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Some of the properties of particleboard made from paulownia

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Abstract The objective of this study was to determine some of the properties of experimental particleboard panels made from low-quality paulownia (*Paulownia tomentosa*). Chemical properties including holocellulose, cellulose, lignin contents, water solubility, and pH level of the wood were also analyzed. Three-layer experimental panels were manufactured with two density levels using urea–formaldehyde as a binder. Modulus of elasticity (MOE), modulus of rupture (MOR), internal bond strength (IB), screw-holding strength, thickness swelling, and surface roughness of the specimens were evaluated. Panels with densities of 0.65 g/cm^3 and manufactured using a 7-min press time resulted in higher mechanical properties than those of made with densities of 0.55 g/cm^3 and press times of 5 min. Based on the initial findings of this study, it appears that higher values of solubility and lignin content of the raw material contributed to better physical and mechanical properties of the experimental panels. All types of strength characteristics of the samples manufactured from underutilized low-quality paulownia wood met the minimum strength requirements of the European Standards for general uses.

Key words Particleboard · Paulownia · Mechanical properties · Thickness swelling · Surface roughness

Introduction

Successful development of wood composite panels in the last 40 years can be attributed to the economic advantage of low-cost wood, other lignocellulosic raw material, and inexpensive processing with various types of binders.[1,2] The use of particleboard has recently increased substantially throughout the world.[1] According to the Food and Agricultural Organization, worldwide particleboard consumption was 56.2 million cubic meters in 1998.[3] The rapid changing economic and environmental needs of society are putting ever increasing pressures on the particleboard industry.[4,5] In practical terms, this means alternative fibers such as underutilized species, fast-growing species, agricultural crops, and other plant fibers will play an important role in manufacture of composite panels such as particleboard.

The paulownia tree is a deciduous species capable of achieving very high growth rates under favorable conditions. It is indigenous to China and Japan, but has naturalized since its introduction in the United States. It covers a range from southern New York southward to Florida and Texas and extends into Arkansas and Oklahoma.[6] It has been highly valued for more than 2000 years in East Asia. Most species of paulownia are extremely fast growing, and can be harvested in 15 years for valuable timber. Low-quality lumber can easily be produced from 6–7-year-old trees. A fully grown paulownia can reach a height of 10–20 m and grows up to 3 m in 1 year under ideal conditions. A 10-year-old tree can measure 30–40 cm in diameter at breast height (DBH) and can have a timber volume of 0.3–0.5 m^3.[6] The wood of paulownia is soft, lightweight, ring-porous, straight-grained, and mostly knot-free wood with a satiny luster. The average reported density of the wood is 0.35 g/cm^3.[6]

Paulownia timber is easily air-dried without serious drying defects. It has a high strength-to-weight ratio, a low shrinkage coefficient, and does not easily warp or crack. Machining and finishing properties of the wood are excellent. In China and some of the other Asian countries, paulownia wood is used for a variety of applications such as furniture, shipbuilding, aircraft, packing boxes, coffins, paper, plywood, cabinetmaking, and molding.[6,7] Paulownia is considered an underutilized species and currently it has no commercial use in the United States, although it is used for home workshop projects. There are also various attempts to generate energy from paulownia chips.

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Table 1. Specifications of the panels and number of samples for each mechanical test

Board type	Density (g/cm^3) and press time	Number of panels	Bending strength		IB	SHS		TS		Surface roughness[a]
			MOE	MOR		Face	Edge	2 h	24 h	
A	0.55, 5 min	10	20	20	30	20	20	20	20	8
B	0.65, 5 min	10	20	20	30	20	20	20	20	8
C	0.65, 7 min	10	20	20	30	20	20	20	20	8

MOE, modulus of elasticity; MOR, modulus of rupture; IB, internal bond strength; SHS, screw-holding strength; TS, thickness swelling
[a]Some of the thickness swelling samples were also used for surface roughness measurement

The main objective of this study is to test some of the properties of particleboard manufactured from underutilized low-quality paulownia trees and to determine if the properties of such panels are similar to those made from other species.

