PROPERTIES OF RICE HUSK PARTICLEBOARDS BONDED BY A BLEND OF TANNIN-CNSL RESIN

J.V. Tesha[§], B. Ndazi, E. Bisanda and S. Karlsson [1]
University of Dar es Salaam, Department of Materials Technology, P. O. Box 35131, Dar es Salaam, Tanzania.
[1] Royal College of Technology (KTH), Sweden.

There are vast quantities of agricultural residues available in Tanzania. Rice husk being amongst those residues is reported to have low resistance to alkalis, high silica content, and have short fibres. These factors have made rice husks not attractive raw materials in panels' production. However, it has been demonstrated that rice husks can be used to develop panel products of low cost and good performance if appropriate indigenous technologies and affordable binders that can bind siliceous materials are used.

This paper provides a summary on the study of the effectiveness of the binding characteristics of a blend of natural adhesive composed of tannin and cashew nut shell liquid (CNSL) on rice husk particleboards. The boards produced were subjected to mechanical and physical properties tests.

The results obtained have indicated that tannin-CNSL resin can be used to produce rice husk particleboards having good physical and mechanical properties if rice husk particles are crushed.

Keywords: Agricultural residues, cashew nut shell liquid, CNSL, particleboards, rice husks, tannin, resin.

INTRODUCTION

There is a lot of worldwide pressure currently being placed upon wood fibre resources than ever before. This has been associated with the rapid increasing population, which places its demands for building materials, furniture, and energy on the limited wood resources. Economic growth and development coupled with technological advancement have also generated unprecedented needs for converted forest products. Concurrently, the energy demands for developing countries have created ever-increasing demands for fuel-wood now being estimated to 50% of total wood fibre consumption (Youngquist et al., 1997). The rate of wood consumption in Tanzania is estimated at twice the rate of tropical woodland regeneration (Skutch, 1997).

Worldwide economic and technological developments have not yet solved housing problems in the developing countries. The majorities of the developing countries' citizens rely heavily on forest resource as a major construction material and cannot afford to build modern houses. The high demand on the limited wood forest resources coupled with the rapid increasing population has generated unexpected regional economic and environmental impacts. This includes the depletion of rain forests and woodlands. People have to walk long distances to look for better pastures, arable lands, and mature forest trees.

The use of wood chips and particles to produce panel products instead of the solid wood is one method of reducing forest resources depletion. This concept began in Germany in the 1970's during wood fibres shortage (Kollmann et al.,

[§] Author to whom correspondence should be addressed

1975). This idea also considered the fact that production of wider panel products is possible when wood particles are bound by adhesive materials than using solid wood.

Further studies (Ndazi, 2001; Ajiwe et al., 1998; Sampathrajan et al., 1991; Shukla et al., 1985) have revealed that most of the agricultural wastes can be developed into certain panel products to replace or complement wood particles and fibres. These wastes currently have no economic uses and are therefore creating disposal problems. Reasons for proposing uses of these resources are that they are immediate low cost materials that can offer certain ecological benefits compared to wood based fibres. It is also because of the fact that most of these residues can be compatible with most of the conventional binders used in binding wood-based particles and fibres (Sampathrajan et al., 1991; Shukla et al., 1985).

Tanzania is among the poorest developing countries that are heavily dependent on agriculture and it generates vast quantities of agricultural residues. It has an estimated annual production of various agricultural residues as shown in Table 1 (Ndazi, 2001; Dyauli, 2000; Planning Commission, 2000).

