Article citation info:
Szada-Borzyszkowski W., Rydzkowski T., Szada-Borzyszkowska M.E., Czajkowska A.H., Thakur V.K., Petrů J. 2026. Effect of Shredded Scots Pine Cones (*Pinus sylvestris*) on the Mechanical Performance of Three-Layer Particleboards. *Drewno. Prace naukowe. Doniesienia. Komunikaty.* https://doi.org/10.53502/wood-210736

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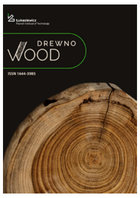
Journal website: https://drewno-wood.pl



Effect of Shredded Scots Pine Cones (*Pinus sylvestris*) on the Mechanical Performance of Three-Layer Particleboards

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Article info
Received: 9 July 2025
Accepted: 15 September 2025
Published: 2 April 2026

Keywords
chipboard
pine cones
recycled biomass
mechanical properties
SEM
surface layer
interfacial bonding

This study investigates the use of shredded Pinus sylvestris (Scots pine) cones as a partial replacement for industrial wood chips in the surface layers of three-layer particleboards. Boards were manufactured with a target density of 700 kg/m^3 and a thickness of 16 mm, bonded with urea-formaldehyde adhesive. Scots pine cone particles were introduced into the surface layers at substitution levels of 10–60% relative to wood chips, while the core layer consisted entirely of industrial chips. The preparation process included drying, milling, classification of cone particles, and hot pressing under controlled temperature and pressure conditions. Standardized tests according to EN requirements were conducted to determine mechanical properties, complemented by scanning electron microscopy (SEM) for structural evaluation. The results showed that all boards met EN 312 flexural strength requirements, with up to 15% improvement in surface screw pull-out resistance at the highest cone content. SEM analysis revealed that pine cone particles have a complex, entangled fibrous structure, unlike conventional chips, enhancing mechanical interlocking with the resin. This improved interfacial bonding contributes to better stress transfer and reduced porosity in the outer layers. Additionally, boards gained unique aesthetic features from the natural coloration of cones. These findings demonstrate that underutilized biomass can be successfully applied in sustainable, structurally sound, and visually appealing wood-based panels.

DOI: 10.53502/wood-210736

Introduction

Particleboard has long been an important material in the construction and furniture industries, valued for its durability, low weight, and ease of processing (Borgin, 1958). The growing demand for particleboard results in increased consumption of wood, particularly pine, as the primary raw material (Rivela et al., 2006). To mitigate this demand and preserve forest resources, recycled wood has become an important component in board production (Nguyen et al., 2023). For instance, a study by Azambuja (Azambuja

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et al., 2018) showed that up to 25% of residues such as MDP panels, plywood, and timber can be mixed with pine chips without negative effects on mechanical performance, while the use of segregated wood waste at the same proportion improved the modulus of elasticity.

Beyond recycled wood, alternative raw materials such as agricultural biomass and wood waste (Sugahara et al., 2019; Madurwar et al., 2012) and recycled by-products (Martins et al., 2021) have been widely studied as substitutes in particleboard production. This approach not only addresses the growing demand for wood-based materials but also supports circular economy principles (Andrzejewski et al., 2024; De Lima Mesquita et al., 2018; Pędzik et al., 2021). Various agricultural and natural residues have been tested as partial replacements for wood particles, including coconut fibres (Taquetti et al., 2023; Viswanathan, 1999), jute stalks (Nitu et al. 2020, 2022), hemp fibres and shives (Battegazzore et al., 2018; Zvirgzds et al., 2022), cotton (Ferrandez-García et al., 2021; Shaikh et al., 2010), and many others (Atoyebi et al., 2021; Lee et al., 2022; Owodunni et al., 2020). Several studies have focused on incorporating pine-derived components into particleboards. A study by Buyuksari (Buyuksari et al., 2010) investigated three-layer boards made from a pine-beech mixture with the addition of Scots pine cones. Their results showed reduced formaldehyde emission and improved water resistance compared to conventional boards, although mechanical properties decreased with higher cone content. Similarly, Santos et al. (2021) reported that the addition of maritime pine needles enhanced bonding strength in particleboards.

Pine cones, a natural component of pine forests, when added to chipboard, pine cones introduce a distinctive structural and visual element. During production, appropriate pressure and temperature changes result in a dense and durable material. The addition of pine cones, rich in natural substances, can affect both the boards' mechanical and aesthetic properties, giving them a characteristic appearance and texture. Moreover, the wood used in these boards should meet high-quality standards, and its sourcing should comply with sustainable development principles (Ferrandez-García et al., 2021).

By advancing towards more innovative and eco-friendly solutions, it is feasible to experiment with additives such as pine cones and needles to enhance both the structural and aesthetic performance of particleboards. The production process typically involves thoroughly mixing shredded wood chips and cones with binding substances, often in the form of synthetic or natural resins, which are critical not only for adhesion but also for mechanical performance and durability (Guler and Ozen, 2004). Such approaches represent a step forward in sustainable manufacturing practices, combining the utilization of underexploited natural resources with modern board production technologies.

