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Processing of hemp and cannabis residue into non-adhesive chipboards and wall panels

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Abstract

As woods are dwindling and agriculture waste burning causes severe air pollution and releases greenhouse gases, the processing of Hemp and lignocellulosic surplus materials into chipboards and other construction elements, may substitute timber and reduce environmental pollution. The presented environmental-friendly technology has the potential of processing hemp and recycling residual materials into industrial woodchip boards and structural elements and without the use of hazardous expensive resins. By applying cold plasma pre-treatment followed by the pressing stage acceptable wood chip standard physical properties are achieved. The irradiation dosage is probably optimal since once exceeding the dosage applied, wood disintegration starts; the process improvement may be related to the pressing configuration. Since the pressing temperature and duration are probably higher than required, the element that may still be aligned is the pressing pressure. Moreover, the positive correlation between sample strength and pressing pressure did not reach a steady state value even when pressing the sample to the maximum possible pressure allowed in the existing equipment (5.5 tons). It is suggested that by increasing the pressing pressure and decreasing the pressing temperature a significant strength improvement will be attained. It is assumed that 20 tons/m2 pressing pressure will be sufficient to attain the desired properties.

Keywords

Plasma, Hemp, Surplus agriculture materials, Constructive boards

1. Introduction

1.1 Fiberboards

Fiberboard is a type of engineered wood product that is made from wood fibers with a particle area of 1 mm to 100 mm. The term “particle area” refers to the area of the largest cross-section of a particle. For a particulate material with particles of different sizes, the particle area is an average of the particle area of individual particles, e.g., a mass-weighted average of the particle areas. They may be categorized as particle board a.k.a. chipboard, low-density fiberboard (LDF), medium-density fiberboard (MDF), and hardboard a.k.a. high-density fiberboard (HDF). LDF density is typically 160-450 kg/m3 and MDF is 600-800 kg/m3. Besides processed wood, fiberboard may comprise fiber sources such as hemp, straw, bamboo, rice husks, and recycled paper (Ira et al. 2020).

Fiberboard is also manufactured from recycled wood chips, obtained by cutting and sorting wood material into small pieces of similar size. For MDF, chips are then steamed to soften them for defibration. A small amount of paraffin wax is added to the steamed chips, transforming them into fluffy fibers. Soon afterward, in a defibrator they are sprayed with an adhesive such as urea-formaldehyde (UF) resin, melamine-formaldehyde (MF) resin, polyurethane resin, epoxy resin, or phenol formaldehyde (PF) resin, which are considered toxic (Ankona et al. 2021). Resins are applied in a concentration of less than 1 weight percent, and down to 0.0001 weight percent, depending on the raw lignocellulosic material (Moezzipour et al. 2018).

The wax prevents fibers from clumping together during storage. The fibers or chips are then arranged into a uniform "mat" on a conveyor belt. This pre-compressed mat is then hot-pressed, in low-density fiberboard (e.g., less than 5 tons/m2) is more difficult to obtain without relying on adhesives, as the voids associated with the low density reduce the particles binding potential (Humar et al. 2017).

1.2 Adhesives

Substances proposed as safer, alternative adhesives include natural latex (Nakanishi et al. 2019), gum Arabic (Abuarra et al. 2014), alkaline-treated soybean protein concentrate (Ciannamea et al. 2012), gluten (Khosravi et al. 2014), urea-oxidized starch (Zhao et al. 2018), and glutaraldehyde-modified cassava starch (Akinyemi, Olamide, and Oluwasogo 2019). Plasma treatment has been used to form a hydrophobic film on wood from relatively nonpolar compounds such as hexamethyldisilane (HDMSO), SF6, ethylene, acetylene, butane and vinyl acetate (Kim, Kim, and Lim 2013; Wang and Piao 2011).

Hardboard is typically prepared from exploded wood fibers that have been highly compressed, resulting in a density of 800-1040 kg/m3. This process requires no additional adhesive (although resin is often added), as the lignin of the wood fibers bonds the hardboard together. Plasma treatment may also be used to increase the wood-wetting properties for subsequent treatments that enhance the wood surface properties of composite material, or for improving adhesion (Peters et al. 2017). The use of oxygen plasma was found to improve the phenol-formaldehyde, urea-formaldehyde, and polyurethane adhesion in wood coating (Acda et al. 2012). The new methodology enables LDF and MDF fiberboard manufacturing from particulate plant-derived material and without any adhesive. The fiberboard density may be less than 500 kg/m3 and the water contact angle no more than 20°.

