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PROPERTIES OF PARTICLEBOARD MADE FROM RECYCLED MUNICIPAL WASTE AND WOOD PARTICLES

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ABSTRACT

Particleboard consumption in the furniture industry is high, and the wood raw material costs required for particleboard production are also high. Therefore, the incorporation of cheaper recycled raw materials into the particleboard structure is welcome and the economic costs of their production are reduced. The aim of this research was to find out the possibilities of processing recycled municipal waste in a commonly produced structure and incorporating it into the particleboard in an optimal proportion. Another goal was to determine the effect of the recycled material proportion on the selected particleboard physical and mechanical properties so that boards can be used for common furniture interior applications. Single-layer particleboard with 10%, 15%, 20%, 25% and 30% of recycled waste were produced, followed by three-layer boards with the proposed optimal 15% recycled waste in their core layer. The following properties of particleboard were tested: flexural strength, swelling, water absorption, density (according to the relevant provisions of EN). The effect of the proportion of recycled waste on board properties was manifested in comparison with the control samples, the reduction of the mechanical values was moderate. The bending strength values of three-layer particleboards with a 15% recycled waste content in their core layer were at an average level of 9.7 N/mm^2. The required level of bending strength of 11 N/mm^2 was not achieved. It was caused by the recycled elements manufactured shapes which were not slim enough and, in combination with the slim wood particles, worsened the properties of the manufactured particleboard. Adjusting the recycled elements' shape and pressing conditions makes achieving the standard required values of the particleboard properties possible.

Keywords: particleboard; recycled plastic waste; physical properties; mechanical properties.

INTRODUCTION

Technologies in the woodworking industry are considering a number of innovations and advances in the use of recycled materials, as the conservation of natural resources and recycling become an increasingly important issue. The trend of today is the recycling of man-made waste, which is suitable, even necessary, to be processed and thereby reduce its volume (Irle *et al.*, 2012, Barbu *et al.*, 2014).

Even manufacturers of wood composite boards are influenced by new trends and increasingly strict ecological criteria. In order to reduce the cost of input raw materials, they are forced to process recycled waste, and therefore the technological equipment and tools used in woodworking plants are adapting to this trend, becoming flexible in processing different input materials (Maloney 1993, Ihnát *et al.* 2020, Lübke and Ihnát 2018, Adeniran 2021).

The advantage of using recycled waste is the increase in market competitiveness for the production of composite materials. Recycled waste can also be used in particleboard production. This is evidenced by a number of research papers by experts from around the world who have dealt with and are engaged in this idea. The use of alternative raw materials such as agricultural biomass and recycled wood waste and by-products in particleboard production. It is a viable approach to respond to the increased global demand for wood-based materials, and it is a key circular economy principle as well as discussed extensively by Lee *et al.* (2022). Nguyen *et al.* (2023) present and discuss the available studies on the utilization of waste wood resource for wood-based panel production. They indicated that the majority of waste wood research was from Europe. Also, Baharuddin *et al.* (2023) conducted an extensive study, and they stated that environmentally friendly or green materials are more commonly used in the furniture making industry. The knowledge of the environmental risks including the depletion of natural resources, the impact of pesticides, as well as the amplifier and enforcement criteria of good practice have led to an increase in the practice of recycling waste materials. Particleboard is used mainly in the furniture industry, but they are used in the production of construction and carpentry products, in construction and in other industries as well. Therefore, a large amount of wood raw material is consumed for the production of particleboard. Wood raw material in the production of particleboard can be replaced to a certain extent with recycled waste; however, due to the diversity of recycled waste used in particleboard, it can cause certain quality problems related to its composition and its changed production technology (Faisal *et al.*, 2022, Sommerhuber *et al.*, 2016, Ajayi *et al.*, 2019).

The aim of this research was to find out and describe the effect of different proportions of recycled plastic municipal waste with a certain standard manufactured structure on particleboard production with its adequate density. The intention was to find out the effect of the amount of recycled plastic municipal waste on the physical and mechanical properties of particleboard and to determine the optimal proportion of a specific type of recycled waste in the core particleboard layer so that the physical and mechanical properties of particleboard do not deteriorate and that particleboard with a certain proportion of recycled waste in their core layer is usable for furniture purposes (Falemara *et al.*, 2015, Ihnát *et al.*, 2017).