Materials and methods

Air-dried sawdust of paulownia wood passing a 0.40-mm screen was used for chemical analysis. Ten 10-g samples were prepared for the analysis. The specimens were placed in a cone of fine mesh screen wire to prevent any loss of the material. Extraction flasks were each diluted with 150 ml of ethanol benzene and other solvents as perscribed by the standard methods.[8,9] Hot and cold water solubility characteristics of the paulownia wood were also determined. Ten 18-g particle samples were used for solubility tests. For the cold water solubility test, 10 samples were each put in a 400-ml beaker and slowly diluted with 300 ml distilled water, making sure that the wood was well wetted and avoided the tendency to float. Extraction was carried out at a temperature of 23°C with constant stirring for 48 h. Material was later transferred to a filtering crucible and washed with 200 ml cold distilled water. For the hot water solubility evaluation, the same amount of the specimens used for cold water solubility test was transferred to a 250-ml flask and 100 ml distilled water was added. Samples were placed in a boiling water bath for 3 h. The contents of the flask were transferred to a filtering crucible, before they were dried and weighed.[9,10] Ten 5-g samples were used for pH measurement of the wood. The specimens were put in 250-ml flasks filled with 150 ml distilled water. The flasks were stirred for 24 h before mixed samples were filtered on a filter paper. A 20-ml of the filtrate was pipetted out and its pH value was measured using a pH meter.[9,11]

Panel manufacture

Three low quality trees with an average DBH of 18 cm were harvested for the raw material. After the foliage was trimmed, the trees were converted into chip using a ring-type flaker. The chips were dried to 15% moisture content for about 2 weeks before they were reduced to particles in a laboratory hammer mill. The particles were later dried to 3% moisture content in an oven. Dried particles were classified into the two size categories of fine and coarse, with oversize and undersize particles removed on a screening machine with 3-mm, 1.5-mm, and 0.8-mm openings. Coarse particles were used for the core layer while the fine particles were used for the face layers of the boards. Particles were blended with the synthesized urea–formaldehyde resin with a solid content of 65%. Based on oven-dry particle weight, 8% and 10% resin were applied using an atomizing spray gun for the core and face layers, respectively. Ammonium chloride was added into the resin as a hardener during the blending process. No wax was used to improve the dimensional stability of the experimental panels. Mats that measured 56.5 × 56.5 × 1.8 cm and composed of 3 layers, were manually formed and pressed in a computer-controlled press at a temperature of 150°C and a pressure of 26.5 kg/cm^2. The ratio of the face thickness to the total thickness, known as the shelling ratio, was 0.33 for all panels. Two types of panels were manufactured: 10 panels with an average density of 0.55 g/cm^3 and pressed for 5 min and 20 panels with an average density of 0.65 g/cm^3 and pressed for 5 min and 7 min, as displayed in Table 1. The panels were kept in a conditioned room with a relative humidity of 65% and a temperature of 20°C until they reached equilibrium moisture content. They panels were then cut into test samples based on EN standards. Modulus of elastcity (MOE) and modulus of rupture (MOR) from static bending, internal bond strength (IB), screw-holding strength in both face and edge of the panels, and thickness swelling of the samples were determined. Mechanical tests were performed on a Universal Instron testing machine with a load capacity of 2000 kgf. In addition to mechanical and thickness swelling tests, surface roughness of the samples were also determined using a fine stylus technique. The Hommel T-500 stylus unit used for the surface evaluation of the samples consisted of the main unit and the pick-up model TkE. The pick up had a skid–type diamond stylus with a 5-μm tip radius and a 90° tip angle. The stylus traversed the surface at a constant speed of 1 mm/s over a 15.2-mm tracing length and the vertical displacement of the stylus was converted into an electrical signal. A presentation of the surface can be obtained in the form of a graph as illustrated in Fig. 1. Average roughness (R_a), mean peak-to-valley height (R_z), and maximum roughness (R_{max}) were used to evaluate the surface roughness of the samples. Detailed description of these parameters was discussed in previous studies.[12–14] Calibration of the instrument was also checked every 100

Table 2. Results of chemical analyses of paulownia compared with literature results for hardwood and softwood

Chemical	Paulownia	Hardwood[a]	Softwood[a]
Holocellulose (%)	78.8 ± 05	68–74	70–81
Cellulose (%)	48.3 ± 04	58–64	55–61
Lignin (%)	22.1 ± 03	17–26	25–32
Hot water solubility (%)	12.8 ± 01	2–5	3–6
Cold water solubility (%)	11.6 ± 02	2–6	3–6
pH	5.38	–	–

