Full Length Research Paper

Sound absorption and print density properties of recycled sheets made from waste paper and agricultural plant fibres

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A number of thin biocomposites through wet lying methods were prepared from old corrugated boards with blends of luffa fibres (LF) and yarn waste (YW) at 15 and 30%. Mechanical, optical, printability and sound absorption properties of manufactured materials were determined. Addition of both LF and YW improved the brightness of control sheets, but unfortunately significantly reduced the burst and tensile indexes. Sound absorption values were found to be improved by both LF and YW parallel to the increase in the air permeability. Thermal stabilities of prepared sheets were also slightly improved by LF and YW as revealed by thermogravimetric analysis (TGA). Furthermore, addition of LF and YW were noted to increase both the changes in print density and tone values of resultant materials. It is concluded that LF and YW could be better utilized with recycled cellulose fibres in producing some insulation and packaging materials.

Key words: Recycling, print density, sound absorption, insulation, luffa fibres, waste textiles.

INTRODUCTION

Panels and sheets to be used in noise polluted areas must have a good sound insulation property. Noise pollution normally refers to unwanted irregular and chaotic sounds which disturb people by interfering with communication, work, rest, recreation, or sleep hence destroying people comfort (Hussain et al., 2002; Chen et al., 2010). When sound waves meet the sound absorbent materials, some is converted to heat and some passes through. Therefore sound absorbing materials are normally needed to be fixed onto a noise isolating material (Ilgun et al., 2010). Performance of a sound absorbing material is governed by both acoustic and non-acoustic properties. While the sound absorbing efficiency is evaluated by the acoustic properties, the non-acoustic properties determine the acoustic response of a material in various applications (Doutres et al., 2010). Static air flow resistivity, porosity, tortuosity, viscous characteristic length and thermal characteristic length are the most important non-acoustic properties of a material.

Plant fibres have a good potential as they are purely natural, biodegradable and available worldwide (Youququist et al., 1994) compared to those of fibre glass, foams and mineral fibres like rock wool as insulation material (Saadatnia et al., 2008). They have been widely used as reinforcement of different thermosetting and thermoplastic resins in the form of not only fibres, but also chips and dusts due to their relative cheapness and recyclability (Kurt and Mengeloglu 2011). There are several reports that natural fibres can be perfectly used in the production of sound absorbing materials too (Chen et al., 2010; Saadatnia et al., 2008; Yuhazri et al., 2010; Ilgun et al., 2010; Ersoy and Kucuk, 2009). Final properties of such materials strongly depend on the blend proportion, formation methods and ingredients. As one of the natural fibres, luffa cylindrical fibres from its fruits, stems or barks were used in the production of some composite materials and filters (Altunisik et al., 2010; Iqbal et al., 2004; Hassan, 2006). However, sound...
Absorption properties of such materials were not reported. Due to its higher surface area and adsorption capacities, luffa fiber is known to be well used in dye adsorption (Altunisik et al., 2010) and waste water treatment (Iqbal et al., 2004). Luffa fibre is therefore believed to be perfectly used in sound absorbing sheets and panels. Yarn wastes from textile industries also contain mainly cellulose and can be utilized in the production of some panels due to its fibrillar cellulosic structure and white colour. Cotton fibre fineness has significant effects on yarn lee strength (Ahmad et al., 2003). Discarded cottons are not suitable for yarn production due to lower fineness and yarn wastes contain quite long fibres compared to woody fibres, hence they can be used in board and paper production due to long fibres and brightness.

Since many sheets and panels are treated, in some degree, by some kind of liquids for printing, painting, coating, quing or preservation purposes, surface properties and porous structure of such materials must be determined and controlled. In printing, for example, the amount of colour pigment left on the applied surface governs the level of print density, a value of image fillers, but had negligible effects on the movements of oil-increased the liquid uptake. Sizing interfered with the reduced air permeability and surface energy hence roughnesses, air permeability, filler content, sizing surface stay, the higher print density is obtained. Surface lightness/darkness. The more pigments on a paper the amount of colour pigment left on the applied surface can be determined and controlled. In printing, for example, (Alireza and Raverty, 2007; Aydemir et al., 2010). Ink penetration and print density influence the print density (Alireza and Raverty, 2007; Aydemir et al., 2010). Ink penetration and print density have a close relationship to ink absorption ability of a material. Porosity is one of the most important factors which influence the absorption of ink vehicles. Ink vehicles are drawn into the pores and inter-fiber spaces of biocomposites by capillary action (Senden et al., 2000; Mattila et al., 2003; Yenidogan, 2010; Aydemir et al., 2010). Aydemir et al. (2010) recently reported that fillers reduced air permeability and surface energy hence increased the liquid uptake. Sizing interfered with the fillers, but had negligible effects on the movements of oil-based ink on papers.

