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Characteristic of particles created by preparatory operations of the particleboard production process

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Abstract: *Characteristic of particles created by preparatory operations of the particleboard production process.* The production of wood-based panels, taking into account material innovations, involves the need to adjust the operation of technological devices to the properties of basic and auxiliary materials. In this study, it was decided to check the particle sizes after sorting raw materials representing 3 groups: forest biomass – pine branches, agricultural biomass - oilseed plant straw, and post-production material. Fractions were taken from the 2.00 mm mesh sieve of a sorter for the core layer of the particleboard and the fractional composition was determined by sieve analysis. The average linear particle dimensions and bulk density of each lignocellulosic raw material were also determined. Due to the varying proportions, it is necessary to adapt the parameters of the technological operations to the specifics of the raw material being processed or to introduce guidelines for the selection of particle sizes guided by their actual average size. Studies have shown differences between the individual materials. This is particularly important, as proper preparation of the raw material translates into the quality of the boards produced from them and the efficiency of the entire process.

Keywords: particle size, process quality, geometry, lignocellulosic raw materials

INTRODUCTION

The particleboard is a panel product made increasingly from wood particles derived from low-value wood raw material in the form of sawmill residues, recycled wood or other lignocellulosic materials, even non-wood materials (Jiang *et al.* 2020). Classical forestry has a long tradition, but the developing economy means that additional options and strategies are needed to harvest enough wood to meet the ever-growing demand and ecological requirements (Grzegorzewska *et al.* 2020). The use of raw materials other than pure wood is one of the main principles of the Sustainable Development Goals. It is important for the bioeconomy and rational use of natural resources.

Interest in alternative sources of raw material for board production has been going on for many years, as indicated by numerous scientific articles (Pędzik *et al.* 2021, Lee *et al.* 2022). The addition of wood from pruning trees of other species including those from gardens and fruit trees (Pędzik *et al.* 2022a, Auriga *et al.* 2019, Kowaluk *et al.* 2020), tree residues after logging from the forest (Pędzik *et al.* 2022b, Moreira *et al.* 2022), recycled wood (Iždinský *et al.* 2020, Yang *et al.* 2007), wood from fast-growing plantations (Szostak *et al.* 2013, Choudhary *et al.* 2015, Nelis *et al.* 2015) or other sources containing wood elements (Simal *et al.* 2014) are being used. Nevertheless, the geopolitical situation, including difficult access to wood and the search for savings is forcing a reach for other options. Increasing diversity and reducing the emphasis on the use of wood in particleboard production is supported by the use of agricultural biomass, i.e. crop residues (Kariuki *et al.* 2020). To the reasons described for why other sources of raw material are needed, one should also add the idea of zero waste, which says to manage products and processes in such a way as to eliminate the harmfulness of residues and reduce their volume, recycle and recover. Included in this idea is the use of post-consumer wood waste from furniture, window frames, demolition wood, wood-based panels, and the most common post-industrial waste like sawmill particles (Diyamandoglu *et al.* 2015). It is known that the use of particles from alternative raw materials including those other than pure wood will involve the use of other binding agents or the use of hybrid binding agents, as well as changes in the preparation of particles for the process. However, such a broad base of lignocellulosic raw materials encourages the search for materials that are most similar in performance to wood or that are economically viable in terms of their ability to harvest the material and extract particles from them.

Often, a several-thousand-percent share of another raw material can contribute to significant savings in the purchase of raw material while not significantly deteriorating and, in some cases, improving the properties of manufactured products (Auriga *et al.* 2021, Borysiuk *et al.* 2020, Dukarska *et al.* 2015, Dukarska *et al.* 2021). To assess the validity and ultimately the efficiency and cost-effectiveness of using alternative sources of raw materials, it is not enough to test the feasibility of producing the boards and checking their quality. To assess the validity and ultimately the efficiency and cost-effectiveness of using alternative sources of raw materials, it is not enough to test the feasibility of producing the boards and checking their quality. The initial step should be to find out the behavior of the raw material groups of interest and check what quality material can be obtained from them. The simplest method is to compare the particle size of lignocellulosic raw materials with that of pine wood particles and, in a second step, to determine the particle yield.

