



Comparative Analysis of Rubberwood, Plywood, and Wood-Plastic Composites for Safe Elderly Toy Applications

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Abstract: The objective of this research was to produce toy products for the elderly to develop the potential in various areas of the elderly. Different types of wood materials, namely rubberwood sawn timber, plywood, and wood-plastic composites, were evaluated for their performance based on mechanical, physical, and chemical properties. Samples were compressed using a compression molding machine. The experimental results were analyzed by Analysis of Variance (ANOVA). The findings showed that all mechanical properties of the elderly toy products manufactured from rubberwood (RW) had higher strength values than those of plywood (PW) and wood-plastic composites (WPCs). The lowest water absorption and thickness swelling values of 4.36% and 2.01%, respectively, were observed in elderlytoy products manufactured from WPCs. In contrast, the minimum Ra value of 1.45 μm was observed. Additionally, the results showed that the three types of materials contain heavy metal content that does not exceed the specified standards, indicating that this product is safe for the elderly. Finally, the elderly toy products made from WPCs showed smooth surfaces, greater agglomeration, and fewer pores and voids, due to the strong interfacial adhesion between the plastic matrix and the rubberwood fiber reinforcement.

Keywords: Comparative analysis; mechanical properties; plywood; wood-plastic composites (WPCs); elderly's toys

1. Introduction

Many concepts about the use of toys and games to develop cognitive, psychosocial, motor, emotional, and linguistic skills play a very important role in children's and elderly people's lives [1, 2]. These toys contribute to the development of elderly's performance while nurturing their natural development and growth. It also plays a key role in fostering self-confidence, creativity, and happiness among the elderly [3]. However, playing with toys enhances attention span, memory, and learning, and the elderly willingly participate, while toys are tools they use while performing these actions. The toys offer many ways to play with them, leaving the elderly in charge; imagine, for example, an experiment as they play [4, 5]. The toys have so many functions; in a sense, they are a right for the elderly, and they must be supported. In particular, open-ended toys can encourage imagination and strengthen many areas of natural development, including communication, creativity, motor skills, and problem-solving [6, 7]. Additionally, the provision of areas for elderly people to engage in activities is important, and safety is essential for reducing the risk of accidents related to toys [2, 8]. These are all health-care components; especially, they should take an active role in ensuring that these processes, which are the most excellent parts of elderly care, are healthy and safe.

Toys and activity-based tools designed for elderly users are gaining recognition for their role in rehabilitation, cognitive stimulation, and leisure, particularly within institutional care settings. In contrast to children, elderly individuals commonly experience reduced grip strength, decreased mobility, sensory impairment, and heightened susceptibility to injury, necessitating distinct and carefully considered design approaches. When produced from wood, such products must reconcile the material's natural and sensory advantages with stringent safety and performance requirements [2]. Ergonomic grip design, appropriate weight and balance, and ease of manipulation are critical factors in minimizing physical strain and fatigue. Furthermore, hygiene represents a significant concern in shared care environments, as untreated wooden surfaces may retain moisture and support microbial growth. Consequently, material selection, surface finishing, and construction techniques play a pivotal role in ensuring product safety, durability, and usability. A comprehensive understanding of these requirements is therefore essential for the effective development of wooden toys intended for elderly users [4, 6].

Among the materials used to produce elderly toys, wooden toys have increased in popularity over recent years due to their simple aesthetic, natural materials, good biodegradability, and greater hygienic properties compared to plastic and metal toys [9,10]. One of the most significant advantages of wooden toys is their staying power. Wood is a natural material with an ageless timestamp [11]. These toys have been in circulation for generations and show no signs of stopping. Generally, plastic toys change with trends and see replacement versions that are bigger and brighter [1, 12]. Also, other materials, such as wood-plastic composites (WPCs), are widely used to produce elderly toys [13, 14], as these materials are biocompatible and biodegradable. It can be made from recycled materials or manufactured from renewable resources [15,16]. In contrast, many plastics contain bisphenol A (BPA), as well as polyvinyl chloride (PVC) and phthalates. In addition to plastic toys not necessarily being the most eco-friendly, the chemical exposure from playing with them is something to consider [16]. Therefore, choose toys made from natural materials, such as solid wood, cloth, paper, or wool. Ideas for plastic-free playthings include games and puzzles made from cardboard or wood, which can be among the best potential development and educational toys [17, 18].

Product design for elderly toys is one of the most significant parts of the manufacturing process. The age group will also tell you what play patterns are appropriate. A toy that is fascinating for the elderly may be of no interest to children. The designer or manufacturer must have experience in developing toy products for older people [6, 16]. Additionally, these toys must foster the development of critical thinking and of emotional, physical, and mental abilities [19, 20]. Also, the toy design is an exciting area of product development where industrial design and elderly psychology are blended. The toys are designed to delight, teach, and inspire curiosity among older people [3, 21]. New toy ideas for the elderly are worth considering, researching, and developing. Engineering product development is the step-by-step process that takes an idea from the concept stage through a working prototype stage to mass production and commercialization [22]. The concept is the management of the entire product design process from ideation and planning to the creation of suitable, high-fidelity designs, ensuring a cohesive, user-centric result, but we need to consider which tool can do the work [23, 24]. Product design tools are processes that help build, visualize, and enhance product models. It can create detailed prototype models for concept development, prototyping, and simulation. These tools frequently include features such as drawing, drafting, analysis, modeling, improvement, and rendering [24]. These features enable designers to seamlessly transition from initial concepts to fully realized designs while maintaining consistency and efficiency [23, 25]. The performance evaluation of the toys, namely mechanical, physical, and thermal properties, is an important part in order to more clearly delineate the formal properties of toys. Product standards determine the prototype depending on each type of use. In addition, safety in use and proper application must be taken into account [26]

Surface coating plays a critical role in the production of toys for the elderly because it directly affects safety, durability, hygiene, and user comfort factors that are particularly important for this age group. As aging is often accompanied by reduced tactile sensitivity, diminished motor control, and increased vulnerability to injury, surface coatings help create smoother, more uniform surfaces that minimize the risk of splinters, abrasions, or sharp edges during handling and use [4,9]. In addition, appropriate surface coatings enhance the durability and longevity of toys by protecting the substrate material from wear, moisture, and

chemical degradation. This protection is especially important for toys used in therapeutic or recreational settings, where frequent handling and cleaning are required. Coatings that provide resistance to water, stains, and microbial growth contribute to improved hygiene and help reduce the risk of infection among elderly users [8,11]. Surface coatings also influence the tactile and visual properties of toys, such as texture, warmth, and color stability, thereby enhancing user engagement and sensory stimulation. Non-toxic, low-emission coatings are essential to ensure user safety, as elderly individuals may be more sensitive to volatile organic compounds or other harmful substances [10]. Overall, the selection and application of appropriate surface coatings are integral to ensuring that toys for the elderly are safe, functional, durable, and supportive of both physical and cognitive well-being.

Thus, the purpose of this research was to promote the potential development and create new opportunities for senior citizens to learn together and benefit from playing with elderly toy products. Different types of raw materials, such as rubberwood sawn timber, plywood, and wood-plastic composites, are evaluated based on their mechanical, physical, and chemical properties. The best material was selected to produce elderly toy products through engineering product design and development. The experimental results were compared to product standards for wooden toys. This finding is important for the elderly to be part of society as healthy individuals at every stage of their development.

2. Materials and Methods

2.1 Materials

Different types of wood-based products, namely rubberwood sawn timber (RW), plywood (PW), and wood-plastic composites (WPCs), were selected for the manufacturing of elderly toy prototypes. These materials are produced from natural materials, are environmentally friendly, and are safe for production and use. The surface appearance and physical characteristics of RW, PW, and WPCs are displayed in Figure 1.

In this work, the RW and PW materials were supplied from the Geefin Rubber Tech Co., Ltd. (Songkhla, Thailand). The PW from rubberwood veneer is produced by selecting mature rubberwood logs and conditioning them through steaming or soaking. The logs are rotary-peeled into thin veneers, which are then dried and graded to remove defects. The veneers are arranged in cross-laminated layers to enhance strength and stability. Adhesive is applied between the layers, and the assembly is hot-pressed under controlled conditions. After pressing, the panels are trimmed and sanded to obtain a smooth, uniform PW surface. The density was targeted for RW and PW at 0.68 and 0.80 g/cm³, respectively, with a 20 mm thickness. Before specimen preparation, in accordance with the testing standards, all samples were conditioned at 20±1 °C and 65% RH for at least 24 hours. For the WPC panels, the composites were manufactured from recycled polypropylene (rPP) as matrix and rubberwood sawdust (RWS) as reinforcement. The rPP pellets with a density of 0.83 g/cm³ and a melt flow index of 0.93 g/10 min at 230 °C was supplied from Withaya Intertrade Co., Ltd. (Samut Prakan, Thailand) and were used as a matrix in WPC samples. The RWS, with a density of 100 kg/m³, used as a reinforcement material in WPCs, was obtained from Plan Creations Co., Ltd. (Trang, Thailand). Before compounding, the RWS were crushed and sieved through a standard sieve with a mesh size of 80 (less than 180 µm) and dried in an oven at 110±5 °C for 8 hours to remove moisture content (1-2%).

