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Dimensional stability improvement of kenaf panels by post-manufacturing hygrothermal treatments using response surface methodology

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ABSTRACT

The potential of various hygrothermal post manufacturing treatments is evaluated in this study to determine the suitable heat treatment and moisture conditions for relieving the internal residual stresses and improving the dimensional stability characteristics of medium density and high density kenaf fiberboards (MDF and HDF, respectively), generally known to have poor dimensional stability. Furthermore, the effects of these conditions on the density and mechanical properties of the panels have been evaluated. The treatment involves conditioning at normal (65% relative humidity, RH) or high humidity (85% RH) and then heat treating these panels at different combinations of temperature and time. The results are statistically analyzed by using response surface method of Design Expert® software. The desirability function is employed to find the treatment conditions that give suitable dimensional stability with minimum compromise on the mechanical properties of the panels. Within the range of experimental conditions, the parameters with maximum desirability are 225 °C, 30 min, 85% RH and 200 °C, 90 min, 85% RH for MDF and HDF panels, respectively. The panels treated under these conditions result in approximately 25–30% reduction in thickness swelling without any significant reduction in their mechanical properties with respect to those of the non- treated panels. However, with more intensive treatment, the thickness swelling within the limits of experimental study can be decreased by approximately 35%. Although some mechanical properties of the panels are compromised under these conditions, they are still above the requirements of ANSI A208.2-2009 and ANSI A135.4-2012 standards.

1. Introduction

Fiberboard manufacturing from non-wood plant fiber sources is becoming increasingly important due to the depletion of natural forests and the desire to limit the utilization of wood sources. Recently, interest has grown in kenaf as an alternative raw material for panel products, especially in south and south-east Asian countries with shortage of wood and wood products supply for building and construction applications (Abdul Khalil et al., 2010). Even though kenaf bast fibers are well known for their excellent mechanical properties, the panels made from these fibers have shown comparatively high dimensional instability and tendency to swell more in comparison to the wood fiber panels (Ali et al., 2014a; Kalaycıoglu and Nemli, 2006). This tendency of kenaf panels can be attributed to the inherent hygroscopicity of kenaf fibers, high hemicellulosic contents, high permeability and the developed residual stresses in fiber mats during hot pressing (Ali et al., 2014b; Ayrilmis et al., 2009; Houts et al., 2001a). For this reason kenaf panels may not be attractive in countries with high level of atmospheric moisture. Thus, kenaf is in a relatively weak position in the global market in comparison to different wood species, commonly used for producing MDF and HDF panels. The potential of kenaf panels to compete with engineered wood panels can be fully utilized by improving their moisture resistant ability. In the preceding studies the authors have shown that dimensional stability of kenaf panels can be improved during panel manufacturing by carefully selecting resin content, moisture level, fiber size and panel density. However, additional resistance to moisture is required to compete with commercial wood MDF/HDF panels (Ali et al., 2014a,b,b).

The combination of heat and moisture has long been recognised for improving wood dimensional properties (Tiemann, 1915; Hillis, 1984). Several studies in the past decade have reported the significance of heat treatment for improving the dimensional stability of wood and wood based panel products (Bonigut et al., 2012;

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Esteves and Pereira, 2008; Garcia et al., 2006; Garrote et al., 2001; Sonderegger et al., 2011). Hemicelluloses, being the major hygroscopic component, degrade by heat treatment which results in an improvement in dimensional stability of the panels. Partial thermal breakdown of hemicelluloses, formation of insoluble polymers, cross linking of cellulosic components, increase in crystallinity and migration of extractives to the surface are considered to be the main causes of improving the dimensional properties in cellulosic fibers (Garcia et al., 2006; Rowell et al., 2002). Heat treatment can also cause dehydration which leads to reduction of free hydroxyl groups and formation of hydrophobic substances due to the cross linking reactions of polymers (Sari et al., 2013).

