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ARTICLE

Preparation and evaluation of chipboard based on wood waste

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Natural resources are being depleted due to deforestation, industrialization and other factors. We are experiencing climate change that is affecting living beings, which is why there has been interest in researching alternatives that help to create substitutes based on waste. This research mentions the processes for the manufacture and characterization of a chipboard. Manufacturing begins with cutting the wood to obtain fine sawdust powder, mixed with phenolic resin and pressed. In the characterization of the chipboard, tests are carried out to evaluate the stress, deformation, bending, density and morphology. The particle board composed of 80% sawdust powder and 20% phenolic resin has the best properties with a density of 603.125 $\frac{kg}{m^3}$, compressive strength of 39.51 $\frac{kg}{cm^2}$, shows a moisture absorption % of 0.01 – 0.07 and a water absorption % of 0.08-0.5 so it could be used for indoor use and P2 furniture production..

1. Introduction

Wood boards are used to manufacture units of various sizes and models. However, pulp and paper manufacturing companies are suffering from material shortages, and the increase in demand for wood materials has raised the price of wood and will increase in the future for furniture manufacturing (Schneider et al., 2018). Currently, the goal is to apply the 3-R concept (Reduce, Reuse, Recycle) to reduce the exploitation of trees for the production of furniture or wooden articles. After several experiments, three techniques based on the 3-R concept are developed with the closed-loop system: repair and reuse of waste wood boards from/to customers, using internally provided products as raw material for furniture; all three met several mandatory criteria of strength and design in a piece of furniture (Handoko et al., 2021).

The problem of wood shortage is so great that research has been carried out in various countries to solve this problem. The aim has been to accurately estimate raw materials containing lignocellulose, evaluating their suitability for the production of composite materials based on their physical properties. Recycled wood and post-harvest waste could replace conventional raw materials in wood-based composites, such as particle board and chipboard. According to moisture and fiber analyses, the most suitable candidate for the production of wood-based composites is softwood (Procházka et al.,

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2021).

In another study, chip geometries were analyzed in order to achieve the density profile (Schneider et al., 2018). Chips and sawdust were used to produce a wood-based substitute, and they were produced as single- and three-layer boards with face layers containing industrial microchips. The mechanical properties determined for single-layer boards in a bending test were used as guidelines for producing three-layer boards with properties that meet the criteria for P2 furniture boards (Mirski et al., 2019). Composites from chipboard, typical waste furniture (fiberboard, particle board, and block board) can be used. In some processes, the cellulose fraction or a fraction was recovered for enzymatic hydrolysis and conversion to bioethanol, in another process, by almost complete removal of hemicellulose at higher pretreatment temperatures, improved crystallinity index and disordered morphology of the pretreated substrates have been obtained (Zhao et al., 2019, 2020).

Experiments have been carried out with sawdust for the manufacture of red bricks (Cultrone et al., 2020), as well as experiments with the parental and reconstituted strains, which were grown using two agricultural wastes such as wheat straw (WS) and a mixture of oak sawdust, wheat straw, millet seeds, cotton seed hull and CO3 (AP) (Valenzuela-Cobos et al., 2020). In another experiment, the production of oxalic acid from sawdust has been explored using a mixture of strong nitric acid and concentrated sulfuric acid with coal fly ash as a catalyst (Kuipa et al., 2021). Sawdust is so widely used that improved strains of P. eryngii were developed by dedicaryotization of commercial strains and production parameters were optimized for local conditions. Using 3.5 kg bags and 21 days of incubation, a substrate of wheat straw (45%) with sawdust (20%), wheat bran (16%) and gluten (5%) produced higher BEs (103%) than a substrate with cotton waste (BE=74%) (Whitaker, 2012). Technology for manufacturing wood particle boards produced with the use of a thermoreactive modified phenol-formaldehyde binder (rezol) has been developed, and its properties have been studied (Yu. V. Pas'ko, 2021).

Currently, techniques are being sought to obtain a chipboard that meets customer specifications, one of the techniques is the electrical method in waste recycling, another technique is the hydrothermal method. With both methods, the practical properties of the boards have been reviewed, including thickness swelling, modulus of rupture, modulus of elasticity and internal bonding. Changes in the chemical composition of the recycled fibers compared to the original fibers have been found, with the hydrothermal method the length of the recycled fibers is reduced, the electrical method performed better than the hydrothermal method (Moezzipour et al., 2018). In another experiment, a medium-density fiberboard and a particle board were tested, and they were compared with a material produced from a coriander biorefinery, the indicators selected to compare the materials were the physical properties (density, bending properties, surface hardness, thickness swelling and water absorption) and emissions of volatile organic compounds (Simon et al., 2020).

