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Application of wood plastic composite in the construction sector

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ABSTRACT: As with all products, minimizing the negative environmental impact of building materials is crucial. Wood-plastic composites (WPCs) are a promising alternative and sustainable material to conventional materials, contributing to ecological efficiency. This innovative composite, combining thermoplastics and natural fibers, benefits from the low density, cost-effectiveness, and workability of wood, while the thermoplastic component prevents moisture ingress and biological attacks. Recycled thermo-plastics are also used in the production of this composite, thus developing circular economy. Wood fibers or powder can be sourced from waste generated during the manufacturing processes of lumber and furniture manufacturers. In window applications, various polymers can be used in the composite mixture, with PVC being widely accepted. The most common manufacturing method is extrusion although injection and molding techniques are also utilized. WPCs may contain 30% to 60% wood particles, with a 50:50 wood-to-plastic ratio being most common. The increasing adoption of WPCs is expected to significantly reduce the use of petroleum-based polymers. As a result of this study, WPC, largely unknown and used minimally in Türkiye, will become widespread and accepted in the construction sector.

Keywords: Composite, Wood, Construction, Plastic, Waste

İnşaat sektöründe ahşap plastik kompozitin uygulanması

ÖZ: Her üründe olduğu gibi yapı malzemelerinde negatif çevresel etkinin minimize edilmesi önemlidir. Ahşap plastik kompozitler (APK), konvansiyonel malzemelere alternatif ve sürdürülebilir malzeme olarak, umut verici bir seçenektir; ekolojik verimliliğin artırılmasına katkı sunar. Termoplastikler ve doğal lifleri (odun vd.) bütünleştiren bu yeni kompozit, odunun düşük yoğunluğu, düşük maliyeti ve işlenebilirlik özelliklerinden faydalanırken; termoplastik bileşen, ürüne nemin girmesini ve biyolojik saldırıyı engeller. Geri dönüştürülmüş termoplastikler de bu kompozitin üretiminde kullanılır, böylece döngüsel ekonomi gelişir. Ahşap lifleri/tozu, kereste ve mobilya üreticilerinin gerçekleştirdiği imalat süresince ortaya çıkan atıklardan elde edilebilir. Pencere uygulamalarında, kompozit karışımda çeşitli polimerler tercih edilebilmekle birlikte PVC kabul görmüştür. Malzemenin en yaygın üretim yöntemi, istenen şekle ekstrüde etmektir, ancak enjeksiyon ve kalıplama da kullanılır. Ahşap-plastik kompozitler (APK), %30'dan %60'a kadar ahşap parçacıkları içerebilir, yaygın şekilde optimum oran olarak %50-%50 uygulanmıştır. Ahşap plastik kompozitler çevre dostu yapılar için giderek daha cazip bir seçenek haline gelmektedir. Bu malzeme kullanımının gelecekte daha da yaygınlaşmasıyla petrol bazlı polimerlerin kullanımının azalmasına büyük bir etki yapacağı muhakkaktır. Bu çalışma sonucunda, Türkiye'de çok sınırlı uygulamada kullanılmış, yeterince tanınmayan APK'nın yaygınlaşarak inşaat sektöründe kabul görmesi hedeflenmektedir.

Anahtar kelimeler: Kompozit, Ahşap, Yapı, Plastik, Atık

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1 Introduction

The use of natural resources and environmental impacts has become as important as traditional evaluation criteria such as quality and cost in decision-making processes with the increasing awareness of environmental problems. In this context, the concept of sustainable production has become increasingly important to ensure efficient and long-term use of natural resources (Hauschild et al., 2005). Minimizing negative environmental impact is very important as it should be in any product, especially for building materials which are the focus of this study. In recent years, the demand for sustainable and durable building materials in the construction sector has increased significantly. Wood-plastic composites have emerged as a promising alternative to traditional materials such as wood, metal and plastic.

