Investigating the Potential of Using Waste Newspaper to Produce Environmentally Friendly Fiberboard

Peng Luo,* Chuanmin Yang, Tao Wang, and Yan He

Waste newspapers (WNPs), composed of mostly wood fibers and small amounts of inorganic fillers and printing ink, are a low-cost, abundant, and readily available form of household waste. Urea formaldehyde (UF) resin is used routinely to produce wood-based panel boards even though it releases harmful formaldehyde. The best way of resolving this issue is to use formaldehyde-free adhesives from renewable resources. Kraft lignin, a readily available, low-cost, and renewable waste product from the pulping industry, is used mainly as a fuel. Kraft lignin has good bonding ability to wood-based panel boards and improves water resistance. In this research, fiberboards were produced using a dry-processing method from recycled WNPs and bonded with kraft lignin instead of UF. The physical and mechanical properties of the produced fiberboards were evaluated. The results showed that the hot press temperature and kraft lignin content remarkably influenced the physical and mechanical properties of the fiberboards. As the hot press temperature and kraft lignin content increased, the overall performance of the fiberboards improved accordingly. The results indicate that WNPs could be a potential sustainable resource for fiberboards production.

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*Contact information: College of Mechanical Engineering, Tianjin University of Commerce, Tianjin 300134, China; *Corresponding author: pengluo@yeah.net*

INTRODUCTION

Newspapers, whose lifespan is very limited, are a readily available form of household waste. Waste newspapers (WNPs) are composed of wood fibers and small amounts of inorganic fillers and printing ink (Jin *et al*. 2015). The recycle and reuse of WNPs is important for forest resources and environmental protection. Most WNPs are recycled and reused as raw materials for newspaper production, with small amounts for low-value products, including paper insulation, compost, and animal bedding (Fan *et al*. 2017). Recycling WNPs back into newsprint paper requires removal of inks by chemical deinking process using large amounts of chemicals such as NaOH, Na_2SiO_3, chelating agents, and surfactants; the deinking process is expensive and environmentally damaging (Kumar and Satyanarayana 2014). In addition, the use of WNPs for the production of newsprint paper has become less promising due to the advent of digital media. Therefore, using WNPs to develop novel high-value cellulose-based materials is an interesting and meaningful task (Srasri *et al*. 2018).

Fiberboards are fibrous panels made up of lignocellulosic materials joined together with a binder (Theng *et al*. 2015). Fiberboards are classified according to their density into high-density fiberboards (density greater than 900 kg/m^3) and medium density fiberboards (density between 400 and 900 kg/m^3). They also differ by the manufacture process: dry or wet forming. In dry forming, synthetic binder typically is applied on fibers with a moisture content between 6 and 12%. In wet forming, a large quantity of water is employed to convert fibrous pulp and form fiber mat, promoting hydrogen bonding (Popescu *et al*. 2020). Little or no synthetic binder is needed for the wet process, and wet-processed fiberboards exhibit uniform density, good mechanical properties, flat surfaces, and excellent workability and paintability. The major drawback for wet process fiberboard production is waste water recovery and treatment, which is an important but difficult issue (Dolezel-Horwath *et al*. 2005; El-Kassas and Mourad 2013; Popescu *et al*. 2020). The dry forming process employs air as the fiber distribution medium and offers an environmentally sound advantage: there is no need to treat waste water because a very small amount of water is consumed. At present, the majority of globally produced fiberboards are dry-processed (Cavdar *et al*. 2010; Popescu *et al*. 2020).

