Reprocessing of Buildings’ Demolition Waste and Utilization for the Manufacturing of New Products

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Abstract: Concrete is multicomponent composite material, consisting of coarse aggregate, fine aggregate, cement and water. Natural aggregates, as well as aggregates obtained after the reprocessing of buildings’ demolition waste, can be used as coarse and fine aggregates. Characteristics of the hardened concrete depend on the raw materials, used for the preparation of concrete mixture, and their characteristics. The objective of the research is to analyse the sources of demolition waste, to describe the reprocessing technology of concrete waste, to investigate the production of the aggregate from the concrete waste, to analyse the main properties of these aggregates — particles’ density, bulk density, granulometric composition, hollowness and other properties, as well as to compare the obtained results with the requirements applicable to the aggregates based on natural materials.

Key words: Demolition waste, concrete waste, aggregate, recycled aggregate, density, hollowness.

1. Introduction

Cement concrete is environmentally clean construction material, produced from the local raw materials: aggregates (sand and gravel), cement and water. This is universal construction material used for the construction of various buildings and constructions, as well as for the production of construction parts.

The choice of construction materials is always determined by quality and price. Both, concrete’s quality, as well as price, largely depend on the raw materials used in the production. In concrete’s production process it is important to reduce costs in any technological stage as much as possible. However, the quality parameters of the final product have to fulfill the defined limits. One of the ways to reduce the production costs is to replace the natural aggregates with the ones, produced from buildings’ demolition waste. Moreover, from ecological point of view, concrete is an ideal material, where it is possible to integrate construction and demolition waste during the manufacturing process.

Demolition and construction waste consists of the following waste materials: reinforced concrete, concrete, bricks, tiles, glass, wood and other materials, obtained during the demolition of the buildings. Larger amount of buildings’ demolition waste consists of concrete and ceramics. Main composition of this waste is shown in Fig. 1.

There are several reasons why the amount of construction and demolition waste is increasing worldwide:
- There are a lot of buildings that are not suitable for exploitation, therefore they have to be rehabilitated or demolished;
- Buildings, even if they are suitable for the exploitation (for instance old factories, farm buildings etc.), lose their functionality, their purpose changes and finally they are demolished (Fig. 2). New constructions replace the old buildings in the same location;
- Construction waste, created during the natural disasters — earthquakes, storms or due to the wars.

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Every year in Europe, 510 million tonnes of construction and demolition waste are created, in USA 325 million tones and in Japan 77 million tonnes. In many countries, such as The Netherlands, Japan, Belgium and Germany, there are schemes and systems developed for the recycling of construction and demolition waste and ensuring the reprocessing of waste materials and their full utilization [1].

The problems of the reprocessing of buildings’ demolition waste are being tackled intensively throughout the world. In Brazil and in 38 states of the USA, the reprocessed concrete waste is used for road construction, and in 11 states — for the production of new concrete. In The Netherlands the dump areas for concrete waste are forbidden at all, except for the waste that is created during the concrete production. In Finland strict laws are employed regulating that all buildings’ demolition waste has to be reprocesses and recycled. In Germany, major part of concrete and reinforced concrete waste is returned to the production line of new products. In Japan, almost all reprocessed concrete and reinforced concrete waste is utilized for road construction. In Australia new projects are planned, to ensure that concrete waste is utilized for the manufacturing of new products [1].

The problems of the reprocessing of buildings’ demolition waste and its utilization are continuously tackled throughout the world, as well as in Lithuania. Nowadays, concrete waste is most often utilized for the road constructions. However, after the exhaustive analysis of this waste and its influence on the characteristics of new products, waste could be used for the production of new products with the required quality.

2. Reprocessing of Demolition Waste

The composition of construction and demolition waste may be different, depending on a building being demolished. When constructions of unfinished buildings are demolished, demolition waste consists of concrete, metal, ceramics. In case the old buildings, that are not rehabilitated and cannot be exploited, are demolished, demolition waste of these buildings demolished consists of concrete, ceramic bricks, tiling or slating, wood, thermal insulation materials, metal and various finishing materials.

![View of the building being demolished in center of Vilnius (Lithuania).](image)
Two main reprocessing methods are employed during the reprocessing of buildings’ demolition waste:

1. Waste reprocessing in concrete breakstone production line or in a special site;
2. Waste reprocessing at a location where waste is created, i.e., at a construction site or at location where building is being demolished.

