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Effects of resin and moisture content on the properties of medium density fibreboards made from kenaf bast fibres

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ABSTRACT

The effects of different factors including resin type, resin content and moisture content on the physicomechanical properties of medium density fibreboard (MDF) panels made from kenaf (*Hibiscus cannabinus* L.) bast fibres are investigated. The Taguchi method of experimental design is employed to determine the effects of the factors and to find the levels of factors that result in desirable properties. Three different commercial resins namely, urea formaldehyde (UF), phenol formaldehyde (PF) and melamine urea formaldehyde (MUF) are used in the manufacturing of kenaf MDF panels. The panels are produced with a target thickness of 9 mm and density of 700 kg/m^3. The results indicate that resin type and moisture content have significant influence on the mechanical properties while resin content is the least significant. On the other hand, for physical properties resin content and moisture content have much lesser influence as compared to resin type. This initial study reveals that kenaf panels produced with MUF resin at higher resin loading and intermediate level of moisture content, show elevated properties in accordance with wood based MDF standard ANSI A208.2-2009 for Grades 130 and 155.

1. Introduction

Medium density fibreboard (MDF) is a traditional composite panel produced by compressing usually refined wood fibres sprayed with synthetic resins or some other suitable bonding material. MDF panels are manufactured by a dry fibre process and thicknesses can range from 2.5 mm to over 40 mm (Halvarsson et al., 2008). The properties of MDF panels are based on the fibres and the adhesive bonding between them. These panels are often used in a variety of non-structural applications, such as furniture, laminated floors, panelling, cabinet doors and underlay of carpet floors (Bowyer et al., 2007).

The demand for wood composite panels, such as MDF and particle board has significantly increased in recent years. This growth in demand in wood deficient Asian countries has helped to boost the North American wood-based panel exports by almost 25% (Clark, 2011). The consumption of wood panels also increased in CIS countries and the Russian federation by 10.6% and 14.2%, respectively in the year 2010–2011 (Clark, 2011). According to a report of the Food and Agricultural Organisation (FAO), in the year 2011 world production of particle board and MDF was 191 million m^3, which is 233% and 61% higher than the production in the years 1980 and 2000, respectively (FAO, 2011).

The increasing demand for wood products has created unforeseen pressure on world forest reserves. The wood panel industry is being confronted with a substantial rise in raw material cost, particularly wood, as well as rising energy and transportation costs (Clark, 2011). Increase in global warming and other environmental issues related to wood production have also raised the question of how to utilise other indigenous rapid growing plants to fulfil the needs of infrastructure applications.

In the past two decades, the interest in non-wood lignocellulosic fibre resources has increased to assist with forest conservation efforts (Kalaycıoglu and Nemli, 2006). The availability of alternative, less expensive non-wood fibrous raw materials is critical to cater to the growing demand of lignocellulosic fibre based panel products (Halvarsson et al., 2008). Consequently, researchers in both academia and industry are seeking alternative sources of lignocellulosic fibre crops. Research has been carried out on a wide variety of non-wood materials in different regions of the world to check their suitability as raw material for fibreboard production. Some of the raw materials explored in previous studies are coconut fibres (Fiorelli et al., 2012), castor stalks (Grigoriou and Ntalos, 2001), bagasse (Xu et al., 2009), wheat straw (Halvarsson et al., 2008), kenaf (Grigoriou et al., 2000; Juliana et al., 2012; Paridah

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et al., 2009), hemp (Pecenka et al., 2008), corn stalks (Kargarfard and Jahan-Latibari, 2011) and cotton stalks (Kargarfard and Jahan-Latibari, 2011).

Kenaf is in an advantageous position when compared with other lignocellulosic fibre crops since it has a short plantation cycle, adaptability to environmental conditions and requires relatively low use of pesticides and herbicides (Wang and Ramaswamy, 2003). Kenaf fibres are widely considered as a suitable biological resource and potential substitute for fossil fuels and wood-pulps (Juliana et al., 2012). Kenaf plant grows to an average height of 4–6 m and attains a stem diameter of 25–35 mm in just four to five months. It produces 3–6 tonnes of dry fibres per hectare that is three to five times more biomass compared to most of wood species (Juliana et al., 2012). In view of these facts and the possibility of planting twice a year, kenaf has a great potential to be used as an alternative source of fibre for MDF and particle board manufacturing (Mossello et al., 2010). India, China and Thailand account for 90% of world kenaf production. In the year 2006, the total kenaf production was 0.32 million tonnes of which India, China and Thailand produced 42%, 25% and 11% respectively (FAO, 2006).