[a] Eroglu[15]

Table 3. Summary of test results of the specimens

Board type	MOE (N/mm^2)	MOR (N/mm^2)	IB (N/mm^2)	SHS (N)		TS (%)		Roughness parameters (μm)		
				Face	Edge	2 h	24 h	R_a	R_z	R_{max}
A	2396 (14.3)	13.91 (11.3)	0.67 (15.8)	454 (14.1)	279 (12.3)	8.9 (11.9)	12.6 (12.0)	12.61 (6.8)	40.49 (6.4)	78.90 (10.2)
B	2437 (15.2)	17.88 (12.9)	0.80 (14.1)	528 (13.2)	319 (14.0)	9.0 (14.8)	13.6 (15.1)	12.13 (11.2)	39.45 (8.2)	82.5 (10.2)
C	2780 (13.2)	21.39 (13.0)	0.85 (13.9)	588 (14.2)	399 (14.4)	10.5 (12.9)	21.1 (13.2)	10.26 (6.9)	37.33 (6.9)	72.60 (9.9)

Numbers in parentheses are coefficients of variation

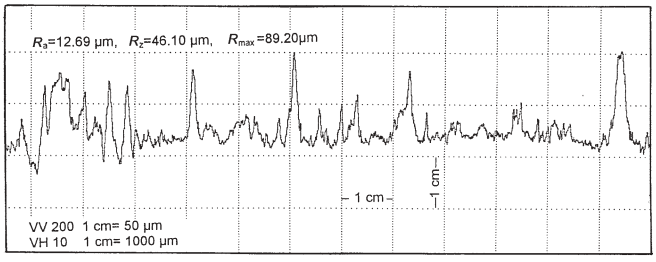

Fig. 1. A typical surface roughness profile of the samples. *VV*, vertical; *VH*, horizontal

measurements by using a standard reference plate with R_a values of 3.02 μm and 0.48 μm. A cut-off length of 2.54 mm, a parameter that differentiates roughness and waviness profiles from each other, was used for the measurements. Twenty roughness measurements were taken from the surface of each panel to evaluate their surface characteristics.

Results and discussion

Results of the chemical analyses of paulownia wood are presented in Table 2. The average holocellulose content of the samples was found to be 78.8% which is higher than that of hardwoods stated in the literature.[15] Based on the findings in this study, average cellulose and lignin content were also determined as 48.3% and 22.1%, respectively. These values are comparable with the values of typical hardwoods.[15] One of the most important chemical properties of wood is its pH level. It has an important role in developing good bonding between resin and particle which results in enhanced panel properties. The average pH value of the samples was 5.38. Urea–formaldehyde used as binder in panel manufacture has a pH value ranging from 5.5 to 6.0, which is very close to that of paulownia wood. Comparable pH values of wood and resin is critical to have a good glueline between particles that influences both the physical and mechanical properties of the panels. Hot and cold water solubility values of the samples are relatively higher than both softwoods and hardwoods investigated in previous studies.[15,16] High solubility of the wood is also desirable during pressing of the mat, which improves the overall properties of the panels.

The physical and mechanical properties of the experimental panels are presented in Table 3. Panels with a density of 0.65 g/cm^3 and pressed for 7 min had the highest values among the three types of specimens. MOE and MOR values for type C panels were 2780 N/mm^2 and 21.39 N/mm^2, respectively. All types of panels made in this study satisfied the MOE and MOR strength requirements for general uses and interior fitments including furniture manufacture stated in the EN standards.[17,18] In a previous study, MOE and MOR values of particleboard panels made from the combination of palm branches and paulownia were lower than those found in this work.[7,30] The minimum MOE requirement for heavy duty load-bearing boards according to EN standards is 2400 N/mm^2. Both type B and C panels satisfied this limit.[19,20] However, the MOE of type A panel was lower than 2400 N/mm^2 (Fig. 2). This can easily be related to the low density of the type A panel and shorter press cycle as compared with those of other panel types.

