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Performance of Formaldehyde Resins and Cement Bonded Particleboards and Understanding its Properties for further Advancement

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Abstract

The objective of this study is to understand and articulate the impact of the mechanical properties of the particleboards made from different bonding system such as, urea formaldehyde, phenol formaldehyde, cement, polymeric methane diphenyl diisocyanate and PTP, containing raw materials from different wood species. It is evident from the detailed studies and data analysis of the work done that the maximum tensile modulus and flexural modulus of particleboard were 4616.3 MPa and 48.0 MPa respectively with thickness swelling 6.3% using urea formaldehyde resin. However with phenol formaldehyde resin the maximum tensile modulus and flexural modulus of particleboard were 5799.5 MPa and 35.14 MPa respectively with thickness swelling 3.9%. The cement bonded particleboard showed maximum tensile modulus and flexural modulus of 7121 MPa and 19.5 MPa respectively and the corresponding thickness swelling was 0.35%. Particleboard made with urea formaldehyde showed maximum value of thickness swelling while cement bonded particleboard showed maximum tensile modulus. Particleboards with urea formaldehyde and phenol formaldehyde resin showed almost comparable flexural modulus.

This paper reviews the relationship of diverse parameters such as resin, hardener, raw material quantity as well as manufacturing conditions on the mechanical and physical properties of the particleboards, based on the published resources from the last 30 years.

Review of Literature

Traditionally, particleboards have been used as an alternative to wood in various applications such as furniture, partition panels etc. The particleboards are being manufactured using raw materials like formaldehyde resin, cement, and wood species under the pressure ranging from 1.42 kg/cm^2 to 2500 kg/cm^2 and the temperature ranging from 27°C to 225°C. Although it is being used for the last 100 years, there have not been many notable improvements in the last two decades. There is a substantial need of the particleboards to comply with the increasing demands of the increasing population.

This review paper has summed up major wood species, binding agents and manufacturing methods used for manufacturing particleboards around the globe.

Urea formaldehyde resin based particleboard

Work done by Laemlasakul [1], on particleboard made from bamboo waste under hot press at 120°C under pressure of 150 kg/cm^2 with 13% Urea Formaldehyde resin, 1% NH_4Cl hardener has showed a density 600 kg/m^3 and tensile modulus of 749 MPa when specimen was conditioned to equilibrium state for 24 hat 55°C. The corresponding Flexural modulus and Thickness swelling were 6.5 MPa and 6.1% respectively. However, under same manufacturing condition but with higher target density of 800 kg/m^3 and when specimen was conditioned to equilibrium state for 24 hat 40°C, the material have showed a higher value of tensile modulus (2166 MPa) and flexural modulus (21.5 MPa) over previous manufacturing condition with a target density 600 kg/m^3. It is evident from this study that the density and the conditioning temperature has considerably influenced in enhancing the tensile modulus and flexural modulus of the material.

Work done by Pan et al. [2], on particleboard made from saline eucalyptus, manufactured under hot pressing,152°C temperature, 3 MPa pressed for 5 min using 7% urea formaldehyde resin and1% ammonium sulphate (hardener) showed a tensile modulus of 1564.2 MPa. The corresponding flexural modulus, thickness swelling and density were 13.6 MPa, 38.28% and 720 kg/m^3 respectively. However, when particleboard manufactured using 4% polymeric methane diphenyl diisocyanate resin (PMDI) under hot pressing temperature 140°C, pressed 3 MPa for 5 minutes resulted a higher tensile modulus (1651.9 MPa) and a lower flexural modulus (10.4 MPa).

Recent work done by Jumhuri et al. [3], revealed that particleboard made from oil palm trunk using 10% urea formaldehyde resin under hot pressing condition showed a tensile modulus of 857 MPa. The corresponding flexural modulus, thickness swelling and density were 5.9 MPa, 75% and 650 kg/m^3 respectively. When the oil palm trunk particles were soaked in hot water for 30 mins and manufactures using same method, resulted increased tensile modulus (864 MPa), flexural modulus (7.1 MPa) and a lower thickness swelling (53%). However, when particles were soaked in NaOH solution (2% conc.) for 30 minutes and particleboard was manufactured using same technique had resulted lower value of both the tensile modulus (839.0 MPa) as well as flexural modulus. It is concluded from this study that treatment of palm trunk particle with hot water and NaOH have showed considerable effect on the tensile modulus, flexural modulus and Thickness selling of the material (Figure 1).

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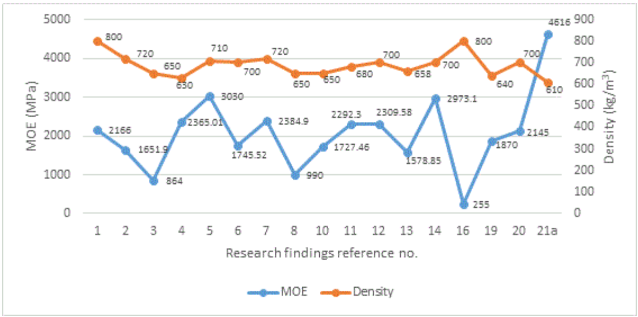

Figure 1: Modulus of elasticity v/s density of particleboards made from UF resin.

Atar et al. [4], reported on three layer particleboard made in combination of wood particles of 90% Pine (*Pinusbrutia*) wood particles, 5% beech (*Fagus orientalis*) wood particle and 5% poplar (*Populustermula*) wood particles (34% chips for face layer and 66% chips for core layer)with urea formaldehyde resin (11% in face layer and 9% in core layer) by hot pressing. Three different hardeners (ammonium chloride, ammonium sulphate, and aluminium sulphate) were added (0.85 wt% for the surface layers and 2.5 wt% for the core layer) to the UF resin. Particleboard with ammonium sulphate hardener showed tensile modulus and flexural modulus of 2030.84 MPa and 12.56 MPa respectively and sample with aluminium sulphate hardener showed tensile modulus and flexural modulus of 1832.30 MPa and 11.09 MPa respectively. However particleboard with ammonium chloride as hardener showed the highest tensile modulus and flexural modulus of 2365.01 MPa and 14.2 MPa respectively. It is evident from this study that type of hardener effects the mechanical property of the material.

