The treatment and properties of construction waste for subsequent use in cement composites

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Abstract. The paper presents the results of construction waste treatment for possible replacement of natural aggregates in cement composites. The individual processes of construction waste treatment for the purpose of obtaining the required fractions 0/4 mm, 4/8 mm and 8/16 mm are described. It deals with the so-called recycled aggregate, which will subsequently be used in cement composites as a substitute for natural aggregate. The properties of individual fractions of recycled aggregate are presented, both in terms of composition, density, water absorption and granulometric, mineralogical and elemental composition.

1. Introduction
Nowadays, the European construction industry generates 820 million tonnes of construction and demolition waste each year, which is about 46% of the total waste generated in Europe. In the USA, construction and demolition waste represents approximately 1/3 of the volume of material in landfills, and in Great Britain, 50% area of a typical landfill is taken by this type of waste [1–3]. According to the average composition of construction and demolition waste, we can find out that about 85% is made of concrete, ceramics and masonry. Although these components constitute the majority, there are often considerable quantities of wood and plasterboard as well [1]. Since it is still more profitable to use natural raw materials instead of recycled materials, a large part of waste is stored in landfills, thereby contaminating and occupying the land resources. Although there is a charge for depositing waste, it is still the most common method of waste management. Some companies illegally process this waste, for example as filler in sacrificial formwork, etc. in order to save money [3,4]. For this and other reasons, the European Commission and other institutions try to control construction and demolition waste, either by reducing its amount or by recycling it [1–3]. Construction and demolition waste can be recycled in several ways. The studies on the use of industrial waste materials in the construction segment may be used as an example [5–9]. The reuse of demolition waste as a secondary raw material has been studied in Asia [10–12] and there are also research projects dealing with the use of construction waste as admixture in concrete to replace Portland cement [13], or to create new building materials [14,15].

2. Materials and methods
Construction rubble from a rebuilt house was chosen as the material for the research of the utilization of construction waste for subsequent use in cement composites. This house is built of bricks, so most of the construction waste was bricks. The construction waste also included wall tiles and mortar, wood, iron, plasterboard, etc.

2.1. Pre-sorting
Construction rubble was free of undesirable admixtures such as pieces of wood, iron, plasterboard, etc. and it was subsequently sorted into the following 3 representative components of construction waste:
2.2. Crushing

Mixed construction rubble was selected for further processing. Its granulometry was adjusted to the size that could be further processed using a crusher. The crushing itself was carried out in several stages on a single jaw crusher Fritsch pulverisette, type: 01.502. In total, the sample was processed on the crusher in three stages, while each crushing stage was followed by a grain size analysis of the sample.

2.3. Grain size analysis

HAVER EML 300 digital plus screening machine was used to determine the granulometry of the crushed sample and a series of sieves with the mesh size of 0.063, 0.125, 0.25, 0.5, 1, 2, 4, 8, 16, 25, 31.5 and 63 were selected. The sample was sieved into the individual grain-size fractions after each crushing stage and they were weighted using Kern 572-49 laboratory scales. The grain size analysis was used to prepare the grain-size curves, and the trend of the development of the proportion of the individual components of the mixed construction rubble in dependence on the degree of crushing was observed within the range of fractions 8/16 and 16/25.

3. Results and discussion

The grain size analysis results after the individual stages of crushing are presented in figures 1 – 3.

Figure 1. Particle-size distribution curve of the first crushing stage.  
Figure 2. Particle-size distribution curve of the second crushing stage.
3.1. Grain size analysis of the first stage of crushing:

Share of the individual components of input material fraction 8/16:
- Mortar: 54.6%
- Tiles: 11.7%
- Bricks: 33.7%

Share of the individual components of input material fraction 16/25:
- Mortar: 10.8%
- Tiles: 40.0%
- Bricks: 49.2%

Calculation of non-homogeneity number $C_u$

$$C_u = \frac{d_{60}}{d_{10}} = \frac{14.41}{0.44} = 32.75$$

where
- $d_{60}$ ... grain size for 60% siftings
- $d_{10}$ ... grain size for 10% siftings

During the first crushing stage, the slot size was 1.3 x 6 cm. The subsequent grain size analysis revealed a mean grain size $d_{50} = 11.13$ mm. The share of the individual components was as follows: fraction 0/4 accounted for 26.3%, fraction 4/8 accounted for 10.0%, fraction 8/16 accounted for 29.7%, fraction 16/25 accounted for 19.4% and fraction over 25 mm accounted for 14.6% of the total weight.