Despite the type of a building being demolished and reprocessing method, main reprocessing stages of the demolition waste are the same: initial preparation of construction and demolition waste, crushing, sorting, metal separation, initial sieving, milling, metal separation, sieving. During demolition of the buildings, excavators, hydraulic alligator shears, metal separation aggregates are used most often. After the demolition works waste is reprocessed by employing special equipment used for the milling and sorting. Shredders (Fig. 3), milling machines, magnetic separators, sieving machines as well as air separators, that separate thermal insulation materials, wallpaper and other impurities from concrete pieces, are used in reprocessing processes.

In Fig. 4, the structural technological scheme of the production of the breakstone from concrete waste is shown.

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**Fig. 3** View of the shredder used to prepare concrete breakstone on site.

**Fig. 4** Structural technological scheme of the production of the breakstone of various fractions from the construction and demolition waste.
After thorough implementation of all breakstone production stages, coarse and fine aggregates of various fractions are obtained. These aggregates, depending on their fraction, are used for the construction of passages and roads, passing ways, sidewalks, as well as for the manufacturing of new construction products.

In Lithuania there are companies, such as JSC “Bionovus”, JSC “Vaidva”, that provide services not only for the demolition of various buildings, for the collection as well as reprocessing of construction waste, but also sell the breakstone produced from the demolition waste. These companies have sites for the demolition and reprocessing of construction waste. In these sites various construction machinery and equipment is used for the demolition of the buildings, reprocessing of construction and demolition waste. In Lithuania mostly only the coarse aggregates are sold, i.e., concrete breakstone with the fractions of 0/10, 0/16, 0/22, 0/63, 10/22, 16/45, 45/80 mm. The most popular and the most expensive breakstone is produced without small fractions, because for the production of this breakstone additional production stages are required, such as cleaning and separation from fine and very fine particles, and this requires additional energy consumption. However, nowadays in Lithuania crushed concrete is utilized only for the base of motorways.

3. Experimental Part

The quality of coarse and fine aggregates determines the strength of the final product, and these aggregates largely influence concrete’s durability. In order to utilize the crushed concrete waste for the production of new concrete products of the required quality, it is important to carry out a lot of investigations necessary to determine the main physical and mechanical properties of the aggregates, produced from the concrete. In addition, it is essential to prepare the recommendations on the quantitative composition of the concrete produced with the analysed aggregates.

During the research, coarse, fine and filler aggregates were prepared from the crushed concrete waste produced at concrete breakstone preparation site. During the preparation, aggregates, together produced in the crushing machines, were sieved with 16, 4 and 0.125 mm sieves. The main properties (influencing the final characteristics of the products) of the aggregates, produced from the concrete waste, were determined. The granulometric composition was determined by employing standard methods described in LST EN 933-2 [2], bulk density—according to LST EN 1097-3 [3], and particles’ density—according to LST EN 1097-6+AC [4]. Comparative characteristics of the aggregates were taken from the standard LST 1974 [5], currently being prepared by TK 19 Technical Committee “Concrete and Reinforced Concrete” of Lithuanian Standards Board.

During the investigation the mineral composition of the filler aggregate was determined. X-ray analysis of the filler aggregate was implemented by using diffraction meter DRON-2 (Cu anode, Ni filter, monochromator, cracks with the size of 1:8:0.5 mm). Operation mode of the tube of diffractometer: $U = 30$ kV, $I = 10$ mA. The recorded diffractogram was decoded by comparing the obtained experimental values of multilayer distances $d$ and specific integral intensity $I/I_0$ values of the lines with the corresponding values in ASTM file.

Crushed concrete waste consists of coarse, fine and very fine particles. During the crushing, concrete fragments through the cement stone, aggregates, bond areas between aggregates and cement stone. During the crushing all three fragmentation cases are possible. During visual inspection it was noticed, that approximately half of the amount of concrete’s aggregate lost a contact with the cement stone, and half of the amount of grains are bonded firmly with the cement stone. General view of the crushed particles is shown in Fig. 5.
3.1 Coarse Aggregate

Coarse aggregate is crushed concrete waste with the size of the particles from 4 to 16 mm. Since the strength of the hardened concrete depends largely on the granulometric composition of the aggregates, initially the granulometric composition (i.e., distribution of aggregate particles in respect to the coarseness, expressed as mass percentage of the particles sieved out through the determined set of sieves) of the coarse aggregate was determined. Results of the test are shown in Fig. 6 where together with the curve of the aggregate of crushed concrete the grey area is shown. This area represents the limits of granulometry (particles sieved out) recommended in the standard LST 1974 for the coarse aggregates.