1.3 Plasma treatment

The method involves plasma irradiation and a pressure of at least 100 kg/cm2. Fiberboard's particulate plant-derived material of at least 1 mm^2 is treated by plasma discharge, such as corona plasma, a dielectric barrier discharge plasma, and a radiofrequency inductive air plasma to activate the fiberboard's particulate material. Following this process, the fiberboard is characterized by normalized maximal stiffness to the plane of the fiberboard of at least 15,000 N/m^2; normalized maximal stiffness perpendicular to the plane of the fiberboard of at least 76,000 N/m^2; a normalized maximal stiffness of the fiberboard parallel to the plane of the fiberboard of at least 600,000 N/m^2, and normalized maximal stiffness parallel to the plane of the fiberboard of at least 1,630,000 N/m^2.

The term “plasma” describes a gas that has been at least partially ionized. Plasma is considered to consist of a mixture of neutral atoms, atomic ions, electrons, molecular ions, and molecules present in excited and ground states and carrying a high amount of internal energy. Plasma is typically generated by subjecting a gas or a gas mixture to elevated heat or a strong electromagnetic field. Most plasma systems use AC electrical power sources and operate at low radio or microwave frequencies. When plasma interacts with a surface, “plasma treatment” is initiated (Acda et al. 2012).

Plasma technology applies to a wide variety of materials, especially lignocellulosic biomass; and thus, may utilize waste materials derived from agriculture and industrial processes. The technology feedstock involved diverse plant-derived materials such as wood chips from palm trees, and cannabis (hemp fibers). Particle board, hardboard and oriented strand board of a plant-derived material joined together, wherein each fiberboard dimension comprises multiple particles. The plant-derived material comprises lignin, cellulose, and hemicellulose as structural components. A plasma-treated material may optionally be characterized by an increase in a particular type of atom or functional group on the material surface, manifested in a high degree of hydrophilicity, relative to a corresponding untreated material. For example, the plasma-treated particulate plant-derived material obtained using an oxygen and/or nitrogen plasma may exhibit an increase in the oxygen and/or nitrogen atoms concentration at the particle surface (Khosravi et al. 2014).

A plasma-treated material (individual particles) is characterized by a water contact angle of no more than 20° in complete wetting (contact angle of 0°). The term "contact angle" encompasses apparent equilibrium contact angles, which are determined by measurement, and contact angles are calculated based on other parameters (Young equation). When a liquid droplet is placed on a solid surface (e.g., a plasma-treated substance), the determination of the contact angle is relatively straightforward, using standard goniometer techniques. The Young equation defines the contact angle θ by the relationship: $\gamma SG = \gamma SL + \gamma LG * cos\theta$, where γSG is the surface energy at the solid-gas interface, γLG is the surface tension at the liquid-gas interface, and γSL is the surface tension at the solid-gas interface. When $\gamma SG > \gamma SL + \gamma LG$ there is no mathematical solution to the equation, and the solid undergoes complete wetting at equilibrium (there is no equilibrium contact angle). The Young equation may optionally be used to determine a contact angle and surface energy based on known (e.g., experimentally determined) or to calculate (Sifuentes-Nieves et al. 2023). The gas is optionally air at a pressure of 1 atmosphere.

The items manufactured comprising fiberboard may include, furniture (e.g., a chair, a stool, a bench, a sofa, a bed, a cradle, a table, a desk, a cupboard, a cabinet, a shelf, a bookcase, a drawer, a chest, a countertop, and/or ready-to-assemble furniture)or a portion thereof (e.g., a frame), construction material (e.g., a scaffold, a door, a roof and/or a floor) or a portion thereof (e.g., a floor underlayment and/or a sound-proofing layer), a home appliance (e.g., a cooking appliance and/or an electrical appliance) or a portion thereof (e.g., a handle), and/or vehicle component (e.g., a door, a dashboard, and/or a rear shelf) or a portion thereof (e.g., an inner door shell). The article of manufacture may optionally comprise an additional material (e.g., wood and/or synthetic polymer) coating at least a portion of the surface of the fiberboard (Sifuentes-Nieves et al. 2023). For example, the article of manufacture may optionally comprise a veneer of wood attached (e.g., glued) to at least a portion (e.g., a visible portion) of a surface of the fiberboard, e.g., to enhance aesthetics and prevent moisture (e.g., outdoor applications and kitchen applications), the fiberboard is optionally coated with a water-resistant material, such as a water-resistant polymer (e.g., melamine resin laminate and polyvinyl chloride).