Work done by Moubarik et al. [5], on particleboard made from corn flour NaOH adhesive and mimosa tannin/hexamine under hot pressing (3.5 MPa pressure at 195°C for 2.6 min) showed a tensile modulus 3030 MPa with corresponding flexural modulus 18.9 MPa and density 710 kg/m^3. However, particleboard with UF resin under same conditions has resulted tensile modulus 2573 MPa, flexural modulus 15.6 MPa.
It is understood from this study that use of corn flour/NaOH adhesive and mimosa tannin/hexamine gave better mechanical property with lower formaldehyde emission as compared to UF resin.

Nemli et al. [6], studied on three layer particleboard from a mixture of 45% beech wood particles, 35% pine wood particles and 20% poplar wood particles with UF resin (8% core layer and 10% face layer) under hot pressing (34.5 kg/m^3 pressure at 200°C for 125 sec) resulted a tensile modulus of 1745.52 MPa, the corresponding flexural modulus, thickness swelling and density were 13.998 MPa, 8.94 % and 700 kg/m^3 respectively. However, 20% wood dust and increased press time (165 sec) did not showed major impact on material properties, it resulted in tensile modulus (1730.66 MPa) with flexural modulus (13.74 MPa) and a lower thickness swelling (6.44%).

Particleboard from saline Athel wood with varying percentages of UF resin and bark content and target density of 650 kg/m^3 was studied by Zheng et al. [7]. It was observed from the results that with 16% UF resin and 8% bark content under hot pressing (3 MPa pressure at 152°C for 5 min) resulted in tensile modulus 2198 MPa with flexural modulus 19.6 MPa and thickness swelling and 14.71%. However using 16% UF resin without bark, resulted tensile modulus 2384.9 MPa, flexural modulus 23.7 MPa and thickness swelling and 12.87% which is better than latter.
Also, use of 4% PMDI resin for making particleboard under hot pressing (3 MPa at 140°C for 8 min) resulted a tensile modulus, flexural modulus and thickness swelling.
It is evident from this study that addition of bark content in the particleboard decreases its mechanical property [8].

The particleboard from *Paraserianthes falcataria* wood particles with 8% UF resin under hot pressing (130 kg/cm^2 at 150°C temp for 3 min) with a target density 650 kg/m^3 were fabricated and studied their performance by Acda and Cabangon [8]. The resulting tensile modulus, flexural modulus and thickness swelling were 990 MPa, 48 MPa and 23% respectively. However use of wood particles and tobacco particle (1:1) resulted lower tensile modulus 680 MPa and flexural modulus 30 MPa.

Yalinkilic et al. [9], worked on particleboard from waste tea (*Camelia sinensis*) leaves using UF resin (10% outer and 8% inner layer) under hot pressing (at 150°C for 5 min under 22 kg/cm^2 pressure) manufactured particleboard having densities 550 kg/m^3, 650 kg/m^3 and 750 kg/m^3 resulted a flexural strength 2.6 MPa, 4.0 MPa and 4.4 MPa respectively. The corresponding thickness swelling values were 25.5%, 24.0% and 19.0% respectively. From this study it is recorded that particleboard with higher density showed higher FS and lower thickness swelling.

Particleboard made up of pine wood particles, poplar wood particles, beech wood particles and oak wood particles in different ratios with UF resin, ammonium sulphate hardener and paraffin emulsion under hot pressing condition with target density of 650 kg/m^3 were studied by Baharoglu et al. [10]. Mixture of 85% Poplar + 5% pine + 5% beech + 5% oak wood particles resulted a tensile modulus of 1209.46 MPa with flexural modulus and thickness swelling 10.27 MPa and 16.97% respectively.
However mixture of 85% Pine + 5% beech + 5% poplar + 5% oak wood particles resulted tensile modulus of 1727.46 MPa with flexural modulus and thickness swelling 13.31 MPa and 14.21% respectively (Figure 2).

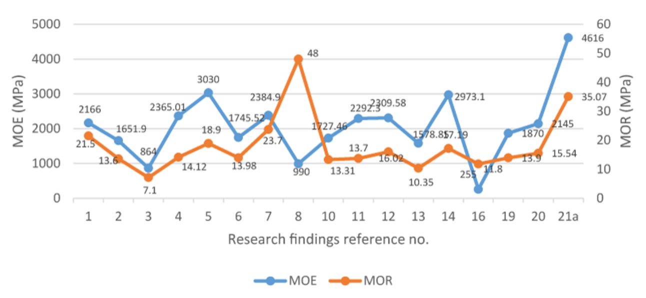

Figure 2: Modulus of elasticity v/s modulus of rupture of particleboards made from UF resin.

Three layer particleboards were fabricated using different ratios of pine wood particles and poppy husk with UF resin (34% chips and 10% UF in outer layer and 66% chips and 8% UF in core layer.) and ammonium chloride hardener under hot pressing condition by Keskin et al. [11]. Pine wood particles showed higher tensile modulus 2292.30

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MPa. However the corresponding flexural modulus 13.70 MPa and thickness swelling 10.22% were not much impressive. Poppy husk resulted a tensile modulus 583.30 MPa with lower flexural modulus 3.24 MPa and thickness swelling and 22.48% [11]. It is interesting to note that mixture of 25% poppy husk and 75% pine wood particles resulted in tensile modulus of 1841.30 MPa with flexural modulus and thickness swelling 11.28 MPa and 10.63% respectively.

Particleboards were made from Industrial wood particles (mixed hardwood species such as hornbeam, beech and oak) and different quantities of walnut shell as raw material was used with UF resin, ammonium chloride hardener under hot pressing condition by Priayesh et al. [12]. Result showed that use of 100% hardwood particles exhibited higher tensile modulus of 2309.58 MPa, flexural modulus 16.02 MPa and thickness swelling 18.16%. Use of 100% walnut shell resulted a tensile modulus of 1152.33 MPa, flexural modulus 5.86 MPa and thickness swelling 10.15%.

