Acoustic Measurement Differences on Trees and Logs from Hardwoods in Wet and Dry Condition

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Abstract

Acoustic velocities measured on standing trees using time-of-flight (TOF) devices have been found to be between 7% and 36% higher for softwoods than those in logs using resonance techniques based on longitudinal frequencies. This effect was explained in three different ways: (1) TOF devices on standing trees measure outerwood containing more mature wood while resonance methods assess the whole cross-section, (2) the variation in the velocity is due to loading conditions in standing trees, while logs are free of loads and (3) the acoustic waves are dilatational waves in the case of TOF measurements on standing trees and one-dimensional longitudinal waves in the case of resonance on logs. This is an important topic considering the fact that resonance methods are considered more accurate for predicting mechanical properties and it has been proposed that correction factors should be applied on TOF measurements.

In the present work, four hardwoods from Irish forests were studied and, on average, TOF velocities measured in the forest above fibre saturation point (FSP) were 19.8% higher than those from resonance measurements taken on logs immediately after felling. However, this difference reduced to 5.4% when the measurements were repeated at a moisture content (MC) of about 18% in the laboratory. Therefore, there is a MC effect on the velocity differences. Furthermore, higher differences were systematically found in older specimens in wet condition. However, this age effect was small in most cases.

Keywords: acoustic velocity, hardwoods, logs, moisture content influence, standing trees

Introduction

Measurement of acoustic velocity on standing trees and resonance on green logs has been successfully used to grade and estimate properties of logs and sawn timber (Wang et al. 2002; Moore et al. 2013; Gil-Moreno and Ridley-Ellis 2015; Krajnc et al. 2019). While the resonance method has the advantage of being more accurate than acoustic time-of-flight (TOF) measurements based on stress wave techniques in applications on logs and sawn timber, the resonance method can be not used on standing trees as measurements should be made on unloaded specimens.

It is well known that velocities obtained by acoustic methods measuring TOF are higher than those obtained from resonance methods in sawn timber (Haines et al. 1996; Íñiguez 2007; Llana et al. 2016). In the case of stress wave measurements on standing trees and resonance measurements in green logs, velocities between 7% and 36% higher were reported by several authors (Chauhan and Walker 2006; Grabianowski et al. 2006; Lasserre et al. 2007; Wang et al. 2007; Mora et al. 2009; Yin et al. 2010; Bertoldo 2014) most of them studying softwoods. Furthermore, Wang (2013) suggested that tree diameter, stand age, operating temperature and wood moisture content (MC) affect tree-log velocity relationships.

The objective of the present work is to study the velocity differences between TOF and resonance measurements on hardwoods in the forest (in wet condition) and in the laboratory (in dry condition) and the influence of age and MC on these differences.

Materials and Methods

Materials

A total of 36 trees with diameters at breast height (DBH) between 80 and 180 mm and logs from the bottom part of these trees (butt log) with an overall length of 25 times its DBH were selected from thinnings of four Irish hardwood species: common alder (*Alnus glutinosa* (L.) Gaertn.), European ash (*Fraxinus excelsior* L.), European birch (*Betula pendula* Roth. & *Betula pubescens* Ehrh.) and sycamore (*Acer pseudoplatanus* L.).

NDT experiments

The TOF of acoustic stress waves over a length (L) of 1 m was measured on standing trees using a TreeSonic (Fakopp, Sopron, Hungary) device and the acoustic velocity (Vel) was determined using Equation (1).

$$Vel = L / TOF \tag{1}$$

A Mechanical Timber Grader MTG (Brookhuis, Enschede, The Netherlands) was then used to determine the fundamental frequency (f) in the longitudinal direction of wet logs, above Fiber Saturation Point (FSP), just after harvesting. The velocity for the logs was calculated using Equation (2):

$$Vel = 2 \cdot f \cdot L_{log} \tag{2}$$

where L_{log} is the log length.

Both NDT measurement procedures were subsequently carried out on dry logs (around 18% MC) in the National University of Ireland Galway Timber Engineering Laboratory.

Results and discussion

Velocities obtained from TOF measurements on standing trees and dry logs were higher than those obtained from the corresponding resonance measurements. Figure 1 shows the differences between TOF and resonance velocities by specimen in the forest (wet) and in the laboratory (dry).

