Manufacturing and characterization of particleboard as partition material made of corn husk bonded using water soluble chitosan adhesive

Kurnia Wiji Prasetiyo[1,2*], Dede Hermawan[1*], Yusuf Sudo Hadi[1], Subyakto[2] Putri Amanda[2], Lilik Astari[2,3] and Wida Banar Kusumaningrum[2]

[1]Forest Products Technology Department, Faculty of Forestry and Environment, IPB University, Bogor, Indonesia
[2]Research Center for Biomass and Bioproducts National Research and Innovation Agency, Cibinong, Indonesia
[3]The Renewable and Sustainable Forest Product Group, The University of Melbourne, Burnley Campus, 500 Yarra Boulevard, Burnley, VIC, Australia

**Corresponding author: dedehe@apps.ipb.ac.id; jundiazzam@yahoo.com*

Abstract
Partition materials based on wood particles and inorganic materials bonded with synthetic adhesives have a negative impact. The purpose of this study was to evaluate the manufacturing and characterization of particleboard as partition material using corn husk to substituted wood-based particles and water soluble chitosan (WSC) as adhesive to replaced synthetic-based adhesive. The WSC content was varied of 6%, 8% and 10% wt. The particleboards were manufactured under the pressure temperature variations of 160, 180 and 200 ^{o}C for 15 min, press pressure of 2.5 MPa and target density of 0.8 g/cm^3. The physical and mechanical properties of particleboards improved in line with increasing WSC content up to 8% and pressure temperature above 160 ^{o}C. The value of MOR and MOE from boards bonded with WSC 8% and pressure temperature of 180 ^{o}C fulfilled the requirement of JIS A 5908 (2003). The sound absorption coefficient of particleboard bonded using WSC 6% was better than other boards. The particleboards absorbed sound at middle to high frequency (> 1000 Hz) and reflected sound at low frequency (80 to 630 Hz). FTIR spectrum shows that the absorption area around 3400 cm^{-1} wavelengths is a little decrease in intensity due to with the increase of pressure temperature. Corn husk particleboard not yet classified as a heat insulator panel. This study suggest that corn husk is feasible to use for particleboard bonded using WSC adhesive as partition material.
Keywords: corn husk, particleboard, partition material, pressure temperature, water soluble chitosan

1 Introduction

Partition is a non-structural component of a building with the main function as a room divider or insulator that is flexible, lightweight, movable, and related to the life cycle of a building. The partition thickness ranging from 6 to 150 mm with a density varying from 0.2 to 1.2 g/cm^3 depending on the partition material and other functions of the partition installation [1-3].

Generally, partitions are consisting of frames and materials. Partition materials (PM) is able to resist sound between rooms that are insulated so that they do not interfere with the adjoined room. The PM is also related to its ability to resist noise, preventing sound from entering or leaving a room or building. The soundproofing level of a partition wall is measured by the sound transmission class (STC) and absorption coefficient (AC) values. On the other hand, research results conducted by Addis et al.[4] mentioned that the impact on the environment related to the use of materials from non-structural components of buildings i.e. partitions (41%), floors (18%), roofs (14%), windows and doors (12%), kitchen furniture (6%) and others (9%). The research shows that partitions have a more negative impact on the environment than other building components.

As an information, the PM on the market based on two main types of raw materials i.e. inorganic and organic. The products of PM made from inorganic materials such as asbestos, gypsum, cement, glass fiber, glass wool and rockwool are not environmentally friendly, non-renewable and have a negative impact on health. The sulfate components of gypsum board are degraded by sulfate-reducing bacteria to produce hydrogen sulfide which is toxic, flammable and hazardous to health [5]. Partition materials for polymer-based sound insulation panels such as polystyrene (PS), polyvinylchloride (PVC) and polyethylene (PE) are also less environmentally friendly and take longer in the natural recycling process [6]. On the other hand, organic-based PM i.e. wood, multiplex, fiberboard and particleboard as an alternative to substituted inorganic materials such as gypsum and cement also have several disadvantages such as limited sources of wood raw materials, relatively low dimensional stability and the presence of formaldehyde emissions.

Currently, particleboard as PM is produced using wood particles as main raw materials with formaldehyde-based adhesives such as urea formaldehyde (UF) and phenol formaldehyde (PF). Formaldehyde-based adhesives can cause health and environmental problems [7, 8]. To overcome the problem such as release of formaldehyde emission, toxic substance and limited supply of solid wood as main raw particleboard manufacturing, alternative non wood-based materials need to be produced using natural adhesives as PM products.

Non-wood based materials for particleboard as PM can use natural fibers from cultivated plants as well as agricultural by-products. In this context, several studies have succeeded in developing substitutes for wood particles using non-wood and agricultural by-products. Karlinasari et al. [9] stated that the medium density particleboard made of Betung bamboo particles (density of 0.8 g/cm^3) was effective as a sound insulation board compared to particleboard with density of 0.5 g/cm^3. According to Kang et al. [10] particleboard composed rice husk and wood sawdust is a potential sound absorbing material because it has a high sound absorption coefficient value. The research results by Wong et al. [11] showed that the Betung bamboo and kenaf particles for particleboard with density of 0.4 g/cm^3 had a higher NRC value which the higher percentage of Betung bamboo particles resulted in a particleboard with a better sound-absorbing value.

Corn plant is one of an agricultural crop which is planted in many countries and can produces about 50% by-products such as corn stalk, leaf, cob, and corn husk which are potential sources of non-wood natural fiber. As an information, corn yields produce corn husk with weights ranging from 10 to 38.38% [12]. It is calculated from the worldwide corn production in 2020/2021 is around 1129.29 million metric tons, so that around 112.92 to 433.42 million metric tons of corn husk can be obtained [13]. A study conducted by De Carvalho Mendes et al. [14] reported that corn husk biomass has holocellulose (73.1%), α-cellulose (35.3%), hemicellulose (37.5%), extractive and water soluble components (13.9%), lignin (7.9%) and ash content (5%). Meanwhile, Ibrahim et al. [15] mentioned that corn husk contained cellulose at 45.7%, hemicellulose at 35.8%, lignin at 4.03% and ash at 0.38%. Mohammed et al. [16] stated that corn husk and cob have the highest percentage of cellulose compared with other natural fibers, such as wheat husk, rice husk, wheat straw, wheat bran and rice straw [17-21].

Among the above identified agricultural by-products of corn plant, corn husk has an additional advantage in terms of suitable application for alternative processed products because it does not collide with the worldwide food stock and it is generally considered as agricultural by-products. Several studies on the use of corn husks have been carried out by Yu et al. [22] for fiberboard bonded PLA, Theng et al. [23] for fiberboard, Sari et al. [24] for sound absorber composite bonded with polyester, Lihua et al [25] for flame retardant composite reinforced PLA.

Meanwhile, to overcome the problem of using formaldehyde-based adhesives and synthetic polymers in the manufacture of particleboard, so that non-formaldehyde-based adhesives from polysaccharide polymers i.e. water soluble chitosan (WSC) is used as substitute adhesive. The WSC is a chitosan derivative which is substituted by a carboxymethyl group in the hydroxyl group (-OH) and an amine group (-NH_2) [26]. WSC is also an amphoteric derivative of chitosan due to its -COOH and -NH_2 groups, so that its application becomes wider, such as antimicrobial, adsorbent, membrane and can be used to increase the mechanical and electrical strength of paper [27-29].

The manufacture of WSC can be prepared by hydrolyzing method, which is a chemical decomposition process using an aqueous solvent with the aim of breaking the chemical bonds of the substance i.e. chitosan [30, 31]. The functional group of WSC can be seen from the FTIR test results that showed a specific functional group similarity with acid soluble chitosan (ASC) i.e. -OH, -NH and -CH groups. The WSC has a molecular weight range from low to moderate and a high degree of deacetylation compared to ASC which generally have only a high molecular weight. This makes WSC have a high solubility level.

