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Study of the utilization of waste from manufacture of cement-bonded particleboards in their re-production

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ABSTRACT

Intention of this article is to present research results in area of modification of existing texture of cement bonded particleboards by secondary product, which is formed during the production of such boards. Considering that mentioned secondary product is not used in any way so far, it is concerned as a waste. It is characterized as relatively fine-grained particular substance, which contains mixture of cement matrix and mineralized chips, whereas these two components can be partially interconnected. First part of the paper shows analysis of alternative raw material itself, as well as proposal of preliminary treatment and dosage into mixture for cement-bonded particleboard production. Further the testing of cement-bonded particleboards of modified composition by above mentioned raw material was done. Examination was carried out with help of setting basic parameters according relevant normative documents (bending strength, density, elastic modulus etc.).

Keywords. Waste, cement-bonded particleboard, modification, analysis

INTRORODUCTION

During industrial production of all sorts of building materials or elements certain amount of by-products is formed. Significant is the fact, that in case of further unutilization of these by-products they are classed as waste. Therein production of cement-bonded particleboards is not an exception. Production line – specifically particleboards processing to the requested format and surface quality - in Czech Republic produces significant amount of such waste, c. 7600 t/year, which is necessary to deposit at the dumping places. Waste deposition represents partly costly finance step and further it strains environment with next possible negative effects. Domestic manufacturer of cement-bonded particleboards already tried to solve modification of composition by addition of mentioned waste into existing prescriptions, though without any success. It was established, that by waste addition into boards production in dosage of approx. 5% without any preliminary treatment of this waste, the boards were characterized by considerably variable parameters. It is possible to assume that with suitable way of treatment and dosage of above mentioned waste, it would be possible to reach relatively constant parameters comparable with common commercially produced cement-bonded particleboards. Interesting findings made in terms of research aimed at similar area are stated among others in the publications (Aggarwal, 1995 and 2008), (Alireza, 2012), (Fuwape, 1993), (Karade, 2010) and (Okino, 2004).

ANALYSIS OF ALTERNATIVE RAW MATERIALS

At the first stage of research it was necessary to target detailed analyzing of considered waste. In light of material base it is mixture of mineralized chips and cement matrix. Taking into account that waste comes from boards processing line, it can be characterized as incoherent particles of size 0-2 mm. These at detailed visual examination contain either chips alone, or cement matrix, eventually partially fixed cement matrix on mineralized chips. First of all it was necessary to separate the waste into individual fractions and analyze them closely. In terms of preliminary treatments waste grinding in vibrating mill was done in 2 different time intervals. For the waste marking in the following text, charts and diagrams (pictures) this coding is used:

- C000 – waste without any treatment,
- C090 – waste grinded in vibrating mill for 90 s,
- C180 – waste grinded in vibrating mill for 180 s.

The following qualities were inspected on the waste:

- visual examination,
- granulometric composition – grading analysis,
- RTG – diffraction analysis for identification of eventual clinker minerals,
- thermal analysis – determination of relative representation of cement matrix and organic filler.

Pictures stated below (see Figure 1 up to 12) show representative samples of analyzed waste.

