2	5.0	11.1	1.8	6.6
190x45	**F5**	-	-	-	-	-
190x45	**MGP10**	22.3	10.5	18.6	2.9	10.7
190x45	**MGP12**	32.8	19.2	28.9	3.9	13.7
190x45	**MGP15**	-	-	-	-	-

Table 4.10 – CoV summary table

Size (mm)	Stress Grade	Bending (f'_b)	Tension parallel to grain (f'_t)	Compression parallel to grain (f'_c)	Shear in beams (f'_v)	Average MoE parallel to grain (E)
90x35	**NS**	60.1%	57.0%	36.6%	38.0%	39.2%
90x35	**F5**	44.4%	40.1%	24.0%	31.4%	24.8%
90x35	**MGP10**	40.7%	39.3%	23.1%	27.5%	20.0%
90x35	**MGP12**	29.0%	32.6%	18.8%	21.6%	12.7%
90x35	MGP15	22.5%	28.7%	16.3%	20.4%	11.7%
190x45	**NS**	54.7%	59.3%	39.2%	40.9%	35.0%
190x45	**F5**	-	-	-	-	-
190x45	**MGP10**	34.7%	43.7%	23.0%	25.9%	19.2%
190x45	**MGP12**	27.2%	31.1%	15.3%	19.2%	11.9%
190x45	**MGP15**	-	-	-	-	-

5 Comparisons with design properties

5.1 Summary

Section 4 presents test results by property, grade and size. Table 5.1 below presents a summary of design ratios from Sections 4.4 to 4.8 by grade and size for easy reference. The characteristic values for each property exceed the design characteristic values from AS 1720.1-2010 as developed in the *2010 MGP Properties Study* (Boughton & Juniper, 2010) indicating adequate performance of the tested products. However, the relativity of the design ratios warrants further discussion, covered in the sections below. The philosophy intended with the MGP grades is that the inferred properties (tension parallel to grain, compression parallel to grain, and beam shear) have conservatism compared to the indicator properties (typically MoE and bending) as generated with a factor, k_{ntp}., discussed further in the following sections.

Table 5.1 – Design ratio summary

Size (mm)	Stress Grade	Bending (f'_b)	Tension parallel to grain (f'_t)	Compression parallel to grain (f'_c)	Shear in beams (f'_v)	Average MoE parallel to grain (E)
90x35	**NS**	N/A	N/A	N/A	N/A	N/A
90x35	**F5**	1.2	1.1	1.5	1.7	1.2
90x35	**MGP10**	1.3	1.4	1.1	1.3	1.1
90x35	**MGP12**	1.3	1.5	1.0	1.3	1.1
90x35	**MGP15**	1.3	1.3	1.1	1.3	1.1
190x45	**NS**	N/A	N/A	N/A	N/A	N/A
190x45	**F5**	-	-	-	-	-
190x45	**MGP10**	1.4	1.5	1.0	1.1	1.1
190x45	**MGP12**	1.3	1.6	1.3	1.2	1.1
190x45	**MGP15**	-	-	-	-	-

5.2 Indicator and inferred property relationships

In this section, only data for the narrow boards has been presented. The data from the tests on wide boards has also been examined, but in most cases, it followed the same trends but differed by the size factor. Where the size factor was similar to the factor used in Table H3.1 in AS 1720.1-2010 it was not presented. However, where the test results for the wide boards showed a different size relationship to that in AS 1720.1-2010, the data from the wide boards has been compared with the data from the narrow boards.

5.2.1 Bending strength and apparent modulus of elasticity

Table 5.1 design ratios show the relationship between MoE design ratio and bending strength design ratio. For the MGP grades the bending strength design ratio is approximately 1.2 times the MoE design ratio, suggesting that the product is typically stiffness limited in production as intended when the MGP design characteristic values were developed (Boughton & Juniper, 2010). However, the bending strength design ratio for F5 is approximately 1.0 times the MoE design ratio. F5 tension strength design ratio is 1.1. This is discussed further in Section 5.2.2.

The *2010 MGP Properties Study* (Boughton & Juniper, 2010) converted data from *1992* and *2003 In-Grade Studies* to reflect revisions in AS/NZS 4063.1:2010 (Standards Australia, 2010b) regarding definitions of bending failures. Data were used to present bending strength to MoE relationships and a range of indicator to inferred property relationships. Those data from the *2010 MGP Properties Study* were referenced and plots recreated in the following sections with data from this *2023 In-Grade Study*. The *2010 MGP Properties Study* developed MGP property relationships relating indicator properties (MoE and bending strength) with inferred properties (tension parallel to grain, compression parallel to grain, and beam shear).

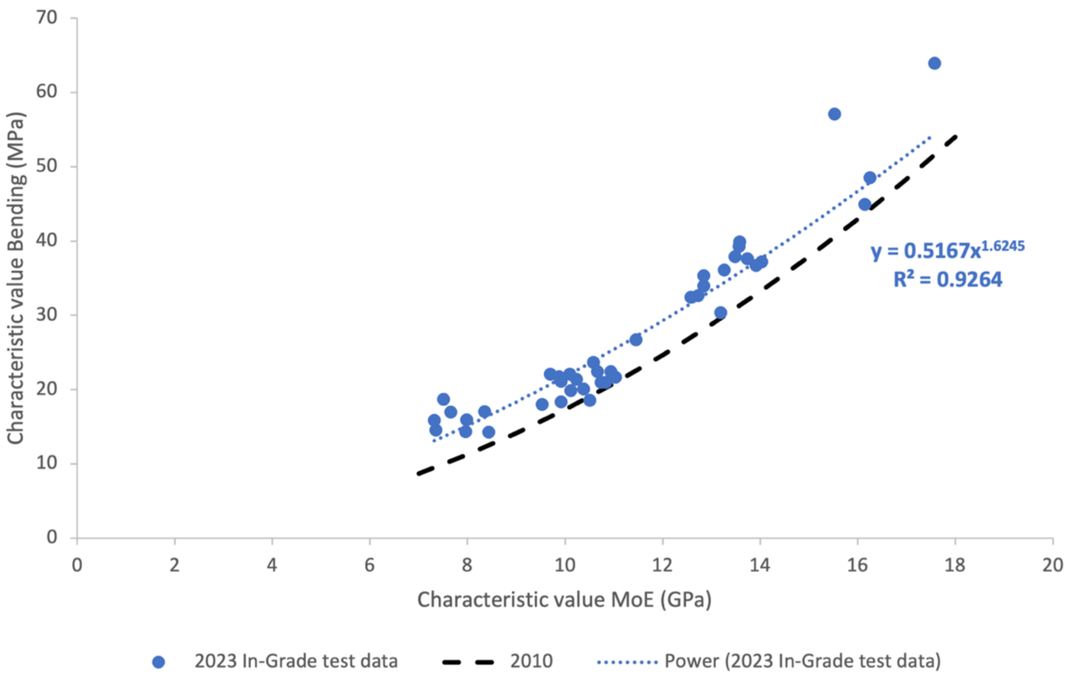


Figure 5.1 – Bending strength to MoE relationship

Figure 5.1 presents the relationship between characteristic bending strength and MoE from *2023 In-Grade Study*. The black dashed line (a lower-bound envelope line) from the *2010 MGP Properties Study* presents the relationship assumed in the development of the MGP grades presented in table H3.1 of