Composite materials are materials formed by combining two or more identical or different types of materials to integrate their best properties into a new and unified material (Şahin, 2000; Clyne & Hull, 2019). A new class of composites has emerged that integrates thermoplastics with natural fibers (such as wood). This innovative composite takes advantage of the low density, low cost, UV resistance, and workability of wood, while the thermoplastic component facilitates flow during melting processes and acts as a barrier to prevent moisture intrusion and biological attacks (Harper & Wolcott, 2004). Wood-plastic composites (WPCs) are composite materials formed by combining wood fibers and/or wood dust with thermoplastics such as polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), polystyrene (PS), or polylactic acid (PLA) through chemical additives (Figure 1). Recycled thermoplastics can also be used in the production of wood-plastic composites (Bal, 2023; Stark, 2001; Ratanawilai & Srivabut, 2022; Leu et al., 2012; Ashori & Nourbakhsh, 2009; Avcı, 2012). The predominant thermoplastic material used in WPC production is polyethylene (Hamel et al., 2013). Wood particles provide structural reinforcement to the product (URL-1, 2024), thereby combining the advantages of wood and plastic materials. The use of wood dust in thermoplastic composite production is attractive due to its low cost, low density, minimal wear during production, abundance, and biodegradability (Mengeloğlu & Karakuş, 2008). WPC material finds application in various fields utilizing products from both the wood and plastic industries, with its usage areas expanding every day. Each application of wood-plastic composites in different fields is an effective way to enhance ecological efficiency. This material class, which has many subtypes, is commonly referred to as "WPC" derived from the initials of "Wood Plastic Composite."

Figure 1. Wood powder and polymeric raw materials in granular form (URL-2, 2024; URL-3, 2024).

In the 1980s, a company in the United States produced wood-plastic composites (WPC) by incorporating 50% wood powder into polyethylene (PE). This composite material was used to manufacture and sell industrial products such as garden furniture, tables, and decking/terrace materials. During the same period, WPC was produced by mixing polypropylene (PP) and wood powder in equal proportions, leveraging extrusion techniques for use in the interior cabin components of automotive sector products. The demand, need, and areas of application for WPC materials in Türkiye and many parts of the world have been increasing over time

(Şahin, 2023). In Asia, the primary WPC markets have been Japan, South Korea, and China since the 1990s (Gardner and Han, 2010). Activities carried out over recent decades have significantly developed the market.

In Figure 2, the trend of wood-plastic composite (WPC) material production volume in the American and European markets can be observed during the first quarter of the 21st century. Germany leads the way in Europe in this regard (Eder, 2010). Additionally, the figure provides insights into the sales performance of WPC in various markets and expectations for the coming years. The WPC market is expected to maintain its growth trajectory, reaching an estimated global value of approximately $12 billion by 2028 with a compound annual growth rate (CAGR) of around 10% (URL-4, 2024).

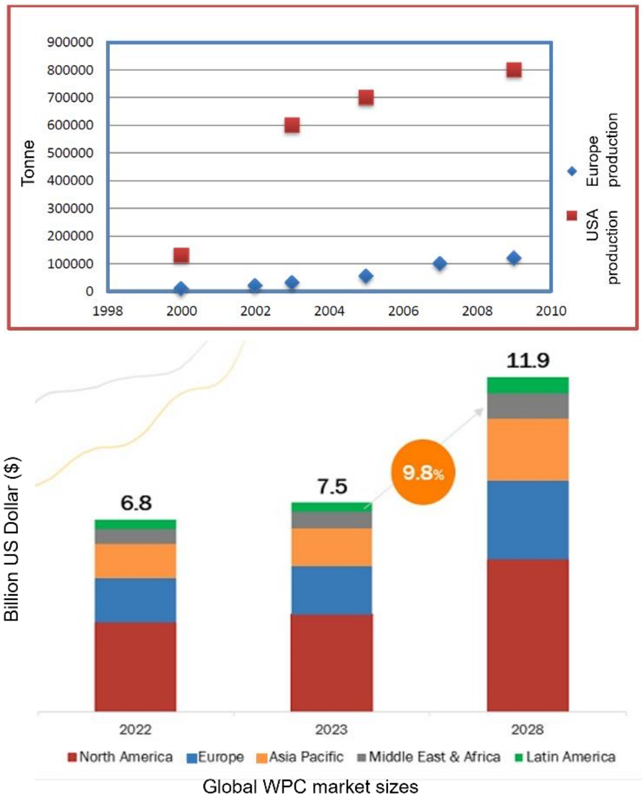

Figure 2. (a) The trend of wood plastic composite material production volume in the US and European markets (Eder, 2010). **(b)** Sales performance and future expectations in various markets (URL-4, 2024).