The aim of this study was to investigate the influence of shredded Scots pine cones on selected mechanical properties of particleboards, specifically bending strength and screw pull-out resistance. The objective was to evaluate whether the addition of pine cone particles can enhance or maintain the structural integrity of the boards without compromising their performance, while also exploring the potential environmental benefits of incorporating this renewable raw material.

Materials and methods

1. Contribution of shredded pine cones to the test panels

The following basic materials were used to produce particleboards with shredded pine cones: 'coarse' chips for the inner layer (*Pinus sylvestris*, moisture content 6–8%), fine chips for the outer layer (*Pinus sylvestris*, moisture content 8–10%), urea-formaldehyde adhesive, and shredded pine cones. The adhesive consisted of urea-formaldehyde resin (93.5% of the adhesive mass), urea (6%), and hardener (0.5%). Fig. 1 shows a view of the individual wood chips and shredded pine cones used in the production of the panels.

The chips, mixed in the right proportions, were combined with adhesive, after which a three-layer

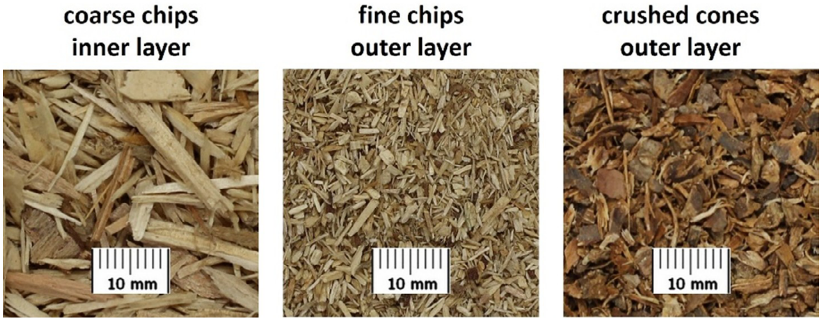


Fig. 1. View of wood chips and shredded pine cones used in the production of the panel

Table 1. Share of individual components of particleboard with shredded pine cones added

no.	Contribution of cones to the outer layer [%]	Chip mass of inner layer [g]	Chip mass of outer layer [g]		Total mass of binder (adhesive) [g]	Total mass of board components M_p [g]
			wood chips	cones		
1	0	715	352.0	0	100	1167
2	10		316.8	35.2		
3	20		281.4	70.6		
4	30		246.4	105.6		
5	40		211.2	140.8		
6	50		176.0	176.0		
7	60		140.8	211.2		

structure was formed and subjected to pressing to achieve the desired density and strength. A 465 × 205 mm mould was used to produce the boards, which, after pressing and due to mat expansion, yielded board sheets with dimensions of 485 × 215 ± 5 mm and a thickness of 16 mm. Table 1 presents the proportions of the components used in the manufactured boards, including the reference sample without pine cones and the variants with different pine cone contents.

For the boards produced, the following proportions of components were used in the layers: 67% for the inner layer and 33% for the two outer layers. The urea-formaldehyde adhesive accounted for 9.37% of the total dry weight of the chips. According to their percentage of the board weight, 67% of the total adhesive was applied to the inner layer, and 33% to the outer layers. To ensure that the adhesive maintained sufficient viscosity for dispensing during the chip sealing process using an injector jet head, the temperature was kept constant at 20 ± 1°C.

The contribution of pine cones to the particleboard structure and surface pattern was evaluated based on mechanical tests and microstructural analysis.

2. Preparing the components for board pressing

The microstructure of the wood chips was analyzed using a Phenom ProX scanning electron microscope (Thermo Fisher Inc., Waltham, MA, USA). The key technical specifications of the device are summarized in Table 2. Granulometric analysis was conducted to determine the proportion of individual size fractions in the samples. These analyses ensured the homogeneity of the mixture and contributed to reproducible mechanical properties of the boards.

The tested materials were subjected to granulometric analysis by determining the proportion of individual size fractions in the sample weights. An LPzE-2e sieve shaker (MULTISERW-Morek, Marcyporeb, Poland) was used in the study. A set of sieves with mesh diameters ranging from 0.08 mm to 8 mm was used to determine the size of the inner layer chips, while sieves with mesh sizes ranging from 0.02 mm to 5 mm were used for the outer layer chips.