However, use of walnut shell and hardwood particle (1:4) resulted a tensile modulus of 2101.58 MPa. The flexural modulus and thickness swelling were found similar to the particleboard with only hardwood particles.

From this study it is evident that use of walnut shell decreased the thickness swelling.

One of the study conducted by Elbadawi et al. [13], for making particleboard from Ailanthus wood with UF and mixture of equal amount of Acacia seyal var. seyal and *Acacia nilotica* tannin under hot pressing condition at 180°C with 150 bar pressure for 7 min. Particleboard with only UF resin resulted a tensile modulus of 1051.82 MPa, a lower flexural modulus 7.79 MPa and showed relatively very high thickness swelling 42.85%. Particleboard with 90% UF and 10% tannin resin resulted a tensile modulus 1443.50 MPa. The flexural modulus, thickness swelling and density 9.60 MPa, 44.58% and 689 kg/m^3 respectively. But the density of previous was lower.

Particleboard with 95% UF and 5% tannin showed a tensile modulus 1578.85 MPa. The flexural modulus, thickness swelling and density were 10.35 MPa, 42.48% and 658 kg/m^3 respectively which is better than previous results.

Study performed by Guler et al. [14], deals with three layered particleboard made from sunflower stalks and Calabrian wood particles in different percentages with UF resin (35% chips, 11% UF in outer layer and 65% chips, 9% UF in core layer), ammonium chloride hardener under hot pressing condition. Use of sunflower stalks resulted a tensile modulus 1800.2 MPa and flexural modulus 15.68 MPa. Application of Calabrian wood particles resulted a tensile modulus of 2204.3 MPa though flexural modulus found to be 17.19 MPa which is considerably good [15].

Interesting use of sunflower stalks and Calabrian wood particles (1:1) exhibited highest tensile modulus of 2973.1 MPa and better flexural modulus and thickness swelling 18.74 MPa and 21.83% respectively. It is evident from this study that equal proportion of sunflower stalks and Calabrian wood particles resulted best mechanical property (Figure 3).

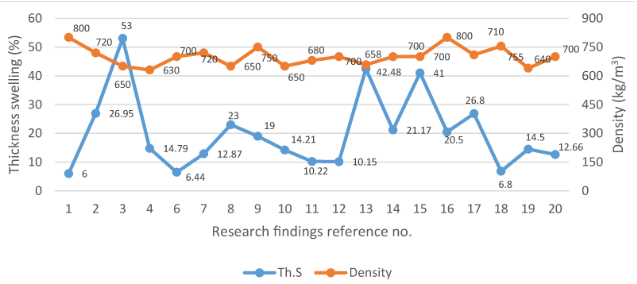

Figure 3: Thickness swelling v/s density of particleboards made from UF resin.

Mechanical properties of particleboard made from wheat straw with 13% UF resin, 1% Ammonium chloride hardener under hot pressing condition using four types. The performance of particleboards made from yellow pine wood particles with 10% urea formaldehyde resin under hot pressing condition were studied by Clausen et al. [16]. Use of wood particle with Oxalic acid extract (0.8%) resulted a tensile modulus, flexural modulus and thickness swelling of 162.0 MPa, 6.8 MPa and 20.5% respectively.

However use of chromated copper arsenate (CCA) treated wood particles showed tensile modulus, flexural modulus and thickness swelling of 225.0 MPa, 11.8 MPa and 25.7% respectively. It is evident that particle treated with CCA resulted better mechanical properties.

Oh et al. [17], studied on particleboard from different types of Korean thinning logs (*Pinusrigida, Pinusdensiflora, Larixleptolepis* and *Quercusacutissima*) with 6% UF resin and 1% wax solid under hot processing condition. Particleboard with Pinusrigida wood particle resulted a flexural modulus 12.5 MPa. The corresponding thickness swelling and density were 43.9% and 702 kg/m^3 respectively.

However, it was observed that particleboard from *Pinusdensiflora* wood particle showed comparatively best results with flexural modulus, thickness swelling and density of 14.6 MPa, 40.2% and 710 kg/m^3 respectively.

Particleboard casted using bamboo chips with different amount of UF resin and wax under hot pressing (3.4 MPa pressure at 200°C for 6 min) was studied by Papadopoulos et al. [18]. Use of 12% UF with 1% wax resulted a flexural modulus and thickness swelling of 16.22 MPa and 9.1% respectively, while use of 12% UF without wax resulted a flexural modulus and thickness swelling of 16.66 MPa and 17.3% respectively. The highest flexural modulus and thickness swelling 19.98 MPa and 14.7% respectively was achieved when 14% UF resin was used without wax.

It is evident from this result that addition of wax decreases the thickness swelling as well as the flexural modulus.

Three layered particle board made from industrial particles (furnish of a mixture of *Pinussylvestries, Fagus orientalis* and *Populustremula*) with UF resin and ammonium chloride hardener under hot press condition was studied by Akyuz et al. [19]. Boards were manufactures using different percentage of hardener in core and face layers resulting in different pH value of resin. Use of 0.4% in face and 1.5% hardener in core layer resulted a tensile modulus, flexural modulus and thickness swelling of 1470 MPa, 9.8 MPa and 18.6% respectively.

However use of 1.0% in face and 3.0% hardener core layer showed a tensile modulus 1870 MPa. And the corresponding flexural modulus and thickness swelling were 13.9 MPa and 14.5% respectively (Figure 4).

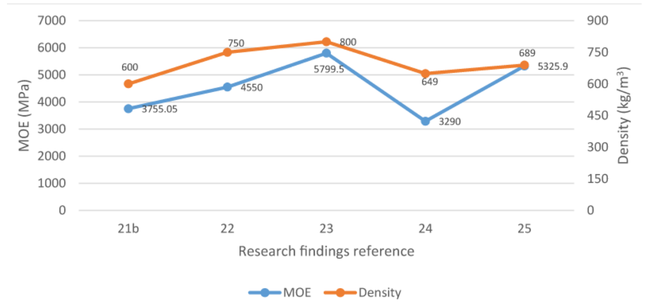

Figure 4: Modulus of elasticity v/s density of particleboards made from PF resin.