AS 1720.1-2010 (Standards Australia, 2010a). The blue dots represent the 90x35 mm *2023 In-Grade Study* results mill-by-mill by grade. Data points above the black dashed line represents mills that tend to be stiffness limited in production. All but one product from one mill tend to be stiffness limited with the current relationship between design characteristic values for bending strength, f'_b and MoE in table H3.1 AS 1702.1-2010 (Standards Australia, 2010a). The blue dotted line represents the line of best fit through the *2023 In-Grade Study* data. It is approximately parallel and offset from the black dashed line. This demonstrates the bending strength to MoE relationship is appropriately represented in AS 1720.1-2010 (Standards Australia, 2010a) for the products tested in the *2023 In-Grade Study*. Relationships for other indicator or inferred properties are discussed in the sections below.

5.2.2 Tension strength parallel to grain

Tension strength parallel to grain is an inferred property for most mills as assumed in the development of the MGP properties for AS 1720.1-2010 (Standards Australia, 2010a). Design ratios in Table 5.1 show that for the MGP grades the design ratio for tension strength (inferred) is approximately 1.1 times the design ratio for bending strength (indicator) for the MGP grades as anticipated. This means that monitoring bending strength in QC testing will generally also confirm tension strength which has a higher margin above the DV. However, F5 design ratio for tension strength is approximately 0.9 times the design ratio for bending strength, meaning that the product is limited by an inferred strength property which makes machine stress grading and verification more complex.

Figure 5.2 presents the *2023 In-Grade Study* tension strength to bending strength relationship along with the *2010 MGP Properties Study* analysis used to generate the current MGP property relationships in AS 1720.1-2010 (Standards Australia, 2010a). There is a strong relationship between characteristic tension strength and characteristic bending strength in this study with an R^2 of 0.87.

The black line in Figure 5.2 includes the k_{ntp} factor for inferred properties. This factor aims to introduce appropriate conservatism for the inferred properties compared to the indicator properties. It aimed to give a 75% confidence that the tension strength exceeded the design property given that the bending strength exceeds its design strength. Figure 5.2 shows that 30 of the 41 mill/grade/size data points from this *2023 In-Grade Study* are above the *2010 MGP Properties Study* relationship and 11 are below; 75% of MGP products have a higher design ratio for tension than bending strength as expected. This demonstrates the tension strength to bending strength relationship represented in AS 1720.1:2010 (Standards Australia, 2010a) for the MGP products is confirmed by the tests in the *2023 In-Grade Study*. The design characteristic tension strength for F5 softwood in AS 1720.1-2010 table H2.1 (Standards Australia, 2010a) does not follow the same relative relationship with the F5 design characteristic bending strength as the MGP grades.

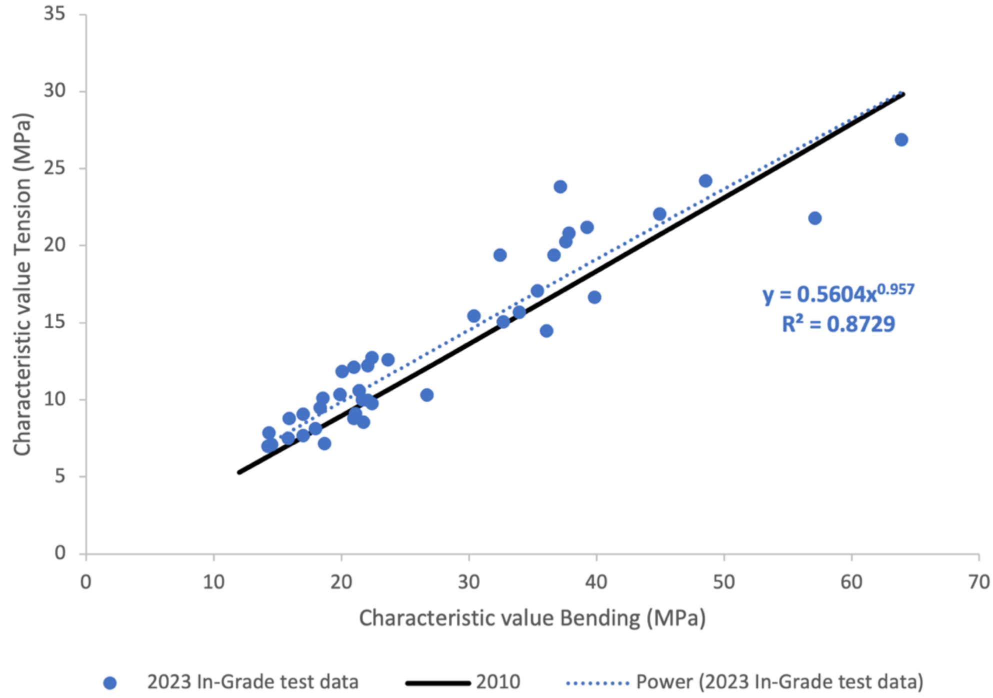


Figure 5.2 – Tension strength vs bending strength

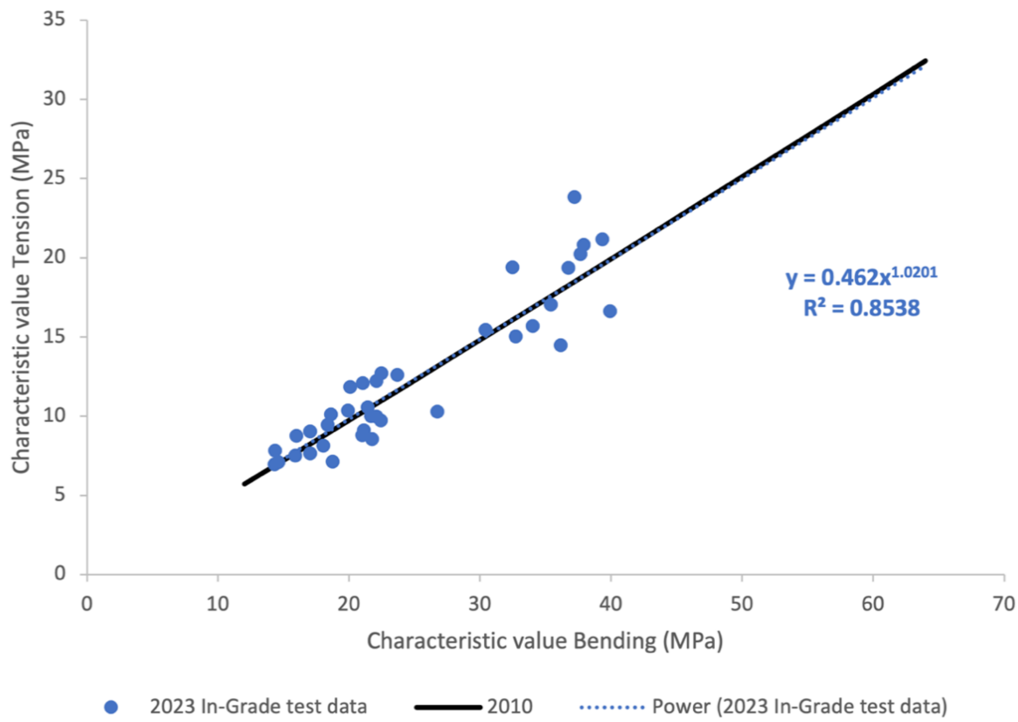


Figure 5.3 – Tension strength vs bending strength excluding k_{ntp} from 2010 data and MGP15 from 2023 data

