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ARC ADVANCED TIMBER HUB – PROJECT 6.1 – MILESTONE REPORT 1

LITERATURE REVIEW ON THE USE OF OUT-OF-GRADE TIMBER IN RESIDENTIAL CONSTRUCTION

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EXECUTIVE ABSTRACT

This document presents a literature review to assist in the development of a new out-of-grade product for the Australian residential market which would offer alternative solutions to meet high market demands, combined with national timber shortages, and maximise the use of available resources in Australia. It provides an understanding on the properties of out-of-grade timber, the type of out-of-grade structural products in national and international standards and the potential uses of such products. The definition of out-of-grade timber from Cherry, et al. (2022) is adopted in this review and defines out-of-grade as timber not meeting the structural framing requirements for Machine Graded Pine (MGP) in AS/NZS 1748.1 (2011) and AS 1720.1 (2010), noting that F8 grades and below in AS 1720.1 (2010) would therefore be defined in this study as out-of-grade timber. The following key points were found:

- Out-of-grade boards are principally sawed from the centre of the logs. This implies the presence of pith and a higher resin content for some species when compared to boards sawn away from the pith. However, higher resin content was found not to be detrimental to the mechanical properties.
- Knots are more frequent and larger in out-of-grade timber. Knots were found to negatively influence the mechanical properties.
- Out-of-grade timber presents high variability in mechanical properties, but still present advantageous properties for structural applications. The MOE was reported as the major reason for grade rejection in Cherry, et al. (2022).
- The characteristic strengths of tested out-of-grade hybrid (*Pinus elliotti* var. *elliottii* × *Pinus caribaea* var. *hondurensis*) pine boards typically met the requirements for MGP10, except for the bending strength of boards with high knot concentration and the perpendicular-to-grain bearing strength of all boards.
- Out-of-grade timber is often associated with juvenile wood which would lead to distortion issues, especially twist.
- International standards have less stringent requirements than the Australian standard AS/NZS 1748.1 (2011) on geometric imperfections for out-of-grade timber. As these international out-of-grade products are also used in framing, the comparison indicates that alternative requirements than in the Australian standard may be acceptable for a new out-of-grade lumber used in residential construction. However, to satisfy modern frame and truss manufacturing methods (such as robotisation), sawmills often have tighter imperfection requirements than in the AS/NZS 1748.1 (2011). This difference needs to be considered in the research.
- Potential applications in the residential market include short elements, such as those used in the subfloor, battens, studs, nogging and roof trusses (webs and bottom plates). Non-load bearing walls may also represent a market opportunity. Wespine in Western Australia is commercialising out-of-grade timber for studs, battens and top plate elements for masonry walls.

If a new out-of-grade framing structural product was to be commercialised, the following aspects would have to be verified:

- The potentiality of high resin content, more frequent and larger knots, and the presence of pith to be accepted by frame and truss manufacturers, as well as builders. Would there be challenges in adoption?
- If the Australian framing market would accept higher levels of geometric imperfections and other characteristics, such as splits, knots and/or through checks. How these characteristics would be integrated into modern or “traditional” framing manufacturing processes? Would it complicate the current manufacturing process.

INTRODUCTION

According to Cherry, et al. (2019), it is common knowledge that significant volumes of sawn Australian softwood do not meet the structural framing requirements for Machine Graded Pine (MGP) in AS/NZS 1748.1 (2011) and AS 1720.1 (2010). The authors mentioned studies with between 27.5% and 57.5% of sawn boards graded as non-structural, and therefore commonly sold as a lost. These large volumes are attributable to growers planting fast growing species (Cherry, et al., 2022), leading to less mature wood with lower mechanical properties (Ramage, et al., 2017). Hardling (2008) mentioned that the recovery of structural products decreases with young trees and estimated that between 82.5% and 88.8% of sawn boards were recovered as Machine Graded Pine (MGP) at the Hyne and Son Tuan mill in Queensland.

Sawn boards failing to meet the MGP structural framing requirements in AS/NZS 1748.1 (2011) and AS 1720.1 (2010), either in terms of stiffness, strength, defects or distortions, are referred in this document as "out-of-grade" or "low-grade", adopting the definition by Cherry, et al. (2022). Therefore, F8 grades and below in AS 1720.1 (2010) would be defined herein as out-of-grade timber. Other definitions encountered in the literature are provided in the next section.