2. Methodology

2.1 Fiberboard preparation

Preparing a fiberboard involves treating a particulate plant-derived material in predetermined particle dimensions, with plasma and compressing the plasma-treated particulate material. The plasma treatment effect is typically controlled by selecting plasma parameters such as the gas mixture, the electric power and energy frequency used to generate the plasma, the plasma's temperature, and the pressure. Additional parameters include exposure time and electron densities. Several gases can be used for generating plasma, including argon, hydrogen, helium, nitrogen, oxygen, steam, CO2, and CO, and mixtures such as air. The gas used to generate air plasma comprises mostly nitrogen and oxygen. Air plasma reacts with the material surface and causes particle adhesion as do gases such as hydrocarbons, siloxanes, fluorine-containing gases, and inert elements such as argon and helium.

Plasma is often classified by its temperature, that is, as thermal, or hot, plasma or as non-thermal, or cold, plasma. In thermal plasma, the gas is nearly fully ionized, whereas in cold plasma the gas is only partially ionized (less than 10%). Cold plasma is preferred as it is relatively easy to handle and readily applied to a material without excessive heating. Plasma is also classified by the pressure at which it is generated (discharged) and can be a low-pressure plasma (vacuum) discharge, an atmospheric-pressure plasma discharge, or a high-pressure plasma discharge. Low-pressure plasma generation and treatment are conducted in a controlled environment inside a sealed chamber, which is maintained at a medium vacuum (usually 2-12 mbar). The gas is typically energized by an electrical high-frequency field. When the chamber is filled with activated plasma all surfaces of a treated object are reached.

A typical low-pressure plasma treatment setup comprises a sealed chamber, a pair of electrodes (a cathode and an anode) electrically connected to an electric power source, and a sample to be treated. A vacuum is typically generated in the chamber using a pump and a valve. The gas or gas mixture enters the chamber through a gas inlet and a valve, and an electromagnetic field is applied, to thereby generate plasma. Atmospheric-pressure plasma treatment is conducted in a plasma chamber in which the pressure approximately matches that of the surrounding atmosphere, or in an open chamber (Fig. 1). Common atmospheric-pressure plasmas include plasma generated by AC excitation (e.g., corona discharge and/or dielectric barrier discharge) and plasma torches and jets. Corona discharge plasma forms by ionization of a fluid such as air in the vicinity of an electrically charged conductor, in the presence of a sufficiently high potential gradient. Plasma torch and plasma jet technology involve plasma creation in an enclosed chamber. The gas flow carries the plasma through a jet head toward the surface of the material to be treated. Plasma jet technology commonly involves the use of a high-voltage discharge (e.g. between 5 and 15 kV in the frequency range of 10 to 100 kHz) to create a pulsed electric charge in an enclosed chamber. A gas is then allowed to flow through the discharge section to form the plasma (e.g., cold plasma). Plasma torch technology typically involves thermal plasma generated by direct current or alternating current. Exposing the particulate plant-derived material to a plasma treatment is effective for a period of at least 10 seconds, depending on the particulate material to be treated, the type of plasma treatment and the desired fiberboard properties (BORMASHENKO, BORMASHENKO, and ANKER 2021).

