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Production of a Wood–Plastic Composite with Wastes from Disposable Masks and Corrugated Cardboard: A Sustainable Post-Pandemic Approach

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Abstract: The increasing demand for disposable textile products, personal care items, and electronic commerce has led to a substantial rise in waste generation, particularly from nonwoven fabric masks (wNWFs) and corrugated cardboard (wCC). This study assessed the feasibility of utilizing these waste materials, which were produced in significant amounts during the COVID-19 pandemic, as both a matrix and reinforcement filler in wood–plastic composites (WPCs). The WPC was fabricated using either two extrusion cycles or thermokinetic homogenization, with both processes being followed by hot pressing. The formulations consisted of virgin polypropylene (vPP), wNWF, and wCC in proportions of 45, 45, and 10 wt %, respectively. The results demonstrated that the composites produced via two extrusion cycles exhibited a tensile strength that was 85% higher and three-point flexural strength three times greater than those produced through thermokinetic homogenization. These findings contribute to advancements in scientific and technological knowledge and offer an efficient solution for managing these types of waste, which continue to be generated post-pandemic.

Keywords: wood–plastic composite; corrugated cardboard; nonwoven fabric mask; polypropylene; polymer composite; waste management; sustainability

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1. Introduction

The global generation of Municipal Solid Waste (MSW) amounts to approximately 2.01 billion tons annually, with projections indicating a significant rise to 3.40 billion tons by 2050, representing an increase of around 70% [1]. Among these wastes, plastics account for 12%, with nonwoven fabric (NWF) waste being particularly notable [1]. This issue has been exacerbated by the COVID-19 pandemic, which has led to a substantial increase in MSW through social isolation and protective measures, further aggravating the environmental problems associated with inadequate waste management and disposal.

NWF is a polymeric material composed primarily of polypropylene (PP) and is extensively used in textile products such as face masks and coats. These NWF products, particularly face masks, offer advantages such as being lightweight, cost-effective, disposable, and easy to use. However, PP, the main component of NWF, is highly resistant to degradation, taking up to 450 years to partially break down [2]. Between 2012 and 2021, the global NWF consumption grew at an annual rate of 7%, with exports peaking in 2021 due to the pandemic [3]. During this period, the production of NWF, especially for Individual

Protection Equipment (IPE), increased considerably, posing significant environmental challenges due to improper disposal and rising amounts of plastic waste [4]. The intensified use of face masks driven by the COVID-19 pandemic and increasing investments in the healthcare and personal care sectors will likely continue driving the global NWF market in the coming years [5]. Moreover, extreme climate events such as heatwaves, forest fires, and frequent storms have heightened the need for respiratory protection, contributing to the sustained demand for face masks [6].

Another residual material whose production and disposal increased during the pandemic is corrugated cardboard (CC). Widely used in the packaging industry, CC consists of virgin or recycled cellulose fibers [7]. The global production of CC reached 172 million tons in 2019, increasing by 7% in two years to 184 million tons in 2021 [8]. Studies indicate that the generation of paper and cardboard packaging waste increased by 40% during the pandemic [9]. This surge can be attributed to the rise in single-use product purchases and the expansion of online shopping and delivery services, which have heightened the demand for packaging materials in express delivery services [10,11].

In response, wood–plastic composites (WPCs) present a promising solution for mitigating the pollution caused by plastic and cellulosic wastes such as NWF and cardboard. WPCs are versatile materials and valued across various industries due to their diverse properties and manufacturing capabilities. These composites typically consist of a continuous polymer matrix and reinforcement fillers that enhance the mechanical strength and hardness of the material [12]. The matrix is commonly made from polymers such as polypropylene (PP) and polyethylene (PE) [13,14]. Since NWF waste (wNWF) from face masks is composed of PP, it can be part of the polymer matrix in WPCs when combined with virgin PP (vPP). The inferior properties of wNWF can be improved by incorporating synthetic or natural fibers as reinforcement fillers [15]. Natural wood waste or fibrous plant-based materials, such as coconut fiber, bamboo, rice husk, or oat husk [16–18], are commonly used to reduce costs and enhance the mechanical properties of the composite [19]. Therefore, CC waste (wCC), derived from cellulose fibers, can be a reinforcement filler.

In addition to their recycling potential, WPCs help reduce the natural wood extraction rate and can replace wood in many significant applications, such as decks, automotive components, cladding, fences, industrial flooring, door frames, and beams [20,21], often offering comparable or superior properties [22,23]. These composites are also more resistant to pests, fungi, moisture, and cracking, with longer durability, lower maintenance required, and greater design flexibility for the construction sector [22–24]. However, there is limited scientific research addressing the use of recycled materials such as wCC as fillers and wNWF as a PP source for the polymer matrix in WPCs, making this a promising area for future research.

