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Radyal Mozaik Parke Üretiminde Kontrplak Uygulaması: Boyutsal Kararlılık ve Mukavemet Özellikleri

Süheyla Esin Köksal[1,*], Orhan Kelleci[2]

[1, 2] Bolu Abant İzzet Baysal Üniversitesi, Mudurnu Süreyya Astarcı Meslek Yüksekokulu, Ormancılık Bölümü, Bolu, Türkiye

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Araştırma Makalesi

Öz – Ahşap esaslı kompozit malzemeler, dayanıklılıkları ve doğal görünümleri sayesinde özellikle iç mekân zemin kaplamalarında yaygın olarak tercih edilmektedir. Bu çalışmanın amacı, film kaplı ve kaplamasız kontrplak levhaların radyal yönde bir araya getirilmesi ile Radyal Mozaik Parke (RMP) üretmek ve bu RMP örneklerinin TSE standartlarına göre fiziksel ve mekanik özelliklerini karşılaştırmaktır. Bu sayede ahşap parkelerde budak gibi kusurların önlenmesi, suya maruz kalma durumunda kalınlığına şişme miktarının azaltılması ve daha geniş alanları tek parça halinde kaplayabilen parkelerin üretilmesi amaçlanmıştır. Radyal yönde üretilen parke örneklerine mekanik ve fiziksel analizler gerçekleştirilmiştir. Su absorpsiyon oranları RMP ve kontrol örnekleri arasında anlamlı bir farklılık göstermemiştir, fakat kalınlığına şişme oranının RMP örneklerinde %70–80 oranında daha düşük olduğu tespit edilmiştir. RMP'lerin nem karşısında boyutsal olarak daha kararlı olduğu belirlenmiştir. Eğilme dayanımı açısından örnekler arasında anlamlı fark gözlenmemiştir; ancak RMP'nin elastikiyet modülü ve vida tutma direncinin klasik kontrplak örneklerine kıyasla daha düşük olduğu belirlenmiştir. Genel olarak, RMP'ler boyutsal kararlılıkları ve estetik avantajlarıyla özellikle nemli ortamlarda uygulanabilecek alternatif bir parke çözümü olarak öne çıkmaktadır.

Anahtar Kelimeler – *Kontrplak, parke, mekanik mukavemet, fiziksel özellikler, radyal mozaik parke*

Application of Plywood in Radial Mosaic Parquet Production: Dimensional Stability and Strength Properties

[1,2] Department of Forestry, Mudurnu Sureyya Astarci Vocational School, Bolu Abant Izzet Baysal University, Bolu, Turkey

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Research Article

Abstract – Wood-based composite materials are widely preferred, especially in interior flooring applications, due to their durability and natural appearance. The aim of the study is to produce Radial Mosaic Parquet (RMP) by combining film-faced and uncoated plywood panels in a radial orientation and to compare the physical and mechanical properties of these RMP samples according to TSE standards. In this way, it is intended to prevent defects such as knots in wooden parquet, reduce the thickness swelling when exposed to moisture, and produce parquet that can cover larger areas in a single piece. Mechanical and physical analyses were carried out on parquet samples produced in radial direction. No significant difference was observed in the water absorption rates between the RMP and control samples; however, the swelling in thickness ratio of the RMP samples was found to be 70–80% lower. It was determined that RMP exhibits better dimensional stability in response to moisture. While no significant difference was observed in terms of flexural strength between the samples, the modulus of elasticity and screw retention strength of the RMP were lower compared to conventional plywood samples. Overall, RMP stands out as an alternative flooring solution, particularly suitable for humid environments, due to its dimensional stability and aesthetic advantages.

Keywords – *Plywood, parquet, mechanical strength, physical properties, radial mosaic parquet*

[1] esinkoksal@ibu.edu.tr
[2] orhankelleci@ibu.edu.tr
*Sorumlu Yazar / Corresponding Author

1. Inroduction

Wood-based materials have been widely utilized in furniture and interior cladding throughout history due to their natural composition, ease of processing, cost-effectiveness, and availability (James Josue & Zamrie Imiyabir, 2015). One of the areas where wood is used most is flooring. Floors are horizontal structural elements that separate building levels and serve as load-bearing, space-defining, and insulating components. They consist of four layers: flooring, underlayment, structural system, and ceiling. Flooring materials protect surfaces from external factors while providing aesthetics, safety, comfort, and functionality (Calloway S., 1997; Hwalla et al., 2025; Özdöl, 2010).

Various materials are used for flooring, including concrete, stone, ceramic, glass, cork, carpet, polymer, rubber, linoleum, metal, and wood. Various types of wood-based flooring materials are currently in use, including solid wood, engineered wood, bamboo, thermowood, marquetry and laminate flooring (Faircloth et al., 2023).

