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A Bibliometric Analysis of Plastic-Wood Composite Production from Wood Waste and Thermoplastic

Un Análisis Bibliométrico de la Producción de Compuestos Plástico-Madera a partir de Residuos de Madera y Termoplástico

Uma Análise Bibliométrica da Produção de Compósitos Plástico-Madeira a partir de Resíduos de Madeira e Termoplástico

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Abstract

Composite plastic-wood is a material that combines distinct substances, such as polymers and wood powder, maintaining their identities even after processing. These composites are widely used in applications such as furniture, construction, and balconies due to their durability, strength, and sustainability. This bibliometric article aims to analyze scientific production on plastic-wood composites, identifying trends and advancements. Using the Scopus platform as a database, 835 articles published between 2010 and 2022 were selected. China and the United States are the most prominent countries in researching these composites.

Thermoplastic polymers like polyethylene, polypropylene, and polyvinyl chloride are widely used, as are wood fibers from species such as pine and eucalyptus.

The most common production techniques are extrusion and injection molding, while mechanical analysis, scanning electron microscopy, infrared spectroscopy, thermogravimetric analysis, and differential scanning calorimetry are the most frequent characterization techniques. These plastic-wood composites have been a sustainable and versatile choice, driving innovation in the industry. This bibliometric analysis provides relevant information for the future development of materials and processes in this field.

Keywords: Wood-plastic composites, Polymers, Wood fibers, Bibliometric analysis.

Resumen

El compuesto plástico-madera es un material que combina sustancias distintas, como polímeros y polvo de madera, manteniendo sus identidades incluso después del procesamiento. Estos compuestos se utilizan ampliamente en aplicaciones como muebles, construcción y balcones debido a su durabilidad, resistencia y sostenibilidad. Este artículo bibliométrico tiene como objetivo analizar la producción científica sobre compuestos plástico-madera, identificando tendencias y avances. Utilizando la plataforma Scopus como base de datos, se seleccionaron 835 artículos publicados entre 2010 y 2022. China y Estados Unidos son los países más destacados en la investigación de estos compuestos. Los polímeros termoplásticos como polietileno, polipropileno y cloruro de polivinilo se utilizan ampliamente, al igual que las fibras de madera de especies como pino y eucalipto. Las técnicas de producción más comunes son la extrusión y la moldeo por inyección, mientras que los análisis mecánicos, la microscopía electrónica de barrido, la espectroscopía infrarroja, el análisis termogravimétrico y la calorimetría diferencial de barrido son las técnicas de caracterización más frecuentes. Estos compuestos plástico-madera han sido una opción sostenible y versátil, impulsando la innovación en la industria. Este análisis bibliométrico proporciona información relevante para el desarrollo futuro de materiales y procesos en esta área.

Palabras clave: Compuestos plástico-madera, Polímeros, Fibras de madera, Análisis bibliométrico.

O compósito plástico-madeira é um material que combina substâncias distintas, como polímeros e pó de madeira, mantendo suas identidades mesmo após o processamento. Esses compósitos são amplamente utilizados em aplicações como móveis, construção civil e varandas devido à sua durabilidade, resistência e sustentabilidade. Este artigo bibliométrico tem como objetivo analisar a produção científica sobre compósitos plástico-madeira, identificando tendências e avanços. Utilizando a plataforma Scopus como base de dados, foram selecionados 835 artigos publicados entre 2010 e 2022. A China e os Estados Unidos são os países mais proeminentes na pesquisa desses compósitos. Polímeros termoplásticos, como polietileno, polipropileno e policloreto de vinila, são amplamente utilizados, assim como fibras de madeira provenientes de espécies como pinus e eucalipto. As técnicas de produção mais comuns são a extrusão e a moldagem por injeção, enquanto as análises mecânicas, microscopia eletrônica de varredura, espectroscopia de infravermelho, análise termogravimétrica e calorimetria diferencial de varredura são as técnicas de caracterização mais frequentes. Esses compósitos plástico-madeira têm sido uma escolha sustentável e versátil, impulsionando a inovação na indústria. Esta análise bibliométrica fornece informações relevantes para o desenvolvimento futuro de materiais e processos nessa área.