This study aims to develop and evaluate the properties of a WPC made from a mixture of vPP, wNWF, and wCC, two of which are waste materials generated in large quantities, particularly during the COVID-19 pandemic. Furthermore, this study aims to compare and assess two WPC production methods: two-cycle extrusion and thermokinetic mixing.

2. Materials and Methods

2.1. Materials

The wNWF was obtained from the controlled disposal of locally purchased surgical NWF masks with a grammage of 0.0025 g/cm^2. Although the masks were new when purchased, they were used for 24 h to simulate real-world conditions. After usage, the masks were sanitized following WHO guidelines for reusable masks. They were washed with water and detergent in a Colormaq LCB semi-automatic washing machine using the "Delicate" cycle. The masks were then soaked in a 0.1% chlorine solution for one minute to ensure decontamination, rinsed thoroughly, and air-dried. After sanitization, non-polypropylene components (such as elastic bands and metallic nose wires) were carefully removed. The wCC, with a density of 0.754 g/cm^3, was sourced from boxes used for packaging and transport. These boxes were supplied by a company that collects and separates recyclable materials in

Ouro Preto, MG, Brazil. The vPP used in this study was provided by Braskem, possessing a flow rate of 3.5 g/10 min and a density of 0.905 g/cm^3 [25].

2.2. Production Method

The wCC and wNWF wastes were shredded using a Marconi knife mill, model MA 580, with a 1.75 mm sieve for size reduction. The shredded cardboard was subsequently dried in a hot-air oven at 150 °C until a constant mass was achieved, ensuring moisture removal. Following this, WPCs were produced containing 10 wt % wCC, 45 wt % vPP, and 45 wt % wNWF. Two production methods were employed: (i) two extrusion cycles followed by hot press molding and (ii) thermokinetic homogenization followed by hot press molding. For comparison purposes, two additional composites were analyzed: one with a similar composition, produced via extrusion and containing 10 wt % wCC and 90 wt % vPP (vWPC), and a commercial WPC (cWPC) available on the market. Table 1 outlines the compositions of each composite produced, along with their corresponding codes.

Table 1. Composite identifications and composition.

Composite	vPP [1] (wt %)	wNWF [1] (wt %)	wCC [1] (wt %)
eWPC [2]	45	45	10
hWPC [2]	45	45	10
vWPC [2]	90	0	10

[1] vPP: virgin polypropylene; wNWF: nonwoven fabric waste; wCC: corrugated cardboard waste. [2] WPC: wood–plastic composite; eWPC: WPC produced via extrusion; hWPC: WPC produced via thermokinetic homogenization; vWPC: WPC produced with only vPP as matrix via extrusion.

For the production of the eWPC (WPC produced via extrusion), a portion of the vPP was extruded with wNWF, while another portion was extruded with wCC. Both mixtures were pelletized using a granulator, model AX Gran, manufactured by AX Plásticos (AX Plásticos: Diadema, Brazil), and subsequently extruded again to form a composite consisting of the three materials: vPP, wNWF, and wCC. The extrusion process was carried out using a laboratory single-screw extruder, model HAAKE Polylab Rheomex 19/25 QC, distributed by Thermo Scientific (Thermo Scientific: São Paulo, Brazil), operating at a temperature of 175 °C across three heating zones, with a screw speed of 45 rpm. After extrusion, the composite material was pelletized once more.

The vWPC, which contained only PP and wCC, was mixed in a single cycle. However, for the eWPC sample, two processing cycles were necessary. The extrusion of materials with different densities, such as vPP in pellet form and the flours of wCC and wNWF in powder form, presented significant challenges. The difference in densities can lead to the natural separation of materials during the feeding of the extruder, resulting in an inadequate mixture. The denser PP tends to accumulate at the bottom of the feeder, while the finer particles of the flour may rise to the top.

When three materials are included, this complication intensifies, as introducing two powdered materials (wCC and wNWF flours) makes feeding the extruder even more challenging. Therefore, two extrusion cycles were chosen: the first was used to mix part of the PP with the wCC flour and another with the NWF flour. This approach minimized the risk of thermal degradation of the materials and optimized the energy use during the manufacturing process.

In contrast, for the production of the hWPC, the materials were mixed in a Drais laboratory homogenizer, model MH-100, produced by MH Equipamentos (MH Equipamentos: Guarulhos, Brazil), to achieve a uniform dispersion of the wCC flour and wNWF within the vPP polymer matrix. The homogenized material was then processed in a knife mill to reduce the particle size.

Figure 1 illustrates the flowchart detailing the preparation of raw materials and the production processes for the eWPC and hWPC, along with the control sample, vWPC (mainly composed of vPP and without wNWF). The testing samples of all composites, excluding the cWPC, were manufactured using the same molding process. The granular (extruded) and powdery (kinetically homogenized) materials were placed in a metallic dumbbell mold with the following dimensions: a narrow section length of 70.0 mm, a narrow section width of 13.0 mm, and a thickness of 3.2 mm. The filled mold was pressed between the plates of a hydraulic press, model SL11 (SOLAB: Piracicaba, Brazil), under a temperature of 180 °C and a load of 25 MPa for 5 min. After pressing, the testing samples were allowed to rest under the same load for 30 min before demolding.