Solid wood flooring is made entirely of natural wood and typically has a thickness ranging from 14 to 22 mm. Because it is a single piece of wood, it is highly durable and can be sanded and refinished multiple times. However, it is sensitive to moisture and temperature changes, which can cause expansion and contraction. Installation requires adhesive or nails to secure it to the subfloor. Engineered wood flooring, provides the appearance of solid wood while being more durable. It consists of three layers: a top layer of real wood (2-4 mm thick), a middle layer of plywood or MDF, and a bottom layer of support wood. Compared to solid wood, engineered flooring is less likely to expand or contract due to moisture. It is also easier to install. However, because the top layer is thin, it can only be sanded a limited number of times (Leggate, 2018).

Bamboo flooring is an eco-friendly option made from compressed bamboo fibers. It is naturally resistant to water and highly durable. Due to its hardness, installation and cutting may be more challenging compared to traditional wood flooring. Bamboo flooring is considered a sustainable choice because bamboo grows quickly and regenerates rapidly (Scheiding et al., 2022).

ThermoWood is a type of heat-treated wood that has increased durability and resistance to moisture. The thermal modification process enhances its stability and prevents decay and insect damage. This makes ThermoWood ideal for high-humidity environments such as bathrooms or kitchens. However, the heat treatment process can reduce the wood's strength (Järvinen et al., 2022).

Marquetry parquet (Mosaic parquet, plank parquet, tile parquet) is made by cutting solid wood pieces of different colors, using hand tools in the past and lasers today, and then joining them together to create simple or complex geometric shapes or natural motifs (Bal et al., 2019). It has an aesthetically pleasing appearance but is quite expensive compared to other types of parquet. It is produced in sizes ranging from 50x50 cm to 100x100 cm. It provides a highly aesthetically pleasing finish to large floors in buildings, but its high cost limits its application (Fawcett, 2007).

Laminate flooring is generally preferred in interior spaces. Laminate flooring has a decorative surface similar to wood but is made of melamine resin and high-density fiberboard (HDF). It typically ranges in thickness from 6 to 12 mm. Laminate is highly durable and resistant to scratches and moisture. It is easy to install using a click-lock system. However, it does not provide the same feel as real wood, and the surface cannot be sanded once it wears out (Sotayo et al., 2020).

Choosing the right type of wooden flooring depends on factors such as usage area, budget, and durability expectations. Solid and engineered wood offers a natural appearance, while laminate and bamboo flooring provide cost-effective and durable alternatives. ThermoWood is an excellent choice for moisture-prone areas. By considering the characteristics of each type, users can make an informed decision about the best flooring for their needs (Jones & Sandberg, 2020).

In this study, a novel mosaic parquet was produces as named “Radial Mosaic Parquet” (RMP). This parquet was designed because it can be preferred for large areas like big shopping centers with low thickness swelling and without knot appearance. This method can be an alternative to marquetry parquet with its easy production, low cost and the possibility of producing larger sizes. Film coated and uncoated plywood were used in RMP production. In this way, it was investigated how the film layer affected the physical and mechanical properties. In addition, two different glues (Polyurethane-PU and Neoprene-NP) were used to investigate how the glue type would affect the parquet strengths. Also, the RMP production method developed in this study offers several advantages for industrial applications. In traditional solid parquet production, the need to groove the edges increases labor time and costs. However, the RMP design eliminates this need. Similar to tile parquet flooring, its simple adhesive application makes installation easier and faster. These features make RMP particularly advantageous for mass production processes and modern production technologies. This reduces labor time during production and simplifies installation, reducing overall costs.

2. Material and Method

The materials and methods used in the study are explained below.

2.1. Materials

18 mm thick plywood (7 ply-pine) whose surface covered with a film (Figure 1a) and uncovered one (Figure 1b) were used to produce the RMP analysis samples. The film used to cover the plywood surface is kraft paper impregnated with phenolic resin. Pressed at high temperatures, the phenolic resin takes on a dark brown color. It forms an effective barrier against water on the board surface. Plywood (made in Russia) were purchased from the local market. 2 different adhesives were used to bond the plywood together. The first is polyurethane adhesive and the second is neoprene (rubber) adhesive. Adhesives were purchased from the local market. Some technical data on the adhesives used are given in Table 1. PU and rubber-based wood glues were used in the study.