While research has been performed to find solutions for out-of-grade timber, it has mainly focussed on its use in Engineering Wood Products (EWP), such as Cross-Laminated Timber (CLT) (Cherry, et al., 2019, da Rosa Azambuja, et al., 2022, da Rosa Azambuja, et al., 2024, da Rosa Azambuja, et al., 2023, Lavisci, et al., 2023, Negri, et al., 2012, Silva do Carmo, et al., 2022, Smith, 2011), stress-laminated columns (Fleming, et al., 2020), nail-laminated products (Gattas, et al., 2024) and glued-laminated floors (Summerville, 2009). Nevertheless, as mentioned in Cherry, et al. (2022) the "development of custom grades to extract suitable timber from the out-of-grade population would optimise its use while providing a reliably performing product". Such custom grades could be used in residential construction, especially that despite out-of-grade timber being a highly variable resource, with highly variable structural properties, it still possesses favourable structural properties (Cherry, et al., 2019). Wespine in Western Australia is commercialising out-of-grade products for specific residential applications, referred to as "Studmate" (Wespine, 2018), "Wesbatten" (Wespine, 2017) and "Masonry top plate" (Wespine, 2005).

For an out-of-grade product to be accepted and used in residential construction, it must have two separate attributes:

- Offer mechanical properties high enough to be designed for a specific application.
- Have limited geometric imperfections and characteristics, such wane, splits or checks, to be integrated in the production line of frame and truss manufacturers and used on-site by builders.

This document presents a literature review to assist in the development of a new out-of-grade product for the Australian residential market which would offer alternative solutions to meet high market demands combined with national timber shortages. It specifically aims at understanding the properties of out-of-grade timber, the structural products in national and international standards meeting the adopted definition of out-of-grade in this report and the potential uses of such products.

First, this document presents various definitions of out-of-grade timber in the literature. Second, the properties of out-of-grade timber, both in terms of mechanical properties and utility requirements, are introduced. Third, existing grades in international standards with characteristic Modulus of Elasticity (MOE) lower than or equal to MGP10 (AS 1720.1, 2010) are presented and discussed. Proposed uses of out-of-grade timber in residential construction are then reviewed. Finally, conclusions are drawn and recommendations on aspects to be looked at for out-of-grade timber to be accepted by truss and frame manufacturers and builders are examined.

DEFINITION OF OUT-OF-GRADE TIMBER

Several definitions of out-of-grade and low-grade timber can be found in the literature. As mentioned in the introduction, Cherry, et al. (2022) defined out-of-grade as "sawn timber that has failed to meet the MGP structural framing requirements of AS/NZS 1748.1 (2011) and AS 1720.1 (2010) which specify minimum characteristic values of stiffness, strength and place limits on defects including resin shake, wane and distortion." Similarly, Gattas, et al. (2024) described out-of-grade timber as "boards failing to attain a structural grade under existing classification systems due to various stiffness, strength, and/or utility-limiting features." Takeda, et al. (1999) characterised low-grade Japanese larch lumbers as lumbers with Modulus of Elasticity (MOE) of about 7.0 GPa. da Rosa Azambuja et al. (da Rosa Azambuja, et al., 2022, da Rosa Azambuja, et al., 2024, da Rosa Azambuja, et al., 2023) defined low-grade timber in North America as No. 2 Common and No. 3 Common graded lumbers (NDS, 2024).

Luppold, et al. (2003) made a distinction between "low-value" and "low-grade" timber: "low-value is an economic concept, i.e., a product is low-value when the market determines the price of that product is low relative to similar products. Low-grade is a physical concept; a product grade is based upon an agreed on protocol (grading system) that classifies material into a quantitative group." Economically, the authors also mentioned that a "material also may become more valuable if a production process is developed to utilize the material."

Koch (1960) provided a detailed definition on the attribute of low-grade timber with "properties that cause wood itself to be termed "low-grade" would include the following:

1. Knotty;
2. Available only in small size;
3. Rotten to some degree or containing insect damage;
4. Weak;
5. Not durable;
6. Not straight grained;
7. Difficult to dry;
8. Unstable, i.e., shrinks and swells excessively;
9. Low in resistance to warping;
10. Difficult to machine;
11. Poor in ability to hold nails and screws;

12. Low in split resistance;
13. Poor in ability to hold finish."

The author also stated that if economic factors are ignored, the previous "negative qualities" can be overcome, for instance by good marketing sense, i.e., "convincing public that a certain portion of these defects are in reality interesting and desirable attributes" or upgrading the product by removing the defects.