Generally, WSC is soluble in water and it become more compatible in many sectors such as pharmaceutical, medicine, and food industries. Several studies have been done to investigate the suitability of WSC at composite film [32], sustainable materials [33], phytoremediation [34], coating material [35], hydrogel [36]. Yu et al. [37] stated that WSC also potential to developed as active packaging film incorporated with cellulose. The properties of WSC which are soluble at neutral pH or in water can increase the solubility and lead to a decrease in acidity, which affects the wider use of WSC as a derivative of chitosan.

Chitosan and its derivatives such as WSC show great potential to be developed as binders or adhesives in the gluing process, with or without additives or cross-linkers [38]. So far, the type of chitosan that has been developed as an adhesive is ASC. Ibrahim et al. [39] developed a cheap and safe adhesive formulation based on mixture of modified lignin and ASC which was tested for its adhesion to wood joints. Meanwhile, Ji et al. [40, 41] has been used ASC as an adhesive that combined with glutaraldehyde for medium density fiberboard (MDF) and with lignin made of sawdust. The study conducted by Ningsi et al. [42] showed that particleboard bonded with ASC as an adhesive still has limited at dimensional stability, screw holding power and internal bonding properties.

The existence of several limitations from ASC as an adhesive for wood panel and composite products has encouraged the development of a chitosan derivative i.e. WSC as an adhesive for wood panel products i.e. particleboard. Meanwhile, the study on the use of WSC as a particleboard adhesive to replace formaldehyde-based adhesives has not yet been carried out. This has become an interesting research object by looking at the specific and unique characteristics of WSC that described previously. For the reason mentioned, the manufacturing of an environmentally friendly partition material made of corn husk particles bonded using water soluble chitosan adhesive was presented in this research. The effect of WSC content and hot pressing temperature on the physical, mechanical, acoustic, chemical and thermal properties of particleboards made of corn husk as PM were evaluated.

2 Materials and Methods

2.1 Preparation of materials

Agricultural by-products used in this research is corn husks. Corn husks were obtained from local agricultural industry in Cibinong West Java Indonesia. Corn husks were processed into particles as particleboard raw materials using a Pallmann ring knives flaker machine. The corn husk particles were screened using a sieving machine to produce uniform size particles. Corn husk particles passing through the 4 mesh and retain at the 14 mesh sizes were dried at 100 °C for 12 h in a technical oven to obtain moisture content less than 5%. Water soluble chitosan (WSC) used in this research as adhesive was provided by CV. ChiMultiguna Cirebon West Java Indonesia (industrial grade; particle size < 150 mesh; moisture regaint < 9.75%; average molecular weight of 153 kDa; degree of deacetylation > 95%; viscosity of 52.88 mPas).

2.2 Manufacture of partition material

Partition material was manufactured in this research is particleboard. Particleboard made of corn husk particles was produced with a target density of 0.8 g/cm^3. The WSC content for particleboard adhesive used were 6%, 8% and 10% (w/w). The WSC as adhesive for particleboard manufacture was prepared by dissolving in distilled water with a ratio of 1:10 (w/v). The corn husk particles mixed with WSC solution as adhesive using drum mixer machine became completely and then put in a technical oven at temperature 80 °C for 12 h which aims to reduce the moisture content of the mixture less than 5%. Furthermore, the mixtures were formed into mold using a forming box. The dimensions of particleboards were 30 x 30 x 0.9 cm (length, width, thickness). The manufacture of particleboard using a SHINTO hot-pressing machine was set under pressure temperature variations of 160 °C, 180 °C, and 200 °C for 15 minutes and press pressure of 2.5 MPa.

2.3 Properties assessment of particleboard

2.3.1 Physical and mechanical properties

Test samples were prepared and conditioned for 1 week at room temperature of 22 to 24 °C and a relative humidity of approximately 60 to 70%. Assessment of the physical and mechanical properties of particleboard according to the JIS A 5908:2003 [43] and ASTM D 1037-1999 [44] standards. The physical properties of particleboard such as density and thickness swelling were tested by the gravimetric method, and the mechanical properties include bending strength i.e. modulus of rupture (MOR) and modulus of elasticity (MOE); internal bonding (IB) and screw holding power (SHP) were tested by a SHIMADZU universal testing machine (UTM) type AG-IS 50 kN. The test sample was carried out in 5 repetitions.

2.3.2 Determination of acoustic properties

Acoustic properties are expressed in the sound absorption coefficient (α). Acoustic test samples were selected based on the best physical and mechanical properties at assessment 2.3.1 with 3 variations of WSC content i.e. 6%, 8%, 10% and pressure temperature of 180 °C. The process of acoustic testing referring to JIS A 1405-1963 (1990) [45] method. The test samples are carried out using an impedance tube with two microphones. Two types sample size was used to measure the α i.e. sample with diameter at 10 cm was used in low frequency ranging from 80 to 800 Hz and sample with diameter at 3 cm was used in middle to high frequency ranging from 1000 to 6300 Hz. This coefficient is calculated by measuring the sound value that comes on the surface of material; which is absorbed; transmitted by partition material and reflected by the surface of particleboard.

2.3.3 Chemical structure analysis

The compatibility between WSC adhesive and corn husk particles in the particleboard was tested by FTIR to determine whether there was a change in the functional groups after hot pressing process. Meanwhile, the corn husk particle and WSC powder were also analyzed in the absorption band at various wave numbers using FTIR All analysis was performed using Universal Attenuated Total Reflectance (UATR) FTIR (PerkinElmer 4000) by placing 2 mg of the sample. All spectra will be recorded at a temperature of 24 °C.

2.3.4 Thermal properties

The thermal properties of corn husk, WSC and particleboard differs in temperature depending on the characteristics of each. All materials were thermally analyzed by a Thermogravimetric Analyzer (TGA) (PerkinElmer 4000). A sample of 7 mg was put into a ceramic pan for thermal analysis. The condition of the tool is set and operated at a temperature of 25 to 500 °C with a heating rate of 10 °C/min. TGA measures the mass loss over time as a function of temperature. Measurement of differential scanning calorimetry (DSC) was performed using the Differential Scanning Calorimeter (DSC) (PerkinElmer 4000). A sample of 7 mg was put into an aluminum pan and operated at a temperature of 25 to 400 °C with a heating rate of 10 °C/min. In addition to its main function as a partition, the particleboard can also be a heat insulator which can be determined through a thermal conductivity test. The measurement of thermal conductivity from board samples with dimension size of 120 x 25 x 0.9 cm (length, width, thickness) were tested by Conductometer (QTM-500) Probe PD-11 at a room temperature of 22 to 24 °C and relative humidity of 60 to 70%.

3. Results and discussion

3.1 Physical and mechanical properties

Figure 1 show the actual density value of particleboard are obtained is varied from 0.68 to 0.80 g/cm3. Meanwhile, the target density of particleboard was set on 0.8 g/cm^3. However, there is a target density value that is achieved and not achieved. It can be seen that particleboard bonded with 8% of WSC and pressed at 180 ^{o}C gave the best real density that same with target density among all boards. The study conducted by Veigel et. [46] and Valarmathi et al. [47] mentioned that the amount and type of adhesive, particle size, and density distribution affect the particleboards properties i.e. density and particles compatibility.