A precision balance WPS 1200/C/2 (RADWAG, Radom, PL) was used to measure the weight of the adhesive components, and a precision balance SBS-TW-6

Table 2. Basic parameters of the Phenom ProX

Parameters	Values
Digital zoom	max. 12x
Electron optical magnification range	160x to 350000x
Light optical magnification	27x to 160x
Resolution, nm	≤ 6 SED and ≤ 8 BSD
Acceleration volta ges, kV	5 ÷ 20
Sample size, mm	Up to 25 (optional 32)
Sample height, mm	Up to 35 (optional 100 mm)
Lifetime of thermionic source (CeB6), hour	to 1500

Table 3. Basic parameters of the WPS 1200/C/2 and SBS-TW-6 balances

		laboratory balance WPS 1200/C/2		
Max. [g]	**Min. [mg]**	**Readability [mg]**	**Operating temperature [oC]**	**Power supply**
1200	500	10	+15 / +30	230V, 50Hz/10.5C AC
		laboratory balance SBS-TW-6		
6	0.2	0.2	0 / +40	230V, 50Hz

(Steinberg Systems, Expondo, Zielona Góra, PL) was used to measure the weight of the chips, shredded pine cones, and the samples for strength testing. The parameters of both balances are presented in Table 3.

A specially designed drum gluing machine (sealer) was used for gluing the chips, a photograph of which is shown in Fig. 2.

The shape and capacity of the sealer drum ensured precise mixing of the board components. By adjusting the drum speed, it was possible to seal chips for several samples at a time. A single load produced enough material for the production of two board formats.

When the chip sealing process was complete, and a 465 × 205 mm mat was formed, it was placed in a hydraulic press with a maximum pressure of 50 × 10^4 N (Fig. 3).

The plates were then pressed using pressure plates heated to 180°C. The RE62 controller (Fig. 3) enabled the temperature to be precisely maintained during the pressing of the boards. This procedure ensured boards of uniform density and mechanical integrity.

3. Strength tests

The mechanical tests were conducted to evaluate the influence of shredded pine cones on the structural integrity and fastening performance of the boards.

In accordance with the PN-EN 310 standard, the board formats were produced for strength testing (PN-EN 310 1994). Three 50 ± 1 mm wide strips were cut from each board format. Six flexural strength test specimens (with different proportions of cones) were prepared for each board type.

The cutting process was carried out precisely, adapting the individual dimensions to the specific test. Obtaining homogeneous specimens with the correct dimensions was important for successful further analysis. The total length of the test specimens should be 20 times the specimen thickness plus 50 mm. For a board thickness of 16 mm, the total length was, therefore, 370 mm. The specimens were then conditioned to constant weight at 20 ± 2^{o}C and 65 ± 5% relative

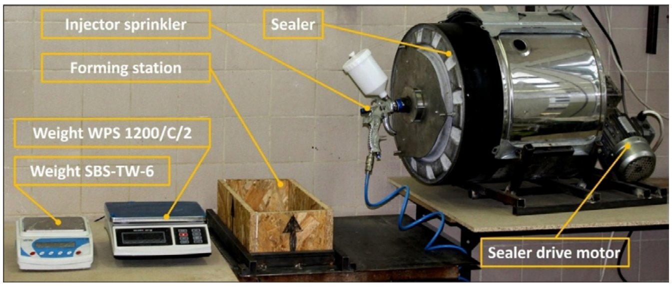


Fig. 2. Station for applying adhesive to chips (gluing machine)

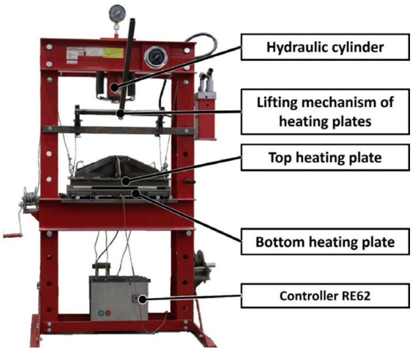


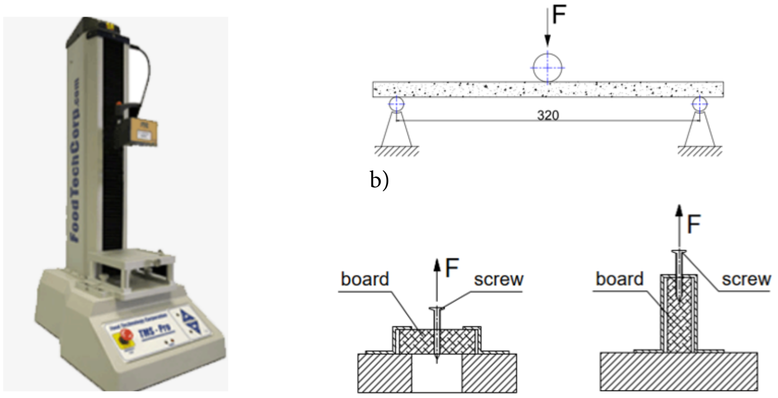
Fig. 3. Board pressing station

a) b) c)

Fig. 4. Preparation of specimens for measuring the force during screw removal in the direction perpendicular to the surface of the board: a) pre-drilling, b) view of screw inserted into the specimen, c) method of fixing the specimen in the holder

a) b) c)

Fig. 5. Method of preparing the specimen for force measurement when removing the screw from the edge of the board: (a) pre-drilled hole, (b) view of the screw inserted into the specimen, (c) method of fixing the specimen in the holder



a) c) d)

Fig. 6. Strength test rig: a) TSM-Pro machine, b) bending strength measuring principle, c) surface screw holding, d) edge screw holding

humidity to ensure repeatable test conditions across all specimens. The thickness and width of each specimen were measured before the strength tests. According to EN 325 standard, the thickness was measured at the intersection of the diagonals (EN 325 2012). The width of each sample was measured at the centre of its length. Using the SBS-TW-6 balance, the weight of each sample was measured. Nine 50 × 50 mm specimens were prepared for each of the screw pull-out tests.