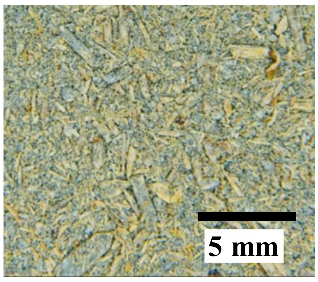

Figure 1. Waste C000

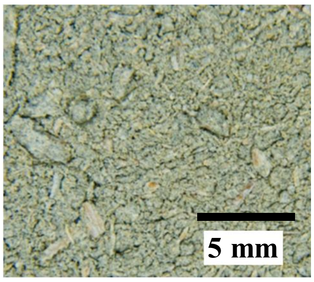

Figure 2. Waste C090

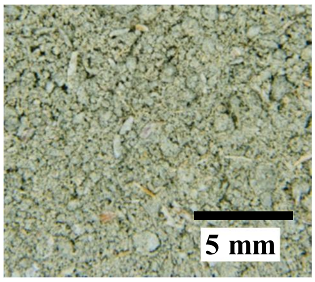

Figure 3. Waste C180

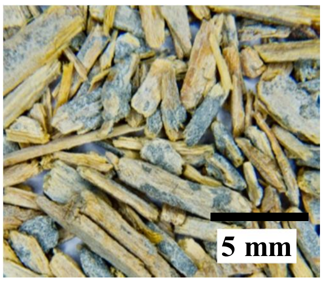

Figure 4. Fraction 1-2 mm – waste C000

Figure 5. Fraction 1-2 mm – waste C090

Figure 6. Fraction 1-2 mm – waste C180

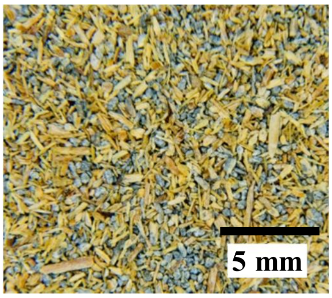

Figure 7. Fraction 0.25-0.5 mm – waste C000

Figure 8. Fraction 0.25-0.5 mm – waste C090

Figure 9. Fraction 0.25-0.5 mm – waste C180

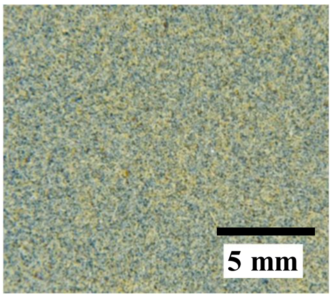

Figure 10. Fraction 0.063-0.125 mm – waste C000

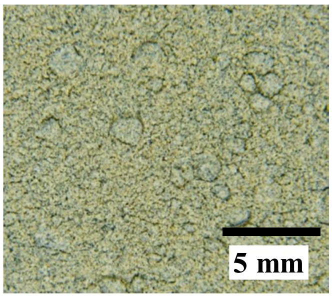

Figure 11. Fraction 0.063-0.125 mm – waste C090

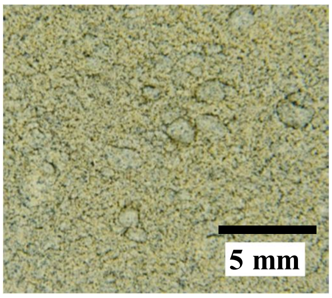

Figure 12. Fraction 0.063-0.125 mm – waste C180

On the base of visual examination it is possible to assume that in the fractions of sample C000 size 0.125 – 2 mm there are more often chips there, on which cement matrix is fixed to elements of wood substance. Fraction 0.063 - 0.125 mm contains both firmly fixed and free cement matrix, and fraction 0 – 0.063 mm is characterized by higher representation of cement matrix grains , where it is no longer possible to identify visually whether it is fixed to the chips or not. From different colour shade of individual fractions it is as well possible partially assume for representation or proportion of cement matrix and wood chips. Grey shade is evident with decreasing size of waste grain, which describes presence of higher amount of cement matrix (see Figure 1, 4, 7 and 10).

Further differences are distinctive as well with increasing time of grinding. First of all it is proportion change (which is relating to shade change) of cement matrix and wood substance in single fractions. Then it is substantial with closer visual observation, that cement matrix fixed to wood mass was partially separated ‚while the same time chips were „disrupted“ as well. It is also obvious on chips of fraction 0.5 up to 2 mm, that during the grinding process certain percentage of free cement matrix particles were „crushed“ into the chips. This is possible to identify by change of original chip shade to light grey colour (see Figure 7 up to 9). Decrease of cement matrix, due to separating grinding process, is very clearly evident on fraction 0.063 up to 0.125 mm (see Figure 10 up to 12). It is obvious here, that shade has changed to „ochre“, which is specific more likely for the wood substance.

In light of suitability of selected separation method, i.e. grinding in vibrating mill, attention will be further paid to definition of proportion for wood substance and cement matrix at gap thermal analysis. Following diagram (see Figure 13) shows grading curve of individual samples of analyzed waste in preliminary treatment dependence, or rather selection of cement matrix from wood substance.