Palavras-Chaves: Compósitos madeira-plástico, Polímeros, Fibras de madeira, Análise bibliométrica.

Introduction

Composites are materials that combine two or more distinct substances with different chemical and physical properties. These components maintain their individual identities even after processing, separated by a clearly defined interface. The adhesion between these components is designed to transfer applied loads to the elements that have higher strength, usually dispersed within the composite matrix. This matrix can be composed of metals, ceramics, or polymers [1].

In particular, wood-plastic composite, also known as Wood Plastic Composite (WPC), consists of a polymer matrix reinforced with wood powder. This wood powder is a combination of wood fibers and particles [2].

The early research on wood-plastic composites dates back to the 1950s when the automotive industry began adding wood powder to polypropylene (PP) to manufacture some interior parts of cars [3]. By the late 1980s, these composites started being used in the production of decks. In Italy, the first wood-plastic composite produced through the extrusion process was patented, composed of 50% wood flour and 50% polypropylene in the form of boards [4].

Currently, wood-plastic composites (WPC) find extensive application in the furniture industry, especially in residential garden benches and chairs, parks, and squares. Their superior durability compared to natural wood when exposed to adverse weather conditions makes them popular due to their resistance and ability to withstand the elements [5]. Furthermore, these composites are widely used in the construction industry as structural elements, including decks, pallets, flooring, door frames, gates, fences, and railway sleepers, providing durability and strength while offering a sustainable alternative to conventional materials [6].

Plastic lumber has gained increasing popularity in the United States over the past two decades, being widely used in the construction of decks and patios. It is estimated that 35% of these structures are built using this composite material. Its preference is due to requiring

less maintenance, being resistant to mold, not rotting, and exhibiting reduced wear caused by exposure to sunlight, saltwater, and humidity [7].

These materials offer a series of advantages over conventional ones, such as an attractive appearance, lightweight nature, ease of handling, and high resistance to moisture, insects, and decomposition [8].

Given the increasing demand for environmentally sustainable solutions, wood-plastic composites have become a versatile and sustainable choice for various projects. The reuse of waste allows an increase in industrial production without the need to establish new forest plantations for WPC production [9].

In this context, conducting a bibliometric analysis is relevant to understanding the current state of research in this field, identifying trends, advancements, and knowledge gaps. Mapping scientific production, relevant sources of information, and prominent research areas can provide a solid foundation for the development of new materials and the optimization of processes in wood-plastic composite manufacturing, thereby driving innovation and sustainability in this promising field.

Therefore, the objective of this research study was to conduct bibliometric analyses and assess the state of the art in studies on wood-plastic composite production. We aimed to gather advancements in this field and provide relevant information for future research. The specific objectives of this study were: i) to quantitatively assess the growth of publications in the last 12 years; ii) to identify the most prominent authors and relevant publications in the field; iii) to analyze the most common types of polymer matrix and wood fibers used; and iv) to identify the most frequently employed characterization techniques.

Materials and methods

In the present research, a bibliometric survey was conducted using the Scopus platform as the database. The

main objective of this study was to analyze the scientific production in the field of plastic-wood composites production, with a special focus on the characteristics of wood fibers and polymers used as constituent materials. The choice of Scopus as the database was due to its reputation as one of the leading multidisciplinary platforms, covering various academic areas including engineering, materials science, chemistry, and other disciplines related to plastic-wood composite research. The selection of publications was based on inclusion

and exclusion criteria. In this regard, English keywords that reflect the object of study were employed. This strategy was adopted to encompass a wide range of studies related to the topic. Thus, the search process was conducted as follows: (TITLE-ABS-KEY ("PVA" OR "PVC" OR "polyvinyl acetate" OR "polyvinyl chloride" OR "polymer") AND TITLE-ABS-KEY ("wood" OR "waste wood") AND TITLE-ABS-KEY ("Wood Plastic Composite"))). The search was conducted in June 2023, taking into consideration the additional restriction of the