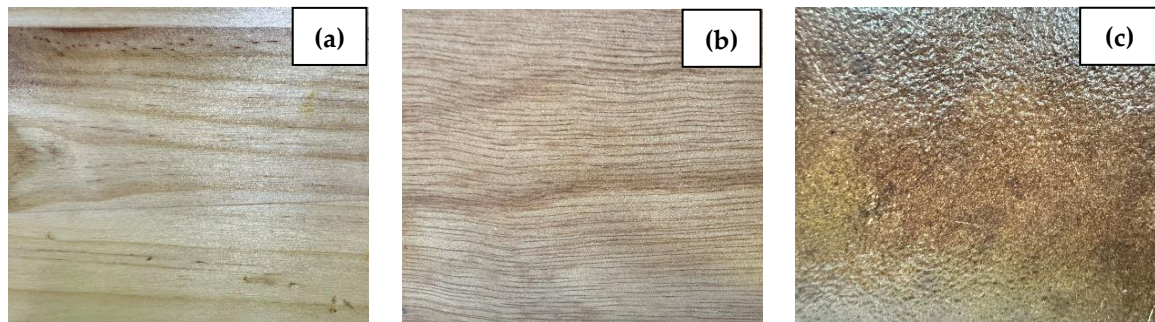


Figure 1. The surface appearances of (a) RW, (b) PW, and (c) WPCs.

2.2 Preparation of the RW, PW, and WPCs samples

The specimens used for all testing were cut in the grain direction from RW and PW, with nominal dimensions of 15 cm (width) $\times$ 100 cm (length) $\times$ 2 cm (thickness). The WPC samples in this research were produced from two stages. Initially, the WPCs' material was mixed at 60 wt% rPP and 40 wt% RWS. The component ratios, namely rPP and RWS, were compounded uniformly and melt-blended in a twin-screw extruder. The seven temperature zones were set in the range from 175 to 200 °C and a screw rotation speed of 50 rpm. The extruded strands were then blown into the air and passed through a cutter, turning them into WPC pellets measuring 3 mm. Subsequently, the WPC pellets were molded in a compression molding machine at 190 °C under 870 psi, with 20 min for preheating, compression, and cooling, respectively. The final WPCs panel size was 25 cm (width) $\times$ 35 cm (length) $\times$ 2 cm (thickness) from a rectangular mold. Finally, all specimens were cut to specific dimensions for mechanical, physical, and thermal tests in accordance with ASTM and JIS standards.

2.3 Surface coating of the RW, PW, and WPCs samples

In this research, the mechanical, physical, and chemical properties were studied under three different conditions. In addition to studying the original wood types, all samples were coated with non-toxic varnish (V) and natural oil (O) by spraying onto the surface of the material. The amount of both Non-toxic varnish and natural oil was standardized across toys. Each coating was applied at approximately 200 g/m², ensuring comparable surface coverage for RW, PW, and WPCs. This uniform application enabled an objective evaluation of the effects of surface treatments on material properties. The coatings were applied using the same method for all specimens. Varnish was applied in two coats by spraying, with light sanding between coats to promote adhesion. Natural oil was applied in two coats by brushing, allowing sufficient absorption into the surface before excess oil was removed. All specimens were coated on all exposed surfaces. After application, coated samples were allowed to cure under controlled ambient conditions (approximately 25 °C). Coated specimens were dried for 1 hr between coats and cured for 3 hrs after the final coat. All samples were fully cured before conducting mechanical, physical, and chemical property tests to ensure stable coating performance. All coating conditions for this study are shown in Table 1.

2.4 Characteristic behavior of the samples

2.4.1 Mechanical properties of samples

The mechanical properties, namely tensile and bending tests, of wood and composite samples were conducted to measure the strength of RW, PW, and WPCs using a Mechanical Universal Testing Machine, Model NRI-TS500-50, from Narin Instrument Co., Ltd. (Samut Prakan, Thailand). The details draw the following conditions of each testing type based on the ASTM standard:

Tensile test

The tensile properties of RW and PW were carried out in accordance with ASTM D143 standards. The tension parallel was applied with a load cell of 5 kN and a crosshead speed of 5 mm/min. The specimen dimensions for the tensile test were 2 cm (width) $\times$ 7 cm (length) $\times$ 2 cm (thickness). For WPC testing, the tensile test was carried out in accordance with ASTM D638 at a crosshead speed of 5 mm/min. Five replications of each formulation were tested at 25 °C for all specimens, and their tensile average values were reported.

Bending test

The three-point bending test of RW and PW was performed according to BS 373 standards, with a crosshead speed of 2 mm/min and a span of 300 mm. The nominal dimension of rubberwood lumber was 2 cm (width) × 7 cm (length) × 2 cm (thickness). For WPC testing, the specimens were tested in accordance with ASTM D790. The composite samples were conditioned with a crosshead speed of 2 mm/min and a span of 80 mm. The specimens were prepared with a nominal size of 100 mm (width) × 13 mm (length) × 6 mm (thickness). All tests were conducted at 25 °C, with five replications for each composition.

2.4.2 Physical properties of samples

Water absorption and thickness swelling tests

The water absorption and thickness swelling of the RW, PW, and WPC samples were measured according to ASTM D570. The nominal dimensions of 2 cm (width) × 4 cm (length) × 2 cm (thickness) were cut from the rubberwood sawn timber and conditioned at 20±1 °C for 24 h. to remove the moisture content (less than 5%). Five replications of the samples were soaked in distilled water for 2 and 24 hours. with a depth of immersion from the samples to the water surface of about 2.54 cm. Initially, the rubberwood lumber specimens were weighed and measured before soaking in water, and their average values were reported. Subsequently, the specimens were periodically removed from the water, dried with tissue paper on the rubberwood surfaces, reweighed, and remeasured at room temperature (25 °C), and immediately returned to the water. For the TS test, the measurements were taken at three locations on each sample: 3 mm from the top and bottom edges, and at the center. The water absorption and thickness swelling of RW, PW, and WPCs samples were calculated according to the following Eqs. (1) and (2):

$$WA_i(\%) = \frac{W_t - W_0}{W_0} \times 100 \quad (1)$$

where WA is the water absorption in percentage, and W_0 and W_t are the sample weights before and after immersion (g).

$$TS_i(\%) = \frac{T_t - T_0}{T_0} \times 100 \quad (2)$$

where TS is the thickness swelling in percentage, and T_0 and T_t are the sample thickness before and after immersion (mm).

Density test

The density of different wood types depends on the weight and volume of the materials. The specimens with dimensions of 2 cm (width) × 2 cm (length) × 2 cm (thickness) were cut from the samples and weighed at room temperature (25 °C). Five replications were measured in each condition. All samples were conditioned at 50 ± 2 °C and 10% RH before density testing. The density of the RW, PW, and WPCs samples was calculated according to the following Eqs. (3):

$$\rho = \frac{m}{V} \quad (3)$$

where ρ is the density of materials, m is the mass of materials, and V is the volume of materials

Surface roughness test

The surface quality of the RW, PW, and WPC samples was determined by surface roughness measurement using a Portable Surface Roughness Measurement Tool (Model SJ-210) from Mitutoyo Co., Ltd. (Bangkok, Thailand). Two roughness parameters, namely average roughness (R_a) and mean peak-to-valley height (R_z), were considered to evaluate the surface characteristics of the samples. Nominal dimensions of 3 cm (width) × 3 cm (length) × 2 cm (thickness) were measured at five replications under a room temperature (25 °C). All data for R_a and R_z were obtained from the digital information. The experimental results were

analyzed for the effects of wood type using a one-way ANOVA, specifically for Ra and Rz responses. Before the physical test, all samples manufactured from RW, PW, and WPC were dried in a convection oven at 50 ± 2 °C for 24 hours to reduce moisture content.

2.4.3 Chemical properties of samples

The toy materials, namely RW, PW, and WPCs were analyzed the 8 heavy metal content such as Antimony (Sb), Arsenic (As), Barium (Ba), Cadmium (Cd), Chromium (Cr), Lead (Pb), Mercury (Hg), Selenium (Se), respectively, the heavy metal elements were determined by national children's toys standard according to ASTM F 963-23 and EN71-3. Additionally, the results were compared with children's toys after the toy materials were coated with various paints or coatings, which is mainly due to the heavy metal compounds contained in the paint pigments. All of the samples weighed approximately 30 to 50 mg. The experimental condition was produced at a room temperature (25 °C).

2.4.4 Morphological observation of samples

A Field Emission Scanning Electron Microscope (FEI Apreo, FEI Company, Oregon, USA) was used to observe voids, cracks, dispersion, and interfacial bonding in the RW, PW, and WPC materials. Before the FE-SEM observation, the sample surface area was coated with gold to prevent electrical charging during imaging. The FE-SEM images were taken at an accelerating voltage of 20 kV with magnifications of 100× and 500×.

