Utilization of Ground Peanut Husk as an Alternative Fiber Material for Particleboard

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Abstract

The potential for using peanut (*Arachis hypogaea*) husks as an alternative fiber for particleboard production was examined at five different levels of melamine-urea-formaldehyde resin (MUF). The resulting panels were evaluated for moisture absorption, thickness swell, flexural properties (modulus of rupture [MOR] and modulus of elasticity [MOE]) and internal bond (IB) strength. MOR, MOE and IB values of panels containing $\geq$6 percent resin met or exceeded American National Standards Institute standards for multiple grades of particleboard although they were weaker than previous reports of commercially produced wood particleboards. Moisture uptake and thickness swell also improved markedly at resin levels >6 percent. The results suggest that peanut husks are an attractive alternative fiber source in combination with the MUF resin system.

Peanuts (*Arachis hypogaea* L.) are an important agricultural crop in many regions of the world. Peanuts serve the dual purpose of providing a food crop while also helping to enhance soil fertility through nitrogen fixation. Over 64 billion kg of peanuts are produced globally with the United States producing 5 percent of this total (Food and Agriculture Organization of the United Nations 2016, 2017). One aspect of peanut production is what to do with the shells, which represent 19.3 billion kg of waste including 746 million kg in the United States. While some of this material can be used for mulch, kitty litter, fuel pellets, or packing materials (National Peanut Board 2018), these represent relatively low-value products whose markets are limited by transportation costs. Identifying alternative value-added uses for peanut husks would help make peanut production more economical.

One potential use for peanut husks would be as a component in composite panel products. These materials have already been examined for use in medium-density fiberboard (Akgül and Tozluoğlu 2008). Preliminary studies have also been undertaken to produce particleboards using urea-formaldehyde resins but the properties generally have been poor (Güler and Büyüksarı 2011, Mgbemene et al. 2014, Benitta Christy and Kavitha 2018, Ikladious et al. 2019). Peanut husks have also been mixed with woody materials using urea-formaldehyde resin with somewhat better results, but the proportion of husks that could be included was limited (Güler et al. 2008). Previous studies have primarily used urea-formaldehyde resins, but there may be an opportunity to utilize other resins, including melamine-urea-formaldehyde (MUF). Although this resin is more costly, it sets more readily and could allow more economical pressing.

Particleboards have a wide variety of uses, especially in nonstructural applications, and can consist of many different cellulosic materials. Peanut husks have chemical compositions that are similar to those for wood, with husks containing 28 percent lignin and 62.8 percent holocellulose compared with 18 to 35 percent lignin and 65 to 75 percent holocellulose for wood (Petersen 1984, Güler and Büyüksarı 2011), suggesting that husks may produce panels with similar properties to those composed of wood.

The objective of this study was to examine the properties of peanut husk particleboards created using MUF resin.

Methods and Materials

Panel manufacturing

Finely ground peanut husk (The Golden Peanut and Tree Nuts Company, Alpharetta, Georgia) with a majority of the particles measuring between 1 and 5 mm long was

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conditioned for a minimum of 2 days at 30 percent relative humidity (RH) and 30°C to a moisture content of approximately 6.5 percent. MUF resin (MUF, SKU 920528) with a solids content of 70 percent was obtained from Arclin USA, LLC (Springfield, Oregon).

Peanut husks (3.375 kg) were mixed with MUF resin to produce panels containing 1, 3, 6, 9, or 12 percent resin (wt/wt). The lower resin levels were selected to determine whether the MUF might result in panels with acceptable properties at resin levels much lower than the 8 to 11 percent resin used with urea-formaldehyde in previous studies (Güler et al. 2008, Güler and Büyüksarı 2011). The materials were thoroughly blended for 5 minutes before being formed into a 45.72 by 42.72-cm box on an aluminum caul plate. A square of plywood was placed over the particles and pressed down to condense the particles. The form was removed and a second caul plate was placed on top. The plates were then placed into a 1-m^2 hot press where they were pressed for 5 minutes at 120°C to a target thickness of 12.7 mm. The press was vented for 2 minutes at a rate of 0.034 mm/s after the press period before the press was opened. The approximately 56 by 56-cm panels were trimmed to 40 cm^2 to remove excess material that was less likely to be fully bonded. One panel each were produced for the 1 and 3 percent resin levels while three panels were produced for the 6, 9, and 12 percent resin levels and the panels were conditioned to constant weight at 23°C and 65 percent RH.

Panel properties

The panels were then cut to produce samples for assessing properties. Each panel was used to produce two 150 by 150-mm square samples to assess moisture uptake, three 50 by 50-mm square samples for measuring internal bond strength, and three 75 by 350-mm-long samples for flexural tests (six samples were cut from the single 1% and 3% resin panels; ASTM International 2017a).