In other words, timber can be classified as out-of-grade timber for any or a combination of the following reasons:

- Do not meet utility requirements (e.g., in terms of imperfections, number and location of knots, splits, wanes, etc) while being structurally sound. Graded products could be partially recovered by cutting the out-of-grade boards into shorter lengths.
- Unsatisfactory strength values, which would be commonly dictated by a low-point MOE measurement or a strength reducing characteristic (e.g., large knot). These characteristics are often localised and graded boards could be partially recovered by cutting the out-of-grade boards into shorter lengths.
- Unsatisfactory MOE. As the MOE is frequently measured as an average value of the boards, no graded products can be recovered by cutting the boards into shorter lengths.

PROPERTIES OF OUT-OF-GRADE TIMBER IN THE LITERATURE

MECHANICAL PROPERTIES

Cherry, et al. (2022) studied the mechanical properties of out-of-grade hybrid pine (*Pinus elliotti* × *Pinus caribaea*) from Queensland, Australia. The authors stated that grading reports from the mill showed that the MOE was the major reason for grade rejection of the hybrid pine sawn boards, with the boards principally sawed from the middle of the trees. For this species, the boards sawn from the middle of the trees typically have a higher resin content that the boards sawn away from the pith (Bailleres, et al., 2006). Kretschmann, et al. (1992) also found that there is a significant reduction of strength and MOE values with increasing juvenile wood.

To assess the mechanical properties of out-of-grade sawn boards, Cherry, et al. (2022) selected three types of samples to be tested. They corresponded to (1) clear samples (with no obvious defects), (2) samples with more than 25% resin content but no obvious other defects and (3) samples with knots and a Knot-to-Area Ratio (KAR) greater than 25%. The samples were tested in bending, compression and tension parallel to grain, bearing perpendicular to grain, and shear. Results showed that:

- The average bending MOE ranged from 5.4 GPa for samples with knots up to 6.9 GPa for clear samples, while the 5th percentile bending Modulus of Rupture (MOR) ranged from 12.6 MPa for samples with knots up to 35.2 MPa for clear samples. The bending results of the samples with resin were close to the clear samples. Only samples with knots did not meet the bending strength requirement for MGP10 in AS 1720.1 (2010).

- The 5th percentile compressive strength parallel to grain of the clear samples equalled to 21.1 MPa. This value increased by 18.9% and decreased by 8.0% for the samples with resin and knots, respectively. All resulting characteristic values were higher than the compressive strength parallel to grain requirement for MGP10 in AS 1720.1 (2010).
- Knots and resin significantly improved the 5th percentile bearing strength perpendicular to grain by 111% and 22% when compared to clear samples. The 5th percentile bearing strength perpendicular to grain of the clear samples was equal to 4.5 MPa. The MOE was a good indicator of the bearing strength perpendicular to grain, and no characteristic values met the requirement for MGP10 in AS 1720.1 (2010).
- The 5th percentile shear strength ranged from 3.7 MPa for samples with knots to 5.1 MPa for clear samples. All characteristic values met the MGP10 requirement for shear in AS 1720.1 (2010).
- When compared to clear samples, knots significantly decreased the 5th percentile tensile strength parallel to grain by 64%. Resin had little effect on this characteristic value. The 5th percentile tensile strength parallel to grain of the clear samples equalled to 28.1 MPa. All sample types passed the requirement for MGP10 in AS 1720.1 (2010). However, the span of the tested samples was shorter that the requirements in AS/NZS 4063.1 (2010) (700 mm instead of 2,720) and the so-called size effect (Barrett, et al., 1995) would have likely negatively affected the calculated characteristic values.
- The presence of pith in the samples decreased the bending MOE and MOR, but had no significant effect of the compression parallel to grain, tension and shear strengths.

Cherry, et al. (2022) compared their test results to the literature on young pine trees and juvenile wood (such as Moya, et al. (2013) and Kretschmann, et al. (1992)) and found similar overall performances to the ones reported in their study. For comparison purposes, in Takeda, et al. (1999), Japanese larch lumbers with MOE of about 7.0 GPa had average tensile strengths parallel to grain ranging between 15 MPa and 20 MPa.

It worth mentioning that the Australian project “Characterising softwood sawn products” (University of South Australia, 2025) has assessed the physical and mechanical properties of a pool of Australian structural softwood timber, including out-of-grade, performing 17,800 tests. However, at the time of writing this literature review, the final report of this project is not available.