Particle boards made with urea-formaldehyde adhesive using sugarcane bagasse, with and without the addition of cellulose nanocrystals, where the elasticity and rupture modulus, water absorption and thickness swelling have been evaluated, with respect to the viscosity of the mixture of cellulose nanocrystals and urea-formaldehyde, the dispersion of the adhesive in the particle board is avoided (Mesquita et al., 2018), continuing with the various experimental evaluations of composites reinforced with waste of different materials, on this occasion, short fibers of sugarcane bagasse were used, conglomerated by ordinary Portland cement and gypsum containing fine ash from the combustion of rice husk (Hernández-Olivares et al., 2020). In sugarcane bagasse, the feasibility of producing laminated wood has been examined, analyzing its mechanical strength properties (Nara Cangussu, Patrícia Chaves, 2021).

Water-soluble phenol-formaldehyde resin modified by an alkyd oligomer has been used to decrease the surface tension of an adhesive composition and improve its distribution on wood particles, the physical and mechanical characteristics of the boards have increased (Ugryumov et al., 2019). On the other hand, studies have been deepened on the acoustic behavior of composite boards made from five different types of natural fibers (bagasse, bamboo, banana, coconut fiber and corn husk) to be used as sound-absorbing materials (Sharma et al., 2020).

Regarding the research with the use of green or natural adhesives, this has contributed to the reduction of health problems and the cost of building construction through the use of said particle board (Owodunni et al., 2020), there is a need to use insulating materials made from plant raw materials, (Gaspar et al., 2020), the damage caused by formaldehyde resin has led to the development of ecological adhesives without formaldehyde, this option covers the strengths, opportunities, weaknesses and threats of soy-based adhesives as a substitute for conventional resins (Bacigalupe & Escobar, 2021).

Going even deeper into the research on the synthesis of phenol-formaldehyde resins, 30% by weight of this resin is replaced by cardanol, it was studied by spectroscopy and differential scanning calorimetry. The resulting resins were used to produce impregnated paper for laminating plywood and particle boards, reducing the impregnation time of kraft paper and improving the surface quality and elasticity of the impregnated paper, allowing to reduce the water absorption of laminated particle board materials and the emission of formaldehyde being less harmful (Shishlov et al., 2021), cardanol with chemical and specific characteristics (antioxidant activity, flame resistance and hydrophobicity), allows to evaluate the physicochemical, physical and mechanical properties, evaluation of the wood-adhesive interface with scanning electron microscopy (SEM), and the combustibility test on a particle board generating favorable results (Corrêa et al., 2022). It is also important to consider that the wood must not be infected with gram-negative bacteria (Wójcik-Fatla et al., 2022).

The present work aims to obtain an economical chipboard from wood waste (sawdust) and phenolic resin with the characteristics of weight resistance, moisture resistance, bending and density for use in P2 type furniture. As well as to describe the production process from the arrival of raw material to the industry that includes the stages of manufacturing and characterization. Manufacturing includes the processes: wood cutting, sawdust dust collection, drying, mixing and pressing. Characterization consists of evaluating the stress, unitary deformation, bending, density, determination of morphology and sizing using scanning electron microscopy (SEM). With the purpose of obtaining an economical board with the characteristics of weight resistance, moisture resistance, bending and density for use in P2 type furniture.

2. Material and Methods

2.1 Materials

For the production of the agglomerate, the raw materials used were fine sawdust powder, which was obtained from the cutting process, and as an adhesive, phenolic resin powder (phenol-formaldehyde) of the Poli Resinas Huettenes brand, novolac type, was used..

2.2 Manufacture

2.2.1 Preparation

For the production of the agglomerate, in the different stages of Figure 1. The following are considered:

- The sawdust must have a humidity less than or equal to 8%, if it does not meet the percentage the sawdust goes through a drying process.

- Specify the percentage of sawdust and phenolic resin.
- Mix the sawdust and resin until obtaining homogeneity in the mixture.
- Apply release agent in the press mold, preventing the mixture from adhering.
- Pour the mixture and distribute it evenly in the mold.
- Cooking is done in the hydraulic press through the following programming:
  a) Idea l temperature of the cooking process at 180 °C at constant pressure.
  b) Pressure of 4500 PSI at constant temperature.