Guler et al. [20], made three layer particleboard using peanut hull wood particles and European black pine wood particles in different ratios with UF resin (8% and 10% in core and outer layer resp.) and 1% ammonium chloride (hardener) under hot pressing condition. Use of only pine chips showed tensile modulus, flexural modulus and thickness swelling of 2145 MPa, 15.54 MPa and 12.66% respectively which is considerably higher than other reported values. However mixture of 25% peanut hull wood particles and 75% pine chips resulted in tensile modulus, flexural modulus and thickness swelling of 1885 MPa, 14.10 MPa and 17.72% respectively.
From this study it is concluded that peanut hull wood particles is a potential raw material that can be added in some specific amount in manufacturing of particle board from pine chips, where higher strength is not required.

McNatt [21], studied the particleboards made from different wood species and found that particleboard made from Douglas-fir with UF resin resulted a higher tensile modulus, flexural modulus and density of 4616.3 MPa, 35.07 MPa and 610 kg/m^3 respectively (Table 1).

Particleboard Raw Material	T.M.	F.M.	Th.S.	W.A.	ρ	Reference
Bamboo Waste	2166	21.5	6.3	-	800	Laemlaksakul [1]
Saline Eucalyptus	1651.9	10.4	26.95	48.22	720	Pan et al. [2]
Palm Trunk	864	7.1	53	130	650	Jumhuri et al. [3]
Pine wood (90%), beech wood (5%) and Poplar wood (5%)	2365.01	14.12	14.79	-	630	Atar et al. [4]
Corn flour-mimosa tannin based adhesives	3030	18.9	-	-	710	Moubarik et al. [5]
45% beech, 35% pine and 20% poplar	1745.52	13.98	8.94	-	700	Nemli et al. [6]
Saline Athel wood	2384.9	23.7	12.87	42.96	720	Zheng et al. [7]
Waste tobacco stalks and wood particles	990	48	23	42	650	Acda et al. [8]
Waste tea leaves	-	-	19.0	63	750	Yalinkilic et al. [9]
Mixtures of pine, poplar, beech and oak wood	1727.46	13.31	14.21	-	650	Baharoglu et al. [10]
Pine wood and poppy husk.	2292.30	13.70	10.22	-	680	Keskin et al. [11]
Walnut shell as raw material	2309.58	16.02	18.16	68.32	700	Priayesh et al. [12]
Ailanthus wood	1578.85	10.35	42.48	104.4	658	Elbadawi et al. [13]
Sunflower stalks and Calabrian pine	2973.1	18.74	21.83	77.39	700	Guler et al. [14]
Wheat straw	-	22.5	41	-	700	Han et al. [15]
CCA-treated wood	255.0	11.8	25.7	42.5	800	Clausen et al. [16]
Korean thinning logs	-	14.6	40.2	64.0	710	Oh et al. [17]
Bamboo chips	-	18.98	14.7	-	743	Papadopoulos et al. [18]
Industrial wood particle	1870	13.9	14.5	-	640	Akyuz et al. [19]
Peanut hull and European black pine	2145.71	15.54	12.66	61.77	700	Guler et al. [20]
Douglas-fir	4616.3	35.07	-	-	610	McNatt [21]

Table 1: Urea formaldehyde based particleboard.

Phenol formaldehyde resin based particleboard

McNatt [21], studied the particleboards made from different wood species and found that particleboard made from Ponderosa and lodge pole pine with PF resin resulted in the tensile modulus 3031.6 MPa with the flexural modulus and density 28.81 MPa and 770 kg/m^3 respectively.

Particleboard from the mixture of rice straw and choir fibers with 14% phenol formaldehyde and 3% polymeric methylene diphenyl diisocyanate resin was casted by Zhang et al. [22] under hot pressing condition. Particleboard manufactured from NaOH treated rice straw resulted in tensile modulus 4550 MPa with flexural modulus and thickness swelling 30.23 MPa and 13.09% respectively.
However particleboard manufactured with the mixture of 60% rice straw (NaOH treated) and 40% coir fibres resulted in tensile modulus 3340 MPa with flexural modulus and thickness swelling 27.77 MPa and 8.32% respectively which satisfied the Chinese Standard of GB/T 4897.6-2003, (load bearing particleboards used in dry condition).

Three layer particleboard was manufactured from mixed hardwood species like chips from oak and lauan (using fine chips for face layer and coarse chips for core layer) by Yang et al. [23]. With 6.5% PF resin under hot pressing condition (2.9 MPa at 180°C temp for 5 min) with target density 800 kg/m^3 resulted in tensile modulus 3988 MPa with flexural modulus and thickness swelling 20.58 MPa and 7.3% respectively.
However using 10% PF resin under same processing condition and target density they achieved tensile modulus 5799 MPa with flexural modulus and thickness swelling of, 30.4 MPa and 3.9% respectively.

Particleboards with same amount of PF but lower density (700 kg/m^3) showed lower mechanical properties (Figure 5).

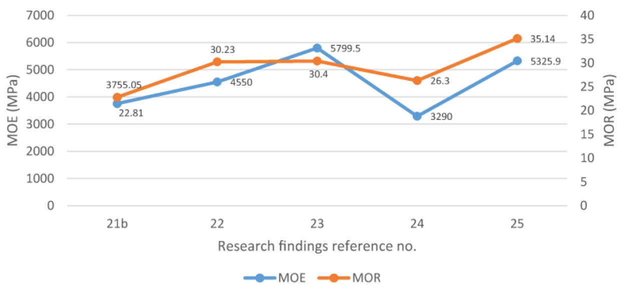

Figure 5: Modulus of elasticity v/s modulus of rupture of particleboards made from PF resin.