MATERIALS AND METHODS

Two types of particles were used in the production of three-layer particleboard. The fraction of fine particles was determined for the particleboard surface layers which did not change either in the case of the reference particleboard or in the case of the investigated particleboard with a modified core layer. The spruce wood particles for the surface layers of particleboard had dimensions from 0.125 mm to 1.0 mm. The fraction of coarser particles was determined for the particleboard core layer. The spruce wood particles for the core layer had dimensions from 0.25 mm to 2.5 mm. In the case of the reference particleboard, coarser particles were used in the core layer in the amount of 100%, in the case of the investigated particleboard with a modified core layer, the share of core particles was reduced to 85%, depending on the weight share of the added recycled waste recommended by this research. The particles for the core layer were dried to a moisture content of 2% and for the surface layers to a moisture content of 4%.

The recycled waste used for the production of the modified core layer of particleboard was based on sorted municipal waste from the refuse-derived fuel (RDF) category and is officially referred to as iRDF (i = innovative). RDF is a fuel produced from various types of waste such as municipal solid waste (MSW), industrial waste or commercial waste.

iRDF is created by high-speed grinding of common municipal waste as a by-product. Recyclable and inert components are first sorted out of municipal waste, e.g. metals, mineral components, bio-components suitable for composting, some types of plastic, cardboard, etc. The remaining component mainly contains non-recyclable plastics (up to 70%), paper, wood, textile materials and usually ends up as energy raw material for cement plants and waste incinerators or, in the worst case, only ends up in a landfill, as there are few capacities for ecological waste incineration (Fig. 1) (Internal unpublished company's materials 2023).

Fig. 1 Ground recycled iRDF waste prepared for its mixing with wood particles and adhesive mixture for the particleboard production.

iRDF as a raw material has the potential for significantly more significant use as a secondary fuel. However, it is necessary to adjust the size of its elements. The result of the innovative high-speed grinding process is the new so-called fractal structure of ground waste elements which enables better compatibility of plastics contained in a heterogeneous matrix (Internal unpublished company's materials 2023).

The company Castor&Pollux s.r.o., Bratislava deals with the processing and use of recycled plastic waste. It also deals with the idea of ecological use and waste recycling by incorporating these raw materials into building materials. After consultations, the use of iRDF as an addition to particleboard was tested as an example of using a certain proportion of iRDF in them and, thus, achieving this waste recycling in structural furniture materials. The company supplied the necessary amount of iRDF raw material in a normally produced structure. It was assumed that despite supposed unsatisfactory shapes, the fractal structure of iRDF after high-speed milling (Fig. 2) could have a good affinity of its plastic elements to the wood particles in the particleboard matrix without the need to increase the amount of applied glue compared to the usual technological procedures of their production (Internal unpublished company's materials 2023).