This work is focused on the analysis of the particles potentially intended to make the inner layers of particleboards using the traditional particle extraction process for wood. The aim was to determine the fractional composition and size analysis of the particles, as well as the bulk density of the fraction taken from the same part of the process, and to relate the results obtained to the rules to be followed to obtain a good quality particleboard in terms of raw material.

MATERIALS

Materials representing three groups of raw materials: forest biomass - pine branches, agricultural biomass - oilseed straw, and post-production residues - wood-based panels representing waste from the production of door leaves. The forest biomass was branches harvested from the crown of the trees from which the logs were taken, while the straw was the residue from the seed collection. The residues - wood-based panels used included softwood, hardwood, particleboard, tubular particleboard and HDF (Fig. 1).

Fig. 1. The residues - wood-based panels prepared for shredding.

These were ground in a Condux mill (Mankato, USA) at a moisture content of approximately 9%. Admittedly, this mill is used to disintegrate the lignocellulosic particles and these are ultimately different from the chips produced under industrial cutting conditions. Nevertheless, with a view to the source of the raw materials to be shredded and their structure, as well as the performance of basic research to show the differences between raw materials of similar shredding quality, rather than the selection of a shredding device and the reproduction of industrial conditions, it was decided to use it. The ground lignocellulosic materials were divided on a vibrating sorter from Allgaier (Uhingen, Germany) into four fractions according to sieve size with a mesh size of: 8.0, 2.0, 1.0 and 0.5 mm. The particles from the 2.0 mm sieve size intended for the core layer of the particleboard were taken for further testing. The poured bulk density (ρ) of each lignocellulosic raw material was determined in the formula:

$$\boldsymbol{\rho = \frac{m_c - m_n}{V}}$$

where:
m_c – the weight of the measuring vessel with the raw material (kg), m_n – the weight of the measuring vessel (kg), V – the capacity of the measuring vessel (m^3). The bulk density measuring vessel equipped with a volume scale with a capacity of 1 dm^3 and dimensions of 105 mm diameter and 120 mm height.

On a laboratory vibrating screen AS 200 taps (Fritsch, Idar-Oberstein, Germany), their fractional composition was determined by sieve analysis. A set of sieves with the following mesh sizes was used: 8.0, 4.0, 2.0, 1.0 and 0.50 mm. Approximately 250 g of shredded material was taken for each analysis. The process was carried out for approximately 15 minutes, with 3 repetitions for each type of raw material. The linear dimensions were then measured: length, width and thickness of 200 particles from each fraction from the sieve analysis. Particles representative of the entire acquired fraction were selected for in-line measurements. Their length and width dimensions were measured with an electronic caliper and their thickness with a thickness meter.

RESULTS

Although the process of grinding the raw material of forest biomass, agricultural biomass and post-production material was carried out in the same way, the distribution of particle sizes and average dimensions from the same sorting sieve are different, especially evident for agricultural raw material. The other 2 groups consist of wood. Simple bulk density tests showed significant differences between the tested groups of raw materials, Table 1. The highest value was recorded for particles from post-production residues, it was as high as 110 kg/m^3.

Table 1. The poured bulk density of fractions for the core layer of particleboard

Group of raw material	Poured bulk density, kg/m^3
Forest biomass	70 ± 2
Agricultural biomass	55 ± 1
Post-production material	110 ± 2

Mean value (n=6) ± standard deviation

The pine wood particles used in the manufacture of board production have a lower density than the assumed nominal density of the boards produced. This relationship can lead to an increase in the bulk density of particles produced by grinding particleboard, among other things (Wronka and Kowaluk 2022). In addition, the structure of particleboard is made fragile by about 10-12% amine resins, so grinding results in short particles with a less slender appearance (Wronka *et al.* 2021).

The sieve analysis shown in Fig. 2 showed that residues post-production raw material has a very similar particle distribution to the forest biomass from Fig. 3. In contrast, the agricultural biomass of Fig. 4 contains markedly more particles in the 1.00-2.00 mm range.