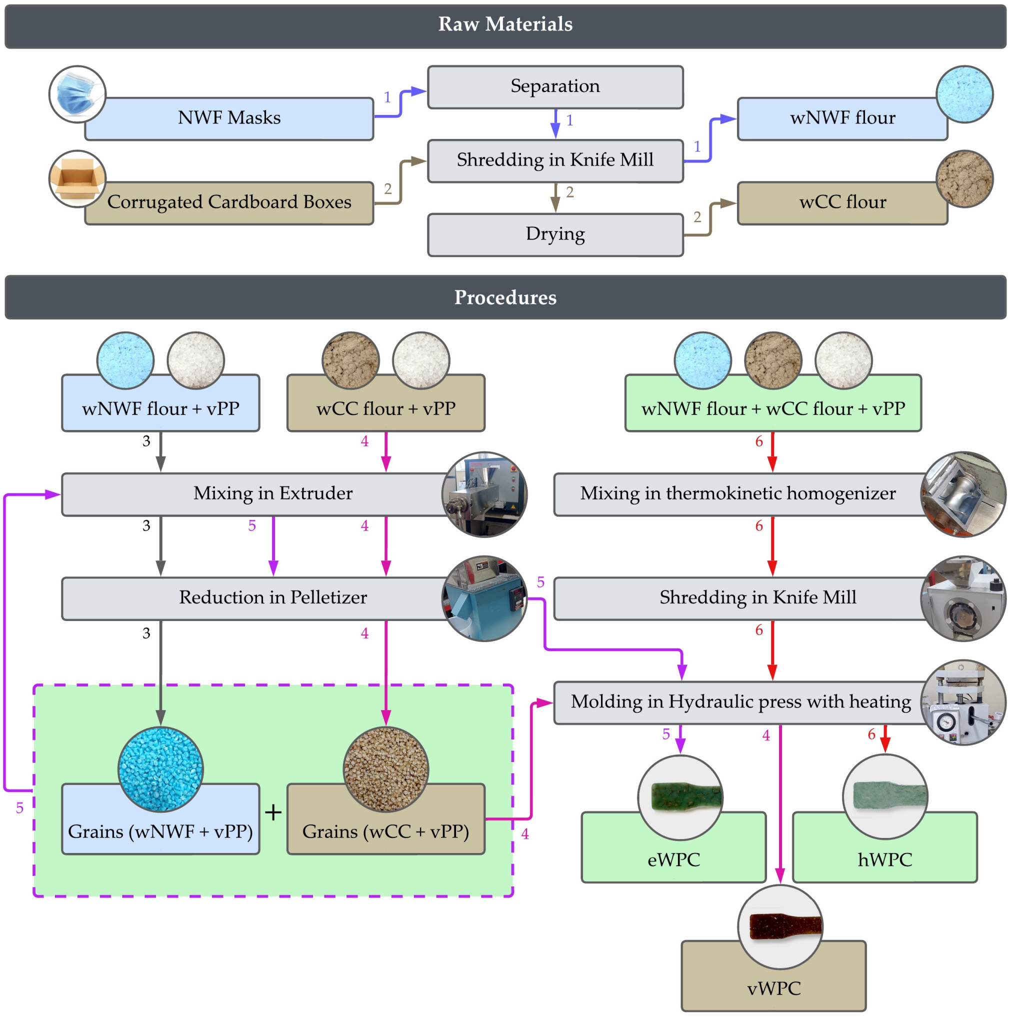

Figure 1. Flowchart of the production of wood–plastic composites (WPCs) with nonwoven fabric waste (wNWF), corrugated cardboard waste (wCC), and virgin polypropylene (vPP).

The utilization of WPC produced from wNWF and wCC presents several key advantages. This approach enhances sustainability by reducing waste and fostering a circular economy, as it recycles materials that would otherwise be disposed of in landfills. It also provides versatility, enabling adaptations for diverse applications across the construction, automotive, and consumer goods industries. Furthermore, it offers environmental benefits by lowering the demand for virgin resources and reducing the carbon footprint associated with composite production. These advantages underscore the relevance and potential impact of our research in advancing sustainable material practices.

2.3. Characterization Methods

Six testing samples from each composite produced were used to determine the tensile and flexural properties and for the comparison of the samples. The tests were performed using an Instron EMIC 23-20 universal testing machine (Instron: São José dos Pinhais, Brazil), following the D638 D790 standards [26,27]. The loading rate was set at 50 and 30 mm/min for the tensile flexural tests conducted at room temperature (≈23 °C). The results were the arithmetic mean of the six samples, with a precision of 0.1%.