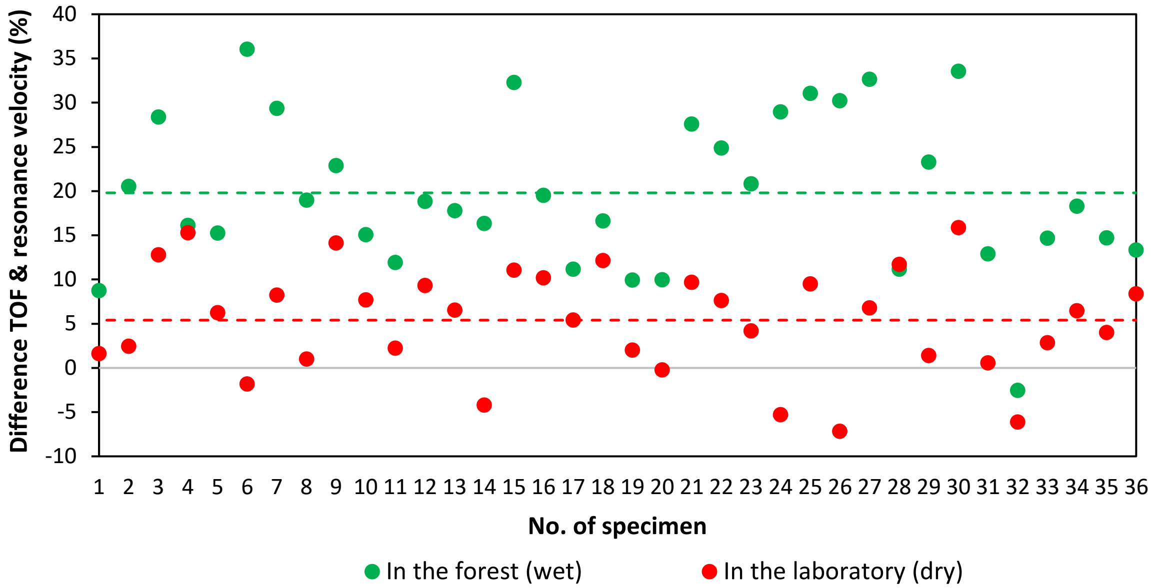

Figure 1 – Differences between TOF velocity and resonance velocity in percentage: Above FSP (wet) and around 18% MC (dry).

Figure 1 shows that velocity differences were higher in the wet than in the dry condition. Velocities obtained from TOF measurements were on average 19.8% higher than resonance velocities in the forest and 5.4% higher in the laboratory. Average differences were circa three and half times higher in wet than in dry conditions. A moisture content effect on the relationship between tree and log NDT measurement has been suggested by Wang (2013). Table 1 shows published results by other authors and the present research findings for measurements in the wet condition.

Table 1 – Differences in acoustic velocity predictions (wet)

NDT device		Species*	Velocity difference (%)	Reference
Stress waves (TOF)	Resonance			
Fakopp 2D	Hitman HM200	Radiata pine	8.7 to 17.5	Chauhan & Walker 2006
Fakopp 2D	WoodSpec	Radiata pine	12.0	Grabianowski et al. 2006
TreeTap	Hitman HM200	Radiata pine	16.0 to 31.0	Lasserre et al. 2007
		Sitka spruce		
		Western hemlock		
Scopemeter	Hitman HM200	Jack pine	7.0 to 36.0	Wang et al. 2007
		Ponderosa pine		
		Radiata pine		
TreeSonic	Hitman HM200	Loblolly pine	32.0	Mora et al. 2009
MicroSecond Timer	Microphone	Chinese fir	9.5	Yin et al. 2010
		Daintree stringybark (H)		
Hitman ST300	Hitman HM200	Lemon-scented gum (H)	20.3	Bertoldo 2014
		Saligna gum (H)		
Hitman ST300	MTG	Sitka spruce	11.2	Simic et al. 2019
		Common alder (H)		
		European ash (H)		
TreeSonic	MTG	European birch (H)	19.8	Present work
		Sycamore (H)		

(H) Hardwood species
*Species common names according to standard EN13556:2003 when possible; when not, according to Miller & Ilic (1992)

As shown in Table 1, differences between TOF and resonance velocities vary between authors. The velocity difference for temperate hardwoods found in the present work (19.8%) is similar to the value of 20.3% found in tropical hardwoods by Bertoldo (2014). Nevertheless, according to Wang (2013) different TOF measurement devices used on standing trees may have different algorithms and trigger settings making it difficult to compare results between authors using different devices. Chauhan and Walker (2006) and Wang et al. (2007) found that differences are related to age and diameter. In Figure 2, the difference in the average velocity measurements by species in the wet condition are seen to increase with age. However, for ash and sycamore, these increases are negligible. In the dry condition, small increases are seen for three species but a decrease was found in the case of alder. It should be noted that this study was carried out on forest thinnings that were young and the differences may be much greater as the age increases.