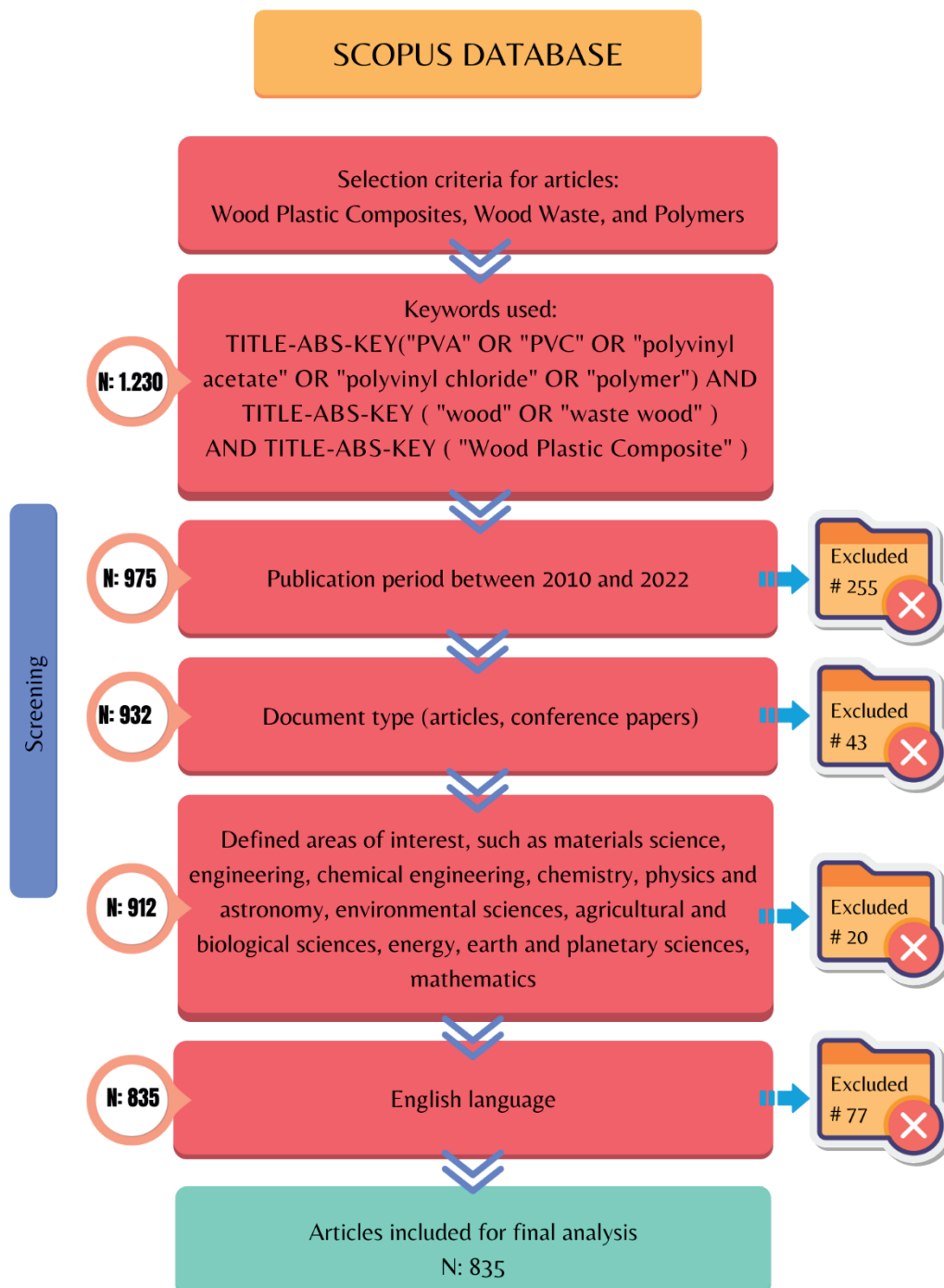


Figure 1: Flowchart for searching Scopus databases for systematic review publications.

publication year, collecting only articles published until the end of 2022.