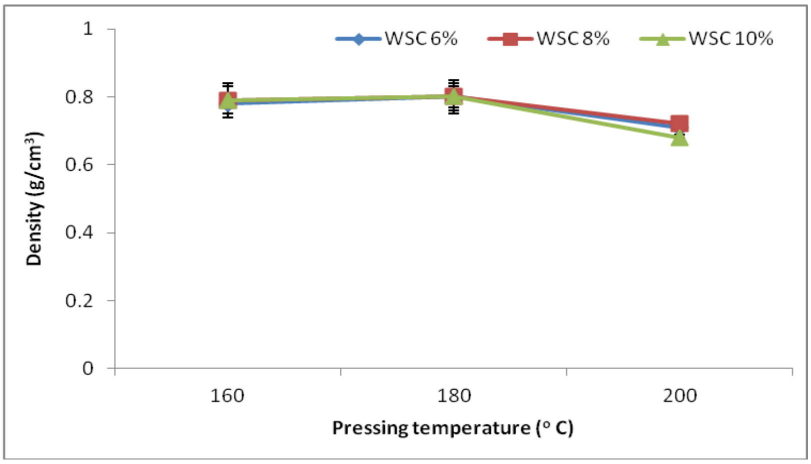

Fig. 1 Rate of actual density from particleboard made of corn husk bonded using WSC

The properties of thickness swelling (TS) from particleboards after being immersed in water for 24 hours are presented in Figure 2. The results shows that the board bonded using WSC of 8% gave the lowest TS (77%) than other compositions. Overall, the TS value of the particleboards does not met JIS A 5908:2003 which mention the maximum value of 12%. However, it can be said that the increasing of WSC content from 6 to 8% and pressure temperature from 160 to 180 ^{o}C can decreased the TS properties of board even though increase slightly at WSC content of 10% and pressure temperature of 200 ^{o}C. The graph illustrates that the temperature with least TS value is 180°C and the increasing TS value trend occur on pressure temperature of 200°C. This result is related to the density value that also increasing on the higher pressure temperature.

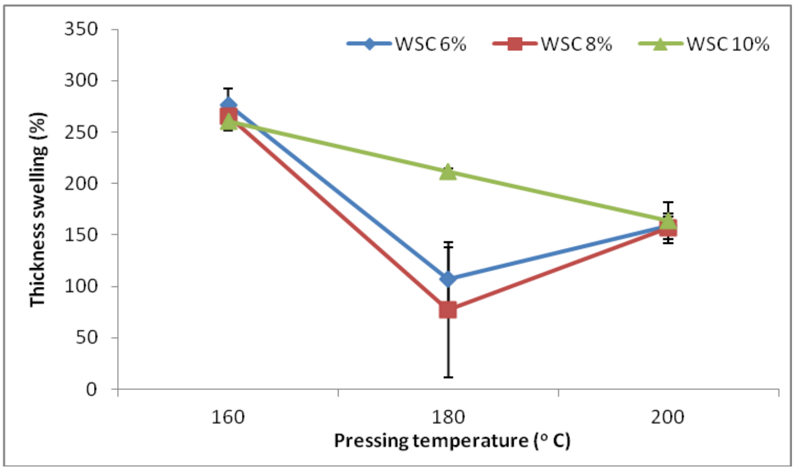

Fig. 2 Thickness swelling of particleboard as partition material

Dimensional instability of a particleboard is a change in the particles form due to compression, which occurs temporarily during compression and will return to its initial form when the particles absorb water. Actually, the TS mechanism of particleboard is more complex, because the particles are actually expected to bind with the matrix, which can prevent TS. The occurrence of TS from particleboard is a combination of the potential thickness recovery of the densified particles, and the breakdown of the matrix bond network.

The bending properties i.e. modulus of rupture (MOR) and modulus of elasticity (MOE) are presented at Figure 3 and 4. The MOR is an indicator of the strength from particleboards to hold and show the flexibility and rigidity of particleboards. Meanwhile, the MOE describes the stiffness properties of the particleboards. Juliana et al. [48] stated that in mechanics, the MOE measures the tendency of the material to bend. It can be seen, the MOR and MOE values of particleboard had a similar trend that increased as the WSC content was increased from 6 to 8% and pressure temperature from 160 to 180 ^{o}C and then decreased.

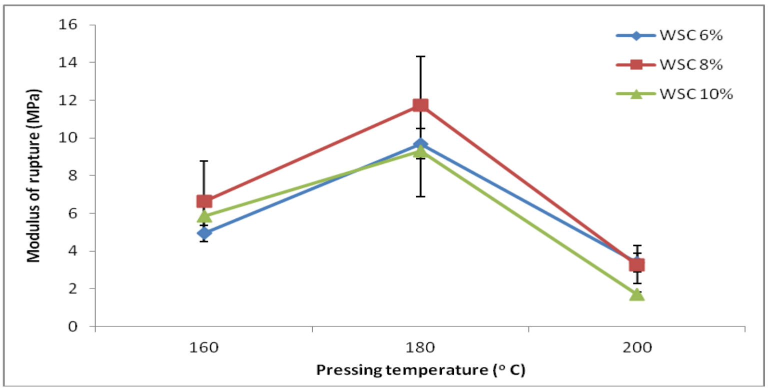

Fig. 3 Modulus of ruptured value from particleboard made of corn husk bonded with WSC

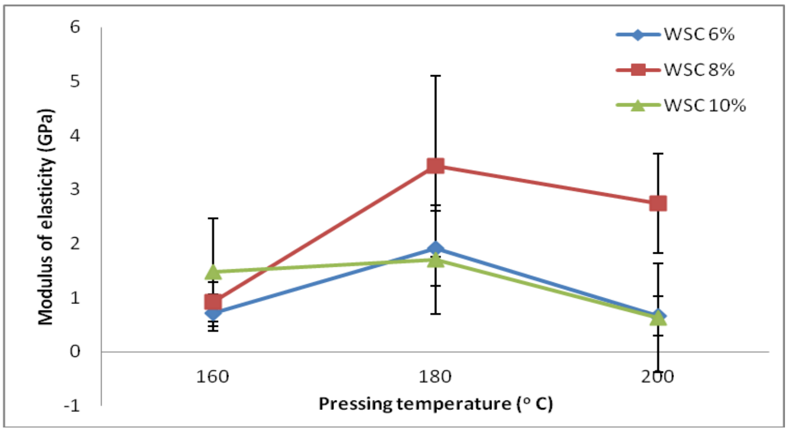

Fig. 4 Effect of WSC content and pressure temperature on the MOE of particleboard

The board bonded with WSC of 8% and pressure temperature of 180 ^{o}C had a better MOR (11.73 MPa) and fulfilled the JIS A 5908:2003 which mention the minimum value of 8 MPa compared to other board compositions. As well as the MOE value (3.43 GPa) that has also met the standard which mention the minimum value of MOE is 2.0 GPa. The research conducted by Sekaluvu et al. [49] informed that particle size and adhesive content affecting the particleboard density, MOE and MOR values from particleboard made of maize cobs bonded synthetic Fevicol resin. The particleboard made of corn husk bonded with WSC also had a better MOR and MOE values compared to particleboard made of maize cobs mixed with synthetic Fevicol resin [49], corn stalk-wood chips particleboards using UF as adhesive [50] and hybrid particleboard made from bamboo veneer waste and rubberwood mixed with UF at content of 12% [51]. It can be said, the WSC is suitable and potential to develop as adhesive for particleboard manufacturing and can improve the bending properties.