Non-renewable petrochemical derived synthetic resins such as urea-formaldehyde and phenol-formaldehyde are common resins used in dry forming process for fiberboard production due to their low cost, water-solubility, ease of use, thermal properties, low cure temperature, and high performance (Moslemi *et al*. 2020; Espinosa *et al*. 2021). About 90% or more of the world’s fiberboard production is produced with these resins (Espinosa *et al*. 2021). However, petroleum-based resins are deemed detrimental to the environment from the public's point of view (Theng *et al.* 2015; Essid *et al.* 2021). The most desirable way of resolving these issues is to use formaldehyde-free adhesives from renewable resources (Prasittisopin and Li 2010). Lignin has a role as a binding agent in the biomass itself (Essid *et al*. 2021). Several studies have been conducted on using different kinds of lignin to produce formaldehyde-free fiberboards (Mancera *et al*. 2012; Angles *et al*. 2001; Velasquez *et al*. 2003). The results of the experiments indicated that fiberboards bonded with kraft lignin exhibited best overall performance (Velasquez *et al*. 2003; Mancera *et al*. 2012). Kraft lignin is a by-product of sulfate cooking wood chips, commonly known as kraft pulping (Velasquez *et al*. 2003; de Baynast *et al*. 2022). During kraft cooking, the native lignin is degraded and dissolved from the wood (Velasquez *et al*. 2003). Kraft lignin can be recovered *via* acid precipitation, ultra-filtration, dialysis, *etc*. The annual global production of kraft lignin is approximately 75,000 tonnes (de Baynast *et al*. 2022). Kraft lignin is underexploited, as it is mainly used as a fuel in the pulp and paper industry (Velasquez *et al*. 2003; Mancera *et al*. 2012).

To date, there is no information on utilizing WNPs with kraft lignin in production of fiberboards. This study determined the technical feasibility of WNPs in production of fiberboards bonded with kraft lignin.

EXPERIMENTAL

Raw Materials

Waste “Tonight Newspaper” published by the Tonight Newspaper Office (Tianjin, China) was used as the raw material. The moisture content of the WNPs was 7.8%. Powdered commercial kraft lignin M0010-25G derived from softwood was purchased from Mingcheng Chemical Products Co., Ltd. (Nantong, China). Its general features were: less than 1% ash content, less than 5% moisture content, greater than 90% total lignin, pH 7 to 8, and dark brown in color.

Fiberboard Preparation

The WNPs were torn into small pieces of about 25 x 25 mm and weighed. The pre-weighed WNPs were soaked in water at ambient temperature for 24 h and subjected to slurrying by a slusher at a 5% consistency for 30 min. The pulps and the desired amount of kraft lignin were disintegrated at 2,000 rpm for 10 min to ensure even fiber and lignin distribution and diluted to 1.2% consistency at ambient temperature. The pulp was placed in a laboratory paper sheet former to remove the excess water by filtering and vacuum suction. The pulp was air dried to 7% moisture content before being placed in a laboratory mold of 150 mm x 150 mm and pre-pressed under 1.5 MPa for 30 s to form a mat. The fibrous mats were hot-pressed in accordance with a three-phase hot press schedule at target temperature. During the first phase, the mat was pressed at 4 MPa for 180 s, and during the second and third phases, the mat was pressed under 2 MPa for 60 s and 1 MPa for 120 s, respectively. The fiberboard was gradually decompressed. The kraft lignin application levels were 10%, 15%, and 20% based on the oven-dried weight of the waste newspaper fibers. The hot press temperatures were 160 and 170 °C. The board thickness was 2 mm, and the target density was 800 kg/m^3. Three panels were made for each manufacturing condition.

Fiberboard Evaluation

After manufacture, the fiberboards were conditioned at 20 °C and 65% relative humidity for 2 weeks. The boards were sawed into test specimens and tested according to the GB/T 17657 (1999) standard for density, internal bonding strength (IB), modulus of rupture (MOR), modulus of elasticity (MOE), 24 h water absorption (WA), and thickness swelling (TS). Analysis of variance (ANOVA) and Duncan's mean separation tests were used to statistically analyze the data obtained with a SPSS software (SPSS Inc., Version 19, Chicago, IL, USA).

RESULTS AND DISCUSSION

Figures 1 through 4 show the mechanical properties and water resistance of the produced panels. As expected the mechanical properties and water resistance increased with the addition of kraft lignin.