Table 1: Estimates of wastes from selected agricultural/plant products (Ndazi, 2001; Dyauli, 2000; Planning Commission, 2000)

Type of Residue	Product (Crop)	Waste Factor	Annual Production	Equivalent Wastes
			(000 tones)	
Corn stalk	Maize	2.00	2638.0	5276.0
Rice straw	Paddy	3.75	681.0	2574.0
Corn cob	Maize	0.25	2638.0	659.5
Bagasse	Sugar cane	3.30	16.8	385.4
Rice husks	Paddy	0.30	681.0	204.3
Cashew nut shells	Cashew nut	0.30	101.0	30.3
Coir	Copra	2.00	3.3	6.6
Coir dust	Copra	-		

It can be seen from Table 1 that corn stalks and rice straw provide the highest quantities of annual agricultural residues. Logistically and economically it is easier to collect rice husks or bagasse than corn stalks and rice straws because the latter are normally left scattered in farms after harvesting. However, they are popularly used for animal bedding and feeds or even as sources of domestic fuel and their collection could be difficult. Rice husks or bagasse can be found easily in large amounts as agro-industrial wastes after extracting the primary (main) product. Much of bagasse is primarily used to provide heat energy in sugar processing industries, which implies that only a smaller amount is left for other applications. Rice husks are therefore the most available alternative for industrial or commercial applications.

BACKGROUND OF LIGNOCELLULOSIC COMPOSITES

It is more likely to think that any lignocellulosic residue could be suitable for manufacturing panel products. However, there are certain important factors that determine which residue is suitable for the manufacture of panel products. Chief among those factors are the performance followed closely by the cost of product.

Technical Performance

Performance is normally the first factor to be considered when developing panel products. In the absence of any performance requirement one could easily produce a composite material. However, when performance is the primary factor, production of a composite material become challenging. Likewise, manufacture of lignocellulosic composites needs an understanding of various factors affecting the binding process when particles and the binder come in contact during mixing and pressing. In order to obtain effective binding between particles and the resin the following are the requirements:

1. The particle chemical composition and surface texture should favour formation of strong adhesive bond (preferably covalent).

2. Particles should have small variability in length and thickness to achieve better bonds.
3. There should not be a large distribution of fine particles, which tends to absorb a considerable and disproportionate amount of resin.
4. Particles should have a reasonable density to reduce the compaction ratio, which can induce residual stresses on the bond formed just after pressing or during moisture regain.

In addition to that the binding material should meet the following requirements:

1. It should be able to spread and wet the surface of the particle after coming in contact.
2. It should possess a good cohesive strength after curing in order: -
    - to carry higher applied stresses and internal strains in high-density boards.
    - to resist high internal stresses induced in the matrix in any direction, as particles tend to move in response to moisture change or internal stresses and strain.
3. It should also be able to resist the effect of moisture with or without the combination of temperature so that the cohesive strength and adhesive bond is not affected.
4. Last but most significant is that the binder must be able to penetrate the cell wall and produce strong bonds (covalent bonds) with the particle.

Combining those factors we find the following general requirements for lignocellulosic composite manufacture.

1. How significant is the particle topology and composition on the interface bond?
2. How much resin is distributed on the particle surface?
3. How much resin is absorbed into the cell walls before forming the mat?
4. How much chemical bonding is needed?
5. How can the manufacturing parameter affect the adhesive bond?

When the mat is densified (compacted) during the hot pressing stage, high deformation of the particles occurs. If there is no sufficient bond to hold these particles together, much higher levels of spring-back and localized strains occurs which lead to catastrophic delamination when the pressed mat is just released from the press. This consequently results into greater dimensional instability especially when the material is under changing relative humidity (Bonfield, 2000; Dinwoodie, 1997; Humphrey, 1997) or water due formation of a lot of voids (Bolton, 1997). However, it is the relative strength of the particles and the adhesive materials that determine whether the failure of the composite should occur at the interface, in the matrix, or through the particles.

When moisture attacks any composite, which has low polymer content the following occurs:

1. Generation of internal stress within the glue line resulting from the movement of particles.
2. Chemical degradation of the matrix due to the action of water.

Thus the only alternative to reduce the harmful effect of the internal stresses is to increase the bond strength by using a resin with higher cohesive strength or using more resin. But for high moisture furnishes resins (e.g. phenolic resins) an increase in amount of resin generates more partial pressures due to hot vapours. The hot vapour generated becomes so destructive on the interface bond (Humphrey, 1997; Bolton, 1997). Only resins with high solid content (low moisture content) or resins with high cohesive strength apply in this case. However, addition of fortifying agents can also improve the adhesive properties of phenol-based resins.