The composite behaviors in the presence of water were analyzed through water absorption and swelling tests conducted according to the ASTM D570 standard [28]. Four testing samples were used for each material, including the comparison composites. They were weighed, and their thickness was measured before and after submersion in distilled water at 24 °C for 24 h, enabling a precise comparison of weight and dimensional changes.

A Thermogravimetric Analysis (TGA) was performed using Shimadzu DTG-60H equipment (Shimadzu: Rio de Janeiro, Brazil) with a heating rate of 10 °C/min in an air atmosphere. The temperature ranged from room to 600 °C, and the TA-60WS® software (Shimadzu: Barueri, Brazil, v. 2.01) was employed to obtain the curve parameters.

Fracture surface analysis, specifically of the cross-sectional area after the tensile test, was carried out through Scanning Electron Microscopy (SEM) images using a TESCAN VEGA 3 microscope (Tescan: São Bernardo do Campo, Brazil) equipped with a tungsten filament electron source. The samples were coated in gold powder using a QUORUM Q150R ES device (Quorum: East Sussex, UK).

3. Results

Figure 2 presents the mean values for the maximum stress and elongation at break during the tensile and flexural strength tests. The composites eWPC, vWPC, and cWPC demonstrated similar elongation at break under tensile stress, approximately 3%, whereas the hWPC showed the lowest elongation, around 1%. Similarly, on the flexural strength test, the eWPC, vWPC, and cWPC exhibited similar elongation values of approximately 4–5%, while hWPC once again displayed the lowest elongation, about 1.5%.

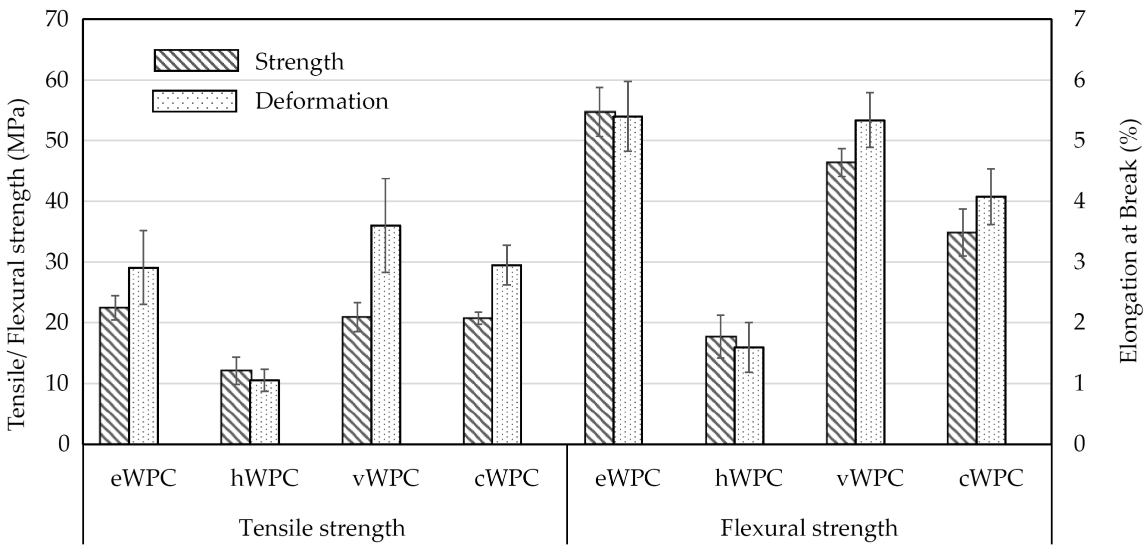

Figure 2. Tensile and flexural strength of the produced WPC of the control samples.

Regarding tensile strength, the eWPC and vWPC achieved the highest values, approximately 22 MPa, followed by the cWPC at around 21 MPa, with the hWPC registering the lowest tensile strength, close to 12 MPa. Similarly, in the flexural strength test, the eWPC and vWPC showed the highest results, approximately 55 and 46 MPa, respectively, followed by cWPC at about 35 MPa, with the hWPC again exhibiting the lowest flexural strength, around 18 MPa.

Figure 3 illustrates the Young's Modulus (modulus of elasticity) of the various WPC samples, including the blend and commercial composite. eWPC and hWPC displayed the highest Young's Modulus, with values approaching 1600 MPa. In contrast, the vWPC exhibited an intermediate Young's Modulus, around 1300 MPa, suggesting lower stiffness than the other WPC types.