After data collection, the identified documents were accessed through indexing portals, and only those that met the following selection criteria were included in this research: a) publication period between 2010 and 2022; b) document type (articles, conference papers); c) defined areas of interest, such as materials science, engineering, chemical engineering, chemistry, physics and astronomy, environmental science, agricultural and biological sciences, energy, earth and planetary sciences, mathematics; d) English language. After screening, the data from the selected articles were downloaded by exporting the information generated by Scopus to a CSV Excel file format.

The search was limited to the title, abstract, and keywords of the articles. The results were initially filtered based on their relevance to the topics addressed by the keywords.

For the bibliometric analysis, the following data were collected and recorded: i) nationality of the authors; ii) affiliations of the authors; iii) research funding agencies involved; iv) field of concentration in which the articles were indexed; v) year of publication of the articles; and vi) journal titles in which the articles were published. Subsequently, to assess the state of the art, the selected articles were analyzed in terms of publication period, publication source, adopted methodology, obtained results, and conclusions reached. This analysis allowed for the evaluation of the existing scientific production and provided a bibliometric overview of studies related to the production of wood-plastic composites using wood waste and specific polymers.

Results and Discussion

A total of 1,230 documents were counted, of which 67.9% were deemed eligible according to the selection criteria, resulting in the inclusion of 835 articles in this research. The remaining 32.1% corresponded to articles that did not meet the parameters established in the scope of this investigation. As illustrated in Figure 1, a total of 63 countries have conducted research related to the subject of study. China had the highest number of articles, with a total of 205, representing 24.6% of the total number of analyzed documents. Following that, the United States had 110 articles, accounting for 13.2% of the total. Other notable countries include Iran (81 articles), Germany (63 articles), Turkey (52 articles), Canada (44 articles), Malaysia (31 articles), Thailand (30 articles), and Finland (28 articles). These 10 countries together represent 77.1% of the total available in the literature, while the remaining 22.9% is distributed among 53 countries. Overall, it is observed that the Americas, parts of Asia, and Europe are the continents that stand out the most in studies related to plastic-wood composites.

The production of plastic-wood composites is notable in these countries due to a combination of favorable factors. These countries excel in the production of these materials due to a robust forestry industry, abundant natural resources, the ability to meet global demand for sustainable materials, and significant investments in research and development. Both in the United States and Europe, Wood-Plastic Composites (WPC) are widely used in sectors such as construction, automotive industry, and other applications. These materials offer benefits such as low maintenance requirements, resistance to mold, decay, solar radiation, marine environments, and moisture [10]. Additionally, the results are from the Scopus database, which indicated that only a few journals have an impact factor.

