Detailed Analysis of Modified By-Product from Cement-Bonded Particle Board Fabrication

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Abstract: - This article presents a study focusing on a detailed analysis of the properties of a by-product from the production of cement-bonded particle boards, specifically cuttings. The volume of cuttings increases with the growth of production every year and these cuttings are not used further. Such cuttings represent landfill waste. Considering the composition of these cuttings, their re-use in the further production of particle board appears to be the most suitable option.

Therefore, cuttings were subjected to adjustment of composition, size-reduction and separation of grain of defined size. Subsequently, all properties relevant to their possible re-use in production of particle boards were established. Thermic and caloric methods were predominantly used to define the contents of wood matter in relation to the cement matrix. Graininess, mineralogical composition and efficiency indexes, etc. were also studied

Key-Words: - Cement-bonded particle board, by-product, waste, alternative raw material, cuttings, grinding, analysis, thermal, calorimetric methods, mineralogy

1 Introduction

Cement composites with organic fillers are quite frequently used construction materials. The reason for using these composite materials is the advantageous combination of a cement matrix with renewable material. Wood chips (serving as a dispersed reinforcement) in cement composites improve their mechanical properties, including bending strength, hardness, impact strength [1], [2], compressive and tensile strength [3], [4].

Nonetheless, there are also certain disadvantages, including low elasticity module, degradation and mineralization in an alkaline environment [5]–[7], size instability, higher variability of physical and mechanical properties [8], [9] including inconsistent reinforcement [10].

Therefore, various additives are used for improved interaction, including the elimination of possible undesirable interactions between the cement matrix and the organic filler. These additives also contribute to limiting volume changes of the wood chips, due to fluctuations of temperature and humidity. The volume changes in chip could result in activating processes leading to gradual degradation of the resulting composite system.

The wood matter contains 40–50% cellulose, 15–25 % hemicellulose, 15–30% lignin, pectin and other compounds [8], [11], [12]. While cellulose is practically insoluble, hemicellulose is soluble in both water and alkaline environments. Lignin is a stable polymer in both alkaline environments and water. Saccharides slow the process of hydrating reactions in the cement matrix. It was found that even low concentrations (0.03–0.15 %) of saccharides (originating in the hemicellulose) have a retarding effect on the beginning of solidification and the strength of cement composites [13].

The presence of saccharides in the cement matrix changes the reaction of tricalcium aluminate (C3A) which is the fastest reacting component of cement. Extraction components contained in the wood matter may also be absorbed onto the cores of calcium hydroxide, slowing the hydration of tricalcium silicate (C3S) [14], [15].

According to [16], [17] the inhibiting compounds (hemicellulose, etc.) cause the formation of an impermeable film around non-hydrated grains of cement, further slowing the formation of calcium hydrosilicates (C-S-H) and portlandite (CH). The addition of the aforementioned mineralization additives enable limiting the negative effects of saccharides (contained in the wood chips) during the course of maturing of the cement matrix.

Cement-bonded particle boards are a typical representative of composites combining a silicate matrix and wood filler. These boards have various applications in construction – floors, ceilings, dividing walls, roofs, concrete forms, etc. But the most common use of cement-bonded particle boards is in offset facades where the cement-bonded particle boards are used as the inset base cladding. The annual production of a Czech producer of cement-bonded particle boards (CIDEM Hranice, a.s.) amounts to approximately 55,000m^3.

At this volume of production, a large amount of by-products from the boards are also created that are not further used. These include dust (from sanding) and cuttings from formatting to required measurements. Of these, cuttings present approximately 4,190 m^3/year (5,000 t/year). These cuttings are parts of the boards of various thicknesses (typically 14 to 24 mm), usually in strips ranging in width from 5 to 20 cm, depending on customer production requirements.

Considering the potential these cuttings offer (given their composition compatibility with the cement-bonded particle boards), there is an opportunity for their return to use. Given that these are larger pieces of material, a suitable system for processing their composition must be chosen.

Several options may be considered – crushing, grinding, the subsequent elimination of undesirable compounds, etc. Therefore, extensive research is necessary for the reuse of cuttings for production of cement-bonded particle boards. Detailed analysis of all properties and relevant factors will enable the effective optimization of cement-bonded particle board production.

The reuse of cuttings for board production will also significantly contribute to improving the environment by decreasing waste volume. Aside from using cuttings for cement-bonded particle boards, other potentially suitable options include using cuttings with modified composition. An interesting option may include use as a dry levelling compound for floors.

A detailed analysis of cuttings from modified composition (such as through a size-reduction process) particularly raises the issue of whether such modification may negatively affect their properties. For example, a rather fundamental question regards possible disruption of the mineralization layer, specifically the mineralization of the wood matter contained in the waste.