Table 1. The mechanical properties analysis of the RW, PW, and WPC samples.

Types of Materials	Tensile test (MPa)	Bending test (MPa)
RW	22.23 (1.23)	73.85 (1.89)
RW (V)	25.56 (1.54)	76.21 (0.96)
RW (O)	24.01 (1.23)	74.22 (1.35)
<i>p-value</i>	< 0.001*	< 0.001*
PW	20.89 (2.01)	62.14 (2.52)
PW (V)	23.56 (1.52)	66.20 (1.57)
PW (O)	21.05 (1.52)	64.20 (1.88)
<i>p-value</i>	< 0.001*	< 0.001*
WPCs	18.91 (1.14)	42.56 (1.14)
WPCs (V)	20.89 (1.10)	44.90 (0.62)
WPCs (O)	19.44 (0.94)	44.01 (1.10)
<i>p-value</i>	< 0.001*	< 0.001*

Note: *Mean within each property is significant ($p < 0.05$)

3. Results and Discussion

3.1 Mechanical properties analysis

The mechanical properties of the RW, PW, and WPC samples were evaluated through tensile and bending tests before producing the elderly's toy. The experimental results were statistically analyzed using five samples per mechanical test at the 5% significance level ($\alpha = 0.05$) [15,18]. The ANOVA analysis revealed significant differences in the properties of samples with various wood types.

3.1.1 Tensile strength analysis

Owing to the widespread application of toys produced from RW, PW, and WPCs, the tensile properties are of great importance. The average values of the tensile strengths are displayed in Table 1. The experimental results show clearly that the three wood types (RW, PW, and WPCs) under three conditions, namely untreated (control sample), non-toxic varnishes (V), and natural oil (O), significantly ($p < 0.05$) affected the tensile strength of the samples. It is first necessary to evaluate the uncoated wood surface samples. Specimens made from RW had higher tensile strength than the samples. The ultimate tensile strength of RW was 22.23 MPa, which was also greater than that of PW (20.89 MPa) and WPCs (18.91 MPa). This may be due to the parallel-to-grain test; it was found that the sample had strength and excellent grain adhesion [16,19]. Previous studies have shown that the strength tested in the direction parallel to the grain was substantially

higher than that tested perpendicular to the grain [7,9]. On the other hand, increasing the number of layers for PW increases the number of interfaces. Load is redistributed across more grain directions and more adhesive bondlines; therefore, tensile-strength concentrations in any single veneer are reduced.

For the RW samples, the application of non-toxic varnish coating yielded the highest tensile strength of 25.56 MPa, corresponding to a 15.0% increase relative to the uncoated RW (22.23 MPa). The natural oil coating also enhanced the tensile strength to 24.01 MPa, representing an 8.0% improvement over the control. Similarly, in the case of PW, treatment with non-toxic varnish increased the tensile strength from 20.89 to 23.56 MPa, reflecting a 12.8% enhancement, while the natural oil coating resulted in a slight improvement to 21.05 MPa. Furthermore, the WPCs coated with non-toxic varnish showed the greatest improvement, with tensile strength increasing from 18.91 to 20.89 MPa, a 10.5% increase. The application of natural oil to WPCs also increased the tensile strength to 19.44 MPa, a 2.8% gain over the uncoated sample. Different types of RW, PW, and WPCs based on tensile strength are compared in Figure 2.

The results demonstrate that coating RW, PW, and WPCs with non-toxic varnish and natural oil led to a measurable improvement in tensile strength compared with uncoated samples. The RW showed the most pronounced increase, likely due to effective oil penetration and enhanced fiber cohesion, which reduced microcrack formation under tensile loading. PW also exhibited improved tensile strength, suggesting that the coating helped stabilize veneer layers and maintain adhesive bond integrity by limiting moisture-induced stresses. In WPCs, the strength enhancement was more moderate but consistent, indicating improved interfacial bonding and stress transfer between the wood filler and polymer matrix. Overall, the coatings reduced surface defects and moisture sensitivity, enabling more uniform load distribution. These findings confirm that environmentally friendly surface treatments can effectively enhance tensile performance across different wood-based materials.

Additionally, these findings confirm the superior performance of non-toxic varnish coatings in enhancing tensile strength across all material types evaluated for elderly toy applications. The observed improvements were statistically significant ($p < 0.05$), supporting the efficacy of both coating methods, with non-toxic varnish demonstrating the most pronounced effect. Additionally, the consistently low standard deviations across measurements indicate high reliability and reproducibility of the results.

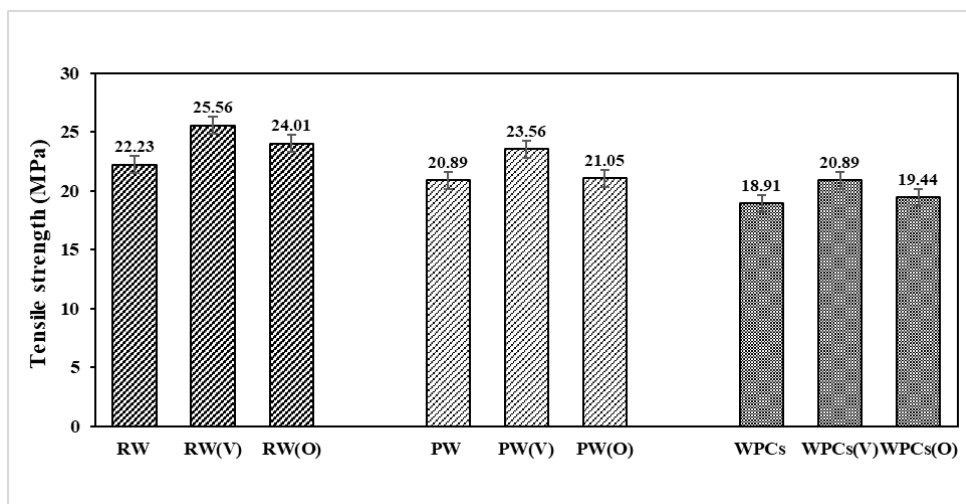


Figure 2. The tensile strength of RW, PW, and WPCs consists of original wood types and wood coated with non-toxic varnishes (V) and natural oil (O)

3.1.2 Bending strength analysis

Three-point bending tests were used to evaluate the strength values of uncoated RW, PW, and WPC samples and of coated surfaces using non-toxic varnishes and natural oil. Average bending strength and statistical analysis (ANOVA) of samples are shown in Table 1. It seems that surface coating of the wood panels significantly ($p < 0.05$) improved the bending strength of the specimens. Compared to RW, PW, and WPCs uncoated the surface, the highest bending strength of RW samples was 73.85, followed by the PW and WPCs

values of 62.14 MPa and 42.56 MPa, respectively. This experiment's results agree with Gao et al. (2019), who reported that the product manufactured from wood had the highest average compression strength compared to plywood and wood composites. However, the results show that the bending strength of RW was similar to that of tensile property [27, 28].

As shown in Figure 3, the samples RW, PW, and WPCs coated with non-toxic varnishes and natural oil as a constituent showed higher bending strength. The RW exhibited the highest bending strength among all tested materials, with an average untreated value of 73.85 MPa. Surface treatment with non-toxic varnish (V) significantly increased the bending strength to 76.21 MPa, reflecting a 3.2% improvement, while natural oil treatment (O) produced a more modest enhancement to 74.22 MPa (0.5% increase). The superior performance of the varnish treatment may be attributed to its enhanced surface hardening and moisture-barrier properties, which likely mitigate microcrack propagation under loading conditions. In comparison, the PW demonstrated a lower initial bending strength of 62.14 MPa but exhibited substantial gains following surface treatment. The application of varnish raised the bending strength to 66.20 MPa (+6.5%), whereas oil treatment increased it to 64.20 MPa (+3.3%). These enhancements suggest that surface treatments reinforce the plywood's laminar structure by improving interfacial adhesion and reducing sensitivity to inherent defects. Furthermore, the WPCs exhibited the lowest baseline bending strength at 42.56 MPa. Nevertheless, similar improvement trends were observed: varnish coating increased the bending strength to 44.90 MPa (+5.5%), while oil coating elevated it to 44.01 MPa (+3.4%). Although WPCs demonstrated lower absolute strength values, the relative improvements following surface treatment indicate that such coatings can effectively compensate for the material's limited internal bonding and matrix cohesion.

