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Influence of the addition of pine chips waste on the properties of the concrete mix

Alicja Krajewska[1*], Monika Siewczyńska[1], Xymena Gross[2]

[1] Department of Civil Engineering, Faculty of Civil and Transport Engineering, Poznan University of Technology, pl. Marii Skłodowskiej-Cuire 5, 60-965 Poznan, Poland
[2] Faculty of Chemical Technology, Poznan University of Technology, pl. Marii Skłodowskiej-Cuire 5, 60-965 Poznan, Poland
* Corresponding author's e-mail: alicja.krajewska@put.poznan.pl

ABSTRACT

This article presents the results of a preliminary study of concrete samples with pine chips: the search for the optimum proportion of concrete mixture and waste in the mix, its workability, and the mortar's bending and compressive strength. By building on the properties of the concrete mix, which reaches its maximum strength value with time, the preparation time of plates is reduced by the pressing and drying process. The effect of the percentage of chips in the mix and the effect of chip fraction on mortar strength - bending test and stretching test are used. The research is conducted to determine the possibility of reusing wood waste in fibre-cement composites for construction applications. Depending on the chip fraction, they gained positive characteristics, the beam with a finer fraction achieved greater strength, similar to a concrete beam. Unground chips, on the other hand, maintained the bond, which did not occur in the finer fraction.

Keywords: pine chips, recycling, chipboard, fibre-cement composite, wood waste, LCA.

INTRODUCTION

Wood is applied in the construction of buildings in various forms, including as construction or decorative elements. When structural elements are produced, there is waste that can be used in various industries. The amount of wood waste is in general large, especially coming from the construction industry. They are mostly burnt in the production of heat and the rest goes to landfill. In 2016, it was estimated that in the European Union, wood waste ac-counts for 50 million cubic meters generated each year [1]. According to Eurostat data from 2023, the packaging industry produces more than 14 million tons of wood waste [2]. The use of recycled materials is becoming increasingly important. Wood waste has many uses, for example as wood-based materials used in construction. This is a way of managing wood waste [3–6].

In Poland, the commonly used material is pine wood, due to its high strength and resilience resulting from its softness and cohesiveness [7]. Wood, which can take a long time to reach the final product, goes through various stages of processing. Once the material is harvested, it is transported to the sawmill to remove the bark and the first defects.

During the processing process (Fig. 1), about half is the finished product, so the other half is waste, which is recovered as a recyclable product, e.g. chips used for the production of various types of board such as OSB or particle-cement board or fibre-board. Wood waste can be divided into two groups [8-11]:

- waste generated from the processing of the target material e.g. wood chips from board processing, pieces of wood with defects,
- waste generated from the consumption of the target product e.g. wooden pallets, construction parts from demolition, wooden parquets, furniture, doors, window frames, finishing elements e.g. laths.

The closed-loop economy involves maximizing the use of not only production waste, but also