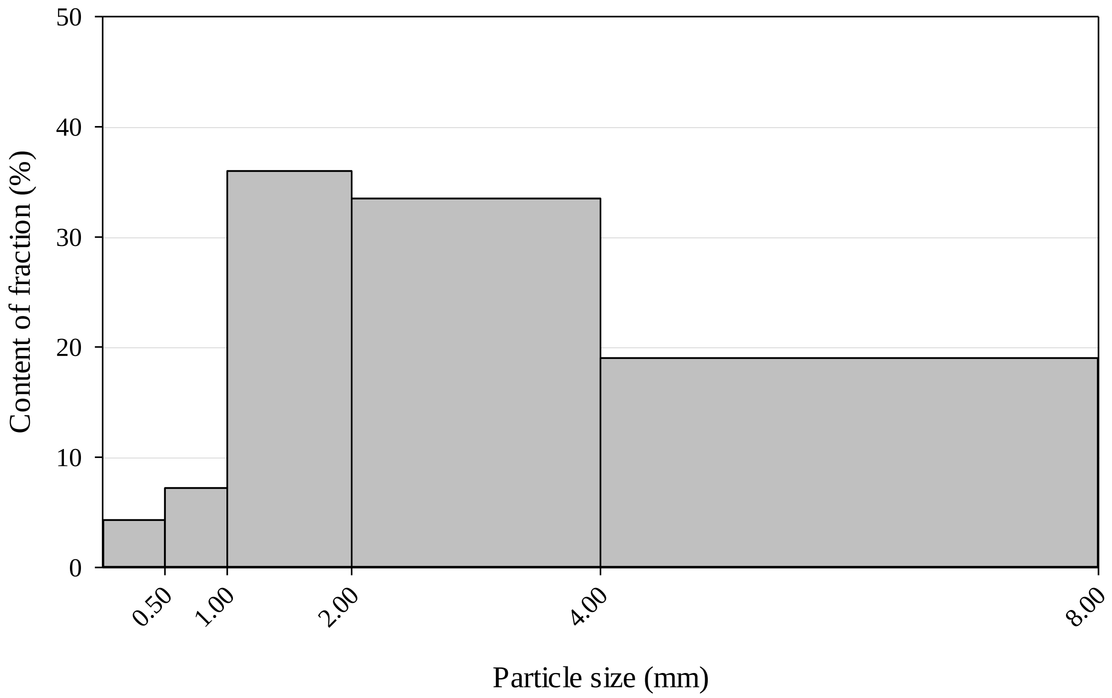

Figure 2. Content of fraction for post-production material.