2.2.2 Manufacturing process

Figure 1 shows the stages for the production of chipboard and its characterization. It begins with the process of cutting yellow pine wood from the state of Michoacán in the Mexican Republic. The cut is made using a band saw (band saw) model FB 740 RS from the Felder brand. A circular saw made up of toothed discs, model GKS 150 from the Bosch brand, is also used. Each cut generates fine sawdust.

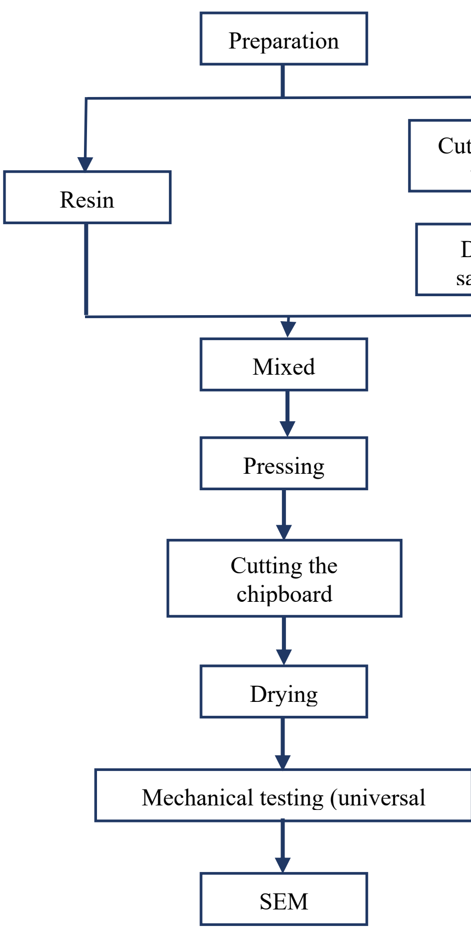

Figure 1. Process diagram.

A hygrometer model TK-100W from AMTAST is used to measure the humidity of the sawdust before and after the drying process, the meter detects the absolute humidity of the sawdust, a horizontal ribbon type mixer model TRBH-1 from TECNI PAC brand, which was used in the mixture of dry and solid powders (sawdust and phenolic resin) in its rotary movement within the interior space to produce a fine and homogeneous mixture, a hydraulic press of our brand that allows working at temperatures of up to 250 °C with a compaction level to press the mixture of materials up to 8000 PSI to form the agglomerate.

A Sanber Chemical brand MT release agent that supports operating temperatures was used to create a barrier between the substrate and the mold surface, eliminating the adhesion of the materials and avoiding damage to the agglomerate.

To carry out the drying process of the agglomerate, a Binder World ED023UL-120V oven was used, as well as an ISOLAB brand desiccator with a 250 mm diameter inside to reduce humidity, allowing the density to be determined.

For the evaluation of the mechanical properties, a universal testing machine, Shimadzu brand, model UH-30A, was used to determine the strength of the chipboard samples.

A DIDACTA ISD/004 bending machine was used. It consists of two parallel supports for the test piece and a bending tip.

In the preparation of the scanning electron microscopy (SEM) samples, the QUORUM brand Q150R sputtering model was used, which is an automatic cathodic sputtering coating machine for non-oxidizing metals, giving the possibility of characterizing morphology and sizing in the HITACHI brand SU3500 SEM model.

2.2.3 Characterization

All experimental tests were performed in triplicate and the standard deviation was obtained.

a) Hygroscopic tests:

After drying the different samples of chipboard and yellow pine wood measuring 4 cm by 4 cm, the samples were placed in a Testmark brand glass desiccator model KX-31200-250 with a diameter of 250 mm inside, to remove moisture and bring them to constant weight.