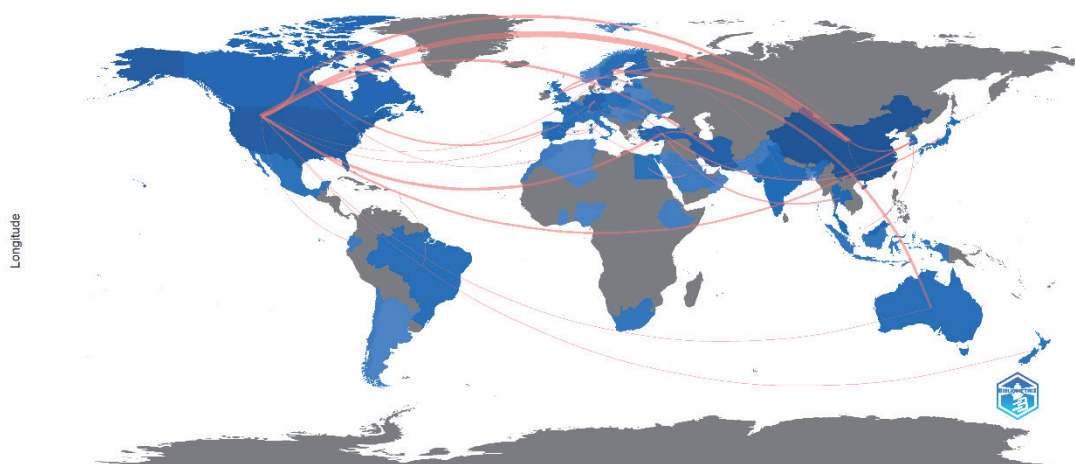


Figure 2: Scientific Production and Collaboration Network among countries.

India has been significantly prominent in research on wood fiber-based composite materials. This is attributed to its large population, abundant forest resources, and government investment in research endeavors. Figure 2 presents a visual representation of the interconnection between countries through scientific collaborations. Upon analyzing the figure, it can be observed that the higher frequency of co-citations is associated with longer lines. A total of 167 international collaborations were found, with notable partnerships including China and the United States, which accounted for 21 joint research projects. Following that, we have the United States and Canada with 7 collaborations, and China and Canada with 6 collaborations. On the other hand, the United States and China had the highest number of collaborations with different countries, totaling 13.

Among the institutions conducting the most research in the field of plastic-wood composites, the leading ones are Northeast Forestry University (169 articles), Beijing Forestry University (62 articles), Tarbiat Modares University (62 articles), Islamic Azad University (55 articles), and Nanjing Forestry University (51 articles), all located in Asia, particularly in China. When comparing the results with the scientific production of the countries, it is observed that Iran and China have the highest frequencies, and they are also the countries where these institutions conduct the largest number of research projects.

Between 2010 and 2013, there was a notable surge in scientific production regarding the studied topic, totaling 268 articles, representing 32.1% of the total. The year 2013 stood out with the highest number of publications, accounting for 75 articles (representing 9.0% of the total), while 2010 had the lowest count, with 59 articles (corresponding to 7.1% of the total). Expanding the analysis to the period from 2010 to 2022 revealed that 2016 was the most prominent year, with 88 articles published (equivalent to 10.5% of the total). The spike in publications in 2016 could be attributed to various factors, including heightened awareness of sustainability and the development of new technologies for wood and plastic composites production. On the contrary, 2018 recorded the lowest number of publications, with only 49 articles (representing 5.9% of the total), possibly due to an economic uncertainty period and a lack of funding for research in this field.

The research found that 2,087 authors conducted research focused on the subject under study. Among the most influential authors in terms of the number of publications, the following stand out: Wang Q, with 25 articles; Ayrimis N, with 18 articles; Kärki T, with 17 articles; Behraves AH, with 15 articles; and HE C, with 13 articles. These authors represent approximately 10.5% of the total publications conducted.



Figure 3: Annual Scientific Production.

Table 1: Authors Classification and their Study Areas in Composites: Thermoplastics, Fibers, and Applications.

