PHYSICAL PROPERTIES OF FURNITURE PANELS FROM MACADAMIA SHELLS

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Abstract
Most food industry activities result in large amounts of by-product that are often treated as waste and sent to landfill. In Australia, the macadamia nut industries generate as much as 28,000 tonnes of empty shells on an annual basis. These by products are under-utilized, often used for garden mulching or ground and used for animal filler, or else incinerated, as their disposal in landfill is cost-prohibitive, through sheer volume.
However, these by-products are perfectly suited to the manufacture of panels, as they come clean and dry after processing, and present excellent physical properties when exposed to high humidity environments, particularly when compared to softwood. This makes them suited to applications such as panel furniture in high moisture environments, including kitchen and bathroom sink countertops or drawers where dimensional, swelling and adhesive problems are often an issue.
This paper presents results of research into panels made from macadamia industry by-products in Australia, identified as being particularly abundant and underused. The matrices of these composite materials have been chosen from non-toxic and organic bonding agents, such as castor oil based adhesives. The present study considers and explores the suitability of these materials for high-moisture environment panel applications. Results are presented for the main physical properties and are compared with mixes already available in the market. The results show that these new materials compare well with commercially available materials, exceeding their performance in several cases, particularly with respect to water absorption and thickness swelling. These new panels have the potential to become a sustainable replacement option for high-humidity environment furniture particleboards, made with waste resources.

1. Introduction
This paper examines the development of sustainable composite materials using macadamia shells as fillers with a non- toxic, natural and renewable adhesive: castor oil. This material is compared with a pine wood and castor oil adhesive panel and with a pine wood and urea formaldehyde (UF) adhesive panel. The results show that the new filler and adhesive provide panels with improved performance compared with commercially available panel materials.

1.1 Macadamia Nut Shells
Macadamia nuts come from plants belonging to the family of Proteaceae and are native to Australia. Australia is the world's main commercial producer of macadamia nuts, producing around 40,000 tonnes a year, out of a total global production of 100,000 tonnes (www.macadamias.org). They are also commercially produced in Brazil, Costa Rica, Bolivia, Hawaii and New Zealand.

The shells and other waste comprise almost 70% by weight of the macadamia nuts. They can be burned in coffee roasting; used as filler in the plastics industry[1]; used as organic waste for gardening, mulching, chicken litter; or as a source of fuel (having a calorific value of 5,500 kcal/kg).

The shell of the macadamia nut is hard and brittle. It has fracture toughness similar to those of common ceramics and glass. The structure of the macadamia nut shell is reasonably isotropic and uniform, very different from that of trees. The main components of the shell are lignin (47%), cellulose (25%), hemicelluloses (11%) and ash (0-2%). The shells have a bulk density of 680 kg/m3, and a moisture content of around 10% [2].

Very limited work has been carried out on the use of macadamia shells in composites , with the only product identified from the literature being Husque, a composite based on pulverized macadamia shells bonded with resin [3, 4]

1.2 Adhesives

Most conventional wood panels use thermosetting (heat curing) adhesive resins, such as phenol formaldehyde (PF) and urea formaldehyde (UF). These adhesives require high curing temperatures (ranging from 130 to 160°C). PF resins are used in the manufacture of plywood and oriented strand board, and are suitable for weather exposure. UF resins are lower cost thermosetting adhesive resins; they are used for interior applications because moisture and excessive heat exposure leads to a breakdown of the bond forming reactions [5-8].

Formaldehyde based adhesives emanate carcinogenic fumes and their use is limited in countries with strict environmental controls [5, 7]. Cost and reliable availability of petrochemicals may also affect the predominance of these adhesives.

This study evaluates a polyurethane adhesive based on castor oil. Polyurethane resins can be derived from either petroleum or vegetable oils; they are compatible with vegetable fibres due to the reaction between the hydroxyl groups of the fibres and the isocyanate groups of the polyurethane [8]. The castor plant (Rícinos communis) is a plant of the Euphorbiaceae family from which castor oil is extracted. The adhesive is non-aggressive to the environment and to humans; handling and curing is at ambient temperature, but it can be accelerated with up to 90 °C temperature [7] and presents strong mechanical strength and resistance to water and UV rays [7, 8]. The adhesive is obtained by cold polymerization of the polyol and prepolymer (castor oil-based) mixture, a reaction leading to the formation of the polyurethane [6].