The samples were exposed to the environment and in an aqueous medium for 48 hours, the process was carried out to know the results about the absorption of moisture in wood and chipboard.

b) Mechanical properties:

To determine the properties, it was necessary to use a Shimadzu brand universal testing machine that allows obtaining the resistance by applying a controlled force, obtaining the values of: stress and deformation with the help of equations (1) and (2).

$$\sigma = \frac{F}{A} \quad \text{Eq. (1)}$$

$$\epsilon_c = \frac{Lo-L}{Lo} \quad \text{Eq. (2)}$$

With respect to equation (2), it is measured by means of the proportion of the contraction of the original length, that is, the thickness is obtained before and after the test of each of the agglomerate samples, in both cases the average and the standard deviation are calculated, the average before the test represents the Lo, after applying the compression deformation test to each of the samples, the calculation is carried out to obtain the L, the data allow to know the unit deformation being a dimensionless data.

c) Flexion:

A DIDACTA brand bending machine, model ISD/004, was used. The load was applied to the specimen at the central point between the supports to determine the mechanical property of the material related to the maximum bending point before breaking.

d) Morphology and sizing:

It is necessary to prepare the samples of chipboard and yellow pine wood by means of sputtering, being covered with a conductive material giving the possibility of being analyzed in the scanning electron microscope (SEM).

3. Result and Discussion

A mixing process similar to that executed by the author (Nukala et al., 2022) was carried out in the mixture of recycled plastic waste and recycled wood waste. In both projects, the dry materials were mixed in various compositions, (Nukala et al., 2022) through a batch mixer to form the composite materials. In the production of chipboard for furniture in this project, the mixture of the materials sawdust and phenolic resin, both in powder form, are homogenized dry, in a hydraulic press in which the temperature was set at 180 °C, a pressure of 4500 PSI and a time of 15 minutes for the production of the chipboard. In both investigations, the wood waste used is pure without any additional treatment.

On the other hand, (Shishlov et al., 2021) the compression of the wood was carried out in a hot press at a constant travel speed with a temperature of 120 to 160 °C. In this process, it is necessary to cool the sample in a compressed state below 80 °C. Subsequently, the samples were cooled to 40 °C.

After compression, a stable dimension is obtained. In these three similar manufacturing processes, there are differences, all with the same objective, seeking good results in their mechanical properties, as well as moisture resistance and density.

Figure 2 shows a chipboard 101 cm long by 9 cm wide and 1.6 cm thick. A uniform color is observed indicating that the cooking temperature and operating pressure are distributed evenly:

3.1 Preparation of the agglomerate product

After having carried out the experiments, the following options were considered for analysis, taking into account the variables of the mechanical properties.

The specifications of each of the chipboard samples at a temperature of 180 °C, with a pressing of 4500 PSI and with a process time of 15 minutes are as follows:

Figure 2. Chipboard.

Table 1. Chipboard specifications.

	Agglomerate 1		Agglomerate 2		Agglomerate 3	
Material	Percentage (%)	Grams (g)	Percentage (%)	Grams (g)	Percentage (%)	Grams (g)
Sawdust	80	1013.60	75	950.25	70	886.90
Phenolic resin	20	253.40	25	316.75	30	380.10
Total	100	1267	100	1267	100	1267

Table 2. Results in the environment and aqueous environment.

Samples	Density kg/m^3	Hygroscopic test % (moisture adsorption in two days)	Water adsorption % (two days)
Yellow pine wood	525 ±1.2	0.88 ±0.01	14.5 ±0.2
Agglomerate 1	603.125 ±1.4	0.07 ±0.0	0.5 ±0.0
Agglomerate 2	704 ±1.5	0.05 ±0.0	0.5 ±0.0
Agglomerate 3	1015 ±2.2	0.01 ±0.0	0.08 ±0.0

3.2 Moisture resistance

This test is applied to samples of chipboard and yellow pine lumber.

(Nukala et al., 2022) mentions that the water absorption tests were carried out in accordance with the ASTM D570 method, in both investigations similar processes were carried out in which the samples were initially weighed and immersed in water under ambient conditions. The percentage of water absorbed in the composite was calculated according to equation (3).

$$w = \left(\frac{w2-w1}{w1}\right) * 100 \quad \text{Eq. (3)}$$

The yellow pine wood and chipboard samples were analyzed at constant weight. In the humidity resistance tests in the environment, the density found for yellow pine wood is 525 kg/m^3 with 0.88% in humidity absorption in two days, with respect to the different agglomerates the results in density .

Chipboard 1 obtained a density of 603.125 kg/m^3, it is the best option in case you want to replace yellow pine products, chipboard 3 has a very high value with 1015 kg/m^3 in density and the results that were obtained In the hygroscopic test, the values are very small, so they could be used in products exposed to the elements or that are in contact with humidity during cleaning without suffering apparent damage. In general, the three agglomerates have very high resistance values. humidity.