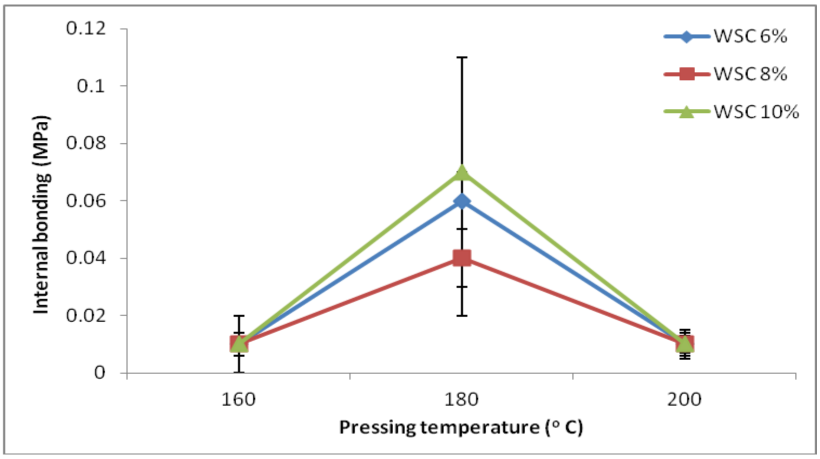

Fig. 5 Internal bonding average value of particleboard

As shown in Figure 5, the internal bonding (IB) values of particleboard ranged from 0.01 to 0.07 MPa. The IB strength of particleboard bonded WSC of 10% and pressure temperature of 180 ^{o}C was slightly higher compared to other board compositions. However, overall, the TS value of the boards does not met JIS A 5908:2003 which mention the minimum value of 0.15 MPa. As we know, the WSC is a natural polymer based on polysaccharides which has hydroxyl groups that are indicated to affect the bonding process between particles and compatibility among WSC and corn husk particles. The IB value of particleboards describes the bonding strength between particles, so it can be used as a parameter to determine the quality of the board where it is related to the applied particleboard manufacturing system. Corn husk particleboard that produced in this study not yet shows a strong bond with WSC in terms of IB values. Khazaeian et al. [52] argued that the IB value of the particleboard affected by increasing particle size, particle content and press temperature. This condition can be seen in the FTIR spectrum that presented in Figure 8.
The screw holding power (SHP) is the ability of the particle board to hold the screws embedded in the particle board. The measurements of SHP show the maximum force exerted on the particleboard in a given area until the screw is released. Figure 6 showed that the value of SHP from particleboard as partition material is varied from 54.17 to 138.02 N. Overall, the value of SHP does not fulfilled the minimum requirements of SHP strength in the JIS A 5908:2003 standard is 300 N.

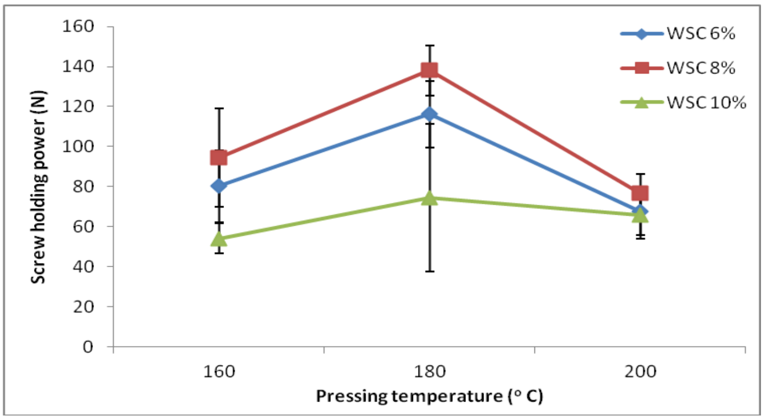

Fig. 6 The value of screw holding power from particleboard as partition material

Similar trend with the MOR and MOE value that the particleboard bonded using WSC of 8% and pressure temperature of 180 ^{o}C had a higher SHP value compared to other board compositions. Melo et al. [53] argued that the value of SHP affected by the density and particle surface bonding area. Particles with a larger surface bonding area caused the contact between the particles with the adhesive to be larger and compatible that causing SHP value to increase. The completeness and ease of the adhesive distribution to the particles and particle geometry were also affected the SHP value of particleboard [48, 54].

3.2 Acoustic properties

The acoustic properties of particleboard as partition material i.e. sound absorption coefficient (α) are given in Table 1 (low frequency ranging from 80 to 800 Hz) and Table 2 (middle to high frequency ranging from 1000 to 6300 Hz).

Table 1. Sound absorption coefficient (α) of particleboard bonded using WSC and pressure temperature of 180 ^{o}C that measured at low frequency (80 to 800 Hz)

Particleboard sample	Frequency (Hz)										
	80	100	125	160	200	250	315	400	500	630	800
WSC 6%	0.04	0.02	0.05	0.03	0.07	0.08	0.05	0.07	0.08	0.06	0.25
WSC 8%	0.00	0.04	0.03	0.01	0.04	0.06	0.04	0.02	0.02	0.08	0.10
WSC 10%	0.09	0.01	0.05	0.07	0.04	0.05	0.08	0.03	0.03	0.09	0.17

The sound absorption coefficient (α) values of particleboard as partition material at low frequency ranging from 80 to 800 Hz are fluctuated and ranged from 0.01 to 0.25. Mostly, the sound absorption coefficient value of the particleboards were low and does not fulfilled the standard which require the minimum value is 0.15 except at frequency of 800 Hz that met the standard. Based on these results, it can be said that particleboards made of corn stalks bonded with WSC is more reflective of sound than absorbing of sound at low frequency. The trend of fluctuation value from sound absorption in this study similar with the research conducted by Karlinasari et al. [9] that studied the sound absorption from particleboard made of Betung bamboo bonded with isocyanate resin of 12% and target density 0.5 and 0.8 g/cm^3.

Table 2. Sound absorption coefficient (α) of particleboard bonded using WSC and pressure temperature of 180 ^{o}C that measured at middle to high frequency (1000 to 6300 Hz)

Particleboard sample	Frequency (Hz)								
	1000	1250	1600	2000	2500	3150	4000	5000	6300
WSC 6%	0.13	0.28	0.16	0.11	0.12	0.26	0.19	0.19	0.28
WSC 8%	0.21	0.25	0.11	0.11	0.11	0.20	0.15	0.17	0.22
WSC 10%	0.24	0.14	0.14	0.12	0.09	0.08	0.07	0.09	0.10

Meanwhile, the value of sound absorption coefficient that measured at middle to high frequency (1000 to 6300 Hz) presented in Figure 8. The sound absorption coefficient ranged from 0.07 to 0.28. The boards that manufactured at WSC 0.6% and 0.8% are showed better values and satisfied the standard which mention the minimum value is 0.15. All values are also fluctuated, however, it is more higher and better than the value at low frequency. The values of sound absorption coefficient in this study are more better than research results already done by Astari et al. [55] measured sound absorption coefficient from corn stalk particleboards using UF, PF and isocyanate as adhesive which all values are also fluctuated and does not met the standard (ranging from 0.001 to 0.016). This is because, corn husk that include thin fibers can move more easily than corn stalk or bamboo which include thick fibers on sound waves. According to the results, the sound absorption coefficient of particleboards made of corn husk bonded using WSC indicated that the boards absorbed the sound at middle to high frequency.

3.3 FTIR characterization

Characteristics of FTIR spectra from WSC and corn husk are presented in Figure 7. The spectra of both materials presented similar functional groups representing polysaccharide structure. The peak around 3300 cm^{-1} represents the -OH stretching in corn husk whereas the peak around 3000 cm^{-1} in WSC represents -OH and -NH vibration of the chitosan structure. The peak around 2900 cm^{-1} and 1375 cm^{-1} corresponds to alkane C-H stretching and CH_3 stretching, respectively. The peak at 2893–2916 cm^{-1} is due to the $-CH_2$ stretching from WSC [56, 57].The peak around 890 cm^{-1} and 1050 cm^{-1} can be attributed to the C-O stretching representing the carbohydrate structure of the polymer. The characteristic peak around at 1620 cm^{-1} and 1520 cm^{-1} can be attributed to amine structure present in the WSC in line with the study conducted by Mourya et al. [58] that WSC or carboxymethyl chitosan has strong FTIR absorption in the area around 1650 cm^{-1} and 1420 cm^{-1}. Meanwhile, the peak around 1408 cm^{-1} found in WSC and corn husk can be attributed to the amide bond. The absorption peak at 897 cm^{-1} indicated the asymmetric deformation of cellulose and hemicellulose units. These data demonstrated that the structures of the main chain of corn husk and WSC were also similar with the research conducted by Hemamalini et al. [59] that investigated the FTIR spectra of WSC and wood pulp.