As mentioned above, wood is the source of saccharides that negatively affect maturing of the cement matrix. Thus mineralization additives must be used in the production of cement-bonded particle boards. In cases where mineralization (specifically the mineralized layer) has disrupted by the modification of cuttings, this effect must be recognized and properly addressed within the production process (e.g. increasing the quantity of mineralizing agents).

2 Methodology

2.1 Modification of cuttings composition

The cement-bonded particle board cuttings (see Fig. 1) were supplied directly from the production line of the CIDEM Hranice, a.s.

Fig. 1 Cuttings as a by-product from formatting cement-bonded particleboards during their production (producer – CIDEM Hranice, a.s.)

Optimum steps in terms of simplicity and effectiveness must be designed for their possible use for cement-bonded particle boards, as well as for their use as a dry levelling compound for floors or other uses.

A jaw crusher (see Fig. 2) was found to be an effective method of size reduction by eliminating particles of undesirable size or composition. A total of three approaches to size reduction were tested, where the jaw distance of the crusher was set to – 6, 8 and 10 mm (also referenced as C06, C08 a C10; see Fig. 2b). Such treated cuttings were subjected to further analysis of all essential properties.

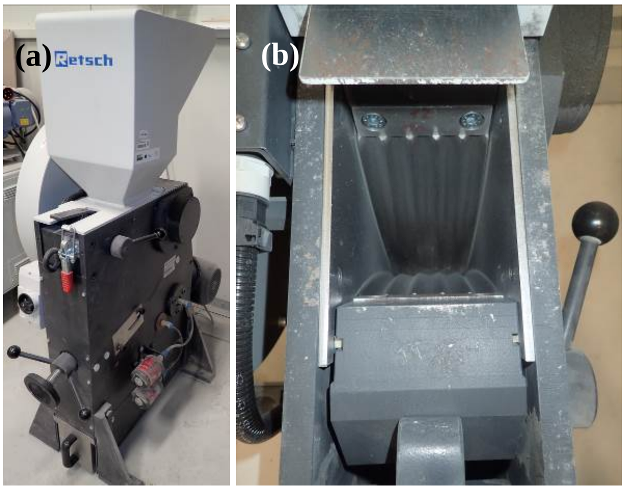

Fig. 2 (a) Jaw crusher (Retsch BB200 Mangan); (b) detail of the crusher jaws

2.2 Particle size determination

Following the size reduction process, all samples were further analyzed with respect to size and distribution of particles using a device based on the laser diffraction principle; see Fig. 3. However, this device is limited by the maximum 2 mm size of grain. Grains over 2 mm were therefore analyzed using sieve analysis up to the necessary size of grains.

For further and more detailed analysis, samples of size-reduced cuttings were divided into several groups according to grain size – 0-0.063 mm, 0.063-0.125 mm, 0.125-0.25 mm, 0.25-0.5 mm, 0.5-1 mm, 1-2 mm, 2-4 mm, 4-8 mm and 8-16 mm. All these groups of grains were separately evaluated and analyzed.

Fig. 3 Device for particle size distribution analysis (Malvern Mastersizer 2000E System EPA5011 including accessories)

2.3 Thermal analyses

In case that the use of particles containing wood matter from the cuttings (or already separated wood chips) was found unsuitable, their use as an additive to a fuel might be considered. Such fuel could be used by devices using energy from pyrolysis energy, such as a several-percent addition to various boilers, etc.

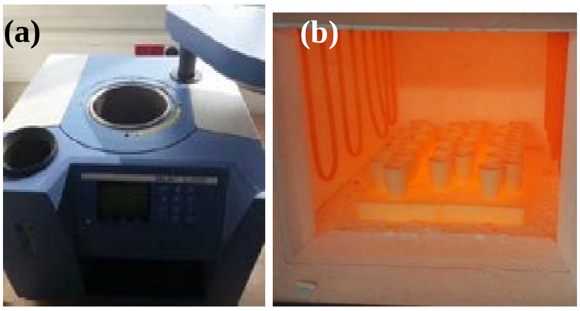

Fig. 4 (a) Device for calorific value determination (IKA C200); (b) Detail of electric furnace during annealing loss (thermal decomposition of samples)

For this reason, a calorific value was also established in case of the cuttings (see Fig. 4a). Therefore, crushed cuttings were separated into several groups according to size of grain and the calorific value was established for each group separately. Calorific value also partly provides evidence of the presence of wood matter within the given group of grains.

With respect to evaluating the ratio of the cement matrix and wood matter in the individual groups of grain, annealing loss (AL) was determined, up to 1000 °C (see Fig. 4b).