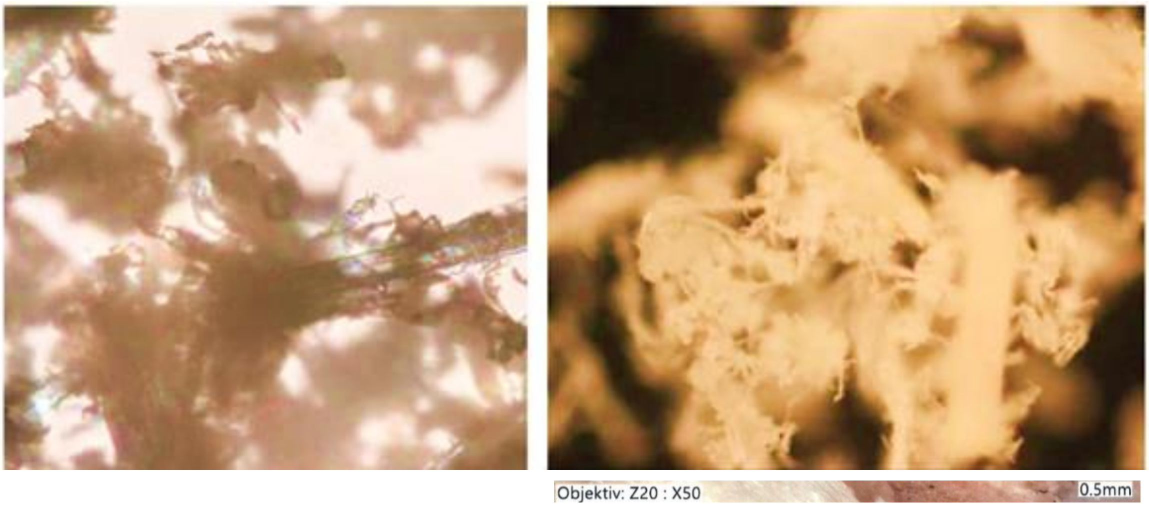

Fig. 2 Microscopic structure of recycled waste iRDF (Internal unpublished company's materials 2023).

Industrial urea-formaldehyde adhesive (UF) was used for the production of experimental particleboard (Pizzi 2018, Dunky 2003, Frihart and Hunt 2010). The adhesive KRONORES PBU 1151 F with dry matter content 68.11%, with viscosity (Ford) 4mm/20°C – 73 s, adhesive pH was 8.45, with the condensation capacity 100°C – 68s was used in the particleboard core layer. In the particleboard surface layers, the adhesive KRONORES PBU 1742 F with dry matter content 69.53%, with viscosity (Ford) 4mm/20°C – 85s, adhesive pH was 8.58, with the condensation capacity 100°C – 46s was used. The adhesive mixture was composed of the adhesive and chemical auxiliary substances (paraffin emulsion and hardener). A hardener (57% aqueous solution of ammonium nitrate) was used in an amount of 4% dry matter per weight of the adhesive used. Paraffin emulsion with a dry weight of 35% in an amount of 0.75%, based on the dry particle weight, was used for the board hydrophobisation.

The laboratory press equipment CBJ 100-11 from TOS Rakovník, Czech Republic was used for particleboard production. Pressing took place according to the usual three-stage pressing diagram for particleboard with a maximum specific pressure of 5.75 MPa and a pressing factor of 8 s/mm of board thickness. The pressing temperature for both types of particleboard was 220 °C (Réh 2017, Réh and Vrtielka 2013, Sellers 1985). The selected pressing parameters used are identical to the pressing parameters used in normal practice in order not to disrupt, prolong or complicate established manufacturing processes in any way.

In the first step, a single-layer particleboard with dimensions of 36 x 26 cm and a board thickness of 1.5 cm was produced in the laboratory. We assumed the density of manufactured particleboard of ρ = 600 kg.m^{-3} and their moisture after air conditioning was w = 6%. Variants of single-layer particleboard were produced with different proportions of iRDF in the entire volume of the board in the amount of 10-30% in increments of 5%. Five sample variants were produced this way. The mass ratio of particles and iRDF was Tsv:R = 100:0; 90:10; 85:15; 80:20; 75:25; 70:30. The adhesive mixture deposit for particles was 11%. Ten boards were made from each variant and subjected to tests: strength in three-point bending (dimensions of test samples 350 x 50 mm), density (dimensions of test samples 50 x 50 mm), swelling (dimensions of test samples 50 x 50 mm), absorbency (dimensions of test samples 50 x 50 mm). It was made ten pieces of reference samples by single-layer particleboard without the addition of iRDF.

After finishing the pressing process, the particleboard was placed in a rack to cool down and subsequently it was air-conditioned for 7 days until its final moisture content of 7% was reached. A total of 50 pieces of single-layer particleboard were produced.

Based on the tests of the single-layer particleboard properties and after their evaluation, it was decided that the optimal proportion of recycled material in terms of the most suitable strength properties of the boards for the subsequent production of three-layer particleboard in their core layer will be 15% of recycled material and 85% of core wood particles. We assumed the density of manufactured particleboard $\rho = 600$ kg.m^{-3} and their moisture after air conditioning should be w = 6%. The adhesive mixture deposit for the core particles was 7%, the adhesive mixture deposit for the surface particles was 11%. To determine the physical and mechanical properties, ten three-layer particleboard with dimensions of 36 x 36 cm and a thickness of 1.8 cm which is the most commonly used in practice, were produced.