In Türkiye, the majority of the WPC sector is dedicated to outdoor flooring, while a significantly smaller portion is used primarily in applications such as pergolas. The purpose of this article is to use WPC as a building material. The market volume of the Turkish wood-plastic composite sector is approximately ten thousand tons. The WPC sector in Türkiye is expected to continue growing, driven by the continuously increasing demand in the construction industry (URL-5, 2024). Some of the companies producing wood-plastic composites in Türkiye are as follows: Hekim Board: Exterior wall cladding profiles and panels. Therrawood: Decks, terraces, exterior cladding, fences, gazebos, railings and prefabricated houses. Make WPC: Deck and outdoor flooring. Burdeck: Tiles, profiles, planters and urban furniture (URL-6 – 9, 2024).

2 Usage Areas

Wood-plastic composites (WPC) have found applications in numerous sectors, with the construction industry being the primary area of use. Table 1 presents these application areas. WPC is commonly employed for outdoor decking, terrace and patio flooring, railings, fences, landscaping timbers, park benches, cladding, exterior siding, prefabricated home panels, window and door frames, trims, and indoor furniture (Stark, 2001; URL-10, 2024; URL-11, 2024). The natural wood appearance of WPC creates a warm and natural ambience while its durable structure ensures long-lasting use. The ability of WPC produced in various colors and textures offers furniture designers a broad creative scope (Figure 4) (URL-10, 2024; URL-12, 2024). When WPC decking is applied around swimming pools (Figure 3), the material's anti-slip property can help prevent potential injuries compared to ceramic-based products such as marble, tiles, or granite, especially when individuals walk barefoot on wet surfaces.

Figure 3. Wood plastic composite application as poolside/deck ground (URL-13, 2024).

Figure 4. Wood plastic composite plate for modern modular kitchen cabinet (URL-14, 2024).

WPC cladding is used for both exterior and interior wall coverings (Figure 5). It adds aesthetic appeal to structures while providing insulation. WPC cladding products are light-weight, easy to install, and contribute to enhancing the energy efficiency of the buildings to which they are applied. WPC is widely used for terraces, balconies, railings, and stairs of residential and commercial structures. Providing sufficient strength and safety, these wooden-looking railings are resistant to moisture, do not rot, do not splinter, do not bend and are quite durable. WPC is increasingly utilized in the production of outdoor furniture, such as benches, tables, and chairs. WPC is among the ideal choices for outdoor applications, considering its durability and resistance to moisture. Furthermore, WPC furniture offers a wide range of design and color options, enhancing aesthetic versatility. Its use for these purposes is also applied in Türkiye. In addition to outdoor applications, WPC is also used for interior applications such as ceiling panels, wall panels, and baseboards. Its ability to be molded into various shapes and finishes makes WPC suitable for decorative purposes (URL-12, 2024). Moreover, wood-plastic composite parts are frequently used in the production of sports and musical instruments. For instance, laminated skis, golf equipment, hockey sticks, and baseball bats are commonly manufactured using wood-plastic composites (Leu et al., 2012; Bayram, 2024).

Figure 5. Application of wood-plastic composite as an exterior building cladding (URL-15, 2024).

Table 1. Application areas of wood plastic composite (Liukko et al, 2007).

Sector	End-Product Market Applications					
Construction	Exterior cladding	Door frames and components	Window frames components	Barge boards	Pre-treated floorboards	
	Ceiling products	Roof covering	Stairs	Timber	Porch	
Interior Architecture / Surfaces	Railings	Curtains and blinds	Channel connections	Flooring	Decorative profiles	Interior panels
	Kitchen cabinets	Parquet	Office furniture	Shelves	Baseboards	Sound insulation coatings
Automotive	Interior panels	Door and chest linings	Cable channels	Luggage racks	Spare tire covers	Trailer floors
Garden / Outdoor	Flooring	Garden sheds, huts, etc.	Garden furniture	Fences and fence connections		
	Park benches	Children's playground equipment	Playground flooring			
Industrial / Infrastructure	Railings	Industrial packaging	Marine piles and partitions	Pallets and crates		
	Quays, piers	Trash cans	Signs			

WPC can be utilized in the production of window and door frames, balancing adequate strength properties with aesthetic considerations. These frames (Figure 6) are resistant to direct exposure to water or liquids, moisture, termites, and decay. They offer good insulation properties, contributing to the energy efficiency of buildings (URL-12, 2024). For window applications, PVC is commonly used as the polymer component in the composite mixture, though other thermoplastics can also be employed. PVC integrated with wood powder is gaining prominence due to its balanced thermal stability, moisture resistance, and hardness. Other attractive parameters include low maintenance and repair costs, absence of cracks and splinters, and high durability. In addition to solid rectangular profiles, window frame designs may also incorporate complex hollow and grooved profiles to reduce costs and weight while maintaining structural integrity. These specialized profiles can be tailored for frame production (Bala, 2018). Andersen Corp. established a PVC-based WPC window line years ago, securing its position in the window market. The company also produces innovative fiberglass-framed window solutions (URL-16, 2024).