2.4 Mineralogical composition

A mineralogical analysis using DTA (differential thermal analysis) was carried out to quantify and eventually identify basic mineralogical and amorphous phases. The intent was primarily the identification of hydrating products in the matrix.

DTA was also used as analytical technique for evaluating mineralogical composition, as well as the mutual ratio of the cement matrix and wood matter in the cuttings. Among other results, the content of essential components in the cuttings (calcite, portlandite, CSH, etc.) was quantified using DTA. This analysis was performed up to do 1000° C, to obtain results comparable to those established through annealing loss. All samples had to be reduced to the grain size of 63 µm for the purposes of DTA analysis.

2.5 Activity index assessment

In principle, this test is based on the EN 450-1 technical standard that is primarily intended for ashes, but a suitably modified process may be generally used for any substitutive additive. The efficiency index characterizes a ratio (in percentages) of compressive strength of standardized test bodies (of 40 × 40 × 160 mm in size) from mortar prepared with an X% of weight formed by a reference cement and Y% of weight by the additive, and the compressive strength of standardized test bodies from mortar prepared from reference cement as X+Y%. The mortars are then tested at the same age, specifically after 28 and 90 days of maturing. Gradual substitution of cement in the ratio of 10, 15 and 20% (of weight) was chosen with respect to the expected activity of the fine-grain ratios obtained from the cuttings.

3 Results

3.1 Modification of cuttings composition

As explained above, the parameters of the cuttings (particle size, separation of matrix and wood matter, etc.) were processed using a jaw crusher. The structure of the individual grain sizes from 0-63 μm to 8-16 mm is depicted on the photographs below in detail (see Fig. 5 to 13). These are only selected details for comparison of modified cuttings, groups C06 and C10. Fraction 0 to 63 μm may be characterized as a very fine powdery substance that upon closer examination did not contain wood chips (see Fig. 5).

Small wood particles could be identified in fractions from 63 μm to 125 μm. These were typically bare wood chips with a minimum of cement matrix attached to their surface (see Fig. 6). The reason for this is that wood chips entering the production of cement-bonded boards are of a considerably larger size. Therefore, the group of grains, ranging from 63 μm to 125 μm contains small wood particles that were formed by damaging the original wood chips during the crushing of board cuttings.

Fig. 5 Detail of particles with size 0 to 63 μm (a) cuttings crushed with jaws set at 6 mm; (b) cuttings crushed with jaws set at 10 mm

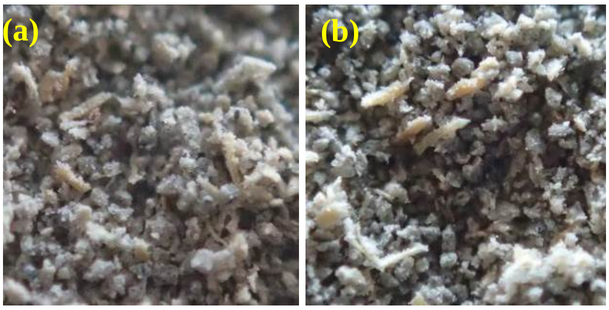

Fig. 6 Detail of particles with size 63 to 125 μm (a) cuttings crushed with jaws set at 6 mm; (b) cuttings crushed with jaws set at 10 mm

The presence of a larger quantity of wood chips was identified in the fraction ranging from 125 to 250 μm. Modified cuttings C10 (see Fig. 7b) contained a slightly larger ratio of wood chips with attached remnants of the cement matrix. Similar to particles ranging from 125 to 250 μm, wood chips containing tightly bond cement matrix on their surface in C10 were also found in fractions, meaning 250 to 500 μm (see Fig. 8) and 500 to 1,000 μm (see Fig. 9) to a slightly larger extent. To the contrary, the mentioned fractions C06 showed a more extensive scope of damage to wood chips. From these aspects, C08 may be characterized as intermediate.