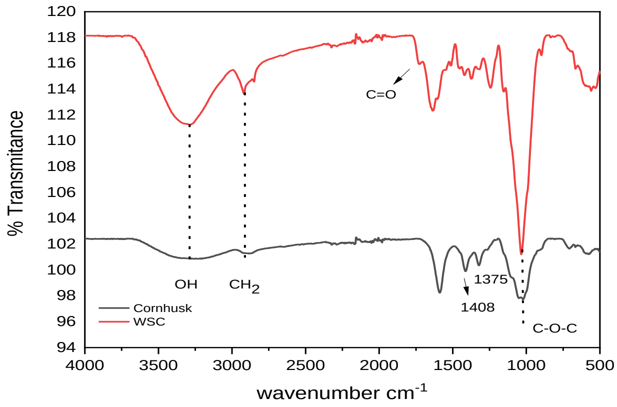

Fig. 7 FTIR spectra of WSC and corn husk as raw material for particleboard manufaturing

Meanwhile, the bonding mechanism of particleboard bonded WSC of 8% with various pressure temperature of 160 °C, 180 °C and 200 °C were evaluated using FTIR spectroscopy and showed in Figure 8. Infra-red spectrum analysis show that the absorption area around 3400 cm^{-1} wavelengths (hydroxyl group) is a little decrease in intensity in line with the increase of pressing temperatures.

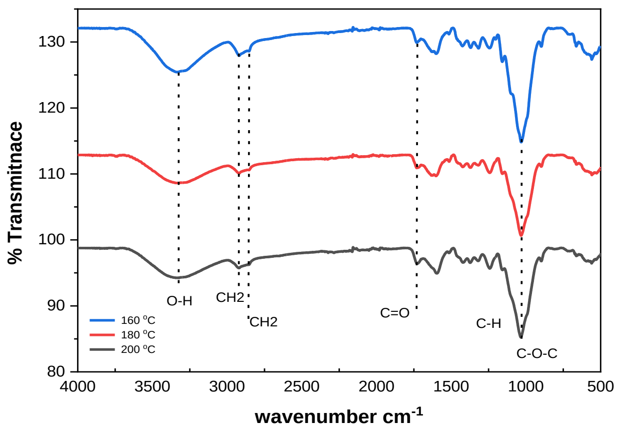

Fig. 8 FTIR spectra of corn husk particleboard bonded with WSC at 8% and pressure temperature of 160 °C (a), 180 °C (b) and 200 °C (c).

According to Gul et al. [60] decrease in absorption intensity at wavelengths around 3400 cm^{-1} signifies the reduction of free hydroxyl groups that effect of the temperature. Absorption bands in the range 2750–3200 cm^{-1} are due to stretching vibrations of CH, CH_2 and CH_3 groups linked to double bonds. The peak at 2800–2900 cm^{-1} showed the absorption of CH_2 from WSC, indicating that WSC adhesive presence and reacted with corn husk particles to form ester linkages. In the region between 2000 $cm^{-1}$and 1000 cm^{-1} which is composed of several bands ascribed to the carboxylate, and amide groups in addition to polysaccharide skeletons [61]. Absorption at 1500–1800 cm^{-1} region show the presence of double bond C=O and C=C show the residual lignin from corn husk [62]. There is no detected significant effect of increasing pressing temperature on this wavelength.

3.4 Thermal characterization

The thermal behavior of corn husk particleboard (CPB) with WSC adhesive was determined in Figure 9 and Table 3. TGA data shows that additional of the WSC to the corn husk as adhesive improve the thermal resistance of particleboards. The data shows that the WSC adhesive had lower thermal degradation but had higher thermal stability than corn husk. Corn husk raw material shows the highest weight lost compare WSC and particleboard. Corn husk raw material had lower of residue as compared with the WSC and particleboard. The residue of corn husk and particleboard were 31.67% and 39.82-41.96%, respectively. Addition of WSC adhesive increasing thermal stability the particleboard, however, increasing pressing temperature in particleboard production did not affect the particleboard's thermal stability. The evaporation of water was occurred in the range of 70 °C to 120 °C as the first stage of decomposition. The second stage of decomposition in case of corn husk, WSC and particleboard were seen between 280 °C to 400 °C. It can be related to the degradation of amorphous region and dehydration of saccharide rings in case of cellulose and chitosan, respectively [59].

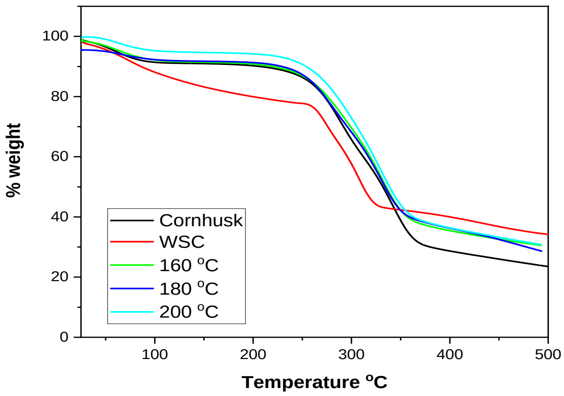

Fig. 9 TG from corn husk, WSC and particleboard that pressing at temperature of 160, 180 and 200 °C

Table 3 Comparison of thermal behavior from corn husk, WSC and particleboard that pressure temperature of 160, 180 and 200 °C bonded using WSC 8%

Sample	Temperature range (°C)	Temperature peak (°C)	Weight loss (%)	Residue (%)
Corn husk	211-374	346	58.13	31.67
WSC	192-324	306	36.26	44.15
CPB 160 °C	200.3-361	328	51.38	39.82
CPB 180 °C	200.9-363	326	51.12	40.38
CPB 200 °C	203-361	325	52.14	41.96

Based on the results, it can be said that the thermal characteristics of all materials showed a similar degradation mechanism which proceeded at different rates. Hemamalini et al. [59] reported that the third stage of decomposition emerged between 400 °C and 500 °C, this can be attributed to the breakdown of crystalline region and degradation of glucosamine groups. It is seen that water soluble chitosan have higher char yield indicating a higher weight residues after the decomposition of fibers. The last decomposition stage begins above 500 °C and is probably a thermo-oxidative process.

Dong et al. [63] mentioned that the DSC determines the enthalpy changes induced by both structural rearrangement and cohesional entanglement in glassy polymer. It has been well known that the glass transition behaviors of polymers are closely related to their thermal and mechanical histories. Therefore, their glass transition behaviors will also change during physical aging.

The DSC thermogram of WSC can be seen in Figure 10. The melting point of WSC is around 130 °C. This peak is related to the evaporation of residual water or solvent from WSC. The temperature which WSC began to melt occurred at 55 °C and started to rise up into temperature at 130 °C. Based on the result, can be said that WSC potential to used as adhesives at temperatures ranged from 150 to 200 °C and more efficient at below 150 °C. Meanwhile, the melting energy (ΔHm) of WSC is obtained at 202.2681 J/g.

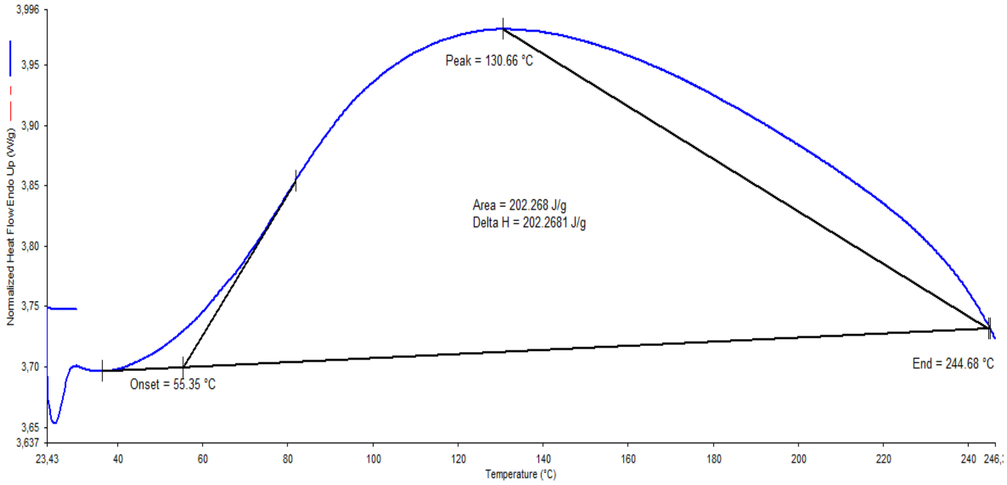

Fig. 10 DSC thermogram of WSC as adhesive in particleboard manufacturing made of corn husk

The result of DSC thermogram similar trend with the study conducted by Ferreira et al. [64] reported that stable heat flow in the chitosan sample was observed; afterward, the exothermic peak began at 270 ^{o}C. This indicates the thermal decomposition process of chitosan (depolymerization, saccharide ring dehydration, decomposition of deacetylated and acetylated chitosan units). Eulalio et al. [65] reminded that it must be taken into account that chitosan is a semicrystalline polysaccharide obtained from a natural polymer and its crystallinity, deacetylation degree and molecular weight influence Tg.
The thermal conductivity (TC) of the particleboards having variations of WSC content as and pressing temperature was measured and showed at Figure 11. The TC values of particleboard ranging from 0.166 to 0.228 W/mK. Based on the results, the particleboard using WSC 10% and pressing at temperature of 200 ^{o}C was 0.166 W/mK and better than other board compositions.