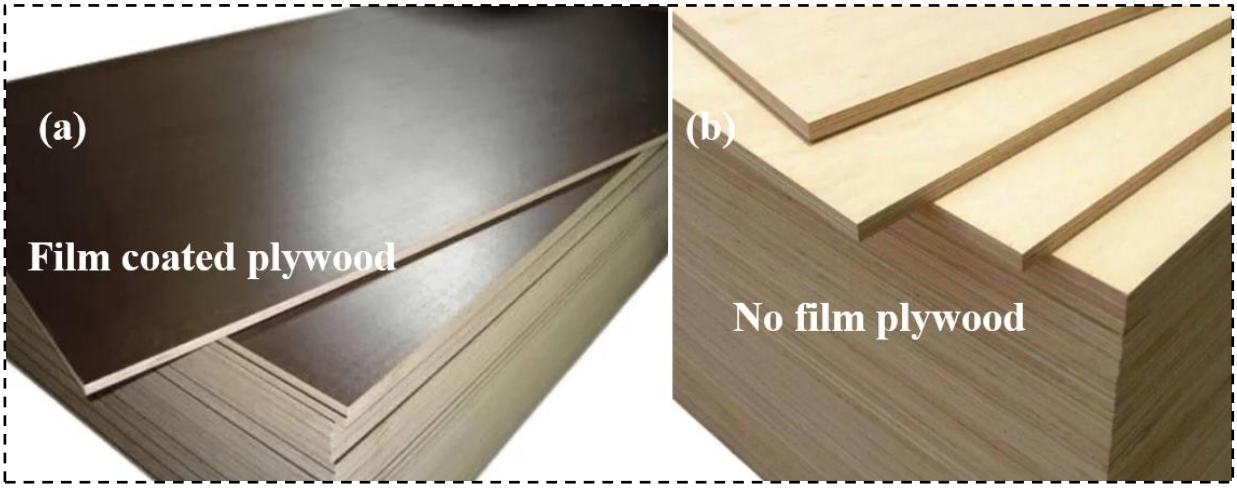


Figure 1. Film coated plywood (a), uncoated plywood (b)

Table 1.
Some technical properties of adhesives

Polyurethane (PU) adhesive properties	
Identify	One component PU
Appearance	Liquid
Flash point	Above 100 ºC
Viscosity	2300 Mpa.s
Density	1.11 g/cm^3
Curing time	7 minutes
Apply quantity	200 g/m^2
Trademark	Henkel®
Polimer base	Polyurethane (OCN-Ph-CH_2-Ph-NCO)
Neoprene (NP) (rubber) adhesive	
Appearance	Liquid (Red-Transparent)
Viscosity	17 ± 4 (Din Cup 6)
Density	0.90 ± 0.02 g/cm³ (20 ± 1°C)
Recommended humidity	65-75%
Recommended temperature	>15°C
Trademark	Neopren (Bally)
Polimer base	Polychloroprene (C_4H_5Cl)

2.2. Preparation of RMP Analysis Samples

Two types of Plywood were used (18 mm x 1250 mm x 2500 mm), which were covered and uncovered (Figure 3a, 3b). Plywood is cut into pieces by cutting in a diagonal saw measuring 500 mm x 500 mm. The surfaces of the cut pieces were lightly sanded with 200 grit sanding paper (Figure 3a). Then the surfaces were thoroughly cleaned with a clean brush. The parts are glued on top of each other using different glues (Figure 3e). First, 3 pieces were glued on top of each other using PU glue (Figure 3c). Bonding process were carried out by 200 g/m^2 glue (Burdurlu et al., 2006). Glues were applied to the surface of the board with a spatula (Figure 3b). Glued specimens are clamped with a hand vise. In this way, it was left under (5 bar, at room temperature, 65% relative humidity) pressure for 24 hours. The same processes have been carried out in NP glue. In this way, a 500 mm x 500 mm board with a thickness of 54 mm (3 pieces 18 mm board overlapped) was obtained. These boards were cut in a diagonal saw (18 mm thickness) in the radial direction (Figure 3d). Totally six sample group were prepared from the cut samples with a thickness of 18 mm (Figure 3f, 3g, 3h, 3i). 7 analysis samples were prepared for each group. For samples produced from film-coated plywood, the symbol "F" was placed at the end of the sample code, and the symbol "S" was placed for non-film-coated samples. For example, PU-F was prepared by gluing plywood with film with PU glue. PU-S, on the other hand, was prepared by bonding filmless plywood with PU.