With respect to the results of the moisture resistance test in an aqueous medium, where the sample was submerged and subsequently left at a constant weight to obtain the density of the yellow pine wood, which was 525 kg/m^3, yielding 14.5 % water absorption in two days. In chipboard 1, the density value is 603.125 kg/m^3, it is still the best option, chipboard 3 is the least viable option. The results obtained in the water adsorption test are very small data, all three agglomerates passed the water adsorption test.

3.2 Mechanical properties

For these tests, a Shimadzu brand universal machine was used, (Nukala et al., 2022) an Instron 5980 universal testing machine was used, both machines allow knowing the mechanical properties. Each of the tests were performed in triplicate and the average values and standard deviation were obtained.

3.3.1 Compression

In yellow pine (Miskdjian et al., 2024) obtained 65 MPa in the load with 0.5% in the deformation, in figure 3 you can see our results that are very similar to obtaining a load of 59 MPa with 0.56% in the deformation, the values obtained in both tests are very similar.

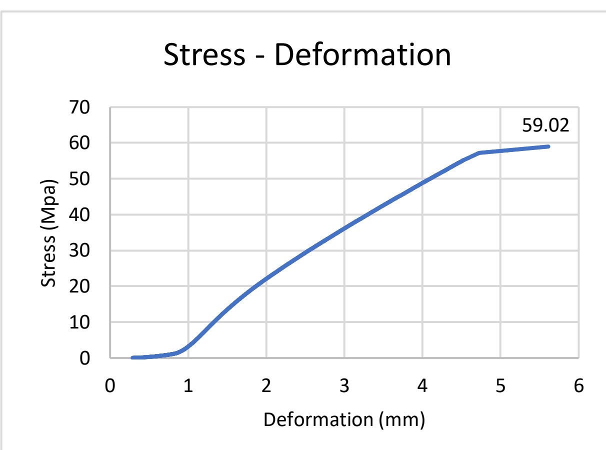

Figure 3. Yellow Pine Bend.

In the tests carried out on the yellow pine, a higher value in the stress is observed with a greater deformation with respect to the samples of agglomerates 1, 2 and 3. In figure 4 a) it is observed that the greater the stress, the greater the deformation. Figure 4 b) shows an increase in the applied load at the same time a greater deformation is generated in the agglomerate.

Table 3. Tests of agglomerates 1, 2 and 3.

a) Stress – Deformation

The yellow pine presents a stress of 59.02 MPa and a deformation of 15%. In agglomerate 1 it has a stress of 57.222 MPa with a deformation < 13%, agglomerate 2 the stress found is 51.916 MPa with a value < 16% in the deformation and agglomerate 3 presents a stress of 43.872 MPa with deformation of 18%.

b) Load – Deformation

Chipboard 1 supports a load of 6200 N, chipboard 2 supports 5060 N and chipboard 3 supports 3910 N. The three chipboards present a deformation < 20% in their elastic zone.

Table 3 shows the results of each test in triplicate and the averages are obtained to obtain the stress and unit strain (see table 4). An average applied load of 6200 N can be observed in chipboard 1. When a greater load is applied, the sample deforms and does not recover its dimension, which indicates that the elastic zone has ended at 6200 N and the plastic zone has begun. of the material, in Figure 4 a) a maximum load of 57.222 MPa can be seen and the average thickness is reduced to 0.469 cm, obtaining the unit strain of 0.293.