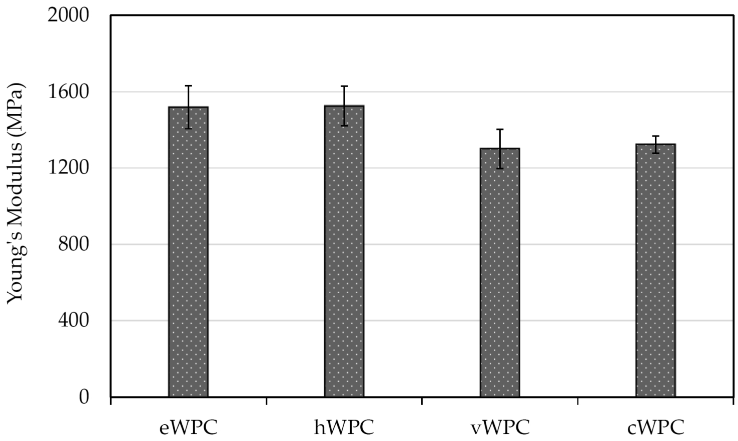

Figure 3. Young's Modulus of WPC and control samples.

The results of the mechanical tests indicate that the eWPC and the vWPC demonstrated superior performance in both tensile and flexural strength. The cWPC showed intermediate performance, while the hWPC exhibited the lowest strength and deformation values. These findings suggest that the production method and composite formulation significantly impacted the mechanical properties. Incorporating wNWF as part of the polymer matrix in the WPC reduced its deformation capacity compared to the virgin matrix WPC, likely due to the recycling process of PP, which tends to make it stiffer and more brittle, thereby decreasing the elongation at break. Conversely, there was a noticeable increase in the modulus of elasticity [29], as shown in Figure 3. Despite achieving similar stiffness, the eWPC exhibited higher deformation than the hWPC, suggesting that the thermokinetic homogenization process may result in more significant alterations in the composite ductility than extrusion.

Regarding tensile and flexural strength, an improvement was observed in the eWPC compared to the control sample vWPC. Both showed the highest tensile strength (around 35 MPa), followed by the cWPC (approximately 30 MPa) and, lastly, the hWPC (around 20 MPa). This enhanced performance in the eWPC can be attributed to the two extrusion cycles used in its production, whereas the vWPC underwent only one extrusion cycle. The additional extrusion cycle in the eWPC led to better distribution and encapsulation of the cardboard filler and the vPP-wNWF mixture. Studies indicate that repeated extrusion cycles can enhance the mechanical properties of composites, with an optimal performance observed around the third cycle. However, beyond this point, the strength tends to decrease due to thermal and mechanical degradation of the polymer matrix chains [30,31].

The hWPC, in turn, exhibited inferior mechanical performance compared to all the other samples. Although it initially achieved greater homogeneity due to using a thermokinetic mixer, this property was likely compromised during further processing in a knife mill, which led to the formation of lumps, as evidenced by the SEM images (Figure 4). Comparative studies suggest that extrusion tends to be less degrading for composites than internal mixers, allowing for more reprocessing cycles without significant loss of mechanical properties [31]. Indeed, only the eWPC sample outperformed the cWPC sample, a commercially available composite, showing an 8.2% increase in tensile strength and a 56.7% increase in flexural strength. Furthermore, the eWPC demonstrated greater stiffness, with a 14.9% improvement over the cWPC. In contrast, the hWPC sample only surpassed the cWPC in Young's Modulus, with a 15.3% increase, while underperforming in the other properties.

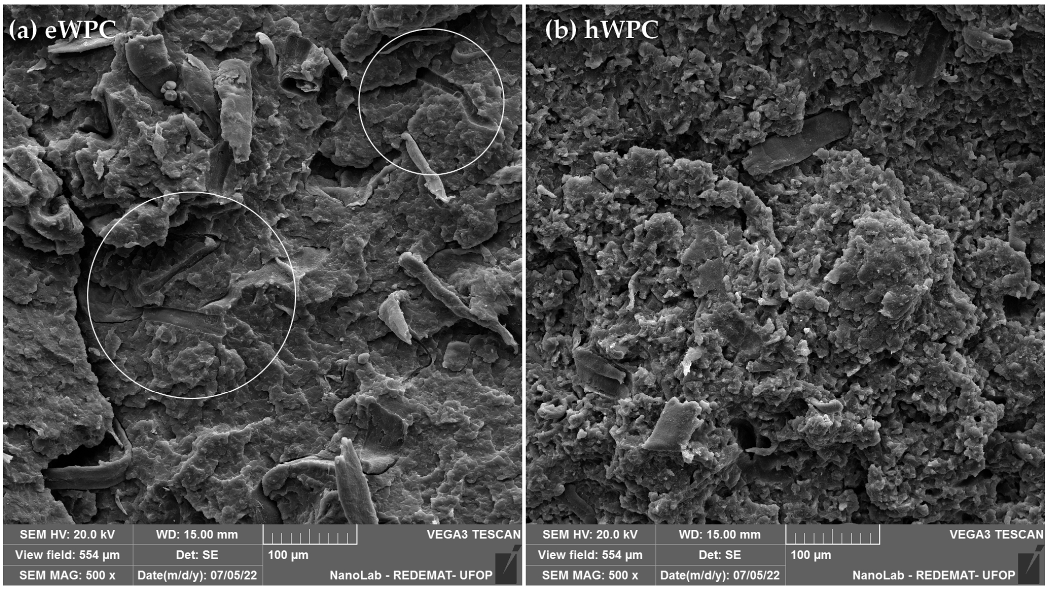

Figure 4. SEM images of the fracture surface after the tensile test of the (**a**) eWPC and (**b**) hWPC samples.