Figure 6. Wood plastic composite (WPC) window frame and its profiles (URL-17, 2024).

3 Material Properties

Wood-plastic composites (WPCs) are highly resistant to abrasion, decay, and deterioration (Stark, 2001). WPCs demonstrate strong resistance to both water and moisture (URL-10, 2024). An additional advantage over wood is the material's ability to be extruded or molded into almost any desired shape. WPCs have great machinability and can be shaped using traditional woodworking tools. Since WPCs are often made using recycled plastics and waste products from the wood industry, they are considered a sustainable material. This is also important in the context of waste management (Stark, 2001). Their production helps reduce deforestation and plastic waste. They are an environmentally friendly material. At the end of their lifespan, WPCs can be shredded and reprocessed into new products (URL-12, 2024). Additionally, they are resistant to bacterial growth due to their hygienic properties. They also do not conduct flames with high safety standards (URL-18, 2024).

Wood-plastic composites (WPCs) are known to exhibit non-linear viscoelastic behavior similar to unfilled polymers. This means that their mechanical responses depend on variables such as stress, temperature, and time (Hamel et al, 2013). Due to the addition of organic matter, WPCs are typically processed at much lower temperatures compared to traditional plastics during extrusion and injection molding. WPCs begin to burn at temperatures around 200°C. Since they melt at lower temperatures, the energy required for manufacturing is reduced. As a rule, the higher the wood/plastic ratio, the lower the melting temperature (URL-1, 2024). It has been observed that WPC materials produced by extrusion have a lower fire risk compared to those made by other manufacturing methods, considering factors like ignition, progression of burning, etc. (Lopez et al., 2022). There are several strategies to enhance the flame resistance of WPCs, which can be broadly categorized into two main approaches. The first involves incorporating flame retardants into the wood-plastic polymer mixture during compression, injection, or extrusion processes. The second strategy involves pre-treating the wood particles with liquid flame retardants through impregnation, followed by combining the particles with polymers using traditional processing methods (URL-11, 2024).

The performance of wood-plastic composites (WPCs) depends on various factors, including the microstructure of the composite, void content, wood-matrix stress transfer efficiency, particle morphology, and the chemical composition of lignocellulose (Hung et al., 2017). WPCs may contain between 30% and 60% wood particles, which significantly reduces the dependence on petroleum-based plastic materials. The wood fibers or dust (sawdust) used in WPC production are typically waste materials generated during lumber processing by manufacturers. These matters are processed to create a more cost-effective and stronger reinforcement product. The type, size, and concentration of wood particles in the composite formulation can be adjusted to achieve different properties (URL-1, 2024; URL-11, 2024; Hung et al., 2017). The effects of wood species on the water absorption, biological degradation, metal corrosion, and color changes of WPCs due to outdoor exposure have been studied and reported. It is known that wood dust from various species can be used as a raw material for WPC production (Fabiyi & McDonald, 2010). Similarly, the selected wood species will influence the final color of the product. Commonly used wood species in WPCs include pine, oak, and maple. Cost is a key factor in these choices. Pine fillers tend to produce lighter-colored products compared to hardwood fillers (URL-1, 2024; URL-11, 2024; Hung et al., 2017).

Research and development activities related to wood-plastic composites (WPCs) primarily focus on enhancing raw materials and optimizing production processes. Examples of studies in this area include the testing of different wood powder or fiber sizes, using various wood species, using wood powder resulting from the break-up of end-of-life wood materials, utilizing lignocellulosic annual plants, and experimenting with different polymer types and mixture ratios (Rowell et al., 1997).