2. Material preparation and testing

The macadamia shells were supplied by Macadamia Processing Co. Limited; located in Lismore, NSW, Australia. The radiata pine wood fibre was a by-product from a panel door manufacturing industry. The castor oil based adhesive was supplied by Kehl Industria e Comercio, Brazil. The UF adhesive was supplied by an industrial manufacturer of particleboard and medium density fibreboard (MDF). Fibres were ground in a milling machine (Ming Lee, model ML-SC); sieved through a 40 mesh screen and dried in a wood drier with air circulation (Binder, model WIB) until the moisture content was reduced to 4 percent, which is the same moisture level used in commercial particleboards, mentioned by Stark et al, in their report [5].

The adhesive was prepared with 1 part of isocyanate and 2 parts of polyol. The amount of castor oil adhesive applied to the fibres was 20%; after recommendation of the manufacturers, and is similar to those in other studies [6, 9, 10].

Both parts of the adhesive were manually mixed. The mixed adhesive was added to the fibres and hand mixed in a bucket.

The fibres impregnated with adhesive were pre-pressed before final hot pressing [9] over an aluminum sheet inside a 40 x 40 x 30 cm frame. The mat was then manually pressed with a wooden cover. The pressing variables were defined after a dynamic mechanical analysis (DMA) test; (measures the rheological behavior of materials) using a Perkin Elmer DMA 7e. The curing properties defined were 18 minutes pressing at 84°C.

The mats were then pressed in a Dumont hot plate press, model 250T; with a 40 cm by 40 cm platen capacity. A 1 cm thick metallic bar was set on each side of the mat to give the final height of the panel. Each batch was pressed and then cooled outside of the press; laying on a flat surface [10]. Once the panels had reached room temperature, 5 cm were cut from each side.

Table 1 presents a comparative table of the samples prepared, including percentages of each of the components and sample id to be used in this study

Tests were carried out on each of the panels to determine the relevant physical, morphological and formaldehyde emissions properties.
The physical properties examined were density, moisture content, thickness swelling and water absorption. These tests were carried out according to ASTM 1037 specifications, with 5 repetitions of each test sample and sizes of 5 cm × 5 cm [5, 11].
The density was measured using a Ludlum 4417 density profilometer. The moisture content was determined from the measured weight loss after drying the samples for 24 hours at 100°C. Thickness swelling was determined from the average of the measured change in thickness at four locations on each sample after immersion in water for 24 hours. Water absorption was determined from the measured weight gain of the panels during the 24 hour immersion period [11].
The formaldehyde emissions were measured following the European Standard EN-120. This method measures the amount of formaldehyde in 100 grams of dry panel (mg/ 100 gr) [5, 12].
The adhesive fibre interaction on the surface of the composites was evaluated using a Hitachi S3400I scanning electron microscope (SEM).

3. Results and discussion

The results of the main physical properties are presented in Table 2.
Stark and the Engineered Wood Products Association of Australasia (EWPAA) [5, 13] describe the densities of particleboards and MDF between 600 and 810 kg/m3. The lowest density among the samples was that of PW CO, with 691 kg/m3, within the parameters described above; followed by PW UF, with 824 kg/m3 which is slightly above the average. The density of MS CO was the highest at 987 kg/m3.
Moisture content is similar in all samples.
Thickness swelling results shows that MS CO, present low thickness swelling (2%); being even lower than what is expected from moisture resistant particleboards and MDFs (between 6 and 10%) [13]. PW CO thickness swelling is higher than MS CO, but still in the range of what can be expected from a standard MDF, as defined by EWPAA [13].
Water absorption results presented in Figure 1 show that MS CO has the lowest water absorption after 24 hours water immersion (11%). PW CO and PW UF presented water absorption results of 43%, and 49%, respectively, which reflect the high hygroscopic nature of radiata pine wood, compared with the macadamia shells.
Risholm-Sundman et al. [14] show that the formaldehyde emissions for pine wood are 0.23 mg/100gr; particle board are between 2 and 3 mg/100 gr; and MDF is 7.5 mg/100 gr. The results of the evaluated samples show that the panels with castor oil adhesive emit minimum levels of formaldehyde, even lower than those of wood. PW UF is in the expected range of MDF panels [14]. These results are presented in table 3.
The adhesive fibre interaction was investigated in terms of adhesive penetration and surface coating through visual inspection of the composite panel's micrographs. SEM images showed, after hot pressing, that the macadamia cells showed extensive penetration of the adhesive. The hollow hexagonal cell structure allowed an easy penetration of the aromatic adhesive forming a strong bond resistant to the effect of moisture.