From the point of view of the visual effect of the modified particleboard, recycled material was added only to the core layer, so that the particleboard surface would remain unchanged in color and structure compared to the unmodified particleboard. The addition of recycled material to the particleboard core layer also has a positive effect on their homogenous all-wood surfaces, as the subsequent particleboard surface treatment, most often by lamination or veneering, can take place in the standard mode without considering the presence of plastic substances in their structure.

Both surface layers of the three-layer particleboard consisted of pure spruce fine particles, and the recycled material was added only to the particleboard core layer, and it was not visible in the board surface. Pressing took place according to the commonly used three-stage pressing diagram, as in everyday particleboard production in practice. The three-layer particleboard was conditioned to a moisture of 7%. Ten pieces of three-layer particleboard with a proportion of recycled plastic waste of 15% were produced. Eight boards were used to determine their properties. Two particleboards were used for visualization, one particleboard was used as a sample of raw particleboard with a modified core layer with recycled material, and the other particleboard was used for veneering to visually document its possible use in the furniture industry.

The determination of selected properties of particleboard produced using recycled waste and wood particles was carried out according to the valid provisions of technical standards (EN 314-1:2004, EN 310:1993, EN 636:2012+A1:2015, EN 317:1993, EN 319:1993, EN 323:1996, EN 309: 2005, ISO 16983:2003, EN 312: 2010).

The three-point bending strength of single-layer particleboard was determined using the TIRA test 2200 testing machine according to the technical standard EN 319:1993.

RESULTS AND DISCUSSION

The density of single-layer particleboard with 10%, 15%, 20%, 25% and 30% of recycled plastic waste did not change itself essentially due to the addition of recycled material, because the calculated weighting values were correct and the laboratory weighing, and all layering were also carried out correctly; the small deviations were caused only by slight imperfect manual particles layering. The densities of the fifty manufactured particleboards were in the range of 555 – 575 kg/m^3 and this is in accordance with the expected calculated values.

Since the density of bulk iRDF (ground plastics, paper, textile) is low compared to wood particles, with the increase of its share in particleboard, it was possible to observe a slight decrease in particleboard density.

The average density of ten three-layer particleboards with a 15% share of recycled material in the core layer reached values in the range of 582 – 597 kg/m^3, it was stable, and it was in accordance with the assumed calculated values.

Table 1 shows the average bending strengths of single-layer particleboard with iRDF proportions from 10 to 30%.

Tab. 1 Average three-point bending strength values of single-layer particleboard with 0%, 10%, 15%, 20%, 25% and 30% iRDF.

Single-layer particleboard composition	Average values bending strength (N/mm^2)
reference values of spruce particleboard (ref.)	5.26 (0.8)*
10 % share iRDF	5.28 (0.7)
15 % share iRDF	5.12 (0.8)
20 % share iRDF	4.59 (1.0)
25 % share iRDF	3.12 (0.9)
30 % share iRDF	2.81 (1.3)

* The standard deviation is given in parentheses

As the proportion of iRDF in single-layer particleboards increased, their bending strength decreased. The highest value of bending strength was achieved by the samples with the smallest added proportion of recycled material of 10%. Particleboard with a recycled content of 15% had almost the same bending strength, there was a minimal difference in strength values. The samples with the highest proportion of 30% of the recycled material achieved the lowest strength. We consider these bending strength results to be understandable and justified, because the ground recycled material did not have such element dimensions that would resemble the particle slenderness, ensuring good bending strength of the boards after they have been pressed. Pressed particles cannot have small and even irregular dimensions, particles are always produced with predetermined dimensions and slenderness. Ground recycled material was far from this requirement. Therefore, the smaller the amount of recycled material added to the particleboard, the more the strength properties of the particleboard will resemble conventional industrially produced particleboard (Ihnát *et al.*, 2020, Adeniran, 2021, Ihnát *et al.*, 2017).