The bond strength could also be increased by changing the chemical composition and/ or surface condition of the particle in such way that it does not only become less attractive to surrounding moisture but also facilitates formation of stronger bonds (Dinwoodie, 1997). Mechanical treatment of the particles has been reported to not only physically but also chemically activate the particle surfaces due to possibilities of opening up chemical reactive surfaces on the particle (Houwink and Salomon, 1965).

Economic Factor

The other important factor in the development of lignocellulosic composites, which sometime affects the choice of the appropriate resin, is the cost. The cost of the binding material contributes a lot to the total cost of the panel product. Conventional synthetic resins usually cost higher than locally extracted natural resins and they have limited uses in developing countries. Therefore, use of natural adhesives as substitutes to synthetic resins in areas where they can be locally developed has been encouraged. If naturally occurring and locally available binders are used, the cost of the binders and subsequent panel products can be reduced.

Cashew nut shell liquid (CNSL) and wattle tannin are different forms of phenol-based natural binding materials (Pizzi, 1991). These binders could produce effective adhesive bonding with rice husks if properly synthesized.

Based on this fact, the Tanzania Industrial Research and Development Organization (TIRDO) has developed a natural binder, tannin-CNSL, for use in binding chipboards and plywood (www.tirdo.org). This resin has never been utilized commercially. In order to facilitate commercial application of this resin, several issues have to be answered such as:

Filler-resin interaction. Effect of interface bonding on the mechanical properties and dimensional stability of the composite produced. The optimum combination of filler and resin in the mixture, which result in a composite with the best properties. The best processing conditions of the composite product and behaviour of the resin under different temperatures.

OBJECTIVE OF THE STUDY

The main objective of this research was to address most of the issues raised in the previous paragraph. This was done by developing rice husk particleboards using tannin-CNSL resin. This includes studying the effects of internal bond strength on the intrinsic and extrinsic properties of the particleboards such strength, dimensional stability, and thermal properties of the resin.

METHODOLOGY

Preparation of Raw Materials

The raw materials used for developing rice husk particleboards were rice husk fillers and tannin-CNSL binder. Rice husks were collected from local rice hulling centres in Dar es Salaam. The materials were prepared for particleboard production at TIRDO. Tannin-CNSL resin was prepared and supplied by TIRDO.

Production of Particleboards

Production of the particleboards was done according to the design specifications of each board. The pressure was fixed at a maximum of 27.6 MPa for the type of press used. The press cycles ranged between 10 and 12 minutes while the temperature ranged between 160 and 190 °C.

Experimentation

The physical and mechanical performances of the particleboards were determined in accordance with (BS 5669, 1989) and ASTM D1037 standards specifications. Thermal properties of husk boards and the resin were also investigated but the results are not included in this paper.

The mechanical properties examined include: falling ball impact strength, internal bond strength, and three point bend flexural properties. These properties were basically considered to be sufficient to give necessary clues about the strength and quality of the adhesive bonds formed.

The physical properties examined were thickness swelling resistance, moisture resistance, water absorption resistance, and porosity.

RESULTS AND DISCUSSION

Properties of Fillers

Rice husks was found to have a bulk density of 99.8 ± 8.9 kgm^{-3} which fall in the range reported in literature (89-114 kgm^{-3}) (Mansaray and Ghaly, 1997). Low-density fillers require high densification (compaction ratio) in order to reduce inherent and inter-particle voids (Bolton, 1997). This has a negative effect because it results into locking up of internal stresses and strains while the resin cures. Immediately after releasing the pressing process, spring-back (reversal strain) occurs (Bolton, 1997; Vital et al., 1998; Xu and Suchsland, 1998), which often lead to interface bond delamination if the resin was not properly cured. This can also occur if the bond formed is not strong enough to counteract the effect of residual strain. This increases the amount of porosity, which leads to both poor physical and mechanical properties of the particleboard produced.

