Measurement of Wood Stiffness in Standing Trees and Logs: Implications for End-Product Quality

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ABSTRACT

At present, mills producing structural timber generally undertake strength grading at the end of the production process, i.e., after buying the material and sawing it into timber which is then dried. This means that any variation in wood stiffness between forest stands and between trees is unknown and unaccounted for until the end of the manufacturing process. Portable stress-wave-based tools provide a cost effective means for predicting the stiffness of the resource, either in standing tree or in log form. Better knowledge of the properties of the available forest resource will allow manufacturers to optimise production capability. By knowing the average properties of their raw material stocks mills will be better able to predict the grade outturn of structural products. They will also be able to segregate out low stiffness stands or logs and use this material to create non-structural products, such as fencing, pallets, etc. Finally, knowledge about the average stiffness of individual logs, could potentially allow a mill to change the cutting pattern in order to maximise the value of each log. In this paper, the application of stress-wave-based tools to the Sitka spruce supply chain in the UK is discussed along with the implications of raw material segregation on timber mechanical properties.

INTRODUCTION

Even in intensively managed forests consisting of even-aged single species stands there is considerable site-to-site and tree-to-tree variation in the physical and mechanical properties of harvested wood. As a result, not all wood produced from managed forests is suitable for products such as structural timber where mechanical properties, particularly bending strength and stiffness, are important. In order to improve the efficiency of the forest-to-mill value chain, it is important to be able to identify wood with certain properties as early as possible in this chain and to direct it to the most appropriate processing stream. Low stiffness material that is unlikely to meet the requirements for structural timber should be directed towards non-structural uses prior to processing. If such material is sent to a sawmill producing structural timber, there is the likelihood that a significant proportion of material could be rejected during the grading process. There are substantial financial and environmental costs associated with downgrading such material; downgraded timber is sold at a lower price for alternative non-structural uses, such as biomass, pulp, fencing, boxing or pallets. Such inefficiency increases operating costs since trees are normally processed and the timber kiln-dried before it is strength graded. There is also the cost of unnecessary transportation to sawmills.

Historically, the segregation of trees and logs has often been made on the basis of external characteristics. While this generally provides valuable information on the volume of timber that can be recovered, it is not a good indicator of the mechanical properties of this timber (Wagner et al, 2003). However, in recent years the use of acoustic (or stress wave)-based instruments for segregating material based on wood properties, particularly modulus of elasticity, has become more common. With the development of portable and simple-to-use time-of-flight and resonance-based tools, the use of acoustics in the forestry sector has increased, particularly in countries such as New Zealand (e.g., Walker and Nakada, 1999; Tseheye et al., 2000), Australia and the United States (e.g., Wang et al., 2000; 2001; 2002; 2004). This technology is beginning to be used more by the European forest industries and in this paper we report on our experiences with using these tools in the managed conifer forests in the United Kingdom.

METHODS

The tools that have been developed measure the speed at which an induced sound (stress) wave travels through a sample of wood. This velocity is proportional to the stiffness of the wood and inversely proportional to its density (ρ) so that wood stiffness can be predicted from stress wave velocity and density, i.e.,

$$E_d = \rho V^2 \tag{1}$$

where E_d is the dynamic modulus of elasticity (N m^{-2}), ρ is the mass density of the wood (kg m^{-3}) and V is the speed of sound (m s^{-1}). When measurements are made on standing trees and freshly felled logs, the density of wood is generally assumed to be constant within and between trees and having a value of 1000 kg m^{-3}.

There are two methods for measuring the velocity of a stress wave travelling through wood. The first is based on the principle that when a stress wave travelling through a wood sample reaches the opposite end, it is reflected and begins travelling in the opposite direction. This pattern repeats itself as the wave is reflected back and forth along the sample. This causes the free ends of the sample to vibrate and the frequency of this vibration can be measured. This approach is often referred to as the resonance method. The velocity can be then calculated from this frequency (f) and the length (L) of the wood sample, i.e.,

$$V = 2lf \tag{2}$$

However, such an approach will only work for felled logs where there is a cut surface to reflect the stress wave. For standing trees, another approach, which is simply to time the stress wave as it travels a fixed distance, must be used. Generally, two transducers are placed on the standing tree at a known distance apart and as the wave passes the first transducer, a timer is started. The timer is stopped when the wave reaches a second transducer and the velocity calculated by dividing the distance travelled by the time taken. This approach is often referred to as time-of-flight.