By summarising the results shown in Fig. 5, it can be stated that the amount of 4 mm size particles in the aggregates produced from the concrete waste is larger than recommended. This can be explained by considering the larger amount of oblong particles in this aggregate. During the preparation, when coarse and fine aggregate fractions were separated from the overall mixture of crushed aggregates, these particles were not sieved out from 4 mm sieve, and stayed on the top of sieve.

The strength of hardened concrete depends largely not only on the granulometric composition of the aggregates, but also on their quality. During the research the main characteristics of the coarse aggregate were determined and provided in Table 1.

Researchers from Spain [6] have determined that particles’ density of 5–40 mm size coarse aggregate, produced from the demolition waste, is equal to 2.32 g/cm³, water impregnation 5%. Group of researchers from China [7] have determined that the density of the aggregate (with the lowest particles’ size of 10 mm) produced from waste materials is 2.49 g/cm³, and water impregnation is 4.26%. Such physical characteristics as density, is highly related to the characteristics of the crushed waste materials. Density
is higher when strong and heavy concrete waste is crushed.

3.2 Fine Aggregate

Fine aggregate is crushed concrete waste with the size of the particles from 0.125 to 4 mm.

As it is for the coarse aggregate, granulometric composition of the fine aggregate influences the characteristics of the concrete. Due to this reason the granulometric composition of the fine crushed concrete waste was determined. The granulometric composition of the natural sand is shown in Fig. 7.

From the graph it can be seen that in the amount of 1 mm size particles of the crushed concrete waste is insufficient. The amount of the sieved out particles with the sizes of 0.5 and 2 mm reaches the minimal recommended limit. In addition, during the sieving, the amount of the particles sieved out through 0.063 mm size sieve reached 1.3%. This amount of very fine particles was created due to the fact that there were fine particles adhered around the pieces of crushed concrete, and these fine particles were not separated during the first sieving stage. Although the amount of the particles sieved out through 0.063 mm size sieve is larger than recommended, this amount satisfies the requirements of standard LST EN 12620:2003 (the amount of sieved out particles must be lower than 3%).

The main characteristics of the fine aggregate were determined and provided in Table 2.

Researchers [6] have determined that the density of 0/5 mm fraction fine aggregate (produced from the concrete and demolition waste) is 2.13 g/cm³, water impregnation 9.30%. Other scientists [7] have identified that the density of the aggregate, which particles’ size is smaller than 5 mm, is 2.3 g/cm³, and water impregnation is 11.86%. The density of the fine aggregate (produced from the concrete waste) used in other research [9] was 2.31 g/cm³, and water impregnation was 10.30%.

After the analysis of aggregates’ properties determined by various scientists, it can be stated that the water impregnation of the aggregates produced from concrete waste is larger than the one of natural aggregates. This increase of water demand can be explained by considering that the structure of the aggregate produced from waste is open-porous, the aggregate has a net of created capillaries, which rapidly absorb water. In addition to this, cement stone's structure, which was opened during the crushing, has larger water impregnation, comparing to the natural rock aggregates.

After the selection of mixture’s composition by employing concrete’s composition selection method used in Lithuania (it is based volumetric method) and after the analysis of common aggregates’ granulometric composition, it can be noted that, when concrete waste is used to replace the aggregates, it is necessary to adjust the amount of fine and coarse
aggregates. The recommended granulometric composition for the aggregates in concrete mixture is provided in Fig. 8. In the figure, the curve is depicted showing the required granulometric composition of the aggregates to be used in the concrete with the maximal particles’ coarseness of 16 mm (LST 1974 “Rules for the Application LST EN 206 1 and Additional National Requirements”) [5]. When natural raw materials in the mixtures are replaced by the crushed concrete waste, the amount of 0.25–2 mm size particles would have to be increased, and the amount of 4–8 mm size particles-decreased.