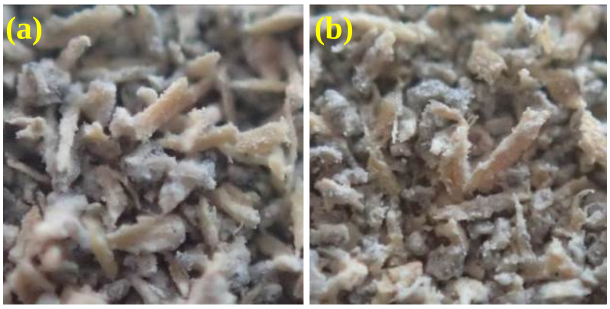

Fig. 7 Detail of particles with size 125 to 250 μm (a) cuttings crushed with jaws set at 6 mm; (b) cuttings crushed with jaws set at 10 mm

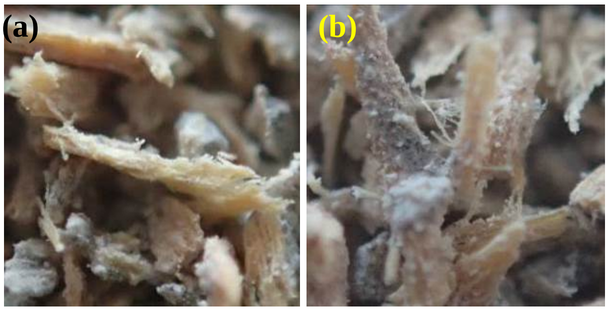

Fig. 8 Detail of particles with size 250 to 500 μm (a) cuttings crushed with jaws set at 6 mm; (b) cuttings crushed with jaws set at 10 mm

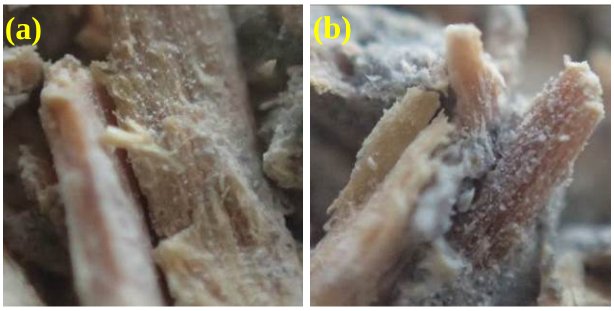

Fig. 9 Detail of particles with size 500 to 1,000 μm (a) cuttings crushed with jaws set at 6 mm; (b) cuttings crushed with jaws set at 10 mm

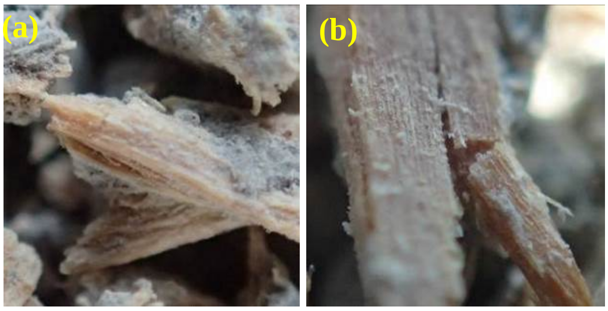

Fig. 10 Detail of particles with size 1 to 2 mm (a) cuttings crushed with jaws set at 6 mm; (b) cuttings crushed with jaws set at 10 mm

This fact could be ascribed to differences in maximum closure of the jaw of the crusher. To achieve a narrower gap, the movement of the jaws causes increased pressure on the entry material (cuttings of cement-bonded particle boards) added to the crusher.

The presence of mostly composite particles containing attached cement matrix and wood chips is apparent from the following photographs (see Fig. 11 to 13).

Fig. 11 Detail of particles with size 2 to 4 mm (a) cuttings crushed with jaws set at 6 mm; (b) cuttings crushed with jaws set at 10 mm

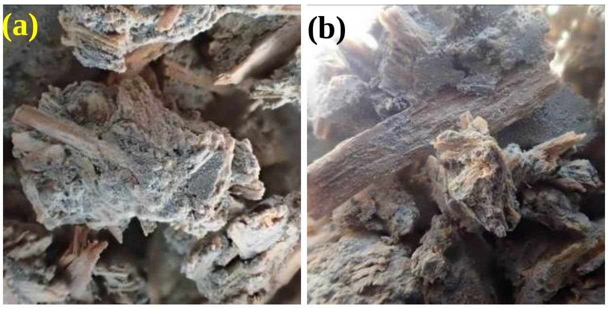

Fig. 12 Detail of particles with size 4 to 8 mm (a) cuttings crushed with jaws set at 6 mm; (b) cuttings crushed with jaws set at 10 mm

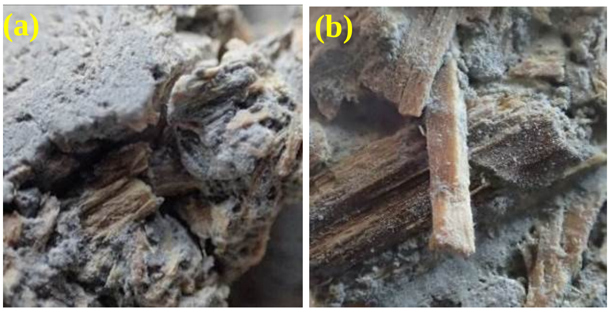

Fig. 13 Detail of particles with size 8 to 16 mm (a) cuttings crushed with jaws set at 6 mm; (b) cuttings crushed with jaws set at 10 mm

As is apparent from a detailed visual assessment, the composition modification of the cuttings (varied methods of crushing) had an effect on their structure, in particular the damage to the wood chips, bonding of the remnants of the cement matrix on the wood chips and possible cracks appearing in larger-size particles (particularly those over 4 mm).