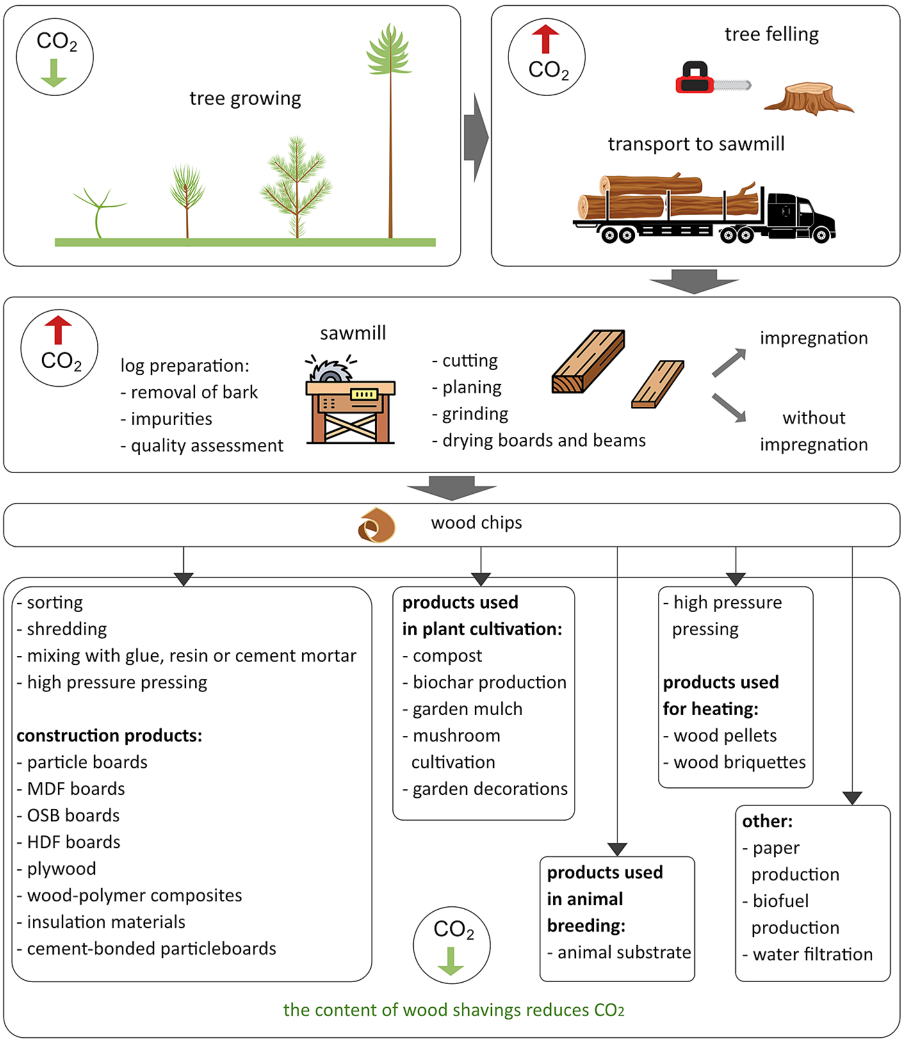

Figure 1. Process of material and waste wood generation

demolition components [12]. The life cycle analysis (LCA) used to assess the environmental impact of individual components or materials looks at five stages: production (A1–A3), construction process (A4–A5), use (B1–B7), C1–C4 end–of–life (C1–C4) and the potential for reuse, repair or recycling (D). The analyses also take into account transport, water and energy consumption [13–14]. The current focus is on the A1–A3 phase to produce as little pollution as possible during the pro–duction of building components, few manufacturers offer a recycling solution for their materials. The A1–A3 phase is very important from a life-cycle point of view, as the embedded materials make up the majority of the building structure. Only a small pro-portion of the finishes are changed during renovations. Wood is a low-emitting mate-rial. The GWP (Global Warming Potential) parameter is significantly lower than for steel or concrete. This is due to the absence of pollutants emitted during extraction. The analyses also take into account the carbon footprint emitted during transport and production of the finished product. Trees absorb CO_2 during growth, resulting in a negative value in the extraction stage component. For wood, which absorbs pollutants, the GWP value is around 4.5 times lower than for steel [15–17]. It is therefore a shame to waste wood waste by landfilling it. The reuse of this raw material can contribute to lowering the GWP of other building products. Currently, chips are used in the production of, among other things, cement and chipboard. Replacing part of the cement matrix in these with recycled chips will reduce the carbon footprint of the product. There are four stages in the production of Portland cement (1) crushing of the raw materials, (2) mixing of the materials in the right proportions, (3) combustion of the prepared mixture, during which a chemical process takes place, resulting in clinker, and (4) grinding of the materials, after pulverizing the clinker with a small amount of mineral, the resulting powder is referred to as Portland cement. In 2016, the consequence of Portland Cement production was 5 percent of global CO_2 emissions, while in 2021 it was already 11 per cent. It is worth noting the third stage, as it is during combustion that the main part of the emitted pollutants is generated. [18–20]. Combustion requires electricity, most of which is produced in Poland from burning coal. In 2019, the share of hard coal and lignite in electricity generation was almost 75% [21]. It can be seen that there is an increasing demand for cement, due to its widespread use in the construction of buildings, road building, dams and bridges, and consequently the pollution created during production continues to increase, so ways are being sought to reduce the GWP parameter of elements containing cement.