The IB values of the specimens ranged from 0.67 N/mm^2 to 0.85 N/mm^2, as illustrated in Fig. 3. All panels were found to comply with the IB strength value of 0.60 N/mm^2, which is the requirement for heavy duty load-bearing particleboard

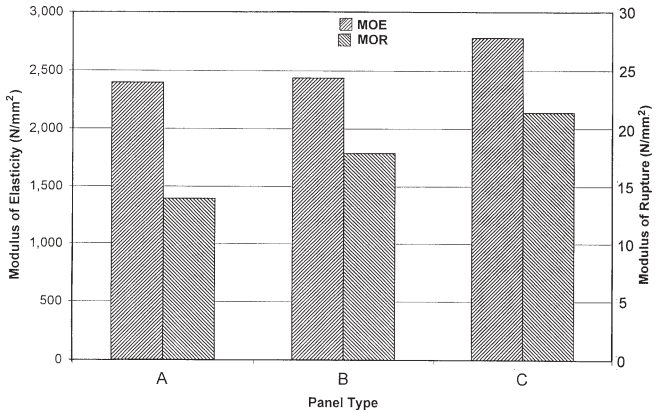

Fig. 2. Bending properties of the panels

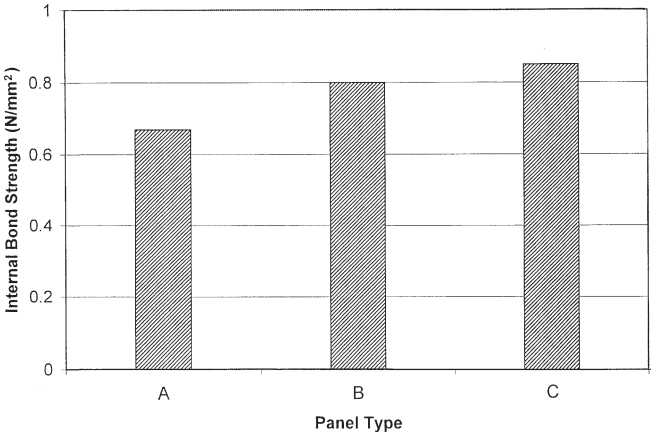

Fig. 3. Internal bond strengths of type A, B, and C panels

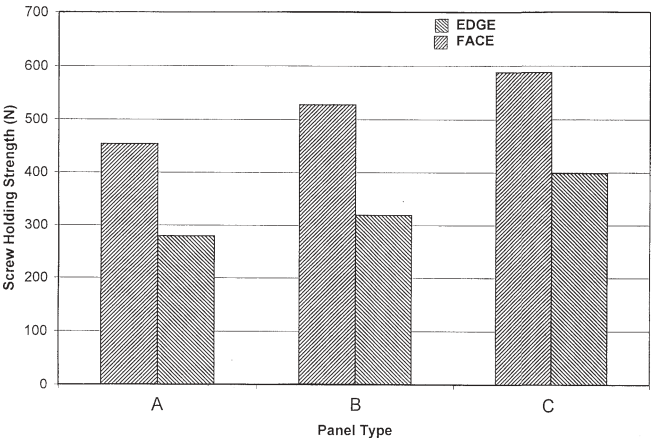

Fig. 4. Face and edge screw-holding strengths of type A, B, and C panels

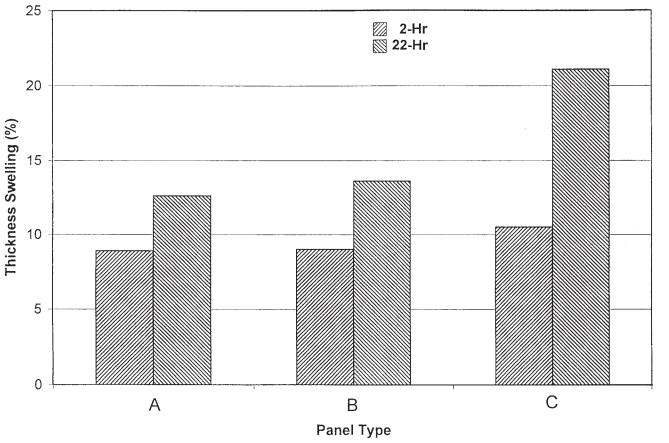

Fig. 5. Thickness swelling of type A, B, and C panels

as stated in the EN standards.[21] Density was the main factor that influenced the mechanical properties of the panels. MOE, MOR, and IB strength values of the specimens increased with increasing board density as determined in previous studies.[22–24] However, types A and B did not show statistically significant differences at a 95% confidence level in their bending strength and IB properties from each other while type C showed significant differences in such properties from types A and B at the same confidence level.