Based on these results, it was decided to press three-layer particleboard with a proportion of 15% recycled material in their core layer, since the bending strength of single-layer particleboard with the addition of 15% recycled material (5.12 N/mm^2) approximately corresponded to the value of the bending strength of single-layer particleboard without the addition of recycled material (5.26 N/mm^2). 15% share of recycled material was chosen for the three-layer particleboard also because its bending strength value is almost similar to the more favorable value of 10% share of recycled material, and by increasing the amount of iRDF used in particleboard (from 10% to 15%), its higher utilization and greater saving of wood raw material occurs.

The determination of the three-point bending strength of three-layer particleboard was also performed on the TIRA test 2200 test machine according to the technical standard EN 319:1993. The bending strength values of three-layer particleboard with a 15% iRDF content in their core layer are shown in Table 2.

Tab. 2 Strength values in three-point bending of three-layer particleboard with a share of 15% iRDF in their core layer.

	Average value (N/mm^2)	**Minimum value (N/mm^2)**	**Maximum value (N/mm^2)**
ref.	11.76**	11.02	14.71
1.	8.86	8.58	9.59
2.	9.42	8.90	9.93
3.	9.69	9.28	10.59
4.	9.78	9.34	10.16
5.	9.82	9.71	10.02
6.	9.90	9.56	10.39
7.	10.02	9.81	11.01
8.	10.12	9.77	10.80
Average value	9.70 (1.7)*	9.37	10.31

* Standard deviation is given in parentheses
** Average value (N/mm^2) for 10 test samples

For particleboard of the P2 category (boards for indoor equipment for use in a dry environment, including furniture), the technical standard EN 312: 2010 sets a minimum bending strength value of 11 N/mm^2. The reference laboratory board made by us from pure spruce particles achieved an average bending strength value exceeding the required limit and this corresponds to our previous experience (Réh 2017, Réh and Vrtielka 2013) as well as that of other authors (Ihnát *et al.*, 2017, Pędzik *et al.* 2021). The bending strength values of three-layer particleboards with a 15% iRDF content in their core layer were at an average level of 9.7 N/mm^2. The required level of bending strength of 11 N/mm^2 was not achieved. The reason is the irregular shape of the recycled material without the necessary slenderness which is common in the case of particles. The particle slenderness ensures sufficient values of particleboard bending strength. In the case of replacing 15% of the thin particles in the core layer with recycled material, the overall strength of the particleboard decreased slightly, understandably.

However, it is not an unsolvable or insurmountable problem. It is possible to slightly increase the amount of applied adhesive mixture (unfortunately, certainly at the expense of production economy) which will ensure the necessary increase in bending strength values above 11 N/mm2. Perhaps intensifying the pressing conditions would be sufficient, e.g. by increasing the specific pressing pressure, higher pressing factor or changing the pressing diagram; all this would need to be verified by further research. With further research, it is possible in any case to verify the amount of added recycled material, naturally downwards or, in particular, to modify the shape of the manufactured recycled elements so that they better meet the needs of their incorporation into particleboard. The fact that some values of particleboard with a 15% recycled content in the core layer were already approaching the limit of 11 N/mm^2 (10.59 or 10.80 N/mm^2, even 11.01 N/mm^2) within the framework of this research, it indicates that most of these proposals will be feasible.

Tests of particleboard thickness swelling and particleboard absorbency after 2 and 24 hours were performed for three-layer particleboard with an iRDF content of 15%.

Determination of the thickness swelling of particleboard with a proportion of recycled material of 15% in their core layer during 2 and 24 hours was carried out according to the provisions of the technical standard EN 317: 1993. Table 3 shows the average swelling values achieved.

Tab. 3 Swelling values after 2 and 24 hours of three-layer particleboard with a proportion of 15% iRDF in their ore layer.