Wood waste as biomass can be sent to the paper industry or used to make building boards or furniture by combining the chips with resin or glue [22, 23]. The chips produced during the first wood treatment stage are clean, without chemical additives, while the demolition pieces may have been chemically treated against fungi and in-sects or painted and varnished [24]. If only the top layer of the item was soaked in protective agents, it can be grinded/sanded off or cut off. It is therefore important to sort the waste, as the resulting chips can have different properties and should therefore be recycled in different ways. It is important to collect the material to be recycled from one location and to use one type of tree consistently, so as to minimize the number of variables so that the end product has similar characteristics. Most construction companies carry out separate waste collection, but this is limited to only a few fractions (wood, gypsum, glass, mineral waste, plastics and metals). More accurate sorting requires more knowledge and commitment from employees and space on site. In addition, there is a problem with the competitiveness of the market for waste collectors in Poland, which generates a large cost that exceeds the actual benefits [25].

There is therefore a need to look for new methods of managing construction waste, including wood. Currently, there are several ways to use wood chips such as OSB or cement-bonded particleboards [26]. The OSB production process goes from drying the material, sorting, mixing the chips and adding the resin, which is the binder, forming the boards and finally pressing to obtain a compact surface [27]. Cement chipboard, on the other hand, for which waste can also be used, is made by mixing shavings, cement, additives and water, then forming layers of boards, pressing, curing, setting and drying [28, 29]. Particleboard is mainly used for stiffening, cladding floors, walls, roofs, even in vehicles, also in the furniture industry [30, 31]. Wood waste can be used as shavings and ground even as a partial alternative to fine aggregate, sand [32].

Due to the increasing use of the wood material, the widespread use of various types of boards and the increasing amount of waste associated with this, further elements are being sought for which wood shavings can be used [33]. Pine chips were used in the study, due to the widespread use of this type of wood in Poland and the large amount of waste. The raw material used in the study was in the form of raw chips, made from wood not contaminated with impregnates. It was used in the preparation of cement chipboard beams. This is a pre-liminary study to determine the direction of further analyses of the properties of cement and chipboard.

MATERIALS AND METHODS

The chips selected for the study came from a sawmill near Poznan, as waste from the processing of pine beams. The raw material was not protected by impregnation, so the influence of external factors such as chemical impregnation was neglected. To determine the moisture content, the material was divided into four samples weighing between 1.2 and 1.5 grams, each weighed before and after drying using a weighing machine. The moisture content results obtained are shown in Table 1.

Tests were planned for a cement-chip composite prepared by adding chips to the mortar standard and beams were formed. Cement during making the beams, then the slabs, CEM II/B-M (V-LL) 32.5 R - Portland cement clinker, silica fly ash and limestone - and CEM V/A (S-V) 32.5R-LH - milled Portland clinker, mineral additives,

Table 1. Moisture of the pine chips

No.	Moisture
	[%]
1.	20.413 +/- 3.805
2.	18.686 +/- 3.805
3.	25.439 +/- 3.805
4.	17.024 +/- 3.805

viz. The main constituents of the cement are Portland clinker (40÷64%), granulated blast furnace slag (18÷30%), silica fly ash (18÷30%) and a setting time regulator (calcium sulphate). It is a cement with a low hydration heat (LH). The first samples are made as 4 × 4 × 16 cm beams, even though the required dimensions are different in the EN 13986 standard for wood-based panels. Preliminary tests aim to determine the optimum formulation, consistency, mixability of the material. The beams provide the opportunity to carry out a flexural strength test, which is crucial for slabs that stiffen the frame structure.

Due to the chips being taken straight from the sawmill, where they are produced as processing waste, there is irregularity in their size (Figure 2). Some chips reach 4 cm. 1.200 ml of pine shavings were measured, varying in weight from 45 to 68 g (at the upper limit the beaker was tapped to put as much as possible in a certain volume, in subsequent cases the shavings were poured loosely).

In the first stage, beams were made with CEM V/A (S-V) 32.5R-LH: three variants of the concrete mix with pine shavings with different chip and w/c contents, and two variants without shavings with an adequate w/c ratio. Concrete mix was added to the measured amount of chips until the whole was covered and combined. The chip mix was then tamped in the moulds twice, one minute each time. The size and irregularity of the shavings did not allow for accurate alignment of the sample, which created a texture on the surface.