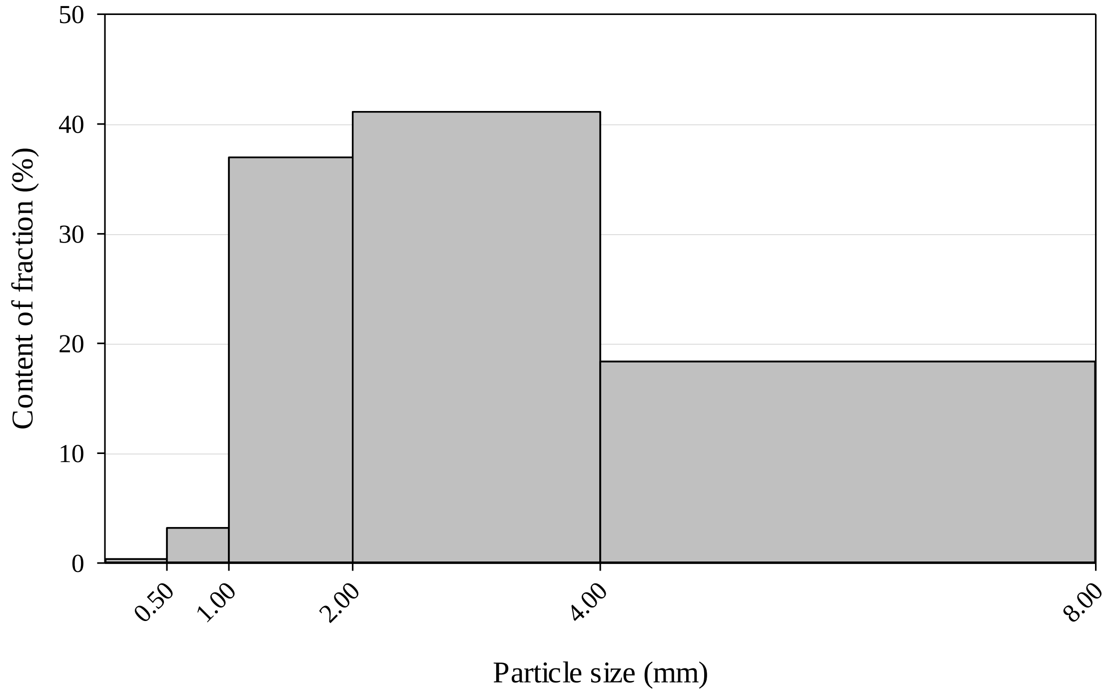

Figure 3. Content of fraction for forest biomass.

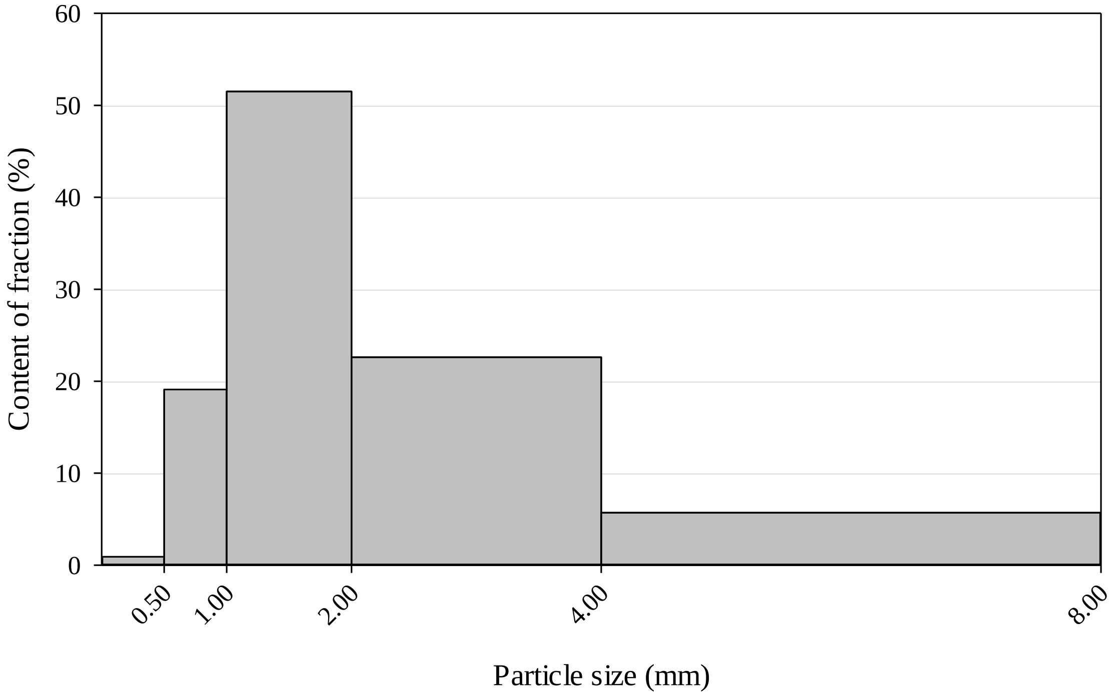

Figure 4. Content of fraction for agricultural biomass.

As can be seen in Fig. 5, 6 and 7, the particles from the residue have more homogeneous dimensions. They are much shorter, almost half the length of those from the forest biomass and slightly less than those from the agricultural biomass. The differences in particle dimensions between the different sieves are also smaller. This situation meant that the volume of the measuring container was more accurately filled, and there were fewer empty spaces.