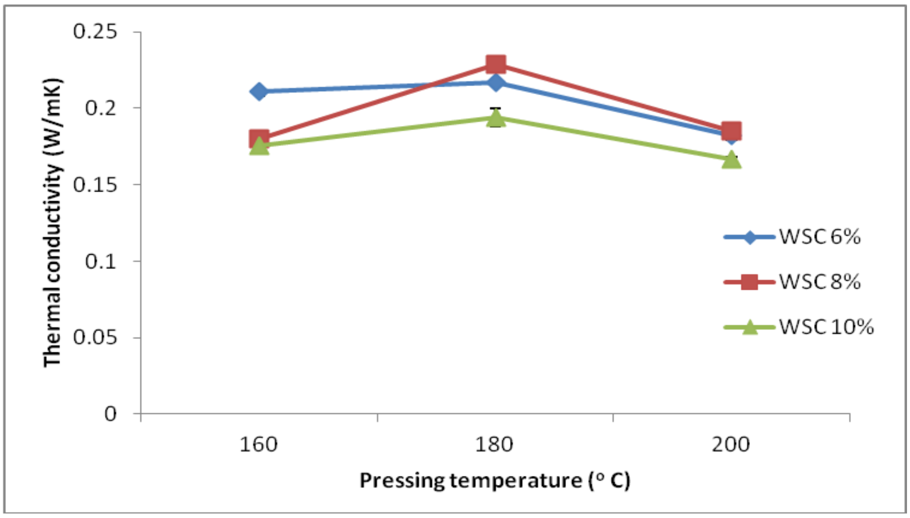

Fig. 11 Thermal conductivity of particleboard as partition material

Generally, the particleboard made of corn husk bonded with WSC in this study is still have a higher TC (0.166-0.229 W/mK) compared to insulation materials such as hemp and flax is 0.052 W/mK; wood fiber is 0.048 W/mK; mineral wool and glass-wool is 0.039 to 0.046 W/mK [66] and particleboard made pine trees bark is 0.06 to 0.09 W/mK [67, 68]; black locust tree bark and poplar bark are around 0.06 W/mK [69, 70] are bonded with formaldehyde based adhesive. In particleboard, radiation is the mode of the heat transfer since there are voids and air pockets. The presence of high amount of voids and air pocket result in difficult heat transfer which means less heat conductor and made the board good thermal insulator. Based on these results, it can be conclude that particleboard bonded WSC not yet classified as a heat insulator panel than insulation panels made of hemp and flax, wood fiber, bark wood particles, mineral and glass-wool that can be seen from the TC values.

4 Conclusion

The effect of the WSC content and pressure temperature on the particleboard properties made of corn husk were already evaluated in this study. Based on the results obtained, the physical and mechanical properties of particleboards were enhanced in line with increasing WSC content up to 8% and pressure temperature above 160 ^oC. The boards made of a combination between WSC 8% and pressure temperature of 180 ^oC had the best properties compared to other combinations. The bending strength (MOR and MOE) values of boards bonded using WSC 8% and pressure temperature of 180 ^oC satisfied the requirement of JIS A 5908 (2003) standard. The particleboards absorbed sound at middle to high frequency (> 1000 Hz) and reflected sound at low frequency (80 to 630 Hz). According to the data, the sound absorption coefficient of particleboards made of corn husk bonded with WSC indicated that the boards absorbed the sound at high frequency and suitable to use as sound partition material. FTIR analysis showed that the absorption area around 3400 cm^{-1} wavelengths (hydroxyl group) is a little decrease in intensity in line with the increase of pressure temperature. The peak at 2800–2900 cm^{-1} showed the absorption of CH_2 from WSC, indicating that WSC adhesive presence and reacted with corn husk particles to form ester linkages. Referring to the data of DSC, the WSC potential to use as adhesives for particleboard manufacturing at temperatures ranging from 150 to 200 ^oC. Particleboard in this study not yet classified as a insulator panel that can be seen from the TC value. Based on all the results, it can be conclude that corn husk is feasible to use for particleboard manufacturing bonded using WSC adhesive as partition material that sustainable and renewable.

Acknowledgements

The authors would to thank for supports and funding from Research Program of Doctoral Dissertation IPB University by The Ministry of Education, Culture, Research and Technology (KEMENDIKBUDRISTEK) Republic of Indonesia in this research. The authors also wish to thank the National Research and Innovation Agency (BRIN) for providing and access the research facilities.

Statements and Declarations:

Competing Interests

The authors reported no potential conflict of interest.

Ethical Approval

Not applicable

Funding

This research was funded by the Ministry of Education, Culture, Research and Technology (KEMENDIKBUDRISTEK) Republic of Indonesia, via PDD scheme with letter No 0054/E5/AK.04/2022.

Data Availability Statement

The study did not report any data.

Author contributions

Kurnia Wiji Prasetiyo designed methodology, performed the experiments, carried out data curation, writing-original draft; Dede Hermawan verified and contributed on conceptualization and supervision; Yusuf Sudo Hadi contributed on conceptualization and supervision; Subyakto contributed on conceptualization and supervision; Putri Amanda prepared and carried out some tests; Lilik Astari contributed on physical-mechanical test and validated methodology; Wida Banar Kusumaningrum performed DSC test and validated methodology. All authors discussed the results and contributed to the final manuscript.

References

1. Mateus R, Neiva S, Bragança L, Mendonça P, Macieira M (2013) Sustainability assessment of an innovative lightweight buildingtechnology for partition walls e Comparison with conventional technologies. Building and Environment 67:147-159.
2. Amer S, Hamoush S, Abu-Lebdeh T (2016) In-plane performance of gypsum board partition wall systems subjected to cyclic loadings. Journal of Constructional Steel Research 124:23–36. http://dx.doi.org/10.1016/j.jcsr.2016.05.013.
3. Wang Q, Zhang C (2018) Fire Safety Analysis of Building Partition Wall Engineering. Procedia Engineering 211:747-754. doi:10.1016/j.proeng.2017.12.071.
4. Addis W, Schouten J (2004) Principles of design for deconstruction to facilitate reuse and recycling. London: CIRIA:p. 38-39.