In this work, a number of thin biocomposites through wet laying methods were prepared from old corrugated boards with blends of luffa fibres (LF) and yarn wastes (YW) at 15 and 30%. Mechanical, optical, printability and sound absorption properties of manufactured materials were determined. It is concluded that LF and YW have potential to be used with recycled cellulose fibres in producing some insulation and packaging materials.

### MATERIALS AND METHODS

#### Pulp preparation and sheet formation

Fibre suspensions from recycled old corrugated board, luffa cylindrica and yarn waste were prepared. Old corrugated board was torn into small pieces, soaked into water overnight followed by mechanical disintegration giving fibre slurry at 1% consistency. Matured dried fruit of luffa aegyptica was cut in 2 cm length, washed with distilled water and beaten at laboratory beater (Tappi T 248 sp-08 method-PFI) for 5 min to have fibrillated pulp suitable for wet formation. Yarn waste (YW) was washed with distilled water and beaten to have evenly dispersed fibre suspension.

The three pulp suspensions were adjusted to 1% consistency. Sheets were prepared at 100 g/m² grammage by filtering fibre suspension through 200 meshed circular wire on a Standard British Handsheet Forming device. Wet fibre mat was placed between blotting papers and cold pressed by a laboratory press operated at 50 psi pressure followed by cylinder drying at 100°C giving a dry sheet with 5% moisture content. Control sheet was made from only old corrugated board pulp. Luffa and yarn waste were blended with control pulp as slurries at 15 and 30% separately and at least 10 sheets were prepared from each blends. Fibre composition of the prepared sheets was given in Table 1.

### Chemical analysis

Luffa fibres and yarn wastes were sampled and prepared according to Tappi T 257 om-85 for chemical tests. Holocellulose and α-cellulose contents were determined according to the chloride and Tappi T 203 om-71 methods respectively. Tappi T 222 om-98 and Tappi T 211 om-93 methods were followed to determine lignin and ash content respectively. The solubility properties were also determined based on alcohol-benzene method (Tappi T 204 cm-97).

#### Mechanical properties

Prepared thin sheets were conditioned in a controlled room set at 23±2°C and 65±2% relative humidity for at least 24 h before testing. The tests done to determine some properties of papers were tabulated with relevant standards in Table 2.

### Optical and printing properties

Brightness and yellowness values of prepared sheets were measured with Elrepho optical analyzer according to TAPPI T 452 om-92.

Sheets were printed with Michael Huber München Resista Cyan

### Table 1. Pulp ratios of sheets prepared.

<table>
<thead>
<tr>
<th>Sheet name</th>
<th>Corrugated board (%)</th>
<th>Luffa (%)</th>
<th>Yarn waste (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Luffa 15%</td>
<td>85</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Luffa 30%</td>
<td>70</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>Yarn waste 15%</td>
<td>85</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Yarn waste 30%</td>
<td>70</td>
<td>0</td>
<td>30</td>
</tr>
</tbody>
</table>
Table 2. Tests and methods followed during sheet testing.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheet conditioning</td>
<td>TAPPI T 402 om-88</td>
</tr>
<tr>
<td>Density (g/cm$^3$) - Bulkness (cm$^3$/g)</td>
<td>TAPPI T-220</td>
</tr>
<tr>
<td>Air permeability (ml/min)</td>
<td>TAPPI T 460</td>
</tr>
<tr>
<td>Breaking index (Nm/g)</td>
<td>TAPPI T 494 om-88</td>
</tr>
<tr>
<td>Breaking length (m)</td>
<td>TAPPI T 404 om-87</td>
</tr>
<tr>
<td>Burst index (kPam$^2$/g)</td>
<td>TAPPI T 403 om-91</td>
</tr>
</tbody>
</table>

Figure 1. Luffa and yarn waste addition reduced the sheets strength.

series offset ink (DIN ISO 2746-1) at Heidelberg Printmaster GTO 52 offset printing machine. Printing processes were performed on ten scale of ton and tram values using Wedge 1982 measuring scale control according to ISO 12647-2 method. Reflection values of printed images were measured by using a Gretag Macbeth SpectroEye reflectometer operated at D50 illumination and 45/0 black geometry.