50% lower density was shown by the oil plant particles characterizing the agricultural biomass groups. These particles were light, which is due to their anatomical structure, and softer and more brittle, as shown in Fig. 4 by the percentages of the fractions. As much as 52% were particles retained on a 1.00 mm mesh size site and passed through a 2.00 mm sieve. Compared to the other two groups of raw materials, whose fractional percentages are very similar, it can be seen that this particle preparation requires adjustment.

In the context of particleboard production, particle length is the most important parameter characterizing raw materials for this purpose. Long particles increase the flexural and tensile strength of particleboard. The slimmer the particle, i.e. the greater the ratio of length to thickness, the greater the surface area of the particles that are bonded to the other particles by adhesive bonding, which allows the high tensile strength along the fibers to be used to a greater extent. Short particles, on the other hand, give the particleboard its tensile strength perpendicular to the plane of the board, thus giving it greater uniformity. Both long and short particles are required to ensure good board quality (Ferreira *et al*. 2014, Farrokhpayam *et al*. 2015. As can be seen from the results shown in Fig. 5, the average particle length of the production residue from a 4.00 mm screen corresponds to that of a 1.00 mm screen for forest and agricultural biomass. Similarly with the average particle thickness. These imbalances must be taken into account when selecting the fractions for the individual layers of the particleboard to obtain the desired quality.

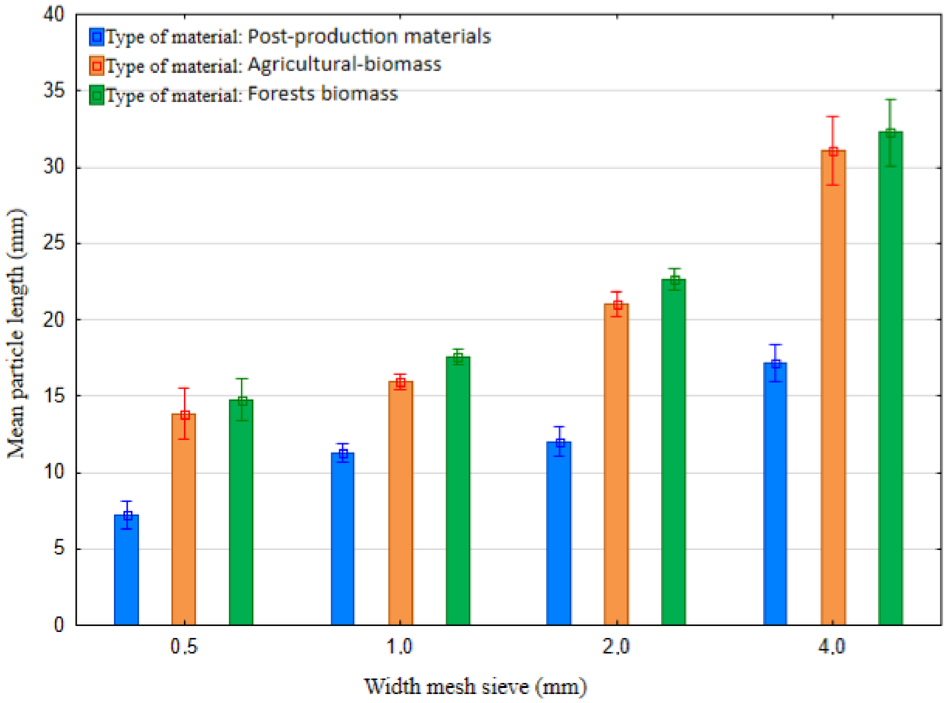

Figure 5. Average particle length of raw materials from dimensional analysis by sieve size.