The higher values of stiffness and flexural strength achieved by the eWPC reinforce its applicability in construction segments, such as the production of decks. Traditionally, these linear wooden elements are widely used in outdoor environments and are constructed with noble woods, such as Ipê (*Tabebuia*) and Itaúba (*Mezilaurus itauba*), which require specific treatments to resist moisture, termite attacks, and decay [32]. However, other species, such as Eucalyptus (*Eucalyptus*), Pine (*Pinus*), and Teak (*Tectona grandis*), are also commonly used [33,34]. The Technological Research Institute (IPT, Instituto de Pesquisas Tecnológicas) in São Paulo provides comparative data on the properties of these natural woods, frequently employed in deck construction.

When comparing the results obtained with the mechanical properties of natural wood, it is observed that the eWPC sample, with a flexural strength of 54.7 MPa, not only surpassed the cWPC sample but also outperformed Green Pine (*Pinus*, 48.0 MPa) [35]. The produced WPC can directly compete with woods recognized for their flexural strength, making it a viable alternative for structural applications. In terms of tensile strength, all the produced samples significantly exceeded the value presented by Ipê (*Tabebuia*, 11.1 MPa), the most resistant wood in this regard among those mentioned. Even the sample with the lowest performance, the hWPC, achieved superior results, highlighting the mechanical advantage of the WPCs.

Although some WPC samples exhibit lower flexural strength than certain natural species, such as those from the IPT, the composites maintain a prominent position due to their versatility, durability, and environmental benefits. Additionally, a WPC offers a more sustainable solution than natural options.

When comparing the data with the results of Stark [36], who evaluated the properties of PP composites with a 20% wood flour load, it is observed that the tensile strength of the samples, especially the eWPC (22.4 MPa), was slightly below the 25.8 MPa obtained by the author. However, all samples exceeded expectations for flexural strength except for the hWPC, suggesting that the composites performed exceptionally well even with a different source load and content. This indicates that the developed formulation offers a remarkable balance between mechanical strength and sustainability, positioning the composite as a promising alternative in the construction materials market.

Figure 4 presents the SEM images of the fracture surface following tensile tests of the eWPC (a) and hWPC (b) samples.

In Figure 4a, several exposed wCC particles can be observed, with some embedded in the matrix and others forming cavities and voids on the fracture surface, matching the shape of the particles (circled areas). These regions suggest that some wCC particles were torn during rupture, indicating a moderate interfacial bonding between the filler and matrix. However, specific failure modes, such as fiber rupture and detachment from the interface, that are typically seen in other studies [37,38] were not identified.

In contrast, the fracture surface of the hWPC (Figure 4b) reveals that the wCC particles appear disconnected and less integrated into the polymer matrix than the eWPC. This observation suggests ineffective interfacial bonding, which explains the inferior mechanical performance observed in the tensile and flexural tests. Additionally, the higher void content in the hWPC can account for its increased water absorption and highlights the presence of a microfracture network within the composite, further affecting its mechanical properties.

Lumps in the poorly homogenized matrix of the hWPC could be attributed to the powdery nature of the mixture before compression molding, resulting from the knife mill processing. This process likely weakens the bonding between particles. Fine particles disperse more quickly, filling the outer regions of the mold while leaving voids in the interior, disrupting the even distribution of the applied load. Conversely, larger grains, such as the pelletized ones in the eWPC, accommodate more uniformly and effectively, better filling the mold's space. This results in a more uniformly distributed load across the press plates, leading to better bonding between the particles and a higher-quality final material.

The results of the water absorption and swelling tests are presented in Table 2. As observed, the WPC containing wCC and wNWF showed no swelling and exhibited low water absorption compared to natural wood. However, the hWPC demonstrated the poorest performance, with 1.67% water absorption. This highlights one of the main advantages of WPCs: their hydrophobic nature compared to the highly hydrophilic properties of natural wood.

Table 2. Mean values of water absorption and swelling of the WPC.

Composite	Water Absorption (%)	Swelling (%)
eWPC	0.230 (0.110) *	0.000 (0.000) *
hWPC	1.668 (0.285) *	0.000 (0.000) *
vWPC	0.207 (0.095) *	2.062 (2.406) *
cWPC	0.292 (0.135) *	0.357 (0.714) *

* Standard deviation.

