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ORIGINAL ARTICLE

Predicting static modulus of elasticity using non-destructive testing: a comparative study of *Populus alba* and *Cedrus deodara*

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ABSTRACT
This reseach paper presents a comparative analysis of the mechanical performance and non-destructive evaluation (NDE) characteristics of *Populus alba* and *Cedrus deodara*, two timber species extensively used in traditional construction in the Himalayan region. 64 specimens were subjected to a comprehensive experimental protocol that included density determination, ultrasonic pulse velocity (UPV) testing, moisture content measurement, and assessment of knot area ratio (KAR), followed by three-point static bending tests to derive the static modulus of elasticity (MOE_{static}). Simple linear and multiple linear regression models were employed to evaluate the predictive relationships between MOE_{static} and the NDE parameters. Results indicated that *Populus alba* exhibited superior stiffness properties (average $MOE_{static} = 10{,}900$ N/mm^2) and higher UPV and density values relative to *Cedrus deodara* ($MOE_{static} = 9{,}800$ N/mm^2). Among the individual predictors, Knot metrics showed the strongest correlation with MOE_{static} in both species, while UPV and moisture content demonstrated significant but species-dependent predictive power. Multiple linear regression models incorporating UPV, density, moisture content, and Weighted Knot Area Ratio (KAR_{wtd}) achieved high coefficients of determination confirming the value of integrated NDE approaches. These findings underscore the importance of species-specific modelling and support the use of multi-parameter non-destructive techniques for accurate timber grading and stiffness estimation.

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1. Introduction

Understanding the mechanical properties of timber, especially the modulus of elasticity (MOE), is essential for its efficient use in engineering applications. The static modulus of elasticity (MOE_{static}) is a key indicator of stiffness and structural performance. However, conventional methods to obtain MOE_{static} require extracting and testing samples, which is time-consuming and damages the material (Ettelaei *et al.* 2019, Papandrea *et al.* 2022). This has spurred interest in non-destructive testing (NDT) techniques that can predict wood elasticity without harming the wood. In recent decades, NDT methods such as stress wave timing, vibration analysis, and ultrasonic pulse velocity (UPV) measurements have been widely explored for evaluating timber quality. Among NDT methods, ultrasonic pulse velocity (UPV) testing has gained prominence for predicting wood stiffness. By sending stress waves (typically ultrasound or sonic waves) through a wood member and measuring the transit time, one can calculate the wave velocity and, in combination with wood density, estimate the dynamic modulus of elasticity (MOE_{dyn}) (Paniagua *et al.* 2022). This MOE_{dyn} can serve as a proxy for MOE_{static} and is often used to infer the timber's static bending stiffness and even strength (Herdová *et al.* 2024). However, MOE_{static} is not governed by a single factor alone. Wood is an anisotropic, heterogeneous material, and characteristics such as density, moisture content (MC), and natural defects (e.g. knots) all influence its stiffness. Density reflects the amount of wood substance in a given volume and generally has a positive correlation with stiffness. Moisture content affects the mechanical behaviour by plasticising the wood fibres. Higher MC tends to reduce stiffness, and it also alters wave propagation speed. Knots, resulting from tree branches, disrupt the wood's grain continuity and often reduce both strength and stiffness locally. Because these factors are interrelated, researchers have developed multivariate models combining several NDT measurements and material properties to predict MOE_{static} more accurately (Herdová *et al.* 2024). Such models often outperform single-parameter predictions, as they capture the combined effects of multiple wood characteristics.

Ultrasonic pulse velocity (UPV) techniques involve sending high-frequency stress waves through wood and measuring the travel time. The appeal of UPV is that wave speed is fundamentally linked to the material's elastic stiffness and density (Chauhan and Sethy 2016). Numerous studies have leveraged UPV to predict stiffness in both standing trees and processed lumber. For example, Hassan *et al.* (2013) used ultrasonic and resonance tests on Scots pine and effectively estimated its stiffness and strength properties (Hassan *et al.* 2013). In fast-growing hardwoods like poplar, researchers have also achieved good prediction accuracy. Ettelaei *et al.* (2019, 2022) applied UPV on poplar wood and showed that, with appropriate empirical corrections, the dynamically measured MOE can closely

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