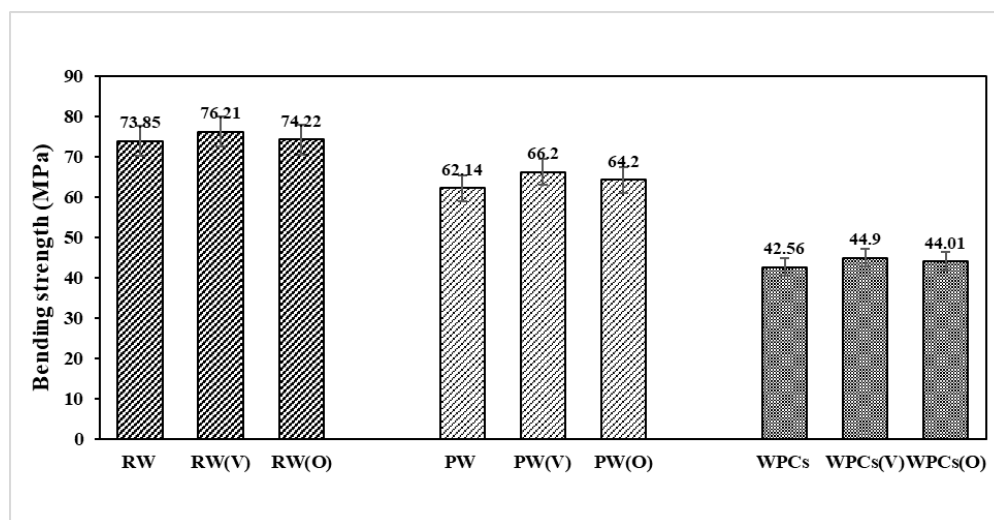


Figure 3. The bending strength of RW, PW, and WPCs consists of original wood types and wood coated with non-toxic varnishes (V) and natural oil (O)

The experimental results showing enhanced bending strength of RW, PW, and WPCs after surface coating with non-toxic varnish and natural oil can be explained by several complementary strengthening mechanisms. Bending performance is highly sensitive to surface integrity because maximum tensile and compressive stresses develop at the outer layers; the applied coatings form a continuous protective film that reduces surface flaws and delays crack initiation under flexural loading. For RW, natural oils penetrate surface pores and cell walls, improving fiber cohesion and reducing moisture-induced swelling and shrinkage, which helps preserve structural continuity during bending. For PW, the coating further stabilizes veneer interfaces and minimizes stress concentration at glue lines. In WPCs, the surface treatment improves interfacial compatibility between wood particles and the polymer matrix near the surface, promoting more effective stress transfer. Additionally, moisture regulation by the coatings reduces long-term degradation and stiffness loss, allowing the materials to sustain higher bending loads before failure [11].

Table 2. The physical properties analysis of the RW, PW, and WPCs samples

Types of Materials	Water	Thickness	Density test	Surface roughness	
	Absorption (%)	Swelling (%)	(g/cm ³)	Ra (μm)	Rz (μm)
RW	7.20 (0.22)	6.56 (0.41)	0.57 (0.01)	4.12 (0.57)	9.77 (0.25)
RW (V)	5.56 (0.39)	3.11 (0.47)	0.61 (0.03)	2.85 (0.91)	7.20 (0.41)
RW (O)	6.98 (0.52)	4.22 (0.55)	0.64 (0.02)	3.45 (0.41)	8.69 (0.66)
<i>p-value</i>	< 0.001*	< 0.001*	0.001*	< 0.001*	< 0.001*
PW	8.85 (0.42)	7.25 (0.12)	0.62 (0.02)	5.69 (0.52)	12.89 (0.20)
PW (V)	5.84 (0.75)	4.35 (0.56)	0.65 (0.02)	3.16 (1.22)	10.56 (0.50)
PW (O)	6.44 (0.19)	5.69 (0.51)	0.70 (0.03)	4.12 (0.57)	11.69 (0.41)
<i>p-value</i>	< 0.001*	< 0.001*	0.001*	< 0.001*	< 0.001*
WPCs	6.25 (0.19)	5.89 (0.22)	0.80 (0.01)	1.98 (0.21)	4.56 (0.61)
WPCs (V)	4.36 (0.27)	2.01 (0.41)	0.83 (0.02)	1.45 (0.85)	3.96 (0.10)
WPCs (O)	5.85 (0.42)	3.89 (0.74)	0.86 (0.01)	2.01 (0.11)	6.58 (0.27)
<i>p-value</i>	< 0.001*	< 0.001*	0.001*	0.001*	< 0.001*

Note: *Mean within each property is significant ($p < 0.05$)

The results underscore the effectiveness of surface treatments, particularly non-toxic varnish, in enhancing the bending strength of wood-based materials. The RW exhibited the highest absolute bending strength, affirming its suitability for elderly toy applications. Although the PW and WPCs demonstrated comparatively lower baseline strengths, both materials showed notable improvements following surface treatment [5, 16]. These enhancements suggest that such treatments may broaden their applicability in contexts that require greater mechanical resilience, including the development of elderly-friendly toys and sustainable furniture designs.

3.2 Physical properties analysis

The physical properties are an important part of evaluating the performance of an elderly person's toy. The responses, namely water absorption, thickness swelling, and surface roughness, are investigated. All experimental results were analyzed using analysis of variance (ANOVA) [18,27]. These physical results make them suitable for product design involving products with toys, especially elderly toys. Thus, it is important to consider this factor when using it in specific applications [28].

3.2.1 Water absorption (WA) and thickness swelling (TS) analysis

Water absorption and thickness swelling are critical indicators of dimensional stability and durability in hygroscopic environments, especially for materials intended for elderly toy applications. Table 2 summarizes the WA and TS values of untreated and treated wood-based composites, including sawn timber (RW), plywood (PW), and wood-plastic composites (WPCs). All treatments significantly affected both parameters ($p < 0.05$), indicating the efficacy of surface protection methods. The WA and TS with different wood and surface coatings are displayed in Figure 4 (a) and (b). Untreated RW exhibited water absorption of 7.20% and thickness swelling of 6.56%, reflecting its porous structure and high moisture uptake. Varnish treatment (RW(V)) significantly reduced WA to 5.56% and TS to 3.11%, representing a 22.8% and 52.6% decrease, respectively, compared to the control. Similarly, oil-treated samples (RW(O)) showed moderate improvements, with WA reduced to 6.98% and TS to 4.22%. The pronounced reduction in TS under varnish treatment highlights the sealing effect of polymeric coatings, which inhibit water ingress into cellular voids and limit dimensional changes. PW displayed the highest baseline water absorption (8.85%) and TS (7.25%) among all material types, likely due to adhesive interfaces and layered grain orientation that promote capillary pathways. Upon varnish treatment (PW(V)), WA dropped significantly to 5.84% and TS to 4.35%, yielding reductions of 34.0% and 40.0%, respectively. Oil treatment (PW(O)) also improved WA and TS, reducing them to 6.44% and 5.69%, respectively. These results suggest that although both surface modifications enhance water resistance, varnish remains more effective in limiting both water uptake and dimensional instability due to its continuous film formation across the surface. WPCs exhibited inherently lower water affinity due to the

hydrophobic nature of thermoplastic matrices, with baseline WA and TS values of 6.25% and 5.89%, respectively. After varnish treatment (WPCs(V)), WA further decreased to 4.36%, and TS decreased to 2.01%, corresponding to reductions of 30.2% and 65.9%, respectively. Oil-treated WPCs (WPCs(O)) recorded WA of 5.85% and TS of 3.89%, showing modest yet notable improvements. The relatively low untreated TS value indicates inherent dimensional stability, which is significantly bolstered by surface sealing, especially with varnish. The data support the conclusion that polymer-based coatings synergize well with composite matrices to suppress moisture-induced expansion further. All sample groups demonstrated statistically significant improvements in both WA and TS upon treatment ($p < 0.001$), affirming the efficacy of protective coatings. Varnish consistently outperformed oil in minimizing water-related degradation across all material types. The highest performance was observed in WPCs(V), which achieved the lowest TS of 2.01%, indicating exceptional dimensional resilience. Conversely, untreated PW exhibited the poorest moisture resistance, underscoring the need for protective strategies in layered wood products.

Moisture-induced dimensional instability can pose significant safety concerns for wooden toys for the elderly, including surface splintering, warping, and microbial growth in moist conditions. The findings of this study indicate that WPCs treated with varnish (WPCs(V)) offer the most stable, moisture-resistant option, making them ideally suited for environments with variable humidity. Varnished sawn timber (RW(V)) and plywood (PW(V)) also performed well, though the inherently hygroscopic nature of natural wood requires careful material selection and treatment optimization. Additionally, the choice between natural and composite materials should consider not only mechanical and acoustic performance (as discussed elsewhere in the paper) but also hygrothermal performance, particularly in elderly care facilities, where product durability and hygiene are paramount [14, 18].

3.2.2 Density analysis

Density is a fundamental physical property that influences a material's mechanical performance, moisture resistance, dimensional stability, and acoustic response, factors critical for elderly toy applications. Table 2 presents the density values of untreated and treated specimens of sawn timber (RW), plywood (PW), and wood-plastic composites (WPCs). Surface treatments with varnish and oil consistently increased density across all material types, with statistically significant differences ($p = 0.001$).