Face and edge screw-holding strength properties were also within the limits of required values stated in relevant standards.[25–27] Panel type C, with the highest density and manufactured with a 7-min press time, had average values of face and edge screw-holding strengths of 588 N and 339 N, respectively (Fig. 4). A statistical trend similar to those mentioned above was also observed for screw-holding strength of the samples.

Based on EN standards, particleboard should have a maximum thickness swelling value of 15% for load-bearing applications.[21] Panel type C gave the highest thickness swelling of 10.5% and 21.1% after soaking for 2 and 24 h, respectively, due to its density of 0.65 g/cm^2 and longer press cycle, as shown in Fig. 5. Springback of the panels as they are soaked in water is transferred in less dimensional stability which is a common behavior of any wood composite.[28–30] In addition, the high thickness of panel type C may be related to the fact that no wax or other hydrophobic substance was used during panel manufacture. However, panel types A and B resulted in satisfactory thickness swelling characteristics when considered against standard values. It appears that additional treatment such as acetylation and heat treatment of particles for the panels with density of 0.65 g/cm^3 and higher would be an alternative way to improve their dimensional stability.[31–33]

Figure 6 shows the R_a and R_z values of the samples. Panel type C made with a 7-min press time had the smoothest surface with average values of 10.26 μm, 37.33 μm, and 72.60 μm for R_a, R_z, and, R_{max}, respectively. This can be related to densified face layers of the samples due to the long press time. Panel types A and B did not show any statistical significant difference at a 95% confidence level. However, type A had significantly better surface roughness characteristics than both of the other panel types. This finding suggests that board density and press time play an important role in determining surface quality and reflects similar results from previous work.[14]

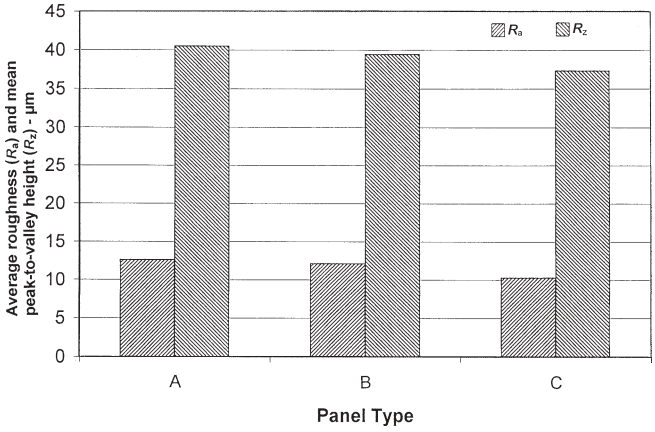

Fig. 6. Surface roughness parameters of type A, B, and C panels

Conclusions

This study determined some of the mechanical and physical properties of experimental particleboard panels manufactured from low-quality paulownia trees. In addition, chemical analyses of the wood from the same trees were conducted. It appears that samples met the basic properties as stated in the standards. Density and press time were the main parameters influencing the physical and mechanical properties of the panels. Chemical analysis revealed that low-quality trees did not adversely affect board properties. Based on the results of this work, low-quality paulownia trees have potential as raw material to manufacture particleboard. In further studies, panels made from the combination of paulownia and other underutilized species could be considered. More than two density levels and press times should be used in order to attain a better understanding of the effect of manufacturing variables on panel properties.