UTILITY CHARACTERISTICS

Cherry, et al. (2019) stated that as the low MOE of out-of-grade timber is often associated with juvenile wood, it contains compression wood which leads to distortion issues, especially twist (Cown, et al., 1996). The authors also listed other characteristics of out-of-grade timber:

- Knots are more frequent and larger in out-of-grade timber, which affects the structural properties (see Section “Mechanical properties”), depending on location, shape and size of the knots. Cherry, et al. (2022) mentioned that knots in juvenile wood have different characteristics than in mature wood, they are clustered, more conical in shape and have connections to the pith.

- The distorted shape in out-of-grade timber may lead to issues with building components, such as sheeting installation and connections. However, the authors mentioned that algorithms can allow designs to fit out-of-grade timber by positioning the resource efficiently (Gattas, et al., 2024).

In terms of utility requirements, apart from values provided in national and international standards (Section “Utility requirements”), to the author’s best knowledge, no publications can be found in the literature on potential acceptance levels for geometric imperfections and allowable characteristics for various structural applications. Acceptable utility limits will likely be application specific.

EXISTING OUT-OF-GRADE PRODUCTS IN NATIONAL AND INTERNATIONAL STANDARDS

MECHANICAL PROPERTIES

To understand how out-of-grade timber as defined in this project may have useful structural properties, Table 1 provides the characteristic mechanical properties of products in the AS 1720.1 (2010) (Australia), NZS AS 1720.1 (2022) (New-Zealand), EN 338 (2016) (Europe) and the National Design Specification (NDS, 2024) (North America) with MOE less than or equal to MGP10 (i.e., 10 GPa). The values are provided for a reference 90 mm × 35 mm (or 2” × 4” equivalent) lumber. Out-of-grade products commercialised by Wespine in Australia are also reported in the table.

Note that all North American grades provided in Table 1 are used for framing or light framing (Blankenhorn, 2001). In Europe, grade requirements differ in national standards to account the variability in resources encountered between countries (Trulli, et al., 2017). Only properties in EN 338 (2016) are reported herein.

For comparison purposes, the bending, compressive and tensile parallel to grain characteristic values of the grades in Table 1 are plotted against the MOE in Figure 1. The figure shows that at a given MOE, the North American standard (NDS, 2024) provides a range of products with a large variation of characteristic values. In bending, the Australian, New-Zealand and European standards provide similar characteristic values. For compression, the F-grades in the Australian standard (AS 1720.1, 2010) and New-Zealand standard (NZS AS 1720.1, 2022) have lower characteristic values than European products (EN 338, 2016) with similar MOE. In tension, the SG grades in the New-Zealand standard (NZS AS 1720.1, 2022) have the lowest characteristic values. The structural products with the lowest MOE are SG6 and No1 framing in the New-Zealand standard, with a MOE of 6.0 GPa.

Table 1: Characteristic values of softwood structural grades with MOE less than or equal to MGP10 in national and international standards for a reference 90 mm × 35 mm (or 2" × 4" equivalent) lumber.

Standard	Grade	Charac-teristic MOE (MPa)	Characteristic strength (MPa)			
			Bending(1)	Tension parallel to grain(2)	Compression parallel to grain(3)	Shear in beams(4)
AS 1720.1 (2010) and NZS AS 1720.1 (2022)	MGP10	10,000	17.0	7.7	18.0	2.6
	F8	9,100	22.0	12.0	18.0	2.2
	F7	7,900	18.0	8.9	13.0	1.9
	F5	6,900	14.0	7.3	11.0	1.6
	F4	6,100	12.0	5.8	8.6	1.3
NZS AS 1720.1 (2022)	SG10	10,000	20.0	8.0	20.0	3.0-3.8
	SG8	8,000	14.0	6.0	18.0	3.0-3.8
	SG6	6,000	10.0	4.0	15.0	3.0-3.8
	No1 Framing	6,000	10.0	4.0	15.0	3.0
EN 338 (2016) (based on bending tests)	C22	10,000	22.0	13.0	20.0	3.8
	C20	9,500	20.0	11.5	19.0	3.6
	C18	9,000	18.0	10.0	18.0	3.4
	C16	8,000	16.0	8.5	17.0	3.2
	C14	7,000	14.0	7.2	16.0	3.0
EN 338 (2016) (based on tension tests)	T13	10,000	19.5	13.0	20.0	3.8
	T12	9,500	18.0	12.0	19.0	3.6
	T11	9,000	17.0	11.0	18.0	3.4
	T10	8,000	16.0	10.0	17.0	3.2
	T9	7,500	14.5	9.0	17.0	3.0
	T8	7,000	13.5	8.0	16.0	2.8
NDS (2024) Suppleme nt (based on visually graded Southern pine)	No1 Non dense	9,650	22.9	16.2	25.7	3.5
	No2	9,650	19.3	12.7	24.0	3.5
	No2 Non dense	8,960	18.3	11.1	24.0	3.5
	No3, and Stud	8,960	11.4	7.6	14.2	3.5
	Construction	9,650	15.2	9.2	24.7	3.5
	Standard	8,270	8.4	5.1	21.6	3.5
	Utility	8,270	4.1	2.4	14.2	3.5

