Effects of Lignocellulosic Bulking Agents Made from Agricultural Byproducts on Physical Properties and Drying Energy Consumption of Duplex Board

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Though potentially useful, agricultural byproducts are often discarded because of the lack of specific applications in many industries. However, they have suitable properties for use in the paper industry, according to recent literature. In this study, the suitability of rice husk, peanut husk, and garlic stem as raw materials for the manufacture of a new lignocellulosic bulking agent was investigated, and the best material to replace a commercial wood powder, widely used in Korean duplex board mills, was determined. Many powders were manufactured from agricultural byproducts, and their effects on the physical properties and drying energy requirements of handsheets were evaluated compared to those of a commercial wood powder. All of the powders improved the bulk and dryness after wet pressing, but a reduction in paper strength was unavoidable. In particular, the powder made from rice husk showed a greater bulk and increase in dryness after wet pressing than the commercial wood powder. These findings indicated that these three agricultural byproducts could be used as raw materials for the manufacture of bulking agents, and rice husk was the best agricultural byproduct to replace commercial wood powder in duplex board mills.

Keywords: Duplex-board; Agricultural byproduct; Rice husk; Peanut husk; Garlic stem; Bulking agent

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INTRODUCTION

A shortage of natural resources, regulations on the utilization of artificial synthetic materials, and environmental concerns have created an impetus for using sustainable resources such as biomass for various industrial applications (Mohanty *et al.* 2000; Van Wyk 2001). Biomass, such as agricultural crops and residues, forest resources and residues, and animal and municipal wastes, is the largest source of cellulose (Reddy and Yang 2005). Agricultural residues or byproducts are generally produced from the cultivation of agricultural crops and are available at a lower cost than other biomass resources. These lignocellulosic agricultural byproducts have been used in various applications, depending on their composition and physical properties (Alslaibi *et al.* 2013; Liu *et al.* 2013; Rehrah *et al.* 2014; Raj *et al.* 2015). However, over 50% of the agricultural byproducts generated while harvesting crops in Korea are discarded because of the lack of specific technologies for industrial applications, according to statistics from the Rural Development Administration (Kook *et al.* 2013). Therefore, a new, practical technique must be developed in order to transform these discarded cellulosic resources into high-value materials.

Commercial wood powder is often used as a bulking agent in the Korean paperboard industry. Wood powder can be utilized to improve paperboard thickness and to decrease drying energy requirements (Lee *et al.* 2014). A Korean patent also reports that wood powder effectively reduces production costs, even though it is more expensive than Korean old corrugated containers (KOCC) (Lee *et al.* 2009). However, wood powder cannot be used in the long term because of concerns about protection of the environment and green growth. Moreover, this lignocellulosic material is also widely utilized in the bioenergy sector, making the supply and price of commercial wood powder unstable (Sung *et al.* 2013). Therefore, there is a need in Korea to find a new material to replace or supplement wood powder to ensure the stable production of paperboard. Many biomass resources were explored, and it was found that lignocellulosic agricultural byproducts had potential as raw materials for the manufacture of paperboard. Previous studies reported that some agricultural byproducts had suitable chemical and physical properties for the manufacture of the organic fillers and kraft pulps used in many paperboard mills (Lee *et al.* 2011, 2013, 2014). Further study is required to determine the best material among three abundantly available agricultural products to replace commercial wood powder.

The aim of this study was to determine the best candidate among the available agricultural byproducts for this purpose, by exploring the ability of each material to improve bulk and reduce drying energy in the manufacture of paperboard. New bulking agents were manufactured from rice husk, peanut husk, and garlic stem by grinding and screening processes. After measuring their fundamental properties, their effects on the bulk and physical strength of handsheets were investigated. To determine the reduction in drying energy, the dryness of sheets containing new bulking agents after wet pressing was also measured.