4. Tables and Figures

Table 1. Contents of the panels being tested and compared.

Sample	Fibre	wt%	Adhesive	wt%
MS CO	Macadamia shells	80	Castor oil	20
PW CO	Pine wood	80	Castor oil	20
PW UF	Pine wood	90	Urea formaldehyde	10

Table 2. Density, moisture content, thickness swelling and water absorption of panels.

Sample	**Property**			
	Density (kg/m3)	**Moisture content (*wt %)**	**Thickness swelling 24 hours (%)**	**Water absorption 24 hours (*wt %)**
MS CO	987	5	2	11
PW CO	691	6	12	43
PW UF	821	5	32	49

*Weight Percent (wt %)

Table 3. UF emissions of Castor oil based composites compared with UF based composites and *UF emissions presented in literature [14].

Sample	**UF (mg/100g)**
MS CO	0.12
PW CO	0.11
PW UF	8
*Pine wood	0.23
*Particle boards	2-3
*MDF	7.5

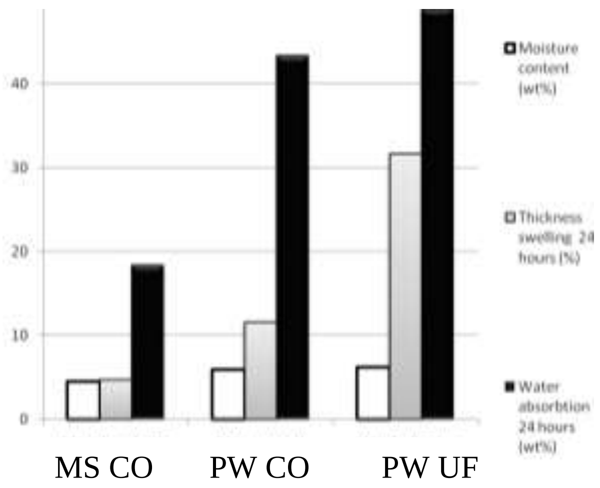
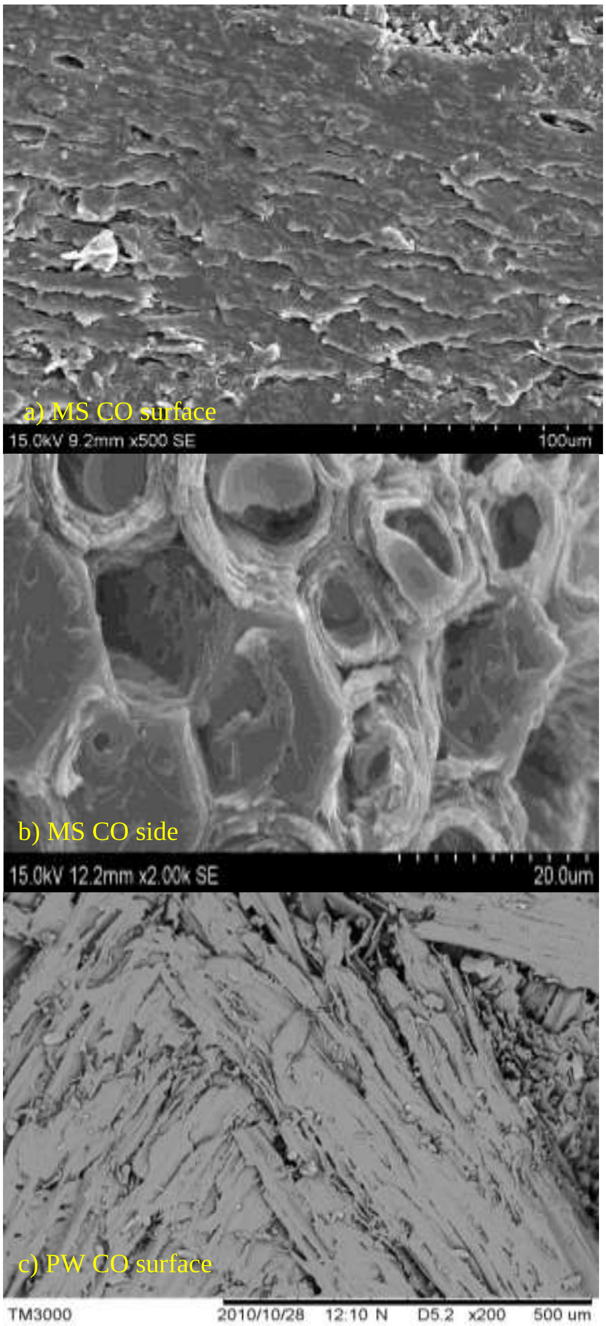