The untreated RW exhibited a baseline density of 0.57 g/cm³, consistent with typical values for lightweight tropical hardwoods. Upon application of varnish (RW(V)), density increased to 0.61 g/cm³, while oil treatment (RW(O)) yielded an even higher density of 0.64 g/cm³, a 12.3% increase over the untreated sample. The density increment is attributable to surface impregnation and pore-filling by finishing agents, which partially saturate the wood's cellular voids. Oil, being more penetrative, likely infiltrated deeper into the lumens and middle lamella, resulting in higher overall mass per volume. These enhancements indicate improved structural compactness, which correlates with greater dimensional stability and resistance to mechanical fatigue, both of which are essential for safe, long-lasting toy use. Plywood samples demonstrated a higher baseline density (0.62 g/cm³) than RW, reflecting their layered veneer configuration and adhesive content. Varnish-treated PW (PW(V)) reached 0.65 g/cm³, while oil-treated PW (PW(O)) showed a substantial increase to 0.70 g/cm³, representing a 12.9% improvement over the untreated variant. The significant density increase in PW(O) may be due to oil penetrating through glue lines and inter-veneer gaps, where it adds mass without significant volumetric expansion. This is due to PW being a laminated composite in which adjacent veneers are bonded by adhesive layers that are not completely impermeable. Micro-voids, capillaries, and discontinuities naturally exist within glue lines due to adhesive shrinkage, incomplete wetting, or pressing conditions. These features act as preferential pathways for oil ingress [1]. This densification is advantageous for toy durability, as it enhances impact resistance and load-bearing capacity while also improving surface smoothness and splinter resistance, thereby enhancing user safety for elderly individuals. WPCs had the highest intrinsic density (0.80 g/cm³) among all tested materials due to the presence of polymer matrices (e.g., polyethylene or polypropylene) and uniformly distributed wood particles. Surface treatments further improved this value to 0.83 g/cm³ (WPCs(V)) and 0.86 g/cm³ (WPCs(O)). The 7.5% increase in density post-oil treatment suggests not only surface adherence but also limited penetration into voids between wood fibers and polymer domains, despite the composite's generally low porosity. The resulting densified surface layer

enhances the moisture barrier properties and abrasion resistance, making WPCs highly favorable for hygienic, durable toy products where surface integrity and long-term cleanliness are crucial.

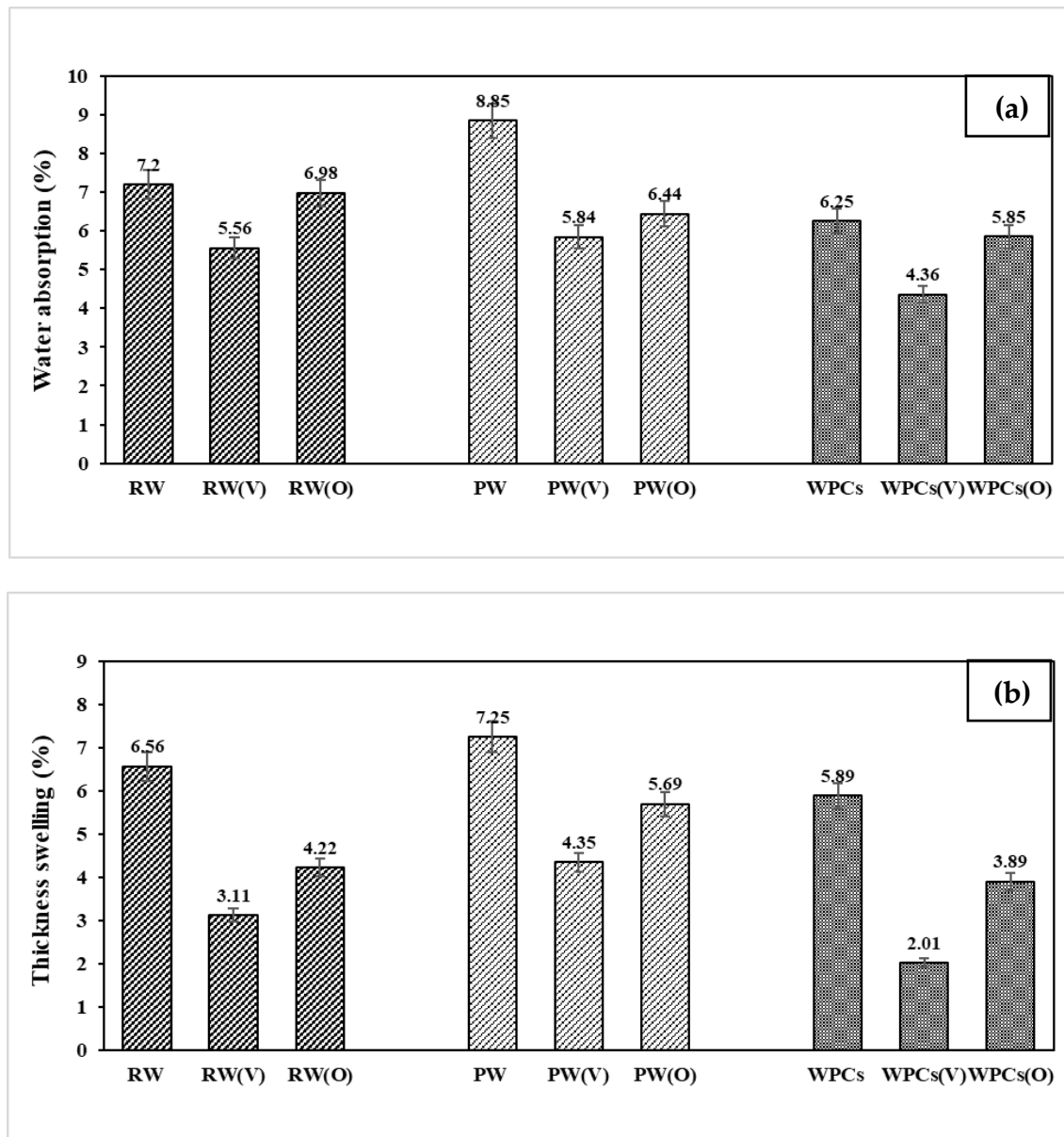


Figure 4. Effect of wood types with uncoated and coated surfaces of RW, PW, and WPCs samples: (a) water absorption and (b) thickness swelling properties.

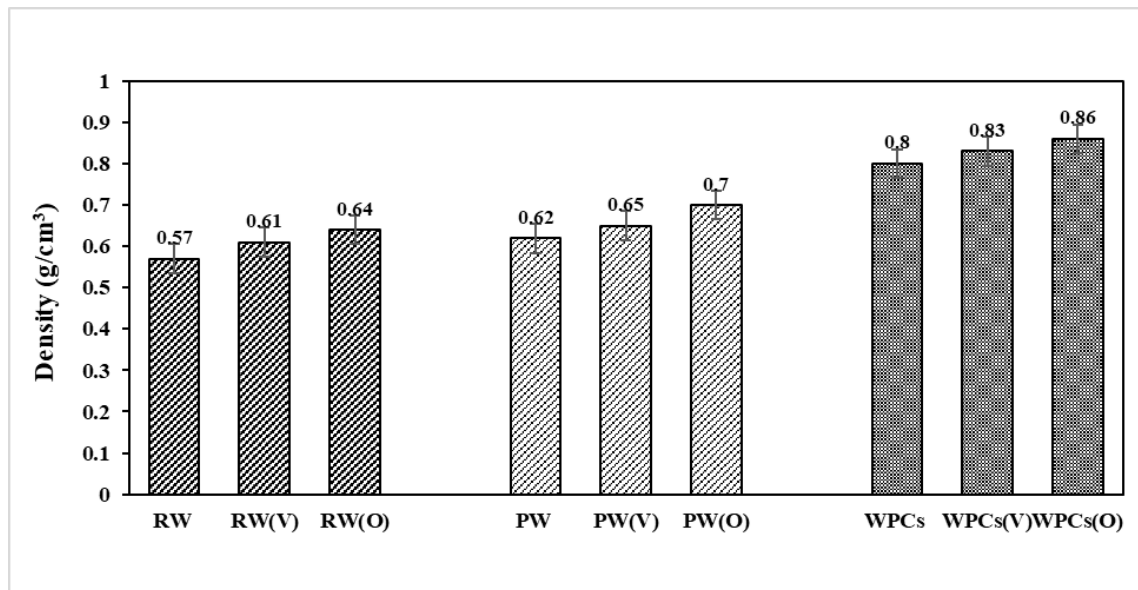


Figure 5. Effect of wood types with uncoated and coated surfaces of RW, PW, and WPCs samples on density analysis

Across all material types, density increases from both varnish and oil treatments were statistically significant ($p = 0.001$), confirming the physical impact of surface modification. Oil consistently produced greater density increases than varnish, likely due to its higher absorption and mass retention within the porous matrix [3,19]. These findings are especially relevant for elderly toy applications, where mechanical durability, dimensional consistency, and weight optimization must be balanced for both usability and safety. Moreover, the higher densities observed in treated WPCs and PW suggest enhanced structural performance, while treated RW remains a viable low-density alternative where lightweight handling is prioritized [11,22].