Table 1 (cont.): Characteristic values of softwood structural grades with MOE less than or equal to MGP10 in national and international standards for a reference 90 mm × 35 mm (or 2” × 4” equivalent) lumber.

Standard	Grade	Charac-teristic MOE (MPa)	Characteristic strength (MPa)			
			Bending[(1)]	Tension parallel to grain[(2)]	Compression parallel to grain[(3)]	Shear in beams[(4)]
NDS (2024) Supplement (machine graded timber)	900f-1.0E	6,890	15.7	6.5	17.3	--
	900f-1.4E	9,650	15.7	10.0	17.3	--
	1000f-1.4E	9,650	17.5	11.3	24.0	--
	1050f-1.2E	8,270	18.3	8.4	20.2	--
	1100f-1.4E	9,650	19.3	13.0	24.7	--
	1200f-1.2E	8,270	21.1	11.1	23.3	--
	1200f-1.3E	8,960	21.1	11.1	23.3	--
	1200f-1.4E	9,650	21.1	11.1	23.3	--
	1250f-1.4E	9,650	21.8	14.9	24.5	--
	1350f-1.3E	8,960	23.6	14.0	26.4	--
	1350f-1.4E	9,650	23.6	14.0	26.4	--
	1400f-1.2E	8,270	24.4	14.9	26.4	--
NDS (2024) Supplement (machine graded timber)	M-5	7,580	15.7	9.2	17.3	--
	M-6	6,890	19.3	11.1	21.6	--
	M-7	7,580	21.1	12.2	23.3	--
	M-8	8,960	22.9	13.0	24.7	--
	M-9	9,650	24.6	14.9	26.4	--
	M-10	8,270	24.6	14.9	26.4	--
	M-13	9,650	27.9	17.8	27.6	--
Wespine (2005, 2017, 2018)	Studmate	Characteristic values not published but grade developed for products which do not meet MGP10, either in terms of stiffness or strength				
	Wesbatten					
	Masonary top plate					

[(1)] Bending values for NDS are the LFRD values corresponding the reference values provided in the standard multiplied by 2.54 as per Clause 2.3.5
[(2)] Tension parallel to grain values for NDS are the LFRD values corresponding the reference values provided in the standard multiplied by 2.70 as per Clause 2.3.5
[(3)] Compression parallel to grain values for NDS are the LFRD values corresponding the reference values provided in the standard multiplied by 2.40 as per Clause 2.3.5
[(4)] Shear values for NDS are the LFRD values corresponding the reference values provided in the standard multiplied by 2.88 as per Clause 2.3.5

