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Chapter

Processing and Properties of Plastic Lumber

Fernanda A. dos Santos, Leonardo B. Canto, Ana Lúcia N. da Silva, Leila Lea Yuan Visconte and Elen B. A. Vasques Pacheco

Abstract

Plastic residue can be processed into composites using wood flour, mineral fillers, plant or synthetic fibers to obtain plastic lumber, a substitute material for natural wood. The composition and processing conditions are largely responsible for the final characteristics of the plastic lumber. Factors such as density, particle size and moisture content in the material to be processed require extruders with specific technical characteristics, in order to reduce the residence time of the plastic inside the equipment, maintain a constant feed rate and ensure good degassing and homogenization of the components. The composites can be manufactured using single-screw, co- or counter-rotating conical or parallel twin-screw extruders. Plastic lumber exhibits different physical and mechanical properties from natural wood, including lower stiffness (elastic modulus) and superior weathering resistance.

Keywords: recycling, plastic lumber, plastic, reprocessing, property

1. Introduction

The increasing generation of plastic waste by industry and in urban areas in recent years has prompted concern in society and efforts to recycle discarded and unused plastic materials [1–3]. Among the alternatives to minimize plastic waste accumulation is using postconsumer plastics to produce plastic lumber as a substitute for natural wood [4, 5].

According to the American Society for Testing and Materials (ASTM) [4, 5], the term plastic lumber applies to products made primarily from plastic (with or without additives), with a rectangular cross-section and size typical of wood products used for building. However, plastic lumber products can also exhibit a circular cross-section, as well as other shapes, with applications such as furniture and farming, among others.

Most plastic lumber products on the market are made from polyethylene, particularly high-density polyethylene (HDPE), but can be obtained using polymers, such as polypropylene (PP), polystyrene (PS) and polyvinyl chloride (PVC), or mixtures of different plastic wastes [6]. Additionally, fillers and additives, such as natural fibers, sawdust [7–9], mineral fillers and glass fiber, can be added to plastic lumber formulations [10, 11].

Both composition and processing conditions are largely responsible for the final characteristics of plastic lumber products. Research and patents demonstrate that

Figure 1.
Examples of different plastic lumber profiles.

different processes and recycling equipment are used to produce plastic lumber [12–15]. Factors such as the properties of the material to be processed, how plastic waste reaches the processing stage, the presence of additives and the moisture content of the material require extruders with specific technical characteristics when compared to processing virgin plastic [12]. These characteristics include shortening the residence time of the plastic inside the equipment, maintaining a constant feed rate inside the extruder and good degassing and homogenization of the material.

Due to their natural origin, wood-based products may exhibit a series of structural defects, such as knots, cracks, warping, wormholes and fungal damage, as well as low-dimensional stability and other imperfections resulting from varying moisture content and drying, which significantly influence the final strength of products and are difficult to control [16].

Plastic lumber has several advantages over natural wood in a number of applications and can be made from used plastics such as bottles, cups, packing and other products with a short useful life, thereby minimizing the accumulation of plastic material in the environment. It can be worked using conventional carpentry tools and planed, sawn, drilled and nailed in the same way as natural wood [6]. The advantages of plastic lumber over natural wood include being waterproof, resistant to weathering, mold and borers, and not requiring regular painting or maintenance, meaning it can be used in environments that natural wood would be unable to withstand for long periods. These include wet or underwater structures such as sea dikes in coastal areas [17, 18]. Plastic lumber can also be used to protect forests by preventing new trees from being felled to make furniture, decking, fencing and piers [6]. Different plastic lumber profiles are shown in **Figure 1**.

2. Background

The oldest records of plastic lumber date back to the early 1970s, when processing techniques for the material were developed in Europe and Japan. The resulting plastic lumber consisted primarily of post-industrial plastic scrap, which was the only source of low-cost plastic available at the time. Nevertheless, the plastic lumber industry did not initially experience significant growth [17].

The Klobbie intrusion system was developed in the 1970s and is based on a combination of conventional extrusion and injection processes. It consists of an extruder coupled to several rotating molds and a tank of cooling water. The plastic material is mixed and melted in the extruder and then forced into one of the molds. Once the

mold is filled, the carousel rotates to allow another mold to be filled. The filled mold is then cooled by passing it through the tank of chilled water before ejecting it. The process is capable of producing thick wall moldings and linear profiles [13, 17, 19].