Natural wood is porous and hygroscopic, capable of absorbing water in both its liquid and gas forms, and is prone to fungal decomposition due to its moisture content [39]. In some wood species, water absorption after 24 h can exceed 80%, leading to significant weight gain and swelling [40]. This weight increase can escalate transportation costs and complicate loading and unloading operations, underscoring another advantage of WPCs over natural wood [41].

The reference samples exhibited dimensional instability, with the vWPC and cWPC showing swelling of 2.06% and 0.36% in thickness, respectively. The eWPC performed best, surpassing all other samples. The two-cycle extrusion may have facilitated better coverage and encapsulation of the filler, which significantly enhances water resistance [42], thereby contributing to the eWPC's lower hydrophilicity compared to the vWPC. Lopez et al. [43] have similarly linked low water absorption in WPCs to the chosen extrusion and processing method, which ensures satisfactory filler encapsulation.

Figure 5 presents the thermogravimetric curves (TG) and their derivatives (DTG) for the raw materials (a) and the produced WPCs (b). The respective temperature and weight loss data are detailed in Table 3.

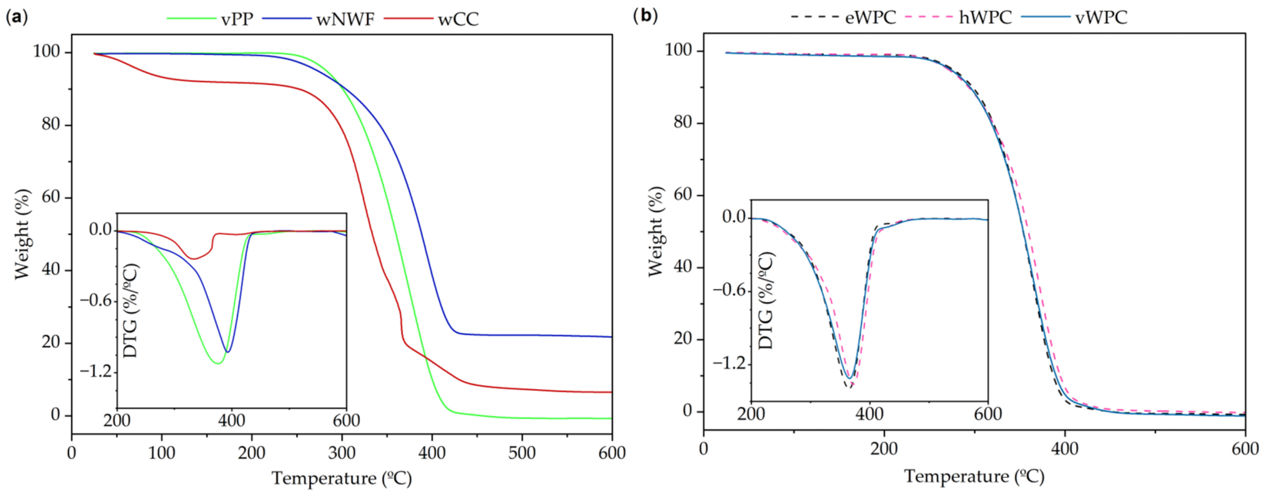

Figure 5. TG and DTG curves of the produced eWPC and hWPC compared to the raw materials (**a**) and control samples (**b**).

Table 3. Thermal degradation and weight loss temperatures of raw materials, WPCs, and control samples.

Sample	T_{Start} (°C)	T_{End} (°C)
vPP	233	376
wCC	217	334
wNWF	224	392
eWPC	227	365
hWPC	220	371
vWPC	232	366
cWPC	203	442

The thermal degradation test results shown in Figure 5a indicate that the thermal behavior of the produced composites closely resembles that of vPP, which constitutes 45 wt % of the composites' total weight. The initial degradation temperatures of the residual raw materials, wNWF and wCC, were 224 °C and 217 °C, respectively. This suggests that both materials are safe for WPCs, provided all processes remain below these temperatures, as in the proposed methodology. The wCC exhibited a slight weight loss between 25 °C and 130 °C early in the test, likely due to moisture loss or the release of other low-molar-mass components [44]. Although the thermal stability of materials in industrial applications depends on operational temperatures and exposure time, the high degradation onset temperature indicates that these materials have sufficient thermal stability to withstand a wide range of operational conditions [45].

In contrast to vPP, the post-consumption materials (wCC and wNWF) exhibited 7% and 22% residual weight percentages, respectively. The residual weight of wNWF is likely due to additives, minerals, or inorganic components that do not completely decompose under the TG conditions [46]. For wCC, the residual weight may be attributed to its wood-derived composition, which contains minerals and ash from incomplete combustion [47]. On the other hand, the interaction between the polymer matrix and the filler in the produced WPCs can lead to a more complete decomposition of the components, resulting in little to no residual weight. This enhanced decomposition is often linked to better dispersion of the filler within the polymer matrix and the possible synergy between components, which facilitates thermal degradation [48].