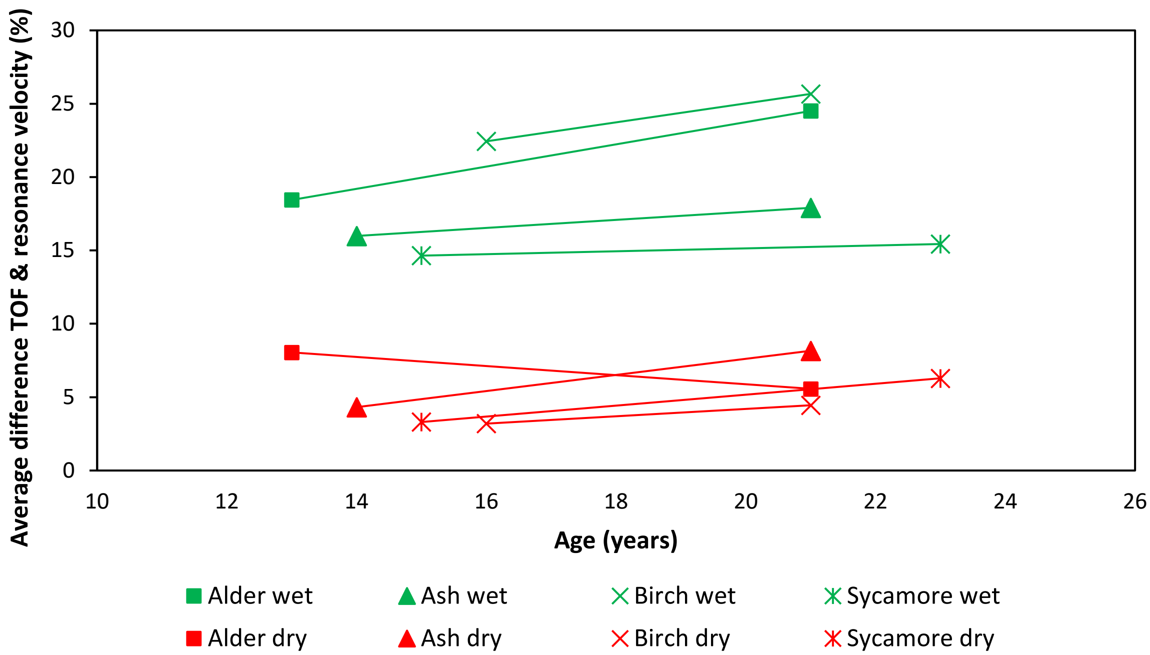

Figure 2 – Average differences between TOF velocity and resonance velocity in percentage by age

Figure 3 shows that the relationship between TOF and resonance velocities is stronger in the wet than in the dry condition. The coefficient of determination for wet specimens at 0.71 is just in the limit of the range from 0.71 to 0.93 reported by Wang et al. (2007) and weaker than 0.91 found by Grabianowski et al. (2006) and 0.81 reported by Mora et al. (2009). As resonance velocity is considered more accurate for estimating mechanical properties (Grabianowski et al. 2006; Wang 2013), relationship models can be used to convert TOF velocity to resonance velocity.

