DEVELOPMENT OF GRADING RULES FOR RE-CYCLED TIMBER USED IN STRUCTURAL APPLICATIONS

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1 INTRODUCTION

Until recently, the usual method of disposal of timber used in structures has been demolition and disposal. For example, at the time of writing, Australians are placing approximately 1 million tonnes of wood waste into landfill sites. However, reduced availability of native hardwoods has created a situation where use of recycled timber has significant environmental and economic potential, particularly where recycled products can be incorporated into new construction or in some cases retro-fitting of existing buildings and structures.

Currently, there are no standards or guidelines for assigning design properties for structural reuse of wood and the use of recycled timber in decorative products tends to rely on subjective application of visual grading rules developed for new timber. In order to address this problem and utilise the recycled timber resource effectively and reliably, the authors have undertaken a research funded by the Forest and Wood Products Association, Australia.

The aim of this project is to develop appropriate (visual) grading systems that take into account the properties of recycled timber; in particular, how the history and previous use of the timber has effected its properties in terms of being fit for purpose in a re-use application. The paper will present the findings of this project to date involving research to quantify the mechanical properties and develop appropriate (visual) grading systems that take into account the properties of recycled timber; for use in both structural and aesthetic applications.

2 BACKGROUND

In many parts of the world including Australia, the traditional “end of life” scenario for structural timbers has been disposal – either by burning or dumping as land fill.

However, in recent times it has been recognised that the use of recycled timber has significant economic potential, particularly where recycled products can be incorporated into new construction or in some cases retro-fitting of existing buildings and structures. Thus the economics of recycled timber products is dependent not only on the “practicality of recovery versus disposal but also on the acceptance of used products in new construction” (Falk, 1994).

Currently, there are no standards or recommendations for assigning design properties for structural reuse of wood and the use of recycled timber in decorative products tends to rely on subjective application of visual grading rules developed for new timber. Recycled or reused timbers potentially include defects which have resulted from the in situ conditions and application of the timber prior to being decommissioned and recycled. For example, “cracks, splits, and checks may be developed from moisture cycling, drying stresses, and/or overstress. Additionally, fastener holes originating from initial construction techniques are commonly present in timbers that may be selected for reuse” (Fridley, Williams & Cofer, 2001).

Thus, in order to utilise the recycled timber resource effectively and reliably, we need to have appropriate (visual) grading systems in place that take into account the properties of recycled timber, in particular, how the history and previous use of the timber has effected its properties in terms of being fit for purpose in a re-use application. The development of grading rules for recycled timber need to take into account such issues – particularly for re-use in structural applications where the presence of defects and the type of loading history can have a significant effect on mechanical properties, resulting in reduced strength when compared with new timber of the same species or strength group.

A significant amount of research has been undertaken in North America (notably by the Forest Products Laboratory in Madison, Wisconsin) that seeks to address some of these challenges to the use of recycled timber and attempt to quantify these effects and how the properties of timber have changed after such timber has been "in-service" for a considerable period of time (Rammer, 1999).

The same issues are apparent in Australia, where there are no specific grading rules that apply to recycled timber used as either Decorative or Structural Products. At present, producers of recycled timber products use the existing visual grading standards AS 2796 and AS 2082 to "grade" material to be "fit for purpose". Whilst these hardwood grading rules can be applied (at least to some extent) to recycled timber, the use of these grading rules which were developed for "new" timbers will have a level of uncertainty associated with them – which can be significant for structural applications.

The main area of uncertainty associated with recycled timber is the fact that in most cases the history of the timber is unknown and as noted by Falk, "From a structural use standpoint, the most distinguishing feature of recycled wood (compared with freshly sawn timber) is the presence of damage. This damage may be a result of the original construction process, building use and/or the deconstruction process" (Falk et al., 1999).

The literature review identified that permitting an allowable hole size half that of the maximum knot size provided for each grade, resulted in a strength that was 70% of the characteristic properties of the control beams, which were "defect free". However, in terms of developing specific grading rules from the test data, Falk (2003) considered that these results were inconclusive due to the limited sample and size of holes in the members and he concluded that the location of the hole may be just as important, if not more important, than the size of the hole.