In some recent studies researchers have investigated the potential of kenaf fibres as an alternative to wood fibres for board manufacturing (Aisyah et al., 2012; Juliana et al., 2012; Kalaycıoglu and Nemli, 2006; Paridah et al., 2009). However, these studies have not comprehensively addressed the effects of multi-variables on kenaf MDF properties. Despite these studies on kenaf MDF manufacturing, an extensive literature search reveals that no report is available on studying the effects of different resins and mixing parameters on the properties of kenaf MDF panels by using an experimental design technique. Moreover, in previous studies the kenaf MDF was produced with UF resin in a laboratory scale with manual fibre/resin mixing and the panels produced with 100% kenaf bast fibres showed poor properties, in particular water soaking properties (Juliana et al., 2012; Paridah et al., 2009). Hence, this current research is carried out with the aim of exploring the potential suitability of kenaf fibres for MDF manufacturing and also to understand the effects of scaling up from the laboratory to a pilot plant. The second aim is to investigate the influence of important materials and manufacturing parameters on the properties of kenaf MDF. The influences of resin type (RT), resin content (RC) and moisture content (MC) on the mechanical properties including modulus of elasticity (MOE), modulus of rupture (MOR) and internal bond strength (IB) and dimensional properties including thickness swelling (TS) and water absorption (WA) have been investigated.

The Taguchi method of experimental design is commonly used to investigate the influence of process variables on a selected response (Roy, 2010). This statistical technique is employed to understand the effect of factors on kenaf MDF properties and to predict the suitable mixing parameters for obtaining desirable kenaf MDF properties. The Taguchi method is also helpful in reducing the number of experiments necessary to understand the effects of process parameters on product response in addition to separating the significant factors affecting the response from less significant factors (Reddy et al., 2012).

2. Materials and manufacturing

2.1. Materials

Washed and carded kenaf bast fibres were imported in bales from The Golden Fibre Trade Centre, Bangladesh. The fibres were too long to be directly used for making boards; hence were chopped to an approximate length of 2–3 mm by a rotary blade pelletiser. The fibre dimensions were examined under a microscope and the aspect ratio determined from the average of 100 fibres was in the range of 27–30. Undersized particles and impurities were removed by fine sieving. The fibres contained about 16% moisture and were oven dried at 80 °C to reduce moisture content to approximately 5%. The fibre density was measured by Archimedes method using canola oil in accordance with ASTM D3800-99 standard. The average density of kenaf fibres measured by this method was 1.48 g/cm^3.

Three types of commercially available thermoset resins UF, PF and MUF selected for this study were supplied by Momentive Specialty Chemicals Inc., New Zealand. The properties of resins are shown in Table 1. Wax was sprayed at a level of 1 wt% (dry base) in relation to kenaf fibres to improve the water resistance properties.

2.2. Selection of process factors and their levels

The bonding quality and performance of MDF panels are mainly determined by the type and quantity of resin system used (Dunky and Pizzl, 2002; Salari et al., 2013). Despite the environmental concerns for formaldehyde emissions, the wood composite industry is still largely relying on formaldehyde based resins (Tang et al., 2009). Secondly, adhesive manufacturers with improved technologies are producing synthetic resins with low formaldehyde emissions, fulfilling the emission regulations worldwide. The widely used adhesives are urea formaldehyde (UF), melamine urea formaldehyde (MUF) and phenol formaldehyde (PF) (Bowyer et al., 2007). The excellent adhesion, low cost, easy handling and colourless appearance have made UF resin a widely used adhesive for panel manufacturing. However, for higher resistance against heat and humidity PF and MUF resins are also used, but they are relatively expensive (Fink, 2005). These three commercially available resins UF, PF and MUF were selected to evaluate their effects on the mechanical and dimensional properties of kenaf panels.

Resin content is closely related to MDF properties (Maloney, 1993). Higher strength and dimensional stability are normally expected with increasing resin level. However, minimum levels are normally used considering the high cost of resins. The resin content is generally varied from 6 to 10% based on resin solid contents (Bowyer et al., 2007; Maloney, 1993). However, resin content was varied from 8 to 12% in the present study considering the lower wettability, high density and lower volume fraction of kenaf fibres as compared to those of wood fibres. The MDF panels made from high density kenaf fibres have been expected to posses slower bonding strength in comparison to those made from wood fibres; hence to get reasonable properties slightly higher resin contents have been used in this study.

Another important factor which significantly affects the adhesion behaviour and resin penetration of MDF panels is the pre-pressing mat moisture content (Aydin et al., 2006; Li et al., 2009; Tabarsa et al., 2011). According to Maloney (1993), mat moisture content is the most significant factor governing panel properties provided that other factors like resin content, press time and temperature are at reasonable levels. During hot-pressing the low densification (kenaf fibre density 1480 kg/m^3, panel density 700 kg/m^3) is expected to cause low steam pressure and easy escape of steam. A similar phenomenon is observed by Dai et al. (2004). Normally, for wood MDF the mat moisture content ranges from 9 to 10% (Bowyer et al., 2007). Hence, more moisture would be required for resin curing compared to wood at a given time. For kenaf panels the effect of moisture content variation from 9 to 15% is studied. The selected factors and their levels are shown in Table 2.

2.3. Experimental design

Taguchi method is a powerful tool to predict the optimum conditions to attain the desirable performance (Roy, 2001; Sahoo,