Figure 5.3 illustrates the good alignment of the *2010 MGP Properties Study* curves and the *2023 In-Grade Study* test data. It presents the characteristic tension strength plotted against the characteristic bending strength for the *2023 In-Grade Study* data with MGP15 removed to better align with data with that was presented in the *2010 MGP Properties Study* (Boughton & Juniper, 2010). The *2010 MGP Properties Study* data on this plot have the k_{ntp} property modification factor set to 1.0. This represents a direct comparison between the *2010 MGP Properties Study* data and *2023 In-Grade Study* data. The dotted blue line of best fit and the black line are virtually coincident. The equation describing the relationship from *2010 MGP Properties Study* is:

$$f_t' = 0.438 \times f_b'^{\,1.035} \tag{5.1}$$

Across the range of bending strength values presented in Figure 5.3 there has been no significant change in the bending to tension strength relationships since the work completed in *2010 MGP Properties Study* was used to derive the MGP design characteristic values in AS 1720.1-2010 (Standards Australia, 2010a).

5.2.3 Compression strength parallel to grain

Table 5.1 compression strength design ratios are equal to or greater than 1.0. However, design ratios for the MGP grades are closer to 1.0 than intended from the relationships established in the *2010 MGP Properties Study*. The high design ratio for F5 indicates a low design characteristic compression value compared to the compression strength tested and therefore indicates a potential opportunity if design characteristic values were to be revised.

The characteristic compression strengths plotted against the characteristic MoE on Figure 5.4 show that 25 of 41 mill/grade/size data points are above the MGP relationship and 16 of 41 below. The test data should have around 75% of points above this line. However, unlike the tension data the compression test data only has a 60% confidence of exceeding its design value given that the MoE just exceeds the design value. In fact, the lines of best fit from the *2023 In-Grade Study* and the *2010 MGP Properties Study* relationship line cross, further indicating slightly lower characteristic compression strength values from this *2023 In-Grade Study* than those used in the MGP property relationships of the *2010 MGP Properties Study*. This is as expected based on the CV results (Table 4.5).

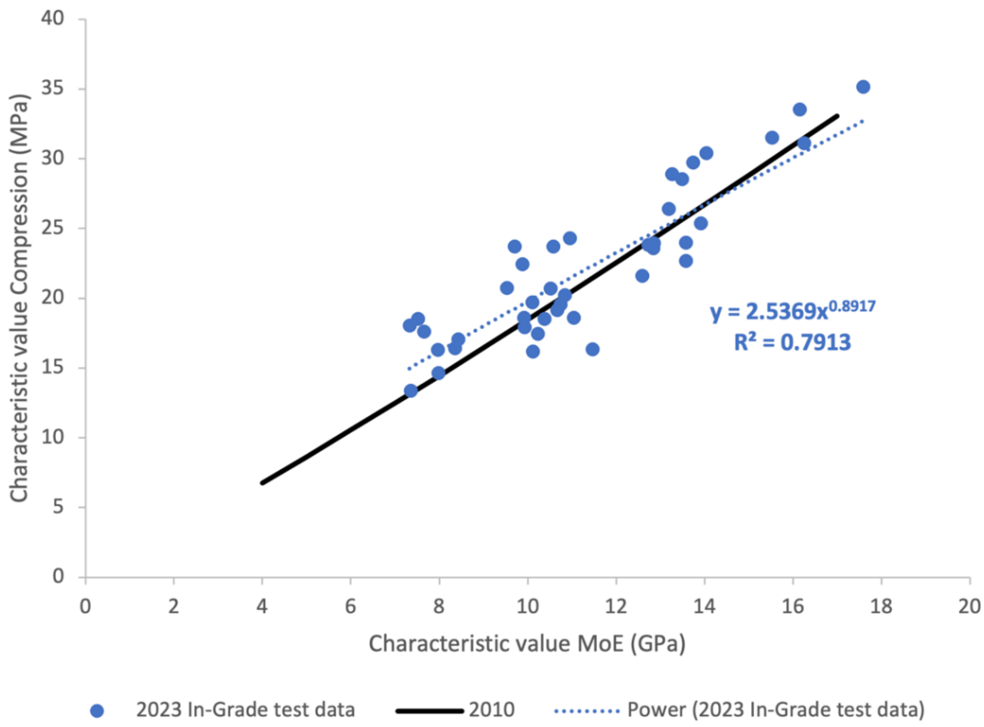


Figure 5.4 – Compression strength vs MoE relationship

This *2023 In-Grade Study* followed the 'alternative procedure' in AS/NZS 4063.1:2010 (Standards Australia, 2010b) with an overall specimen length of 8*d*+2000 mm cut into eight sub-sets of shorter length pieces. The source data used in the *2010 MGP Properties Study* relationships (Boughton & Juniper, 2010) were based on the *1998 In-Grade Study* that adopted a shorter test specimen of 30*b*; 1050 mm compared to 2720 mm for this study for 90x35 mm sections. It is hypothesised that the characteristic compression strength would be influenced by the test specimen length adopted. To confirm this, a special analysis considered three of the middle sub-set pieces (pieces 4, 5, 6) of the eight, totalling 1020 mm, to simulate the compression characteristic values that this study would have achieved with a test specimen length similar to the *1998 In-Grade Study*. Design ratios calculated with this simulation are presented in Table 5.2. These values average 1.09 times the design ratios for 90x35 mm MGP products and average 1.07 times the design ratios for 190x45 mm MGP products tested to the 'alternative procedure' in AS/NZS 4063.1:2010 (right hand column in Table 5.2 for reference taken from Table 4.5). They are closer to the values expected for an inferred property, but still lower than the values for tension strength and shear strength for the same sizes.