A through-hole with a diameter of 5 ± 0.1 mm was drilled in the specimens intended for screw removal in a direction perpendicular to the surface of the board. A screw corresponding to the parameters of a euro hinge screw with an external diameter of 6.3 mm (internal diameter 4.9 ± 0.1 mm) was screwed into the hole, as shown in Fig. 4.

A hole with an external diameter of 3.5 ± 0.1 mm was drilled 30mm deep in the specimens for screw removal from the edge. A mounting screw with a diameter of 5 ± 0.1 mm (inner diameter 3.4 ± 0.1 mm) was screwed into the hole, as shown in Fig. 5.

The actual strength tests of the samples were carried out using the TSM-Pro (Fig. 6a), which is provided by the Department of Food Industry Processes and Equipment at the Faculty of Mechanical Engineering and Power Engineering of the

Koszalin University of Technology. Once the necessary instrumentation had been prepared, the load tests could be conducted under controlled laboratory conditions.

During the flexural strength tests, each specimen was placed flat on the supports with its longitudinal axis perpendicular to the support axis (Fig. 6b). The loading rate was 11 mm/min, chosen so that specimen failure occurred within 60 ± 30 seconds. Screw removal tests were performed from the perpendicular surface, according to the schematic in Fig. 6c, and from the edge, according to the scheme in Fig. 6d. The screw removal tests were conducted at a displacement speed of 10 mm/min.

The flexural strength fm of each specimen was calculated according to the following relationship:

$$f_m = \frac{3 \cdot F_{max} \cdot 320}{2 \cdot b \cdot t^2} \tag{1}$$

where: F_{max} – maximum load in N, b – specimen width in mm, t – specimen thickness in mm.

The flexural strength for each group of specimens, with different proportions of crushed cones, was calculated as the arithmetic mean of the tested specimens.

Flexural strength and screw pull-out resistance values were calculated as arithmetic means, and the standard deviations were determined for each group of specimens with different proportions of crushed cones.

Results and discussion

Analysis of the particle size fraction of the shredded material (Fig. 7) indicates that the cones show slightly different granulometric characteristics after the shredding process compared to fine pine chips. Approximately 20-30% of the shredded material is a dust fraction, with particles no longer than 1 mm in diameter. Shavings with a size between 1 mm and 2 mm account for the largest share of the material structure, at around 60%.

To analyze the microstructure of the raw materials used in the outer layers of the particleboard, scanning electron microscopy (SEM) observations were carried

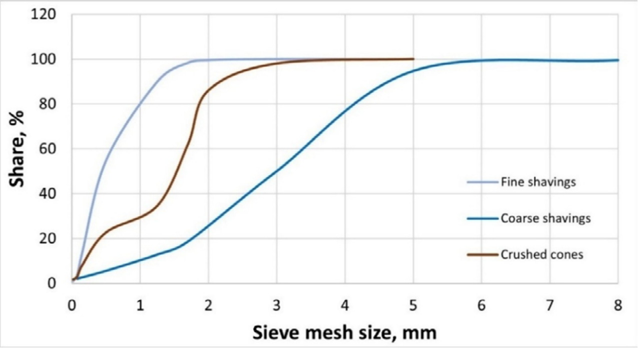
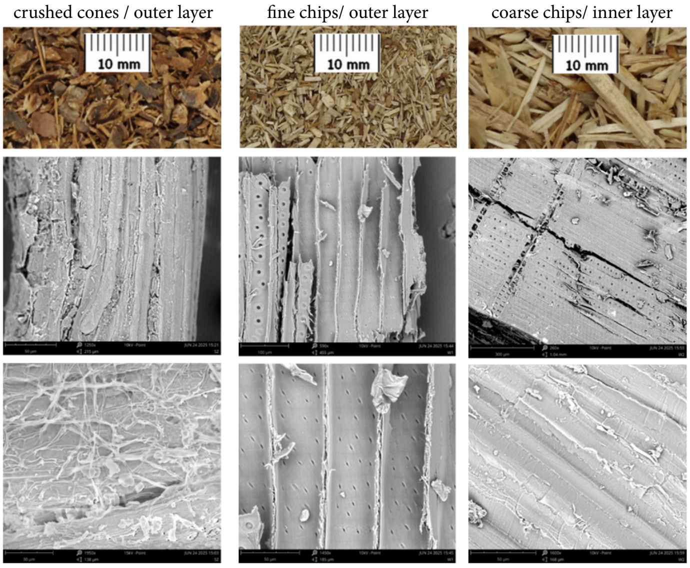