The inclusion of wood fibers in plastics improves the bending and tensile properties of the resulting composites compared to pure plastics (Hung et al., 2017; Fabiyi & McDonald, 2010). Using finer wood powder (smaller than 125 µm) can enhance the tensile and flexural strength of WPCs and reduce swelling caused by water absorption. Experimental studies have proven that using larger particle-sized wood powder increases moisture absorption and swelling in specific proportions (Leu et al., 2012). The bond between wood and plastic is typically weak due to the hygroscopic nature of wood and the hydrophobic properties of plastic, leading to challenges in stress transfer between the wood and plastic phases. To address this issue, compatibilizers are employed to improve the stress transfer between wood and plastic and form interfacial bridges between the two materials (Avcı, 2012; URL-11, 2024). Maleic Anhydride Polypropylene (MAPP) is a commonly used compatibilizer in WPCs to enhance the compatibility between polypropylene (or other thermoplastics) and wood dust, thereby improving the microscopic interfacial bond between wood particles (fibers) and the plastic matrix (Xue et al., 2007). The optimal concentration of the compatibilizer (MAPP) and lubricant (zinc stearate) in WPCs is 3% (Leu et al., 2012). Adding the right amount of compatibilizer can improve mechanical properties and significantly reduce swelling (Leu et al., 2012; Adhikary et al., 2008). Studies have verified that MAPP usage prevents the formation of irregularly shaped micro-voids or defects in the WPCs (Adhikary et al., 2008). However, excessive use of compatibilizers and lubricants can cause significant swelling due to the formation of bonds between the molecules of the additives, which in turn negatively impact mechanical properties. It has been found that maintaining the wood content at 50% or less provides the best mechanical properties. Wood content exceeding 50% leads to a decrease in both the physical and mechanical properties of WPCs (Leu et al., 2012). As the proportion of wood powder increases, the density of the composite also increases (Avcı, 2012). The dimensional stability and strength properties of wood-plastic composites can be improved by increasing the polymer or compatibilizer binding additives content (Adhikary et al., 2008).

When examining the stress-strain behavior of HDPE-wood powder composites under tensile loading, it was observed that the addition of wood powder increases the stiffness of the composite material while the strain at break decreases. As the wood powder content increases, the yield and tensile strength, as well as the tensile modulus, increase while the material becomes less ductile, meaning it becomes more brittle and durable. The elasticity modulus (E) increases continuously as the wood powder content increases in HDPE WPC composites. On the other hand, composites with a higher HDPE content exhibit greater ductility and a higher breaking strain. Composites with the addition of the MAPP compatibilizer have higher bending strength compared to unmodified composites (Adhikary et al., 2008).

When a wood-plastic composite material is in direct contact with water for prolonged periods, it negatively impacts the material’s mechanical properties. Over time, the wood powder absorbs water and tends to swell, leading to the formation of micro-cracks, and the bond between the plastic and wood weakens (Ratanawilai & Srivabut, 2022; Lopez et al., 2022). As the wood dust (fiber) content increases, more water absorption points are formed, causing more water absorption, which accelerates the infiltration of water through capillary effect. (Ashori & Nourbakhsh, 2009; Adhikary et al., 2008). Experiments using waste wood-derived wood powder and HDPE-based hot-pressed WPCs have shown that using smaller wood powder particles improves the material’s water absorption and swelling properties (Chen et al., 2006). The addition of MAPP (maleic anhydride polypropylene) as a compatibilizer is known to reduce water absorption. In WPCs with MAPP, the parameters related to the wood powder-polymer ratio are less variable compared to those without MAPP WPC composites. MAPP also reduces the effects of water absorption and swelling, allowing changes in the wood content to have a minimal effect on the overall properties of the WPC (Adhikary et al., 2008; Markarian, 2005).

WPC products require less maintenance than natural wood. They are more economical and easier to maintain as they do not require painting, varnishing or sealing. They are easy to clean and can withstand harsh weather conditions without deteriorating (URL-12, 2024). Issues such as cracking and color degradation, which are seen in PVC window frames due to temperature and load, don’t occur in WPC window frames. These specifications make them ideal for window frames as they are constantly exposed to external conditions. Table 2 compares wood, plastic and wood-plastic materials in terms of various properties.

When comparing products made from WPC materials to those made from Medium-Density Fiberboard (MDF), a material considered indispensable in the wood industry, the following conclusions can be drawn:

- Both WPC and MDF products have values ranging from 20 to 40 MPa in terms of tensile strength (Avcı, 2012; Gardner & Han, 2010; Xue et al., 2007; URL-19, 2024). WPC is highly durable and weather-resistant, making it an ideal choice for outdoor or wet areas. MDF exhibits lower resistance to moisture and decay and may require maintenance.
- WPC panels can be assembled using a clip and rail system, making installation and removal easier. MDF panel installation is done by nailing or gluing them to the wall.