EXPERIMENTAL

Materials

Rice husk, peanut husk, and garlic stem were supplied from Daeyoung PowerTec (South Korea). The effects of the new bulking agents were compared against commercial wood powder produced by G-biotech (South Korea). KOCC pulp was used to produce laboratory handsheets, and cationic polyacrylamide (C-PAM) (Percol 175) obtained from Ciba Specialty Chemicals (South Korea) was used to retain the powders in the wet web.

Methods

Preparation of agricultural byproduct bulking agent

Agricultural byproducts were washed with tap water and dried at 120 °C for 24 h because they contained many contaminants, including sand and stones. The oven-dried rice husk, peanut husk, and garlic stem were pulverized into small particles using a grinder (WB-01, Sanplatec, Japan) at 25,000 rpm for 20 sec. The ground powders were fractionated by a vibratory sieve shaker (J-VSS, Jisico, Korea) equipped with a 60-mesh sieve. Because the portions that could not pass through a 60-mesh sieve were deemed to be harmful to the surface properties of paperboard, according to a Korean patent (Lee *et al.* 2009) and a previous study (Lee *et al.* 2014), they were removed; the rejected portion was about 20%. The average particle size of the bulking agents was measured using a particle size analyzer (1090 LD, CILAS, France). This device employs diffraction of laser light, together with application of Mie and Fraunhofer scattering theories. To evaluate the aspect ratio of powders, the average fiber length and fiber width of the powders was measured using a fiber analyzer (FiberLab, Metso, Finland) and the particle shape of the powders was captured using a scanning electron microscope (JSM-5600LV, JEOL, Japan).

Handsheet manufacture and measurement of physical properties

Handsheet preparation was carried out as outlined in a previous study by Kim *et al.* (2015). After KOCC was soaked for 18 h, disintegration was carried out at 10% consistency for 30 min using a standard disintegrator (Disintegrator, Daeil Machinery Co., Ltd, South Korea) according to TAPPI T205 (2006). The disintegration time was determined by checking whether the individual fibers were separated completely. The KOCC furnish was diluted to 0.5% consistency for the handsheet manufacturing step. The agricultural byproduct powders were added to the KOCC furnish and mixed for 1 min at 600 rpm, and 0.1% C-PAM was added and mixed for 1 min at 600 rpm. Handsheets with a grammage of 100 g/m^2 were made from this furnish, according to TAPPI T205 (2006). The handsheets were wet-pressed at 345 kPa for 5 min and dried at 120°C using a laboratory wet press (Model 326, Wintree Corporation, Japan) and a cylinder dryer (Cylinder dryer, Daeil Machinery Co., Ltd, South Korea), respectively. The handsheets were conditioned at 23 °C and 50% RH to maintain their moisture content at 8%. Before measuring their physical properties, the surfaces of the handsheets were visually scrutinized to identify the applicability of organic powders and surface extrusion. Bulk (TAPPI T411 2010), breaking length (TAPPI T494 2006), burst strength (TAPPI T403 2010), compressive strength (TAPPI T818 2007), and stiffness (TAPPI T543 2005) were measured to identify the effects of the new bulking agents on the physical properties of paperboard.

Evaluation of reductions in the drying energies of handsheets

The reduction in the drying energy requirements of the handsheets was evaluated by the same method used in a study by Kim *et al*. (2015). The moisture content of the wet web was determined by the quality of the sheet forming and wet pressing (the after-pressing moisture content), and this measure was selected to indicate the potential drying energy requirement of each handsheet. Peel (1999) reported that an increase of 1% dryness reduces the heating requirement in the dryer section by about 4%, and it was expected that a lower after-pressing moisture content, indicating a lower amount of water that has to be removed in the drying stages, meant a lower drying energy requirement. Therefore, the reduction in drying energy was evaluated by measuring the increase in dryness after wet pressing and computed as shown in Eq. 1. The handsheets used for these measurements were prepared and pressed in the same manner as those used for the physical testing. After wet pressing, the moisture content of each handsheet was measured using a dry oven (WiseVen, Daihan Scientific, Korea).

$$Reduction\ in\ drying\ energy\ (\%) = \frac{M_0 - M_1}{M_0} \times 100 \qquad (1)$$

where M_0 is the after-pressing moisture content of a sheet containing no bulking agent, and M_1 is the after-pressing moisture content of a sheet containing bulking agent.