3.2.3 Surface roughness analysis

Surface roughness plays a pivotal role in determining tactile comfort, safety, hygiene, coating adhesion, and aesthetic appeal, all of which are crucial for elderly-oriented products. The roughness parameters R_a (arithmetical mean deviation) and R_z (mean peak-to-valley height) are presented in Table 2 for all untreated and treated material types. Results demonstrate that both varnish and oil surface treatments significantly improved surface smoothness, with varnish performing better in most cases.

As shown in Figure 5, the untreated sawn timber exhibited moderate surface roughness, with $R_a = 4.12 \mu\text{m}$ and $R_z = 9.77 \mu\text{m}$, indicative of the naturally open grain structure and cellular porosity of raw wood. In the absence of coating, the results indicate that surface roughness is strongly influenced by specimen preparation. Differences in machining method and cutting direction resulted in noticeable variations in surface texture, including fiber tearing and tool marks. Sanding procedures further modified roughness by reducing machining defects, with finer grit sizes producing smoother surfaces. In PW, the alternating veneer orientations amplified these effects, resulting in non-uniform roughness across specimens. Surface finishing before measurement reduced roughness by filling surface irregularities and limiting fiber protrusion. Overall, the findings highlight the need for consistent and controlled specimen preparation to ensure reliable surface roughness measurements.

After varnish application (RW(V)), roughness was reduced to $R_a = 2.85 \mu\text{m}$ and $R_z = 7.20 \mu\text{m}$, corresponding to 30.8% and 26.3% reductions, respectively. This is attributed to the film-forming nature of varnish, which fills in surface voids and levels micro-irregularities. Oil treatment (RW(O)) also improved surface characteristics, yielding $R_a = 3.45 \mu\text{m}$ and $R_z = 8.69 \mu\text{m}$, though its effect was less pronounced than that of varnish. Oils primarily penetrate surface fibers, enhancing grain definition rather than forming a uniform surface layer. These improvements are critical for reducing splinter risk and enhancing tactile safety, especially in hand-held toys for the elderly. Plywood exhibited the highest initial roughness of all materials, with $R_a = 5.69 \mu\text{m}$ and $R_z = 12.89 \mu\text{m}$, due to interfacial undulations between veneers and inconsistent grain

directions. Varnish treatment (PW(V)) significantly reduced surface irregularity to $R_a = 3.16 \mu\text{m}$ and $R_z = 10.56 \mu\text{m}$, resulting in 44.5% and 18.1% reductions, respectively. Oil treatment (PW(O)) achieved moderate reductions to $R_a = 4.12 \mu\text{m}$ and $R_z = 11.69 \mu\text{m}$, still offering improved smoothness but with limited peak-to-valley correction. These changes suggest that while oil improves the surface at a microstructural level, varnish is more effective in sealing and leveling layered wood products. For elderly toy applications, smoother plywood surfaces enhance cleanability and reduce the potential for microbial harborage in micro-crevices. Untreated WPCs had the lowest baseline roughness among all materials, with $R_a = 1.98 \mu\text{m}$ and $R_z = 4.56 \mu\text{m}$, owing to the homogeneous dispersion of wood particles in the polymer matrix and minimal grain irregularities. Varnish-treated WPCs (WPCs(V)) further improved smoothness, with $R_a = 1.45 \mu\text{m}$ and $R_z = 3.96 \mu\text{m}$, which represents reductions of 26.8% and 13.2%, respectively. Interestingly, oil-treated WPCs (WPCs(O)) had a slight increase in R_z to $6.58 \mu\text{m}$, despite a nearly unchanged R_a ($2.01 \mu\text{m}$). This suggests that non-uniform oil absorption or partial surface aggregation might have introduced localized peaks or valleys, increasing peak-to-valley variation. Despite this, the overall surface profile remained smoother than untreated wood-based materials. The excellent surface quality of WPCs, especially when varnish-treated, reinforces their suitability for products that require high tactile comfort, low microbial retention, and aesthetically pleasing finishes. All of the experimental results are shown in Figure 6 (a) and (b)

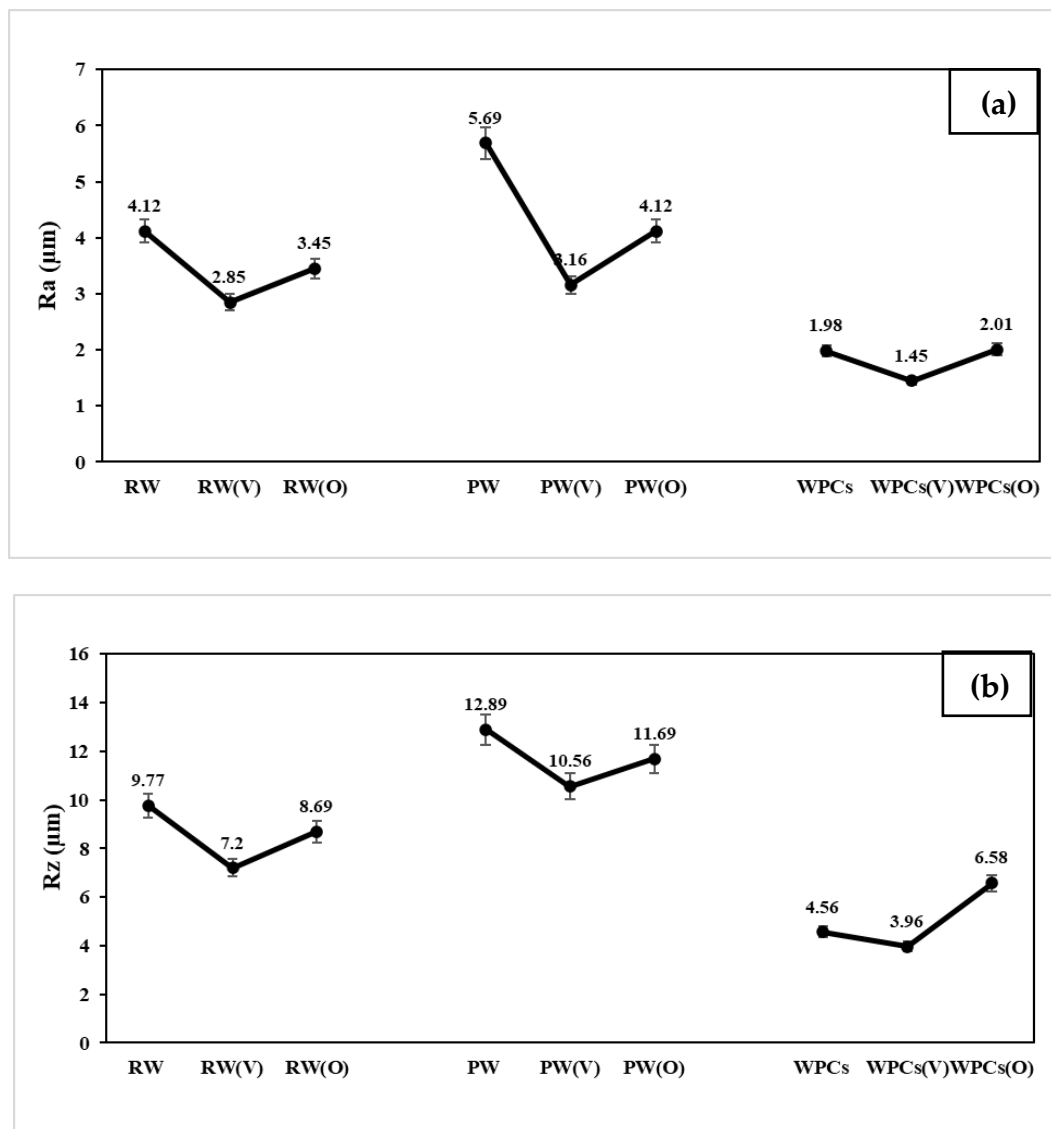


Figure 6. Effect of wood types with uncoated and coated surface of RW, PW, and WPCs samples on surface roughness properties: (a) R_a and (b) R_z .

Statistical analysis confirmed that all surface treatments produced significant improvements in Ra and Rz values across material types ($p < 0.05$). The largest improvements were observed in sawn timber and plywood, both of which have naturally uneven or fibrous textures. Varnish outperformed oil in all cases due to its ability to create a uniform sealing layer that masks surface irregularities. In elderly applications, surface roughness is more than an aesthetic concern—it directly impacts usability, hygiene, and injury prevention. Materials with smoother surfaces are less likely to harbor pathogens, cause skin irritation, or lead to splinters. Thus, varnish-treated WPCs, followed by varnish-treated RW and PW, emerge as optimal candidates for safe and ergonomic toy surfaces.