On the basis of the calculation of the non-homogeneity number, it can be stated that the mixed construction rubble after the first stage of crushing is non-homogeneous, because it does not meet the criterion of $C_u < 5$ and has the value of 32.75.

3.2. Grain size analysis of the second stage of crushing

Share of the individual components of input material on sieve 8/16:
- Mortar: 33.5%
- Tiles: 25.1%
• Bricks 41.4 %

Share of the individual components of input material on sieve 16/25:
• Mortar 2.7 %
• Tiles 85.6 %
• Bricks 12.7 %

Calculation of non-homogeneity number $C_u$

\[ C_u = \frac{d_{60}}{d_{10}} = \frac{7.85}{0.241} = 31.57 \]  

where

$\begin{align*}
    d_{60} & \text{ grain size for 60% siftings} \\
    d_{10} & \text{ grain size for 10% siftings}
\end{align*}$

During the second crushing stage, the slot size was 0.9 x 6 cm. The subsequent grain size analysis revealed a mean grain size $d_{50} = 5.67$ mm. The share of the individual components was as follows: fraction 0/4 accounted for 42.0%, fraction 4/8 accounted for 18.6%, fraction 8/16 accounted for 33.3%, fraction 16/25 accounted for 5.6% and fraction over 25 mm accounted for 0.5% of the total weight. On the basis of the calculation of the non-homogeneity number, it can be stated that the mixed construction rubble after the second stage of crushing is non-homogeneous, because it does not meet the criterion of $C_u < 5$ and has the value of 31.57.

3.3. Grain size analysis of the third stage of crushing

Share of the individual components of input material on sieve 8/16:
• Mortar 29.1 %
• Tiles 36.5 %
• Bricks 34.4 %

Share of the individual components of input material on sieve 16/25:
• Mortar 0.0 %
• Tiles 93.8%
• Bricks 6.2%

Calculation of non-homogeneity number $C_u$

\[ C_u = \frac{d_{60}}{d_{10}} = \frac{5.63}{0.27} = 20.85 \]  

where

$\begin{align*}
    d_{60} & \text{ grain size for 60% siftings} \\
    d_{10} & \text{ grain size for 10% siftings}
\end{align*}$

During the third crushing stage, the slot size was 0.5 x 6 cm. The subsequent grain size analysis revealed a mean grain size $d_{50} = 4.03$ mm. The share of the individual components was as follows: fraction 0/4 accounted for 49.0%, fraction 4/8 accounted for 25.5%, fraction 8/16 accounted for 24.4%, fraction 16/25 accounted for 0.9% and no material was captured in fraction over 25 mm. On the basis of the calculation of the non-homogeneity number, it can be stated that the mixed construction rubble after the third stage of crushing is non-homogeneous, because it does not meet the criterion of $C_u < 5$ and has the value of 20.85.

The trend monitoring results of the development of the share of the individual components of the mixed construction rubble depending on the stage of crushing within the fractions of 8/16 and 16/25 are presented in figures 4 and 5.
**Figure 4.** Share of individual components, fraction 8/16.

Figure 4 presents the composition of the materials on sieve 8/16. It shows that mortar with the smaller crusher slot has a downward trend in the representation in mixed construction rubble as it passes into finer fractions due to the low strength of this material. The tiles show the opposite trend and smaller slot size means their higher share in the mixed construction rubble. This is due to the shape of the tiles and the characteristics of the crusher design, where the tiles fall through the slot more easily and do not become tinier. The brick material, despite a small fluctuation in the second stage of crushing, retains the share of about 37.

**Figure 5.** Share of individual components, fraction 16/25.

Figure 5 presents the composition of the materials on the 16/25 screen. It shows that the mortar has the same trend as in case of the 8/16 screen. The dominant representation of tiles in this fraction follows the trend of the 8/16 fraction, which is due to the design of the crusher. The brick material has a downward trend of representation in the mixture, which implies that it is well crushable by this type of crusher.

**4. Conclusion**

Based on the results of the tests of the examined material, we can conclude that:

- The crushing of mixed construction rubble using the selected jaw crusher is not suitable, because of the content of ceramic tiles, which fall through the crusher slot due to their shape and are not crushed as result of that.

- The share of the individual components of mixed construction rubble in 8/16 fraction was almost equal after the third crushing stage, however, the grain size curve shows that the percentage of the finer shares of fraction 0/4 has increased to 49% of the sample weight.

- The increase in the amount of fine shares of fraction 0/4 is caused by the low strength of the mortar contained in the mixture, which results in its transition to finer fractions. This corresponds to the decreasing share of mortar in fractions 8/16 and 16/25.

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