Recipes with chips contained between 4.3 and 7.34% of this material (by weight) [Table 2]. After the concrete had set after 24 hours, the beams were unformed, a disturbed and irregular surface can be seen to form the texture (Fig. 3). Due to the size of the pine chips, the surface of the beams is not uniform. Over time, however, this provides opportunities. With the prospect of using the recipe to make

Figure 2. Fraction of the chips (photo by A. Krajewska)

Figure 3. Texture of sample with chips after deformation (photo by A. Krajewska)

Table 2. Recipe of the trial samples

Sample	w/c	Chips	Concrete mixture			Percentage by mass		
			Cement	Water	Sum	Chips	Cement	Water
	[-]	[g]	[g]	[g]	[g]	[%]	[%]	[%]
1	0.5	68	874.67	437.33	1312	4.93	63.38	31.69
2	0.65	59	796.97	518.03	1315	4.29	58.00	37.70
3	0.5	57	480	240	720	7.34	61.78	30.89
4	0.5	0	657	657	1314	-	50	50
5	0.65	0	458	852	1310	-	35	65

slabs, they could form the bracing and façade of a building. Concrete building facades are becoming increasingly popular, so the element would fit in with current architectural trends [34].

After 8 days for beams with chips and 7 days for beams without chips, the first bending test was performed to determine the recipe with the highest bending strength. A visible crack develops during the bending test, but the log does not break in two (Fig. 4). This is due to the use of long chips of up to approximately 4 cm, which effectively hold the joint (Fig. 4). This is an advantage when using the material as a stiffening plate, as even in the event of a crack it will hold the structure together despite the loss of strength. In order to obtain a specimen for compression testing, the beam must be independently broken, split or repeatedly bent to obtain two sections. Figure 5 shows the beam after breaking, looking as if the second part has been torn out. Chips behave similarly to dispersed reinforcement, for which steel, glass or polypropylene fibres are commonly used. Their function is to improve strength, deformation characteristics [35]. Despite the lower bending strength for a specimen with chips, a crack is formed despite exceeding the strength, whereas a specimen without chips splits in two after exceeding the strength.

Figure 4. Scratching of a beam with a large chip fraction after exceeding the bending strength (photo by A. Krajewska)

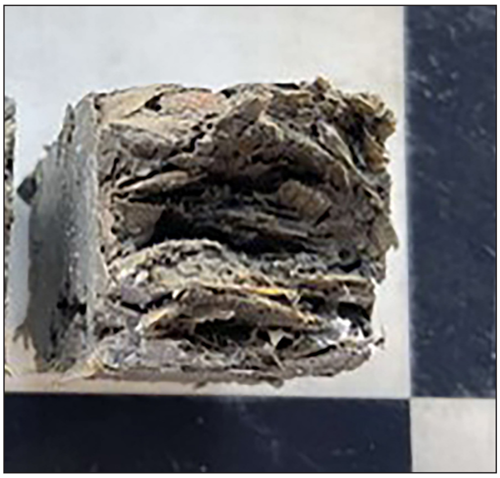

Figure 5. Section of a beam with a large chip fraction (photo by A. Krajewska)

During the compression test, the plunger is pressed into the sample, which had to be stopped by hand. Despite the appearance of visible cracks, the test would continue (Fig. 6). Due to the fact that wood is soft compared to concrete, the plunger did not sense significant resistance and pressed into the beam. Its deterioration is evident, de-spite the failure to complete the test. A total of 16 chip specimens were made with this fraction, a result without manual stopping was obtained in only one test.

RESULTS

The results confirmed the choice of formulation 1 (Fig. 7). Despite the high initial strength, sample 1 achieved the lowest increase in strength, relative to the strength after 7 days, of the group of samples containing chips - 49%. The strength of sample number 3 (with chips) increased by about 65%, but is lower than sample number 1 by about 0.5 MPa. On the other hand, considering the growth value, samples 1 and 3 were similar at 1.432 and 1.518 MPa, respectively. The flexural strength of sample No. 4 increased by more than 70 percent, increasing by 2.356 MPa. This is a result of the absence of chips in the sample, as concrete reaches its strength after 28 days, so 100% of the material has improved.