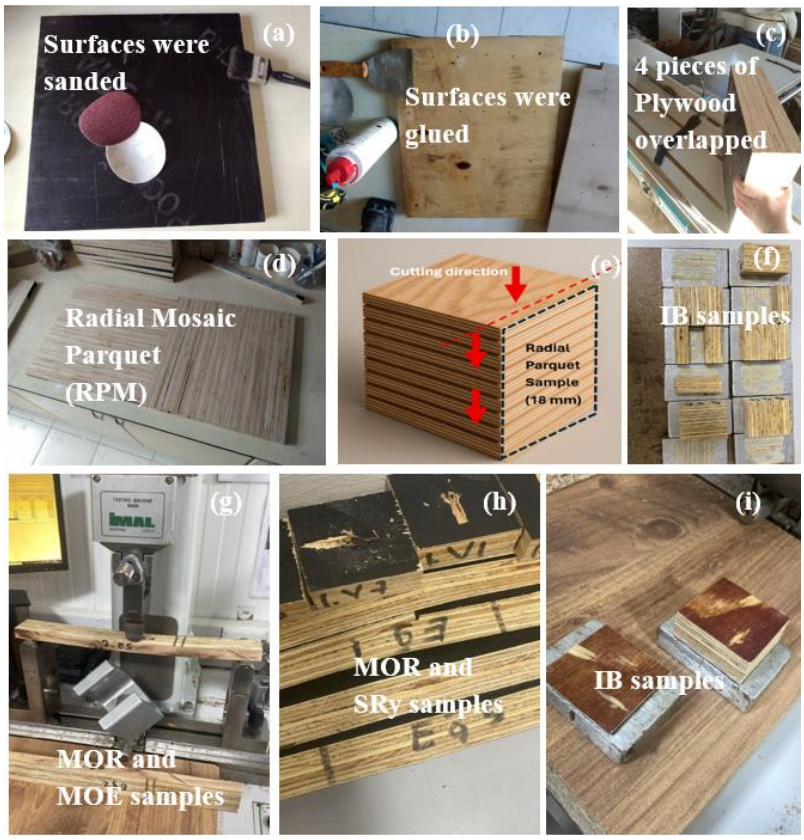


Figure 2. Sample preparation process (a), (b), (c), produced RMP (d), cutting plan (e) and analysis samples (f), (g), (h), (i)

2.3. Method

Mechanical and physical characterization of the samples was carried out according to the relevant TSE standards. The following physical and mechanical properties were determined using available standard: density (TSE EN 323, 1999); thickness swelling (TS) after 2 and 24 hour of water immersion (TSE EN 317, 1999); water absorption (WA) (TSE EN 317, 1999); internal bond strength (IB) (TSE EN 319, 1999); modulus of rapture (MOE) (TSE EN 310, 1999) and modulus of elasticity (MOR) (TSE EN 310, 1999). Screw withdrawal resistance (SR) (TS EN 320, 2011).

The statistical analysis of the results was performed using SPSS software. Prior to performing ANOVA, the assumptions of normality and homogeneity of variances were tested. Normality was assessed using the Shapiro-Wilk test, and homogeneity of variances was checked with Levene's test. As no significant deviations were detected ($p > 0.05$), these assumptions were considered satisfied. A one-way analysis of variance (ANOVA) with a significance level of $p \leq 0.05$ was applied to identify statistically significant differences between the samples. Post-hoc comparisons among groups were conducted using Duncan's test to further evaluate group differences.

3. Results and Discussion

Characterization of RMP samples was carried out by physical and mechanical analysis methods. The analysis results are given below.

3.1. Physical Analysis Results

The physical properties of RMP samples are presented in Table 2 and Figure 4–5. The density values of the samples vary between 550–624 kg/m³. The highest density was measured in the control group CTRL-S sample (624 ±19 kg/m³), while the lowest density belongs to the CTRL-F sample (550 ±13 kg/m³).

Table 2.
Physical analysis results of RMP samples

Samples	TS2h (n:7) (%) P<0.05*	TS24h (n:7) (%) P<0.05	WA2h (n:7) (%) P<0.05	WA24h (n:7) (%) P<0.05	Density (n:7) (kg/m³) P<0.05
CTRL-F	2.2 (±0.7)** B***	5.9 (±0.6) B	23 (±4.7) B	49 (±2.9) C	550 (±13) A
PU-F	1.9 (±0.8) B	1.7 (±0.5) A	30 (±1.3) C	55 (±2.9) D	600 (±35) B
NP-F	1.0 (±0.7) A	1.4 (±0.7) A	23 (±1.8) B	44 (±8.6) BC	571 (±4) A
CTRL-S	3.1 (±0.5) C	7.1 (±0.5) C	15 (±1.5) A	41 (±6.4) B	624 (±19) C
PU-S	2.7 (±0.7) BC	1.4 (±0.5) A	30 (±0.8) C	56 (±1.0) D	572 (±5) A
NP-S	0.8 (±0.6) A	1.1 (±0.6) A	21 (±2.3) B	35 (±1.4) A	600 (±16) B

* Significant value, ** Standard deviation, *** Indicates that the differences were determined by One-Way ANOVA followed by Duncan's post-hoc test.