References

1. Anon (1994) Technical information and physical properties of paulownia wood. World Paulownia Institute. Lenox, GA
2. Anon (2003) Lyn van de Hoef, Box Hill Customer Service Center. Department of Primary Industries/Department of Sustainability and Environment, Victoria, Australia
3. Cooper PA, Baltinecz JJ, Flannery F (1999) Agricultural waste materials for composites: a Canadian Reality. Center for Management Technology Global Panel Based Conference, Kuala Lumpur
4. Ntalos GA, Grigoriou AH (2002) Characterization and utilization of wine pruning as a wood substitute for particleboard production. Ind Crops Prod 16:59–68
5. Rowell RM (1995) A new generation of composite materials from agro-based fiber. Proceedings of 3rd International Conference on Frontiers of Polymers and Advanced Materials, Kuala Lumpur, Malaysia, pp 659–665
6. Flynn H, Holder C (2001) Useful wood of the world. Forest Products Society. Madison, WI
7. Clad W, Pommer E (1980) Manufacture of particleboard from kiri (*Palownia tomentosa*, Fam. Scrouphulariaceae) Holz Roh Werkst 38:385–391
8. TAPPI T-257 (1995) Sampling and preparation wood analysis. TAPPI Standards. Narcross, GA 30092
9. Wise LE (1962) Wood chemistry, vol 1. Reinhold, New York
10. TAPPI T-204 (1997) Solvent and extraction of wood and pulp. TAPPI Standards. Narcross, GA 30092
11. Hameed M (2000) On the behavior of natural trends of particleboard properties made of *Pinus sylvestris* L. against synthetic binder contents. Ph.D. Dissertation. Forest Products Department, Gottingen University, Gottingen, Germany
12. Hiziroglu S, Holcomb R, Xu Q (2002) Manufacturing particleboard from eastern redcedar. Forest Prod J 52:72–76
13. Hiziroglu S (1999) Surface roughness analysis of wood composites: a stylus method. Forest Prod J 46:67–72
14. Hiziroglu S, Graham M (1998) Effect of press closing time and target thickness on surface roughness of particleboard. Forest Prod J 48:50–54
15. Eroglu H (1998) Fiberboard industry. Karadeniz Technical University. Publication No: 304, Trabzon, Turkey, p 212
16. Yusuf S (1996) Properties enhancement of wood by cross-linking formation and its application to the reconstituted wood products. Ph.D. Dissertation Kyoto University, Kyoto, Japan.
17. EN 310 (1993) Wood based panels. Determination of modulus of elasticity in bending and bending strength. European Standardization Committee, Brussels
18. EN 312–3 (1996) Particleboard specifications. Part 3: requirements for board for interior fitments (including furniture) for use in dry conditions. European Standardization Committee, Brussells
19. EN 312–4 (1996) Particleboard specifications. Part 4: requirements for load-bearing boards for use in dry conditions. European Standardization Committee, Brussells
20. EN 312–6 (1996) Particleboard specifications. Part 6: requirements for heavy-duty load bearing boards for use in dry conditions. European Standardization Committee, Brussells
21. EN 317 (1993) Particleboard and fiberboards. Determination of swelling in thickness after immersion. European Standardization Committee, Brussells
22. Hofstarnd AD, Moslemi A, Garcia JF (1984) Curing characteristics of wood particles from nine northern rocky mountain species mixed with portland cement. Forest Prod J 34:57–61
23. Goker Y, As A, Kalaycioglu H, Akbulut T (1993) Some of the technological properties of particleboard with *Pinus brutia* and European birch. Proceedings of International Symposium on *Pinus brutia*, Marmaris, Turkey, pp 692–699
24. Kalaycioglu H, Ors Y (1993) Technological properties of particleboard produced from maritina pine. J Agric Forest 17:737–751
25. BS 5669 (1979) Wood chipboard and methods of test for particleboard. British Standards Institution, London
26. BS 2604 (1970) Resin bonded wood chipboard. British Standards Institution, London
27. EN 319 (1993) Particleboard and fiberboards. Determination of tensile strength perpendicular to plane of the board. European Standardization Committee, Brussells
28. Hall H, Gertjajensen R, Smith E, Carl CG, Degroot RC (1984) Preservative effect on mechanical and thickness swelling properties of aspen waferboard. Proceedings of Workshop on Durability of Structural Panels, Pensacola, FL
29. Maloney T (1997) Modern particleboard and dry-process fiberboard manufacture. Miller Freeman, San Francisco, CA
30. Nemli G, Kalaycioglu H, Alp A (2001) Suitability of date palm (*Phoenix dactyliferia*) branches for particleboard production. Holz Roh Werkst 59:411–412
31. Unchi S (1996) Acetylation of *Acacia mangium* wood fibers and its application in MDF manufacture. Ph.D. Dissertation. Faculty of Forestry, University Pertanian Malaysia, Serdang, Malaysia
32. Volz KR (1973) Properties of the panels manufactured from the bark of spruce, pine, and beech. Holz Roh Werkst 31:221–229
33. Wisherd KD, Wilson B (1979) Bark as supplement to wood furnish for particleboard. Forest Prod J 29:35–40