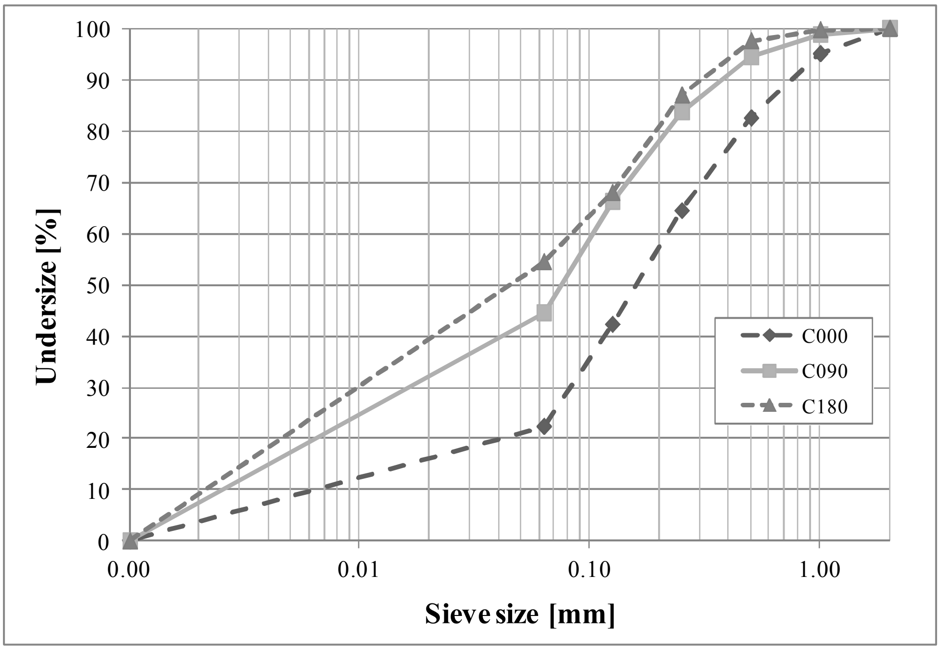

Figure 13. Comparison of grading curves in dependence on time of grinding

Above grading curves (see Figure 13) shows differences in granulometric composition of individual samples. Grinding effect´s become evident at interval 0 – 90 s, when the granulometric differences for samples C090 and C180 are much smaller. From point of view of energetic, including economic costingness of grinding process with higher waste amount it is possible to claim, that waste grinding for 180 s appears as non-effective. On the base of two above mentioned facts only samples C000 and C090 were considered for further research (modification of cement-bonded particleboards texture). Considering the possibility of using the waste as fine-grain addition agent it can be found significant especially the changes in representation of fraction 0 – 0.063 mm. Diagram (see Figure 13) shows, that during 90 s of grinding in vibrating mill representation of fine particles increased from approx. 22% to approx. 45% , which is double amount against original sample C000. From point of view of possible active waste participation in hydration reaction of cementing compound RTG diffractive analysis was performed. By this method substantial mineralogical phases were identified. Attention was focused on clinker materials, which presence indicates possible participation during hydration reactions within reapplication of examined alternative raw material for cement-bonded particleboards production. Results of RTG diffractive analysis are shown in the following table (see Table 1).

Table 1. RTG diffraction analysis results – C000

Sample	**Identified mineral**	
	Name	**Chemical formula**
C000	portlandite	$Ca(OH)_2$
	β–quartz	SiO_2
	calciumhydrosilicate I	CSH I
	bellite	C_2S

Sample	Identified mineral	
	Name	Chemical formula
	ettringit	$C_3A.3CaSO_4.32H_2O$
	calcite (aragonit)	$CaCO_3$

The following diagram (see Figure 14) compares losses by annealing for individual fractions, rated through thermal method DTA (differential thermal analysis). These values describe weight loss in temperature interval of 250 – 550 °C, which is accompanied by exothermic delay, typical for decomposition of some wood species (Sokolář, 2004). The reason for definition of this value was to identify wood substance in individual fractions of analyzed waste depending on pre-treatment time by grinding.