In United Kingdom, the IML Hammer (Instrumenta Mechanic Labor GmbH, Germany) tool, which is based on the time-of-flight approach, was used to make measurements on 64 Sitka spruce stands growing at various locations throughout Scotland and northern England (see Moore et al., in press). These stands were mostly between 35 and 45 years of age which is the typical rotation age for commercial stands in the UK. At each site, 10 trees were selected and their stress wave velocity measured using the IML Hammer. Based on these measurements, 12 sites were selected which spanned the full range of stress wave velocity measurements. At each of these sites the 10 trees measured with the IML Hammer were felled and up to three 3-m-long logs were cut from each tree. The stress-wave velocity of each of these logs was measured using the HM-200 (Fibre-gen, Auckland, New Zealand) resonance-based tool. Logs were then extracted and taken to a sawmill where they were processed into structural timber with cross-sectional dimensions of 100x47 mm. Timber was then transported to the laboratory and stored in a conditioned room until it attained constant moisture content (approximately 12%). Four-point bending tests were then carried out in accordance with EN408 (CEN, 2003) to determine modulus of elasticity and modulus of rupture of the timber.

RESULTS

There was a strong relationship observed between E_d calculated from measurements made on individual standing trees using the IML hammer and E_d calculated from measurements made on the butt log cut from these trees using the HM-200 (Fig. 1, R^2=0.600).

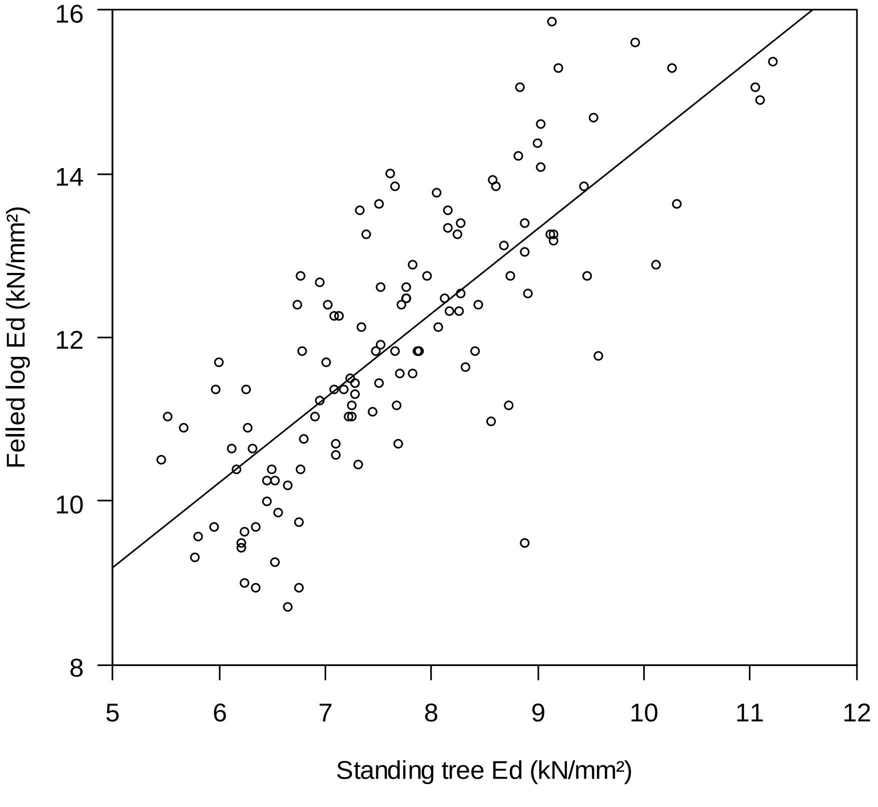

Figure 1. Comparison of tree-level values of dynamic modulus of elasticity from measurements made on standing trees and on freshly-felled butt logs. The solid line was fitted using ordinary least squares regression.

Due to adverse weather conditions preventing access to the sites, it was only possible to extract logs from 9 out of the 12 sites. However, for these sites there was a strong relationship between the mean modulus of elasticity of the timber cut from a site and the average stress wave velocity measured on trees at the site (R^2=0.76; Fig. 2). This relationship was slightly stronger when the stress wave velocity measurements were made on logs using the HM-200 (R^2=0.82; Fig. 3).