3.2 Particle size determination

Modifying the size reduction process in the jaw crusher was significantly apparent. The differences are shown in curves in the graph below (see Fig. 14). In the case of C06 and C08, the difference was more notable in terms of larger grains, specifically from 2 mm upward. To the contrary, in case of a greater distance of the jaws, at 10 mm, the course of the graininess curve is notably different in the range from 63 µm to 8 mm. The difference between C08 and C10 in the range from 500 µm to 8 mm fluctuates in the interval of 8 to 15%, which could be considered a significant divergence.

With regard to the usability of the cuttings with modified composition, increased fineness is desirable. Upon considering the course of all graininess curves however, the 8 mm setting between the crusher jaws appears optimal.

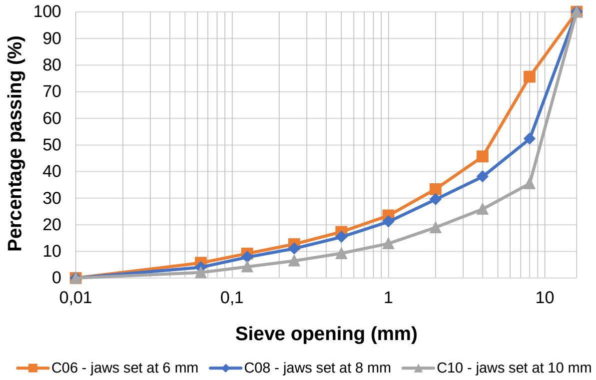

Fig. 14 Particle size analysis of crushed cement-bonded particleboard cuttings for all settings of jaws (6 to 10 mm)

Graininess curves show very similar values of fluctuations in grain size up to 63 µm.

3.3 Thermal analyses

Subjecting the modified samples to thermal analyses is very important from the perspective of further possible uses of cuttings. The reason for this is the considered application of this alternative material into silicate construction materials. This requires an understanding of the ratio between the matrix and wood chips in the individual fractions of cuttings. The size-reduction process causes proportional changes (gradually separating the cement matrix from wood matter, the wood chips and matrix are further refined, etc.).

The results establishing the calorific value (see Fig. 15) provide evidence regarding two fundamental facts: the first if the given matter's ability to release energy in form of heat during its burning. This could be used for various burning processes (boilers or other equipment in heat plants, power plants, etc.; through modification of an existing fuel). The above graph highlights increased calorific values of grains ranging from 1 to 8 mm. The value of fractions ranging from 8 to 16 mm is approximately the same with parameters of intact cement-bonded particle boards. In the direction from 2 mm to 0 mm grains, the calorific value decreases. Fractions from 0 to 63 µm show zero calorific value.

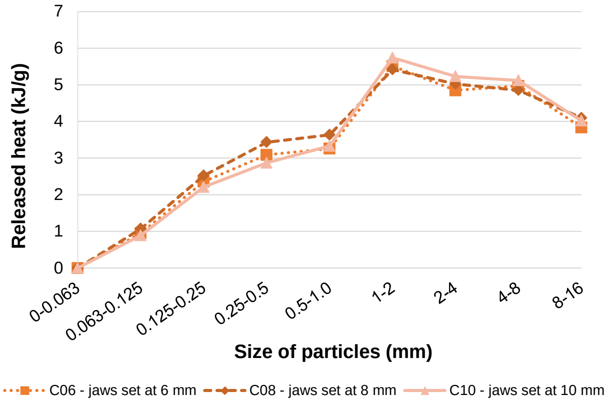

Fig. 15 Calorific value analysis of crushed cement-bonded particle board cuttings for all settings of jaws (6 to 10 mm)

This relates to the second important fact that partly indicates the presence of wood mater in the samples analyzed. It may therefore be possible to partially estimate the changing ratio of wood chips and cement matrix in relation to the fluctuations of calorific value. As apparent from the above graph (see Fig. 15), the only fraction among the examined variants C06 to C10) that does not contain wood matter is the group of grains ranging from 0 to 63 µm. All other fractions above 63 µm contain certain ratios of wood chips.