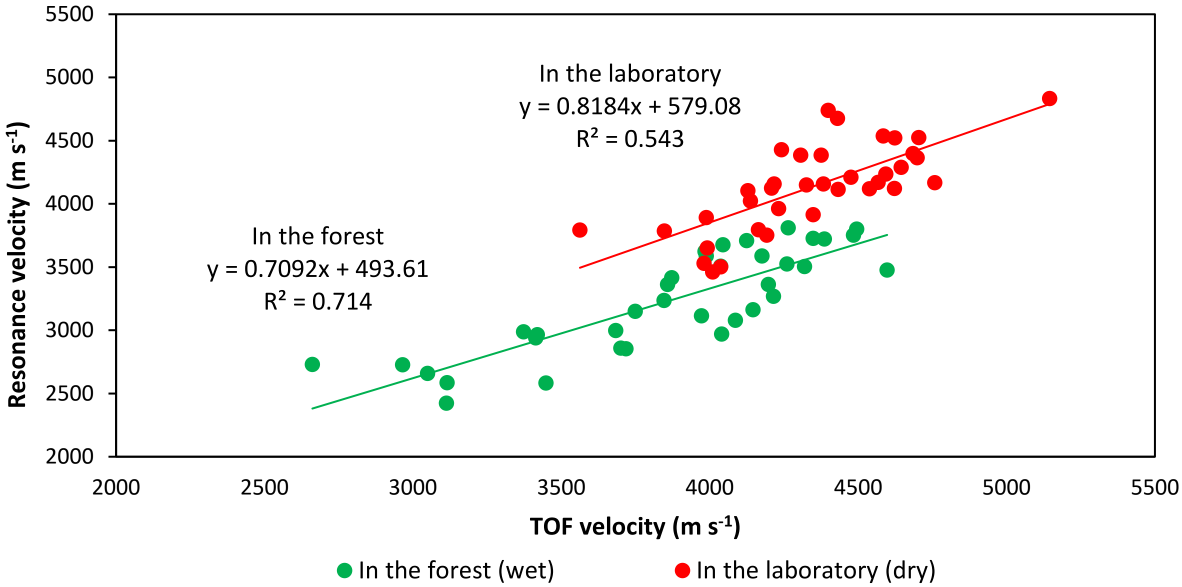

Figure 3 – Relationship between resonance and TOF velocities

The higher velocity found using TOF devices on standing trees compared to those from resonance methods on logs has been explained in different ways by several authors. Chauhan and Walker (2006) and Grabianowski et al. (2006) attributed the differences to the fact that stress waves devices measure only the outerwood containing more mature wood, while resonance methods assess the whole cross-section. In the present study, thinnings containing a very small proportion of mature wood were used. Furthermore, in order to elucidate if this explanation is applicable here, TOF was measured in the dry condition on the surface, in the same way as on standing trees, and on the ends, similar to the resonance method. As seen in Figure 4, higher velocities were found for the end-to-end measurements than for the surface ones, which is the opposite of what was expected. Therefore, this explanation is not applicable to the present case.

According to Bertoldo and Gonçalves (2015), acoustoelasticity could explain these differences based on the variation in the velocity due the fact the standing trees are loaded while logs are free of loads. In the present study, in addition to taking TOF measurements on standing trees in the wet condition, TOF velocities were obtained on unloaded logs in the dry condition. While higher differences were found in the wet condition (Figure 1), differences still remained for the tests on the unloaded dry logs. Hence, the differences found in the wet condition can only be partially explained by the influence of loading conditions.

Wang et al. (2007) suggested that the differences could be based on dilatational waves in case of TOF measurements on standing tress and one-dimensional longitudinal waves in case of resonance methods on logs. Additionally, they found lower differences in small diameter trees because stress waves would propagate in those cases more as one-dimensional longitudinal waves. Chauhan and Walker (2006) also found less difference in young trees. In the present work, smaller differences were found in younger trees in all cases except dry alder (Figure 2).

From the point of view of the authors of the present research work, the theories found in the literature partially explain the differences found here.