5. Hafez I, Tajvidi M (2020) Laminated Wallboard Panels Made with Cellulose Nanofibrils as a Binder: Production and Properties. Materials 13 1303. doi:10.3390/ma13061303.
6. Korjenic A, Zach J, Hroudova J (2016) The use of insulating materials based on natural fibers in combination withplant facades in building constructions. Energy and Buildings. http://dx.doi.org/10.1016/j.enbuild.2015.12.037.
7. Salem MZM, Böhm M (2013) Understanding of formaldehyde emissions from solid wood: An overview. BioResources 8(3):4775–4790. doi: 10.15376/biores.8.3.4775-4790.
8. Ferdosian F, Pan Z, Gao G, Zhao B (2017) Bio-based adhesives and evaluation for wood composites application. Polymers. 9 (2). doi: 10.3390/polym9020070.
9. Karlinasari L, Hermawan D, Maddu A, Martianto B, Lucky IK, Nugroho N, Hadi YS (2012) Acoustical Properties of Particleboards Made From Betung Bamboo (*Dendrocalamus asper*) as Building Construction Material. BioResources 7(4):5700-5709.
10. Kang CW, Oh SW, Lee TB Kang W, Matsumura J (2012) Sound absorption capability and mechanical properties of a composite rice hull and sawdust board. J. Wood Sci (2012) 58:273–278. doi: 10.1007/s10086-011-1243-5.
11. Wong JW, Yeo WS, Paridah MT (2017) Sound absorption properties of kenaf bamboo particleboard at various mixing ratio and density. AIP Conference Proceedings 1902 020001 (2017). American Institute of Physics. https://doi.org/10.1063/1.5010618.
12. Dirgantara, Made (2013). Karakterisasi Mekanik Biokomposit Klobot Jagung Sebagai Bahan Dasar Plastik Biodegradable. Skripsi: Jurusan Fisika Fakultas Matematika dan Ilmu Pengetahuan Alam IPB University.
13. (USDA) World Agricultural Production. Ekon. APK 2021. Available online: https://www.fas.usda.gov/data/world-agricultural production (accessed on 24 November 2022).
14. De Carvalho Mendes CA, De Oliveira Adnet FA, Leite MCAM, Furtado CRG, De Sousa AMF (2015) Chemical, Physical, Mechanical, Thermal and Morphological Characterization of Corn Husk Residue Cellulose. Chem Technol 49 (9-10): 727-735.
15. Ibrahim MIJ, Sapuan SM, Zainudin ES, Zuhri MYM (2019) Extraction, Chemical Composition, and Characterization of Potential Lignocellulosic Biomasses and Polymers from Corn Plant Parts. BioResources 14(3): 6485-6500.
16. Mohammed AABA, Hasan Z, Omran AAB, Kumar VV, Elfaghi AM, Ilyas RA, and Sapuan SM (2022) Corn: Its Structure, Polymer, Fiber, Composite, Properties, and Applications. Polymers 2022 14 4396. https://doi.org/10.3390/polym14204396.
17. Jagwani D, Joshi P (2014) Deportation of Toxic Phenol From Aqueous System By Wheat Husk. Int J Plant Anim Environ Sci 4:58–64.
18. Jiang D, An P, Cui S, Sun S, Zhang J, Tuo T (2020) Effect of Modification Methods of Wheat Straw Fibers on Water Absorbency and Mechanical Properties of Wheat Straw Fiber Cement-Based Composites. Adv Mater Sci Eng 2020 5031025.
19. Bouasker M, Belayachi N, Hoxha D, Al-Mukhtar M (2014) Physical characterization of natural straw fibers as aggregates for construction materials applications. Materials 7:3034–3048.
20. Passoth V, Sandgren M (2019) Biofuel production from straw hydrolysates: Current achievements and perspectives. Appl Microbiol Biotechnol 103:5105–5116.
21. Onipe OO, Beswa D, Jideani AIO (2017) Effect of size reduction on colour, hydration and rheological properties of wheat bran. Food Sci Technol 37:389–396.
22. Yu X, Lihua Lv, Wei C, Wang X, Cui Y, Ouyang Y (2013) Fabrication and Properties of Corn Husk Fiber/Polylactic Acid Fiberboard. Advanced Materials Research. Vol 753-755 pp 798-801. doi:10.4028/www.scientific.net/AMR.753-755.798.
23. Theng D, Arbat G., Aguilar MD, Vilaseca F, Ngo B, Mutje P (2015) All-lignocellulosic fiberboard from corn biomass and cellulose nanofibers. J. Industrial Crops and Products 76: 166-173.
24. Sari NH, Wardana NG, Irawan YS, and Siswanto E (2017) Corn Husk Fiber-Polyester Composites as Sound Absorber: Nonacoustical and Acoustical Properties. Advances in Acoustics and Vibration Volume 2017 Article ID 4319389 7 pages https://doi.org/10.1155/2017/4319389.
25. Lihua LV, Bi J, Fang YE, Qian Y, Zhao Y, Chen R, Su X (2017) Extraction of Discarded Corn Husk Fibers and Its Flame Retardant Composite. Tekstil ve Konfeksiyon 27(4).
26. Tungtong S, Okonogi S, Chowwanapoonpohn S, Phutdhawong W and Yotsawimonwat S (2012) Solubility, viscocity, and rheological properties of water-soluble chitosan derivates. Maejo International Journal of Science and Technology 6(02):315-322.
27. Nada AMA, El-Sakhawy M, Kamel S, Eid MAM, Adel AM (2006) Mechanical and electrical properties of paper sheets treated with chitosan and its derivatives. Journal Carbohydrate Polymer 63:113-121. doi:10.1016/j.carbpol.2005.08.028.
28. Boricha AG and Murthy ZVP (2010) Preparation of N, O-carboxymethyl chitosan acetate blend nanofiltration membrane and testing its performance in treating industrial wastewater. Chemical Engineering Journal 157(2): 393-400.
29. Farag RK and Mohamed RR (2013) Synthesis and characterization carboxymethyl chitosan nanogels for swelling studies and antimicrobial activity. Journal of Molecules 18(1):190-203.

