EVALUATION OF SUGARCANE STRAW LIGNIN AS A COMPATIBILIZING AGENT IN POLYSTYRENE COMPOSITES REINFORCED WITH VEGETABLE FIBERS

João A. Lopes [1], Ana K. F. Carvalho[2], Heitor B. S. Bento[3], Paulo H. S. Oliveira[1] & Bruno C. Gambarato[1]*

[1] *Department of Material Science, University Center of Volta Redonda – UniFOA, Volta Redonda, Brazil.*
[2] *Department of Basic and Environmental Sciences, School of Engineering of Lorena – USP, Lorena, Brazil.*
[3] *Department of Bioprocess Engineering and Biotechnology, School of Pharmaceutical Sciences - UNESP, Araraquara, Brazil.*
* *Corresponding author's email address: bruno.gambarato@foa.org.br*

ABSTRACT

Lignin, a significant byproduct of sugarcane biorefineries, exhibits diverse industrial applications. This study investigates the efficacy of sugarcane straw lignin as a compatibilizing agent in high impact polystyrene (HIPS) composites reinforced with vegetable fibers. Composites were formulated using HIPS matrices infused with fibers from three biomasses: pine sawdust, sugarcane bagasse, and coconut fiber, at concentrations ranging from 10% to 20%. Up to 10% lignin, obtained through an organosolv process employing acetic acid, was incorporated. Thermogravimetric analysis and mechanical testing (including tensile, flexural, and impact assessments) were conducted for comprehensive characterization. The thermogravimetric analysis facilitated kinetic investigation into thermodegradation, revealing physicochemical parameters inherent to each biomass structure. Factorial analysis demonstrated statistically significant enhancements in mechanical properties —tensile and flexural — following lignin supplementation. Synergistic effects between biomass and lignin contents underscored optimal phase compatibility in lignin presence. Notably, incorporation of 10% lignin resulted in up to a 40% improvement in composite mechanical properties.

Keywords: Organosolv. Tensile. Flexural. Design of Experiments. Biocomposites.

1 INTRODUCTION

Sugarcane straw lignin, a byproduct of sugarcane processing, holds promise as a compatibilizing agent in polymer composites, offering a sustainable solution to enhance the mechanical properties and compatibility of such materials. In recent years, there has been a growing emphasis on utilizing lignocellulosic biomass as renewable resources for composite materials due to their abundance and environmental benefits[1].

The significant advantage of employing biocomposites lies in the potential for plastic reuse, improved solid waste management in agro-industries, and the reduction of petroleum-derived content in the resulting material, leading to enhanced physical and mechanical properties. Within this framework, high impact polystyrene (HIPS) emerges as a favorable candidate for biocomposite composition due to its versatility and widespread usage across various applications[2].

This study aims to evaluate the effectiveness of sugarcane straw lignin as a compatibilizing agent in polystyrene composites reinforced with vegetable fibers, such as sugarcane bagasse, coconut fiber, and pine sawdust. Understanding the role of lignin in enhancing the interfacial interactions between the polymer matrix and reinforcing fibers is essential for optimizing the mechanical properties and overall performance of these composites. By systematically investigating the morphological, mechanical, and thermal properties of the composites, this research contributes to advancing sustainable materials science and the development of eco-friendly composite materials for various applications[3].

2 MATERIAL & METHODS

Organosolv sugarcane straw lignin

Initially, a 500 mL glacial acetic acid solution was prepared with a water proportion of 8:2 (v/v). Following this, 30 g of dry biomass was introduced into the solution. The resultant mixture underwent heating to 110°C and vigorous stirring within a glycerin bath for a duration of 1 hour, succeeded by vacuum filtration. The resulting residue underwent successive washing with deionized water until achieving a neutral pH, subsequently being subjected to drying. The solution underwent concentration to 50% of its initial volume. Subsequently, it was cooled to 8°C over a period of 24 hours and precipitated through the gradual addition of ice-cold deionized water under vigorous stirring. The precipitated lignin was obtained through centrifugation at 1500X.

Formulation of biocomposites

For the formulation of the composites, High Impact Polystyrene (HIPS) was employed as the polymeric matrix, along with three types of plant biomass (sugarcane bagasse, coconut fiber, and pine sawdust), and organosolv lignin. To assess the influence of lignin, formulations were designed following a complete 3^2 factorial design, with factors including biomass content (0%, 10%, and 20%) and lignin content (0%, 5%, and 10%). The biocomposites were prepared using a thermokinetic homogenizer, followed by milling and injection at 200°C.

Analytical Methods

Organosolv lignin was characterized using Fourier-transform infrared spectroscopy (FTIR) in the 400 – 4000 cm^{-1} region on a Perkin Elmer Spectrum GX infrared spectrometer. The different formulations of biocomposites were characterized through tensile and flexural mechanical tests following ASTM standards D638-03[4] and D790-03[5].