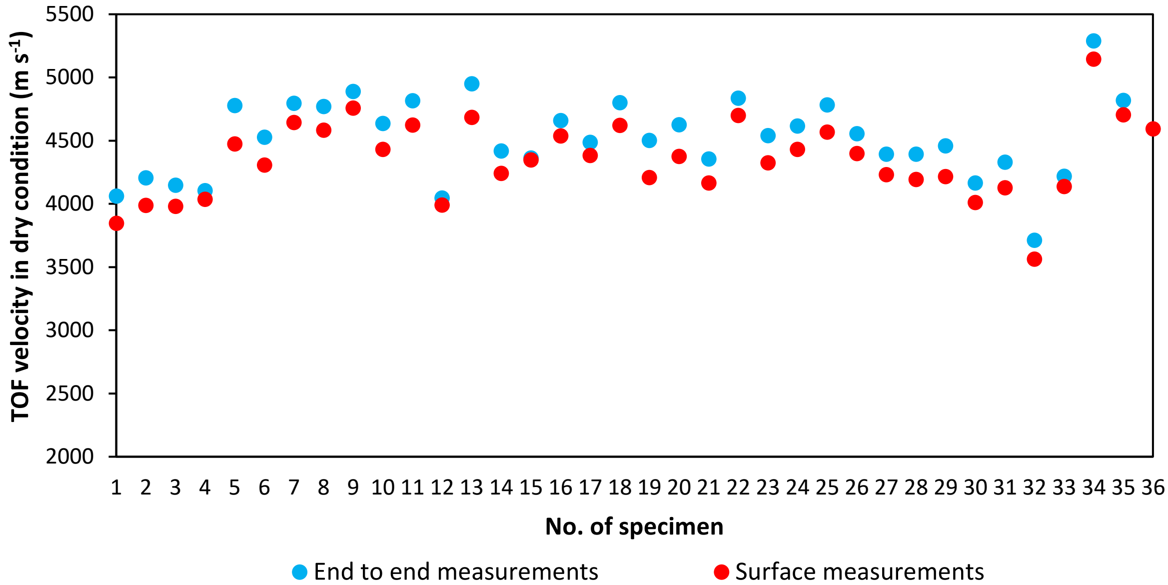

Figure 4 – Velocity obtained from TOF in dry condition: on the ends and on the surface

Conclusions

Acoustic velocities measured on standing trees using TOF measurements have been found to be 19.8% higher than those in wet logs using resonance techniques based on longitudinal frequencies and 5.4% higher when measurements were repeated at 18% MC. These values show a clear MC effect on the differences between TOF and resonance velocities.

As has been reported in the literature in case of softwoods, velocity differences in hardwood thinnings were found to be dependent of the age of the trees. However, this effect was small in most cases.

There is a clear relationship between velocities from TOF and resonance measurements allowing conversion between one and the other. This relationship is stronger in wet than in dry conditions, but weaker than the softwood relationships found in the literature.

The results, based on 36 logs from four hardwood species, require validation with a larger sample, but give indications regarding TOF and resonance velocities differences and the influence of MC.

Acknowledgments

This work has been carried out as part of the project Exploitation And Realisation of Thinnings from Hardwoods (E.A.R.T.H.) funded by the Department of Agriculture, Food and Marine of the Republic of Ireland under the 2015 Call for Research Proposals (Project Ref: 15-C-666).

The authors would like to thank Mr. Jerry Campion and Mr. Derek Gibson from Teagasc for their technical support in the fieldwork, Mr. Dan Connolly, Mr. John P. Gill, Mr. Liam Mooney, Mr. Kevin O'Connell and Mr. Ivan Ryall for freely supplying the material and Mr. Conor Fahy from ECC Teoranta for kindly allowing us to dry the timber in their facilities. Furthermore, Ms. Rachel Keane and Mr Colm Walsh from National University of Ireland Galway for their helpful technical assistance in the laboratory testing.

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United States Department of Agriculture

Proceedings

21st International Nondestructive Testing and Evaluation of Wood Symposium

Freiburg, Germany
2019

Forest Service, Forest Products Laboratory
Forest Research Institute Baden-Württemberg
Forest Products Society
International Union of Forest Research Organizations

General Technical Report
FPL–GTR–272

September
2019

Abstract

The 21st International Nondestructive Testing and Evaluation of Wood Symposium was hosted by the Forest Research Institute Baden-Württemberg (FVA) in Freiburg, Baden-Württemberg, Germany, September 24–27, 2019. This symposium was a forum for those involved in nondestructive testing and evaluation (NDT/NDE) of wood and brought together many international researchers, NDT/NDE users, suppliers, representatives from various government agencies, and other groups to share research results, products, and technology for evaluating a wide range of wood products, including standing trees, logs, structural lumber, engineered wood products, and wood structures. Networking among participants encouraged international collaborative efforts and fostered the implementation of NDT/NDE technologies around the world. The technical content of the 21st symposium is captured in these proceedings. Full-length, in-depth technical papers for the oral presentations and several of the poster presentations are published herein. The papers were not peer reviewed and are reproduced here as they were submitted by the authors.

Keywords: International Nondestructive Testing and Evaluation of Wood Symposium, nondestructive testing, nondestructive evaluation, wood, wood projects

September 2019

Wang, Xiping; Sauter, Udo H.; Ross, Robert J., eds. 2019. Proceedings: 21st International Nondestructive Testing and Evaluation of Wood Symposium. General Technical Report FPL-GTR-272. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 724 p.

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