Heat treatment is an energy consuming process which can greatly increase the production cost of panels. Therefore, thermal treatment processes should be carefully selected according to the characteristics of the panel product to minimise the deterioration of desirable mechanical properties, reduce the associated energy consumption, and improve the panel dimensional properties. The heat treatment, especially for panel products, can be divided according to the means of application: pre-treatment (at fiber level before manufacturing), treatment during panel consolidation and post-manufacturing treatment (Ayrilmis et al., 2009). Hygrothermal pre-treatment can significantly improve dimensional properties and sorption behavior of wood fiber based particle boards and OSB panels, also it does not limit the choice of adhesive used as it does not affect adhesive bonding (Ayrilmis et al., 2011; Sari et al., 2013; Boonstra et al., 2006; Paul et al., 2006). On the other hand, Holt et al. (2014) have concluded that post-manufacturing heat treatment results in significantly better dimensional properties than pre-manufacturing treatment for agricultural fiber panels. The post-manufacturing heat treatment (after panel consolidation) is considered direct, easy, cost competitive and can also be used to impart specific panel properties and to release compressive residual stresses (Del Menezzi and Tomaselli, 2006). The post heat treatment for wood composite panels is carried out with either saturated steam or dry environment under specific temperature and time conditions. Although sufficient treatment time is necessary for adequate heat treatment, a reduced thermal exposure time is favorable for maintaining appearance, properties and economical aspects of the panels. Bonigut et al. (2012) have shown that post-manufacturing heat treatment can positively influence wood MDF dimensional properties. Moreover, these treatments can also relieve residual stresses developed during panel consolidation. The moisture and temperature differences between the surface and core layers of the panel are responsible for the development of these residual stresses. Houts et al. (2001b) have shown that for wood MDF panels the residual stresses can be significantly eliminated by hygrothermal conditioning under heat and moisture. They have also observed a significant correlation between the magnitude of residual stresses and thickness swelling for wood based MDF panels. The disadvantage of heat treatment could be inferior mechanical properties and higher brittleness. However, the influence of heat treatment on lignocellulosic panel products is not yet fully understood and needs further investigations (Del Menezzi and Tomaselli, 2006).

Response surface methodology (RSM) is now-a-days widely used for process optimization with a relatively small number of systematic experiments that can reduce cost, time and resources (Ferreira et al., 2013; Islam et al., 2012). In this study, RSM with *D*-optimal design of Design Expert® software is used to find suitable post-manufacturing treatment conditions. Besides, the desirability function, a well-recognized technique, is employed for optimization of treatment parameters to achieve maximum improvement in the dimensional stability without compromising the mechanical properties of kenaf panels (Islam et al., 2009; Jeong and Kim, 2009; Derringer, 1980).

The aim of this research is to use RSM to systematically investigate the effects of post-manufacturing treatments for kenaf panels and their correlation to panel density, moisture sorption characteristics and mechanical properties. To accomplish these objectives, a number of identical kenaf panels were made at two density levels with melamine urea formaldehyde (MUF) resin. It has already been shown by the authors (Ali et al., 2014a) that for kenaf panels, within the used experimental conditions MUF resin out performs other commercially available resin systems (urea formaldehyde and phenol formaldehyde) when used at 12% resin content and 12% pre-pressing mat moisture level. In this study, the panels have been further treated at different levels of temperature, exposure time and moisture, which will be explained in the later sections.

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 approximate length of the carded fibers received was 25 mm. The fiber clumps removed manually from the bales were run through a hammer mill to segregate the individual fibers. They were further chopped to approximate lengths of 4–5 mm by a rotary blade pelletiser. The aspect ratio determined from the average of 100 fibers was 92. The fibers contained about 16% moisture and were oven dried at 80 °C to reduce the moisture content to approximately 5%.

The commercially available MUF thermoset resin was sourced from Momentive Specialty Chemicals Inc., New Zealand. According to manufacturer specification, the MUF resin contained approximately 9.8% melamine, 39.8% urea and 24.6% formaldehyde contents by weight percentages. The solid content in the resin was 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 fibres.

2.2. Manufacturing of kenaf panels

The manufacturing of kenaf panels was carried out at the MDF pilot plant of Scion in Rotorua, New Zealand. The dried and as received fibers were mixed in certain percentages to maintain 12% moisture content for each trial. The MUF resin at 12% w/w was sprayed into the flow of fibers with a pneumatic spray gun at 3.5 bar (350 kPa) pressure. The resinated fibers were collected and homogenously placed into a wooden forming box. The pre-pressing of resinated fibers was carried out by compressing them using a manual hydraulic press to form a compact fiber mat. After forming, the box was gently removed and the mat was transferred to the aluminium caul plate for pressing. The pre-pressed resinated mat was transferred into parallel flat platens (300 × 300 mm) of a computer controlled oil-heated press. The fiber mat was pressed at 180 °C for 300 s following a three step pressing schedule (Thoemen and Ruf, 2008). Higher than normal MDF pressing time (10–15 mm/s) is used in this pilot plant study to achieve the best bond quality. Faster pressing times will be investigated in a future study.

The press was released at the end of the pressing cycle for ten seconds to release the steam and gases from the panel before complete opening. The panels (290 × 270 mm) were prepared with a nominal thickness of 9 mm. Mat pressure and thickness were numerically controlled and measured by computerized system. After removal from the press, the panels were air cooled at ambient temperature. Panels were manufactured in triplicate for each treatment condition for medium and high density kenaf panels. The target densities for medium and high density panels were