Table 3. Heavy metal content based on chemical analysis from different RW, PW, and WPC materials

Elements	Initials	RW (mg/kg)	PW (mg/kg)	WPCs (mg/kg)
Antimony	Sb	12.44	13.45	20.62
Arsenic	As	3.56	4.78	5.01
Barium	Ba	256.21	285.69	331.02
Cadmium	Cd	20.54	22.01	28.56
Chromium	Cr	15.89	17.20	19.52
Lead	Pb	8.14	10.14	14.19
Mercury	Hg	21.09	22.02	26.10
Selenium	Se	156.23	159.85	193.82

3.3 Chemical properties analysis

The evaluation of toxic and recalcitrant heavy metal content in elderly toys is critical to ensure environmental health and safety [1,3,4]. Although several techniques have been developed to address the heavy metal content of children's and the elderly's toys, they still face many challenges. In addition, there is still a lack of a comprehensive and insightful understanding of the relevant mechanisms. Generally, the prevalent methods for heavy metal content elimination, such as physical separation and chemical decomplexation, are briefly presented and evaluated. In particular, the characterization methods for heavy metal content, which provide valuable information on the speciation distribution of heavy metals, are underlined and discussed. In this work, the heavy metal content elimination of elderly's toy was measured using chemical decomplexation with eight elements, namely Antimony (Sb), Arsenic (As), Barium (Ba), Cadmium (Cd), Chromium (Cr), Lead (Pb), Mercury (Hg), and Selenium (Se), as shown in Table 3. Compared to toy products according to the ASTM F 963 standards (ASTM 2008), which are watercolor products that can be touched directly with their hands. It is found that the amounts of Sb, As, Ba, Cd, Cr, Pb, Hg, and Se must not exceed 60, 25, 1,000, 75, 60, 90, 60, and 500 mg/kg, respectively [5]. As expected, the RW, PW, and WPC materials can be used to produce the elderly's toy. The toy made from RW had lower heavy metal content than that of PW and WPCs. The results show the minimum heavy metal content values of 12.44, 3.56, 256.21, 20.54, 15.89, 8.14, 21.09, and 156.23 mg/kg, respectively. The outcome of this study agreed with toy safety directive migration limits that define ranges for heavy metals like Cd, Pb, As, and Sb in scraped toy material, for example, the Cd (20.54 mg/kg) lies close to some total content limits for wood (50 mg/kg) and below many toy migration thresholds [29]. Pb (8.14 mg/kg) and As (3.56 mg/kg) are well below many regulatory benchmarks (Pb is often allowed 90 to 160 mg/kg in toy material analyses), indicating low total content relative to industry limits. Sb (12.44 mg/kg) is also below many established migration-based values (45-560 mg/kg in toy materials) [30].

In general, the higher the heavy metal content, the more colorful and bright the toys are. Previous industrial studies have shown that the brighter the color of toys, the higher their heavy metal content, such as Pb. Pb compounds mainly cause this in paint pigments such as yellow, red, and white, which can maintain bright colors for a long time. This may suggest that the brighter the color, the more likely it is that there will be a large amount of Pb [2,7]. Additionally, the heavy metal content causes damage to elderly's health. The surface coating may introduce heavy metals into the body through contact friction with the human body or through the action of a suitable solvent. It can be stated that the heavy metal content can migrate into the

human body through a suitable medium. FE-SEM micrographs of elderly toys made from different materials are shown in Figure 7. Micrographs of the toy with RW, PW, and WPCs are shown in Figures 7(a), 7 (b), and 7 (c), respectively. The outcome of this study found that the elderly's toy manufactured from WPC material had a higher density than those manufactured from RW and PW materials. This might explain the high density of the elderly's toy made from WPCs, due to the rubberwood flour containing high amounts of lignin and natural waxes, which produce better dispersion and adhesion to non-polar hydrocarbon plastics. Additionally, the use of additives, such as filler-added composite materials, and the compounding of non-cellulosic products, such as lignin, hemicellulose, and waxes, makes it easier for the rubberwood particles to adhere to the recycled polypropylene matrix. High-density toy products resulted in higher toy weight [14,28]. For the elderly's toy, this suggests that this factor is a part of variety for learning, it stimulates the muscle response of the elderly, especially small muscles (fine motor skill) in muscle parts from the wrists, palms, and every finger, because most wooden or wood composite toys are quite heavy and not light [18,20]. Therefore, the elderly were able to get some exercise by touching weighty toys. This is a way to train the elderly to notice, feel, and differentiate volume and weight.

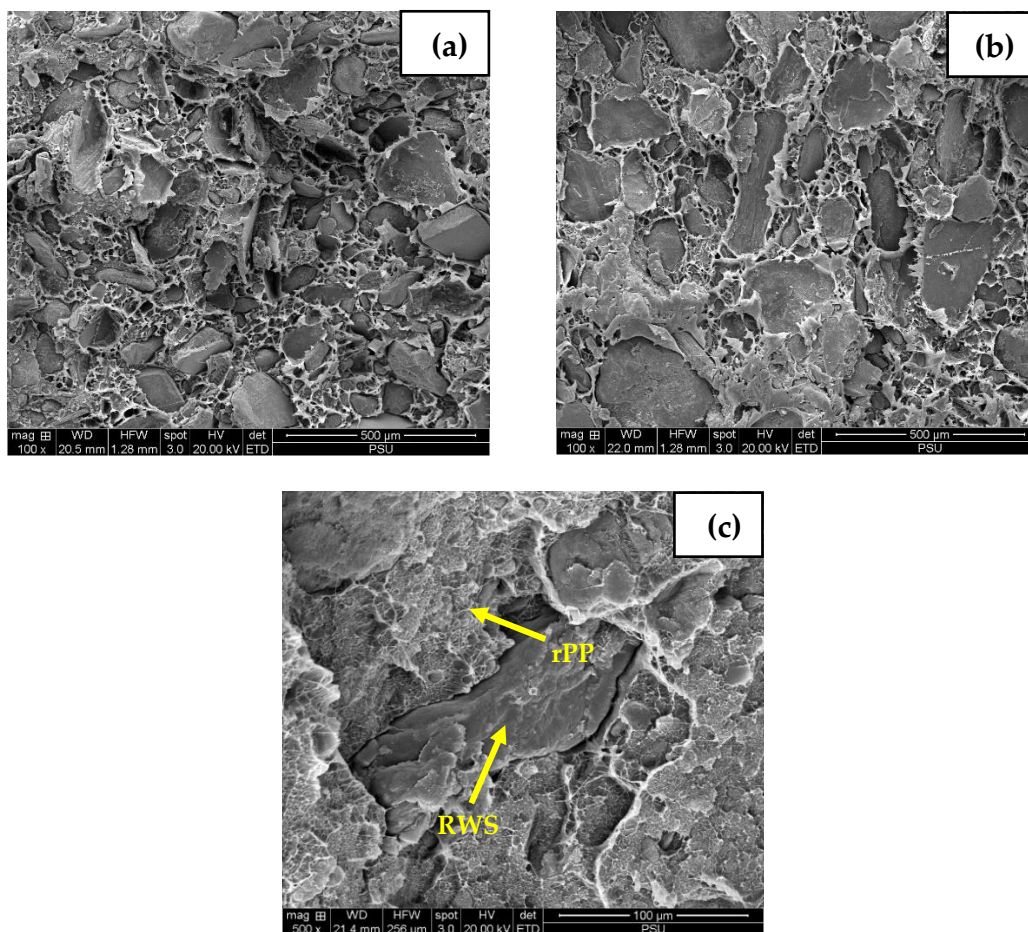


Figure 7. FE-SEM images of the different types of materials at magnifications of 100×: (a) RW, (b) PW, and (c) WPCs.

4. Conclusions

The goal of this research is to develop toys that enhance the potential of older people in various areas. The elderly's toy products were evaluated for their performance based on mechanical, physical, and chemical properties to ensure appropriate use for the elderly. The following conclusions could explain these results:

- All mechanical properties, namely tension and bending tests, showed that the elderly's toy products manufactured from RW had enhanced strength values compared to those of the PW and WPC samples.

- The lowest WA and TS properties, 4.36% and 2.01%, were observed in elderly toy products manufactured from WPC samples, whereas the minimum Ra value of 1.45 μm was observed in WPC samples.
- The density of the samples increases with both varnish and oil treatments. Oil consistently produced greater density increases than varnish. The highest surface treatments were improved for WPCs, with values of 0.83 g/cm³ (V) and 0.86 g/cm³ (O).
- Both the varnish and oil surface treatments significantly improved the smoothness of the samples' surfaces. The minimum Ra value of 1.45 μm was observed in WPCs.
- Heavy metal content, based on chemical analysis, of elderly toy products manufactured from different RW, PW, and WPCs was found to be within specified standards, indicating that these products are safe for the elderly.
- The surface observation of the samples and the product is clearly explained by the presence of fractures and cracks. The elderly's toy products made from WPCs showed smooth surfaces, greater agglomeration, and fewer pores and voids, due to the strong interfacial adhesion between the plastic matrix and the rubberwood fiber reinforcement.

Based on the study's experimental results, several limitations can be identified. The study focused on a limited number of wood types and did not account for long-term durability and aging effects typical of care facilities. In addition, user-based evaluations involving elderly participants were not included. Future research should expand the range of materials and coatings, examine long-term safety and hygiene performance, and incorporate usability testing with elderly users to better inform design and material selection.