The test results of "notched" timber undertaken as part of the Australian project have confirmed similar findings. Both the experimental and analytical studies concluded (logically) that the presence of holes in timber affect its strength of the timber. Furthermore, the presence of a hole decreases the reliability, or level of safety, of a flexural member. The tests undertaken by Falk concluded that the reduction in reliability caused by a 44.5mm hole is not significantly different compared to that of a 25.4mm hole. The reliability, however, is significantly affected by assumptions made with respect to hole location.

If the hole is assumed to be located at the point of maximum moment, the reduction in reliability is approximately twice as much as when the hole is assumed to be located randomly within the central third of the length. This effect was also observed in the tests undertaken as part of the current project and it is important to note that the effect of edge notches or holes is quite critical and creates a significant stress concentration, with a corresponding reduction in moment capacity for a beam.

3 DETAILS OF THE R&D PROJECT

At the outset of the project, a number of specific considerations in relation to recycled timber which the project would need to address were identified, including the following:

- The need for development of Stress Grades that are based on the species, size and distribution of characteristics, that would be preferably compatible with existing visual grades;
- The need for development of Appearance Grades that account for expected 'characteristics' common to recycled timber products;
- Recognition of the variations in moisture content of recycled timber – noting that most members would have originally been installed unseasoned and would now be in a seasoned or semi-seasoned condition – at least on the surface;
- The moisture content in the core of large end-section members may exceed AS 2082 requirements and, therefore, unseasoned stress grades would apply. The outer case of the member may, however, be in a seasoned condition which would take most of the loading;
- The need to define appropriate limits for sizing tolerances, squareness and straightness – noting that there is likely to be a need for specific requirements for recycled timber;
- Recycled large end sections develop large checks, splits and loose gum veins during its time in service – all of which potentially reduce the mechanical properties of timber members;

- Recycled wood may be unsound, particularly with large end sections which develop large checks, splits and loose gum veins during their service life;
- Decay pockets and wood surrounding nail and bolt holes may have decay but in areas that are difficult to inspect; noting it is necessary to quantify the effects of mechanical damage;
- Acknowledgement that characteristics of recycled timber may alter with time – particularly duration of load or degrade effects on timber which would affect the strength of the timber;
- Requirements to develop specifications regarding preservative treatments pursuant to current Australian preservative treatment standards;
- The development of a comparable and reliable marking system or grading stamp.

Whilst all of these issues need to be addressed for recycled timber used in structural applications, it was recognised that many of them are not particularly relevant to appearance products such as wall panels and flooring – although minimum standards of performance would need to be defined for the later concerning definition of "fit for purpose" criteria.

4 GRADING OF APPEARANCE (OR DECORATIVE) PRODUCTS

The grading of appearance products presents grading agencies with some inherent difficulties. The term "appearance', as defined for traditional timber products, defines timber without or with very limited natural blemishes. Design specifications requiring the use of recycled timber is undoubtedly for aesthetic reasons. The 'character' of recycled timber allows it to provide a warmth and desirable appearance in structural applications.

The appeal of recycled timber is that it will have features and characteristics as a result of its previous use. This in turn, effectively limits its appearance grade when current standards of visual assessment are carried out. It must, therefore, be recognised that product performance and appearance can differ in the marketplace with recycled products when compared to products produced to Australian Standard 2796 – Timber – Hardwood – Sawn and Milled Products.

The current Standard (AS 2796) specifies three appearance grades. The grading system categorises timber with respect to the number and size of features present in the selected piece. The grades range from those with small features (referred to as Select Grade) to large features (referred to as High Feature Grade). In all other respects, that is moisture content, tolerances and machining imperfections, there is no difference between the grades.

Characteristics of recycled timber; in particular, holes; checks; stains; and discolouration are contrary to the features specified in visual grading of new timbers. The High Feature Grade requirements in the Standard specify tolerances that would be exceeded by much of the recycled timbers under assessment, for example, the existence of bolt and nail holes.

"It is in these aspects that the grading rules are contrary to the nature of recycled timber. As well as features such as bolt and nail holes, staining is often evident and there are other aspects of past use which can also influence the appearance. Surface checking for example can be more prevalent and influence the appearance of the finished product, with staining more likely within the checks. Similarly, water marks and other contact with steel can result in discolouration." (Timber Queensland, 2006).