Table 5.2 – Compression parallel to grain results simulated shorter specimen

Compression parallel to grain *(f'c)* [~ 30*b* specimen length]							AS/NZS 4063.1:2010
Size (mm)	**Grade**	**Count**	**CV (MPa)**	**CoV**	**DV (MPa)**	***DR***	***DR***
90x35	**NS**	493	14.1	34.6%	N/A	*N/A*	*N/A*
90x35	**F5**	551	18.5	24.7%	11.0	*1.7*	*1.5*
90x35	**MGP10**	749	21.3	24.1%	18.0	*1.2*	*1.1*
90x35	**MGP12**	327	26.6	20.2%	24.0	*1.1*	*1.0*
90x35	**MGP15**	109	36.1	17.4%	30.0	*1.2*	*1.1*
190x45	**NS**	473	13.5	35.8%	N/A	*N/A*	*N/A*
190x45	**F5**	-	-	-	-	-	-
190x45	**MGP10**	431	20.3	23.6%	18.0	*1.1*	*1.0*
190x45	**MGP12**	191	30.5	16.7%	23.0	*1.3*	*1.3*
190x45	**MGP15**	-	-	-	-	-	-

Figure 5.5 presents the characteristic compression strengths plotted against the characteristic MoE for the *2023 In-Grade Study* results in accordance with AS/NZS 4063.1:2010 (blue) and the results with a simulated specimen length similar to that from the *1998 In-Grade Study* and the basis for the *2010 MGP Properties Study* relationships (green). Figure 5.5 shows that 34 of 41 mill/grade/size data points are above the MGP property relationship line and 7 of 41 below; this is closer to the intended relationship of 75% of points above this property relationship line compared to the longer test specimen tests in accordance with AS/NZS 4063.1:2010 adopted in this study.

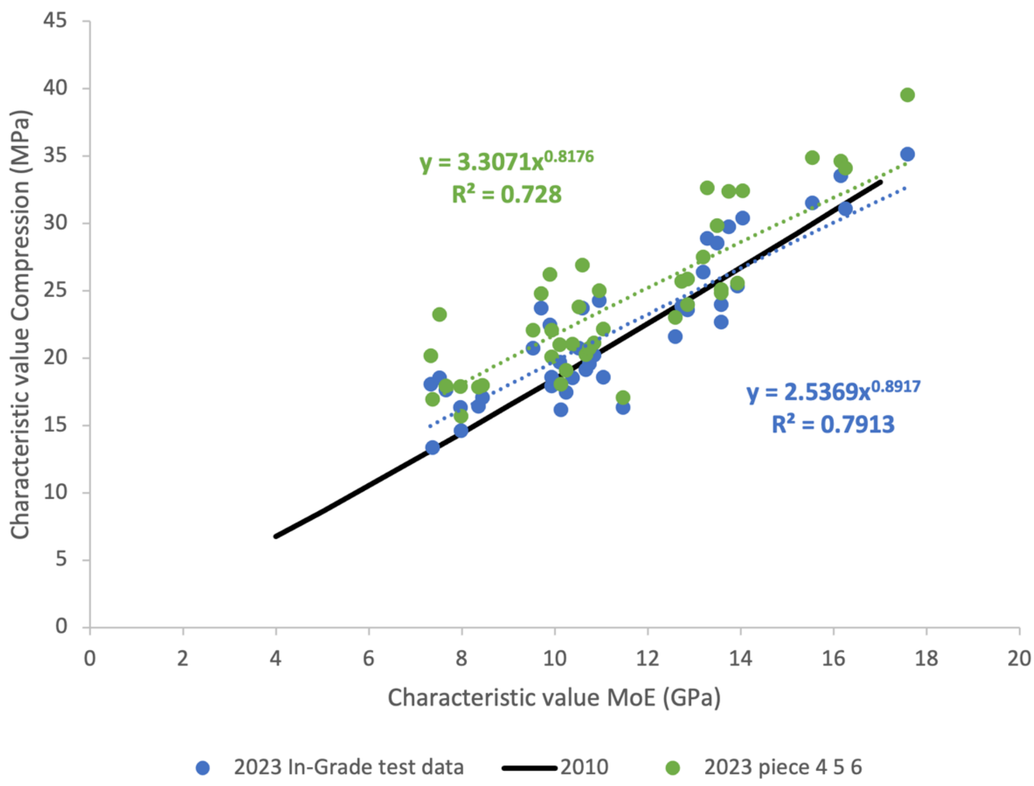


Figure 5.5 – Compression strength vs MoE relationship including simulated shorter specimen

ISO 13910:2014 *Timber structures – Strength graded timber – Test methods for structural properties* (International Organization for Standardization, 2014a) does not specify test specimen length for compression strength parallel to grain. An alternative test procedure using short sub-set pieces is permitted under ISO 13910:2014 provided the relationship between the full length and short sub-set tests is established for the population. At the time of writing this report a further study has commenced looking into the influence of specimen length on the compression characteristic value, and relative performance of the full specimen length vs 'alternative procedure' for compression testing in AS/NZS 4063.1:2010.

5.2.4 Beam shear strength

Table 5.1 beam shear design ratios are all greater than 1.0. Design ratios for 90x35 mm MGP product are 1.3 which is generally as anticipated from the *2010 MGP Properties Study* relationships. Design ratios for 190x45 mm product are closer to 1.0 indicating that the size effect relating to beam shear strength could be refined to better account for the wide (>140 mm) boards.

Figure 5.6 presents the characteristic beam shear strength vs characteristic MoE for the 90x35 mm boards in blue and 190x45 mm boards in orange. The *2010 MGP Properties Study* relationships presented in Figure 5.6 (black line) indicates that the MoE (indicator) vs beam shear strength (inferred) relationship for the 90x35 mm narrow boards (≤140 mm) is appropriate as adopted in the MGP properties in AS 1720.1-2010 (Standards Australia, 2010a), but slightly conservative; 38 of 41 mill/grade/size data points from this *2023 In-Grade Study* are above the *2010 MGP Properties Study* relationship line and three are below. The line of best fit through the 190x45 mm wide board data (orange) is close to the MGP beam shear to MoE relationship as presented in AS 1720.1-2010 (grey line); the impact of size on the beam shear strength results is not sufficiently represented by the size effect in the design characteristic values in AS 1720.1-2010.