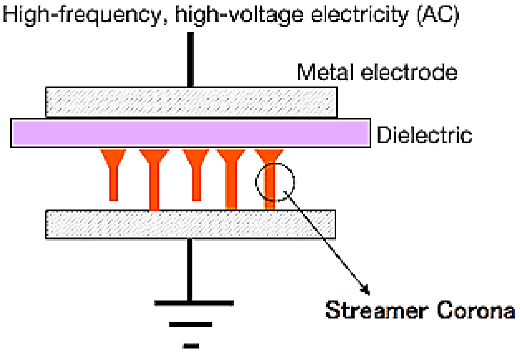

Fig. 1 schematic diagram of corona plasma assembly

The plasma treatment is generated by an electromagnetic field application that is applied at a radiofrequency (RF) energy in a range of from 1 to 200 MHz, and typically from 10 to 20 MHz. The radio frequency power ranges from 1 W to 100 W, and mostly from 5 W to 50 W. The plasma treatment is generated by high voltage current application (alternating or non-alternating current), for example, by glow discharge, electric arcing, or corona discharge. In one scheme particulate material is exposed to plasma treatment in a sealed rotating vacuum chamber (lower than 1000 Pa), or in a similar chamber at atmospheric pressure. The plasma treatment sample temperature can be from 10 °C to 100 °C, for example, at ambient temperature (20 to 25 °C). The particulate plant-derived material is placed in a manner that separates particles of the particulate material from one another, thereby facilitating exposure of the particle surfaces to the plasma. The plasma-treated adhesive-free particulate material is compressed to attain direct contact with one another. The pressure is at least 1 ton/m2 and up to 100 tons/m2 and commonly between 2 tons/m2 to 5.5 tons/m2. The compressing temperature is at least 50 °C and up to 250 °C, but commonly is lower than 100 °C. The duration is at least 10 minutes and up to 120 minutes, but usually from 10 to 40 minutes.

The plant-derived materials diversity may allow the selection of low-cost and readily available materials; for example, waste materials (e.g., from agriculture and industrial sources), such as (without limitation) wood shavings, sawdust, products (e.g., wood or paper products) collected for recycling, pruned plant parts, and residues (e.g., plant parts not utilized in the main product) of crops such as cannabis, sugar cane, cotton, or cereal crops (e.g., straw, husks, corn stalks). The fiberboard is substantially devoid of adhesives that refer to any substance added to the particulate plant-derived material described herein which promotes adhesion between particles of the plant-derived material (particulate materials derived from plants are excluded from the definition of adhesive. The adhesive is a polymer (e.g., synthetic polymer), referred to herein interchangeably as a "resin". The polymer may optionally be a thermosetting polymer (which may optionally be added in a monomeric form that polymerizes following application) and/or a thermoplastic polymer.

The method further comprises forming a layered fiberboard, with a plurality of layers characterized by different properties, thereby combining the advantages of the different layers. For example, the fiberboard comprises a "sandwich" of two outer layers the outer is stiff and strong, and the inner is low-cost and lightweight. The different layers may be from different sources, relatively cheap waste material; versus a stronger, but costlier, material such as high-quality wood chips in different particle sizes or shapes for the outer layer. The different layers may optionally be prepared as separate fiberboard samples that are then joined by compression or may be formed by placing different types of plasma-treated particulate material in a layered fashion prior to compressing. The method further comprises attaching cladding to at least one surface of the fiberboard with a layer of a polymer and/or a wood veneer (Fig. 2).

2.2 Fiberboard physical properties

The fiberboard is characterized by a maximal stiffness and optionally a normalized maximal stiffness. The term “maximal stiffness” refers to a ratio Fimax/Omax, wherein dmax is the maximal displacement upon application of a force in an indicated direction (e.g., parallel or perpendicular to the plane of a fiberboard sample) before the sample undergoes a complete detachment (e.g., tearing upon application of a tensile force in a parallel direction, or breaking upon application of a tensile force in a perpendicular), and Fmax is the force at maximal displacement. Herein, the term “normalized maximal stiffness” refers to a maximal stiffness divided by the thickness of a sample (e.g., in a direction perpendicular to the plane of the sample, a normalized maximal stiffness of the fiberboard perpendicular to the plane of the fiberboard is at least 10,000 N/m2. The normalized maximal stiffness of the fiberboard parallel to the plane of the fiberboard is at least 400,000 N/m2. The normalized maximal stiffness of the fiberboard perpendicular to the plane of the fiberboard is at least 76,000 N/m2 and the normalized maximal stiffness of the fiberboard parallel to the plane of the fiberboard is at least 1,630,000 N/m2. Alternatively, or additionally, the fiberboard may be characterized by a modulus of rupture (MOR) and/or a modulus of elasticity (MOE), as determined according to standards EN 312:2003 and/or ANSI A208.1. An MOE of the fiberboard is at least 1800 MPa, according to EN 312:2003), and at least 2400 MPa according to ANSI A208.1.(APA 2018)

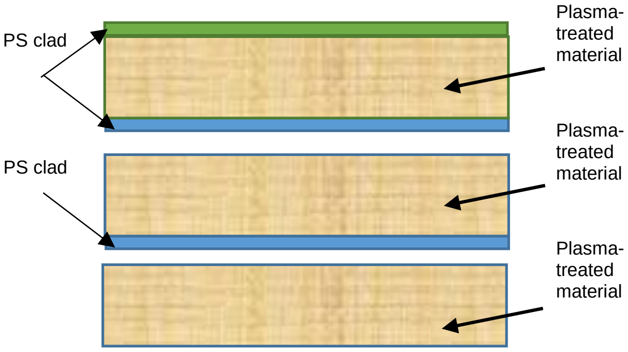

Fig. 2 Three cladding options, whereas the no-cladding is the most challenging.