RESULTS AND DISCUSSION

Agricultural Byproduct Bulking Agent Properties

Various lignocellulosic bulking agents were manufactured from agricultural byproducts, as shown in Fig. 1. Figure 1(d) shows the commercial wood powder that is widely used in duplex board mills in South Korea. All of the bulking agents made from agricultural byproducts showed no great difference, in color or appearance, from the commercial wood powder. Table 1 shows the average particle size and aspect ratio of the bulking agents tested. The rice husk powder showed the highest particle size, and the peanut husk powder showed the lowest. The wood powder and garlic stem powder showed a higher aspect ratio than the rice husk and peanut husk powders. Figures 2 and 3 illustrate the particle shape of the various powders. The surfaces of the rice husk and garlic stem powders were smoother than those of the peanut husk and wood powders. Despite the differences in particle size and shape, no limitations were observed, such as severe surface extrusion of sheets (Lee *et al*. 2014), relative to the application of these new organic fillers as raw materials for the manufacture of paperboard, compared to commercial wood powder.

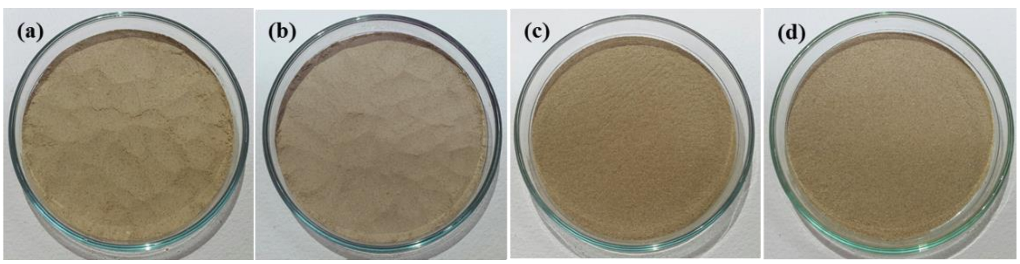

Fig. 1. Images of lignocellulosic bulking agents: (a) rice husk, (b) peanut husk, (c) garlic stem, and (d) commercial wood powder

Table 1. Average Particle Size and Aspect Ratio of Bulking Agents

Agricultural Byproduct	Rice Husk	Peanut Husk	Garlic Stem	Commercial Wood Powder
Average Particle Size (μm)	175.9	94.4	118.7	116.7
Aspect ratio	5.50	5.30	6.50	6.49

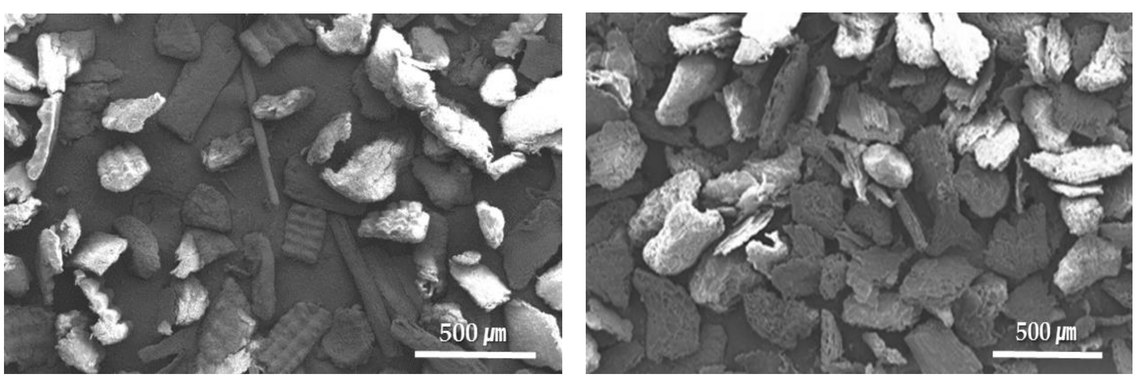

Fig. 2. Scanning electron micrographs of the rice husk (left) and peanut husk (right) powders (50X magnification)