The IB values of fiberboards with addition of kraft lignin were between 0.62 MPa and 0.84 MPa, which were enhanced significantly in comparison with the fiberboards without kraft lignin (Fig. 1). Increase of kraft lignin content significantly improved the IB. The fiberboards with 10% kraft lignin content hot pressed under 160 and 170 °C upgraded the IBs by 82.3% and 91.2% in comparison with the fiberboards without kraft lignin, respectively. Sample manufactured with 15% kraft lignin content and two hot press temperatures, namely 160 and 170 °C, resulted in increases in IB values of 94.1% and 97.4%, respectively. The sample manufactured using 20% kraft lignin content and two hot press temperatures, namely 160 and 170 °C, led to increases in IB values by 1.15 and 1.54 times, respectively. This clearly indicated that the IBs of the fiberboards were significantly improved with kraft lignin addition. Increasing lignin content resulted in enhanced IBs. IB is affected by the bond between fibers (Luo *et al*. 2022). Lignin, with different functional groups such as hydroxyl, carbonyl, or carboxylic groups (Dominguez-Robles *et al*. 2018), helps to form inter-fiber bonds (Quintana *et al*. 2009; Mancera *et al*. 2012; Luo *et al*. 2022). The fiberboards manufactured at 170 °C showed higher IBs than those produced at 160 °C.

The lignin melting better at higher temperature, thus leading to the formation of improved inter-fiber bonds (Luo *et al*. 2022; Velasquez *et al*. 2003). Similar results have been reported by Luo *et al*. (2022) and Velasquez *et al*. (2003). The IB values of fiberboards produced with kraft lignin, except for the panel produced with 10% kraft lignin at 160 °C, met the national standard of China for general purpose medium density fiberboard used in dry conditions (GB/T 11718-2021).

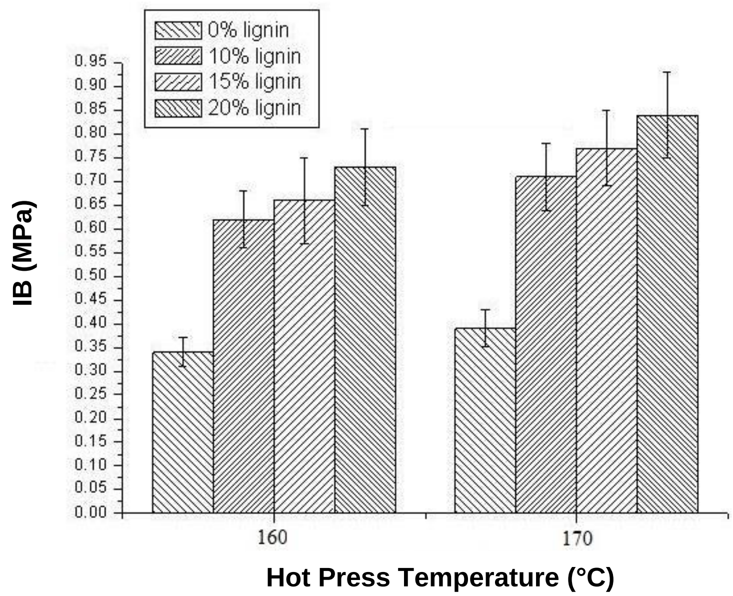

Fig. 1. IB of fiberboards with various amount of Kraft lignin under different hot press temperatures