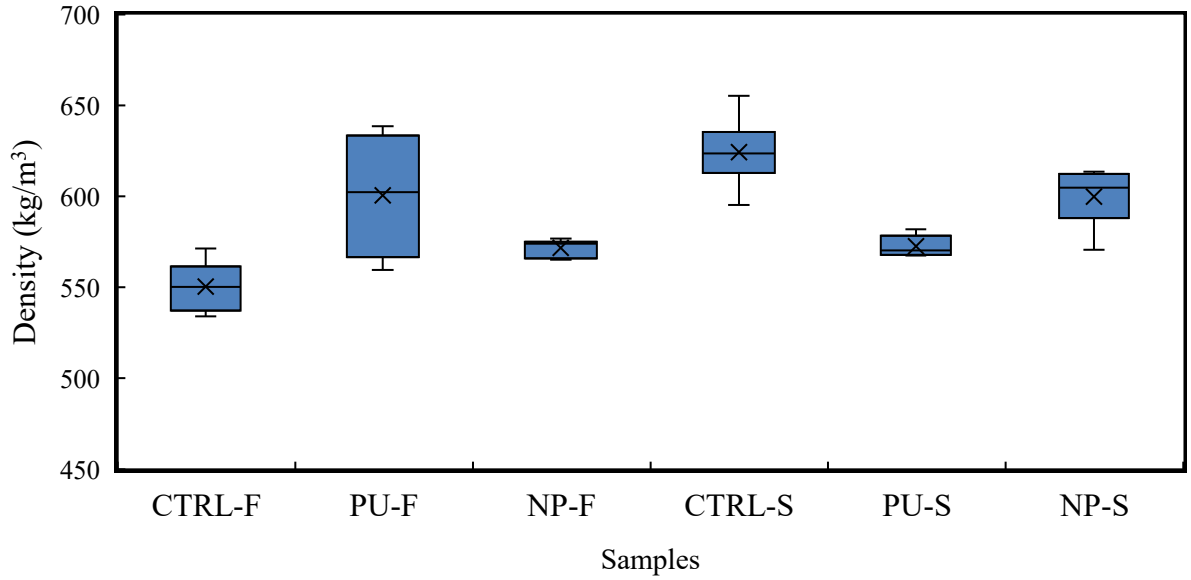


Figure 3. Density of RMP samples

This change in density must have been caused by the film layer or the glue used (PU and NP). Because all samples were cut from the same plywood plate. Especially the PU and NP added S group samples exhibited higher density compared to the F group. Since the surface coating material consists of impregnated kraft paper, it caused an increase in density. It has also been reported in the literature that the density of the coated boards increases (Aksu et al., 2016; Istek et al., 2010).

When the thickness increase (TS) results were examined, the lowest TS value was measured in the NP-F sample (1.0 ±0.7%) in 2 hours of water contact, followed by PU-F (1.9 ±0.5%) and NP-S (0.8 ±0.6%). In the 24-hour period, similarly, NP-F and NP-S samples showed very low thickness increase (1.4 ±0.7% and 1.1 ±0.6%, respectively). These findings indicate that NP glue improved dimensional stability against water better than PU glue.