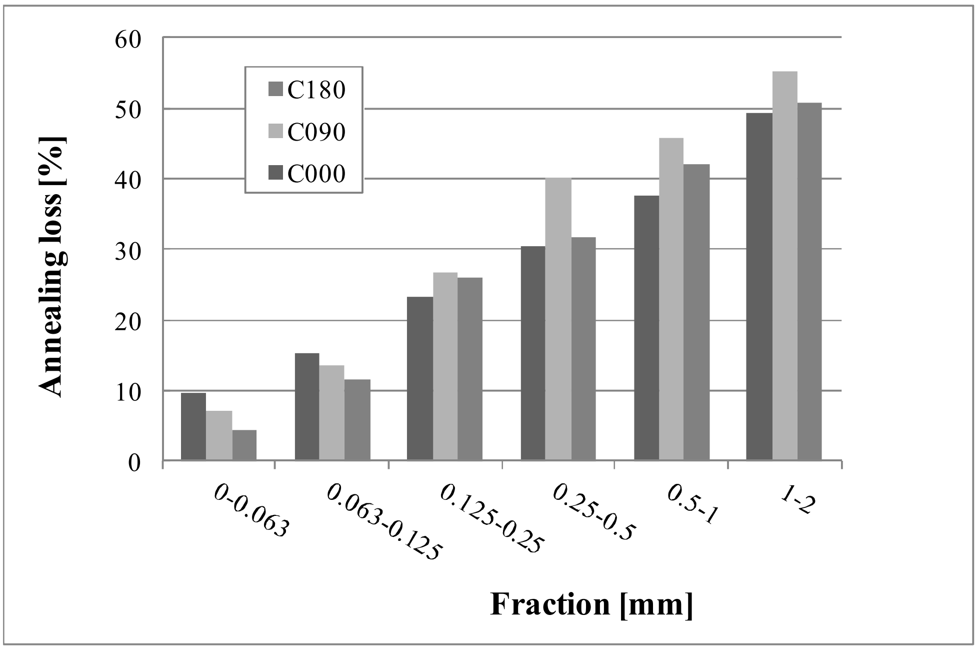

Figure 14. Relation between waste annealing loss and time of grinding

The results of annealing loss show the fact that the lowest percentage annealing losses are for fractions of sample C000 size 0.125 mm - 2 mm against C090 and C180. By contrast the sample C090 declaring the highest annealing loss (again because of higher wood substance factor). For the 2 lowest fractions (0 - 0.063 mm and 0.063 - 0.125 mm) annealing loss declines with the grinding time. This is caused by higher presence of cement matrix. Top limit temperature of analyzed interval (550 °C) was selected with respect to the research result stated in (Sokolář, 2004). Next substantial anticipation was the fact that during temperatures higher than 550 °C $CaCO_3$ is decomposed, which causes higher weight losses for fractions with higher presence of cement matrix.

FORMULAS DESIGN

Formulas of modified composition were designed with consideration of results and findings made within above stated waste analysis from cement-bonded particleboard production. Considering the efficiency – rate of energetic costingness of separative/grinding process –

for the mixture only C000 and C090 were used. Existing mixture formula for production of cement-bonded particleboards consists of the following components:

- Portland cement – 50 % (in weight) or 25 % (in volume),
- water (including water glass) – 30 % (in weight) or 10 % (in volume),
    - water-cement ratio – c. 0,5,
- chips – 18 % (in weight) or 63 % (in volume),
- additives – 2 % (in weight and in volume – aluminium suphate).

By RTG diffractive analysis only presence of bellite was established. Furthermore accelerating of cementing compound is done during cement-bonded particleboard production process. It is possible to assume, that cement matrix contained in considered waste will not notably participate on hydrating reactions during the re-production of cement-bonded particleboards. From this reason the possibility of waste dosing as substitute component was rejected. For modification the waste was considered as addition in amounts of 5, 10 and 15 % (in weight – taken for amounts of all components of referential formula).