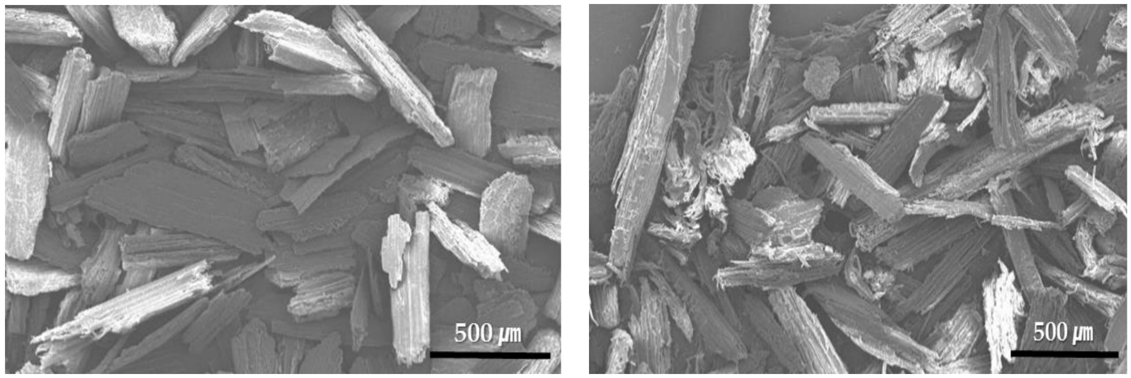

Fig. 3. Scanning electron micrographs of the garlic stem powder (left) and wood powder (right) (50X magnification)

Effects of Bulking Agents on the Physical Properties of Handsheets

The effect of bulking agent addition on the bulk of the handsheets is shown in Fig. 4. Most of the bulking agents increased the bulk of the handsheets; the rice husk powder added the greatest bulk, even higher than that of the commercial wood powder, indicated by the dashed line. It has been reported that bulking agents containing larger particles proved the most effective at increasing bulk (Lee *et al*. 2014), so the larger particle size of the rice husk powder was likely the reason for the greater bulk in the handsheets compared to the commercial wood powder. This result indicates that agricultural byproducts can be used as raw materials for the manufacture of bulking agents to improve the bulk of paperboard.

As shown in Fig. 5, the breaking length and burst strength of the handsheets generally decreased, as the amount of bulking agents increased. Figure 6 shows the effect of bulking agents on the compressive strength and stiffness of the handsheets; the results indicate the same trends as breaking length and burst strength. Some researchers have reported that materials which increase sheet thickness also decrease the area of fiber bonds, thus paper strength (Krogerus 1997; Seo *et al*. 2014). This decrease in paper strength cannot be avoided when bulking agents, including agricultural byproduct powders and commercial wood powder, are added to paperboard, but the type of agricultural byproduct and the amount of bulking agents can be selected to compensate for the deterioration in paper strength as a result of the increase in bulk. The rice husk powder showed the highest bulk and stiffness among three powders. This increase is a significant advantage, as stiffness is a very important quality for paperboard.