	2 hours			24 hours		
	thickness	thickness difference	swelling	thickness	thickness difference	swelling
	(mm)	(mm)	(%)	(mm)	(mm)	(%)
ref.	18.11	+ 2.21	12.2	18.11	+ 5.09	28.1
1.	18.13	+ 6.44	35.5	18.13	+ 8.54	47.1
2.	18.15	+ 6.39	35.2	18.15	+ 7.92	43.6
3.	18.22	+ 6.42	35.2	18.22	+ 7.81	42.9
4.	18.07	+ 6.49	35.5	18.07	+ 7.65	42.3
5.	17.91	+ 5.89	32.9	17.91	+ 7.90	44.1
6.	18.02	+ 6.11	33.9	18.02	+ 8.33	46.2
7.	18.08	+ 6.42	35.5	18.08	+ 8.62	47.7
8.	18.10	+ 6.02	33.3	18.10	+ 8.29	45.8
average	18.08	+ 6.36	34.6 (1.0)*	18.08	+ 8.13	45.0 (1.9)*

* Standard deviation is given in parentheses

The thickness swelling of particleboard with 15% recycled content in their core layer during 2 and 24 hours is slightly higher than the values of standard spruce particleboard. The reason is the presence of absorbent recycled particles in the particleboard core layer. The swelling values of modified particleboard with recycled material are not significantly higher compared to unmodified particleboard and they are acceptable. By properly and consistently covering the entire surface of the boards with an interior finish (decorative veneers, laminates) incorporated in furniture applications (including edges), slightly increased swelling values of modified particleboard are less significant.

Determination of the water absorption of particleboard with a proportion of 15% recycled material in their core layer during 2 and 24 hours was carried out according to the customary practices, as the technical standard is currently not valid. Table 4 shows the average achieved water absorption values.

Tab. 4 Water absorption values after 2 and 24 hours of three-layer particleboard with a proportion of 15% iRDF in their core layer.

	2 hours			**24 hours**		
	weight	**weight difference**	**water absorption**	**weight**	**weight difference**	**water absorption**
	(g)	**(g)**	**(%)**	**(g)**	**(g)**	**(%)**
ref.	30.09	+ 8.96	29.7	30.09	+ 21.81	72.5
1.	29.20	+ 30.69	105.1	29.20	+ 37.66	129.0
2.	29.41	+ 27.84	94.7	29.41	+ 33.72	114.7
3.	29.17	+ 28.09	96.3	29.17	+ 32.80	112.4
4.	28.87	+ 27.45	95.1	28.87	+ 32.49	112.5
5.	28.55	+ 27.02	94.6	28.55	+ 31.85	111.6
6.	29.36	+ 29.12	99.2	29.36	+ 37.12	126.4
7.	29.51	+ 28.77	97.5	29.51	+ 35.16	119.1
8.	29.11	+ 28.39	97.5	29.11	+ 34.88	119.8
Average	29.15	+28.42	97.5 (3.2)*	29.15	34.46	118.2 (6.2)*

* Standard deviation is given in parentheses

The proportion of recycled material of 15% in the particleboard core layer affected their water absorption which increased significantly; basically, three times compared to standard spruce particleboard. It is again possible to justify this fact by the presence of absorbent recycled elements in the particleboard core layer. The water absorption of standard particleboard is always higher, but the modified particleboard core layer using the iRDF component in the proportion of 15% worsened the water absorption even more. The composition of iRDF (ground fine plastics, paper, various textile components, etc.) with disturbed surface homogeneity is an environment that absorbs and retains water. This increases the weight of the examined samples over time and the water absorption increases. The particleboard water absorption is problematic, and older (Maloney 1993, Youngquist 1999, Kamke and Lee 2007) and newer publications (Réh and Vrtielka 2013, Pędzik *et al.*, 2021, Benthien and Ohlmeyer 2013) draw attention to this fact.

The elimination of the particleboard water absorption of with a proportion of 15% iRDF in their core layer can also be considered in connection with the appropriate and consistent closure of the entire surface of the boards with an interior surface treatment (decorative veneers, laminates) incorporated in furniture applications (including edges) and thereby preventing the ingress of water or increased air humidity into them.