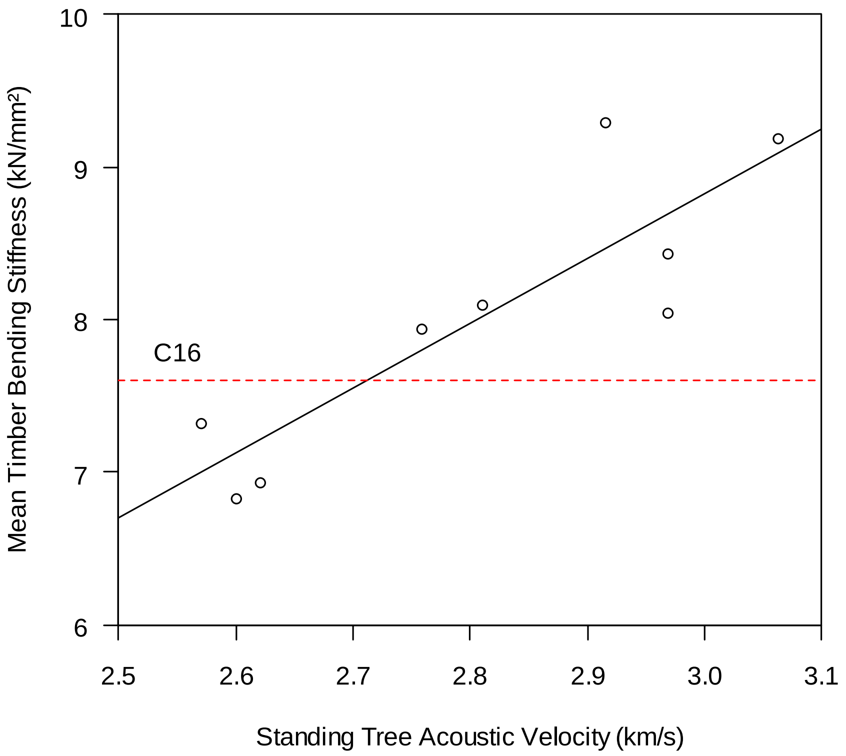

Figure 2. Relationship between the mean standing tree acoustic velocity at a site and the mean bending stiffness of timber cut from a site.

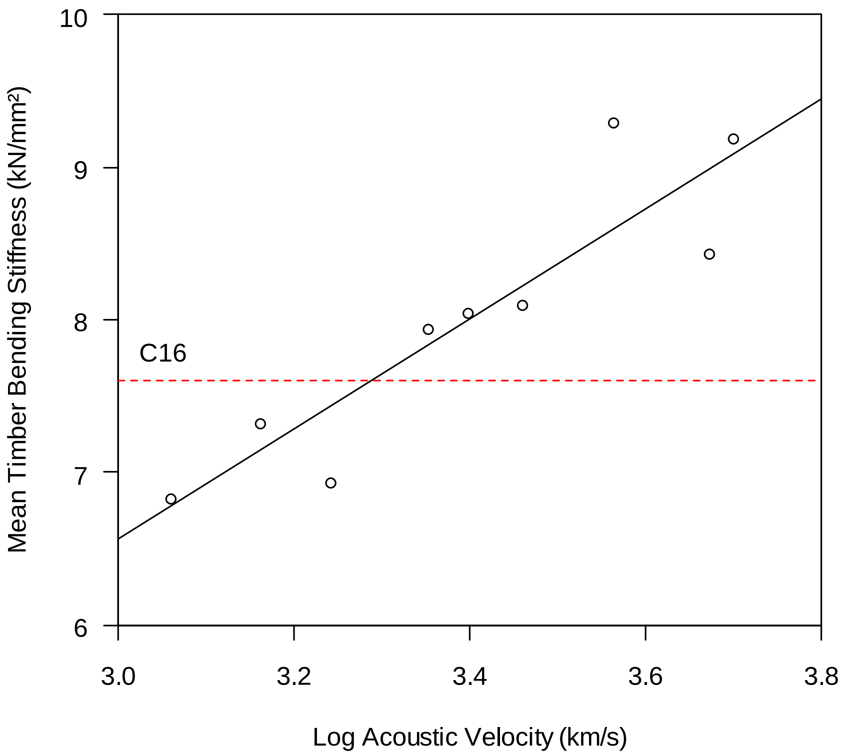

Figure 3. Relationship between the mean log acoustic velocity at a site and the mean bending stiffness of timber cut from a site.

These results indicate the potential for the use of acoustic tools to be used to segregate material prior to processing. The strong relationship between timber stiffness and measurements of acoustic velocity made on both standing trees and logs allows timber buyers to choose which stands to purchase for conversion into structural timber. It could also allow mills to segregate logs into batches and to then alter the cutting patterns for the lower stiffness logs in order to produce timber that will not be rejected during the grading process. Currently, research is being undertaken to investigate this problem as well as the general issue of trying to integrate this technology into the forest-to-mill supply chain and the timber grading process.

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