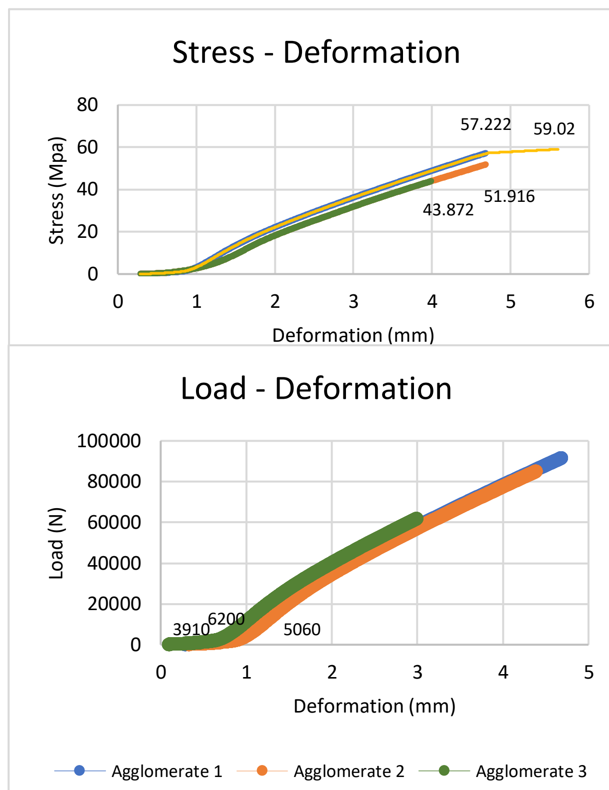

Figure 4. Curves of yellow pine and chipboards 1, 2 and 3.

	Aggomerate 1			Agglomerate 2			Agglomerate 3		
Samples	**Force (N)**	**Thickness (cm)**	**Deformation (cm)**	**Force (N)**	**Thickness (cm)**	**Deformation (cm)**	**Force (N)**	**Thickness (cm)**	**Deformation (cm)**
1	6210	1.60	0.470	5064	1.60	0.473	3921	1.60	0.390
2	6187	1.60	0.465	5059	1.60	0.471	3899	1.60	0.385
3	6203	1.60	0.473	5057	1.60	0.477	3910	1.60	0.366
Average	6200 ± 9.3	1.60	0.469 ±0.002	5060 ± 2.89	1.60	0.474 ±0.002	3910 ± 8.94	1.60	0.380 ±0.02

Table 4. Stress and unit strain test on agglomerates 1, 2 and 3.

Aglomerate 1		Aglomerate 2		Aglomerate 3	
Stress ($\frac{kg}{cm^2}$)	Unit strain	Stress ($\frac{kg}{cm^2}$)	Unit strain	Stress ($\frac{kg}{cm^2}$)	Unit strain
39.51	0.293	32.249	0.296	24.919	0.2375

Table 5. Bending test on chipboards 1, 2 and 3.

	Agglomerate 1			Agglomerate 2			Agglomerate 3		
No	Load (kN)	Weight (kg)	Mechanical bending (cm)	Load (kN)	Weight (kg)	Mechanical bending (cm)	Load (kN)	Weight (kg)	Mechanical bending (cm)
1	0.60	61.183	1.50	0.50	50.986	1.80	0.40	40.789	2.50
2	0.60	61.204	1.50	0.50	51.023	1.80	0.40	40.790	2.50
3	0.60	61.171	1.50	0.50	50.998	1.80	0.40	40.789	2.50
Average	0.60	61.186 ±0.02	1.50	0.50	51.002 ± 0.03	1.80	0.40	40.789 ±0.001	2.50

In the author's experimentation (Shishlov et al., 2021), the compressive strength in the radial direction of compressed softwood is 58.9 MPa. This indicates that the value displayed in Figure 4 a) in the chipboard, with 57.22 MPa being the best result in this research, is below compressed wood. This is because the chipboard is composed of waste.

3.3.1 Flexion

Table 5 shows the values obtained from the three samples. Where chipboard 1 supports an average load of 0.60 kN equivalent to 61.19 kg, where the recorded value of 1.50 cm represents the maximum bending being the breaking point of the chipboard. Likewise, the average results obtained from agglomerates 2 and 3 are located, which support a lower load, although they present a greater mechanical bending.

3.2 Morphology

In the research of Nukala et al. (2022), the morphology of the compounds was carried out in an SEM HITACHI 3030 scanning electron microscope with a voltage ranging between 10 kV and 15 kV. With respect to the morphology of the agglomerate composed of sawdust and resin, a HITACHI brand SU3500 SEM with a voltage of 5.00 kV was used in this study.

The preparation of the yellow pine wood samples and the chipboard were carried out by means of sputtering, the analysis of the internal structure and its components analyzed in the SEM scanning electron microscope which used an electron beam to obtain the following results:

In figure 5 a) the sample of semi-soft yellow pine wood shows the dimensions of the fibers, they were identified from 19.2 µm (micrometers) to 39.9 µm, being fibers of different thicknesses, the spacing between fibers is also visible in which sap is transported, therefore it absorbs more moisture compared to agglomerate. In the research of (Shishlov et al., 2021) in figure 4 b) the scanning electron microscope image of the cross section of the compressed Scots pine is displayed, the fibers are shown without spacing.