Some obvious connections emerge from the evaluation of all performed property tests of modified particleboard with the addition of iRDF. The reference sample of single-layer particleboard had an average density of 605 kg/m^3. The densities of the modified single-layer particleboard were lower, ranging from 555 to 575 kg/m^3. The density of bulk iRDF is low compared to wood particles, with the increase of its share in particleboard it was therefore possible to observe a slight decrease in the particleboard density. Recycled plastic waste absorbs the adhesive (applied in the mixture) to a higher degree than wood particles and, in addition, when pressed, it cushions more than wood particles, so that the internal structure of the pressed board is loosened. Therefore, this phenomenon will manifest itself in a small decrease in the board's density and, understandably, it will also manifest itself in the increased water absorption and swelling of the modified boards.

If recycled material was used in the core layer of three-layer particleboard, it means that the density in the particleboard core layer was lower than in the particleboard surface layers consisting of pure spruce particles without the presence of recycled material. The lower density of the particleboard core layer is a natural thing for all common particleboard types but the presence of recycled material in it reduced its density even more. This could be observed in the fractures in the test bodies after the bending strength test, and it can be verified more precisely by further research when measuring the density profiles of different types of modified particleboard. These observations are consistent with the works of other authors dealing with similar issues (Adeniran 2021, Réh 2017, Benthien and Ohlmeyer 2013, Tudor *et al.*, 2020).

In the thickness swelling of three-layer particleboard with a 15% share of recycled material, it was possible to record a significant increase in the board thickness after 2 hours, up to twice as much. Recycled waste as an additive to particleboard has greater hydrophobic properties compared to wood, and in addition, in pressed particleboard, during the standard process of particleboard production, it creates small gaps in its structure for the possible ingress of water or increased air humidity. We assume that the recycled waste, in addition to insufficient adhesion with the wood particles with the creation of gaps for water penetration, probably also absorbed the paraffin emulsion which was added as a chemical auxiliary substance to the adhesive mixture to increase the particleboard hydrophobicity (Fig. 3). The diverse structure of iRDF which does not help to maintain good physical and mechanical properties of modified particleboard, is evident.

Municipal waste could serve as potential raw materials for particleboard manufacturing. However, every type of municipal waste has its own issue that prevents it to be used effectively. Municipal waste is among the possible materials for particleboard manufacturing as particleboard manufactured from it often displayed satisfactory physical and mechanical properties. Still, in some case, the incorporation of some portion of municipal elements are necessary to further enhance its performance (Lee *et al.*, 2022).

Study of Santos *et al.* (2021) presents a challenging approach that addresses the efficient management of the organic fraction of municipal solid waste by hydrothermal carbonization for the development of novel sustainable materials. By adjusting the technological parameters of the manufactured boards, they achieve their suitable properties when incorporating municipal waste shares and they conclude that this way of using municipal waste is feasible.

The objective of study of Harshavardhan and Muruganandam (2017) was to use municipal dry waste, plant waste and saw dust collected from various sources to make particle boards with each individual item as well as a combination of these in various ratios. The physical and mechanical properties of these boards were determined by using a series of tests like moisture content test, water absorption properties, thickness swelling, tensile test, compressive test, and flexural strength. The results were compared and most of the samples were found to comply with the IS standards.

These findings are also consistent with the results of the work of Baharuddin *et al.*, (2023).

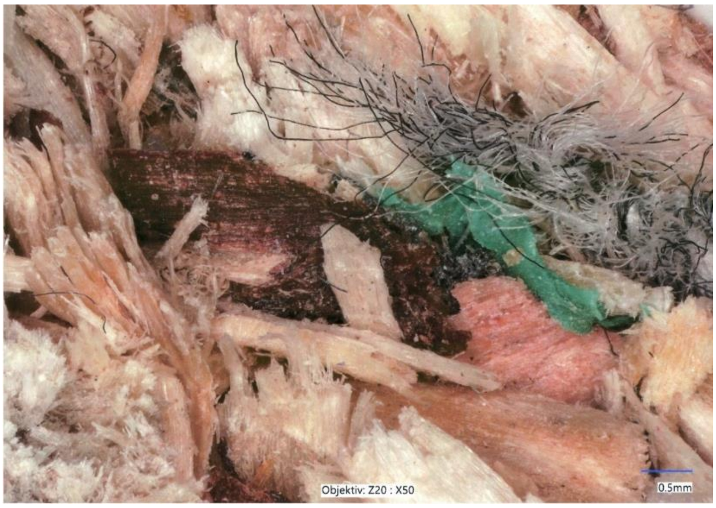

Fig. 3 Microscopic structure of the core layer of modified particleboard with the presence of recycled iRDF waste.