The possibility of separated dosage of individual and only picked waste fractions was further considered as well. Below there is summary of proposed formulas, which were subjected to further analysis:

- REF – reference formula,
- C00-1, 2, 3 – formulas with content of 5, 10, 15 % C000,
- C09-4, 5, 6 – formulas with content of 5, 10, 15 % C090,
- C09-7, 8, 9 – formulas with content of 5, 10, 15 % C090, which was used only in fractions 0 - 0.063 mm, 0.063 - 0.125 mm and 0.125 - 0.25 mm,
- C09-10, 11, 12 – formulas with content of 5, 10, 15 % C090, which was used only in fractions 0 - 0.063 mm and 0.063 - 0.125 mm.

Fractions bigger than 0.25 mm were dosed with chips ,whereas fraction of grain size smaller than 0.25 mm were incorporated into the mixture together with cement bond. Sample production of cement-bonded particleboards consists in total of 4 phases (mixing and pressing of the mixture, curing and following board finishing to the requested format). During the mixing the components a mineralization of wood chips presents very important step. This way better stability to chemical attack, humidity and water absorption resistivity of chips is reached. Therefore afore mentioned amount of water includes two components – water for cement paste and for mineralization of chips (in combination with water glass, separate mixing). So it was supposed that chips contained in the analyzed waste embody only minimum absorption of water owing to their earlier mineralization. Water volume was the same as the original boards for all designed formulas. All these steps of the production process were done in laboratories of Faculty of Civil Engineering in Brno. Procedures of individual works were chosen in the way to correspond as much as possible to production procedures of company CETRIS.

RESULTS AND DISCUSSION

The following diagrams (see Figure 15, 16) show average values of reached parameters for individual formulas. For each formula were prepared four samples, which were tested and once measured to gain indicated values. All determinations were carried out according relevant normative documents. The following parameters were monitored:

- density according to ČSN EN 323,
- bending strength according to ČSN EN 310,
- modulus of elasticity in bending according to ČSN EN 310,
- transverse tensile strength perpendicular to the plane of the board according to ČSN EN 319 (further in text as transverse tensile strength).

Since the boards of formula with content of 15% C090 in fraction range 0 – 0.25 mm and further 0-0.125 mm (i.e. formulas C09-6 and C09-9) showed significant marks of incoherence and structure faults when de-moulding, these were not submitted for relevant physico-mechanical tests.

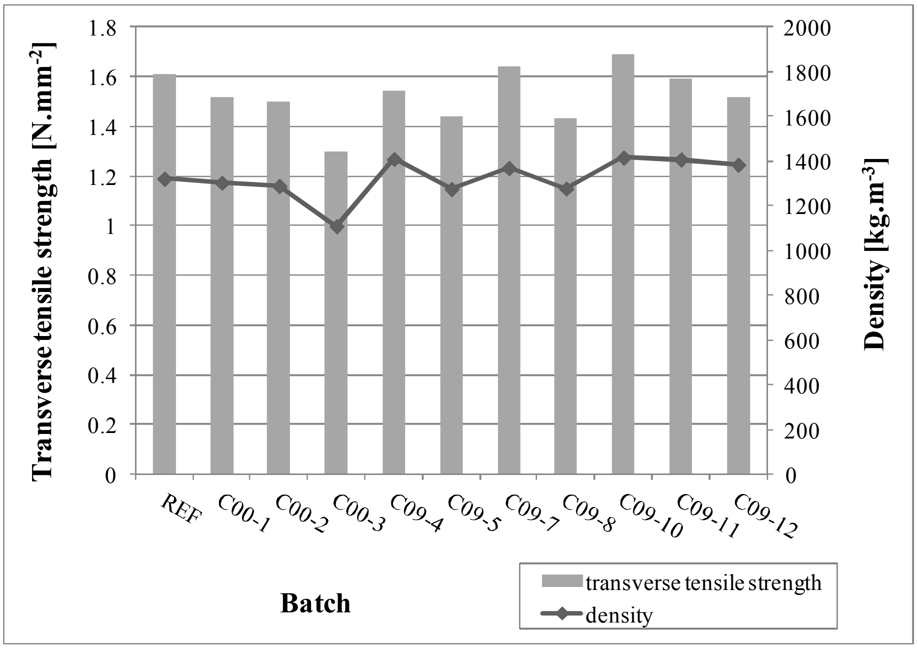

Figure 15. Comparison of average values – transverse tensile strength and density