A fiberboard MOR is at least 12 MPa according to EN 312:2003 or at least 16.5 MPa according to ANSI A208.1. The fiberboard may be in the form of a fiberboard or may be clad with a layer of polymer or metal on at least a portion of at least one surface. For example, the fiberboard may optionally be single-clad or twin-clad (on opposite sides). While Polystyrene is an exemplary polymer for cladding, a wood or metal veneer (thin layer) may be attached to one or more surfaces of the fiberboard, to strengthen the fiberboard, and/or to improve the aesthetics of the fiberboard (e.g., by providing an appearance of conventional wood).

3. Results

3.1 First stage

Adhesive-free fiberboard prepared of palm trees (palm chips) was shredded to form thin flakes and treated with a corona plasma discharge over the course of 0.5-3 minutes. Fiberboard-free polymeric binder was then prepared from the plasma-treated material by applying pressure (1, 2, 3 or 4 tons per m2 for 30-40 minutes at a temperature of 150 °C. Fiberboard samples were prepared in three forms: twin-cladded, single-cladded, and non-cladded (Fig. 2), using polystyrene as a cladding material.

The mechanical properties of the obtained fiberboard samples were determined by a tension test using a maximal stiffness parameter, calculated as: Fmax/⍰max, wherein ⍰max is the maximal displacement before the sample undergoes complete detachment, and Fmax is the force at maximal displacement. Stiffness was determined both for force parallel to the plane of the sample, which may be regarded as resistance to tearing; as well as for force perpendicular to the planer of the sample, which may be regarded as resistance to breaking. The mechanical properties of the fiberboard portion of exemplary polystyrene-clad fiberboard samples were calculated by subtracting the stiffness of a polystyrene sample from the total stiffness of the polystyrene-clad fiberboard sample. The mechanical properties of the fiberboard in exemplary single-clad samples are summarized in Table 1.

Adhesive-free fiberboard prepared by plasma treatment of cannabis-derived material Fiberboard samples is prepared according to procedures like those described in Example 1, except that waste material from cannabis (e.g., from hemp fiber production) and/or sawdust is used instead of palm-derived waste material. The mechanical properties of obtained samples are determined as described hereinabove. The method is simple (involving a few steps) and does not waste material.

Fiberboard samples were prepared from palm-derived waste material according to procedures like those described in Example 1, except that dielectric barrier discharge plasma was used instead of corona discharge plasma. The mechanical properties obtained from samples are determined as described hereinabove.

3.2 Second stage

Cold air plasma creates a complex surface functionalities mixture, which influences the organic materials' physical and chemical properties, which enhances their adhesive properties. Once the initial stage experiments demonstrated mechanical properties enabling the manufacturing potential of fiberboards, particleboards, chipboards, hardboards, and engineering materials without polymer binder from cannabis fibers and palm waste, hardwood and softwood were also evaluated. Canadian spruce and aspen chips were shredded and sieved to chip fraction smaller than 1cm and the sample preparation configuration was set to the method described in the previous section. Three bending tests were done for spruce and about 30 tensile strength tests were done for both spruce and aspen with Lloyd EZ 50 testing machine (Fig. 3). The strength test results (Table 2), suggest that tensile strength is above the demanded in the Israeli OSB standard and bending is about a third of the required measure, but with demonstrated strategy to attain the required strength during the next stage of R&D.

Table 2. The exemplary results of the TI 1913/EN310 sample strength test with reference standard of 0.3 N/mm2 for tensile strength and 9 N/mm2 for bending strength.