The ranges of data in the MOR and MOE for the control were from 12.31 to 14.83 MPa and from 1619 to 1932 MPa, respectively (Figs. 2 and 3). Inclusion of kraft lignin resulted in significantly increased MOR and MOE. The comparison of the fiberboards without kraft lignin and with 10% kraft lignin revealed very good results. The MORs increased from 12.31 and 14.83 MPa to 22.37 and 28.36 MPa, 81.7% and 91.2% higher after kraft lignin addition. An increase in kraft lignin dosage from 10 to 15 and to 20% resulted in an increment of MOR from 22.37 to 29.52 and to 32.46 MPa at 160 °C and from 28.36 to 31.75 and to 35.83 MPa at 170 °C, respectively. MOE followed the same trend as MOR. MOR and MOE are widely affected by the inter-fiber bonds and individual fiber geometry and strength (Mancera *et al*. 2012). Stronger bonding strength among fibers helps to improve MOR and MOE (Velasquez *et al*. 2003; Mancera *et al*. 2012). Similar results have been reported by Velasquez *et al*. (2003) in the study of production of *Miscanthus sinensis* fiberboard with kraft lignin. The incorporation of kraft lignin upgraded the mechanical properties of the panels because the bonding properties of lignin raised the connections between the cellulosic fibers (Angles *et al*. 2001; Mancera *et al*. 2012). The minimum requirements of MOR and MOE in the Chinese National Standard GB/T 11718 (2021) for medium density fiberboards for general use under dry conditions are 27 MPa and 2700 MPa, respectively. As shown in Figs. 2 and 3, all the panels produced with kraft lignin addition except for the panels made with 10% kraft lignin at 160 °C satisfied the requirement specified by the Chinese standard.

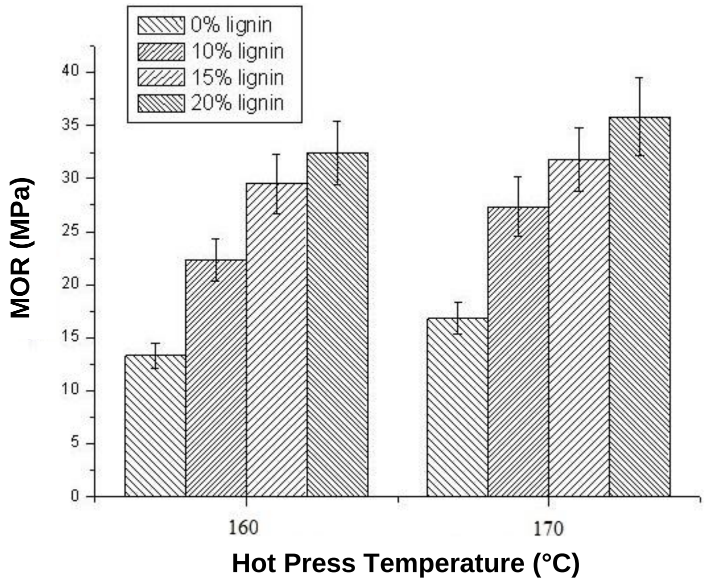

Fig. 2. MOR of fiberboards with various amount of kraft lignin under different hot press temperatures

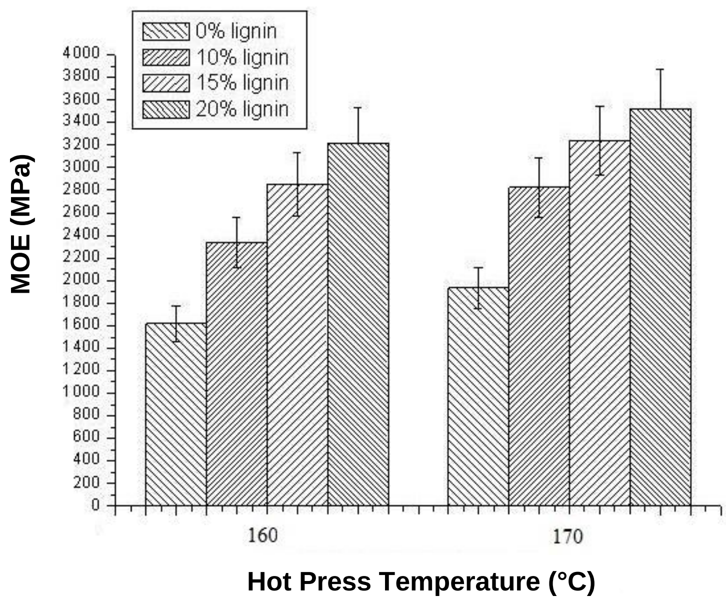

Fig. 3. MOE of fiberboards with various amount of kraft lignin under different hot press temperatures

