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Implications of fiber characteristics and mat densification on permeability, compaction and properties of kenaf fiber panels

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ABSTRACT

In the manufacturing of medium density and high density fiberboards the fiber characteristics and mat density substantially influence mat permeability, compaction pressure and panel's physicomechanical properties. In this paper, the permeability and compaction response of kenaf bast fiber mats are experimentally determined at three fiber lengths for both dry and resinated fiber mats with various levels of mat densification. The mats of long fibers have demonstrated higher permeability and require higher compaction pressure than short fiber mats at the same level of densification. Furthermore, kenaf panels in the density range of 800 kg/m^3 to 1100 kg/m^3 are manufactured with commercial melamine urea formaldehyde resin and three fiber categories. The panels are evaluated to demonstrate the effects of these factors on a panel's physicomechanical properties. The higher compaction pressure and good stress distribution with long fibers have resulted in higher mechanical properties than those of short fiber panels. On the other hand, a decrease in fiber length has lowered the mat permeability, resulting in significant improvements in dimensional properties. The panel physicomechanical properties can also significantly improve by increasing the panel density. The high density kenaf panels have shown excellent mechanical properties which are well above the standard requirements of MDF and HDF panels according to (ANSI, A208.2: 2009) and (ANSI, A135.4-2012) standards.

1. Introduction

The demand for medium density and high density fiberboard (MDF and HDF) panels is increasing in many regions of the world (El-Kassas and Mourad, 2013). Refined wood fibers are commonly employed as raw material for producing these panels. However, lack of raw wood material, especially in wood deficient countries, has encouraged the investigations on the use of plant fibers for producing non-structural composite panels (Aisyah et al., 2013; Biswas et al., 2011; Fiorelli et al., 2012; Grigoriou et al., 2000; Halvarsson et al., 2008, 2009; Okuda and Sato, 2004; Paridah et al., 2009). In addition, researchers have also combined waste biomass with wood fibers to manufacture composite panels (Abdul Khalil et al., 2010a; Nourbakhsh et al., 2010). Kenaf is a promising non-wood fiber crop that has attracted the attention of many researchers in the panel manufacturing industry due to their excellent properties, high fiber yield and short plantation cycle (Wang and Ramaswamy, 2003). However, the panels produced so far with kenaf bast fibers have shown moderate mechanical properties and poor dimensional properties as reported in previous studies (Juliana et al., 2012; Paridah et al., 2009; Kalaycıoglu and Nemli, 2006; Walther et al., 2007). It is still a challenge to establish a suitable manufacturing process to produce kenaf panels that can compete with wood based panels in terms of performance.

Kenaf bast fibers are well known for their excellent mechanical properties; the tensile strength and modulus of a single kenaf fiber can be as high as 750 MPa and 66 GPa, respectively (Ashby, 2013). The negative aspects when comparing with wood fibers are that kenaf fiber's hemicelluloses content is about 8% higher than that of wood fiber, while the proportion of lignin content is only 60% of the commonly used wood materials for panel products (Shmulsky and Jones, 2011). Moreover, kenaf fibers have high density, thick cell wall structure and high ash content compared to those of the most of wood species. Mechanically separated kenaf bast fibers are fiber bundles usually composed of three to five elementary fibers glued together by a pectin interface (Amel et al., 2013). The diameter of a typical kenaf fiber bundle is two to three times higher than that of refined wood fiber. Thicker kenaf bast fibers result

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in lower aspect ratios than those of refined wood fibers of similar fiber lengths. Kenaf fiber density is significantly higher than commonly used wood fibers. Normally, the high density species are not preferred for low and medium density panel manufacturing due to their lower compaction ratios (panel density/species density) and higher void content compared to low density species for a specific panel density (Li Shi et al., 2006; Woodson, 1976). The strength of kenaf fibers can be better utilized for HDF as the fiber strength has little influence in low density fiberboards (LDF). In HDF, the increased number of fiber contact points and intimate bonding result in failure within the fibers, while in LDF the failure usually occurs in the glue bonding (Li Shi et al., 2006).

It is well established that the processes of mass and heat transfer are important during hot pressing of MDF and HDF panels (Thoemen and Klueppel, 2008; Thoemen and Humphrey, 2006). These processes determine the moisture and temperature distributions within the panel and the rate of temperature rise in the panel core. They also influence the adhesive cure and development of density profiles. Mat permeability and compaction ratio have crucial roles in heat and mass transfer. The thicker cell wall and stiffer fiber bundles of kenaf bast fibers may result in different mat permeability and compaction response when compared to those of wood fibers. The permeability and compaction response can also describe the viscous flow through mat structure which has numerous complex fiber shapes and geometries that create macrovoids. The higher void contents reduce the inter fiber contacts and adversely affect the panel's mechanical and physical properties (Dai et al., 2007); as the increase in the size and number of voids results in higher permeability. Mat densification appears to be a straight forward solution to reduce the void content. However, excessive densification may result in higher compaction pressures, spring back, increased thickness swelling and heavier panels (Dai, 2001; Sackey and Smith, 2010). Therefore, as a compromise, it is necessary to identify the mixture of fiber sizes that results in lower mat permeability and improved inter-particle contacts at a reasonable level of mat compaction and density.