In another study by Fuwape [24] revealed that made particleboard from sitcka spruce wood particles with 10% PF resin under hot pressing condition resulted in tensile modulus 3290 MPa with flexural modulus and thickness swelling 26.30 MPa and 19.6% respectively. But use of Mangrove tannin – PF resin (70% tannin and 30% PF) resulted in tensile modulus 2990 MPa with flexural modulus and thickness swelling 20.50 MPa and 49.37% respectively. Again using a different Quebracho tannin – PF resin (70% tannin and 30% PF) resulted in tensile modulus 2660 MPa with flexural modulus and thickness swelling of 18.4 MPa and 64% respectively.

It clearly indicates that use of natural adhesives gave comparable strength but poor thickness swelling.

Ramaker and Lehmann [25], made particleboards from Douglas fir forest residue wood flakes with 5% PF under hot pressing (180°C for 10 minutes) resulted in tensile modulus, flexural modulus and thickness swelling of 5325.9 MPa, 35.14 MPa and 18.1% respectively with density of 689 kg/m^3. However using Lodge pole-pine forest residue wood flakes resulted in tensile modulus 4891 MPa with flexural modulus and thickness swelling 23.9 MPa and 52.9% respectively with density of 689 kg/m^3.

It can clearly be stated that particle boards from both wood flakes with same density gave comparable strength but lodge pole-pine wood gave poor thickness swelling (Table 2).

Particleboard Raw Material	T.M.	F.M.	Th.S.	W.A.	ρ	Reference
Aspen	3755.05	17.02	-	-	600	McNatt [21]
Rice straw and coir fibers	4550	30.23	13.09	-	750	Zhang et al. [22]
Mixed hardwood species	5799.5	30.4	3.9	-	800	Yang et al. [23]
Sitcka spruce wood using natural adhesive	3290	26.3	19.6	90	649	Fuwape et al. [24]
Douglas fir and Lodge pole-pine forest residue	5325.9	35.14	7.8	18.1	689	Ramaker et al. [25]

Table 2: Phenol formaldehyde based particleboard.

Note: T.M: Tensile Modulus (MPa); F.M: Flexural Modulus (MPa); Th.S: Thickness Swelling in 24 h (%); W.A: Water Absorption in 24 h (%); ρ: Density (kg/m^3).

Cement bonded particleboard

Cement bonded particleboard made from mixed tropical hardwood (*Triplochitonscleroxylon, Khayaivorensisand Terminalia superba*) with Portland cement is to wood ratio 2.5 and 3% calcium chloride by Badejo [26], when pressed under 1.23 N/mm^2 for 24 hr period with flake thickness of 0.25 mm resulted tensile modulus 4820 MPa with flexural modulus, thickness swelling and density of 4820 MPa, 11.15 MPa, 0.35% and 1200 kg/m^3 respectively. However when pressed under same condition but with flake thickness of 0.50 mm resulted in a lower tensile modulus 3930 MPa with flexural modulus, thickness swelling and density of 3930 MPa, 10.75 MPa, 0.75% and 1200 kg/m^3 respectively. Particleboards with density of 1050 kg/cm^3 and 1125 kg/cm^3 sowed lower strength.

Okino et al. [27], made cement bonded particleboards from cupressus spp. wood particles with CP II-F 32 Portland cement and 4% $CaCl_2$ when pressed under 4.0 MPa for 12 hours showed tensile modulus 6481 MPa with flexural modulus, thickness swelling and density of 11.1 MPa, 1.5% and 1290 kg/m^3 respectively. it is interesting to note that when the wood particles were boiled for 4 hours and then pressed under same condition showed a better tensile modulus 7121 MPa with corresponding flexural modulus, thickness swelling and density 12.4 MPa, 1.8% and 1330 kg/m^3 respectively.

Manufacturing of cement bonded particleboard from western Australian mallee eucalypt species with Portland cement is to wood ratio 2.0 and 2% calcium chloride by Semple et al. [28], when pressed under 60 kN for 24 h resulted in average tensile modulus 500 MPa with flexural modulus and thickness swelling of, 1.0 MPa and 4.7% respectively. However particleboard manufactured with pine radiata wood particles gave tensile modulus 2850 MPa and flexural modulus 5.72 MPa.

In another study by Hermawan et al. [29], revealed that cement bonded particleboard made from oil palm frond particles with Portland cement is to wood ratio 2.7 under cold pressing condition resulted in tensile modulus 4300 MPa with flexural modulus and thickness swelling of, 14.4 MPa and 1.8% respectively. Again with Portland cement is to wood ratio 2.7 but this time with 10% magnesium chloride, under cold pressing condition resulted in a higher tensile modulus 5600 MPa with flexural modulus and thickness swelling 22.5 MPa and 4.1% respectively.

However keeping Portland cement is to wood ratio of 2.7 but with 5% magnesium chloride, under cold pressing condition resulted in slightly better tensile modulus 5700 MPa with flexural modulus and thickness swelling 19.5 MPa and 2.2% respectively.

It is clear from this study that some specific amount of magnesium chloride added in the mixture influence the tensile modulus, flexural modulus and thickness swelling (Figure 6).

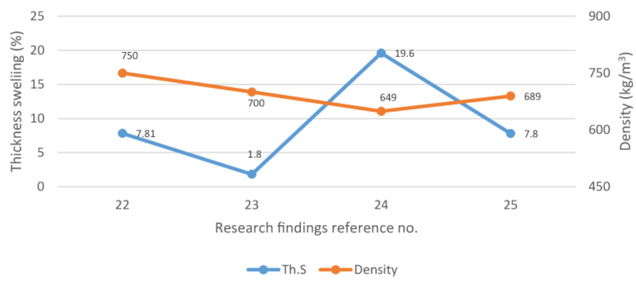

Figure 6: Thickness swelling v/s density of particleboards made from PF resin.