The 24 h TS is a key parameter in describing dimensional stability of fiberboards (Mancera *et al*. 2012). The 24 h TS values of the fiberboards are presented in Fig. 4. Compared with the fiberboards without kraft lignin, the TS of the fiberboards with kraft lignin were lowered significantly. The reason for the decrease of TS is probably due to the improved interfiber bonding caused by the presence of lignin at the fiber surface (Flandez *et al*. 2012; Mancera *et al*. 2012). The 24 h TS decreased significantly with increasing Kraft lignin dosage and hot press temperature. These results were consistent with the studies conducted by Angles *et al*. (2001) and Velasquez *et al*. (2003). Kraft lignin was able to offer a resistance to water penetration and reduce the amount of water that enters and swells the cell wall (Angles *et al*. 2001; Mancera *et al*. 2012). Enhancing hot press temperature from 160 to 170 ℃ resulted in decreased TS. This result is in good agreement with Velasquez *et al*. (2003) who produced *Miscanthus sinensis* fiberboards with externally added kraft lignin under similar conditions. The 24 h TS of all fiberboards produced satisfied the thickness swelling requirement for general uses as stipulated by the GB/T 11718 (2021) standard (45%).

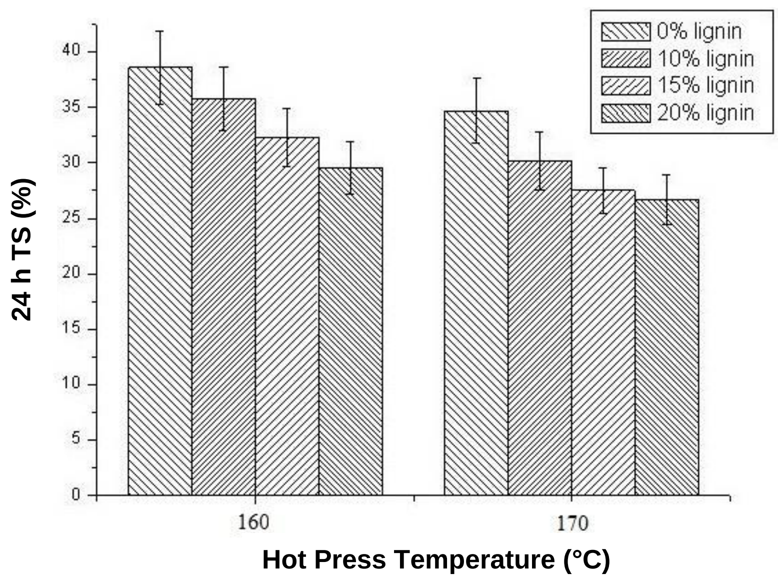

Fig. 4. 24 h TS of fiberboards with various amount of kraft lignin under different hot press temperatures

CONCLUSIONS

1. Fiberboards were successfully produced using waste newspaper (WNP) bonded with kraft lignin for the first time. Mechanical properties and water resistance of the fiberboards were evaluated. The fiberboards bonded with kraft lignin showed significantly improved mechanical properties and water resistance in relation to those produced without externally added kraft lignin. Increase of hot press temperature and kraft lignin content positively influenced mechanical properties and water resistance of the panels.
2. All the panels produced with kraft lignin addition except for the panels made with 10% kraft lignin at 160 ℃ satisfied the requirement specified by the Chinese National Standard GB/T 11718-2021 for medium density fiberboards for general use under dry conditions.
3. Using WNPs in fiberboards production bonded with kraft lignin, not only eases wood raw material shortage, but also generates healthy, environmental and socioeconomic benefits.

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