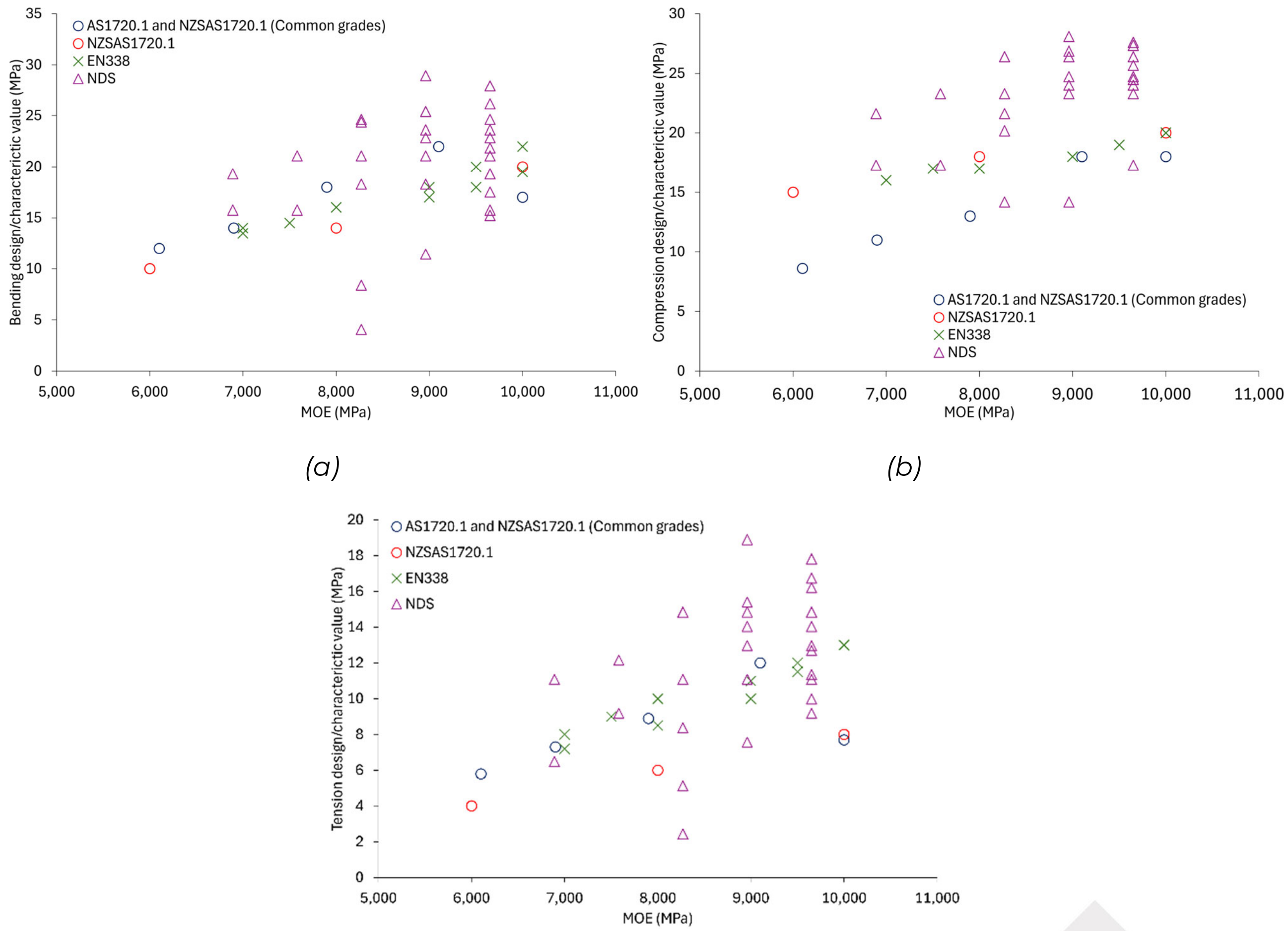

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Figure 1: Characteristic strengths of timber with MOE less than or equal to MGP10 in national and international standards against MOE for a reference 90 mm × 35 mm (or 2” × 4” equivalent) lumber, (a) bending, (b) compression parallel to grain and (c) tension parallel to grain

UTILITY REQUIREMENTS

Utility requirements in national and international standards for softwood with MOE less than or equal to 10,000 MPa (i.e., corresponding to MGP10) are provided in Table 2 for a reference 3 m long, 90 mm × 35 mm (or 2" × 4" equivalent) lumber. The Australian standard AS/NZS 1748.1 (2011) states that the limits provided in the table are appropriate for "general use framing structural timber". Contrary to Australia, the European standard (EN 14081.1, 2019) and North America standard for Southern pine (SPIB, 2021) have grade dependant utility requirements. Additionally and similar to the characteristic values, utility requirements differ between European countries (Trulli, et al., 2017). Only the requirements in EN 14081.1 (2019) are reported herein.

Table 2 shows that the set geometric imperfections for all grades in the AS/NZS 1748.1 (2011) is more restrictive that the maximum imperfections criteria in Europe and North America. Splits and/or through checks are also permitted for timber with MOE less than or equal to MGP10 in Europe and North America, when it is not permitted in Australia. The comparisons indicate that alternative requirements than the ones stated in AS/NZS 1748.1 (2011) may be acceptable for a new out-of-grade lumber used in residential construction. However, to satisfy modern frame and truss manufacturing methods (such as robotisation), sawmills often have tighter imperfection requirements than in the AS/NZS 1748.1 (2011) (Guitierrez, 2025). Also, tighter tolerances may be enforced by building regulation authorities (Victorian Building Authority, 2015). This difference between standards and practice needs to be considered in the research.

Table 2: Utility requirements of softwood structural grades with MOE less than or equal to MGP10 in national and international standards for a reference 3m long, 90 mm × 35 mm (or 2" × 4" equivalent), lumber.