Fuwape and Oyagade [30], made cement bonded particleboard from afara wood flakes with Portland cement is to wood ratio 1.5 with 3% calcium chloride under cold pressing resulted in tensile modulus 2226 MPa with flexural modulus, thickness swelling and density 15 MPa, 4.0% and 1400 kg/m^3 respectively. But with Portland cement is to wood ratio of 2.3 with same 3% calcium chloride under cold pressing resulted in tensile modulus 2054 MPa with flexural modulus, thickness swelling and density of 5 MPa, 12.0% and 800 kg/m^3 respectively.
However maximum tensile modulus of 3297 MPa was achieved when they used Portland cement is to wood ratio 2.3 with 3% calcium chloride under cold pressing with corresponding flexural modulus, thickness swelling and density, 12 MPa, 1.4% and 1400 kg/m^3 respectively. Paricleboards with density 1200 kg/cm^3, 1000 kg/cm^3 and 800 kg/cm^3 showed lower mechanical properties.

In a study, cement bonded particleboard made from yellow-poplar and sweetgum wood particles by Lee and Hse [31]. Use of yellow poplar wood particles with taking cement is to wood ratio 2 and addition of 5% sodium pentachloropentate under clod pressing resulted in tensile modulus and flexural modulus of 1040.39 MPa and 3.11 MPa respectively. However use of sweetgum wood particles with same content and processing condition resulted in tensile modulus and flexural modulus of 737.23 MPa and 2.04 MPa.

Deng et al. [32], made gypsum-bonded particleboard from wood particles of some wood species: *Populusdavidiana, Betulaplotyphylla, Quercusmongolica and Piceaabies*. Keeping wood is to gypsum ratio of 0.25 and water is to gypsum ratio of 0.35 and manufacturing under cold pressing condition resulted in tensile modulus 1978 MPa with flexural modulus and thickness swelling of, 3.14 MPa and 3.29% respectively.
However addition of 10% cement helped them achieve the tensile modulus 2599 MPa with flexural modulus and thickness swelling 3.78 MPa and 1.20% respectively. Addition of 15% cement resulted in tensile modulus 2112 MPa with flexural modulus and thickness swelling 3.29 MPa and 1.67% respectively and addition of 20% cement resulted in tensile modulus, flexural modulus and thickness swelling of 2414 MPa, 3.54 MPa and 3.10% respectively. It is clear from this study that maximum strength is achieved by addition of 10% cement (by weight) in gypsum (Table 3).

Material	T.M.	F.M.	Th. S.	W.A.	ρ	Reference
Mixed tropical hardwood	4820	11.15	0.35	32.9 5	120 0	Badejo [26]
Cupressus spp.	7121	12.4	1.8	12.6	133 0	Okino et al. [27]
Western Australian mallee eucalypt species	2850	5.72	-	-	-	Semple et al. [28]
Oil palm frond	5700	19.5	2.2	-	120 0	Hermawan et al. [29]
Afara wood	3297	12	1.4	13	140 0	Fuwape et al. [30]
Yellow-Poplar and Sweetgum	1040.3 9	3.11	-	-	513	Lee et al. [31]
Gypsum	2599	3.78	1.20	20.9	122 0	Deng et al. [32]

Table 3: Cement bonded particleboard.

Polymeric methane diphenyl diisocyanate resin based particleboard

Wang and Sun [33], made particleboard from wheat straw and corn pith (used in 70:30 ratio) with soy protein isolate and 4% methylene diphenyl diisocynate. Mixture with 40% moisture content under hot pressing condition resulted in tensile strength of 3.24 MPa with density 340 kg/m3. However particleboard made with density of 310 kg/m^3 resulted in tensile strength of 2.65 MPa. It can be concluded that the tensile strength is influenced by the density of particleboard (Figure 7).

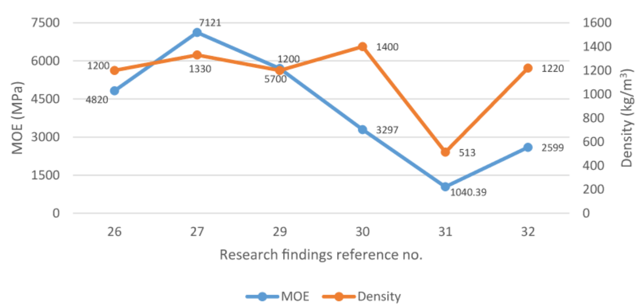

Figure 7: Modulus of elasticity v/s density of cement-bonded particleboards.

Binder-less particleboard

Hasim et al. [34], made binder-less particleboard from oil palm trunk particles under hot press temperature of 160°C resulted in flexural modulus and thickness swelling of 3.1 MPa and 63% respectively. Again when hot pressed with 180°C temperature resulted in flexural modulus and thickness swelling of 4.9 MPa and 37% respectively. However best result was achieved when hot pressed at 200°C with flexural modulus and thickness swelling of 5.8 MPa and 18 % respectively.

PTP thermosetting resin based particleboard

Bouillon et al. [35], made particleboard from wheat straw with 5% PTP polymeric material from triglycerides and polycarbonic acid anhydrides) thermosetting resin and 1% 2-methylimidazole as catalyst

Citation: Chaturvedi R, Pappu A, Mishra RK (2016) Performance of Formaldehyde Resins and Cement Bonded Particleboards and Understanding its Properties for further Advancement. Int J Waste Resour 6: 215. doi:10.4172/2252-5211.1000215

when hot pressed at temperature of 200°C resulted in tensile modulus, flexural modulus and thickness swelling of 2000 MPa, 7 MPa and 145% respectively. However use of 17% PTP gave tensile modulus, flexural modulus and thickness swelling of 3200 MPa, 18 MPa and 25% respectively.

It is evident from the study that amount of PTP used, influenced the tensile modulus, flexural modulus and thickness swelling of the particleboard (Figure 8).