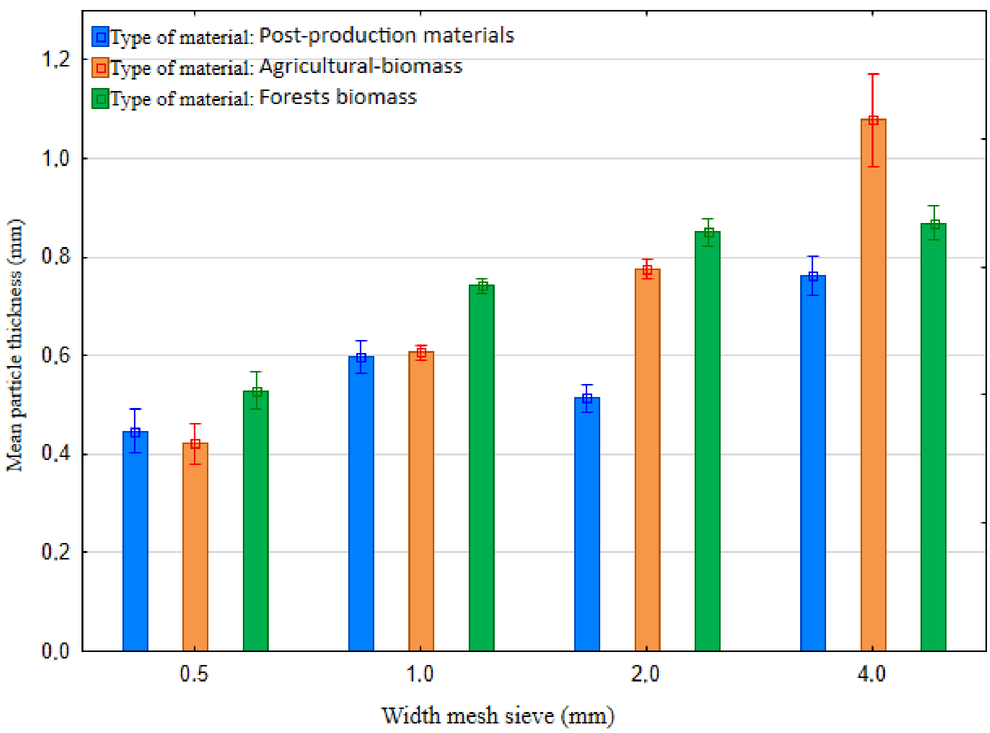

Figure 6. Average particle thickness of raw materials from dimensional analysis by sieve size.