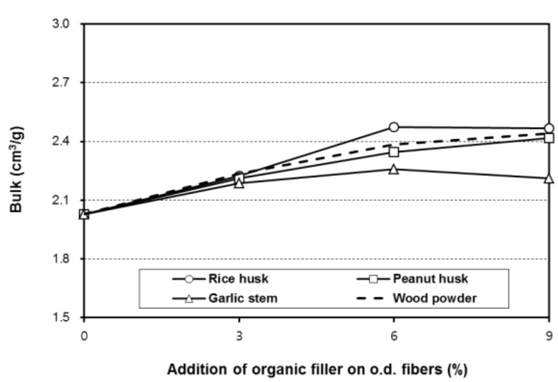

Fig. 4. Effect of the addition of bulking agents on the bulk of handsheets

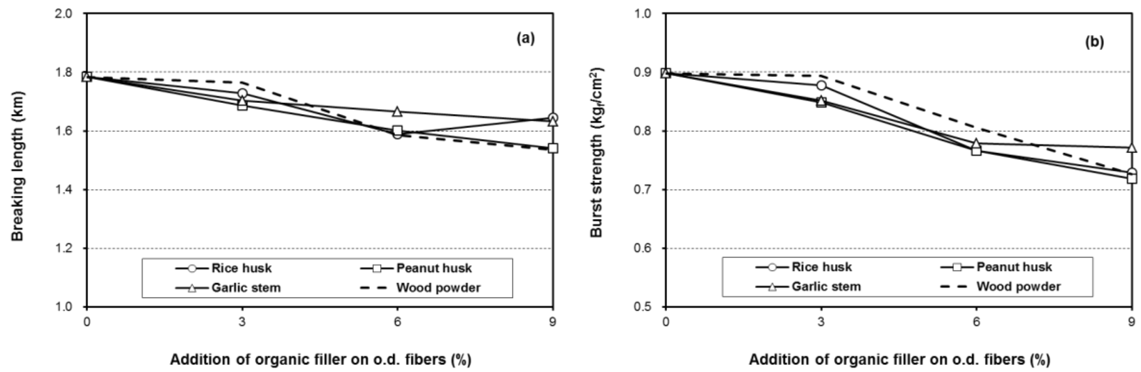

Fig. 5. Effect of the addition of bulking agents on the breaking length (a) and burst strength (b) of handsheets

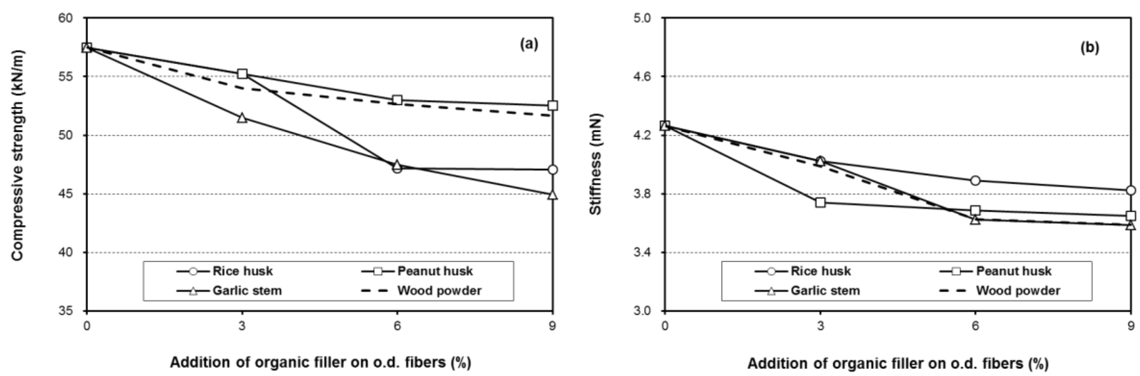

Fig. 6. Effect of the addition of bulking agents on the compressive strength (a) and stiffness (b) of handsheets

Effects of Bulking Agents on Drying Energy Reduction of Handsheets

The papermaking process consumes vast amounts of drying energy, which is a critical element of the cost of production of paperboard. Peel (1999) reported that an increase of 1% sheet dryness reduces the heating requirement in the dryer section by about 4%, so increasing the dryness of the wet web after wet pressing is one of the most important aims in the quest to reduce energy consumption. Recently, many researchers have tried to increase the dryness of the wet web after wet pressing (Hwang *et al*. 2013; Kim *et al*. 2014a,b; Seo and Kim 2014) in South Korea. In this study, the reduction in drying energy was calculated in relation to the final after-press moisture of the sheets, with and without bulking agents (Lee *et al*. 2015).