- WPC can be produced in various colors and textures, including wood patterns, while MDF can be painted or veneered to create different surfaces.
- WPC is more expensive than MDF, but its superior features outweigh this disadvantage. The cost per square meter of WPC is approximately two to three times that of MDF (URL-19, 2024). Its low maintenance requirements and extended lifespan render it a cost-effective choice in the long run (URL-12, 2024).
- While MDF swells when liquid or water seeps in, WPC is waterproof. However, it has been shown that WPC still absorbs a small amount of moisture, but at a much slower rate compared to solid wood.
- MDF can be used for up to 10 years, while WPC can last for 50 years.
- While WPC can be easily shaped into different shapes, MDF cannot be easily transformed into different shapes.
- Some harmful chemicals and substances may be used in the production of MDF. However, no chemicals or hazardous substances are used in the production of WPC (URL-11, 2024; URL-19, 2024).

Table 2. Comparison of wood plastic composite general material properties with wood and plastic (Bala, 2018).

Material properties	Wood plastic composite	Wood	Plastic
Resistance to sunlight and aging	+++	+	++
Natural wood appearance	+++	++++	+
Moisture resistance	+++	+	+++
Resistance to water absorption	+++	+	++++
Resistance to biological pests (insects)	++++	+	++++
Ease of machinability	++++	++++	+
Ease of maintenance	+++	+	++
Nailing ability	++	+++	+
Low expansion ratio	+++	+++	+

A wide range of waste produced in various industries can be used in the production of wood-plastic composites (WPC), thus promoting the development of a circular economy. The source of the recycled plastics used in recycled WPC is typically municipal solid waste facilities. In addition to plastic bottles, containers, bags, accessories, cups, packaging materials, etc., automotive industry waste can also be used as raw materials (Ramli, 2024). The properties of waste plastics are similar to those made from original materials. Many experiments have shown that there is only a minor change in the mechanical properties of recycled polyethylene compared to the original PE (Ashori & Nourbakhsh, 2009, Adhikary et al., 2008). Furthermore, the granules of recycled plastics are cheaper compared to pure plastic granules (Adhikary et al., 2008). The evaluation of recovered plastics and the development of new value-added products are becoming increasingly important (Ashori & Nourbakhsh, 2009).

4 Production Methods

The most common manufacturing method for wood-plastic composites (WPCs) is extrusion, although injection molding and compression molding are also employed (Stark, 2001 & Ratanawilai & Srivabut, 2022; Hamel et al., 2013; URL-12, 2024; Kumari et al., 2007). In terms of water resistance and mechanical properties, materials produced through injection molding and extrusion molding have been found to perform better than those produced via compression molding (Kumari et al., 2007). Additives such as colorants, coupling agents, UV stabilizers, blowing agents, foaming agents, and lubricants help tailor the final product to its target application. Coupling agents, used at concentrations ranging from 3% to 5% of the mixture, improve interfacial adhesion between the plastic matrix and wood powder filler by creating a strong bond. These additives also facilitate optimal processing conditions. WPCs can be molded to incorporate intricate wood grain patterns. Extruded WPCs can be fabricated in both solid and hollow profiles (Figure 7) (Stark, 2001; Ratanawilai & Srivabut, 2022; Leu et al., 2012; URL-11, 2024; URL-12, 2024). From a manufacturing perspective, processing WPCs is quite similar to processing conventional petroleum-based plastics. As the material behaves similarly, large-scale investments in new machinery and equipment are generally unnecessary (URL-1, 2024).

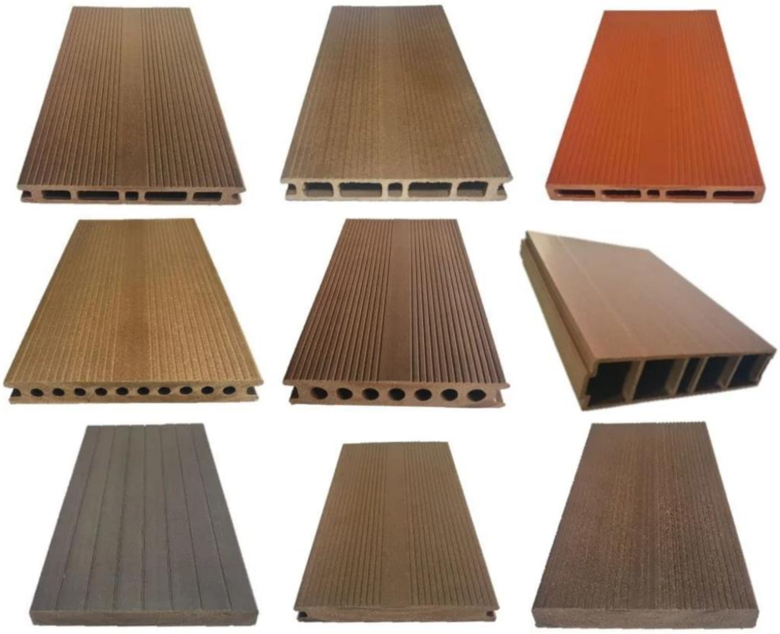

Figure 7. Wood plastic composite (WPC) profiles (URL-20, 2024).