Print density values of tested handsheets were measured with Gretag Macbeth Spectra Eye device adjusted at D50 illumination, 2° monitoring and 0/45 black area (ISO 12647-2, 2004; ISO 12647-3, 2005).

Thermogravimetric analysis (TGA)

TGA was performed on a NETZSCH STA 409C/CD model device at a heating rate of 20°C/min. Samples were examined under flowing nitrogen (10 ml/min) over a temperature range from ambient to 1200°C.

Sound absorption

The sound absorption coefficients of prepared materials were determined by the impedance tube method according to ISO 10534-2 and ASTM E1050-98 methods (Ersoy and Kucuk, 2008; Chen et al., 2010). Different acoustical parameters for the frequency range between 500 to 4800 Hz were measured by a complete acoustic material testing system, featuring Bruel and Kjaer PULSE$^{\text{TM}}$ interface. Horizontally situated impedance tube kid has a loudspeaker fixed at its one end acting as a sound source. Test sample was prepared in a diameter of 29 mm to place into measurement tube at a pre-adjusted depth. Test materials were stucked into a foam backing before the measurement, to be able to better analyse the sound absorption properties of thin test sheets.

RESULTS

Effects on sheet properties

Mechanical properties of the prepared sheets were significantly decreased by the addition of both yarn waste and luffa fibres as shown in Figure 1. YW addition caused greater reduction in both breaking and burst indexes than luffa addition did. It was noted that the density of control
Figure 2 shows the air permeability and breaking length of prepared sheets. Breaking lengths of sheets were significantly reduced by luffa and yarn waste addition as the air permeability was improved.

Chemical analyses showed that yarn waste was made of almost cellulose (92%) along with very low level of hemicellulose (3.2%) and extractives (0.8%) (Table 3).

### Table 3. Chemical components of pulps used.

<table>
<thead>
<tr>
<th>Component (%)</th>
<th>Luffa fibre</th>
<th>Yarn waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>α-Cellulose</td>
<td>63.0</td>
<td>92.0</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>18.0</td>
<td>3.2</td>
</tr>
<tr>
<td>Lignin</td>
<td>11.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Extractives</td>
<td>3.4</td>
<td>0.8</td>
</tr>
<tr>
<td>Ash</td>
<td>0.4</td>
<td>0.1</td>
</tr>
</tbody>
</table>

### Table 4. Optical values of materials used.

<table>
<thead>
<tr>
<th>Pulp</th>
<th>Whiteness (ASTM)</th>
<th>Brightness (ISO)</th>
<th>Yellowness (ASTM)</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bleached softwood fibre (Reference)</td>
<td>87.51</td>
<td>83.60</td>
<td>5.81</td>
<td>94.95</td>
<td>-0.38</td>
<td>3.21</td>
</tr>
<tr>
<td>Yarn waste</td>
<td>78.20</td>
<td>67.25</td>
<td>19.75</td>
<td>48.04</td>
<td>1.08</td>
<td>5.51</td>
</tr>
<tr>
<td>Luffa</td>
<td>70.21</td>
<td>60.52</td>
<td>25.15</td>
<td>48.00</td>
<td>1.43</td>
<td>7.13</td>
</tr>
<tr>
<td>Old corrugated pulp</td>
<td>39.37</td>
<td>31.11</td>
<td>30.20</td>
<td>69.02</td>
<td>2.94</td>
<td>11.68</td>
</tr>
</tbody>
</table>

Optical values of handsheets prepared from 100% of luffa, yarn waste and corrugated board pulps were displayed in Table 4 along with that of bleached softwood pulp as reference. The optical values of handsheets prepared with the blends of control pulp, luffa and waste
yarn pulp were not presented here.

As shown in Figure 3, print densities of all tested samples decreased in different rate and leveled out on fourth day. The greatest changes in the print density occurred in a sheet containing 30% yarn waste. Figure 4 illustrates the changes in the tone values of tested handsheets.

**Thermogravimetric analysis (TGA)**

Figure 5 shows the TGA curves of control samples and samples containing 30% luffa and yarn wastes.

**Sound absorption**

Thin sheet samples prepared for sound absorption tests were glued and sticked on a backing foam for proper placements in the impedance tube. Measurements on the foam, the glued foam and the foam having samples sticked on the surface showed that the glue on the backing foam slightly increased the sound absorption coefficient between 500 to 1500 Hz frequencies (Figure 6).

It was found that both luffa fibre and yarn waste additions improved the sound absorption value of control sheets (Figure 7).