When the particles were broken, the effect of spring-back and resilience immediately after compression was significantly reduced and the amount of porosity was also decreased, which suggests that there has been an improvement in the interface bond strength.

The rice husk particles were found to have a moisture content of 11.6% similar to that found in literature (5-12%) (Mansaray and Ghaly, 1997). This range of moisture content is necessary to keep the particles in a comfortable non-brittle manner.

The best processing parameters for production of the particleboards were found to be at a temperature of 170°C and press time of 11 minutes for the pressure setting of 27.6 MPa.

Physical Properties of the Particleboard

The results have also shown that porosity is not only dependent on the effect of compaction but also on the amount of resin used. When the resin content was increased it was found that there was a corresponding increase in porosity. Since the density was fixed, the increase in was probably a result of other factors. Tannin-CNSL blend is a high moisture content furnish resin. When the mat was pressed at high temperatures, the vapour formed interfered with resin cure and adhesive bonding of the resin with rice husk particles leading to an increase in porosity.

It was also noticed that an increase in the density of rice husk boards resulted in an increase of porosity. This was probably attributed to the large springing back of rice husks as the compaction ratio was increased. As a result this affected its internal bond strength.

Resistances of the particleboards to water absorption and thickness swelling were found to be dependent on the density of the husk board. Densification has also another positive effect in particleboards. It also increases the interface binding stresses between rice husk particles and the resin (Shukla et al., 1985). An increase in interface binding stresses implies a subsequent increase in the interface (internal) bond strength. Strong interface bond suggests that there will be minimum water absorption and subsequent thickness swell due to minimum voids content in the particleboard. This however, was found to be more apparent in crushed rice husk particleboards than uncrushed rice husk particleboards. This could also suggest that manipulation of rice husks particle size distribution in the particleboard can improve the interface bonding and subsequently reduce the amount of porosity.

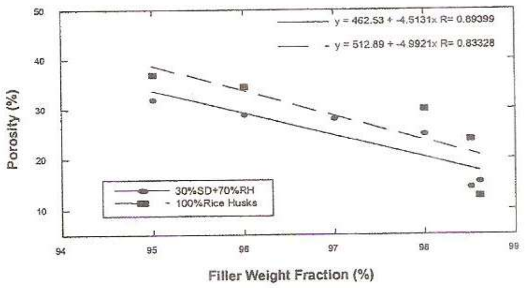

Figure 1 Effects of filler weight fraction on the porosity at a targeted density of $1200 kgm^{-3}$

The lowest value of thickness swelling for crushed rice husk particleboard was still higher than the minimum value recommended in the BS standard (BS 5669, 1989) for 1-hour soaking period (Table 2).

Reasons for lower values of thickness swelling than those given in BS standard could probably be due to the weak internal bond strength between rice husk particles and the resin. Poor chemical and/ or physical interaction between them could be the major reason for that the same formulation has worked well with wood chips according to plant trial test results shown in Table 2. In addition to this, the high reactivity of tannin towards formaldehyde, a large flavonoid molecule, and presence of non-phenolic compound in tannin affects greatly its adhesive bonding with rice husks (Kollmann et al., 1975).

Table 2 Mechanical Properties of Different Particleboards (Note: IB means internal bond)

Composition	Thickness Swell (%)	MOR (MPa)	MOE	IB Strength (MPa)
HT-CNSL-wood particle board (wet)	-	20.75	-	-
HT-CNSL-crushed rice particle boards	19.50	7.00	1527	0.20
PF-rice husk particle boards	5.39	22.56	-	0.88
BS 5669: 1989 (Part 2)	8.62	13.00	2500	0.34
CAN3-0188.3-M82 Grade Y	-	14.00	2800	-

Mechanical Properties

The results show that crushed rice husk particleboards were found to have superior mechanical properties compared to those in which the particles were not crushed. With the increase in board densities and resin content, the mechanical properties of the boards were found to increase. The reason for this was probably due to an increase in adhesive bond strength due to an increase in uniform binding stresses as the compaction ratio was increased.