Water absorption and thickness swell

The 150 by 150-mm blocks were conditioned to constant weight at 23°C and 65 percent RH and then thickness was measured at four marked locations on each panel. The panels were then immersed in distilled water at room temperature (~20°C) for 2 hours, then removed from the water and wiped clean of any adhering droplets before being air-dried for 10 minutes. The samples were weighed and then thickness was remeasured at the original four locations. The samples were then returned to the water for an additional 22 hours, after which the weighing and thickness measurements were repeated (ASTM International 2017a). The resulting measurements were used to calculate percent moisture absorption and thickness swell. Measurements were performed on two samples from each of two panels prepared with 6, 9, or 12 percent resin but only 2 samples in total from the 1 and 3 percent resin panels.

Internal bond strength

Internal bond strength (IB) was assessed using a modification of ASTM Standard D7519 (ASTM International 2017b). Briefly, aluminum ''pull blocks'' were glued to the 50 by 50-mm samples using a hot glue gun. The samples were pulled apart at a rate of 2 mm/min on a Sintech universal test machine. Six samples (three per panel) were tested for each resin level. Maximum load at time of failure was recorded and used to calculate internal bond strength according to ASTM D7519 (ASTM International 2017b), equation 2.3 IB:

$$\mathrm{IB} = \frac{P_{\max}}{ab}$$

where $P_{\max}$ = maximum load (N), a = width (mm), and b = length (mm). The type of failure was noted as glue failure (separation of the sample from the aluminum block), surface failure (a separation occurring in the top or bottom 10% of the sample), and centerline failure (a failure occurring in the middle 80%).

Flexural testing

The 75 by 350-mm-long beams were conditioned to constant weight at 23°C and 65 percent RH before being subjected to third point loading on an Instron universal testing machine. Load was applied at the center of the 300-mm span at a rate of 6 mm/min. Load and deflection were continuously monitored and the resulting data were used to calculate modulus of elasticity (MOE) and modulus of rupture (MOR) as described in ASTM Standard D1037 (ASTM International 2017a). Six samples were evaluated for the 6, 9, and 12 percent resin panels, while only three beams could be tested for the 1 and 3 percent resin treatments because the materials tended to fail while being handled.

Data analysis

The results were used to calculate means and standard deviations. These values were compared with the requirements for particleboard as described in American National Standards Institute (ANSI) Standard 208-1 (ANSI 2016) as well as with data presented in the US Department of Agriculture (USDA) Wood Handbook (USDA 2010).

Results and Discussion

The panels had a mottled appearance with dark spots that appeared to be remnants of the peanut seed coats, but the panels were otherwise smooth and did not flake when touched.

Water absorption and thickness swell

Water immersion for 2 hours resulted in large weight gains in panels with 1 or 3 percent resin, while weight gains decreased by over one-third as resin content increased to 6 percent and then continued to decline with further resin increases (Table 1). Increased resin content was associated with a steady decrease in water uptake in panels immersed for an additional 22 hours, although the differences between 9 and 12 percent resin were slight, suggesting that additional resin provided no added moisture resistance.

Water immersion of panels containing 1 or 3 percent resin for two hours resulted in >30 percent increases in thickness, and levels increased to >50 percent with an additional 22 hours of immersion (Table 1). The results indicated that these resin levels were inadequate for providing swelling resistance to the panels. Thickness swell results were consistent with previous studies using slightly higher levels (6%) of urea-formaldehyde resin on softwood furnish (Young No and Kim 2007). Increasing resin content to 6 percent in our tests produced a marked reduction in

Table 1.—Effect of resin content on thickness swelling and weight uptake in peanut husk panels after 2 and 24 hours of water immersion. Values represent means while figures in parentheses represent one standard deviation.

Resin content (%)	Thickness swelling (%)		Weight gain (%)	
	2 h	24 h	2 h	24 h
1	31.9 (1.5)	58.9 (1.2)	28.5 (3.7)	70.2 (1.6)
3	31.3 (10.7)	50.0 (5.2)	33.9 (2.2)	57.9 (10.3)
6	7.1 (1.5)	17.6 (3.5)	9.3 (2.1)	20.2 (2.2)
9	4.5 (1.7)	10.3 (2.5)	6.0 (1.6)	13.6 (3.8)
12	3.4 (1.5)	7.9 (2.4)	4.7 (1.4)	10.2 (3.2)

thickness swelling after 2 or 24 hours. Increasing resin content to 9 percent produced a further reduction in swelling. Increasing the resin level to 12 percent produced a less noticeable effect, suggesting that additional resin content was not useful for this property, although other steps such as adding wax-sizing agent or postpressing thermal treatment might be useful (Xiangquan et al. 1997, Xu et al. 2009).