The 'characteristics' that enhance the appeal of recycled timbers are considered not to have such a detrimental effect on its performance as current grading standards perceive; such characteristics merely modify its performance. As such, it is considered that the incompatible sections regarding appearance grades create a catalyst for developing grading standards that do not limit the value and possible reuse option for recycled timber. From work undertaken to date, a three tier grading system for character is considered appropriate:

- 'Clean' 'Rustic' 'Rustic Overlay' could be the grade names
- Rustic overlay grade should not be used in any "structural" applications (such as flooring, and as such might only be used in flooring as an overlay
- Nail holes, Borer and Marine borer activity needs to be included as a feature
- Specialist sizes may be considered appropriate – for example testing to confirm use of thinner flooring or panelling may be used to demonstrate "equivalency" with new material
- Specification of "random" sizes may also be considered acceptable provided the product is installed as "fit for purpose" (may be a construction issue beyond the scope of the Standard)

- The “old board” market (reused but not re-machined) could be permitted under the above provisions for recycled timbers
- There may be a need to prohibit certain species on the basis of previous use / history. For example, Turpentine sourced from a wet environment tends to open up when re-used in dry environments.

5 GRADING OF STRUCTURAL PRODUCTS

It was decided that quantification of the strength reducing effects of characteristics would be addressed in part, during the testing stages of this project. From the initial testing, the following recommendations were made to link the current visual grading Standard (AS 2082) with the additional “characteristics’ inherent in recycled timber members.

a) Bolt holes (including any localised soft rot) would be treated as knots extending through the full cross section of the timber.
b) Effects of variable moisture content must be considered – for large section members, recycled timber should be considered as unseasoned unless evidence of verified or tested MC's are available.
c) Where the extent of any piping has been quantified, this material should be deducted from the gross cross section of the timber for design purposes.
d) Notches and some natural defects may also reduce the effective cross section and where this is the case, the design cross section should be defined as the gross section less the effected area. Additionally, the stress concentration effect of a notch must also be considered.
e) Flexibility in tolerances is necessary and specific size availability (based on the minimum effective cross section) may need to be the basis of supply.
f) As a general rule, timber that has come from internal environments and not subjected to heavy, long term loads should be considered to be at least 1 stress grade lower than that indicated for new timbers graded using AS 2082. For heavily loaded timbers, or where the previous loading history is unknown, the recycled timber should be considered to be at least 2 stress grades lower than that indicated for new timbers graded to AS 2082 (Fuller, 1999).
g) AS 3818 Timber – Heavy structural products – visually graded which permits off-centre heart in large end sections. It permits off centre heart and requirements differ between beams and columns. Revisions to AS 2082 will permit heart anywhere within a section within certain nominated percentages.

5.1 GRADE LIMITATIONS AND GRADING FOR STRUCTURAL APPLICATIONS

AS 2082 provides limitations on the amount characteristics or combination of characteristics in the wood. Specifically, section 1.9.4 refers to mechanical damage inflicted on the timber. This would be a common feature of timber recycled via a deconstruction process. Checks and bolt holes are common features of recycled timber and would often exceed tolerances outlined in section 1.9, without additional fabrication. New provisions will be required to cover characteristics of recycled timbers used in structural applications, in order to permit better resource utilisation.

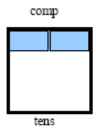
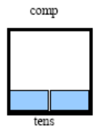
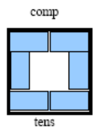
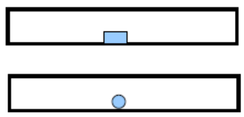
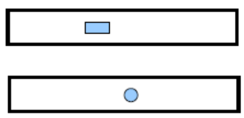
To some extent, this is offset by the fact that timber that was original sourced from old growth forests is generally clear and denser than faster growing species manufactured today – noting that knots are often less common in older, dense wood. It must be remembered that customers often seek recycled timber for its aesthetic appeal. ‘Characteristics’ limited by AS 2082 are a common selling tool for the recycled timber products, where appearance is an essential design criterion, in addition to providing adequate strength.

Recycled timbers may be retrieved in parcels containing various species and grades. The species with the lowest mechanical properties will dictate the assigned grade for the parcel of timber and therefore re-grading of the whole parcel would be necessary. Specific tolerances include seasoning checks, splits, end splits, shakes and the development of loose gum veins. These are all considered common characteristics of recycled timber and require specific tolerances for these products. If recycled wood has a significant amount of treatment or is painted, this layer may need to be removed for the ease of identification and visual grading / assessment of the likely properties of the timber.