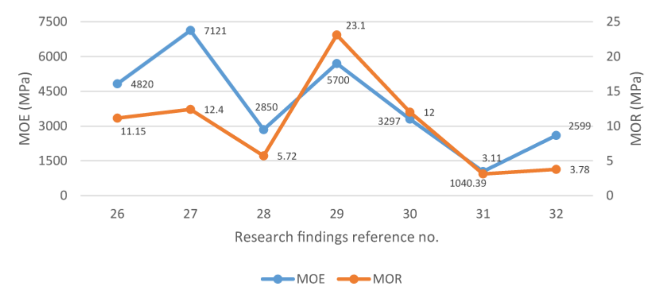

Figure 8: Modulus of elasticity v/s modulus of rupture cement-bonded particleboards.

interesting to note and understand that cement bonded particleboard showed a high tensile modulus (maximum value of 7121 MPa) but comparatively low flexural modulus (average value of 9.7 MPa), therefore these cement bonded particleboard cannot be used where higher bending is required. Cement bonded particleboards shows excellent fire resistant property. Waste can be disposed of in above ground construction waste landfills without causing any emission of harmful gases (Figure 9).

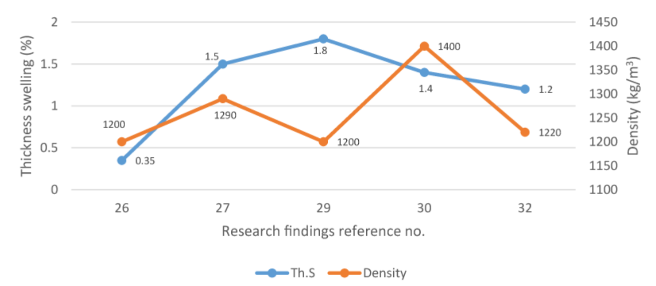

Figure 9: Thickness swelling v/s density of cement-bonded particleboards.

Challenges and shortcomings with particleboard

Current challenges with the urea formaldehyde bonded particleboard: Extensive review work done in the present study revealed that particleboard manufactured with urea formaldehyde resin are mainly medium density particleboards, generally between 640-800 kg/m^3. They usually exhibits greater thickness swelling (average value 23.67%) therefore not suitable for humid environment. UF bonded particleboards are generally not fire resistant. Tensile modulus of UF bonded particleboards are high enough (average value 2056.7 MPa) to be used in commercial purposes, but not generally enough for industrial or structural purpose (ANSI A208.1-1999). Flexural modulus is good enough for general purpose load bearing in dry conditions (Chinese standard GB/T 4897). UF bonded particleboards are available widely.
However one concern is formaldehyde emission, acute formaldehydeexposure via inhalation causes eye, nose, and throat irritation andeffects the nasal cavity. UF bonded particleboard are not fully green material.

Current challenges with the phenol formaldehyde bonded particleboard: Particleboard manufactured with phenol formaldehyde resin are mainly medium density particleboards generally between 640-800 kg/m^3 (IS 12406:2003).
PF bonded particleboard exhibits greater value of thickness swelling (average value 11.3%) therefore only suitable for dry environmental conditions. Tensile modulus and flexural modulus is generally high enough to be used in heavy duty load bearing boards in dry conditions (ANSI A208.1-1999). In general PF bonded particleboard are also not fire proof and the consumption of PF bonded particleboards less than that of UF bonded particleboards.

Current challenges with the cement bonded particleboard: Particleboard manufactured with cement are mainly high density particleboards generally above 1200 kg/m^3. Cement bonded particleboard generally exhibits very of thickness swelling (average value of 1.4%) therefore can be used in humid environments. It is

Summary

Urea formaldehyde resin based particleboard

The performance of urea formaldehyde particleboard made out of Douglas-fir wood particles has resulted a maximum tensile modulus of 4616.3 MPa.

The performance of urea formaldehyde particleboard made out of *Paraserianthesfalcataria* wood particles has resulted a maximum flexural modulus of 48 MPa.

The performance of urea formaldehyde particleboard made out of bamboo chips (*Dendrocalamus Asper*) has resulted a minimum thickness swelling of 6.0%.

The average TM, FM and thickness swelling with UF resin in particleboard are 2056.7 MPa, 18.0 MPa and 23.67% respectively.

Phenol formaldehyde resin based particleboard

The performance of phenol formaldehyde particleboard made out of chips from Oak and Lauan tree has resulted a maximum tensile modulus of 5799.5 MPa.

The performance of phenol formaldehyde particleboard made out of Douglas-fir wood flakes has resulted a maximum flexural modulus of 35.14 MPa.

The performance of phenol formaldehyde particleboard made out of chips from Oak and Lauan trees has resulted a minimum thickness swelling of 1.8%.

The average TM, FM and thickness swelling with PF resin in particleboard are 4544.1 MPa, 27.8 MPa and 11.3% respectively.

Cement bonded particleboard

The performance of phenol formaldehyde particleboard made out of Cupressus spp. wood particles of phenol formaldehyde particleboard made out of oil Palm frond particles has resulted a maximum flexural modulus of 23.10 MPa.

The performance of phenol formaldehyde particleboard made out of chips from three tropical hardwood species (*Triplochitonscleroxylon, Khayaivorensis and Terminalia superba*) has resulted a minimum thickness swelling of 0.35%.

The average TM, FM and thickness swelling in cement bonded particleboard are 3918.2 MPa, 9.7 MPa and 1.4% respectively.