In order to achieve a higher percentage of use of a low GWP material such as wood, consequently low carbon, the chip content of the sample was increased. To achieve this result, additional samples were made with the new formulations of the corresponding 14.9 per cent chip weight (with sample load) and 23.8 per cent chip weight. After

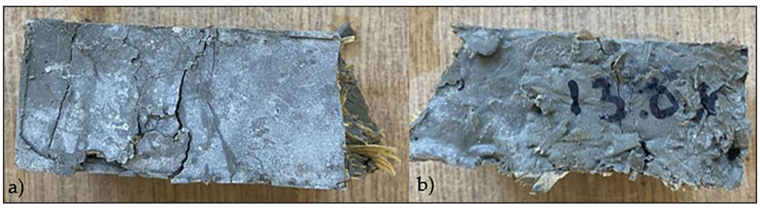

Figure 6. Section of a beam with a large chip fraction a) side; b) top (photo by A. Krajewska)

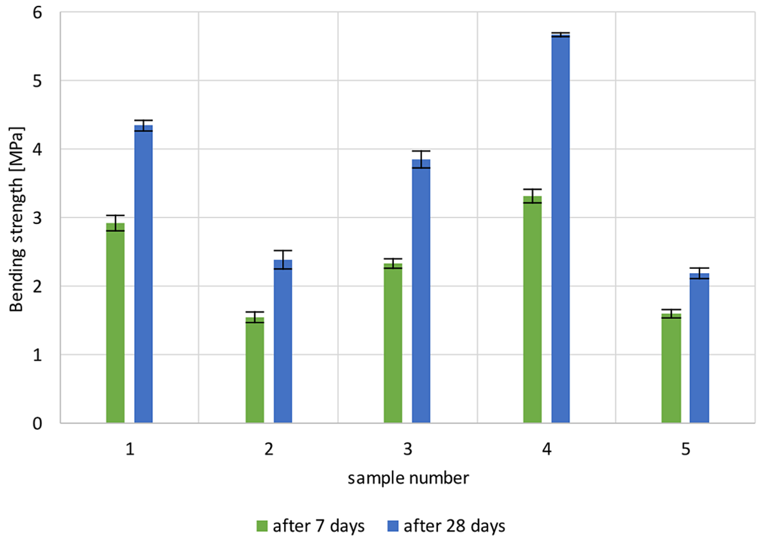

Figure 7. Bending strength measured after 7 and 28 days

two days, they were taken out of the moulds. Already at the 23.8% chip content in the recipe, mixing difficulties appeared. The 23.8 per cent variant failed on pull out attempt due to too little slurry, which did not allow the chips to be adequately joined together. The shavings were visibly surrounded by the concrete mix, but the amount of mix did not allow for a stable sample. The sample with the lower chip content was topped up. This was done to create conditions similar to those that occur when the material is compressed. This has the effect of reducing the space between the chips. 3 bales were made after testing, a flexural strength of 0.229 MPa was achieved after 7 days (one bales tested), and 0.574 MPa after 28 days (one bales tested), it was not possible to obtain a result from the third bales due to a lack of reading. Therefore, adding more chips did not translate into better strength parameters. Further samples will be made ac-cording to recipe 1 (Table 3 and 4).

Change in chip fraction and type of cement for comparison of the changes that would occur with a different type of cement and a finer chip fraction, sample 1 (with chips) and sample 4 (without

Table 3. Bending strength after 7 days

Lp.	Bending	
	After 7 days	Standard deviation
	MPa	
1.1	3.731	0.411
1.1	4.651	
1.2	4.413	0.344
1.2	3.644	

Table 4. Bending strength after 28 days

Lp.	Bending	
	After 28 days	Standard deviation
	MPa	
1.1	4.315	0.538
1.1	5.261	
1.1	5.123	
1.1	4.522	
1.1	4.234	
1.2	5.643	0.748
1.2	5.827	
1.2	4.421	
1.2	5.972	
1.2	4.885	

chips) were repeated with CEM II, as they obtained the highest flexural strength at the same time with a lower w/c (Figure 7). To improve the consistency associated with the chip fraction, the chips were milled, to a finer and more regular fraction, from which beads of recipe 1 for CEM II were again made (Fig. 8).