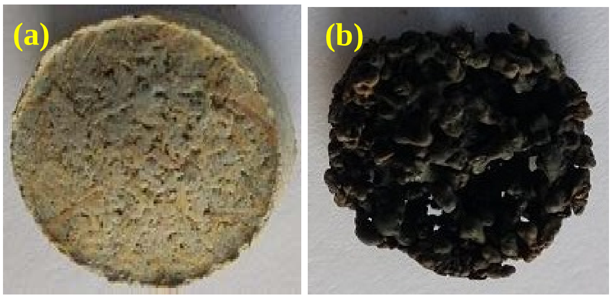

Fig. 16 Sample of C08 (particle size 1 to 2 mm); (a) before and (b) after calorific value analysis

The differences in the course of calorific value curves prove the effect of different conditions of the size-reduction method. C10 shows lowest calorific values up to the 1 mm size of grain and highest from 1 to 8 mm. Therefore, a redistribution of wood chips and cement matrix does take place, although to a lesser degree. The trends of the C06, C08 and C10 copy each other.

Annealing loss (see Fig. 17) approximately corresponds to calorific values.

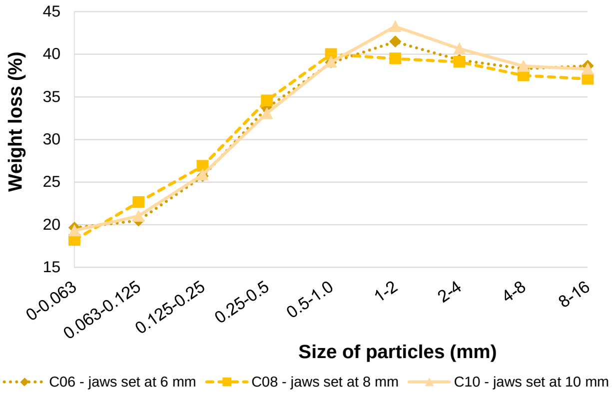

Fig. 17 Annealing loss analysis of crushed cement-bonded particleboard cuttings for all settings of jaws (6 to 10 mm)

Loss of weight of the 0 to 63 µm fraction is very important for the assessment of the ratio between wood chips and cement matrix. This is the fraction that characterizes the cement matrix (similarly to the evidence shown in evaluating calorific value). It was possible to establish an approximate weight loss of the wood matter by subtracting the annealing loss of the 0 to 63 µm fraction from the annealing loss of other fractions. Therefore, the content of wood matter dominates in the group of grains ranging from 1 to 2 mm. To the contrary, a very high ratio of cement matrix was found in grains up to the size of 125 µm.

3.4 Mineralogical composition

Various processes take place along with the pyrolysis of the composite containing a cement matrix and organic filler. Therefore, several changes may occur at the same temperature – for example the decomposition of certain hydrating products (CSH gels or phases, portlandite, etc.) along with concurrent decomposition of wood.

The below tables (see Table 1, 2) list all reactions identified through the assessment of the differential thermal analysis. It is apparent, that the decomposition of wood covers a rather wide temperature interval (230 to 700 °C) characteristic for the decomposition of the components of the cement matrix. This was evident through the presence of exothermal effects in the temperature interval of 230 to 700 °C. Another reason for such wide intervals is that the wood chips are quite completely mineralized in the cement-bond particle boards. The effective mineralization then increases the maximum temperature necessary for decomposition of such wood chips.

Table 1. Temperature intervals of decomposition for each mineralogical component, incl. wood particles in cuttings

60–120 °C	230–350 °C	410–440 °C	460–550 °C
water leak	exothermic decomposition of wood	exothermic decomposition of wood	decomposition of $Ca(OH)_2$
	decomposition of CSH gels	decomposition of CSH gels	residual decomposition of wood

Table 2. Temperature intervals of decomposition for each mineralogical component, incl. wood particles in cuttings

550–700 °C	730–850 °C	850–1000 °C
second phase of CSH gels decomposition residual decomposition of wood	decomposition of carbonates, mostly $CaCO_3$	residual decomposition of carbonates

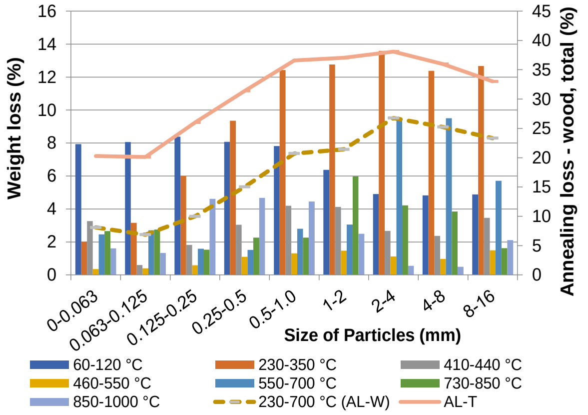

Fig. 18 Evaluation of differential thermal analysis of crushed cement-bonded particleboard cuttings C06 (jaws set at 6 mm)

In view of the results of calorific value and annealing loss tests, the cuttings fraction 0 to 63 µm could be considered in all cases (meaning for C06, C08 as well as C10) to be the matrix component decomposition (see Fig. 18 to 20). From this perspective, the AL-T curve is significant, characterizing the temperature interval in which both wood and the cement matrix decompose.