3 RESULTS & DISCUSSION

Figure 1 shows the FTIR spectrum of lignin isolated from sugarcane straw using the organosolv process. It exhibits typical characteristics of HGS lignins, including a band at 1709 cm^{-1} associated with unconjugated carbonyls and carboxyls, as well as a band at 1509 cm^{-1}, indicative of vibrations of lignin aromatic rings. The band at 1225 cm^{-1} suggests C-C, C-O, and C=O stretches in lignin G structures. Additionally, the presence of carbohydrates is evidenced by the band at 1086 cm^{-1}.

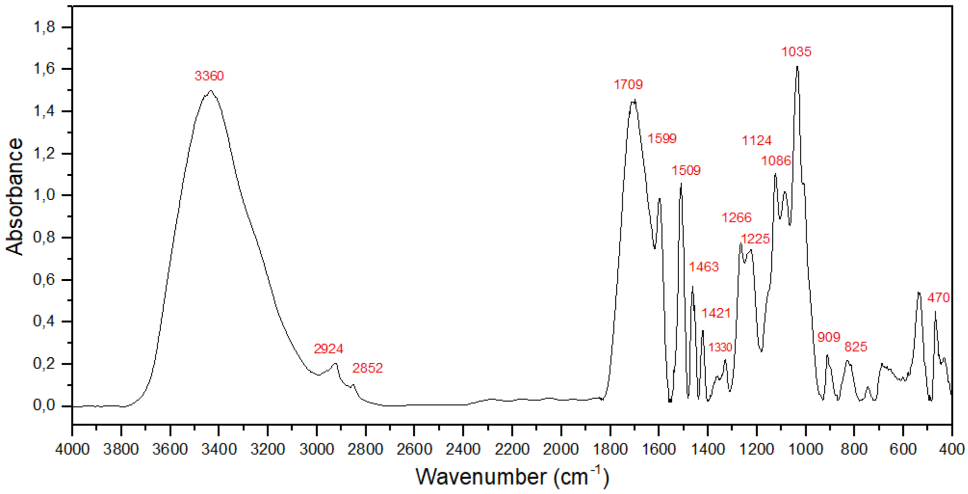

Figure 1 FTIR spectra of organosolv sugarcane lignin

Table 1 presents the highest results obtained for the mechanical properties (Young's Modulus and Flexural Modulus) of the biocomposites. The materials containing 20% biomass and 10% lignin demonstrated the greatest improvements in tensile and flexural strength.

Table 1 Young's Modulus (YM) and Flexural Modulus (FM) of the Composites, MPa

Biomass	Lignin	Sugarcane bagasse		Coconut fiber		Pine sawdust	
		YM (MPa)	FM (MPa)	YM (MPa)	FM (MPa)	YM (MPa)	FM (MPa)
0%	0%	358 ± 21	1562 ± 94	358 ± 21	1562 ± 94	358 ± 21	1562 ± 94
20%	10%	563 ± 27	2240 ± 107	629 ± 18	2422 ± 109	599 ± 33	2581 ± 126

Figure 2 presents the response surfaces for the variables Young's Modulus and Flexural Modulus, considering the studied compositions. The response surfaces and the statistical study showed that there is an interaction, that is, a combined effect between lignin and each of the biomasses, demonstrating a compatibilizing effect of lignin. The results were statistically validated by analysis of variance, as shown in Table 2.

Table 2 ANOVA parameters

Factor	Young's Module		Flexural Module	
	p-value	R^2	p-value	R^2
Lignin x Bagasse	0,010347	0,944	0,021991	0,929
Lignin x Coconut Fiber	0,013991	0,935	0,009207	0,974
Lignin x Pine sawdust	0,008007	0,961	0,010442	0,989