Direction	Wood	size [mm]	Width [mm]	Thickness [mm]	Tmax sp	σmax [N/mm²]
Bending	B.S.	D < 5.6	23.6	7.55		1.27
Bending	B.S.	D < 5.6	69.5	9.94		3.57
Bending	B.S.	D < 5.6	78.0	6.30		2.58
Tensile	B.S.	D < 5.6	40.8	7.11	255	0.88
Tensile	T.A.	5.6<D<10	49.6	7.94	318	0.81
Tensile	T.A.	D < 5.6	47.2	6.87	350	1.08
Tensile	T.A.	D < 5.6	47.1	6.65	476	1.52
Tensile	T.A.	D < 5.6	50.5	7.28	320	0.87
Tensile	B.S.	D < 5.6	45.6	6.10	269	0.97
Tensile	B.S.	D < 5.6	47.4	5.92	263	0.94
Tensile	B.S.	D < 5.6	44.8	6.46	234	0.81

Sample	Material	Pressure, tons	Sample thickness mm	Maximal Stiffness, N/m	Maximal Stiffness, normalized N/m²	Maximal Stiffness, N/m	Maximal Stiffness, normalized N/m²
1	Palm	2.0	5.2	670150	128875	21483	3255
2	Palm	3.0	5.3	2036450	699300	32323	6465
3	Palm	1.0	7.6	2893850	380770	65161	8688
2a	Palm	3.0	3.1	2031350	655274	101839	19584
2b	Palm	3.0	3.6	2570550	714042	83136	20784
5	Palm	2.0	5	2182650	436530	85420	17084
6	Palm	4.0	2.7	2741050	1015204	4453	1781
3a	Palm	1.0	3	1334250	444750	14499	4833
2c	Palm	3.0	6.2	3122150	501953	37957	6659
APA	Other		6.35		1630000		76000

Table 1. Maximal stiffness and maximal stiffness normalized to thickness in parallel and perpendicular directions of exemplary single-clad fiberboard samples prepared from palm waste Parallel Perpendicular (APA 2018)

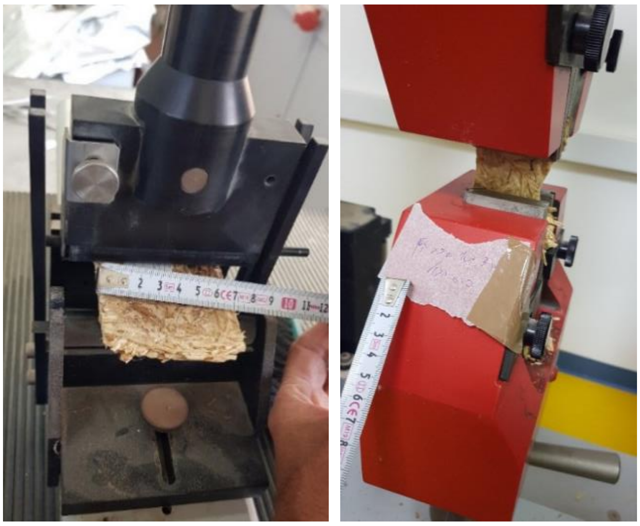

Fig. 3 photos of the spruce chipboard sample tensile (Right) and bend testing (left).

3.3 Third stage

The raw materials were given for evaluation by the Israeli Cannabis Farmers Association. Cannabis boards were made in a similar process as for the Canadian woods and palm material. Since the Cannabis material came as uniform chips with lengths of about 1-2 cm and thicknesses of about 0.3 cm respectively; no sieving was needed. 11 tension test results are detailed in Table 3.

The average of σ_{max} from 3 tests with large roller was 2.98 [N/mm2].

The average of σ_{max} from 4 tests with small roller was 1.79 [N/mm2].

The average of σ_{max} from two tests without plasma was 1.72 [N/mm2].

In all cases there are no values that exceed three times the standard deviation and this means that all values are valid.

Table 3. The exemplary results of the TI 1913/EN310 sample strength test with reference standard of 0.3 N/mm2 for tensile strength and 9 N/mm2 for bending strength.

	plasma	Roller	σ_{max}	Tmax	Thickness	Width	Year	Month	Day
			[N/mm^2]	[N]	[mm]	[mm]			
65	+		2.070	380	3.8	48.3	2023	August	31
66	+		2.718	384	3	47.1	2023	August	31
67	+	small	1.778	282	3.14	50.5	2023	August	31
68	+	small	1.426	260	3.66	49.8	2023	August	31
70	+	small	1.431	208	3	48.45	2023	August	31
73	+	small	2.542	401	3.12	50.56	2023	August	31
74	+	Big	2.667	446	3.47	48.19	2023	August	31
75	-	small	1.939	279	2.85	50.5	2023	August	31
76	-	small	1.492	200	2.82	47.52	2023	August	31
77	+	Big	2.952	503	3.39	50.26	2023	August	31
78	+	Big	3.306	573	3.4	50.97	2023	August	31

Fig. 4 photos of the spruce chipboard sample tensile (Right) and bend testing (left).