Characteristics	**Appendix B of AS/NZS 1748.1 (2011)**	**EN 14081.1 (2019)**	**SPIB (2021) (only provided for No 2, No 3 and utility with reference to SPIB (2023))**
Resin pockets	Not extending from one surface to the opposite surface and no greater than the width of the piece in individual length	Not mentioned	Not mentioned
Splits and/or through shakes	Not permitted	*Above C18 and T11*: Not permitted *For C18, T11 and below*: No greater than 1 m or ¼ the length of the piece in length	*No 2*: No greater than 1.5 times the width (splits) or 610 mm (through shakes) in length *No 3 and Utility*: No greater than 1/6 of the length (splits) or 1/3 of the length (through shakes) in length
End splits and/or end through shakes	No greater than the lesser of twice the width of the piece and 200 mm in aggregate length at each end and no greater than ½ the width of the piece in individual length	*Above C18 and T11*: No greater than the width of the piece in length *For C18, T11 and below*: No greater than twice the width of the piece in length	*No 2*: No greater than 1.5 times the width in length *No 3 and Utility*: No greater than 1/6 of the length of the piece in length
Spring	No greater than 9 mm	*Above C18 and T11*: No greater than 12 mm *For C18, T11 and below*: No greater than 18 mm	*No 2*: No greater than 12.5 mm *No 3 and Utility*: No greater than 19 mm
Twist	No greater than 7 mm	No greater than 11 mm	*No 2*: No greater than 16 mm *No 3 and Utility*: No greater than 22 mm
Bow	No greater than 30 mm	*Above C18 and T11*: No greater than 15 mm *For C18, T11 and below*: No greater than 30 mm	*No 2*: No greater than 38 mm *No 3 and Utility*: No greater than 70 mm
Cupping	No greater than 1.8 mm	No limit	*No 2*: No greater than 0.8 mm *No 3 and Utility*: No greater than 1.6 mm

Table 2 (cont.): *Utility requirements of softwood structural grades with MOE less than or equal to MGP10 in national and international standards for a reference 3m long, 90 mm × 35 mm (or 2" × 4" equivalent), lumber.*

Characteristics	**Appendix B of AS/NZS 1748.1 (2011)**	**EN 14081.1 (2019)**	**SPIB (2021) (only provided for No 2, No 3 and utility with reference to SPIB (2023))**
Heartwood	Not mentioned	Not mentioned	Not mentioned
Sapwood	Not mentioned	Not mentioned	Not mentioned
Sound knots/burls	Not mentioned	Permitted as defined by grade, but: *Above C18 and T11*: No greater than 1/4 width of piece on face and ½ of thickness on edge in diameter *For C18, T11 and below*: No greater than ½ width of piece on face and ¾ of thickness on edge in diameter	*All grades*: Knots to be well-spaced *No 2*: No greater than 32 mm at the edge and 38 mm at centreline on wide face in diameter. *No 3*: No greater than 44 mm at the edge and 51 mm at centreline on wide face in diameter. *Utility*: No greater than 63 mm anywhere on wide face in diameter.
Loose knots	Not mentioned		*No 2*: No greater than 32 mm in diameter and one loose knot/hole (or equivalent smaller holes) per linear 610 mm *No 3*: No greater than 44 mm in diameter and one loose knot/hole (or equivalent smaller holes) per linear 305 mm *Utility*: No greater than 38 mm in diameter and one loose knot/hole (or equivalent smaller holes) per linear 305 mm

Table 2 (cont.): *Utility requirements of softwood structural grades with MOE less than or equal to MGP10 in national and international standards for a reference 3m long, 90 mm × 35 mm (or 2" × 4" equivalent), lumber.*

Characteristics	**Appendix B of AS/NZS 1748.1 (2011)**	**EN 14081.1 (2019)**	**SPIB (2021) (only provided for No 2, No 3 and utility with reference to SPIB (2023))**
hecking	Not mentioned	*All grades*: Depth no more than ½ the thickness of the piece *Above C18 and T11*: No greater than 1 m or ¼ the length of the piece in length *For C18, T11 and below*: No greater than 1.5 m or ½ the length of the piece in length	Surface seasoning checks permitted
Wane, want	No greater than 1/3 and ½ of the width of the edge and face, respectively on which it occurs in aggregate or individually	No greater than 1/3 of the full edge and/or face of the piece	*No 2*: No greater than 1/3 of both thickness and width on full length of the piece or no greater than 2/3 the thickness and ½ the width for up to ¼ the length of the piece. *No 3 and Utility*: No greater than ½ of both thickness and width on full length of the piece or no greater than 7/8 the thickness and 3/4 the width for up to ¼ the length of the piece.
Slope of grain	Not mentioned	*Above C18 and T11*: No greater than 1 in 10 *For C18, T11 and below*: No greater than 1 in 6	*No 2*: No greater than 1 in 8 *No 3 and Utility*: No greater than 1 in 4

PROPOSED USES OF OUT-OF-GRADE TIMBER IN RESIDENTIAL CONSTRUCTION

Different uses of out-of-grade timber in residential construction were proposed in the literature, but no published work was found to validate the appropriateness of these uses.

