Grading Green Timber Using Compression Waves

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Abstract

Being a natural product, timber has inherently variable properties. For the purposes of structural use, one of the important properties is the longitudinal stiffness of the timber. The longitudinal stiffness of timber varies greatly from tree to tree and within a tree. Currently, mechanical graders are used to stiffness grade the final, dried, dressed product to remove unsuitable timber and to classify timber for specific purposes. Reject rates can easily be as much as 30%. It would be useful from an efficiency point of view to grade green timber and remove reject timber before cost is incurred from further processing. Unfortunately, the rough-sawn, sap-filled green timber cannot be passed through a normal mechanical grader. One solution is to use an acoustics approach, where compression waves are generated in the timber and the propagation of the waves measured. From simple calculations of the speed of compression wave propagation in the timber, and measurements (or prior knowledge) of the density, the stiffness of the timber can be determined. This paper examines the principal of the acoustic measurements and the currently applied technology. The relationships between the acoustic measurements of green timber stiffness and mechanically-determined dried, dressed timber stiffnesses are shown.

Introduction.

The use of acoustics as a non-destructive quality assessment tool has a fairly short history in the timber and wood products industries; it is only in the last ten years or so that the timber industry has been using a significant number of such assessment tools. This situation might be compared to that of, say, the concrete industry where standard tests to determine quality using acoustic methods have been around since the 1940's.

In a way this reflects the state of the timber industry around the world: people used to cut the select timber from old-growth trees which consistently produced high-quality wood, but now are forced to use as much timber as possible from fast-grown, plantation trees.

These fast-grown plantation trees produce a more variable range of wood properties; in particular, certain growing regimes, types of trees, and climates can produce significant quantities of low-quality wood. As a result, the end users are demanding more certainty about the timber they receive, and are expecting the timber industry to deliver.

One of the main uses of timber is for structural purposes (to make buildings), and it is in this area this paper focuses, particularly solid-sawn timber.

In the structural timber area, the most common method of grading timber has been visual: where timber with large knots is removed by way of a skilled person identifying the defective piece. If performed correctly, such grading is effective in identifying timber which might break in use, because it is the presence of knots which can cause timber to very weak at one point.

However, one of the more important qualities of a piece of structural timber is its stiffness, and the timber produced from plantations can have a very variable stiffness – it not unusual to have a factor of five variation in the stiffness of timber from the same tree species, and a factor of ten is quite possible.

The problem is that it can be very difficult to quickly identify the stiffness of a piece of timber manually. As a result, non-destructive means are often used to assess the stiffness of timber.

Devices used to perform this in the sawmill are often called Machine Stress Graders, and the resulting wood is said to be machine stress graded (or rated). Such mechanical devices determine the stiffness by applying a bending force to the timber, as it is run lengthways through the machine.

These machines often spray a dye on the timber as it passes through – the colour representing a stiffness range for the section of timber it is sprayed on (e.g. a green mark might indicate a stiffness of between 9 to 11 GPa).

Unfortunately, these machines which use force to bend the timber have a number of limitations:–

- They require that the wood be planed (dressed) to achieve an accurate result,
- They need to set up for a particular cross-sectional dimension of timber.
- They require that the infeed and

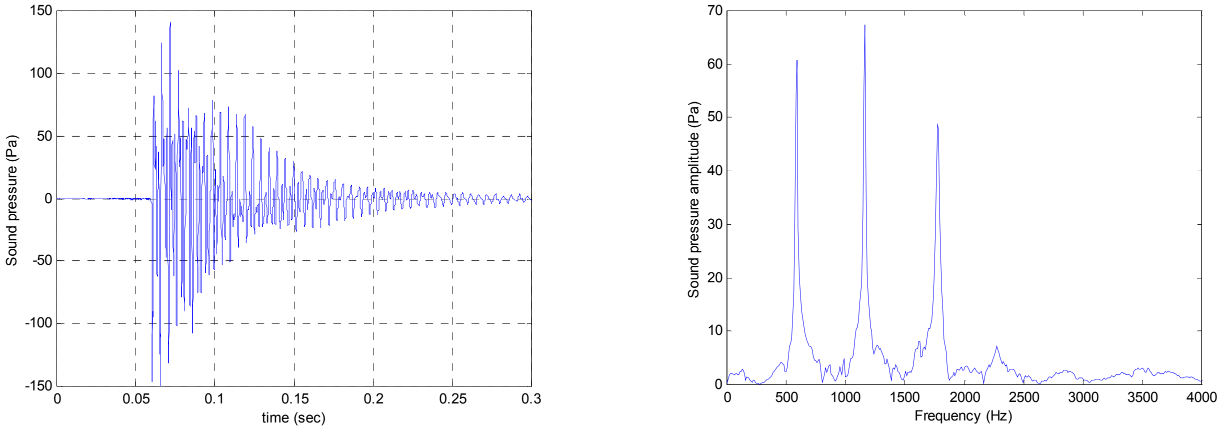

Figure 1: Example of time and frequency plots of the sound pressure produced at the end of a 4m long piece of 200x50mm Douglas Fir after being hit with a pneumatic hammer.

outfeed of the timber be carefully designed so that this does not bend the timber outside of the machine and hence influence the results.