Fig. 7. Granulometric analysis of chips used in board production


crushed cones / outer layer

fine chips/ outer layer

coarse chips/ inner layer

Fig. 8. SEM images: a) structure of shredded pine cones, b) fine wood chips, c) coarse wood chips

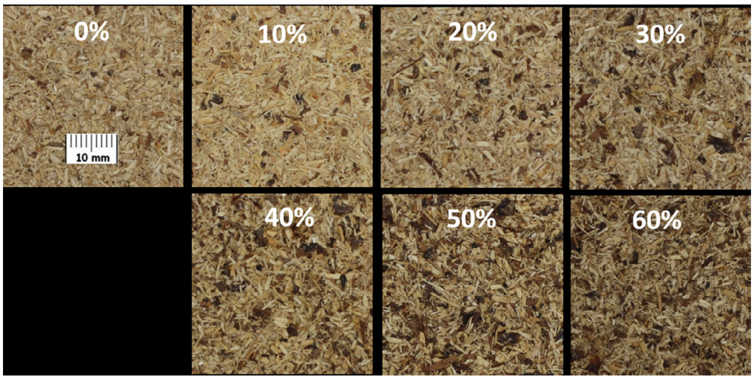


Fig. 9. Surface view of boards with different % of ground pine cones in the outer layer

out using a Phenom ProX microscope (Thermo Fisher Scientific, USA). The results are presented in Fig. 8.

Shredded Scots pine cones (Fig. 8a), used as an alternative to conventional fine wood chips, exhibit an irregular, three-dimensional fibrous structure. The visible entanglement and networking of fibers lead to mechanical interlocking between particles, which translates into improved mechanical adhesion within the resin matrix. This morphology enhances interfacial bonding and thus facilitates more effective stress transfer within the composite. As a result, the addition of shredded pine cones positively affects the flexural and surface tensile strength of the final boards. Furthermore, the high variability in particle orientation and structure allows for more efficient filling of voids, reducing porosity and improving the uniformity of the outer layers.

In contrast to conventional fine wood chips shown in Fig. 8b, which are flatter and more randomly oriented, the multidirectional and disordered fiber arrangement in the pine cone material enables better mechanical anchoring within the adhesive resin. The reinforcement of internal bonding within the material contributes to improved flexural and surface tensile strength of the finished board.

Moreover, due to the natural variability in fiber orientation and shape, these particles can more effectively fill voids, contributing to reduced porosity and greater structural uniformity of the outer layers of the particleboards.

The microstructure of the inner layer of the board, presented in Fig. 8c, remains unchanged regardless of the material used in the outer layer—both in conventional particleboards and those incorporating shredded pine cones. SEM images reveal a typical structure of coarse wood chips arranged to ensure the essential strength parameters and structural rigidity.

Pressing particleboards with crushed pine cones using a hydraulic press (Fig. 3) took 350 seconds under varying pressure. Fig. 9 shows the external surfaces of the produced boards.

As the proportion of crushed cones in the outer layer of the board increases, a characteristic pattern in the form of dark field/strip particles can be seen on its surface.

The average thickness and density values obtained for each of the six samples were summarized and are presented in Table 4.

According to the PN-EN 312 standard, the thickness tolerance should be ±0.3 mm. The average thickness values of the samples fall within this range (PN-EN 312 2005). The largest deviations of approximately 1.5% from the expected thickness of 16 mm were observed for samples containing 20% and 40 percent split cones in the outer layer. Such deviations may have resulted from the non-uniform distribution of shavings in the individual layers.

The analysis of the densities of the samples showed that the maximum differences in density of the boards with shredded cones added, compared to the boards without additives, were a maximum of 0.55%. On the other hand, with regard to the assumed board density of 700 kg/m3, the board densities measured during the experimental tests were no more than 1% lower than assumed. The slight reduction in board density may have been due to material losses during the chip sealing process (some of the chips remain on the walls of the drum sealer) and losses during board forming due to the stacking of chips on the edges of the board. Although a pre-mould of 465 × 205 mm was used to form the board carpets, 485 × 215 ±5 mm board formats were obtained after pressing. Due to the lack of constraints on the side edges of the compressed board, some of the material at the edges moved freely, creating a board with a non-uniform and insufficient density at the outer edges of the board. Both the thickness and density mean values are very stable, while the standard deviation (SD) can vary significantly depending on the proportion of cones. The greatest variations occur in the thickness of the boards, with a 60% share of cones, and in the density, with a 50% share of cones in the outer layer of the board.