Researcher	Thermoplastic	Natural Fiber	Main Application
WANG Q	Polypropylene	Wood fiber	Automotive components
AYRILMIS N	Polylactic acid (PLA)	Flax fiber	Packaging materials
KÄRKI T	Polyvinyl chloride (PVC)	Hemp fiber	Construction materials
HE C	Polyamide (PA)	Bamboo fiber	Textile materials
BEHVARVESH AH	Polyethylene (PE)	Cellulose fiber	Nanocomposites
FRIEDRICH D	Polystyrene (PS)	Kenaf fiber	Recycling and reprocessing
JIANG L	Polypropylene (PP)	Sisal fiber	Fiber surface modification
KAJAKS J	Polyethylene terephthalate (PET)	Jute fiber	Packaging applications
OU R	Polymethyl methacrylate (PMMA)	Coconut fiber	Electrical and thermal properties
WU Q	Polybutylene terephthalate (PBT)	Soy fiber	Reinforcement in composites

In the context of analyzing the 835 documents, the three most globally cited papers were identified as follows: “Waste Management” (KAZEMI NAJAFI S, 2013) received a total of 252 citations, followed by “ACS Sustainable Chem Eng” (LIU L, 2016) with 228 citations, and “Polymer Degradation and Stability” (STARK NM, 2010) with 200 citations. Regarding the most influential authors considering all published articles, author Wang H accumulated 201 citations in his works. His most cited paper, “Construction and Building Materials” (WANG W, 2015), received 40 citations. On the other hand, the second most contributing author recorded 580 citations in his works, with the article “Polymer Degradation and Stability” from 2011 receiving 127 citations. These citation numbers reflect the relevance of these works in the field, indicating their impact and influence in the scientific community.

A total of 253 journals have published articles on the production of plastic-wood composites using wood waste and polymer matrix. Table 1 presents the top 10 journals with the highest number of published documents and their research areas. Notably, the journal *Bioresources* stands out as a recognized platform for disseminating original research and analyses related to lignocellulosic

materials, chemicals, and their applications, with a total of 58 published articles. Following that, we have Advanced Materials Research with 41 articles, Polymers with 31 articles, the Journal of Thermoplastic Composite Materials with 30 articles, and the Journal of Applied Polymer Science with 29 articles. These journals focus on publishing research related to materials, polymers, and thermoplastic composites.

Table 2: Relevant Sources by Number of Published Articles, Research Area, and Journal Metrics Indicators.

Sources	Research Area	Articles	JIF*	SNIP**
Bioresources	Studies related to the use of renewable biological resources	58	5.107	6.175
Advanced Materials Research	Research on advanced materials and their applications	41	1.295	2.356
Polymers	Studies on polymers, including synthesis, characterization, and applications	31	4.152	6.768
Journal Of Thermoplastic Composite Materials	Research on thermoplastic composite materials	30	1.456	2.871
Journal Of Applied Polymer Science	Studies applied in polymer science and technology	29	2.311	4.291
Annual Technical Conference - Antec, Conference Proceedings	Annual conference on advances in the polymer industry	20	0.281	0.681
Construction And Building Materials	Studies on building materials, performance, and sustainability	19	5.884	7.882
Journal Of Reinforced Plastics And Composites	Research On Reinforced Composite Materials	17	1.499	2.953
Polymer Composites	Studies on polymeric composite materials	17	3.097	5.556
Composites Part B: Engineering	Research On Composite Materials And Their Application In Engineering	16	4.153	6.832

* Journal Impact Factor; **The average number of citations for items recently published in the journal, contextualized by the field of knowledge.

In the present study, a total of 5,415 relevant keywords were identified in the research area. Figure 4 presents the word cloud of the 20 most frequent keywords, with particular emphasis on the term “wood plastic composite” (WPC). This term refers to the composite material resulting from the mixture of wood residues, known as “wood flour,” and thermoplastic polymers such as polypropylene. It serves as the central and essential term that defines the material under study.

These words have higher occurrence because they represent the key terms used in the field, encompassing aspects such as the mechanical properties of the material, the use of coupling agents to improve adhesion, microscopic analysis techniques, water absorption, composite processing, addition of fillers, and the importance of recycling for sustainability. These keywords reflect the fundamental and relevant aspects being investigated and discussed in the context of plastic-wood composites.