Figure 7 shows the moisture content and the reduction in drying energy of a sheet containing bulking agents after wet pressing. As the bulking agents were added to the handsheets, the after-press moisture content decreased. The rice husk powder showed the highest reduction in drying energy, and the peanut husk powder was also as effective as the wood powder in reducing drying energy. Because the bulking agents made from the rice husk and peanut husk were relatively more hydrophobic than KOCC, the addition of lignocellulosic bulking agents increased the amount of hydrophobic material in the sheets and, therefore, the dryness of the sheets after wet pressing.

Figure 8 shows that the reduction in drying energy increased linearly with the bulk of the sheets, indicating that bulk was the most important factor in predicting the drying energy reduction of the bulking agents.

It was concluded that rice husk was the most effective material for the manufacture of a bulking agent and that the rice husk powder was a satisfactory replacement for commercial wood powder in a paperboard mill.

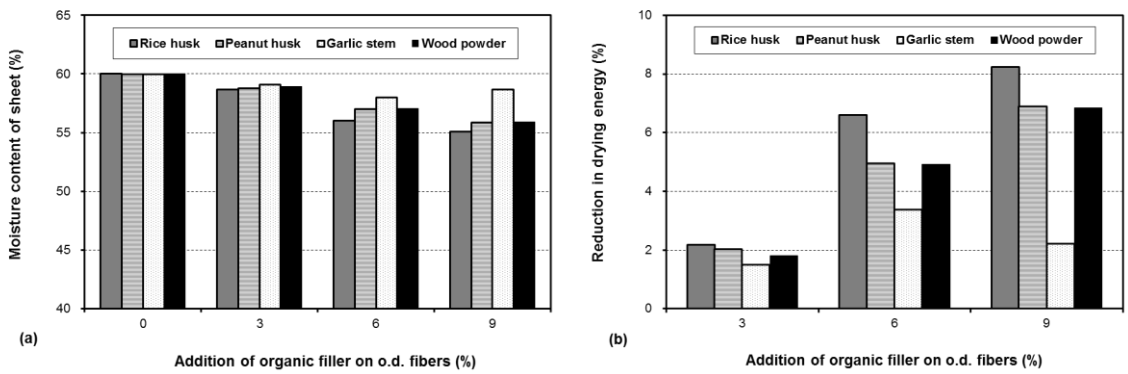

Fig. 7. Moisture content of sheet containing bulking agents after wet pressing (a) and reduction in drying energy (b)

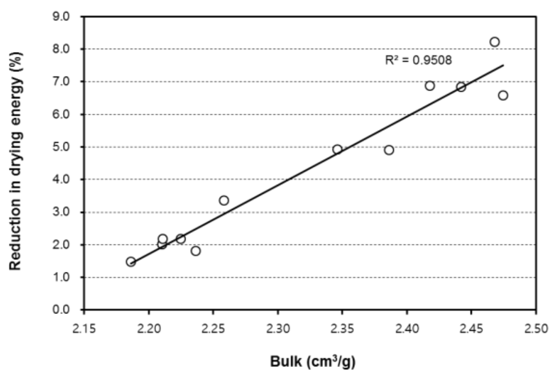

Fig. 8. Relationship between reduction in drying energy and bulk of sheets containing bulking agents after wet pressing

CONCLUSIONS

1. New bulking agents were manufactured by grinding and screening from rice husk, peanut husk, and garlic stem, and their effects on bulk improvement and drying energy reduction were investigated for potential application in duplex board.
2. There were no limitations to the application of new bulking agents in the manufacture of paperboard, as no severe deterioration of the surface properties of handsheets was observed compared to commercial wood powder.
3. The new bulking agents and the commercial wood powder improved the bulk and dryness after wet pressing, but a reduction in paper strength was unavoidable for all of the bulking agents.

4. Rice husk was the most effective material for the manufacture of a bulking agent, and rice husk powder could replace commercial wood powder in a paperboard mill.

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