Due to the use of a smaller fraction, the combination of mix and chips was considerably smoother than with the original chip size (Fig. 9). This translated into the ability to even out the surface of the beam, the texture of which, despite the lack of regularity, was smoother than with unground chips.

After 7 days, both formulations with shavings reached comparable values, their flexural strength was higher than that of the concrete beam. In view of this, the pine chips improved the

Figure 8. Fraction of chips a) after blend, fine fraction b) before blend, thick fraction (photo by A. Krajewska)

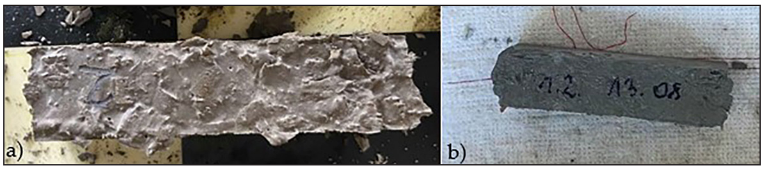

Figure 9. Texture of beams top side a) Sample 1.1 with thick fraction, b) Sample 1.2 with fine fraction (photo by A. Krajewska)

initial strength for the beams. However, after 28 days, the flexural strength of the concrete beam increased significantly and reached the highest value of the tested variants. A significant increase was also recorded with variant 1.2, which used a finer fraction of chips, its strength was similar to the concrete variant, lower by only 5.6% (Fig. 10). Due to the Due to the small number of samples, the standard deviation value was increased by using the Student-Fisher coefficient.

For the bending test, it is worth noting that, due to the smaller chips, the specimen be-haves similarly to the base concrete variant. It cracks into two parts, allowing the material to be obtained for the compression test without problems (Fig. 11). The problem of not being able to read the force did not arise during the compression test. Also in this situation, the sample behaves similar to the concrete variant, the finer chips do not soften the entire beam.

The difference in beam cross-sections after bending for different chip fractions is also apparent. The specimen in 1.2. in this case again resembles the concrete specimen, where the cross-sectional surface is relatively smooth, the chips are considerably short-er and do not protrude as significantly from the surface as in specimen 1.1. (Fig. 11, 12).

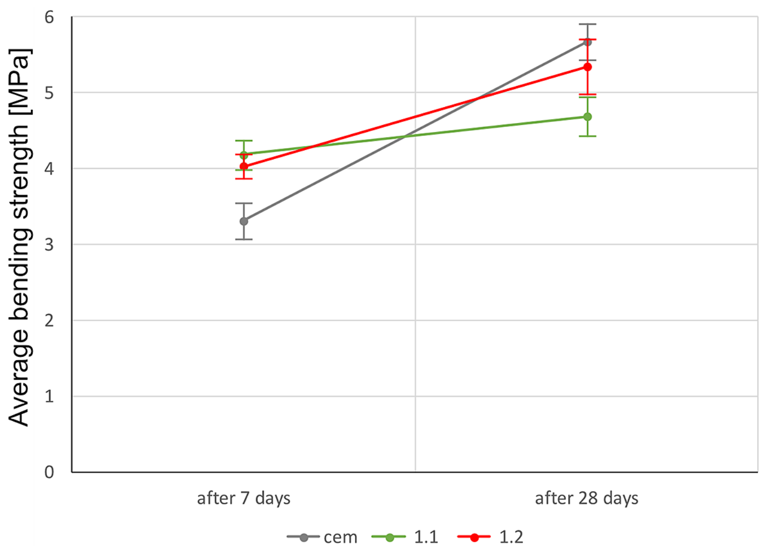

Figure 10. Comparison of strength increase for beams with and without different chip fractions