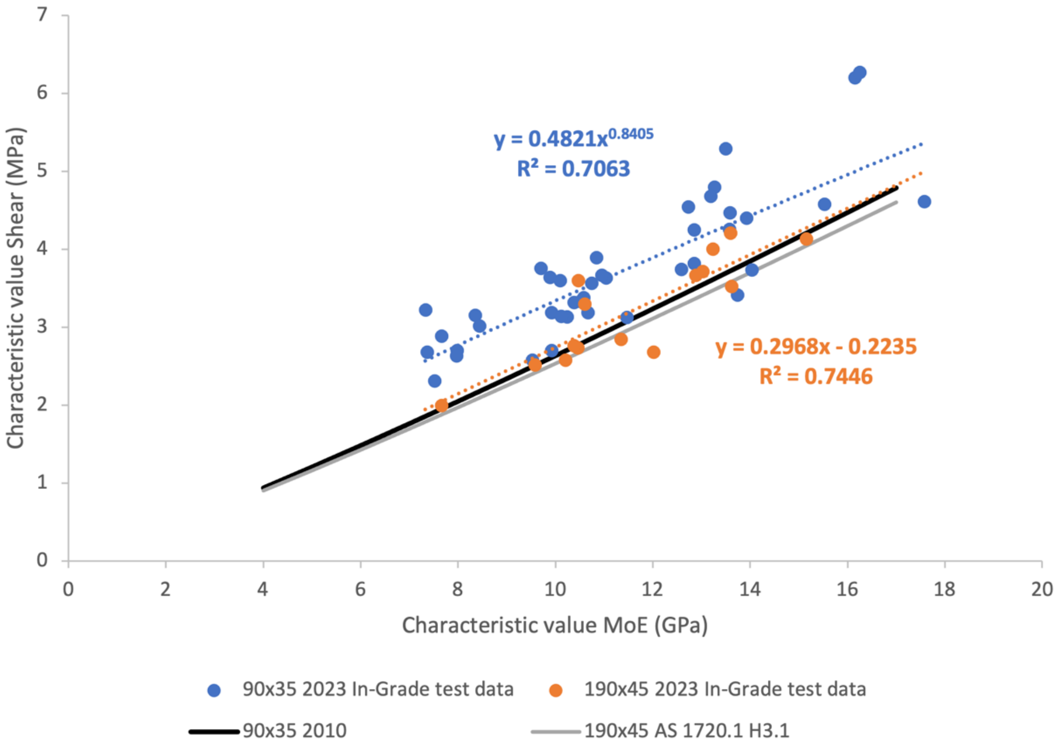


Figure 5.6 – Beam shear strength vs MoE

The beam shear test method in AS/NZS 4063.1:2010 (Standards Australia, 2010b) is an approximation of a short, deep beam loaded in service simulating a lintel, for example. In this test method failure can be triggered by a shear failure or an in-grade bending failure. This *2023 In-Grade Study* captured failure mode for the beam shear testing. Figure 5.7 and Figure 5.8 present beam shear strength CFDs with data separated by failure mode for each grade for 90x35 and 190x45 mm respectively. For the current MGP grades the population including bending failures aligns well with the population when separated to present only shear failure modes, therefore the MGP results from beam shear strength testing with this method can be analysed as a single group, rather than separating by failure modes. (See also Table 5.3.)

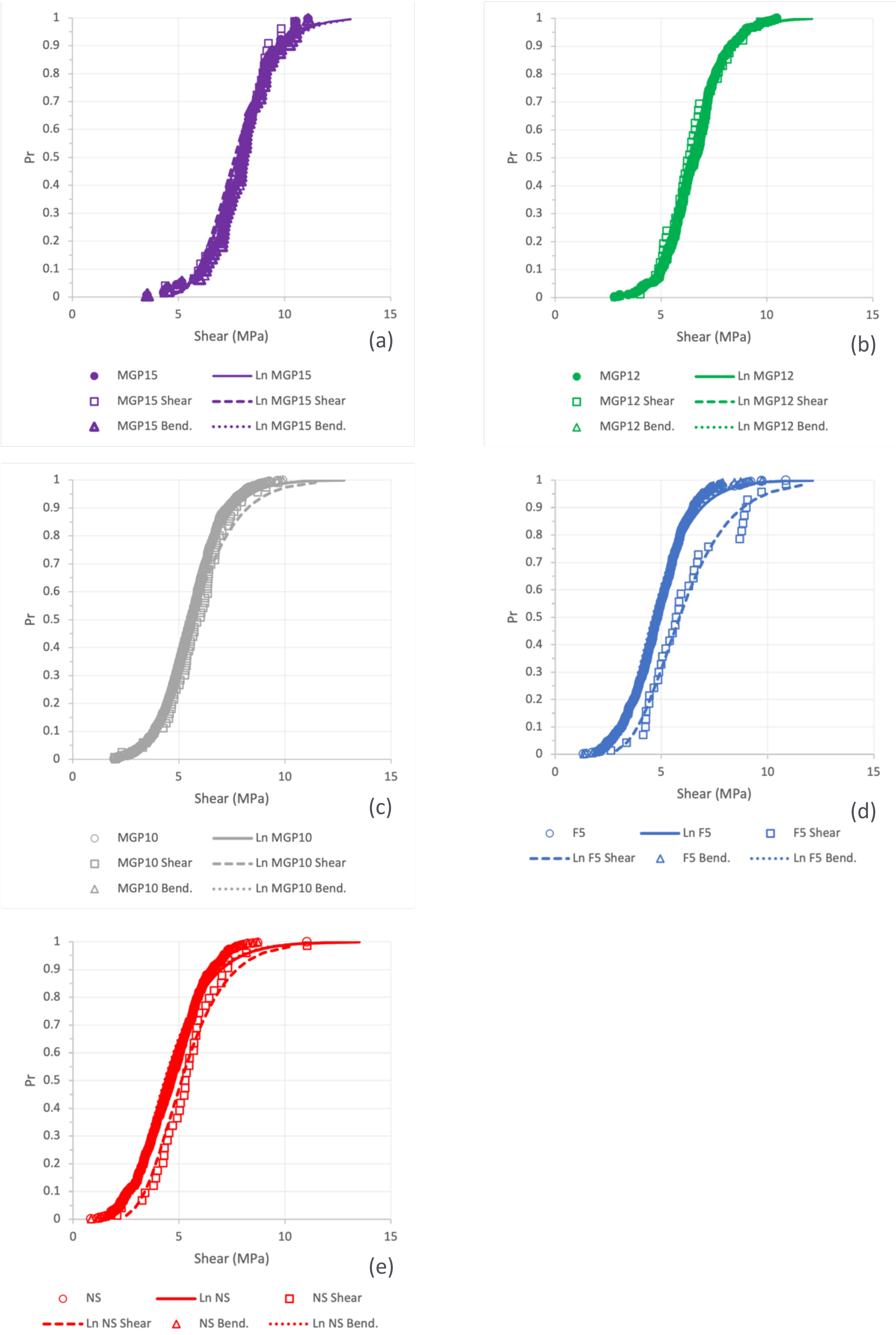


Figure 5.7 – 90x35 mm beam shear strength by failure mode: (a) MGP15, (b) MGP12, (c) MGP10, (d) F5, and (e) NS.