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References

- [1] Mustafa, O. Contribution of plays and toys to children's value education. *Asia J. Res. Educ. Soc. Sci.* **2018**, *4*, 146-149. <https://doi.org/10.20448/journal.522.2018.42.146.149>
- [2] Dag, N.C.; Turkkan, E.; Kacar, A.; Day, H. Children's only profession: Playing with toys. *North. Clin. Istanbul.* **2021**, *8*, 414-420. <https://doi.org/10.14744/nci.2020.48243>
- [3] Dauch, C.; Imwalle, M.; Ocasio, B.; Metz, A.E. The influence of the number of toys in the environment on toddlers' play. *Infant. Behav. Dev.* **2017**, *50*, 78-87. <https://doi.org/10.1016/j.infbeh.2017.11.005>
- [4] Komis, V.; Karachristos, C.; Mourta, D.; Sgoura, K.; Misirli, A.; Jaillet, A. Smart toys in early childhood and primary education: A systematic review of technological and educational affordances. *Appl. Sci.* **2021**, *11*, 8653. <https://doi.org/10.3390/app11188653>
- [5] Guha, S.; Murthy, K. Understanding the role toys in child development: Special focus on traditional channapatna toys. *Indian J. Appl. Res.* **2017**, *7*, 406-410. <https://doi.org/10.36106/IJAR>
- [6] Gao, H.; Fu, J.; Xing, X. Research on the design of children's toys and teaching AIDS based on sound science. *E3S Web of Conferences.* **2021**, *179*, 02025. <https://doi.org/10.1051/e3sconf/202017902025>
- [7] Bai, O. Research on the design of interactive children's vocal enlightenment toys based on audiovisual association experience. *Occup. The. Int.* **2023**, 35495176. <https://doi.org/10.1155/2023/9824371>

- [8] Lang, L. Research on design method of children's teaching assisted toys based on STEAM education. *Open J. Soc. Sci.* **2021**, *9*, 628-635. <https://doi.org/10.4236/jss.2021.99046>
- [9] Gavrilova, M.; Sukhikh, V.; Veresov, N. Do executive function and family factors predict children's preference for trendy over classic toys? An experimental investigation. *Front. Psychol.* **2023**, *14*, 1-6. <https://doi.org/10.3389/fpsyg.2023.1190876>
- [10] Ma, M.Y.; Lee, Y.H. Children with autism and composite tactile-visual toys during parent-child interaction. *Interact. Stud.* **2014**, *15*, 120-124. <https://doi.org/10.1075/is.15.2.13ma>
- [11] Salim, R.; Johansson, J. The influence of raw material on the wood product manufacturing. *Procedia CIRP.* **2016**, *57*, 764-768. <https://doi.org/10.1016/j.procir.2016.11.132>
- [12] Rodrigues, M.O.; Abrantes, N.; Gonçalves, F.J.M.; Nogueira, H.; Marques, C.J.; Gonçalves, A.M.M. Impacts of plastic products used in daily life on the environment and human health: What is known? *Environ. Toxicol. Pharmacol.* **2019**, *72*, 103239. <https://doi.org/10.1016/j.etap.2019.103239>
- [13] Elsheikh, A.H.; Panchal, H.; Shanmugan, S.; Muthuramalingam, T.; El-Kassas, A.M.; Ramesh, B. Recent progresses in wood-plastic composites: Pre-processing treatments, manufacturing techniques, recyclability and eco-friendly assessment. *Clean. Eng. Technol.* **2022**, *8*, 100450. <https://doi.org/10.1016/j.clet.2022.100450>
- [14] Khamtree, S.; Homkhiew, C.; Srivabut, C.; Ratanawilai, T.; Rawangwong, S.; Hiziroglu, S. Evaluation of mechanical properties of composites made from recycled plastic and waste rubberwood using multiply-response surface optimization as green building materials. *Fiber. Polym.* **2023**, *24*, 2819-2834. <https://doi.org/10.1007/s12221-023-00266-w>
- [15] Homkhiew, C.; Srivabut, C.; Boonchouytan, W.; Ratanawilai, T.; Rawangwong, S. Optimization of the physical properties of recycled plastic hybrid composites reinforced with Rubberwood flour and crab shell flour for underwater use. *Compos. C: Open Access* **2023**, *12*, 100411. <https://doi.org/10.1016/j.jcomc.2023.100411>
- [16] Hala, B.; Kamal, G.; Hamid, E.; Denis, R.; Rachid, B.; Qaiss, A.E.K. Mechanical, thermal, and rheological properties of polypropylene hybrid composites based clay and graphite. *J. Compos. Mater.* **2016**, *51*, 36-43. <https://doi.org/10.1177/0021998317690597>
- [17] Laraba, S.R.; Rezzoug, A.; Halimi, R.; Wei, L.; Yang, Y.; Abdi, S.; Li, Y.; Jie, W. Development of sandwich using low-cost natural fibers: Alfa-Epoxy composite core and jute/metallic mesh-Epoxy hybrid skin composite. *Ind. Crops. Prod.* **2022**, *184*, 115093. <https://doi.org/10.1016/j.indcrop.2022.115093>
- [18] Homkhiew, C.; Cheewawuttipong, W.; Srivabut, C.; Boonchouytan, W.; Rawangwong, S. Machinability of wood-plastic composites from the CNC milling process using the Box-Behnken design and response surface methodology for building applications. *J. Thermoplas. Compos. Mater.* **2024**, 1-20. <https://doi.org/10.1177/08927057241248036>
- [19] Guo, G.; Finkenstad, V.L.; Nimmagadda, Y. Mechanical properties and water absorption behavior of injection-molded wood fiber/carbon fiber high-density polyethylene hybrid composites. *Adv. Compos. Hybrid Mater.* **2019**, *2*, 690-700. <https://doi.org/10.1007/s42114-019-00116-5>
- [20] Liu, H.; Wang, J.; Gong, C.; Cheng, F. Morphology and mechanical properties of PVC/straw-fiber coated with liquid nitrile-butadiene rubber composites. *J. Appl. Polym. Sci.* **2016**, *133*, 44119. <https://doi.org/10.1002/app.44119>
- [21] Kara, N.; Cagiltay, K. Smart toys for preschool children: A design and development research. *Electron Commer. Res. Appl.* **2020**, *39*, 100909. <https://doi.org/10.1016/j.elerap.2019.100909>
- [22] Xian, Y.; Wang, C.; Wang, G.; Ren, W.; Cheng, H. Understanding the mechanical and interfacial properties of core-shell structured bamboo-plastic composites. *J. Appl. Polym. Sci.* **2015**, *133*, 43053. <https://doi.org/10.1002/app.43053>
- [23] Prabhu, R.; Mendonca, S.; Souza, R.; Bhat, T. Effect of water absorption on the mechanical properties of alkaline treated bamboo and flax fiber reinforced epoxy composites. *Trends. Sci.* **2022**, *19*, 5779. <https://doi.org/10.48048/tis.2022.5779>
- [24] Xue, L.; Yi, X.; Zhang, Y. Research on optimized product image design integrated decision system based on Kansei Engineering. *Appl. Sci.* **2022**, *10*, 1198. <https://doi.org/10.3390/app10041198>

-
- [25] Lu, R.J.; Feng, Y.X.; Zheng, H.; Tan, J.R. A product design based on interaction design and axiomatic design theory. *Procedia CIRP*. **2016**, 53, 125-129. <https://doi.org/10.1016/j.procir.2016.07.061>.
- [26] Essabir, H.; Boujmal, R.; Bensalah, M.O.; Rodrigue, D.; Bouhfid, R.; Qaiss, A.E.K. Mechanical and thermal properties of hybrid composites: oil-palm fiber/clay reinforced high density polyethylene. *Mech. Mater.* **2016**, 98, 36-43. <https://doi.org/10.1016/j.mechmat.2016.04.008>
- [27] Srivabut, C.; Homkhiew, C.; Rawangwong, S.; Boonchouytan, W. Possibility of using municipal solid waste for manufacturing wood-plastic composites: effects of natural weathering, wood waste types, and contents. *J. Mater. Cycles. Waste Manag.* **2022**, 24, 1407-1422. <https://doi.org/10.1007/s10163-022-01443-4>
- [28] Saeb, M.R.; Moghri, M. Application of response surface methodology in describing fusion characteristics of rigid poly(vinyl chloride) / nanoclay/ wood flour/ calcium carbonate hybrid nanocomposites. *J. Vinyl. Technol.* **2014**, 34, 183-190. <https://doi.org/10.1002/vnl.21387>
- [29] Guney, M.; Zagury, G.J. Bioaccessibility of As, Cd, Cu, Ni, Pb, and Sb in toys and low-cost jewelry. *Environ. Sci. Technol.* **2013**, 48, 1238-1246. <https://doi.org/10.1021/es4036122>
- [30] Fadaei, A. An investigation into the present levels of contamination in children's toys and jewelry in different countries: a systematic review. *Rev. Environ. Health.* **2023**, 38, 601-611. <https://doi.org/10.1515/reveh-2022-0064>