Figure 5b reveals that all composites, including the pure samples, underwent a single significant weight loss event. The produced WPCs and the control samples demonstrated similar thermal behavior. Despite undergoing two extrusion cycles, which can potentially harm the thermal degradation [49], the eWPC's incorporation of recycled PP may have enhanced the thermal stability of the mixture [50]. This stability allowed the eWPC to exhibit thermal behavior closer to that of the vWPC, which passed through only one extrusion cycle but used a vPP matrix. While the cWPC sample displayed inferior physical and mechanical performance compared to the eWPC, it had the highest thermal stability, with a maximum degradation temperature that was 21% higher than the eWPC's. However, the raw materials used in the production of the cWPC remain unknown, which may have influenced this difference in performance.

The produced WPC possesses properties that make it highly suitable for construction materials, particularly in applications like residential decking, outdoor furniture, and architectural elements. Its versatility in esthetics and functionality provides a sustainable solution for wCC and wNWF while reducing the need for natural resource extraction.

The WPC demonstrates excellent technical characteristics, including low water absorption and swelling, high flexural and tensile strengths, and favorable thermal performance. These attributes highlight its potential for a wide range of applications. Additionally, by using vPP, a colorless matrix, the resulting WPC closely replicates the appearance of natural wood (as shown in Figure 1), enhancing its appeal and facilitating its acceptance as a viable substitute for traditional wood. This natural wood-like esthetic is especially beneficial for applications where a conventional, organic look is preferred.

When recycled polypropylene is used in the matrix, the residual pigmentation from the recycled material influences the final composite color. The greenish hue of the hWPC results from the combination of blue pigment from wNWF masks and the yellowish tone of wCC, for example. If recycled materials are sorted by color, it becomes possible to produce color-controlled composites solely from the inherent pigments of the recycled raw materials, eliminating the need for additional pigmentation.

The versatility of the WPC extends to opportunities where color is essential or desirable. For example, a colorful WPC could be ideal for playground equipment, park benches, or urban furniture—applications where vibrant, durable materials are in demand. The ability to manufacture these composites without artificial pigments simplifies production, reduces costs, and lowers the environmental impact.

4. Conclusions

This paper investigated the mechanical, physical, thermal, and microstructural properties of wood–plastic composites (WPCs) produced using waste materials generated extensively during the COVID-19 pandemic, specifically corrugated cardboard waste (wCC) and nonwoven fabric waste (wNWF) from face masks, incorporated into a virgin polypropylene (vPP) matrix. Both wCC and wNWF were suitable for application as reinforcement filler and matrix components, respectively, provided they are processed at temperatures below 217 °C, where cardboard degradation occurs. Overall, the produced composites exhibited better thermal stability and physical properties than the control samples. The extruded WPC (eWPC) surpassed a commercially available WPC (cWPC) in terms of tensile and flexural properties, water absorption, and swelling, highlighting its potential as a sustainable alternative. The SEM analysis of the eWPC suggests that the interfacial bonding between the filler and matrix could be further enhanced by incorporating coupling agents.

Although this study focused on pandemic-related waste, it is essential to note that residual materials such as NWF face masks and cardboard continue to be generated, maintaining the relevance of this work and its potential impact on the three pillars of sustainability. From an environmental perspective, incorporating these waste materials as raw components for composite production reduces the demand for natural resources, promotes a circular economy, and reduces improper disposal. Socially, the paper raises awareness about the importance of waste management and presents opportunities for developing new production chains and generating employment in the recycling industry and composite manufacturing. Economically, using residual materials can lower production costs and open new markets for sustainable and innovative products.

The hWPC exhibited inferior results in the mechanical and physical tests, and the SEM analysis revealed weak interfacial bonding between the raw materials. Using the knife mill after the thermokinetic homogenization process may have compromised the homogenizing properties of the paste formed in the homogenizer. However, the homogenized material displayed a more uniform color than the eWPC, in which wCC particles were visible within the vPP and wNWF matrix.

Future research should explore combining both processes, starting with thermokinetic homogenization, followed by extrusion after the homogenized paste has passed through the knife mill. The final material should be pelletized and hot-pressed. Additional recommendations include evaluating the effects of coupling agents on a WPC's properties, chemically characterizing the wNWF and wCC waste materials, incorporating other types of Individual Protective Equipment (IPE) made from NWF as a source of recycled PP, and adding pigments to improve market acceptance by enhancing the visual appeal and emotional connection to natural products.

In conclusion, this research advances the science and technology of composite materials while offering an innovative solution to address the waste generated mainly during the pandemic. By transforming discarded materials into valuable resources, it points to a more sustainable and resilient future where innovation and environmental responsibility are closely intertwined.

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