Fig. 1. Moisture content, thickness swelling and water absorption tests results.



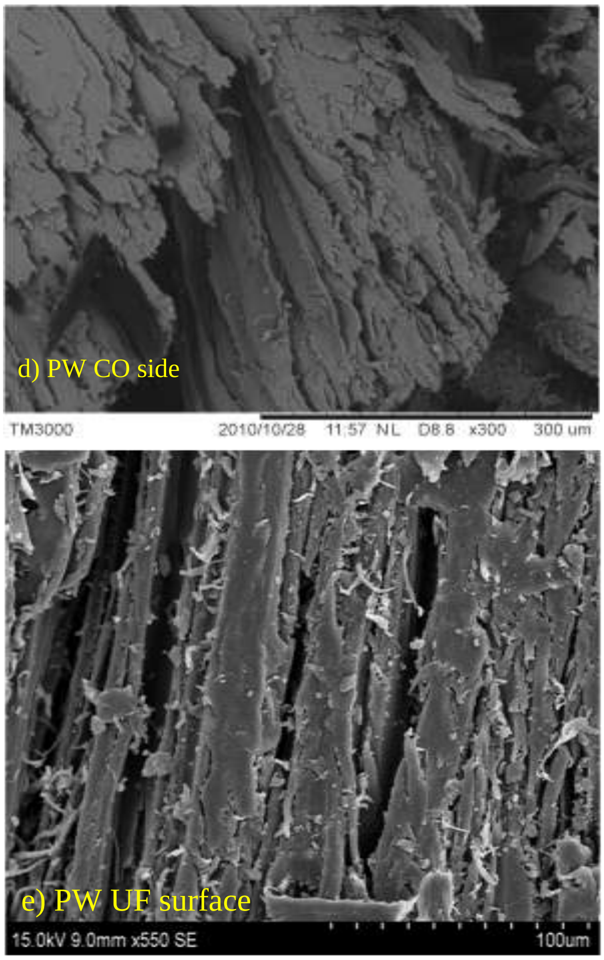


Fig. 2. Morphological characterization of the a) surface of macadamia shells – castor oil adhesive, b) side of macadamia shells – castor oil adhesive, c)surface of pine wood – castor oil adhesive, d) side of pine wood – castor oil adhesive, e) pine wood – urea formaldehyde adhesive composites.

4. Conclusion

This study has considered the use of macadamia shells that are underutilized and therefore present the potential to be used in composite material panel fabrication. We have shown that the macadamia shells have acceptable properties for use as composite material filler. The water absorption is strongly related to the fiber structure as well as to the adhesive type. The macadamia shell / castor oil composite material proposed and evaluated in this research presents a new opportunity for panel furniture application. Its physical properties show that it is applicable in panel furniture for high moisture environments.

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