The performance of WPCs is significantly influenced by the particle size of fillers; therefore, wood powders are classified using sieves. Different sieve mesh sizes ensure that the wood powder particles meet the desired dimensions. The obtained wood powders are subjected to a drying process in drying ovens at 100±5 °C until fully dried (Figure 8). Subsequently, the polymer and wood powder are blended with a very small amount of paraffin-wax adhesive in a high-speed mixer to achieve a homogeneous mixture. The mixture is heated in an extruder to a temperature slightly below the combustion point of the materials (Şahin, 2023). The temperature is maintained between 170-200 °C during the extrusion process (Ratanawilai & Srivabut, 2022; Kumari et al., 2007). The molten mixture exiting the extruder is cooled in water and then converted into particles using a crusher machine. The dried particles, which have zero moisture, are processed into the final product through plastic injection molding (Şahin, 2023). Since processing variables have a critical impact on the final product, technological parameters require precise control. For example, extremely low or high cylinder temperatures, excessive high screw speed, or injection speed can result in surface defects in the composites (Lopez et al., 2022). The primary role of lubricants in the WPC processing cycle is to improve the wettability of wood powder and enhance slippage between wood and plastic particles (internal lubrication), and/or ensure the smooth and homogeneous manufacture of the product in the extruder (external lubrication) (Leu et al., 2012). Specially engineered extruders tailored for the direct extrusion of WPCs are available, and research and development activities in this field are ongoing (Markarian, 2005). WPCs can be painted or colored to suit nearly any design scheme (URL-11, 2024). After obtaining profiles with a consistent cross-section and several meters in length through the extrusion process, the material exhibits an appearance similar to plastic. The profiles are then processed in a unit where thermoplastic wood texture is applied, brushed, or sanded on the desired surfaces, achieving a perfect wood-like appearance (Figure 8) (Bayer et al., 2017).

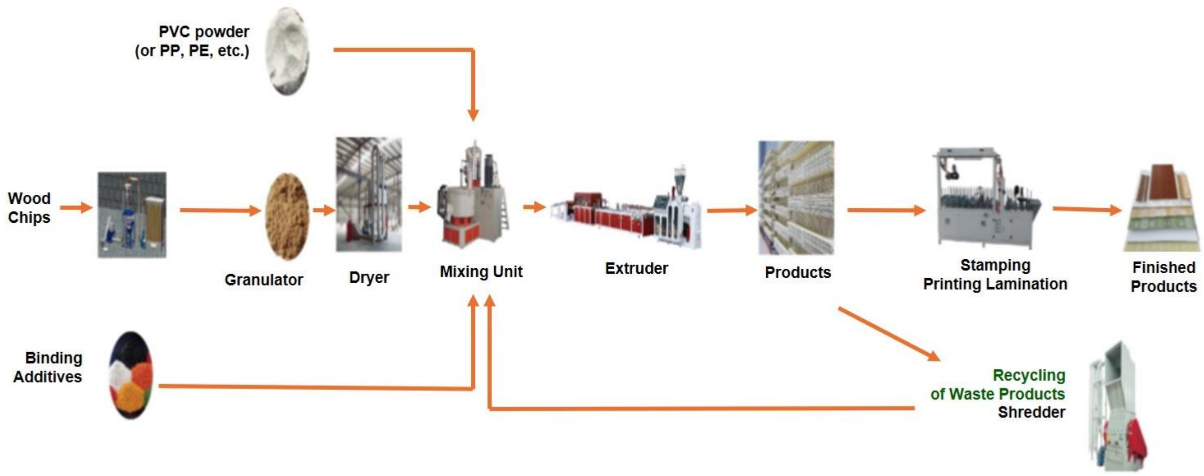

Figure 8. Wood plastic composite (WPC) production process (URL-21, 2024).