Impact Strength

The Impact strength was also found to have higher values at high board densities and higher resin contents (Figure 2 & 3). Crushed rice husk boards were found to have the impact strength as high as 36-to 43-mm/mm of board thickness. There was no significant difference on the effect of husk board density on the impact strength as shown in Figure 2, despite an earlier comment that binding stresses were increased at those ends. However, the minimum falling ball impact strength recommended in the British Standard was less than the maximum values obtained with crushed and uncrushed rice husk particleboards at higher densities and higher resin content. BS (BS 5669, 1989) recommends the minimum impact strength for general-purpose particleboards equal to 34-mm/mm of board thickness.

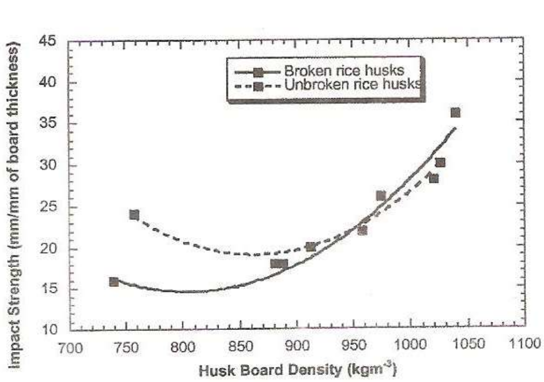

Figure 2. Effects of density on the impact strength of rice husk particleboard

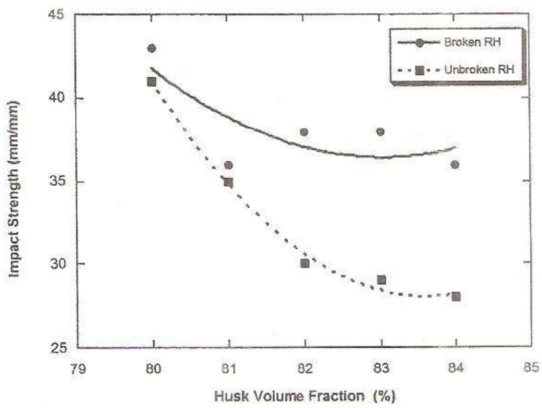

Figure 3. Effects of tannin-CNSL resin content on the impact strength

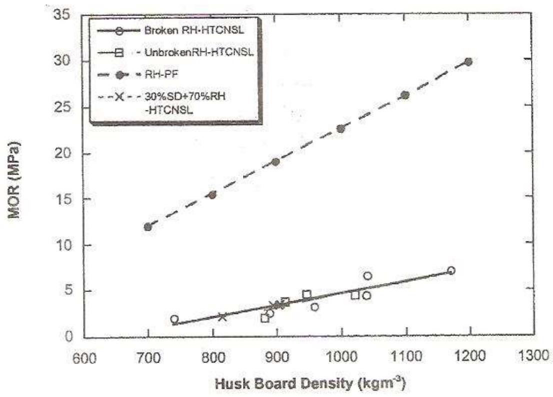

Figure 4. Effects of density on the MOR of rice husk particleboard

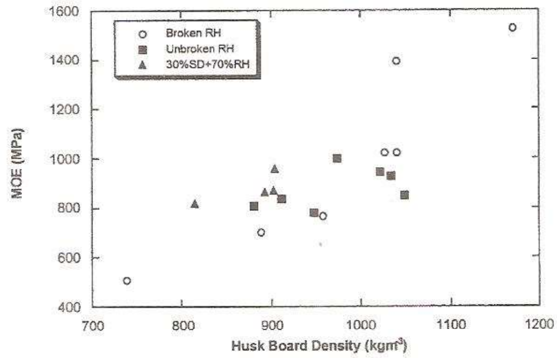

Figure 5. Effects of density on the MOE of rice husk particleboard

Three-point Bend Flexural Strength

The bending strength (MOR) and stiffness (MOE) of the particleboards were found to increase as the density and resin content were increased (Figure 4 and 5). Since the MOR and MOE measure properties at the surface of the particleboard, this suggests that there was effective binding at the board surface due to occurrence of uniform binding stresses caused as the mat was densified (Shukla et al, 1985).