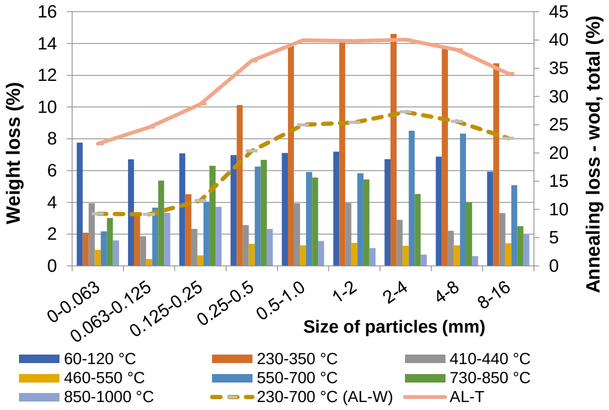

Fig. 19 Evaluation of differential thermal analysis of crushed cement-bonded particleboard cuttings C08 (jaws set at 8 mm)

Another interesting finding was the identification of two unrelated ranges in which the exothermic processes took place (230–350 °C and 410–600 °C, where the exothermic processes most notably occurred). The exception was the fraction 0-63 µm, where no reaction with an exothermic effect was identified.

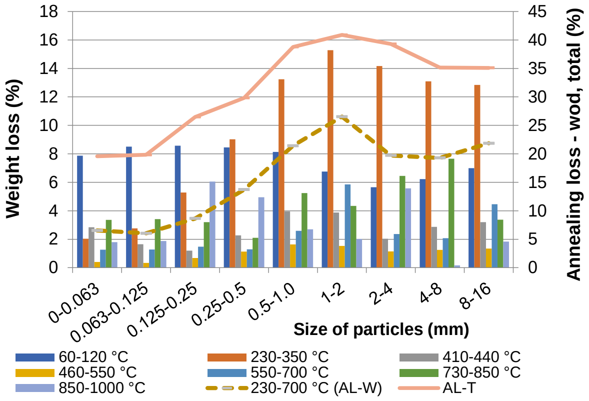

Fig. 20 Evaluation of differential thermal analysis of crushed cement-bonded particleboard cuttings C10 (jaws set at 10 mm)

Comparing the weight loss values obtained, it is apparent (in case of all three graphs – see Fig. 18 to 20) that the largest differences of the course occurred in the range of 230–350 °C. This is also the range in which exothermic processes were recorded. Therefore, it is evident that up to the temperature of 350 °C se the largest ratio of contained wood matter is decomposed in all cases of modified cuttings, meaning C06, C08 and C10. The columns in these graphs represent only the residual ratios of the individual components, not their overall content in the specific sample. Varying distribution of the wood chips was confirmed, as the intervals of the weight loss values (of the individual fractions) C06, C08 a C10 differ.

Cuttings with modified composition contain the most wood matter in the range of particles 0.5 to 4 mm. Based on residual values, the largest quantity of wood chips was identified in C10 specifically in the 1-2 mm fraction (see Fig. 20). These results and hypotheses are further confirmed from the perspective of calorific values and furnace annealing loss (see Fig. 15 and 17). As is apparent from the graphs (see Fig. 18 to 20), the AL-W curve (decomposition of primarily wood matter) practically copies the interval of AL-T (weight loss of all components).

3.5 Activity index assessment

Another opportunity for using modified cuttings in construction materials as an alternative raw material is their application as additives or substitution compounds. In the last phase of the research, such cuttings with modified composition were applied as a partial replacement for cement in mortars containing inorganic filler.

The graph below (see Fig. 21) shows the results of compressive strength assessment up to 90 days of maturing. Cuttings C08 were selected as samples, with respect to the results of the previous analyses, as well as to the crushers most often used within industry.

Given that the intent was the replacement of the filler, only grain ranging from 0 to 63 μm was selected, as it does not contain wood matter.