6 TESTING PROGRAM

In order to quantify mechanical properties for specific types of recycled timber, a testing program was designed with the aim of trying to identify the extent to which aging and duration of load effects from previous load histories have effected the bending properties of members fabricated from large end section previously used timbers. The test program is summarised in Table 1 below.

TABLE 1: Proposed Testing Program – Recycled Hardwood Timbers

Timber description	Cross section	Length required	Number Required	Proposed testing	Comments	Sketch
(1) Sawn timber beams	150 x 50 or 125 x 50	3.0m	30	MOE, MOR, density check and mc's	Cut from large timbers previously subjected to high loads (wharf structures). Cut from compression side of girders Same strength group (SG1 or 2) if possible – species ID if possible	
(2) Sawn timber beams	150 x 50 or 125 x 50	3.0m	30	MOE, MOR, density check and mc's	Cut from large timbers previously subjected to high loads (wharf structures). Cut from tension side of girders Same strength group (SG1 or 2) if possible – species ID if possible	
(3) Sawn timber beams	150 x 50 or 125 x 50	3.0m	30	MOE, MOR, density check and mc's	Cut from large timbers previously subjected to low to moderate loads (bridge girders, metal roof structures or domestic history). Identify location in original girder. Same strength group (SG1 or 2) if possible	
(4) Sawn timber columns (HI)	150 x 150	0.6m	30	Compression strength and stiffness, density check and mc's	Heart in columns – determine compression capacity; heart "boxed" – nominally in middle half, but possibly on edges	
Timber description	**Cross section**	**Length required**	**Number Required**	**Proposed testing**	**Comments**	**Sketch**
(5) 15mm end butt flooring	15 x ??? (whatever is preferred width)	1.8m	30	MOE, MOR, density check and mc's – identify effects of visual characteristics	Check "equivalency" of boards cut from old rectangular timbers with other flooring products	
(6) Girders / large sawn sections	350 x 350 or similar	6.0 to 7.5m	10	MOE, MOR, density check and mc's.	Optional – full scale tests; ideally girders with some possible degrade that might be considered "borderline" in terms of re-use as solid sections. Develop "pre-selection" grading rules for either structural or aesthetic re-use	
(7) Sawn timber beams – notched on edge	150 x 50 or 125 x 50	3.0m	30	MOE, MOR, density check and mc's	Rectangular sections with notches or holes on tension side – nominally 20% loss of section Same strength group (SG1 or 2) if possible	
(8) Sawn timber beams – rot pockets or notched away from edge	150 x 50 or 125 x 50	3.0m	30	MOE, MOR, density check and mc's	Rectangular sections with notches or holes in middle 50% zone, – nominally 30 – 40% loss of section Same strength group (SG1 or 2) if possible	

GENERAL NOTES:

- Test series 1 and 2 are required to attempt to quantify suspected differences in strength between the tension and compression sides of beams exposed to long term bending under large loads.
- Test series 3 will quantify long term strength reductions for timber previously used in low load level applications.
- Test series 4 will hopefully validate the use of heart material that is the left over after cutting off edge beams / boards from large end section timbers
- Test series 5, should ideally have species ID so that comparison can be made with "new" timber floor boards of greater thickness
- Test series 6 is aimed at identifying the "limits" of visible defects (particularly on edges) to quantify effects on strength and develop some simple pre-selection grading rules for large timbers
- Test series 7 & 8 should ideally be sourced from the same type of material used in Test series 3, so that a comparison can be made between defect effected and non defect timbers, with the aim of quantifying the strength reduction effects of notches and holes.

In the first stage of testing, 90 pieces of timber (each 125 x 50 mm) have been assessed, from items 1 to 3 of Table 1 - focusing on material that has been cut from girders where the variations in the structural capacity of timber in the compression side of a girder can be compared to the tension side. The members were cut from large section material nominally at least 300mm x 300mm from either structural grade 1 or 2 timbers. This cutting pattern is illustrated in Figure 1. Visual assessment of the timber confirmed that the material was predominately Structural Grade 2, with about 20% meeting Structural Grade 1 requirements and believed to be Grey Iron Bark.