**DISCUSSION**

**Effects on sheet properties**

The breaking and burst indexes of prepared sheets were remarkably reduced by both yarn waste and luffa fibre
addition (Figure 1). Greater reductions in the density of handsheets were also noted, while the air permeability was significantly increased (Figure 2). The increased air permeability suggests the reduction on specific contact area between fibres in a material which is significantly important for strength properties. Lower the specific contact area is generated, weaker the material is produced (A’Inson et al., 2006). Chemical analyses showed that

**Figure 5.** Thermal stabilities of test samples.

**Figure 6.** Effects of gluing and sample on the sound absorption of backing foam.
yarn waste was made of almost cellulose (92%) along with very low level of hemicellulose (3.2%) and extractives (0.8) (Table 3). Hemicellulose and extractives found in yarn waste were attributed to the treatment chemicals used during yarn production such as starch and wax. Hemicellulose is known to promote fibre-fibre bonding and important for strength development (Imamoglu et al., 2002). This is probably why luffa addition (higher hemicellulose content, 18%) made smaller reduction on sheet’s strength properties compared to that of yarn waste addition.

Optical and printing properties

As seen, yarn waste and luffa pulps have considerably better optical values than old corrugated pulp has (Table 4). Brighter and whiter fibres are mostly preferred for the production of biocomposites like sheets and panels. Blending of yarn waste and luffa fibres improved the optical values of resultant materials to some degree.

Print density is the term used to define the colour intensities of printed images on a material. The ink droplets transferred on a material get adsorbed into the structure as well as spreading over the surface in time depending on the properties of susbstrate, ink, printing technique and drying methods (Senden et al., 2000; Mattila et al., 2003). As shown in Figure 3, print densities of all tested samples decreased in different rate and leveled out on fourth day. The greatest changes in print density occurred in a sheet containing 30% yarn waste. The reduction in the print density was attributed to both higher porosity value as confirmed by the air permeability test (Figure 2) and also absorbent properties of luffa fibre and yarn wastes. Sheets with porous structure and absorbent fibres consume more inks and takes more pigment particles which gave lower print density as previously reported by some researchers (Navaz et al., 2008; Wang et al., 2008; Aydemir, 2010).

The area of contact between an ink droplet and substrate surface gets expanded parallel to ink spreading which is defined as tone value. The ink on a paper
surface simultaneously travels both in vertical and horizontal directions (Senden et al., 2000; Aydemir, 2010). Figure 4 suggests that sheets with porous structure disturbed the ink spreading more and gave wider ink contaminated areas. Ink movement on control sheets were seemed to be limited on the surface, but actually occurred in vertical direction. It is suggested that control sheets mostly had microcapillary in more uniform distribution while sheets containing luffa fibres and yarn wastes had pores in bigger and variable sizes.

Thermogravimetric analysis (TGA)

It is visible at the TGA curves that at the first stage after initial loss of moisture, a sharp weight loss is clearly visible indicating mass decomposition between 290 to 480°C heating range. After 480°C, gradual weight lost continued up to 900°C. Luffa fibre and yarn waste seem to improve thermal stability above 400 to 700°C.

Sound absorption

The control sheets stucked on the backing foam were significantly increased the sound absorption coefficient especially between 500 to 3250 Hz frequency. Although tested material is quite thin compared to those studied in previous works, it clearly confirms the recent reports that cellulosic fibres have a good sound absorption potentials (Ersoy and Kucuk, 2009; Chen et al., 2010; Yuhazri et al., 2010).

It was found that luffa addition at 30% made the highest increase in sound absorption coefficient between 3400 to 4750 Hz. It is believed to be due to porous structures of sheets which created a barrier for the sound waves.

Conclusions

Luffa fibre and yarn waste improved the brightness and opacity of control sheets made of old corrugated pulp to some extent as well as slightly helping thermal stability of sheets between 400 to 700°C. Addition of luffa fibre and yarn waste on the other hand made the sheets more porous increasing air permeability values and reducing sheets densities. Porous sheets allowed more ink penetration at a faster speed hence increased changes in both print density and tone values. Furthermore, burst and breaking indexes of control sheets dramatically decreased by the presence of both luffa fibre and yarn wastes. Sound absorption coefficient of sheets, however, considerably improved. It is concluded that luffa fibre and yarn waste can be perfectly utilized in the production of boards and panels to be used as sound insulation materials. Some filler coatings on such materials could be suggested to improve the printability properties. Some resins and strength additives may be also utilised in such materials to produce stronger boards.

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