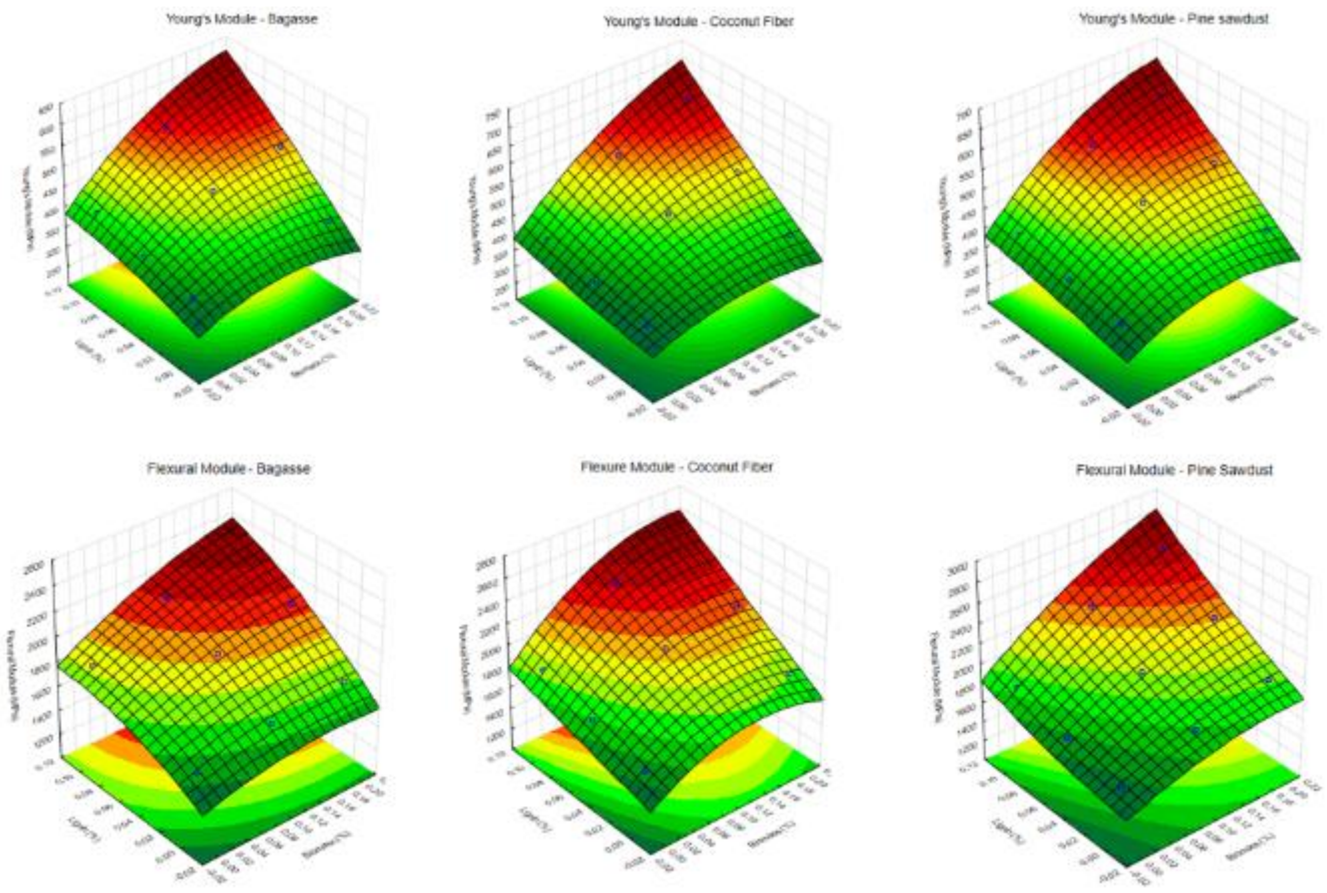

Figure 2 Response surfaces for Young's Modulus and Flexural Modulus of each composite

4 CONCLUSION

The organosolv treatment with acetic acid was efficient in extracting lignin from sugarcane straw. Analyses showed that the lignin precipitated from the liquor is typical HGS lignin, with the presence of xylan carbohydrates. All composites exhibited superior tensile and flexural mechanical properties compared to pure HIPS. The best results were obtained in formulations containing 20% biomass and 10% lignin, achieving increases of over 40% in mechanical properties. Lignin proved to be an effective compatibilizing agent in these formulations, a fact validated by Analysis of Variance.

REFERENCES

[1] ABDULKAREEM, S. A., ADENIYI, A. G., AMOSA, M. K., RAJI, S. A. 2020. Development of plastic composite using waste sawdust, rice husk and bamboo in the polystyrene-based resin (PBR) matrix at ambient conditions. In: Valorization of biomass to value-added commodities. Springer, Cham, 2020. 423-438.

[2] ZHOU, X., HE, T., JIANG, Y., CHANG, S., YU, Y., FANG, X., ZHANG, Y. 2021. A Novel Network-Structured Compatibilizer for Improving the Interfacial Behavior of PBS/Lignin. ACS Sustainable Chemistry & Engineering. 9 (25), 8592-8602.

[3] PHIRI, R., RANGAPPA, S. M., SIENGCHIN, S., OLADIJO, O. P., DHAKAL, H. N. 2023. Development of sustainable biopolymer-based composites for lightweight applications from agricultural waste biomass: A review. Advanced Industrial and Engineering Polymer Research, 6 (4), 436-450.

[4] ASTM D638-03. Standard Test Method for Tensile Properties. DOI: 10.1520/D0638-03.

[5] ASTM D790-03. Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. DOI: 10.1520/D0790-03.

ACKNOWLEDGEMENTS

Authors thank UNIFOA/FOA for the scholarship and resources provided for the development of this research.