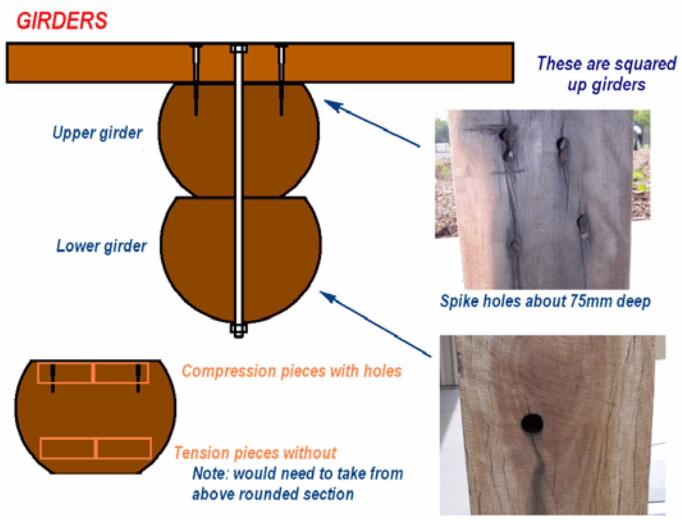


Figure 1 – Typical large end section timbers used in Bridge Girders

Following the initial breakdown the 50 mm thick flitches from the tension and compression sides of the girders were re-sawn into two pieces with nominal dimensions of 125 x 50 mm. The final test material therefore contained a mix of characteristics including spike holes and bolt holes as well as checking and natural features. However, from a visual assessment, the timber material was considered to be relatively clean of defects resulting from the recycling process.

In addition to MOE and MOR testing undertaken on these test pieces each stick of timber was also allocated a 'grade' based on an ultra sonic hand held grader. The results of this study are reported elsewhere.
Due to the nature of recycled timber, containing nail holes, bolt holes and possibly decay around such characteristics, it was of interest to determine how such a device would perform.

7 ANALYSIS AND RESULTS

The first stage consisted of two sets of trials. Trial 1 consisted of 60 pieces of timber, extracted from large structural members that had been previously subjected to high loads. 30 pieces were cut from the tension edge and 30 from the compression edge of the larger members, as noted in Items 1 & 2 in Table 1. Trial 2 consisted of 30 pieces of timber cut from large timbers previously subjected to low to moderate loading. The cutting patterns were in accordance with Item 3 in Table 1.

The second stage of testing involved determination of MoE and MoR for the following specimens:

1. 170 x 50 – 15 of each
2. 190 x 50 – 15 of each
3. 120 x 50 – notched, 14 of each with 25mm circular hole at edge (similar to item 7)
4. 120 x 50 – notched, 14 of each with 50mm diameter hole at centre (similar to item 8)
5. 50 x 50 small clears – 28 of each sampled from 3 & 4 above.

In addition to these tests, assessment of 150x150mm (boxed in heart) column sections and flooring boards was also undertaken as noted in Table 1, under Items 4 & 5 respectively.

7.1 Stage 1: 125x50 sections

Test data from the first stage identified that the difference in the various methods for predicting 5th percentile values is considered significant for the number of specimens, particularly when comparing the compression only with the pooled values using a Weibull tail analysis. However, in practice it will not generally be possible to know the precise location from where a piece of timber has been cut, nor the loading history of the parent member from which the sawn pieces have been extracted.

Analysis of the pooled data indicated that the 5th percentile characteristic strength for all the recycled members (irrespective of extraction location) is approximately 45 MPa, which is about 56% of the strength for new F27 timbers. Whilst it must be recognised that this reduction in strength is the influenced by numerous factors (such as degradation and damage), it is interesting to note that this value is essentially consistent with the duration of load factor of 0.57 used in AS 1720.1, for long term permanent loads. An estimate of 60% of new strength is probably appropriate. It should however be noted that this strength reduction effect is likely to be the result of weathering in combination with load history, and as such it represents a complex mechanism that should not be over simplified.

7.2 Stage 2: Other sizes and notch effects

The MoR results for the 190 deep members were considered to be visually graded as F14 (f'_b = 40 MPa) or F11 (f'_b = 32 MPa) then the characteristic bending strength would be approximately 53% or 65% of the assumed “as new” grade strength respectively. Similarly, if the 170 deep members were visually graded as F17 (f'_b = 50 MPa), the test data suggests that the bending capacity is approximately 64% of the “as new”. The small clear data indicates that a similar strength reduction effect was apparent for the 120 x 50 members, prior to the introduction of the holes.