Table 4. Thickness and density of board samples with the addition of shredded pine cones

Contribution of cones to the outer layer [%]						
0	10	20	30	40	50	60
Average board thickness [mm]						
16.02	16.04	15.77	15.92	15.77	15.86	15.95
Standard deviation of average plate thickness [mm]						
0.13	0.05	0.12	0.17	0.03	0.11	0.19
Density of the board [kg/m^3]						
693.1	693.6	694.5	694.7	697.0	697.0	694.4
Standard deviation of density of the board [kg/m^3]						
16.59	14.35	19.88	19.84	4.58	21.01	10.56

Table 5. Flexural strength of the board

Contribution of cones to the outer layer [%]						
0	10	20	30	40	50	60
Bending strength [N/mm^2]						
11.39	11.38	11.22	11.15	11.09	11.10	11.17
Standard deviation of bending strength [N/mm^2]						
0.57	0.53	0.44	0.42	0.60	0.62	0.57

Table 6. Force required to remove the screw

Contribution of cones to the outer layer [%]						
0	10	20	30	40	50	60
Force surface screw holding [N]						
785.3	788.6	806.0	826.2	843.5	882.2	902.9
Standard deviation of force surface screw holding [N]						
103.30	86.62	87.96	84.83	70.20	58.53	108.10
Force edge screw holding [N]						
1374.8	1349.3	1361.4	1371.7	1359.1	1367.7	1392.1
Standard deviation of force edge screw holding [N]						
145.55	174.96	253.57	74.75	226.91	146.61	158.41

Table 5 presents the results of the flexural strength obtained for each of the six samples of the board specimens as a function of the proportion of crushed cones in the outer layer of the board.

In their study, Buyuksari (Buyuksari et al., 2010) showed that the addition of shredded pine cones throughout the chips of both the middle and outer layers decreased the flexural strength of boards with higher shredded pine cone content.

In the analyzed studies, boards with crushed pine cones added only to the outer layer, due to their relatively high modulus of elasticity and natural stiffness, may contribute to an increased load-bearing capacity despite the partial replacement of wood particles. In addition, during hot pressing, these elongated fibers can preferentially align in the plane of the panel, and the roughness of the pine cone particle surface can promote mechanical interlocking with the cured adhesive, improving stress distribution and bending properties. The analysis of the flexural strength results showed that, for all samples tested with the addition of shredded pine cones only in the outer layer, the

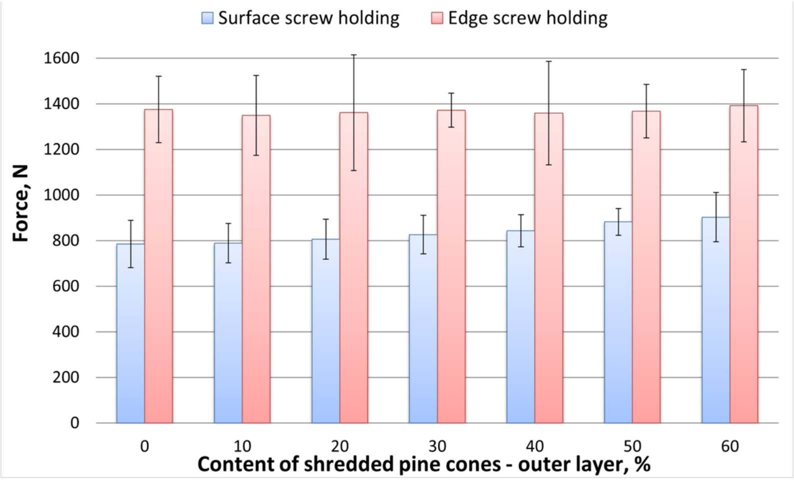


Fig. 10. The value of the force required to pull the screw from the perpendicular surface of the board (surface screw holding) and from the edge of the board (edge screw holding) for different proportions of shredded cones in the outer layer of the board

obtained strength values are close to those specified in the PN-EN 312 standard (PN-EN 312 2005) and, at the same time, declared by leading manufacturers of wood-based boards, which is a minimum of 11 N/mm². This indicates that the tested boards meet the required durability standards, demonstrating their quality and suitability for industrial applications. Compliance with these reference values allows us to conclude that the manufactured boards can be safely used in furniture constructions requiring a certain mechanical strength. This is crucial from an engineering perspective. Standard deviations show variability in individual measurements – they range from 0.42 to 0.62 N/mm², which means slight differences in accuracy or homogeneity of the sample in a given measurement. An additional advantage is the visual effect in the form of dark longitudinal bands on the surface of the boards (Fig. 9).

The analysis of the bending force waveforms for all the tests carried out with shredded pine cones, only in the outer layer, showed similar bending force build-up characteristics of the board. Maximum force values were reached approximately 40–50 seconds after the start of the test, followed by rapid (approximately 5 seconds) failure of the specimen.

Table 6 shows the results of measuring the forces obtained for each of the nine required to pull the screw out of two typical locations in the assembly of board structures: the surface screw holding (Fig. 6c) and the edge of the board (Fig. 6d).

The analysis of the forces required to remove the screw from the perpendicular surface and from the edge of the board provided information on the joint strength for different contents of shredded cones in the board. Fig. 10 presents a comparison of the forces required to extract the screw from the perpendicular surface (surface screw holding) and from the edge of the board (edge screw holding).