Technologies developed from the 1980s onwards include Advanced Recycling Technology (Belgium), Hammer's Plastic Recycling (United States) and Superwood (Ireland). The equipment developed by Advanced Recycling Technology, denominated ET/1 *(*Extruder Technology 1), is an adiabatic extruder capable of processing mixed waste plastics with different densities to produce posts, rods, stakes, boards, etc. The process used by Hammer's Plastic Recycling differs somewhat from the Klobbie system and generates thick wall parts such as pallets, animal feeders and bench brackets, as well as linear profiles such as planks [19].

Other processes have been developed for the continuous extrusion of profiles under cooling, such as Mitsubishi Petrochemical's Reverzer process to manufacture large cross-section products. There have also been historical experiments with compression molding, such as the Recycloplast process developed in Germany [17, 19] to produce thick wall parts such as pallets, benches and grates.

Following the abovementioned efforts in equipment design, attention turned to the composition of plastic lumber, and wood-plastic composites (WPC) emerged in the 1990s to replace wood with recycled plastic lumber in decking and fencing [16, 18]. Also in the 1990s, pioneering studies on plastic recycling for the development of plastic lumber began at the Institute of Macromolecules of the Federal University of Rio de Janeiro, under the supervision of Professor Eloisa Biasotto Mano, the first line of research in the area at university level. In 2009, at the same institute, a laboratory scale plastic recycling machine and pilot scale equipment were developed at the Center of Excellence in Recycling and Sustainable Development (NERDES).

Despite the development of technology to obtain recycled PL, lack of standardization prevented its use by the construction industry in the early 1990s, particularly in structural applications. The Plastic Lumber Trade Association worked to establish a set of ASTM standards initially applicable to plastic lumber made from high-density polyethylene (HDPE) [16, 20].

Wood-plastic composites (WPC) are an important segment of the plastic lumber market [16, 21].

In addition to their application in decking, American manufacturers use WPC to replace plywood in fencing, windows and panels [22], and the composites are also being considered in the production of roofing and cladding [6, 23, 24].

Plastic lumber has been used in marine environments as a replacement for natural wood treated with chromated copper arsenate (CCA) due to its rot resistance and high durability, as well as the environmental preservation it provides because no harmful chemicals are used in its manufacture [25, 26]. Recent studies have shown that copper, chromium and arsenic are continuously released by CCA-treated wood in marine environments [18, 27–29]. By contrast, the disposal of metal and organic contaminants from plastic lumber in river or seawater is low and no highly toxic compounds have been identified [30].

The timber market and industry are searching for more sustainable products, and plastic lumber is a viable alternative in railway tie manufacturing, for example [31].

3. Processing

Although the composition of plastic lumber varies, the market consists primarily of companies that manufacture HDPE-based plastic lumber and those that use plastic composites and wood waste [16]. This has contributed to greater interest in the search for wood-plastic composite (WPC) processing technologies.

Composite	Type of screw extrusion	Tensile strength (MPa)	Izod impact strength (kJ/m^2)—unnotched
PP/wood flour: 70/30 wt%	Single-screw	25	7
	Twin-screw	28	10

Table 1.
Mechanical properties of polypropylene (PP) composites filled with wood flour made using different manufacturing processes [33].

In general, WPC are manufactured by extrusion, whereby the molten material is forced through a matrix and formed into a continuous profile in the desired shape. Extrusion is a process whereby plastic and other additives are melted, mixed, homogenized and formed into long continuous profiles typical of construction materials [21], in either simple solid shapes or complex hollow structures [6, 22, 32].

Wood-plastic composites can be produced in single-screw, co- or counter-rotating conical or parallel twin-screw extruders or piggyback extruders [21, 32]. Manufacturing companies use different types of extruders and processing strategies [21], with some employing a single-screw extruder for the final shaping process [21], or use a twin-screw extruder for mixing and mold the final artifact in another extruder. Other manufacturing companies use a range of piggyback extruders, one to homogenize the mixture and others for shaping [21]. The screws are specifically designed to bind the wood residue to the polymer matrix in order to evenly disperse it in the polymer [24].

Various types of extruders used lead to significant differences in the properties of plastic lumber. Yang et al. [33] studied the properties of WPC and polypropylene (PP) composites filled with rice husk flour (RHF) made using different manufacturing processes. The authors used single- and twin-screw extrusion systems and found that WPC processed in a twin-screw extruder exhibited better mechanical properties when compared to the composite obtained by single-screw extrusion, attributing these results to better wood dispersion in the former process (**Table 1**). They also observed that the presence of a maleic anhydride-grafted polypropylene (MAPP) compatibilizer [34, 35] improved the mechanical properties of the RHF-filled PP composite when compared to the composite without the compatibilizing agent [33].