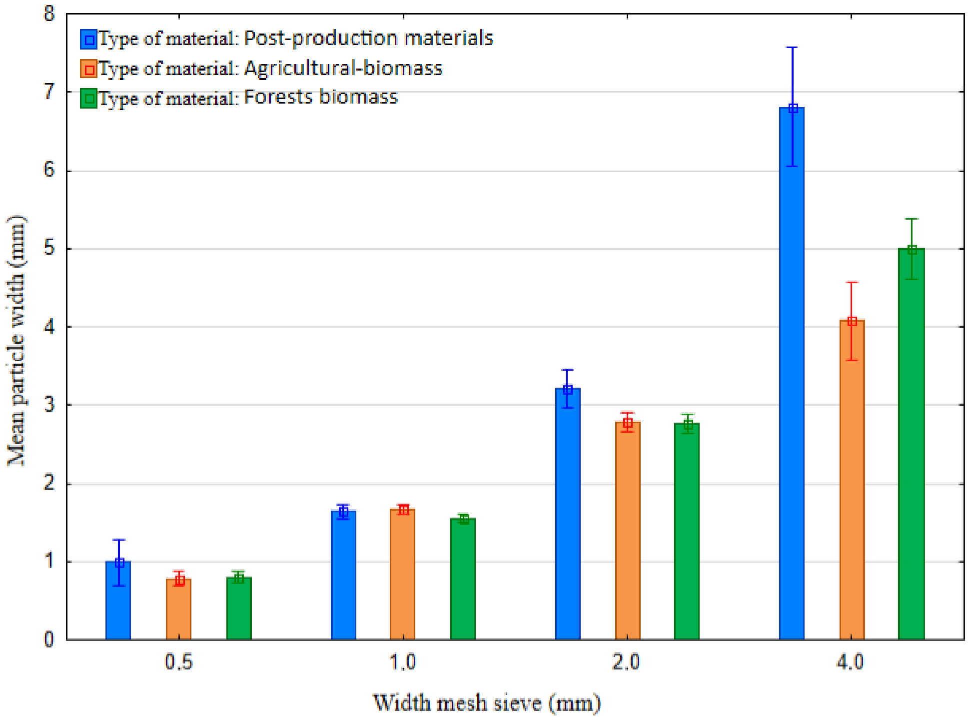

Figure 7. Average particle width of raw materials from dimensional analysis by sieve size.

Smaller particle size is a good characteristic, especially for alternative raw materials for particleboard production, where too much swelling of the boards in thickness is a common problem. Larger particle thickness results in an unfavorable increase in swelling per thickness and reduces bending strength. Agricultural biomass particles are similar in average length to pine particles and decrease evenly with decreasing sieve mesh size. The largest particles, however, are coarser than those of forest biomass, and for sizes of 1.00 mm and below resemble those of post-production. Perhaps the largest particles are covered by a layer of crumb found in oilseed straw, which affects their thickness. It is advantageous for as many particles as possible to cross with each other striving for a homogeneous board structure. Considering that in the mixture of forest biomass particles, more than half of the proportion are particles remaining on the 1.00 mm sieve, the proportion of slender particles is not high.

On this basis, it is speculated that from agricultural biomass, taking particles according to the same procedure as forestry particles, the resulting quality of the slabs, especially in terms of tensile strength, may be challenging. The studies carried out show the importance of adapting the process to the type of raw material being processed. Furthermore, it is necessary to introduce guidelines for the selection of particle sizes guided by their actual average size. Evaluation of the quality of technological particles is a key factor determining the efficiency of the process because lignocellulosic materials differ in terms of material indices.

CONCLUSIONS

On the basis of the tests carried out, the particles extracted from the three different groups of raw material in precisely the same way are of different sizes. They differ both in linear dimensions and in the quality of the fineness described by the percentage of particles during dimensional analysis. The particles from the post-production residue are characterized by a significantly smaller length compared to the forest and agricultural raw material. The forest biomass yielded the largest particles. When extracting particles from raw materials of different groups, their different structure must be considered. Due to the fact that the proportions are different, it is necessary to adjust the parameters of technological operations to the specificity of the processed raw material or to introduce guidelines for the selection of particle sizes guided by their actual average size. This will enable operational efficiency in obtaining particles of the desired size and better quality particleboard.

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Streszczenie: *Charakterystyka cząstek z części przygotowawczej w procesie produkcji płyt wiórowych.* Produkcja płyt drewnopochodnych, uwzględniająca innowacje materiałowe, wiąże się z koniecznością dostosowania pracy urządzeń technologicznych do właściwości materiałów podstawowych i pomocniczych. W niniejszej pracy postanowiono sprawdzić wielkości cząstek po sortowaniu surowców reprezentujących 3 grupy: biomasę leśną - gałęzie sosnowe, biomasę rolniczą - słomę rośliny oleistej oraz materiał poprodukcyjny. Frakcje pobrano z sita o oczkach 2,00 mm z sortownika, którą zazwyczaj przeznacza się nawarstwę rdzeniową płyty wiórowej. Dla tej frakcji określono skład frakcyjny za pomocą analizy sitowej oraz również średnie liniowe wymiary cząstek i gęstość nasypową dla każdego surowca lignocelulozowego. Badania wykazały różnice pomiędzy poszczególnymi materiałami. Ze względu na zróżnicowane udziały frakcji, konieczne jest dostosowanie parametrów operacji technologicznych do specyfiki przetwarzanego surowca lub wprowadzenie wytycznych dotyczących doboru wielkości cząstek, kierując się ich rzeczywistym średnim rozmiarem. Jest to szczególnie istotne, gdyż odpowiednie przygotowanie surowca przekłada się na jakość produkowanych z niego płyt i efektywność całego procesu.

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