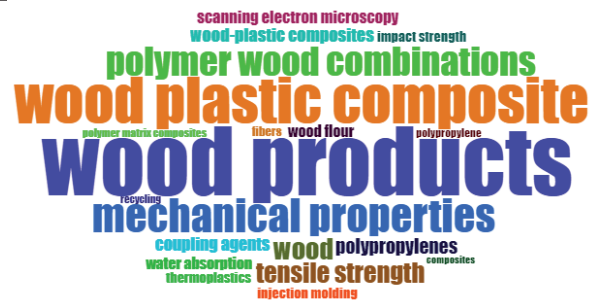


Figure 4: WordCloud of Keywords Related to the Research Study.

Wood-plastic composite (WPC) is a composite material in which the matrix is composed of a polymer. This composite can be produced using thermoplastic or thermosetting polymers, but thermoplastics are the most commonly employed in WPC manufacturing [2]. In the articles of the present bibliometric study, thermoplastic polymers were the most frequently mentioned for the production of plastic-wood composites. Thermoplastic polymers are characterized by a reduction in intermolecular forces when heated, which gives them flexibility. When cooled, these materials regain their original rigidity. This ability for repeated heating and cooling is one of the key advantages of thermoplastic polymers [11].

The polymers most widely explored by the authors were Polyethylene (PE) in its various forms, such as Low-Density Polyethylene (LDPE), High-Density Polyethylene (HDPE), and Linear Low-Density Polyethylene (LLDPE). Polypropylene (PP) was also extensively studied, as it is a versatile polymer known for its high chemical and thermal resistance. PP is used in a wide range of applications, including packaging, textile fibers, automotive parts, and household utensils, among others. Additionally, Polyvinyl Chloride (PVC) was addressed, being recognized for its resistance to corrosion and fire. PVC finds use in piping, electrical cable coatings, flooring, window profiles, and various other applications. The dispersed phase, also known as reinforcement, plays a fundamental role in providing strength, stiffness, and other specific properties to the composite material. In addition to increasing heat resistance, corrosion resistance, and conductivity, the reinforcement can be designed to meet different requirements of the new material [12].

In the composition of the plastic-wood composites in this particular study, the authors predominantly used wood fibers from different tree species such as pine, eucalyptus, and oak. In addition to natural fibers, the use of residues from the furniture industry, such as Medium Density Fiberboard (MDF), was observed in some cited studies. These wood fibers play a crucial role as reinforcement components within the plastic matrix, providing greater mechanical strength to the composites. Natural wood fibers are obtained directly from wood through mechanical processes such as defibration and can come from a variety of tree species. In addition to the mentioned species, wood

processing residues, such as furniture scraps, pallets, or reclaimed wood from construction, can also be employed in composite production, presenting a sustainable alternative that contributes to waste reduction [13].

In order to enhance the production and performance properties of Wood-Plastic Composites (WPC), additives are added to the mixture [2]. The articles mention that the main additives used are Coupling Agents, which function to improve the adhesion and interaction between the plastic matrix and the wood fibers. Commonly represented by silanes and maleates, coupling agents enhance the compatibility between the two components. Additionally, Lubricants are mentioned as additives that improve the processing of the composite by reducing friction between the wood fibers and the plastic matrix. These lubricants facilitate the molding and shaping process of the material.

Wood-plastic composites based on lignocellulosic particles and thermoplastics can be primarily produced

through two processes: extrusion and hot-pressing.

Simplistically, the extrusion process involves heating the polymer together with the wood fibers.

On the other hand, the hot-pressing process involves the production of panels by applying pressure and temperature [8].

Injection molding and extrusion are the most prevalent production techniques identified in the analysis of articles on the production of plastic-wood composites.