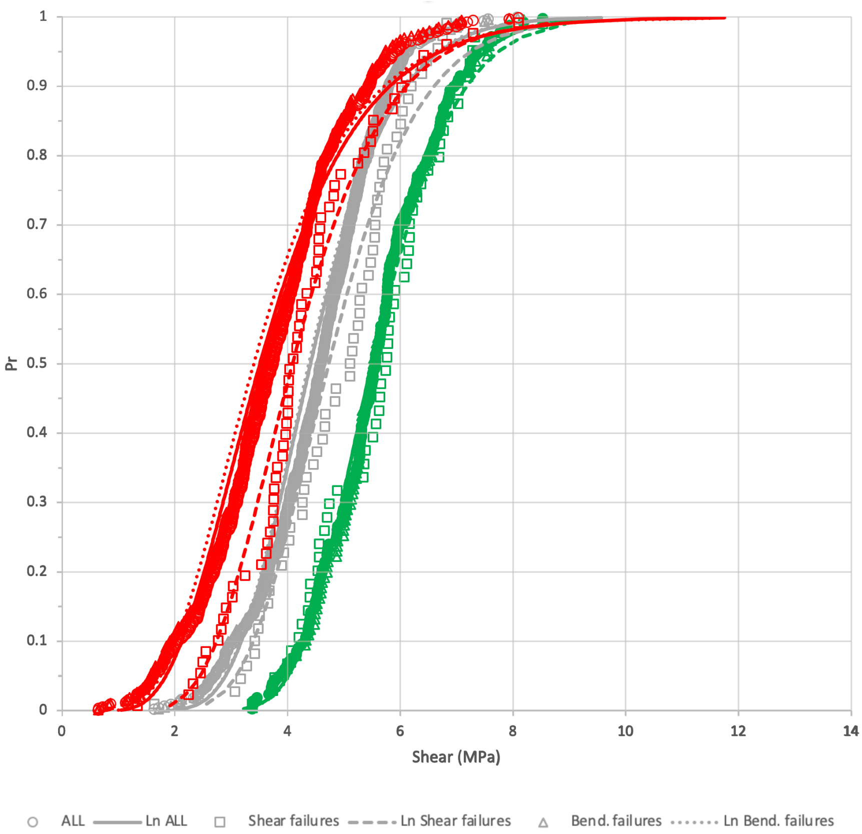


Figure 5.8 – 190x45 mm beam shear strength by failure mode

Table 5.3 presents results separated by failure mode. The beam shear strength calculated considering only shear failures increases as grade increases, as anticipated. Shear failures represent a higher beam shear strength than the *bending only failures* or *all failures* for F5. The proportion of bending to shear failures increases as grade decreases for the MGP grades. This is as anticipated given that the grades with lower bending strength requirements are likely to have strength reducing features that impact the beam shear strength from this test method, making it more likely that low strength pieces will have bending failures rather than shear failures.

Table 5.3 – Beam shear results by failure mode

		Shear in beams (*f'*$_v$)								
		All failures			Shear failures			Bending failures		
Size (mm)	Grade	Count	ln5%ile (MPa)	CoV	Count	ln5%ile (MPa)	CoV	Count	ln5%ile (MPa)	CoV
90x35	**F5**	547	2.8	31.4%	35	3.4	33.0%	512	2.8	30.7%
90x35	**MGP10**	739	3.5	27.5%	58	3.5	30.3%	681	3.5	27.2%
90x35	**MGP12**	325	4.5	21.6%	44	4.5	21.5%	281	4.5	21.7%
90x35	**MGP15**	106	5.6	20.4%	38	5.5	20.1%	68	5.6	20.7%
190x45	**MGP10**	411	2.9	25.9%	55	3.1	26.3%	356	2.9	25.8%
190x45	**MGP12**	185	4.0	19.2%	52	3.9	20.8%	133	4.0	19.1%

Results from this study suggest the beam shear strength test methodology in AS/NZS 4063.1:2010 (Standards Australia, 2010b) is an appropriate test method as an approximation of potentially shear-critical elements in service, and that consideration of bending failures and shear failures together is appropriate for the current MGP grades. The beam shear strength result considering all failure modes together is an accurate means of calculating beam shear strength for the higher grades, and conservative for the lower grades (<MGP10) that may be limited by bending failure modes.

At the time of writing this report a further study has commenced that will collect additional data on beam shear strength. The study will include beam shear strength characteristic values, failure modes across the grades, and the size effect of beam shear strength.

5.2.5 Density

Design ratios for density cannot be calculated in this study as there are no characteristic design values for density in AS 1720.1-2010 (Standards Australia, 2010a). In AS 1720.1-2010 density is related to connection performance through Joint Design (JD) groups covered in AS 1720.2-2006 (Standards Australia, 2006) Table 3 as 'Average Minimum density at 12% moisture content'. The detail of the JD density requirement is covered in AS 1649-2001 *Timber – Methods of test for mechanical fasteners and connectors* clause 1.8 (Standards Australia, 2001). AS 1649 requires that the 'mean air-dry density' for the timber selected to represent the joint group in connection tests is at the 'bottom end of the range' of densities given, which relate in turn to those values presented in AS 1720.2-2006 (Standards Australia, 2006); 380 kg/m^3 for the lowest value in the JD5 range and similarly 480 kg/m^3 for JD4. This implies that the connection strength is characterised by densities near the bottom of the density distribution of a stress-grade. Figure 5.9 and Figure 5.10 present density CFDs for 90x35 and 190x45 mm products from this *2023 In-Grade Study* with average minimum density requirements from AS 1720.2-2006 Table 3 (Standards Australia, 2006) for JD5 (380 kg/m^3) and JD4 (480 kg/m^3)

overlaid as relevant for MGP10 and MGP12/15 respectively as presented in Table H3.1 AS 1720.1-2010 (Standards Australia, 2010a).