Although the result values of density (see Figure 15) show the differences among individual formulas, it is possible to state that these are relatively comparable figures. Formula C09-10 shows the highest average density, specifically 1416 kg.m^{-3}. It contains 5 % of grinded waste C090 separated into the fraction of grain up to 0.125 mm. By contrast, formula C00-3 shows the lowest average density, specifically 1109 kg.m^{-3}. It contains 15% addition of waste C000 non-separated. These relatively inexpressive differences most likely relate to powder density of analyzed waste. In the concrete – when using only fine fractions (i.e. up 0.125 mm ,which contains the majority of cement matrix against wood mass) powder density is evidently lower, compare to use of waste non separated or non-grinding. Powder density is then connected with compaction – pressing of mixture for cement-bonded particleboards production.

Next watched parameter was perpendicular tensile strength of the board plane. Above diagram (see Figure 15) shows similarity of trend of this watched value and density. The boards of formula C09-7 and C09-10 reached values exceeding perpendicular tensile strength of board with referential formula, i.e. 1.6 N.mm^{-2}. C09-11 was marked with the figure almost comparable with referential formula. The most negative effect of waste addition – C000 is shown on tensile strength for dosage of 15 %. From history of average values for perpendicular tensile strength indirectly results, that the waste – even containing clinker mineral – bellite can be used as inert admixture. In case of bigger fractions dosage with increasing waste quantity the parameters of cement-bonded particleboards are significantly decreased.

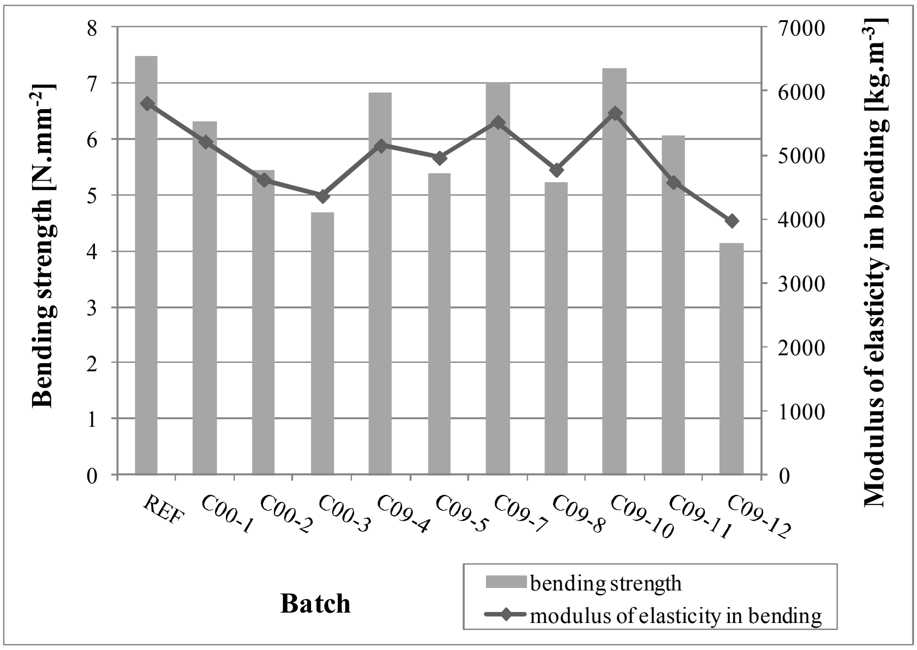

Figure 16. Comparison of average values – bending strength and modulus of elasticity in bending

Through comparing values of the strength and modulus of elasticity in bending (see Figure 16) with density and perpendicular tensile strength of the board plane (see Figure 15) it can be found, that these trends are of similar character. Indeed in the case of strength and elasticity modulus in bending it can be seen more significant decrease of these monitored parameters when amount of admixture-waste is increased. The boards produced according modified formula C09-10, i.e. containing 5 % of waste with fraction up to maximum of 0.125 mm, reach parameters comparable with referential boards. Similarly it is possible to evaluate as well the formula C09-7, i.e. containing 5 % of waste with fraction up to max. 0.25 mm grain.