According to Väätsi [14], extrusion and injection systems are the most commonly used in the manufacturing of these composites. In the extrusion stage, the mixture of plastic and wood fibers is introduced into an extruder, where it is subjected to high temperatures and pressure. During this process, the mixture is melted and homogenized, resulting in a continuous material that can be molded into profiles, sheets, or other desired forms. The extrusion technique offers efficiency and versatility in the large-scale production of plastic-wood composites and is

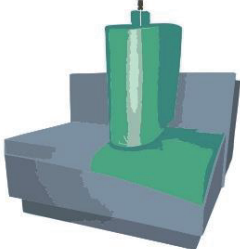
	Universal Testing Machine Traction: tensile strength, modulus of elasticity, yield strength, elongation at break Flexion: flexural modulus, flexural strength, rupture modulus Compression: compressive strength, compression modulus Impact: impact strength, absorbed energy
	Scanning Electron Microscopy (SEM) Microstructure, surface morphology, chemical composition
	Fourier Transform Infrared Spectroscopy (FTIR) Chemical composition, functional groups, molecular interactions
	Thermal Analysis Thermogravimetric Analysis (TGA): chemical composition, mass loss, decomposition temperature Differential Scanning Calorimetry (DSC): calorimetry, absorbed or released energy, phase changes

Figure 5: Key Characterizations Conducted and Their Properties.

widely adopted in the industry [15].

During the injection molding process, the thermoplastic material is fed into an injection molding machine, where it is heated and transformed into a molten state. The molten material is then injected at high pressure into a closed mold, which has a cavity with the desired shape for the part. The material fills the mold and is held under pressure until it cools and solidifies. Finally, the mold is opened, and the plastic part is ejected [16].

The most widely employed techniques by the authors in this bibliometric survey for the characterization of plastic-wood composites were mechanical analysis (tensile, flexural, compressive, and impact tests to determine fundamental properties), scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), thermogravimetric analysis (TGA), and differential scanning calorimetry (DSC). These techniques were selected to obtain comprehensive information about the mechanical properties, structure, morphology, chemical interactions, thermal behavior, and moisture absorption of these composites.

The selection of wood and plastic types for plastic-wood composite production depends on the desired properties and specific application needs. The analysis of these articles allowed for the identification of the most commonly used wood types, with pine and eucalyptus standing out due to their availability, affordable cost, and favorable mechanical properties such as strength and durability. Regarding plastics, the data gathered indicated that polypropylene (PP), polyethylene (PE), and polyvinyl chloride (PVC) are frequently selected due to their advantageous mechanical properties. The analysis of scientific articles contributes to the informed choice of materials by providing important information on the characteristics and performance of plastic-wood composites in the specialized literature.

Conclusion

In conclusion, this bibliometric study provides a comprehensive overview of the state of research on plastic-wood composites. The results highlight the growing relevance of these materials, driven by the demand for sustainable solutions and the need to reduce the use of natural resources. The bibliometric analysis conducted in this study has revealed several trends and advancements in the research on plastic-wood composites. China and the United States emerge as the most prominent countries in this area, with a significant number of publications. The most commonly used thermoplastic polymers are polyethylene, polypropylene, and polyvinyl chloride, while the most common wood fibers are derived from species such as pine and eucalyptus. These findings provide valuable insights into the current state of research

and the materials and techniques being employed in the development of plastic-wood composites.

The most commonly used production techniques are extrusion and injection molding, which enable efficient and large-scale production of the composites. In terms of characterization, mechanical analysis, scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), thermogravimetric analysis (TGA), and differential scanning calorimetry (DSC) were the most frequently employed techniques to evaluate the properties and structure of the composites.

These techniques provide valuable insights into the mechanical behavior, morphology, chemical interactions, thermal stability, and other key aspects of the plastic-wood composites.

In summary, plastic-wood composites have emerged as a versatile and sustainable choice for various projects, driving innovation and sustainability in the industry. The bibliometric analysis provided in this study contributes to the understanding of the current state of research in this field by identifying trends, advancements, and knowledge gaps. It serves as a solid foundation for the development of new materials and the optimization of processes in the manufacturing of plastic-wood composites.

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