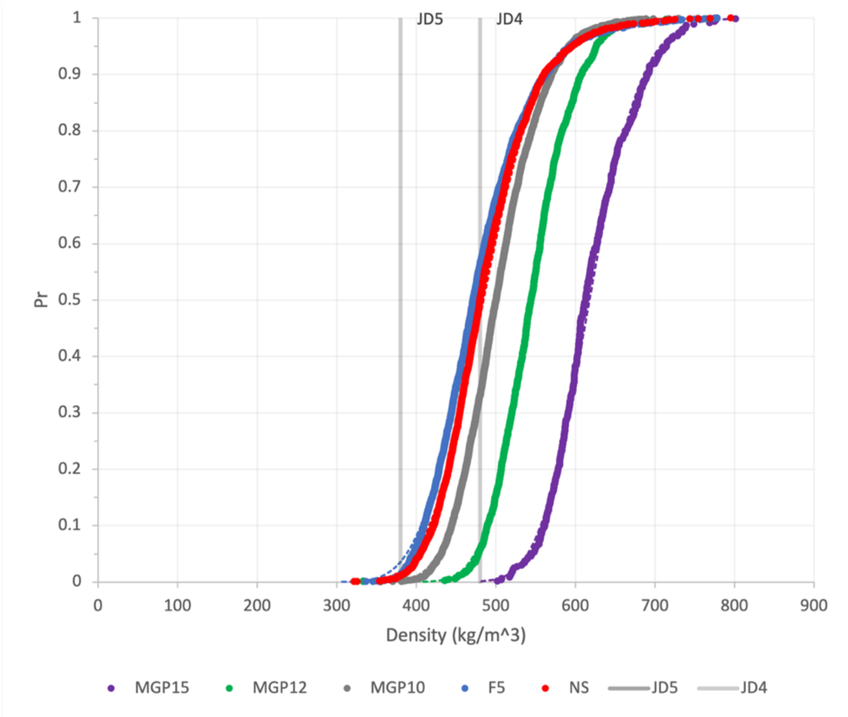


Figure 5.9 – 90x35 mm density at 12%MC with JDs overlaid

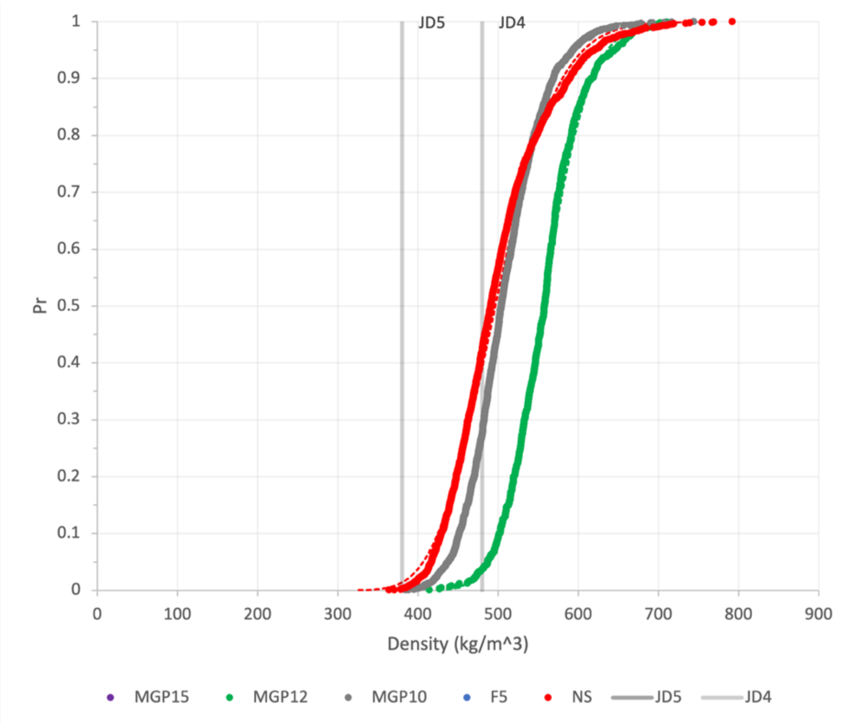


Figure 5.10 – 190x45 mm density at 12%MC with JDs overlaid

Revisions to AS 1720.1-2010 (Standards Australia, 2010a) connection design are planned, at the time of writing this report. Revision to connection design will follow a design process similar to international models adopting the European Yield Model and variations thereof. Such models require characteristic density data for use in strength design models for connections. Characteristic densities are therefore calculated in this *2023 In-Grade Study* using AS/NZS 4063.2:2010 Appendix B2 Method 1 (Standards Australia, 2010c) for strength properties. Characteristic densities by size and grade are presented in Table 4.1. MGP10 90x35 and 190x45 mm populations have similar density as measured on the whole-of-board. MGP12 190x45 mm has higher CV for density than 90x35 mm boards which is likely influenced by the absence of MGP15 product recovered from above MGP12 in 190x45 mm.

CV for densities cannot be directly related to the JD groups given the differences in calculation between CVs and JD densities, but qualitatively considering Figure 5.9 and Figure 5.10 CFDs for discussion;

- MGP10 satisfies the density requirement for JD5, if 380 kg/m^3 is taken as a minimum.
- Approximately 65% of MGP10 meets the density requirement for JD4, if 480 kg/m^3 is taken as a minimum.
- Approximately 95% of MGP12 meets the density requirement for JD4, if 480 kg/m^3 is taken as a minimum.
- MGP15 meets the density requirement for JD4, if 480 kg/m^3 is taken as a minimum.

Figure 5.11 and Figure 5.12 present the property relationship between density and MoE for 90x35 and 190x45 mm. The blue dots represent each mill and product CV MoE plotted against CV density. The blue dotted line is the linear best fit through the mill data. This relationship is adjusted to generate the proposed relationship between CV MoE and density design characteristic values (grey line) which is the lower-bound of the mill-by-mill CV Density to CV MoE mill-by-mill relationships from this study. The relationship (grey line) is the same for both 90x35 and 190x45 mm (narrows and wides) and is represented by;