References

1. Laemlaksakul V (2010) Physical and mechanical properties of particleboard from bamboo waste. World Academy of Science, Engineering and Technology 4: 276-280.
2. Pan Z, Zheng Y, Zhang R, Jenkins BM (2007) Physical properties of thin particleboard made from saline eucalyptus. Industrial Crops and Products 26: 185-194.
3. Jumhuri N, Hashim R, Sulaiman O, Wan Nadhari WNA, Salleh KM, et al. (2014) Effect of treated particles on the properties of particleboard made from oil palm trunk. Materials and Design 64: 769-774.
4. Atar I, Nemli G, Ayrilmis N, Baharoğlu M, Sari B, et al. (2014) Effects of hardener type, urea usage and conditioning period on the quality properties of particleboard. Materials and Design 56: 91-96.
5. Moubarik A, Mansouri HR, Pizzi A, Charrier F, Allal A, et al. (2013) Corn flour-mimosa tannin-based adhesives without formaldehyde for interior particleboard production. Wood Science and Technology 47: 675-683.
6. Nemli G, Aydın I, Zekoviç E (2007) Evaluation of some of the properties of particleboard as function of manufacturing parameters. Materials and Design 28: 1169-1176.
7. Zheng Y, Pan Z, Zhang R, Jenkins BM, Blunk S (2006) Properties of medium-density particleboard from saline Athel wood. Industrial Crops and Products 23: 318-326.
8. Acda MN, Cabangon RJ (2013) Termite resistance and physico-mechanical properties of particleboard using waste tobacco stalk and wood particles. International Biodeterioration and Biodegradation 85: 354-358.
9. Yalinkilic MK, Imamura Y, Takahashi M, Kalaycioglu H, Nemli G, et al. (1998) Biological, physical and mechanical properties of particleboard manufactured from waste tea leaves. International Biodeterioration and Biodegradation 41: 75-84.
10. Baharoğlu M, Nemli G, Sari B, Birtürk T, Bardak S (2013) Effects of anatomical and chemical properties of wood on the quality of particleboard. Composites Part B: Engineering 52: 282-285.
11. Keskin H, Kucuktuvek M, Guru M (2015) The potential of poppy (Papaver somniferum Linnaeus) husk for manufacturing wood-based particleboards. Construction and Building Materials 95: 224-231.
12. Pirayesh H, Khazaeian A, Tabarsa T (2012) The potential for using walnut (Juglans regia L.) shell as a raw material for wood-based particleboard manufacturing. Composites Part B: Engineering 43: 3276-3280.
13. Elbadawi M, Osman Z, Paridah T, Nasroun T, Kantiner W (2015) Mechanical and physical properties of particleboards made from Ailanthus wood and UF resin fortified by Acacias tannins blend. J Mater Environ Sci 6: 1016-1021.
14. Guler C, Bektas I, Kalaycioglu H (2006) The experimental particleboard manufacture from sunflower stalks (Helianthus annuus L.) and Calabrian pine (Pinus brutia Ten .). Forest Product Journal 56: 56-60.
15. Han G, Zhang C, Zhang D, Umemura K, Kawai S (1998) Upgrading of urea formaldehyde-bonded reed and wheat straw particleboards using saline coupling agents. J Wood Sci 44:282-286.
16. Clausen CA, Kartal SN, Muehl J (2001) Particleboard made from remediated CCA-treated wood: evaluation of panel properties. Forest Products Journal 51: 61-64.
17. Oh Y, Cha J, Kwak J (2003) Properties of particleboard from Korean thinning logs. Test, 53: 67-69.
18. Papadopoulos AN, Hill CAS, Gkaraveli A, Ntalos GA, Karastergiou SP (2004) Bamboo chips (Bambusa vulgaris) as an alternative lignocellulosic raw material for particleboard manufacture. Holz Als Roh - Und Werkstoff 62: 36-39.
19. Akyüz KC, Nemli G, Baharoğlu M, Zekoviç E (2010) Effects of acidity of the particles and amount of hardener on the physical and mechanical properties of particleboard composite bonded with urea formaldehyde. International Journal of Adhesion and Adhesives 30: 166-169.
20. Guler, Copur, Tascioglu (2008) Particleboards using mixture of peanut hull (Arachis hypoqaea L.) and European Black pine (Pinus nigra Arnold) wood chips. Bioresource Technology 99: 2893–7.
21. McNatt DJ (1980) Basic engineering properties of particleboard. FPL 206: 1–16.
22. Zhang L, Hu Y (2014) Novel lignocellulosic hybrid particleboard composites made from rice straws and coir fibers. Materials and Design 55: 19-26.
23. Yang TH, Lin CJ, Wang SY, Tsai MJ (2007) Characteristics of particleboard made from recycled wood-waste chips impregnated with phenol formaldehyde resin. Building and Environment 42: 189–195.
24. Fuwape JA (1994) Short Communication, Natural Adhesive-Bonded Particleboards. Bioresource Technology 48: 83-85.
25. Ramaker TJ, Lehmann WF (1976) High-performance structural flakeboards from Douglas-fir and Lodgepole pine forest residues. USDA Forest Service Research Paper FPL: 286.
26. Badejo SOO (1988) Effect of flake geometry on properties of cement-bonded particleboard from mixed tropical hardwoods. Wood Science and Technology 22: 357-369.
27. Okino EY, De Souza MR, Santana M, Alves MVDS, De Sousa ME, et al. (2005) Physico-mechanical properties and decay resistance of Cupressus spp. cement-bonded particleboards. Cement and Concrete Composites 27: 333-338.
28. Semple KE, Cunningham RB, Evans PD (2002) The suitability of five Western Australian mallee eucalypt species for wood-cement composites. Industrial Crops and Products 16: 89–100.
29. Hermawan D, Subiyanto B, Kawai S (2001) Manufacture and properties of oil palm frond cement-bonded board. Journal of Wood Science 47: 208-213.
30. Fuwape JA, Oyagade AO (1993) Bending strength and dimensional stability of tropical wood-cement particleboard. Bioresource Technology 44: 77–79.
31. Lee AWC, Hse CY (1993) Evaluation of Cement-Excelsior Boards made from Yellow-Poplar and Sweetgum. Forest Products Journal 43: 50-52.
32. Deng Y, Furuno T, Uehara T (1998) Improvement on the properties of gypsum particleboard by adding cement. Journal of Wood Science 44: 98–102.
33. Wang D, Sun XS (2002) Low density particleboard from wheat straw and corn pith. Industrial Crops and Products 15: 43–50.
34. Hashim R, Said N, Lamaming J, Baskaran M, Sulaiman O, et al. (2011) Influence of press temperature on the properties of binderless particleboard made from oil palm trunk. Materials and Design 32: 2520–2525.
35. Boquillon N, Elbez G, Schenfeld U (2004) Properties of wheat straw particleboards bonded with different types of resin. Journal of Wood Science 50: 230-235.