In addition to extrusion, processing technologies such as injection and compression molding can also be used to produce WPC [36], with the composite formulation adjusted according to processing requirements. For example, the low viscosity needed for injection molding may limit the wood residue content in the formulation [21]. Experts from the WPC industry claim that injection molding has significant potential, with the ability to produce complex shapes, whose growing number of applications includes products such as tiles and cladding [9, 37].

A number of aspects should be considered when processing WPC. Moisture content and particle size should be tightly controlled to prevent discontinuities and parts with defects due to the presence of bubbles or stains caused by thermo-oxidative processes [34, 38]. Thus, as a primary requirement, wood waste must be pre-dried, and degassing zones must be used to remove residual moisture during processing. One of the factors directly affected by the moisture content of the lignocellulosic reinforcement is the output of the extrusion line: the higher the moisture content of the particles, the lower the throughput due to the longer residence time needed to devolatilize the composite [39, 40]. As such, the longer the material remains inside the extruder, the more susceptible it is to thermomechanical degradation.

Additionally, the low thermal stability of cellulose (200–220°C) is a limiting factor in the process, except when residence times are minimal. Exposing wood waste

to temperatures above this range releases volatile compounds, causing discoloration and odor and making the composite brittle [36]. This has restricted the use of thermoplastics in WPCs to major commercial resins such as polyolefins (PE and PP), styrenics (PS, HIPS and ABS) and polyvinyl chloride (PVC), which can be processed at temperatures below cellulose degradation [9, 21].

Another factor that hampers WPC processing is the low density of wood waste, which makes it difficult for the residue to pass through the small openings typical of plastic processing equipment, leading to a decline in throughput [41].

Processing WPC can be classified into four distinct categories. In pre-drying and premixing, wood waste is pre-dried at moisture levels below 1% and the material is fed into a counter-rotating twin-screw extruder along with the polymer, usually in the form of a powder. The dry blend of polymer, wood and additives is prepared in high-intensity Henschel mixers before being fed into the extruder [42]. The dry blend is then fed into the extruder using a Crammer feeder. Given the narrow residence time distribution of the material in the system and limited thermal energy generation, counter-rotating twin-screw extruders are used primarily for PVC conversion due to its thermal instability [12, 40].

Pre-drying wood and feeding the polymer and wood residue into the extruder separately (pre-dry; split feed) allow better control of the residence time of the wood filler during processing [42]. High capacity twin-screw extruders with side feeders are generally used in this type of process, where the residue is mixed with the molten polymer, passing through distributive mixing and degassing zones.

A third process involves feeding wet wood residue into the extruder first, followed by the molten polymer (wood first; melt feed). Two simultaneously operating extruders are needed, the first to dry the wood and a second smaller extruder to plasticize the polymer and additives [42]. An example of this type of system is the Woodtruder®, equipped with a counter-rotating twin-screw extruder designed to remove moisture from wood fiber even at high levels (1–8% moisture content). The process includes a primary counter-rotating parallel twin-screw extruder (L/D 28:1) and a satellite extruder with either one or two screws depending on the polymer used. The primary extruder dries the wood fiber and then mixes it with the polymer, while the satellite extruder melts the polymer and returns it to the primary extruder [32].

In many ways, processing wood waste in parallel twin-screw extruders is similar to processing neat polymers [32]. Although standard feeders are generally used for polymers, gravimetric ones are needed to feed the wood waste into the twin-screw extruder. The feed rate is automatically adjusted by the controller to increase feeding efficiency, circumventing the problems caused by wood fiber bulk density fluctuation. The screws drive the residue forward as the heat from the barrel and screws is transferred to the material, heating both the wood and the water in the wood fibers and releasing moisture.

The WoodTruder system uses a set of two extruders. The wood fibers enter the feeding zone of a counter-rotating parallel twin-screw extruder with a special venting section to draw moisture, while the molten polymer is added in sequence via a side mounted, single-screw extruder. The mixture then enters the compression section of the primary extruder to more easily blend the two components [32, 42]. Degassing occurs after compression in order to remove volatile components from the polymer or residual moisture from the wood fiber. The completely dried homogenized mixture then moves into a different zone to increase the pressure flow through the head. Melting temperatures are typically between 170 and 185°C. Temperatures above 200°C should be avoided in order to reduce wood degradation. In addition to wood fibers, the WoodTruder system can also process rice hulls, sisal, peanut shells and a range of other materials [32].