The presence of high pull-out forces may indicate an optimal fit between the screw and the material, as well as the durability of the joint in service. This is particularly important in applications where the forces acting on the joint are significant. As the proportion of shredded cones in the outer layer of the board increases, the force required to pull out the screw also increases. Incorporating shredded cones thus enhances the board's capacity to retain fastenings. In specimens where the proportion of shredded cones in the outer layers was 60%, the force required to pull out the screw increased by up to 15% compared to a control board without this addition. This considerable enhancement in strength indicates that shredded cones can serve as an effective structural reinforcement for wood-based boards, which may be significant in the context of their potential use in construction or furniture, where high resistance to mechanical loads is required. The smallest standard deviation (SD), and therefore the greatest uniformity of the process, was obtained at 50% cones, while the greatest fluctuations occurred at 0% and 60%. The screw pull-out force from the edge remained within 1360–1392 N, with the highest repeatability achieved at 30% cones (SD = 74.75 N) and the largest variations at 20% cones (SD = 253.57 N).

In conclusion, the analysis of the results clearly shows that the amount of shredded cones in the outer layer does not affect the edge strength of the board in terms of the force required to pull out the screw. This is because the key factor determining edge strength is the homogeneous composition of the chips in the inner layer of the board, which remains constant in the analyzed samples.

Conclusions

The study demonstrates that shredded Scots pine cones can be successfully incorporated into the outer layers of three-layer particleboards without significantly compromising their mechanical properties. The following conclusions can be drawn:

1. Flexural strength of the boards was not significantly affected by the addition of pine cones (10–60% in the outer layer), with variations not exceeding 2.64%.
2. Perpendicular screw pull-out resistance increased with higher pine cone content, reaching up to a 15% improvement at 60% addition, while edge screw withdrawal strength remained largely unchanged.
3. Board density (700 kg/m³ ±1%) and thickness (16 mm ±0.3 mm) remained consistent across all samples, confirming material homogeneity and stable manufacturing.
4. Mechanical performance is generally maintained or slightly enhanced due to the fibrous structure of pine cone particles, which improves interfacial bonding with the adhesive.
5. Aesthetic properties of the boards are improved, giving them a natural, organic appearance suitable for eco-friendly interior applications.
6. SEM analysis confirmed that pine cone particles have a highly fibrous, entangled structure, enhancing mechanical interlocking, reducing porosity, and supporting improved screw-holding capacity.

Overall, shredded pine cones offer a sustainable, structurally sound, and visually appealing alternative for modifying wood-based panels, combining functional performance with innovative aesthetic qualities.

Conflict of interest

The author(s) declare(s) that there is no conflict of interest concerning the publication of this article.

References

Andrzejewski J, Barczewski M, Czarnecka-Komorowska D, Rydzkowski T, Gawdzińska K, Thakur VK., (2024): Manufacturing and characterization of sustainable and recyclable wood-polypropylene biocomposites: Multiprocessing-properties-structure relationships. Industrial Crops and Products 2024;207:117710. https://doi.org/10.1016/j.indcrop.2023.117710

Atoyebi OD, Aladegboye OJ, Fatoki FO., (2021): Physico-Mechanical Properties of Particle Board made from Coconut Shell, Coconut Husk and Palm Kernel Shell. IOP Conf Ser: Mater Sci Eng;1107(1):012131. https://doi.org/10.1088/1757-899X/1107/1/012131

Azambuja RDR, De Castro VG, Trianoski R, Iwakiri S., (2018): Utilization of construction and demolition waste for particleboard production. Journal of Building Engineering 2018;20:488–492. https://doi.org/10.1016/j.jobe.2018.07.019

Battegazzore D., Alongi J, Duraccio D, Frache A., (2018): All Natural High-Density Fiber- and Particleboards from Hemp Fibers or Rice Husk Particles. J Polym Environ; 26(4):1652–1660. https://doi.org/10.1007/s10924-017-1071-9

Borgin K., (1958): Development of the particle board industry in europe. Journal of the South African Forestry Association 1958;32(1):56–71. https://doi.org/10.1080/03759873.1958.9630878

Buyuksari U., Ayrilmis N., Avci E., Koc E., (2010): Evaluation of the physical, mechanical properties and formaldehyde emission of particleboard manufactured from waste stone pine (*Pinus pinea* L.) cones. Bioresource Technology 2010;101(1):255–259. https://doi.org/10.1016/j.biortech.2009.08.038

De Lima Mesquita A., Barrero N.G., Fiorelli J., Christoforo A.L., De Faria L.J.G., Lahr F.A.R., (2018): Eco-particleboard manufactured from chemically treated fibrous vascular tissue of acai (Euterpe oleracea Mart.) Fruit: A new alternative for the particleboard industry with its potential application in civil construction and furniture. Industrial Crops and Products 2018;112:644–651. https://doi.org/10.1016/j.indcrop.2017.12.074

EN 325: 2012, (2012): Methods for measuring the thickness, length and width of test pieces of wood-based panels. Polish Committee for Standardization.