The highest value of MOE obtained from crushed rice husk particleboards was less than that recommended for exterior grade particleboards in the Canadian Standard and British Standard (Table 2). The highest MOE was 1527 MPa, which is less than 2800 MPa and 2500 MPa recommended by CAN and BS Part 2 (BS 5669, 1989). It can also be pointed out that the weak interface bond formed between rice husk particles and tannin-CNSL resin was the main contributing factor. The MOR results are very low compared to those obtained with PF resin (Table 2).

The internal bond (IB) strength apart from behaving in similar manner like other mechanical properties, it was less than the minimum recommended in BS Part 2 (BS 5669, 1989) for general-purpose boards. The highest IB strength obtained was 0.20 MPa, which is less than 0.34 MPa recommended in BS Part 2 (BS 5669, 1989).

Thermal Properties

Tannin-CNSL resin has shown that it can be used up to the temperature of 170°C without significant decomposition, according to thermo-gravimetric analysis. However, its glass transition temperature is about 112°C according to differential scanning calorimetry (DSC). In practice practical polymers are used below this temperature because beyond this, profound changes in the mechanical and physical properties start to occur. The transition temperature obtained was almost similar to that found with other phenolic resins and was also found to depend on the degree of cure. Thermal decomposition characteristic of the resin was almost similar to that of phenol formaldehyde (PF) reported by Kopf (1990).

From the DSC curves, the kinetics of reaction of the resin was found to have the first endothermic peak at 144°C, followed by the second peak at 168°C. The resin without CNSL was found to have the first endothermic peak at 102°C and the second peak at 168°C (Calve et al. 1995). This suggests that CNSL reacted with formaldehyde in preference to tannin at the first peak as proposed by Calvé *et al.* (Calve et al. 1995). He also suggested that the chain building up of the condensation (major) reaction of tannin follows at the second main endothermic peak.

CONCLUSIONS

Tannin-CNSL blend resin is a promising binder for rice husk particleboards provided the interface bonding is improved by increasing the physical and or chemical interaction between rice husks and the binder. This suggests that natural adhesives could be used for binding plant fibres and agricultural wastes in a more efficient manner as it is for synthetic resins.

The low internal bond strength obtained was found to have profound effects on the overall performances and quality of the husk boards.

Earlier reaction of CNSL with formaldehyde facilitated a cross-linking reaction and cure of tannin-CNSL resin. This reaction is probably the one that has contributed to the improved properties of the matrix.

Thermal properties of the resin were more or less similar to those of conventional phenolics.

5. RECOMMENDATIONS

Future studies aimed at improving the internal bond strength of rice husk particleboard using tannin-CNSL as a primary binder, should take into account several factors. Some of these factors include:

1. Improving the adhesive properties of tannin-CNSL resin, which are most responsible for enhancing the physical and chemical interaction between this resin and rice husks.
2. Modifying the physical and or chemical properties of rice husk particles to enhance interface bonding between rice husks and tannin-CNSL resin.

It is also recommended that long-term performance characteristics of rice husks particleboards such as creep, bond durability test, and biodegradation resistance should be examined in future studies.

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ACRONYMS

TIRDO	Tanzania Industrial Research and Development Organization
CNSL	Cashew nut shell liquid
KTH	Kungliga Teknisca Högskolan
PF	Phenol Formaldehyde
DSC	Differential Scanning Calorimetry
MOR	Modulus of Rupture
MOE	Modulus of Elasticity
IB	Internal Bond (Strength)
BS	British Standard

HT Hydrolysed Tannin
ASTM American Society of Testing Materials

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