The fourth WPC production process uses wet wood and separate feeding of the polymers and additives (wood first, split feed), whereby the wet wood residue is fed into the extruder first and the polymer and additive are subsequently introduced into the barrel via a side feeder. However, this process typically requires longer extruders (L/D 44 or 48:1) with degassing zones located close to the feeding zone to remove moisture from the wood, which is not always possible [42].

Changes in moisture can lead to melt consistency problems in processes where an extruder is used to dry the wood fiber, making pre-dried wood a safer alternative.

4. Properties

The physical and mechanical properties of plastic lumber differ from natural wood parts with the same dimensions [6, 16, 17]. One of the most significant differences is the lower stiffness (modulus of elasticity) of plastic lumber. Pine and oak typically have a modulus of at least 6.9 GPa, which is higher than that of plastic lumber without a filler.

Mechanical properties of polymers depend on the time and temperature at which stress is applied. Plastic lumber is subject to permanent deformation (creep) under long-term loads [17, 18]. The strain rate depends on the amount and duration of the stress applied, as well as temperature. Moreover, changes in size as a result of temperature are more marked in plastic lumber than natural wood [8].

Drawbacks of plastic lumber include its low resistance to heat and flame in relation to the slow burn of natural wood, intense heating when exposed to direct sunlight and slow cooling. These problems can be mitigated by placing a small opening between adjacent planks, allowing air to flow around them and generating a cooling effect [17] or by producing hollow or foamed profiles.

These differences mean plastic lumber is generally unsuitable as a direct replacement for natural wood of a similar shape and size, since the resulting structures may exhibit unacceptable deformation under load or buckle over time due to their own weight [17, 43].

The abovementioned features limit the use of plastic lumber in structural applications such as support posts for decks. Most plastic lumber in decks is used as flooring, where the flexural modulus is less critical. The properties of this synthetic material change with the addition of fillers or compatibilizers or by promoting crosslinking of the base polymer [32].

Different compositions have been used to modify the physical and mechanical properties of plastic lumber and thereby ensure a larger number of applications with better results, the most noteworthy being those containing wood waste. One of the benefits of wood-plastic composites (WPC) is that they provide an alternative for waste from the lumber industry, which requires special attention as a low density material that needs a significant amount of storage space. Furthermore, using plant fibers in polymer composites improves the mechanical performance of conventional plastics, reduces environmental impacts, ensures recyclability and lowers costs [9, 44].

Wood fillers also increase the stiffness of composites, improve their machinability and are less expensive than polymer resin. Given the increasing use and importance of WPC, different authors have studied the effects of adding wood fiber on the mechanical properties of plastic lumber [7, 9, 43, 45–47]. **Table 2** shows flexural modulus results of three composites made with the same filler, however in three different polymer matrices.

Research by Solís and Lisperguer [48] indicates that adding wood waste reduced the impact strength of WPC (**Table 3**).

Type of polymeric matrix in composite	Flexural modulus (GPa)
Polyethylene	1.7
Polypropylene	2.1
Polystyrene	4.9

Table 2.
Flexural modulus values as a function of plastic matrix in lumber samples with 25 wt% of wood flour [27].

Amount of wood flour (wt%)	Impact strength (kJ/m^2)
0	10.0
20	2.3
10	1.9

Table 3.
Impact strength of HDPE and wood flour composite [48].

Carroll et al. [43] evaluated the shear strength of Duraboard® plastic lumber planks made from a compound of recycled plastic and sawdust under load and high temperatures. Mechanical tests were also conducted simulating winter (−23.3°C) and summer conditions (40.6°C). The results under winter temperatures showed that plastic lumber exhibits tension, compression and flexure properties comparable to those of natural wood, but lower strength under simulated summer conditions, albeit with acceptable values. The findings demonstrate that plastic lumber pieces should be larger than their natural wood counterparts to compensate for these differences. The high temperature modulus of the plastic lumber was lower than that of natural wood, which increases structural deformation when submitted to loading. This behavior is evident in a number of decking applications. The low stiffness of plastic lumber planks makes them prone to buckling under their own weight. In the case of long plastic lumber planks, the distance between the support posts should be smaller and/or thicker planks should be used when compared to natural wood decking [17, 18, 43].

Glass fiber has also been used as a filler to reinforce WPC, which can significantly increase the elastic modulus and stiffness of PL, albeit not to the extent of natural wood [10, 11].