5 Conclusion and Suggestions

Wood-plastic composites can be applied in various fields where both wood and plastic sector products are used, and their application areas are expanding every day. The low cost of wood dust, its low density, minimal wear during production, abundant availability, and its biodegradability in nature make it an attractive material for use in thermoplastic composite production. Each application in different fields is an effective way to enhance ecological efficiency. The use of recycled thermoplastics is considered in the production of wood-plastic composites (WPC). The thermoplastic material primarily used in WPC production is polyethylene. However, PVC is commonly preferred for window frames, and the utilization of recycled PVC can also be considered. In this context, recycling existing PVC window frames for use in WPC production may be possible.

- Wood-plastic composites (WPC) have found application area in many sectors, particularly in the construction industry. In Türkiye, a large portion of the WPC sector is dominated by outdoor flooring (decking), while a much smaller segment is particularly used in applications such as pergolas. The WPC industry is expected to continue growing with the continuously increasing demand in the construction sector. In recent years, WPC has begun to partially replace some traditional and new engineered wood products. The use of petroleum-based polymers (plastics) will certainly decrease significantly as the use of WPC materials becomes more widespread in the future. Additionally, WPCs are more cost-effective compared to polymer types. Supporting and prioritizing research and development of WPC materials, which continue to improve and grow, is crucial for the wood and plastic industries.
- Wood-plastic composites (WPC) can contain wood particles ranging from 30% to 60% which significantly reduces dependence on petroleum-based plastic materials. Keeping

the wood content at 50% or lower has provided the best mechanical properties. WPC and MDF products have been found to have similar tensile strength, with values ranging between 20 and 40 MPa. Wood fibers/dust (sawdust) can be obtained from waste materials produced during the manufacturing process of lumber and furniture producers. The type, size, and concentration of the wood particles in the composite formulation can be adjusted to achieve different properties. It is known that wood dust from many species can be used as raw material for WPC production. Incorporating wood fibers into plastics improves the bending and tensile properties of the resulting composites compared to pure plastics. This is also significant for the preservation of Türkiye's forest resources.

- The most common production method for wood-plastic composites is extrusion, where the material is extruded into the desired shape; however, injection molding and compression molding are also used. In terms of water resistance and mechanical properties, materials produced through injection molding and extrusion molding have been found to perform better than those produced by compression molding. Additives such as colorants, binders, UV stabilizers, blowing agents, foaming agents, and lubricants help tailor the final product to the target application requirements. The optimum concentration of maleic anhydride polypropylene (MAPP) as a binder in WPCs is 3%. Adding an appropriate amount of binder can improve mechanical properties and significantly reduce swelling. Products can be created in both solid and hollow profiles with the extrusion method, which is also preferred in window frame production. Since the material behaves similarly, large-scale investments in new machinery and equipment are not required.
- Research and development activities related to WPC (Wood-Plastic Composites) primarily focus on improving raw materials and production processes. Ongoing and upcoming studies include various wood dust or fiber sizes, testing various types of wood, using wood dust obtained from the disintegration of expired wood materials, and using various polymer types and mixing ratios. The quality of WPC products has been continuously improved with the advancement of WPC production technology and deficiencies encountered in production and use have been eliminated. The mission of the WPC sector in Türkiye and the world is to ensure that WPC is used more widely and as a higher quality building material, its performance is fully utilized and better services are provided to the sector.
- The use of WPC, which has become more visible in Türkiye in recent years with its application in open space/plaza arrangements by metropolitan municipalities and in some residential projects, has gained momentum, especially with the increase in construction projects supporting detached living. It is observed that WPC is increasingly incorporated into the architectural designs of sites/residences used in interior spaces, exterior cladding, or landscaping arrangements. This trend is expected to continue growing with the effect of competitive pricing policies and its share in the construction sector is expected to increase.

As a result of this study, the use of wood-plastic composites as an environmentally friendly solution for building materials, particularly window frames in green building projects, is recommended as a sustainable and energy-efficient option in the construction sector. In residential and other buildings, WPCs can be used to create more sustainable homes and provide window frames that align with modern design trends. WPCs will continue to play an important role in window frame production in the future. In this way, the need for aluminium profiles used in existing PVC windows will be eliminated. This material will also fill an important gap in waste management, providing a balanced solution in both performance and aesthetics, solidifying its position in the construction industry.

Author Contribution

Beytullah Başeğmez: Conceptualization, Determination of the methodology, Data curation, Formal analysis, Investigation, Project administration, Visualization, Writing – original draft, Writing – review & editing, Resources, Checking, Validation.

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Conflict of Interest Statement

The author declares no conflict of interest.

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