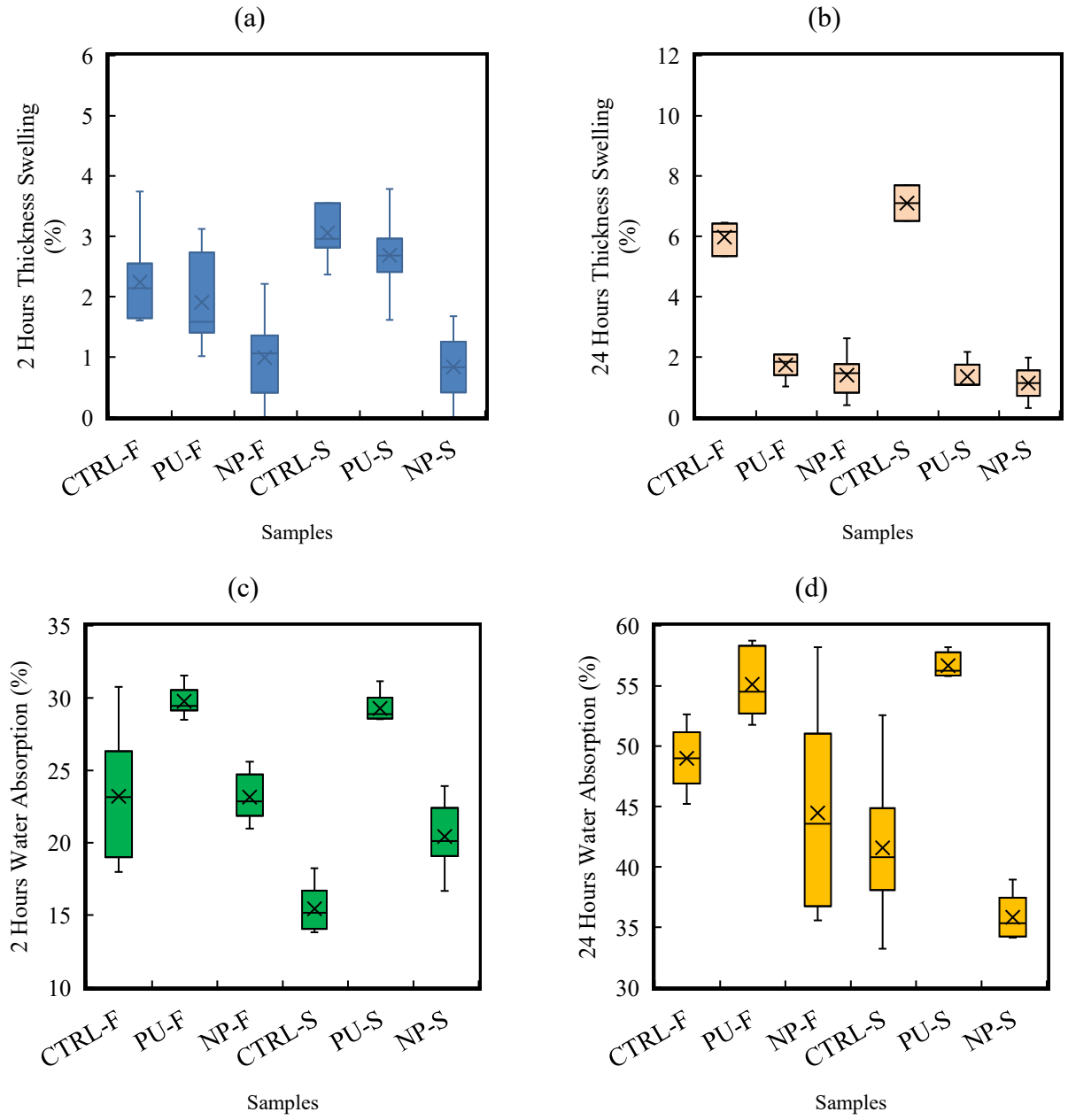


Figure 4. Physical properties of RMP, thicknesses swelling (a) and (b), water absorption (c) and (d)

RMPs bonded with NP and PU glues had higher TS2h results compared to the control group. In the TS24h results, the RMP sample bonded with NP glue absorbed less water than the control sample. In the 2-hour absorption period (WA2h), PU-S and PU-F samples showed the highest values (30 ±0.5% and 30 ±1.3%, respectively) and were exposed to more water. In contrast, CTRL-S and NP-S samples showed the lowest water absorption rates (15 ±1.3% and 21 ±2.3%, respectively). This situation shows that PU glue can increase permeability to water, whereas NP glue decreases permeability. In 24-hour water absorption rates (WA24h), PU-added samples again exhibited high values (PU-S: 56 ±1.0%; PU-F: 55 ±2.9%), while NP-S showed the lowest value (35 ±1.4%) and stood out as the most durable structure.

These results reveal that RMP produced with NP and PU glues provide a significant advantage in terms of dimensional stability and water resistance. RMP showed less swelling despite taking in more water. This is a desired feature for a parquet. NP-added samples exhibited the best physical performance with both low thickness increase and low water absorption rates.

The literature also indicates that neoprene-based adhesives are preferred in wood composite applications due to their high elasticity and water resistance. Schwarzenbrunner et al. (2020), in their study examining the water resistance properties of different adhesive types, noted that elastomer-based adhesives (e.g., polychloroprene) provided higher dimensional stability compared to traditional PVAc adhesives.

Similarly, Efhamisisi et al. (2016), in plywood samples produced with alternative adhesives, demonstrated that elastomer-based adhesives (PMDI and similar) offered high bonding quality and water resistance, particularly with their low pressing temperature and short curing time. The additives used in this study also increased the biological durability of the elastomer systems. Furthermore, Frihart (2015), in his study evaluating the historical development of adhesives used in wood-based products, noted that polychloroprene-based adhesives are widely preferred for parquet and flooring materials, particularly those applied in humid environments. This preference stems from neoprene's advantages, such as its high moisture resistance and adhesion strength.

In this context, neoprene-based adhesives are an effective alternative in wood parquet systems in terms of both physical strength and protection against environmental factors.

3.2. Mechanical Analysis Results

The mechanical properties of RMP samples are presented in Table 3 and Figure 6. The highest result in terms of internal bonding strength (IB) values was obtained in NP-S sample (2.66 ±0.45 MPa). This was followed by PU-F (1.83 ±0.33 MPa) and NP-F (1.28 ±0.33 MPa) samples, respectively. This situation shows that especially the surfaces bonded with NP glue and cut in the radial direction allow the glue to form a more effective interface with the wood. On the other hand, the conventional plywood-based CTRL-F sample had the lowest IB value (0.54 ±0.24 MPa), which revealed that the industrially produced plywood-based control samples had a weaker internal bond structure compared to the alternatives in mosaic form. In the perpendicular adhesion analysis of RMP samples, the separation occurred at the interfaces of PU and NP glues. The samples did not exhibit radial delamination.