30. Arianie L, Idiawati N (2011) Penentuan lignin dan kadar glukosa dalam hidrolisis organosolv dan hidrolisis asam. Jurnal Sains dan Terapan Kimia. 5(2):140-150.
31. Xia Z Wua S, Chen J (2013) Preparation of water soluble chitosan by hydrolysis using hydrogen peroxideInternational. Journal of Biological Macromolecules 59 (2013) 242– 245. http://dx.doi.org/10.1016/j.ijbiomac.2013.04.034.
32. Jiang SJ, Zhang X, Ma Y, Tuo Y, Qian F, Fu W, Mu G (2016) Characterization of whey protein-carboxymethylated chitosancomposite films with and without transglutaminase treatment. Carbohydrate Polymers 153 153–159. http://dx.doi.org/10.1016/j.carbpol.2016.07.094.
33. Dang NTT, Chau TTL, Duong HV, Le HT, Tran TTV, Le TQ, Vu TP, Nguyen CD, Nguyen LV Nguyen TD (2017) Water-soluble chitosan-derived sustainable materials: towards filaments, aerogels, microspheres, and plastics. Soft Matter 13 7292-7299. DOI: 10.1039/c7sm01292f
34. Guo J, Yang J, Yang J, Zheng G, Chen T, Huang J, Bian J, Meng X (2020) Water-soluble chitosan enhances phytoremediation efficiency of cadmium by *Hylotelephium spectabile* in contaminated soils. Carbohydrate Polymers (2020). doi: https://doi.org/10.1016/j.carbpol.2020.116559.
35. Baek EJ, Garcia CV, Shin GH, Kim JT (2020) Improvement of thermal and UV-light stability of β-carotene-loaded nanoemulsions by water-soluble chitosan coating. International Journal of Biological Macromolecules 165 (2020) 1156–1163. https://doi.org/10.1016/j.ijbiomac.2020.10.008.
36. Liu X, Xiao C (2020) Formation of self-healable fire-retardant water-soluble chitosan/chemically cross-linked polyvinyl alcohol/ Cu(II) gel. Environ Technol Innov 20:101087. https:// doi.org/ 10.1016/j.eti.2020.101087.
37. Yu SH, Hsieh HY, Pang JC, Tang DW, Shih CM, Tsai ML, Tsai YC, Mi FL (2013) Active films from water-soluble chitosan/cellulose composites incorporating releasable caffeic acid for inhibition of lipid oxidation in fish oil emulsions. Food Hydrocolloids 32 (2013) 9e19. http://dx.doi.org/10.1016/j.foodhyd.2012.11.036.
38. Patel AK (2015) Chitosan: emergence as potent candidate for green adhesive market. Biochem Eng J 102:74–81. https:// doi.org/ 10. 1016/j. bej. 2015. 01. 005
39. Ibrahim V, Mamo G, Gustafsson P, Hatti-kaul R (2013) Production and properties of adhesives formulated from laccase modified Kraft lignin. Ind. Crop Prod 45:343–8.
40. Ji X, Li B, Yuan B, Guo M (2017) Preparation and characterizations of a chitosan-based medium-density fiberboard adhesive with high bonding strength and water resistance. Carbohydrate Polymers 176:273–280. http://dx.doi.org/10.1016/j.carbpol.2017.08.100.
41. Ji X, Guo M (2018) Preparation and properties of a chitosan-lignin wood adhesive. International Journal of Adhesion and Adhesives S0143-7496 (17) 30221-X. https://doi.org/10.1016/j.ijadhadh.2017.12.005.
42. Ningsi DW, Suhasman, Saad S (2019) Characteristic of Chitosan Adhesive from Shell Shrimp Litopenaeus vannamei and Their Application For Producing Particleboard. The 14th Pacific Rim Bio-Based Composites Symposium. IOP Conf. Series: Materials Science and Engineering 593 012015. doi:10.1088/1757-899X/593/1/012015.
43. (2003) Japanese Standard Associatoin (JSA) Japanese Industrial Standard (JIS) A 5908:2003 Particleboards.
44. (1999) American Standard Testing and Material (ASTM) D 1037-99 Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials. Philadelphia (USA): ASTM International.
45. (1990) Japanese Standard Associatoin (JSA) Japanese Industrial Standard (JIS) A 1405:1963 Methods of Test for Sound Absorption of Acoustical Material by the Tube Method.
46. Veigel S, Rathke J, Weigl M., Gindl-Altmutter W (2012) Particleboard and oriented strand board prepared with nanocellulose-reinforced adhesive. Journal of Nanomaterials, Vol. 2012, Article ID 158503:1-8.
47. Valarmathi T, Palanikumar K, Latha B (2013) Measurement and analysis of thrust force in drilling of particleboard (PB) composite panels. Measurement 463:1220–1230.
48. Juliana AH, Paridah MT, Rahim S, Azowa IN, Anwar UMK (2012) Properties of particleboard made from kenaf (*Hibiscus cannabinus* L.) as function of particle geometry. Journal Materials and Design 34:406-411.
49. Sekaluvu L, Tumutegyereize P, Kiggundu N (2014) Investigation of factors affecting the production and properties of maize cob-particleboards. Waste and Biomass Valorization 5: 27–32.
50. Guler C, Sahin HI, Yeniay S (2016) The potential for using corn stalks as a raw material for production particleboard with industrial wood chips. Journal of Wood Research 61(2): 299-306.
51. Nurhazwani O, Jawaid M, Paridah MT, Juliana AH, Hamid SA (2016) Hybrid Particleboard Made from Bamboo (*Dendrocalamus asper*) Veneer Waste and Rubberwood (*Hevea brasilienses*). BioResources 11 (1): 306-323.
52. Khazaeian A, Ashori A, Dizaj MY (2015) Suitability of sorghum stalk fibers for production of particleboard. Carbohydrate Polymers 120:15-21. http://dx.doi.org/10.1016/j.carbpol.2014.12.001.
53. Melo RR, Stangerlin DM, Santana RRC, Pedrosa TD (2014) Physical and Mechanical Properties of Particleboard Manufactured from Wood, Bamboo and Rice Husk. Materials Research 17(3): 682-686.
54. Astari L, Prasetiyo KW, Suryanegara L (2018) Properties of particleboard made from wood waste with various size. IOP Conference Series: Earth and Environmental Science 166:17-23.

55. Astari L, Syamani FA, Prasetiyo KW (2019) Physical, mechanical and acoustical characteristics of particleboard made from corn stalk (*Zea mays* L.). Jurnal Riset Industri Hasil Hutan Vol.11 No.1. DOI: http://dx.doi.org/10.24111/jrihh.v11i1.4344.
56. Wu S (2011) Preparation of water soluble chitosan by hydrolysis with commercial α-amylase containing chitosanase activity. Food Chem 128:769–772. https:// doi.org/10.1016/j.foodchem.2011.03.111.
57. Pervez MN, Stylios GK (2018) Investigating the synthesis and characterization of a novel “green” H2 O2-assisted, water-soluble chitosan/polyvinyl alcohol nanofiber for environmental end uses. Nanomaterials 8: https://doi.org/10.3390/nano8060395.
58. Mourya VK, Inamdar NN, Tiwari A (2010) Carboxymethyl chitosan and its applications. Adv Mater Lett 1:11–33. https://doi.org/10.5185/amlett 2010.3108.
59. Hemamalini T, Vikash N, Brindha P, Abinaya M, Giri Dev VR (2020) Comparison of acid and water-soluble chitosan doped fibrous cellulose hemostat wet laid nonwoven web for hemorrhage application. International Journal of Biological Macromolecules 147: 493–498. https://doi.org/10.1016/j.ijbiomac.2020.01.085.
60. Gul W, Khan A, Shakoor A (2017) Impact of hot pressing temperature on Medium Density Fiberboard (MDF) performance. Advances in Materials Science and Engineering. https://doi.org/10.1155/2017/4056360.
61. Basta AH, Khwaldia K, Aloui H, El-Saied H (2015) Enhancing the performance of carboxymethyl cellulose by chitosan in producing barrier coated paper sheets. PAPER CHEMISTRY Nordic Pulp & Paper Research Journal Vol 30 no (4) 2015.
62. Syahfitri A, Hermawan D, Kusumah SS, Ismadi, Lubis MAR, Widyaningrum BA, Ismayati M, Amanda P, Ningrum RS, Sutiawan J (2022) Conversion of agro-industrial wastes of sorghum bagasse and molasses into lightweight roof tile composite. Biomass Conversion and Biorefinery. https://doi.org/10.1007/s13399-022-02435-y.
63. Dong Y, Ruan Y, Wang H, Zhao Y, Bi D (2004) Studies on Glass Transition Temperature of Chitosan with Four Techniques. Journal of Applied Polymer Science Vol. 93:1553–1558 (2004). doi: 10.1002/app.20630.
64. Ferreiraa SA, Castilloa OS, J. Santanab TM, Garcíaa DAM, Núñez-Colína CA, Grijalva-Verdugoc C, Villa-Lermad AG, Morales-Vargasa AT, J. Rodríguez-Núñeza R (2020) Production and physicochemical characterization of chitosan for the harvesting of wild microalgae consortia. Biotechnology Reports 28 e00554 https://doi.org/10.1016/j.btre.2020.e00554.
65. Eulalio HYC, Rodrigues JFB, Santos KO, Peniche C, Lia Fook MV (2019) Characterization and thermal properties of chitosan films prepared with different acid solvents. Revista Cubana de Química Vol 31 no. 3: 309-323.
66. Volf M, Diviš J, Havlíka F (2015) Thermal, moisture and biological behaviour of natural insulating materials. 6th International Building Physics Conference IBPC 2015 Energy Procedia 78:1599 – 1604.
67. Kain G, Barbu MC, Hinterreiter S, Richter K, Petuschnigg A (2013) Using bark as a heat insulation material. BioResources 8 (3): 3718–3731.
68. Kain G, Güttler V, Barbu MC, Petutschnigg A, Richter K, Tondi G (2014) Density related properties of bark insulation boards bonded with tannin hexamine resin. Eur J Wood Prod 72:417–424. http://dx.doi.org/10.1007/s00107-014-0798-4.
69. Pasztory Z, Mohacsine IR, Borcsok Z (2017) Investigation of thermal insulation panels made of black locust tree bark. Construction and Building Materials 147:733–735. http://dx.doi.org/10.1016/j.conbuildmat.2017.04.204.
70. Pasztory Z, Tsalagkas D, Horvath N, Borcsok Z (2019) Insulation Panels Made from Thermally Modified Bark. Acta Silv Lign Hung Vol 15 Nr 1: 23–34. DOI:10.2478/aslh-2019-0002.