Figure 5 b) shows the micrograph of small and large particles of the agglomerate identified with the number 1, with measurements of 2.6 µm to 23.4 µm respectively. In the upper part, some irregular shapes are visible that were spaced randomly with different measurements.

Regarding the polymer and wood agglomerate analyzed by (Nukala et al., 2022), in the morphology there is a good union showing good physical and mechanical properties compared to the experimentation of the particle board samples, there is also a union and compaction with acceptable mechanical properties. In both investigations there was a good mixture until homogenization, this allowed obtaining an agglomerate with uniform results in mechanical properties. It is considered that the agglomerates have very good resistance because they show good union and there are no separations, and the percentage of moisture absorption is very low, being almost zero. With respect to (Shishlov et al., 2021), in compressed wood due to natural growth in which knots and fluctuations are generated, different levels of mechanical resistance are obtained, therefore resistance and rigidity are subject to natural fluctuations.

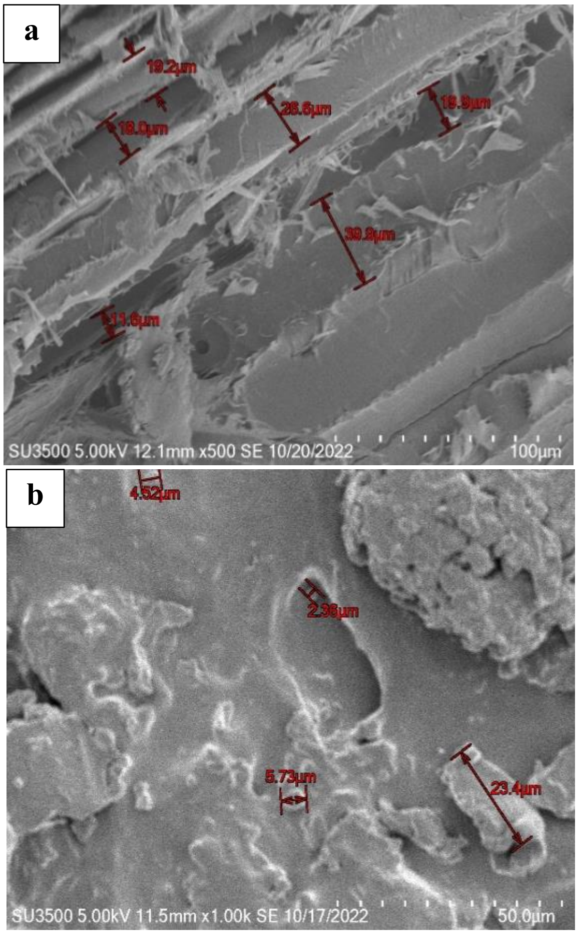

Figure 5. Morphology a) Yellow pine wood fibers b) Micrograph of chipboard1.

4. Conclusion

In this research, we have experimented with the manufacturing and characterization of the chipboard. The test results indicate that chipboard 1, composed of 80% fine powder sawdust and 20% phenolic resin manufactured at a temperature of 180 °C with a time of 15 minutes and a pressing of 4500 PSI, offers more advantages compared to the other agglomerates.

The density of this agglomerate is 603.125 $\frac{kg}{m^3}$, in the water absorption test in the environment, it was obtained 0.07%, and in the aqueous medium, it was 0.5%; in both cases, the test was applied for 48 hours. The density value is very close to the value of yellow pine wood, with 525 $\frac{kg}{m^3}$, with these results indicating that the chipboard is very effective in resistance to humidity.

With respect to the mechanical properties, that is, the resistance to perpendicular compression, chipboard 1 supports 39.51 $\frac{kg}{cm^2}$ in its elastic zone, although if more load is applied it can support 57.222 MPa with almost 5 mm in deformation, The value obtained is very close to that of yellow pine with a load of 59.02 MPa with 5.5 mm in its deformation.

The bending resistance in the longitudinal direction supporting a load of 61.19 kg offers considerable resistance; on the other hand, the results obtained from the scanning electron microscope indicate that there is a strong union of the particles, as well as a very good compaction.

The results of this agglomerate show excellent resistance to humidity with an acceptable value in density, as well as good resistance to compression and bending. This was observed in the tests in the elastic stage, being an effective agglomerate with good results in properties. mechanical, it meets all the properties for the production of P2 furniture, although according to the literature review, additional experiments can be continued to obtain better results. In future research, other agglomerates can be experimented using various materials.

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