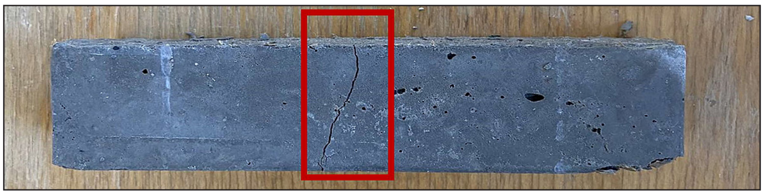

Figure 11. Scratching of a beam with fine chips after exceeding the bending strength (photo by A. Krajewska)

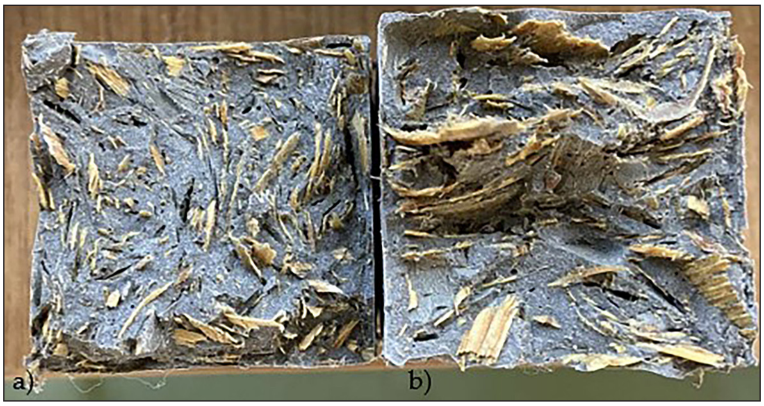

Figure 12. Comparison of cross-sections of beams with different fractions a) fine, b) thick (own photo)

CONCLUSIONS

Based on the research conducted, it was found that both unground chip and smaller fraction bales show advantages (Fig. 13) depending on their intended use.

Based on the results of the conducted research, the following conclusions were drawn:

- When using pine shavings in the original size, the process is shorter as it does not require a grinding step. With a small amount, it did not significantly affect the length of the study, but when analysing mass production there would be additional time required to obtain the correct fraction. The need for suitable equipment and electricity increases - with this fact comes the economic aspect as well as the ecological one, which is important when using recycled materials.
- Beams with chips of a larger fraction, when tested for flexural strength, held the joint despite exceeding their strength. This is a significant difference compared to specimens with a smaller chip fraction and specimens without chips, which separated into two parts when their strength was exceeded in this test.

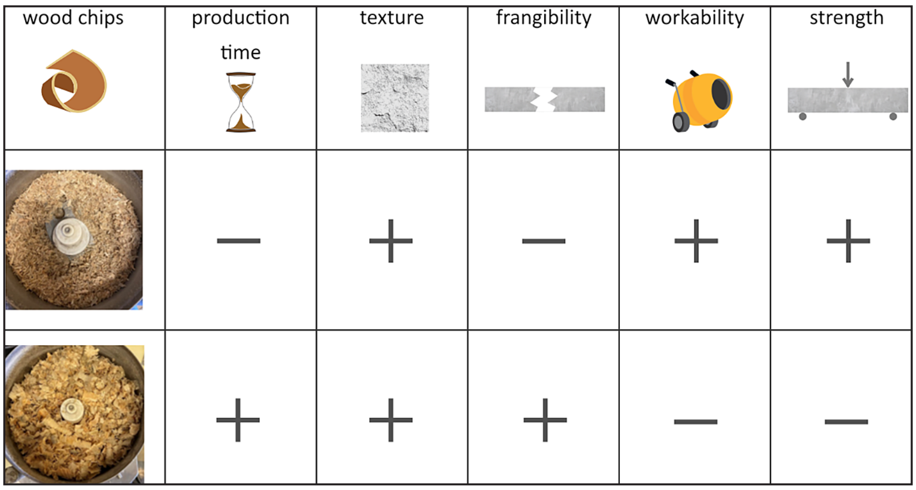

Figure 13. Comparison of the characteristics of the mixture and the sample in relation to the chip fraction (own graphic)

- The advantage of the beam with the finer fraction was its strength, whose growth pattern was similar to the concrete beam. Initially (in the test after 7 days), the chips in both cases improved the strength, which was higher than the strength of the beam without chips. However, when the concrete reached its full strength (after 28 days), the beam with the fine chip fraction achieved a lower result, much closer than the beam with larger chips.

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