The preceding discussion suggests that complex relationships exist between panel properties and fiber characteristics. Realizing the importance of panel permeability and its effects on panel processing and properties, a number of studies have been carried out in the past on wood composites to characterize air permeability in terms of particle geometry, mat density and process characteristics (Bolton and Humphrey, 1994; Dai et al., 2005; Sackey et al., 2008). Wang et al. (2006) suggest that panel manufacturing conditions should be adjusted according to the species permeability. Thoemen and Klueppel (2008) conclude that for wood composite panels mat permeability not only depends on mat density and flow direction, but also varies by material type and its characteristics. Recently, significant variations in the strength and density of wood and rice straw panels due to change in fiber size and processing conditions have been reported (Ghanbari et al., 2014).

However, to date, to the best of our knowledge no study has been conducted on the permeability and compaction response of kenaf bast fibers and their effects on panel properties. The objective of this study is to investigate the effect of fiber length and mat densification on the permeability and compaction response of kenaf fiber mats. To study the influence of fiber length, kenaf mats were prepared with three categories of fiber lengths: long, medium and short. A number of compaction and permeability tests were carried out for both dry and resinated mat samples. Further, the kenaf panels were manufactured with three fiber length categories and three density levels to understand the effects of these factors on mechanical and dimensional properties of kenaf panels. The broader goal was to engineer high performance kenaf panels and to characterize the effects of the fiber characteristics on panel properties.

2. Materials and methods

2.1. Materials

Cleaned and carded kenaf bast fibers were acquired in bales from The Golden Fiber Trade Centre, Bangladesh. The average length of fibers received was approximately 25 mm. They were further chopped by a rotary blade pelletizer and three fiber categories (long, medium and short) were selected by screening them through different mesh sizes. Table 1 summarizes the properties of the three fiber classes. The fibers contained about 16% moisture and were oven dried at 80 °C to reduce the moisture content to approximately 5%. The fiber cell wall density was measured by Archimedes principle using canola oil in accordance with ASTM D3800-99 standard. The average density of kenaf fibers measured by this method was 1480 kg/m^3. For a comparative analysis, the refined softwood (pine wood) fibers supplied by Scion, New Zealand were used and the average cell wall density of these wood fibers was 1385 kg/m^3.

The commercially available thermoset resin melamine urea formaldehyde (MUF) was sourced from Momentive Specialty Chemicals Inc., New Zealand. According to manufacturer specifications, the MUF resin contained approximately 9.8% melamine, 39.8% urea and 24.6% formaldehyde content by weight percentage. The solid contents in the resin were 63% by weight and viscosity was in the range of 120–150 cPs. The percentage of resin loading for panel manufacturing was determined as a proportion of resin solid weight to the oven dried weight of kenaf fibers. In our preceding publication on kenaf panels, within the experimental conditions MUF resin outperformed than other commercially available resin systems (urea formaldehyde and phenol formaldehyde) when used at 12% resin content and 12% pre-pressing mat moisture level (Ali et al., 2014).

2.2. Physical properties of fibers

The dimensions and aspect ratios (AR) of the chopped kenaf fiber samples were determined using a Leica microscope and the averages of 100 values of these measurements are shown in Table 1 along with the physical properties. The similar values for refined pinewood fibers (softwood) conventionally used in New Zealand fiberboard industry are also reported for comparison. The bulk densities of kenaf fibers and wood fibers were determined by sifting dry

Table 1
Average fiber dimensions, aspect ratio (AR) and bulk density of kenaf and wood fibers mats. Values in brackets are standard deviations.

Fiber characteristics	Softwood fibers	Long fibers	Medium fibers	Short fibers
Mean fiber length (mm)	2.9 (0.55)	5.87 (2.5)	3.15 (1.6)	1.96 (1.31)
Fiber aspect ratio (AR)	79.7 (6.35)	101.7(23.8)	55.8 (33.3)	34.4 (22.1)
Mat thickness (mm)	128.34 (2.19)	77.6 (2.54)	47.8 (1.31)	32.2 (1.15)
Bulk density (kg/m^3)	37.57 (0.93)	61.9 (2.88)	102.9(3.64)	151.6 (7.2)
Fiber cell wall density (kg/m^3)	1385	1480	1480	1480
Lumen (%)*	65**	31***	31	31
Tissue density (kg/m^3)	484	1021	1021	1021

*Determines the density of fiber tissue; for example, 1385 × 0.35 = 484 kg/m^3; **Shmulsky and Jones (2011); ***Amel et al. (2013).