Table 3.
Mechanical analysis results of RMP samples

Samples	IB (MPa) P<0.05	MOR (MPa) P<0.05	MOE (MPa) P<0.05	SRy (Newton) P<0.05	SRk (Newton) P<0.05
CTRL-F	0.54 (±0.24) A	54 (±9) C	7423 (±902) C	2594 (±238) C	2016 (±237) BCD
PU-F	1.83 (±0.33) C	48 (±3) BC	6023 (±223) B	1693 (±198) AB	1884 (±198) ABC
NP-F	1.28 (±0.33) B	47 (±5) BC	5932 (±473) B	1524 (±179) A	1696 (±178) A
CTRL-S	1.10 (±0.27) B	42 (±9) AB	5391 (±722) B	2564 (±166) C	2263 (±165) D
PU-S	1.09 (±0.14) B	43 (±4) AB	5501 (±413) B	1781 (±89) B	2127 (±89) CD
NP-S	2.66 (±0.45) D	40 (±3) A	3792 (±364) A	1740 (±137) B	1786 (±137) AB

* Significant value, ** Standard deviation, *** Indicates that the differences were determined by One-Way ANOVA followed by Duncan's post-hoc test.

When evaluated in terms of Modulus of Rupture (MOR), the highest bending strength was observed in the CTRL-F sample (54 ±9 MPa). While PU-F and NP-F samples had similar MOR values, all S group samples (especially NP-S) exhibited relatively lower values. This suggests that surfaces cut in the radial direction showed lower resistance to bending loads due to fiber orientation.

Modulus of Elasticity (MOE) values also showed similar trends. The highest MOE value was again observed in the CTRL-F sample (7423 ±902 MPa), followed by PU-F (6023 ±223 MPa) and NP-F (5932 ±473 MPa). The radially cut NP-S sample showed the lowest modulus of elasticity (3792 ±364 MPa). These findings show

that classical plywood surfaces are more advantageous than mosaic parquet alternatives in terms of bending rigidity; However, it is revealed that the adhesive type and cutting direction significantly affect this property.