The effect of introducing the circular “notches” was quite pronounced for the edge hole, but less so for the hole in the centre of the boards – which was to be expected. Clearly the edge notch creates a stress concentration and even if the 5th percentile MoR’s were recalculated based on the depth of solid timber to the hole location (95mm), the values are still only about 60% of that indicated by the small clear data. By contrast, the effect of the centre hole amounts to a reduction in bending strength of 5 to 10% when compared to the small clear values, despite the fact that some 40% of the section had been removed.

Based on this data it is recommended that the strength reduction effects of edge notches be considered in all designs utilising recycled timber, perhaps using the methodology specified in AS1720.1 holes or notches that are at least 30mm from an edge can be deemed to have negligible effect on bending, but will need to be considered for axial loads in the same manner as for new timbers. Appropriate visual grading rules will need to be developed to provide guidance for limiting the size and location of edge notches and quantifying the corresponding strength reduction – particularly for tension and bending loads.

8 CONCLUSIONS AND RECOMMENDATIONS

Based on the test results, it can be concluded that application of existing visual grading rules (AS 2082) can be used to assign properties for timber cut from larger members (and not containing defects such as degrade and bolt holes) on the following provisos:

1) MoE values are valid and can be assumed to be similar to those of new material.

2) MoR values must be reduced when compared to new material to take into account duration of load effects. These reductions are estimated to be between 35% for material with a load history of short term / low magnitude loading (such as roof structures with light weight cladding), and 50% for material with a load history of longer term / high magnitude loading (such as warehouse / wharf storage floors).

3) If the loading history of the recycled timber is not known, a conservative value of 55% to 60% of new timber strength for the same visual grade would be appropriate (which is normally a reduction of two stress grades).

Two interim grading documents are currently being prepared and both drafts have been developed in consultation with relevant industry groups. In the final report, specific recommendations will need to be developed specifying how these grade properties will be assigned using the VSG rules.

The first deals with Appearance Grade products and is based on AS 2796, but incorporates specific clauses for classification of recycling characteristics and their “impact” on appearance – such as holes from fasteners and surface “imperfections” resulting from previous usage.

The second draft details structural grading rules for recycled hardwood timber and has been prepared as a blend of both AS 2082 and AS 3818 to cover both smaller end-section material and larger end-section material included in AS 3818. The draft will be a stand alone document specific to recycled timber and considers separately smaller end-section timber where there is closer alliance to AS 2082 and larger end-section timber that is more closely aligned to AS 3818.

Due to the inherent differences between recycled and "new" timber, traditional "strength groups" have not been used in the draft, however a similar concept referred to as "Species Group" has been included, so that species of recycled timber displaying similar properties and characteristics affecting the stress grade can be grouped together. This has been done to facilitate an efficient means of applying the stress grades, whilst at the same time keeping the number of rules to a workable minimum.

It should also be noted that the draft documents are being developed as interim "Industry Standards" to provide an orderly introduction into the marketplace, within a shorter time frame than would be possible implementing using the "Standards" development process. Whilst the documents are specific to recycled timber, they have also been developed to be very much in line with current applicable Australian Standards, with the intention that after "evolution", the documents will achieve full "Standards" status.

It is anticipated that the outcomes of this project will enhance the use of recycled timber products in the market place, whilst at the same time providing appropriate standards for defining "fit for use applications" and ensuring safe characteristic properties are used by designers when using recycled timber members in structural applications.

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There has been a growing movement to utilize biomass, in the face of global warming, a serious shortage and depletion of fossil resources, and the consequent rise in prices. A typical biomass resource is wood. It is a resource converted from carbon dioxide in the atmosphere through photosynthesis of solar energy. This circulating resource returns to carbon dioxide through combustion or biodegradation. Wood species and its uses are remarkably diverse. The most important aspect of wood—renewable or sustainable resources using solar energy—is that human beings commit themselves to their production. The use of wood for timber engineering has direct influence on human life, affecting people involved and producing wider ripple effects on the community and various fields. In other words, its role is driving force and efficiency is not the only measure. We need to take account of forests, which are the place for production, and of the ecological system, in which living creatures co-exist. Deeply concerned with issues of climate and environment, we must be always aware of the need for cooperation in terms of “space” (in same generation) and “time.” (beyond generations).

The 10th WCTE Conference 2008 in Miyazaki, Japan received many abstracts and proceedings for presentations with topics of interest spanning the spectrum of the timber engineering field.

We do hope these reports are effective and instructive for mutual understanding between these sectors and will also connect into “the next ones”.

WCTE 2008 Chair
Dr. Takanori Arima