Internal bond strength

IB values of panels containing 1 or 3 percent resin were extremely low and three of the 1 percent resin specimens failed as they were placed into the test machine (Table 2). The presence of fines in the peanut husk material may have contributed to the lower IB values because they would consume resin without markedly contributing to bond properties (Cheng et al. 2016). Increasing the resin content from 3 to 6 percent resulted in a nearly 10-fold increase in IB values. Further increases in resin content produced mixed results, although average IB strengths for the 6, 9, and 12 percent resin panels all met the minimum requirements for M-0, M-1, M-S, LD-1, and LD-2 grades; and panels with 6 or 9 percent resin met the minimum requirement for the M-2 grade as described in ANSI Standard 208 (ANSI 2016). Comparisons with the range of values presented in the Wood Handbook (0.360 to 0.426 kPa) suggested that IB values for the panels with 6 to 12 percent MUF were in the lower half of the distribution range (USDA 2010).

Increasing resin content also altered the failure mode of the panels (Table 3). All of the 1 percent resin panels that could be tested and all 3 percent samples failed at the center, suggesting inadequate bonding; whereas those with 6 percent resin had an equal number of failures in the face and center. Increasing resin content to 9 or 12 percent resulted in more face failures, suggesting that surface characteristics of the panel had become more important than internal bonding. All panels were manufactured with a single layer of particles of the same dimensions and with a uniform resin content across the thickness. Commercial panels would typically have layers with different particle geometries as well as differing resin levels that might be able to more evenly distribute load across the panel. In general, the IB values and failure modes suggest that resin contents >6 percent produced panels that would be acceptable in a commercial application.

Table 2.—Effect of resin level on density, internal bond (IB) strength, modulus of elasticity (MOE), and modulus of rupture (MOR) of peanut husk panels. Values represent means while figures in parentheses represent one standard deviation.

Resin content (%)	Density (kg/m^3)	IB strength (kPa)	MOE (MPa)	MOR (MPa)
1	971.6 (9.0)	27.1 (5.3)	3,539.4 (583.3)	3.8 (0.6)
3	1,029.9 (21.0)	39.8 (4.2)	5,055.8 (207.4)	6.2 (0.2)
6	1,075.3 (13.6)	363.2 (45.4)	3,695.3 (336.9)	9.6 (1.3)
9	1,102.0 (9.9)	425.9 (108.4)	4,205.5 (237.7)	10.9 (0.8)
12	1,111.9 (28.1)	398.6 (72.6)	3,912.5 (375.9)	10.8 (0.7)

Table 3.—Effect of resin content on failure modes of peanut husk particleboard panels tested for internal bond strength. Dashes represent no failures of this type.

Resin content (%)	No. of samples by failure mode		
	Broke in handling	Face failure	Center failure
1	3	—	3
3	—	—	6
6	—	3	3
9	—	4	2
12	1	4	1

Flexural properties

MOE of the panels was extremely variable between treatments and there was no consistent effect of resin content on this property ($r^2 = 0.07$; Table 2). All of the panels met the ANSI Standard 208.1 minimums for all panel grades (ANSI 2016). The lack of a resin content effect is perplexing because higher resin levels should equate to better bonding, as evidenced by the improved IB values, which should then translate to stiffer panels. It is unclear why this was not observed in these materials, although panel density differences may have also accounted for these differences. Density should have a much greater effect on panel properties than resin content (Eslah et al. 2012), but density differences between panels were only 12 percent because resin content increased 12-fold (Table 2). Comparisons with the range of MOE values presented in the Wood Handbook (2.8 to 4.0 GPa) suggested that the MOE of the peanut husk panels were in an acceptable range, although the two treatments with lower resin content would clearly be unacceptable based upon their IB values.

MOR values were very low in panels with 1 percent resin and then steadily improved as resin content was increased to 3 and then 6 percent (Table 2). Further increases in resin content to 9 or 12 percent produced only minor improvements in MOR values, which would be consistent with the IB results, although the resulting MOR values became more uniform. Increased density with higher resin levels could help account for some of these differences, although the density increases were slight (Warmbier and Wilczyński 2016).

MOR values for all resin contents met the minimum ANSI 208.1 requirements for panel grades LD-1 and LD-2 while those with 6, 9, or 12 percent resin also met grade M-0 (ANSI 2016). The M-1 grade was only met with the 9 and 12 percent resin panels. Resin content was highly correlated with MOR ($r^2 = 0.99$), although the relationship appeared to flatten at higher resin levels. MORs for peanut husk panels fell well below the range of values reported for wood-based particleboards in the Wood Handbook (USDA 2010). The results indicate that peanut husk panels can meet some panel specifications but only at higher resin loadings. These results would be consistent with previous results, with peanut husk panels with 8 to 11 percent urea-formaldehyde and suggest that the use of MUF did not markedly improve properties (Güler et al. 2008, Güler and Büyüksarı 2011).

Conclusions

Peanut husks were an acceptable substitute for wood in particleboards, although panels had slightly lower mechanical properties. Increasing resin content improved panel properties, but increases >6 percent produced less substantial changes that might not justify the added resin costs. Further studies evaluating different ratios of wood and peanut husks might be useful for enhancing panel properties.

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