- The timber needs to run lengthwise through the machine, and hence to have a large throughput the timber needs to be moved fast, often requiring a large machine which is, in turn, expensive. The cheapest machine grader starts at NZ$170,000, and the very fast ones will be around $500,000 or more.

Acoustic-based grading machines.

There are a number of ways one could grade a piece of timber using acoustic means, but in solid-sawn timber, which is essentially a long, non-homogeneous elastic bar, it appears that the most accurate and easy way is to generate longitudinal vibration in the timber piece and to record the resonances of this vibration. Noting the length of the timber and the resonant frequencies gives one an estimate of the wavespeed of the longitudinal vibration according to

$$v = \frac{2}{n} L f_n$$

where L is the length of the timber f_n is the eigen-frequency of mode n. One should be careful to note that wood is non-homogeneous, so for example, you are unlikely to find that $f_2 = 2f_1$. The stiffness is then given by the relation

$$E = \rho v^2$$

where E is the Young's Modulus, r is the density and v is the wavespeed. Again, note that wood is non-homogeneous, and that these values should be regarded as average approximations or estimates.

Figure 1 shows an example of the responses obtained using an acoustic grading system.

The A-grader.

Over the last few years, Forest Research has done trials on using acoustic resonance to grade Radiata Pine and Douglas Fir structural timber grown in New Zealand. Comparisons were made with other grading methods and commercial technologies, and it was found that deriving timber stiffness from acoustic resonance tended to give more consistent agreement with the standard benchmark laboratory test and quality assurance test (a four-point bending method) than other techniques.

The other techniques consist primarily of three-point bending the timber over short lengths of the timber as it is forced through a set of rollers connected to loadcells.

Figure 2: An example of a New Zealand timber processing chain.

The first notable application of using acoustic resonance to grade solid-sawn timber on the processing chain of a sawmill occurred when the Dynagrader was produced (www.dynagrade.com) about ten years ago in Sweden.

Earlier acoustic or vibration tools were produced, but were limited to portable tools which could only manually test a few pieces a minute. The Dynagrader was able to be set up in a mill and could process and grade dry timber as it went by on the timber chain.

The Dynagrader had a mechanical hammer on a spring that caught on the timber as it went by and hit the timber on the end producing a resonance in the timber that was picked up by one or more microphones [Larsson, 2002].

The Dynagrader is not totally suitable for the New Zealand situation in that it is specifically designed and set up to grade European species of timber. In addition, the mechanical hammer arrangement seems to be rather dependent on the timber being carefully presented to the hammer, and could be prone to being damaged by the occasional board which is not sitting correctly on the processing chain (Radiata Pine is prone to warping after drying, and these warped pieces can be difficult to control on a processing chain).

One final negative point about the Dynagrader is that the price seems to be quite excessive at about $300,000.

About a year ago, Forest Research decided to pursue the development of an acoustic-based grading machine with a forward-thinking engineering company, Falcon Engineering. The aim was to have a New Zealand product which was developed for New Zealand (and Australian) timber and for their sawmill and grading requirements, at a price which is more acceptable to the smaller New Zealand sawmills (less than half the Dynagrade price).

By March this year, the first prototype/demo version was ready and was shipped to Australia to be shown at the AusTimber 2004 show for forestry and saw milling.

The first 'A-grader' was born. This demo was a device, which could grade short shooks of timber intended for finger jointing into studs. In this device, the shooks of timber were weighed on loadcells to determine density and then acoustically excited with a loudspeaker horn driver emitting a known signal, and an accelerometer was used to measure the response of the shook. The accelerometer was mounted on two pneumatic cylinders so that it would follow the shook for a brief time as it passed.

Since then, we have installed a system in Red Stag sawmill in Waipa, which is used to grade rough -sawn, kiln-dried radiata pine and douglas fir structural timber of lengths from 2.4 to 6m, and dimensions of up to 300mm wide. For this system, loadcells weigh the timber, lasers measure the dimensions, a pneumatic hammer is used to excite the wood, and a microphone is used to listen to the response of the wood.

The hammer's acceleration and mass are such that the resulting resonating sound generated by the end of the timber is loud enough to be easily distinguished above the significant background noise in the sawmill (the background noise is about 95dB).

In this application of grading rough-sawn timber, it is of great benefit to be able to grade the timber before it is dressed for structural use. The reason being that timber of low stiffness, which can't be sold for structural use, can fetch a better value rough-sawn than being dressed. As stated before, mechanical graders don't work well with rough-sawn timber.

Grading green wood.

While one effective application of the A-grader is for the final grade of timber after it has been dried, one of the main potential applications for the A-grader in a sawmill is for the pre-grading of timber just after it has been cut from the log and is still green (i.e. full of water and sap).