$$\rho_k = 16.61\ E + 235 \qquad (5.2)$$

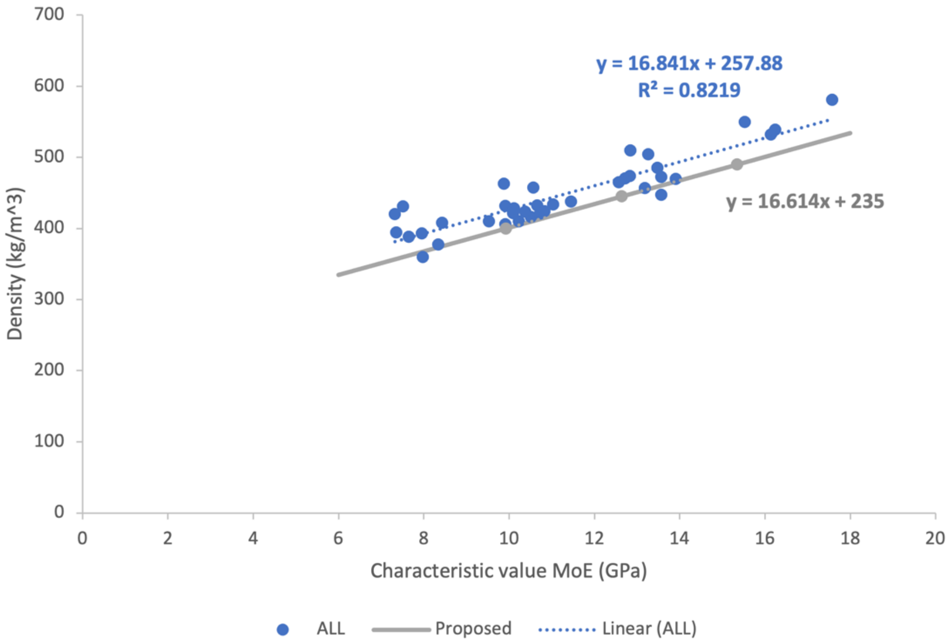


Figure 5.11 – 90x35 mm Characteristic Density to MoE relationship

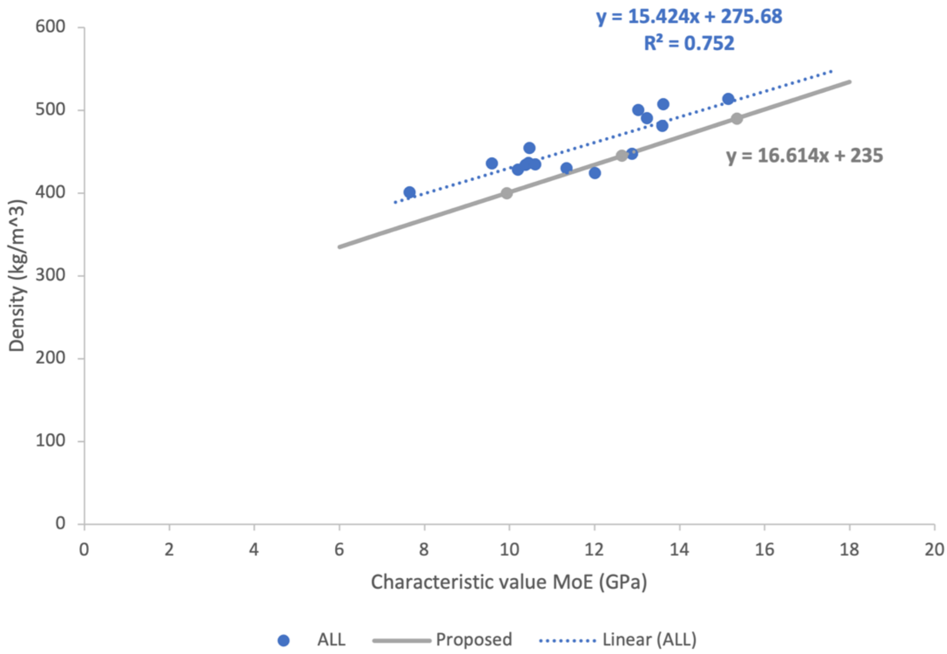


Figure 5.12 – 190x45 mm Characteristic Density to MoE relationship

Characteristic design density values at 12% moisture content evaluated using Equation (5.2) at the design MoE are presented in Table 5.4, rounded to the nearest 5 kg/m^3.

Table 5.4 – Proposed density design characteristic values by stress grade (narrows)

Stress grade	MoE DV *(E)* (GPa)	Density DV *(ρ_k)* (kg/m^3)
MGP10	10	400
MGP12	12.7	445
MGP15	15.2	490

The proposed design characteristic density is equal for narrows and wides in a given grade which is appropriate given density is measured as a board average.

5.3 Length to depth relationships

This *2023 In-Grade Study* sampled boards of minimum 4.8 m length. AS/NZS 4063.1:2010 (Standards Australia, 2010b) uses random position testing to characterise structural properties. Shorter boards allow for less potential randomisation of test position. Longer length pieces will have higher random properties than shorter length pieces since in longer pieces there is a higher probability that the random test location does not contain the lowest strength part of the piece. Randomisation of test position is not possible when the sample piece is the same length as the test piece, as the grade limiting feature of the board will be located in the test piece and the test results then converge on the biased position test result. This impacts the relationship between grading parameter threshold and characteristic values by length. In the case of optimised / trim / cut-in-two solutions (with boards shorter than the 4.8 m used in this *2023 In-Grade Study*) the grading parameter thresholds in production should increase to respond to the reduction of randomisation of the test location to preserve the property characteristic values of the tested population.

A parallel study *Developing a technical basis for biased testing structural property verification method of Australian sawn softwood* (Shanks, 2023) discusses board length to depth ratios impacting random to biased position relationships. This is of interest in developing potential biased position verification testing.

5.4 Summary/Opportunities

- Populations of tested properties are well represented by log normal distributions.
- All Characteristic Values (CVs) are greater than Design Characteristic Values i.e. Design Ratios > 1.0
- CoVs are as expected.
- MGP grades are stiffness or compression limited (low compression CVs discussed and subject to further investigation to establish the influence of the alternate method of test).
- Relative relationships between indicator and inferred properties are generally as established in the current MGP properties in AS 1720.1-2010 Table H3.1 (Standards Australia, 2006).
- Agnostic grading profiles have been captured for the majority of the sampled and tested material.
    - *OPPORTUNITY: Agnostic profiles can be used in future studies to review existing timber grades to maximize utilization of resource and align major and minor properties with application.*
- F5 is limited by tension strength (not an *Indicator property* for most mills).
    - *OPPORTUNITY: Potential to review existing timber grades to be better suited to machine stress grading and modern application, and/or reduce F5 (softwood) tension design characteristic values.*
- Compression results exceed Design Characteristic Values but are lower than anticipated.
    - *Follow-on project commenced at the time of writing investigating specimen length, and full specimen length vs alternative compression test method in AS/NZS 4063.1:2010 (Standards Australia, 2010b).*
- Shear in beam results for 190x45 mm (wides) exceed Design Characteristic Values but are lower than anticipated.
    - *Follow-on project commenced at the time of writing looking at shear values, size factor and test method in AS/NZS 4063.1:2010 (Standards Australia, 2010b).*
- Characteristic (5%ile) values for density have been developed for each of the tested grades and a relationship is proposed to represent density design characteristic values relative to MoE.
    - *OPPORTUNITY: Design Characteristic Values of density by grade better align with densities of product, maximizing utilization and value. Design Characteristic Values for density are proposed to be included as a requirement for MGP grades for inclusion in Standards updates, and to be used in development of fastener design models.*

6 Conclusions

The *2023 In-Grade Study* represents a significant national collaboration. Timber was sampled across 13 mills and pooled nationally for characterisation. The contributing mills represent 90% of Australian-produced machine graded structural sawn softwood. In-Grade testing across major (indicator) and minor (inferred) properties demonstrated that the nationally pooled resource exceeds the design values required for the sampled and tested grades, indicating that mill grading processes within the framework of AS/NZS 1748:2011 are performing as anticipated.

Relative relationships between properties were compared to those used in *2010 MGP Properties Study* (Boughton & Juniper, 2010) in defining the MGP properties currently presented in AS 1720.1-2010. Bending strength, MoE, and tension strength parallel to grain relationships developed in *2010 MGP Properties Study* remain valid. Differences identified in compression parallel to grain results has led to a follow-on research project (commenced at the time of writing). Beam shear to MoE relationship for 'narrows' as developed in *2010 MGP Properties Study* is valid, but the size effect of 'wides' requires further work, which has commenced at the time of writing.

Design characteristic values for density have been proposed for use in future development of AS 1720.1 connection design models. A relationship between characteristic density and MoE has been proposed to allow future development of characteristic design values for density if the MGP grades are modified with changing MoE requirements.

The project has produced a legacy dataset of ~17,000 characterisation tests across bending strength, apparent modulus of elasticity in bending, tension strength parallel to grain, compression strength parallel to grain, and beam shear strength. The dataset includes material that achieved a structural grade and material below the lowest structural grade. Mill data was used to generate an agnostic grading profile for the sampled timber. Together, the grading profiles and test results across all grades and non-structural timber provides a powerful tool for industry in future considerations around possible distribution of the MGP grade properties.

Acknowledgements

Thanks to NIFPI Mt Gambier and FWPA for the opportunity to complete this *2023 In-Grade Study*.

This project would not have happened without the enthusiastic support of the contributing mills and the mill teams sampling, labelling, sorting and shipping the boards.

Thanks to the *Project Delivery Steering Group* for guidance in the 50+ regular meetings working through the planning and delivery of the 2023 In-Grade Study.

Special thanks to Andy McNaught for his technical support and wisdom, drawing from many decades of experience and service to the Australian timber industry.

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