Breslin et al. [27] studied long-term variations in the mechanical properties of recycled plastic lumber made from HDPE with 20% fiberglass used to build a pier. The results of dimensional stability assessment indicated no significant variation in sample dimensions. Additionally, hardness showed no significant change over time.

However, individual hardness measurements of the exposed cross-section varied considerably along the surface (22 ± 16–36 ± 9 units on the Shore D scale). The authors attributed this result to the porous internal structure of the plastic lumber, making it denser closer to the surface. As such, since the properties of the porous core differ from those at the outer surface, plastic lumber should always be tested at different internal and external points in order to obtain conclusive results [43]. There was no significant difference in compressive strength until the nineteenth month of exposure to extreme weather conditions. The flexural modulus showed a high degree of variation between duplicate samples of plastic lumber profiles. Although the flexural modulus measured in the cross-sectional direction did not vary significantly between the first and nineteenth month of exposure, a substantial variation was measured over time, with the greatest change recorded in the summer months. According to the authors [43], varying cross-sectional bending

Composition (wt%)		Tensile modulus (MPa)
Glass fiber	Wood fiber	
0	0	810
25	0	2310
0	8	980
25	8	2900

Table 4.
Plastic lumber tensile modulus of HDPE reinforced with glass fiber and/or wood fiber [10].

modulus values may be due to the heterogeneity of the material. Significant bending modulus variations should be taken into account when designing plastic lumber structures.

George and Dillman [10] analyzed glass fiber filler used to reinforce plastic lumber made from recycled HDPE. Additionally, the authors tested different formulations containing wood fiber and compared the effect of the content of each filler on the mechanical properties of the composites. The results showed that glass fiber significantly improved stiffness and promoted a greater increase in tensile and flexural moduli when compared to wood fiber (**Table 4**).

In some cases, adding glass fiber to plastic lumber for applications that come into contact with the skin, such as benches and handrails, can cause skin irritation. Glass fiber is also associated with a disease that affects the lungs in a manner similar to asbestos [41]. As such, these types of applications should be avoided.

Ledur et al. [49] developed a plastic lumber made from a mixture of polyethylene (PE) urban waste and ethylene-vinyl acetate (EVA) copolymer industrial waste filled with calcium carbonate. It was compounded in a Drais batch mixer and hot compression molded as rectangular-shaped sheets. An urban trash container prototype was prepared from the plastic sheets and a hundred trash containers passed a pilot test.

Other types of fillers have been studied for use in plastic composites, particularly natural components such as sisal, jute, hemp and coconut fiber [9, 11, 50, 51]. Wambua et al. [11] produced polypropylene composites reinforced with lignocellulosic fibers and found mechanical property values similar to those reported in the literature for glass fiber-reinforced PP composites.

Natural fibers offer a number of advantages over mineral or synthetic fillers as reinforcement in polymer composites, including less equipment abrasion, lower density of the final product, low cost and greater abundance.

One of the difficulties encountered in plastic lumber technology is the wide range of raw polymers, whose composition is beyond industrial control. This diversity results in polymer blends with coarse phase separated morphologies, which inevitably lead to incompatibility of properties. Possible solutions include adding a compatibilizer to the polymer blend or generating in situ molecular changes in the components through reactive extrusion to allow bonds to form between the polymer chains of the different phases [34].

Wood fiber/polyolefin composites widely used to obtain plastic lumber are incompatible because the thermoplastic material is nonpolar, while cellulose is polar, thereby requiring compatibilization using coupling or interfacial adhesion agents. Processing aspects, compatibilization and properties have been investigated by several authors [34, 42, 47].

Initially, the compatibilizer or coupling agent in contact with the filler surface should interact strongly with the fibers through strong covalent bonds, acid-base

interactions or hydrogen bonds. The compatibilizing agent should contain a sufficient number of functional groups to allow reaction with cellulose hydroxyl groups. Another aspect to consider is the length of compatibilizer chains, which should be long enough to allow molecular entanglement with the polymer matrix in the interphase through mechanical anchoring [42]. Some authors [34, 52] have reported surface treatment of the fiber as a means of optimizing the compatibilization process.

Studies demonstrate that the modulus values of WPC increase slightly in relation to neat polymers, but with no statistically significant differences. However, there is almost no variation in tensile strength between neat HDPE and maleinized-polypropylene (MAPP) composites, although the former exhibited lower impact strength in relation to the other samples. This result is attributed to better adhesion between the fiber and polymer matrix, allowing better stress transfer to the fiber [9, 34, 50–52].