4. Discussion

Residual organic material is causing severe environmental hindrance as CO2 emitters, either while decomposing or through incineration. In the latter case they also cause severe air pollution (Ankona et al. 2021). Since these lignocellulosic materials are potential raw materials for engineered wood, the best practice for their utilization is the production of constructive woodchip boards, in several constellations (BORMASHENKO et al. 2021). At present chipboard manufacturers apply hazardous and expansive binders during the manufacturing process. Although the wood encapsulates most of these hazardous materials (Lieberman et al. 2015), during the product's lifetime cycle there is minor release of problematic volatile substances such as phenols.

The fiberboard may be formed from individual fibers, such as wood fibers (e.g., in medium-density and/or high-density fiberboard); and/or wood strands (flakes), wood chips, shavings and/or sawdust (e.g., as in particle board or oriented strand board). Alternatively, or additionally, the plant-derived material may comprise other than wood. Plant-derived materials other than wood may include bast fibers from plants such as cannabis (hemp), jute, ramie and other nettles, casaba, esparto, dogbane, hoopvine, kenaf, beans, linden, wisteria, mulberry tree and/or papyrus plant); leaf fibers (e.g., from plants such as abaca, sisal, bowstring hemp, henequen, phormium and/or yucca); seed and/or fruit fibers (e.g., from plants such as coconut (coir), cotton, kapok, milkweed, and/or luffa); straw and/or husks (e.g., from cereal crops such as wheat, rye, oat and/or rice); sugar cane residue; bamboo fibers; and paper (e.g., waste paper for recycling). Such non-wood materials are commonly rich in cellulose.

In the first stage, successful experiments were carried out with Australian Hemp and palm waste demonstrating nearly sufficient mechanical properties for manufacturing fiberboards, particleboards, chipboards, hardboards, and engineering materials without polymer binder.

In the second stage The Canadian hardwood and softwood evaluation indicates to potential recycling of these residual raw materials into industrial woodchip boards and structural elements. The suggested recycling process does not involve using hazardous thermosetting polymer binders. Thus, enabling the solution of a severe ecological problem. Thermosetting polymers are completely excluded from the process. The process includes the stage of the cold plasma pre-treatment of the wood waste. The obtained samples were mechanically tested. While tensile strength seems to be acceptable the bending strength demands improvement.

In the third stage the optimal combination that was elucidated for sample preparation (irradiation of 20 minutes and pressing at various pressures at temperature of 50 °C), was applied to residual cannabis material. The samples demonstrated better physical properties than of the Canadian soft and hard woods (Table 3). The reason for that is probably higher lignin concentration in the grass compared to the cellulose and hemi-cellulose rich woods.

5. Conclusions

All evaluated materials including cannabis chips, Canadian hardwood and softwood indicate to potential recycling of these residual raw materials into industrial woodchip boards and structural elements. The suggested process does not involve the use of hazardous thermosetting polymer binders. Thus, enabling an optimal solution of a severe ecological problem. The process includes cold plasma pre-treatment stage, followed by pressure of between 7 to 10 tons/m2. The mechanical testing suggests that while tensile strength seems to be acceptable the bending strength demands improvement. Taking into mind that the irradiation dosage is probably optimal since once exceeding the dosage applied, wood disintegration starts; the process improvement may be related to the pressing configuration. Since the pressing heat that was elucidated from the preliminary study is probably high enough or even a little too high and pressing duration above one hour did not improve the sample strength, the element that may still be aligned is the pressing pressure. Moreover, a correlation between sample strength and pressing pressure was identified in the preliminary stages and did not reach a steady state value even when pressing the sample to the maximum possible pressure allowed in the existing equipment (5.5 tons). For the next R&D step, it is suggested that by increasing the pressing pressure and maintaining pressing temperature to 50 oC a significant improvement in the bending strength will be attained. This improvement in the manufacturing procedure is possible by using a stronger temperature-controlled pressing machine capable of at least 20 tons/m2 pressing pressure. To find the optimal pressing pressure, an incremental increase in pressing pressure will be applied in sample preparation, until the chipboard strength reaches a steady state, indicating the maximal potential strength of the suggested non-adhesive chipboards. An additional strategy is the production of wall panels with steel foil cladding that will allow to maintain pressing pressure as low as 5 tons/m2.

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