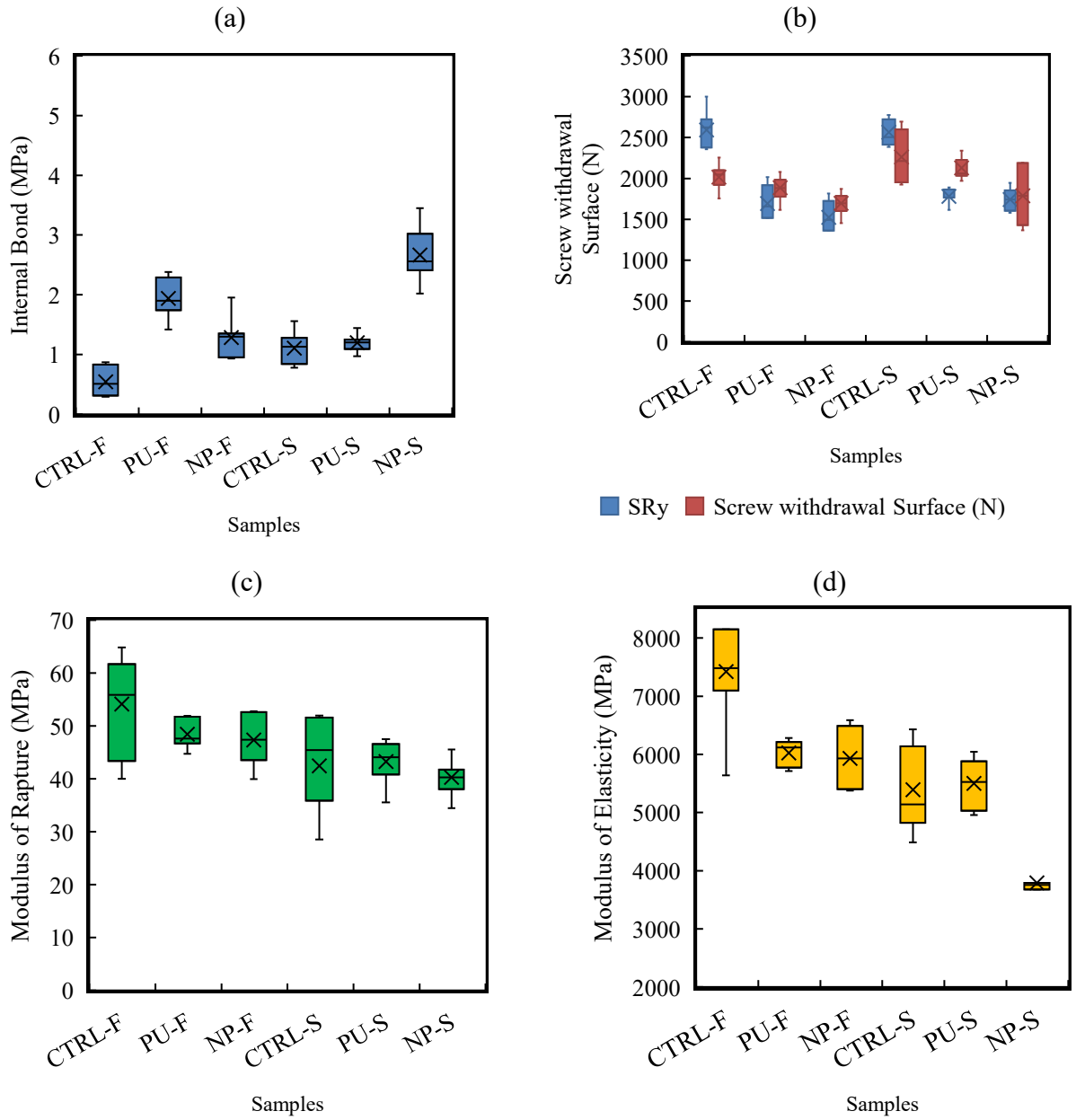


Figure 5. Mechanical strength of RMP, internal bond (a), screw withdrawal (b), modulus of rapture (c), modulus of elasticity (d)

In the screw pull-out resistance tests (SRx and SRk), the CTRL-S sample attracted attention with its high surface (SRx = 2564 ±226 N) and edge (SRk = 2263 ±165 N) screw pull-out values. In particular, the edge screw pull-out resistances of the PU-S and NP-S samples were also found to be high. The PU-S sample had the second highest SRk value with 2127 ±89 N. These results show that the mosaic structure cut in the radial direction provides higher mechanical adhesion due to the orientation of the fibers perpendicular to the screw axis.

Overall, mosaic parquet samples bonded with polyurethane (PU) and neoprene (NP) adhesives showed competitive or superior performance compared to the classical plywood-based samples, especially in terms of internal adhesion and screw adhesion. However, the classical plywood-based CTRL-F sample still maintains

its superiority in properties such as bending resistance and elasticity. These findings show that the chemical structure of the adhesives, wood surface orientation and fiber direction should be evaluated together.

Studies on the characterization of wood composites produced using neoprene adhesives are quite limited. Some of the studies can be summarized as follows.

Schwarzenbrunner et al. (2020) compared different adhesive systems in composites developed for biodegradable ski cores and reported that the MOE and MOR values in panels produced with elastomeric adhesives were more consistent and durable compared to traditional adhesives. This was attributed to the ability of rubber-based adhesives, such as polychloroprene, to form a flexible bonding bridge during adhesion.

Fang et al. (2017) also investigated the mechanical and interfacial properties of laminated wood panels bonded with high-density polyethylene (HDPE) film. The thermoplastic adhesives used in this study were shown to increase mechanical properties such as flexural strength, shear strength, and perpendicular tensile strength by modifying the wood's surface. Similarly, considering that polychloroprene-based adhesives also exhibit such elasticity, the obtained strength values can be compared.

Furthermore, in three-layer plywood produced with the environmentally friendly cartanol-based epoxy adhesive systems developed by Zhu et al. (2022), wet shear strength reached 1.11 MPa, and modulus of elasticity reached levels higher than those of conventional formaldehyde-based systems, with a 48% increase. These results demonstrate that elastomer adhesives positively impact mechanical performance criteria such as screw retention and adhesion strength.

4. Conclusion

In this study, the physical and mechanical properties of radial mosaic parquet (RMP) samples obtained by cutting plywood sheets in the radial direction and bonding them with polyurethane (PU) and neoprene (NP) adhesives were evaluated. As a result of the experimental analyses, it was determined that RMP samples offered advantages over traditional plywood-based parquets, especially in terms of dimensional stability.

Physical analyses showed that RMP samples with NP additives attracted attention with their low thickness increase (TS) and water absorption (WA) rates. The NP-S sample exhibited the lowest swelling and water absorption properties.

The mechanical test results showed that the NP-S sample showed better performance, especially in terms of internal bonding strength (IB). This shows that the glue forms a stronger bond with the wood on surfaces cut in the radial direction and bonded with neoprene. In terms of bending strength (MOR) and modulus of elasticity (MOE), the conventional plywood (CTRL-F) samples reached higher values than the RMP samples.

As a result, radial mosaic parquet production offers a sustainable and aesthetic alternative to conventional parquet systems thanks to its low swelling rate, homogeneous and knot-free pattern advantage and alternative glue applications. It has the potential to be used especially in humid environments or large area applications. RMP flooring allows for production in large sizes. By cutting plywood sheets glued together to an 18 mm thickness using a band saw, RMP flooring can be produced in 50 x 50 cm or 50 x 100 cm dimensions. RMP flooring is estimated to be quicker to produce and less costly than traditional flooring. A feasibility study is required for definitive results. For RMP flooring, we recommend 100-grit sanding followed by a polyester surface coating.

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Author Contributions

Süheyla Esin KÖKSAL: Conceptualization, Methodology, Data curation, Formal analysis, Writing-original draft.

Orhan KELLECİ: Conceptualization, Methodology, Data curation, Formal analysis, Writing-original draft.

Declaration of Conflicting Interests

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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