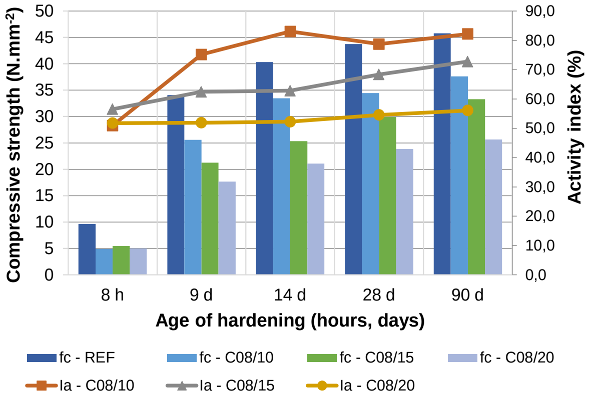

Fig. 21 Compressive strength and activity index assessment of mortars containing crushed cement-bonded particle board cuttings C08 (jaws set at 8 mm)

The results indicate a congruent interval in the early aging, meaning 8 hours. With increasing age, the effectiveness index slightly increases in cases of 15% substitution, while in case of the 20% substitution it is nearly constant.

The 10% substitution of the bonding component with cuttings appears to be the best, where after 14 days of maturing, the effectiveness index reached approximately 80%. With respect to the following optimization, approximately up to 8% of substitution of the bonding compound may be considered maximum.

The minimal value of the effectiveness index after 90 days is 85% (which is also valid for type II active additives). To utilize a larger amount of these alternative raw materials, it should be considered an additive, rather than a substitution compound.

4 Conclusion

Based on the results obtained, it may be concluded that the modification of the composition of this by-product from production of cement-bonded particle boards plays an essential role from the perspective of the specific properties of this alternative raw material, limiting its potential use as a material for the production of construction materials.

The size-reduction process and separation of the individual fractions achieved a rather good-quality product for further use. The findings indicate a potential option for wider use of this by-product in construction materials (as opposed to its current disposal in landfills). Its re-use in cement-bond particle boards as well as use as a dry levelling compound appear promising. This is particularly apparent from the perspective of material compatibility.

The detailed analyses presented in this article proved the fine fractions of cuttings with modified composition could be considered for use as substitute components of cement bond (for example back in cement-bonded particle boards) up to 10%, with only a minor decrease of material properties of the final composite.

Large quantities of wood matter in separated cuttings were particularly identified in grain ranging from 1-2 mm. The use of particles ranging from 0.5 to 2 mm (or possibly 4 mm) may be considered as a substitute for wood chips in cement-bonded particle boards, which contained higher amounts of wood matter in comparison with other fractions.

The use of separated cuttings of modified composition, specifically fractions 1 to 4 mm, appears suitable for use as dry levelling compounds. However, these options and methods of application (both in cement-bonded particle boards and as a dry levelling compound) are subject to verification through follow-up detailed research.

Another interesting option is also the addition of modified cuttings (with higher content of wood matter) for fuel used in various thermal processes.

An example could be production of cement or self-bonding sintered porous fly-ash aggregate (as covered, for example, by authors [18] through [20]). The calorific values reached indicate the development of a certain amount of heat energy. Therefore, savings of the primary fuel may be achieved along with consumption of thus-far unused by-product.

Using a thermal process (at the temperatures above 1200 °C and suitable conditions for cooling) the remnants of the cement matrix attached to the wood chips (of the cuttings) could partly transform again into active matter, containing clinker minerals.

Another significant finding is the fact that the wood chips in the individual separated fractions of the cuttings (that underwent size reduction), despite disruption to their surface, were difficult to decompose during thermal exposure. This fact points to a very effective mineralization of wood matter.

Additionally, it is apparent that modification of the composition through crushing failed to significantly disrupt the mineralization of wood chips. This information is particularly important in relation to the option of using cuttings (containing wood matter) in cement composites, where this problem would be highly likely eliminated, as it includes the presence of saccharides in wood (as covered, for example, in [13] through [17]).

The method of size reduction should be subsequently modified to achieve the desired properties of the cutting, obtaining mostly fine ratios (also the verification of the possibility of using a ball or planetary mill could be considered) or perfect separation of wood matter, etc.

Aside from the technically oriented outputs above, the environmental benefits should also be highlighted. The use of cuttings in form of recycling instead of their disposal has a positive effect on the sustainability of the modern construction industry.

This paper was realized with the financial support from the national budget via the Ministry of Industry and Trade under the project F30072 “Effective optimization of cement-bonded particleboards production waste utilization for manufacturing new competitive building materials”. This paper has been worked out also under the project No. LO1408 "AdMaS UP - Advanced Materials, Structures and Technologies", supported by Ministry of Education, Youth and Sports under the „National Sustainability Programme I".

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