Ferrandez-García A.A, Ortuño TG, Ferrandez-Villena M., Ferrandez-Garcia A., Ferrandez-García M.T., (2021): Evaluation of Particleboards Made from Giant Reed (*Arundo donax* L.) Bonded with Cement and Potato Starch. Polymers 2021;14(1):111. https://doi.org/10.3390/polym14010111

Guler C., Ozen R., (2024): Some properties of particleboards made from cotton stalks (*Gossypium hirsitum* L.). Holz als Roh- und Werkstoff 2004;62(1):40–43. https://doi.org/10.1007/s00107-003-0439-9

Lee S.H., Lum W.C., Boon J.G., Kristak L., Antov P., Pędzik M. i in., (2022): Particleboard from agricultural biomass and recycled wood waste: a review. Journal of Materials Research and Technology 2022;20:4630–4658. https://doi.org/10.1016/j.jmrt.2022.08.166

Madurwar M.V., Ralegaonkar R.V., Mandavgane S.A., (2012): Application of agro-waste for sustainable construction materials: A review. Construction and Building Materials 2012;38:872–878. https://doi.org/10.1016/j.conbuildmat.2012.09.011

Martins R.S.F., Gonçalves F.G., Segundinho P.G.D.A., Lelis R.C.C., Paes J.B., Lopez Y.M., i in., (2021): Investigation of agro-industrial lignocellulosic wastes in fabrication of particleboard for construction use. Journal of Building Engineering 2021;43:102903. https://doi.org/10.1016/j.jobe.2021.102903

Nguyen D.L., Luedtke J., Nopens M., Krause A., (2023): Production of wood-based panel from recycled wood resource: a literature review. Eur J Wood Prod 2023;81(3):557–570. https://doi.org/10.1007/s00107-023-01937-4

Nitu I.P., Islam M.N., Ashaduzzaman M., Amin M.K., Shams M.I., (2020): Optimization of processing parameters for the manufacturing of jute stick binderless particleboard. J Wood Sci 2020;66(1):65. https://doi.org/10.1186/s10086-020-01913-z

Nitu I.P., Rahman S., Islam M.N., Ashaduzzaman M., Shams M.I., (2022) Preparation and properties of jute stick particleboard using citric acid–glycerol mixture as a natural binder. J Wood Sci 2022;68(1):30. https://doi.org/10.1186/s10086-022-02039-0

Owodunni A.A., Lamaming J., Hashim R., Taiwo O.F.A., Hussin M.H., Mohamad Kassim M.H. i in., (2020): Adhesive application on particleboard from natural fibers: A review. Polymer Composites 2020;41(11):4448–4460. https://doi.org/10.1002/pc.25749

Pędzik M., Janiszewska D., Rogoziński T., (2021): Alternative lignocellulosic raw materials in particleboard production: A review. Industrial Crops and Products 2021;174:114162. https://doi.org/10.1016/j.indcrop.2021.114162

PN–EN 310: 1994, (1994): Wood-based panels – Determination of modulus of elasticity in bending and of bending strength.

PN–EN 312: 2005, (2005): Particleboards – Specifications.

Rivela B., Hospido A., Moreira T., Feijoo G., (2006): Life Cycle Inventory of Particleboard: A Case Study in the Wood Sector (8 pp). Int J Life Cycle Assessment 2006;11(2):106–113. http://dx.doi.org/10.1065/lca2005.05.206

Santos J., Pereira J., Ferreira N., Paiva N., Ferra J., Magalhães F.D. i in., (2021): Valorisation of non-timber by-products from maritime pine (Pinus pinaster, Ait) for particleboard production. Industrial Crops and Products 2021;168:113581. https://doi.org/10.1016/j.indcrop.2021.113581

Shaikh A.J., Gurjar R.M., Patil P.J., Paralikar K.M., Varadarajan P.V., Balasubramanya R.H., (2010) Particle boards from cotton stalk [Internet]. 2010;Available from: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://staging.icac.org/tis/regional_networks/asian_network/meeting_5/documents/papers/PapShaikhA.pdf. Accessed May 2025

Sugahara E., da Silva S., Buzo A.L., de Campos C., Morales E., Ferreira B., i in., (2019): High-density particleboard made from agro-industrial waste and different adhesives. BioRes 2019;14(3):5162–5170. https://doi.org/10.15376/biores.14.3.5162-5170

Taquetti V.B., Silva V.V., Chaves I.L.S., Oliveira R.G.E., Maffioletti F.D., Ferreira G. i in., (2023): Performance of eucalypt particleboard with the addition of farm waste. Heliyon 2023;9(12):e22760. https://doi.org/10.1016/j.heliyon.2023.e22760

Viswanathan R., (1999): Mechanical properties of coir pith particle board. Bioresource Technology 1999;67(1):93–95. https://doi.org/10.1016/S0960-8524(99)00065-6

Zvirgzds K., Kirilovs E., Kukle S., Gross U., (2022): Production of Particleboard Using Various Particle Size Hemp Shives as Filler. Materials 2022;15(3):886. https://doi.org/10.3390/ma15030886