When studying market opportunities and challenges for low-grade hardwood timber in the US, Cumbo, et al. (2003) explained that "market stability and market profitability were important factors in deciding to enter a new market for low-grade lumber … market size and competition were of less importance."

Koch (1960) mentioned that low-grade timber can be used in short elements, such as short subfloor grids, battens and short elements in roof truss. Similar applications are proposed by Hyne timber (2025) for their lowest grade (F5 in AS 1720.1 (2010)) consisting of short studs, noggings, battens, truss webs and bottom plates. These applications are also reflected by the out-of-grade products commercialised by Wespine (Wespine, 2005, Wespine, 2017, Wespine, 2018) for studs, battens and top plate on masonry walls.

Another application would be for internal non-load bearing walls. While the Australian standard AS 1684.2 (2021) requires graded timber to be used for such walls, no research can be found in using out-of-grade-grade timber for such application, where the internal non-load bearing walls are only subjected to bending and shear forces from internal wind pressure and horizontal impact load.

CONCLUSION AND RECOMMENDATIONS

This document presented a literature review on the uses of out-of-grade timber (defined herein as timber not meeting the structural framing requirements for MGP10 in AS/NZS 1748.1 (2011) and AS 1720.1 (2010)) in residential construction. While most studies on the use of out-of-grade timber have focussed on the manufacture of EWP, the following key points were found on the properties and uses of out-of-grade timber in the residential market:

- Out-of-grade boards are principally sawn from the centre of the logs. This implies the presence of pith. For hybrid pine, such boards were also found to have a higher resin content than boards sawn away from the pith. However, higher resin content was found not to be detrimental to the mechanical properties.
- Knots are more frequent and larger in out-of-grade timber. They also have different characteristics than in mature wood (clustered, more conical in shape and have connections to the pith). Knots were found to negatively influence the mechanical properties.
- Out-of-grade timber presents high variability in mechanical properties but still presents advantageous properties for structural applications. The MOE was reported as the major reason for grade rejection.
- The characteristic strengths of tested out-of-grade hybrid pine boards typically met the requirements for MGP10, except for the bending strength of boards with high knot

concentration and the bearing strength perpendicular to grain of all types of tested boards.
- As out-of-grade timber is often associated with juvenile wood, it contains compression wood which leads to distortion issues, especially twist. International standards have less stringent requirements than the Australian standard AS/NZS 1748.1 (2011) on geometric imperfections for structural products with MOE lower than or equal to MGP10. As these international products are also used in framing, the comparison indicates that alternative requirements than the ones stated in AS/NZS 1748.1 (2011) may be acceptable for a new out-of-grade lumber used in residential construction. However, sawmills often have tighter imperfection requirements than in the AS/NZS 1748.1 (2011) to meet modern frame and truss manufacturing methods. This difference between standards and practice needs to be considered in the research.
- Regarding utility requirements, splits and/or through checks are permitted in international standard for timber with MOE less than MGP10.
- Potential applications in the residential market include short elements, such as subfloor, battens, studs, nogging and roof trusses (webs and bottom plates). Non-load bearing walls may also represent a market. Wespine in Western Australia is commercialising out-of-grade timber for studs, battens and top plate on masonry walls.

If a new out-of-grade framing structural product was to be commercialised to meet high market demands combined with national timber shortages, the following aspects would have to be verified:

- The potentiality of high resin content, more frequent and larger knots, and the presence of pith to be accepted by frame and truss manufacturers, as well as builders. Would there be challenges in adoption?
- If the Australian framing market would accept higher levels of geometric imperfections and other characteristics, such as splits and/or through checks. How these characteristics would be integrated into the framing manufacturing process? Would it complicate the current manufacturing process.

ACKNOWLEDGEMENT:

This research was conducted by the ***Australian Research Council Research Hub to Advance Timber for Australia's Future Built Environment*** (project number IH220100016) funded by the Australian Government."

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