During the production process of single-layer particleboard at a pressing temperature of 220 °C, the melting of some recycled elements on their surface in contact with the pressing plates was observed, and thus impaired handling when removing the boards from the press. This phenomenon worsened as the proportion of recycled material in the particleboard increased. It was necessary to gently separate the boards mechanically from the pressing plates of the press, and this slightly disturbed the boards surface structure. The presence of recycled material in the structure of single-layer particleboard and therefore also on their surface was evident (Fig. 4). In the production of three-layer particleboard without the presence of iRDF in the surface layers, this phenomenon understandably did not occur.

Fig. 4 Recycled iRDF together with wood particles present on the surface of pressed single-layer particleboard.

The surface of one pressed modified three-layer particleboard with veneering was upgraded for demonstration purposes. Its appearance (Fig. 5 left) was excellent, the presence of iRDF in its structure is understandably invisible. The presence of iRDF in the core layer of the three-layer particleboard was not visible even in the surface layers of raw particleboard without surface treatment (Fig. 5 right).

Fig. 5 Modified three-layer particleboard with the presence of 15% iRDF in the core layer surface treated with veneering for demonstration purposes (left) and raw particleboard with the presence of 15% iRDF in the middle layer without surface treatment (right).

CONCLUSION

In the research, attention was paid to determining the influence of the proportion of recycled iRDF plastic waste in single-layer and three-layer particleboard on selected physical and mechanical properties.

All produced particleboard with iRDF addition had deteriorated properties compared to unmodified particleboard. In the thickness swelling of three-layer particleboard with a 15% share of recycled material, up to a two-fold increase in thickness was recorded compared to the reference sample and a several-fold increase compared to the EN 317 standard, which sets the permissible swelling for particleboard to a maximum of 8%. It is assumed that recycled plastic waste is more hydrophobic than wood spruce particles. Moreover, in the particleboard structure, it will create spaces for water to penetrate into them during the production process. And in addition, recycled plastic waste (ground fine plastics, paper, various textile components, etc.) also absorbs the paraffin emulsion added to the adhesive mixture for particleboard pressing.

The bending strength of single-layer particleboard decreased with the increasing proportion of recycled material in the board. Recycled iRDF is produced regardless of its shape; its structure is irregular, without the necessary slenderness and strength which is common in the case of wood particles. The slenderness of the pressed particles during the particleboard production ensures their sufficient values of bending strength. In the case of replacing 15% of the thin particles in the core layer with recycled material, the overall strength of the particleboard decreased slightly, understandably (Samek 1989).

For furniture particleboard type P2, the technical standard EN 312 sets a minimum bending strength value of 11 N/mm^2. The bending strength of three-layer particleboards with a 15% iRDF content in their core layer was at an average level of 9.7 N/mm^2. Irregular shapes of recycled material without the necessary slenderness, were also reflected in the reduction of the mechanical properties of the produced modified particleboard. However, this deficiency can be solved. It is possible to increase the amount of applied adhesive mixture, intensify the pressing conditions, e.g., by increasing the specific pressing pressure, using a higher pressing factor, or changing the pressing diagram. Of course, this will increase the production cost, but the saved funds for wood raw material can balance this item. All this needs to be verified by further research and to be proven by more detailed calculations. With further research, it is possible to verify the amount of added recycled material, naturally downwards or, in particular, to modify the shape of the produced recycled elements so that they better meet the needs of their incorporation into particleboard.

If the producer of grounded iRDF waste solves the production of its elements in terms of a more homogeneous structure and slenderness of the produced shapes (it has promised), it will be possible to follow up on the previous research and develop a full-fledged three-layer particleboard with the presence of a certain amount of recycled iRDF in its core layer and thus saving the financial resources invested in purchasing wood raw material.

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