cbecimat26
26° Congresso Brasileiro de Engenharia e Ciência dos Materiais
22 a 26 de novembro de 2026
Costão do Santinho
Florianópolis-SC

Regression Models for Hardwood Mechanical Properties as a Function of Fiber Angle

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Introdução

The mechanical properties of wood are traditionally estimated using the Hankinson formula (1921), as established in ABNT NBR 7190-1 (2022). This model was originally developed for conifers and compression tests, which may lead to inaccuracies when applied to hardwoods and to other stress modes. Given the growing structural use of tropical hardwoods, regression alternatives that better capture their distinct anisotropic behavior across the fiber inclination angle are needed for reliable engineering design.

Objetivos

This study aimed to determine specific regression models to estimate strength and stiffness as a function of the fiber inclination angle (θ) in hardwoods, providing a species-specific alternative to the standard Hankinson formula for structural elements subjected to off-axis loading.

Metodologia

A systematic literature review across the Web of Science and Scopus databases identified 11 experimental studies, yielding about 740 observations covering species such as Cupiúba, Pereiro, Amescla, Peroba-mica, and Eucalyptus saligna. Data were fitted with Linear, Exponential, Logarithmic, and Geometric regression models based on Analysis of Variance (ANOVA), validated via P-value significance, R^2, and Mean Absolute Percentage Error (MAPE) against the normative Hankinson formula.

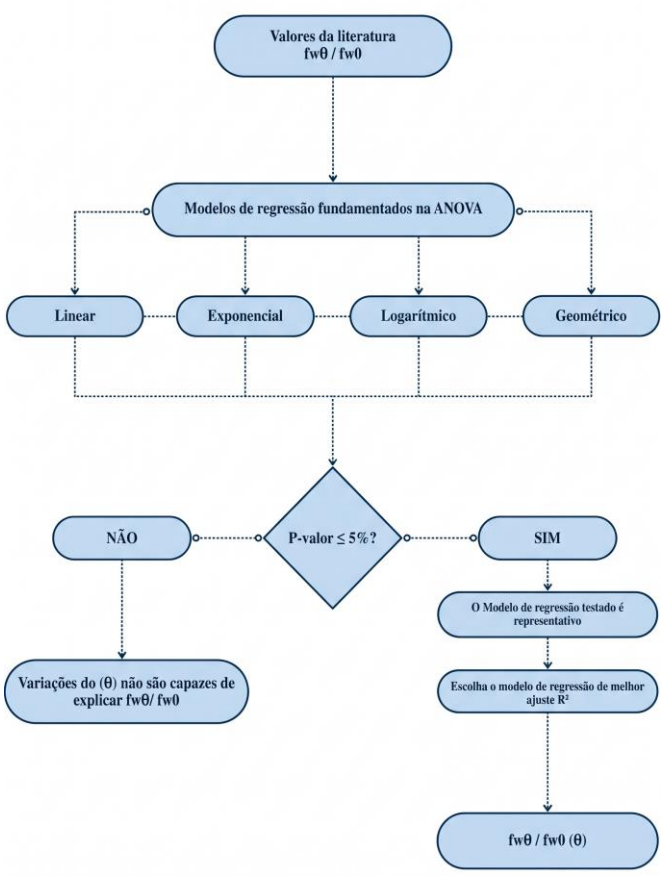


Figura 1:Fluxograma para análise estatística dos modelos de regressão.

Resultados e Discussão

Most adjustments yielded R^2 values above 90%, with the Geometric model emerging as the most frequent best fit for describing the non-linear degradation of mechanical properties. The inherent anisotropy of hardwoods leads to distinct failure modes, such as fiber crushing in compression versus shear at intermediate angles, captured more accurately by the proposed models than by the standard Hankinson formula.

Autores	Modelos	Espécies	Er (%)	
			Hankinson (1921)	Modelo de Regressão
Nicolas et al. (2006a)	Geométrico	Sitka spruce	19,98	3,53
Nicolas et al. (2006b)	Geométrico	Goupia glabra	18,10	4,95
Todeschini (2009)	Geométrico	Goupia glabra	11,07	6,08
Finger et al. (2010)	Geométrico	Pereiro	14,42	6,05
Nicolas et al. (2011)	Geométrico	Goupia glabra	10,95	5,97
Gupta et al. (2011)	Linear	Douglas-fir	16,33	3,67
Mantilla et al. (2013)	Logarítimico	Amescla	6,14	2,66
Logsdon et al. (2014a)	Logarítimico	Peroba-mica	1,91	4,32
Logsdon et al. (2014b)	Geométrico	Peroba-mica	20,20	7,77
Carrasco et al.(2015)	Exponencial	Eucalyptus saligna	4,28	1,19
Mantilla et al. (2016)	Exponencial	Eucalyptus saligna	3,64	1,36

Tabela 1: Erros percentuais absolutos médios cometidos na estimativa de melhor ajuste obtidos por espécie.

Conclusões

The proposed regression models provide a robust, engineering-oriented alternative to the Hankinson formula for the structural design of timber joints and elements subjected to off-axis loading, particularly for hardwood species underrepresented in current normative provisions. Future work should expand the dataset and validate the models under combined loading conditions.

Referências

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 7190 (2022) - Projeto de Estruturas de Madeira**. Rio de Janeiro: ABNT. 75p.