This is something which has not been easily done before by any in-line grader, and has great potential to reduce cost and energy consumption for the timber industry.

The current practice is to cut up the timber, dry it and dress it for structural use, and then test it for stiffness. The trouble is that up to 30% of the timber (depending on

Figure 3: The A-grader 'head' which strikes the end of the timber with a pneumatic hammer and listens to the response with a microphone.

the source of the logs) does not meet the minimum requirements for stiffness for structural use.

This is great if you don't mind incurring the cost of processing that 30% of your timber to end up with something that is less valuable than what you started with: a low stiffness piece of timber is more valuable green and rough-sawn so that it can be treated and used for outdoor purposes.

Sawmills would clearly like to be able to identify the stiffness of a piece of timber when it is green so that they can redirect the piece somewhere else to not incur the extra cost of processing and to get more money for it.

Fortunately, at least for the species of wood important to New Zealand structural wood sawmills, there is a clear relationship between the stiffness of green wood and the stiffness of dry.

This is because, although there are different moisture contents in wood when a tree is felled, the cell walls of recently felled trees are always fully saturated with water and any extra water just resides inside the cells.

So, for example, the difference between the stiffness of green and dry radiata pine is about 25%, even though the moisture content for the green timber can vary from 40% to almost 200% (moisture content is defined as the ratio of the mass of the water in the timber to the mass of the other stuff (wood fibres) [Bodig, 1982].

One could use a mechanical grader to do the job, but Mechanical graders do not work at all well with green, sap-filled, rough-sawn timber: the timber travels between rollers and the rollers soon get covered in sap. Having said this, Forest Research did develop a mechanical grader called the 'E-grader' which does not use rollers and can be used to grade green timber, but unfortunately it is relatively slow.

The application for using some acoustic technique for this situation of grading green timber is obvious, and it is in this area where the industry interest in the 'A-grader' tool is the greatest.

Figure 4 shows the relationship between the stiffness of a number of pieces of green timber measured using acoustic resonance and the stiffness of the same kiln-dried and dressed timber measured using a standard four-point bending method.

As can be seen, the relationship is very good, particularly when one appreciates the non-homogeneous nature of timber and the fact that testing methods are different. The reason for using the four-point bending method as a comparison is that such a method is used for quality assurance testing of timber.

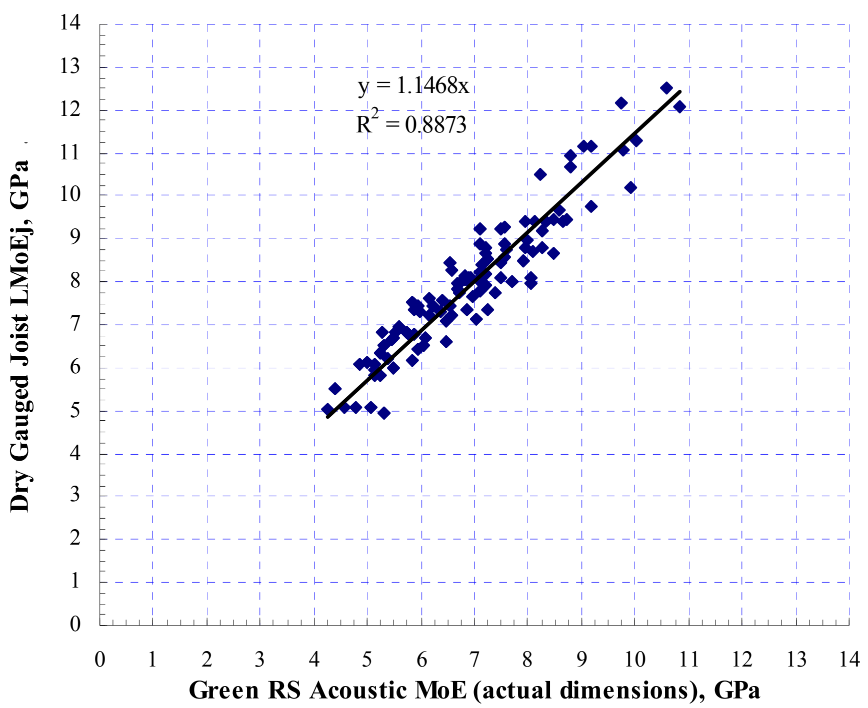

Figure 4: The relationship between acoustically measured stiffness of green timber and the stiffness of the same dry, dressed timber measured in a four-point bending test.

Conclusions.

It is clear that acoustic resonance is a useful method for obtaining the stiffness of timber as long as the density of the timber can be measured.

One advantage of using an acoustic technique such as this is that it doesn't require expensive devices to excite the timber and to measure the response of the timber.

Another advantage is that the process is mostly non-contact, with just a brief contact required to excite the timber, making it suitable for grading timber while in the green state.

References.

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