Figure 17. Detail of sample structure by formula REF (fracture area after bending strength test)

Figure 18. Detail of sample structure by formula C09-10 (fracture area after bending strength test)

On above presented pictures it can be seen the structure in fractured area after setting-up of strength and modulus of elasticity in bending. On purpose the comparison of representative samples by formula REF a C09-10 is done. These samples were achieving similar parameters. In the structure of C09-10 it can be visually identified bigger number of pores than it can be found at sample REF. This is most probably the reason for slight reduction of strength characteristics and elasticity modulus. At the current phase of research impact of water factor was not analyzed. It is possible to assume, that with optimization of water dosage for formulas C09-10 a C09-11 will be possible to achieve comparable parameters to those of currently commercially produced cement-bonded particleboards. With next correction of water factor and modification of additives amount (softener) the same time it would be theoretically possible to reach sufficient parameters as well for formula with 10% of waste C090 of max. grain size 0.125 mm.

CONCLUSION

In terms of research presented in this article the possibility of using the waste from production of cement-bonded particleboards and its re-production was analyzed. The first stage of the research was aimed to analyze characteristics of waste itself. It was found that it is granular loose substance with fractional range of 0 - 2 mm. Waste from production line for cement-bonded particleboards contain both wood mass and cement matrix. From this reason attention was paid to set up proportion of chips and cement matrix. To reach the best results, suitable treatment for the waste was considered as well. Treatment of granulometric composition and further partial separation of filler and connective component of the waste was done in vibrating mill. With help of sieve analysis and differential thermic analysis it was established that by 90 s grinding fine waste parts are increased, i.e. grains of size up to 0.125 mm rise from c. 40 % up to 70 %. Further it was proved that cement matrix is separated from mineralized chips during the grinding, which has become evident at decrease of annealing loss for fractions 0 - 0.063 mm and 0.063 - 0.125 mm. Furthermore reduction of annealing loss value shows the increase of amount of cement matrix against the chips. All findings done in terms of examination of waste characteristics were taken into account for designing the formula with modified composition. It was proved by testing of basic physic-mechanical parameters of cement-bonded particleboards, that it is possible to consider waste dosage at range of 5-10% for objective usage. However the waste has to be modified, especially in relation to granulometric structure, separation of cement matrix and cleanup of fractions bigger than 0.125 mm. On the base of reached results it is possible to state that with further optimization of water factor, the waste in amount up to 10% would be possible to use for re-production of cement-bonded particleboards. It is substantial as well, that during waste treatment in vibrating mill for 90s and with following utilization of fractions under 0.125

mm, approx.70% of this waste is used. Remaining 30 % would be theoretically possible to use in the section of production line, where accelerated curing is done. Domestic manufacturer manages boiler for burning of wood chips. With reference to waste treatment, when cement matrix is separated from bigger fractions of the waste, it is possible to assume, that these fractions contain mostly mineralized wood substance, which could be thermal decomposed in the boiler. In this way it would be theoretically possible to use all waste rising during production of cement-bonded particleboards. Significant fact is that waste would be imposed during the re-production of these boards. In next step of the research it would be suitable to target the optimization of water dosage, eventually softening additives. Further, as important could be characterized study of changing volume of water for the hydration in dependence on the wood chips ratio in the waste. Integral part of following research should be as well analysis of other requested parameters including verification of formulas in semi-industrials conditions of production. Very interesting option of testing parameters in semi-industrial conditions of production is using of non-destructive methods – for determination strength and modulus of elasticity in bending. Significant findings are stated among others in publication (Brožovský, 2005).

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