In addition to compatibilizers, other additives are used to improve the properties and appearance of the final product, such as impact modifiers, colorants, flame retardants, antioxidants, UV stabilizers, lubricants, stabilizers and biocides.

One way of altering the properties of plastic lumber is by modifying the molecular structure of one or more component polymers through exposure to ionizing radiation. Irradiation has the advantage of being a clean, continuous easy-to-control process [53–56]. It promotes the formation of crosslinks parallel to chain scission as well as double bonds. Crosslinking causes an increase in molecular weight, which typically improves properties, whereas chain scission reduces molecular weight and decreases properties in general [54].

Martins et al. [54] assessed the effects of ionizing radiation on IMAWOOD® plastic lumber made from recycled polyethylene (around 75% low-density polyethylene—LDPE and 25% HDPE), using irradiation produced by industrial equipment with a ^{60}Co source. The specimens received total doses of 10, 500, 1000 and 2000 kGy. The authors concluded that irradiation in air increased the tensile strength of IMAWOOD®, although a decrease in elongation at break was observed with ductile-brittle transition. Additionally, from an engineering standpoint, IMAWOOD® offers the best conditions for certain applications after irradiation because it is less brittle.

One alternative to improve the mechanical properties of wood fiber-reinforced plastic lumber is through crosslinking using silane [57–60].

Studies have shown that crosslinked composites obtained by addition of silane display greater toughness, impact strength and interfacial adhesion than composites without silane [57, 58]. Additionally, the formation of crosslinks in the polymer matrix reduces buckling when the material is overloaded [57].

Bengtsson and Oksman [58] analyzed the effects of silane on the mechanical properties of wood-HDPE composites. The silane-grafted composites were stored at different moisture levels (in a sauna and temperature chamber) to determine how this parameter affects the degree of crosslinking in the composites. Experiments conducted with different amounts of vinyltrimethoxysilane in the presence of small amounts of peroxide indicated that the samples stored in the sauna showed the highest degree of crosslinking, which was calculated by measuring the gel content and swelling ratio. The results demonstrated that the samples exposed to the highest moisture level exhibited a higher degree of crosslinking. Water was responsible for the hydrolysis of methoxy groups to silanol, increasing the degree of crosslinking in the material stored in the sauna. The flexural modulus and flexural strength of neat HDPE were higher than those of the silane-grafted composites. In contrast to

neat plastics, the crosslinked composites showed better flexural strength than the material without silane.

The improved flexural strength is likely due to greater wood-polymer adhesion, enabling stress transfer from the polymer matrix to the wood fibers when the material is overloaded. The authors [58] attributed the superior adhesion to the covalent bond between wood and polyethylene to condensation or free-radical reactions. Furthermore, hydrogen bonding between the silanol groups grafted onto polyethylene and the hydroxyl groups of wood, as well as van de Waals forces between condensed silane in the wood and the polyethylene matrix, can improve adhesion between phases.

Lower creep was observed in the crosslinked composites when compared to those without crosslinking. This behavior may be related to the reduced viscous flow in the matrix due to crosslinking and better adhesion between the polymer matrix and wood flour [57–60].

Bengtsson et al. [57] evaluated mechanical property variations in WPC treated with silane containing different wood fiber concentrations. The stress-strain curves of the silane-treated composites indicated increased stiffness of the material with the addition of wood flour, in addition to a decline in ultimate strength. There was a significant increase in tensile strength with a rise in wood flour concentration, in contrast to the behavior reported by other authors [33, 61], whereby tensile strength declined with an increase in wood flour content. The authors attributed this behavior to greater interfacial adhesion between the wood and plastic promoted by silane addition.

5. Final remarks

In addition to adding value to postconsumer plastic packaging waste and preventing deforestation, plastic lumber offers other significant benefits, including resistance to fungi and insects and eliminating the need for painting and maintenance.

Its easy processing and the possibility of obtaining different compositions demonstrate the wide variety of properties and applications of plastic lumber. However, when replacing a traditional material with another, it is important to consider the required performance of the product, the application and the cost-effectiveness of the replacement in order to prevent any technical problems related to the characteristics of the two materials and ensure successful usage.

Thus, research is needed to develop new technologies aimed at obtaining recycled material with superior properties at lower economic, environmental and social costs, in order to increase the number of applications for plastic lumber as a replacement for natural wood and help reduce plastic waste accumulation.

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