3.3 Filler Aggregate

Filler aggregate very fine powder of natural or artificial origin, dispersive industrial waste and pigments, utilized for the production of the composite materials, in order to improve their structure, physical and mechanical properties or to give them specific features. In the research, the filler aggregate, obtained during the crushing of buildings’ demolition waste, which particles’ size is smaller than 0.125 mm, was analysed. Main characteristics of the filler aggregate were determined and provided in Table 3.

In order to utilize the filler aggregate produced from concrete waste it is necessary to know not only the main characteristics of the filler aggregate — particles’ density, bulk density and specific surface, but also its chemical composition. Chemical composition of the filler aggregate produced from concrete waste is provided in Table 4.

After the X-ray analysis of the filler aggregate implemented during the research, its mineral composition was determined. X-ray pattern is shown in Fig. 9. We can notice that the main minerals of this raw material are as follows: silica Q (0.137, 0.138, 0.145, 0.154, 0.167, 0.182, 0.197, 0.213, 0.223, 0.228, 0.246, 0.335, 0.425 nm), calcite K (0.152, 0.160, 0.187, 0.198, 0.209, 0.250, 0.304, 0.385 nm), dolomite D (0.180, 0.201, 0.219, 0.240, 0.269, 0.402 nm), feldspars F (0.319 0.324 nm), portlandite P Ca(OH)2 (0.491) dominates as well, illite I (0.100 nm).

Considering the results of X-ray analysis of the filler aggregate, it can be assumed that its mineral composition is related to the initial material used for the crushing.

Since cement forms quite a large part of costs in concrete production, there is a search of the ways to replace a part of cement by fine aggregates — filler aggregates. According to standard LST 1577:1999 [10], a part of the cement can be replaced by the filler
Table 3  Characteristics of filler aggregate.

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<th>Filler aggregate</th>
<th>Parameter and its value</th>
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<tr>
<td></td>
<td>Bulk density (g/cm³)</td>
<td>Particles’ density (g/cm³)</td>
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<tr>
<td>Crushed concrete waste</td>
<td>0.95</td>
<td>2.50</td>
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<td>0/0.125 mm</td>
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Table 4  Chemical composition of filler aggregate.

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<th>Chemical composition, %</th>
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Fig. 9  X-ray pattern of filler aggregate: Q—quartz; K—calcite; D—dolomite; F—feldspars; P—Portlandite; I—illite.

aggregate. Mass ratio between filler aggregate and Portland cement cannot exceed 15%.

When chemical composition of the filler aggregate is known, it can be compared with cement’s chemical composition, provided in Table 4. It can be noticed, that the major part consists of CaO and SiO₂.

After analysis, it was determined that specific surface area of the cement is 3,950 cm²/g and the one of the filler aggregate from concrete waste is 2,904 cm²/g. Bulk density is similar: for the cement is 1.02 g/cm³, for the filler aggregate is 0.95 g/cm³.

During the research, surface area of both, cement and filler aggregate was analysed, size and shapes of their particles were compared. In Fig. 10 composite Portland limestone cement CEM II/A-L 42.5 N surface photo is shown.

In the photo, it can be seen that the shape of the powder of Portland cement is irregular, and size of the largest particles reaches 50 μm.

Fig. 10  Surface view of cement’s particles.
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(Fig. 11) Surface view of the particles of the filler aggregate produced from concrete waste.

Fig. 11 shows the surface area of the filler aggregate produced from concrete waste. The particles of the obtained filler aggregate have irregular shape and different size. Part of the particles have larger diameter than the one of the particles of Portland cement and reach up to 100 μm.

When the view of the filler aggregate from concrete waste and the view of the particles of Portland cement are compared, it can be noticed that particles’ surface is similar — sharp, edges are not rounded. In the filler aggregate, larger particles have larger diameter than in the Portland cement. However, in the Portland cement more finer particles (up to 5 μm) exists than in the filler aggregate. Therefore, by considering the provided photographs of the cement and filler aggregate, it can be concluded that the filler aggregate from concrete waste can replace a part of binding material.

4. Conclusions

After this study, the authors get some conclusions as the following:

1. In every country unexploited and dangerous buildings as well as constructions of various purpose exist and they are being demolished little by little. After the demolition works a lot of concrete and other construction waste remain. Therefore, its reprocessing and utilization issues are significant and are tackled actively;

2. The structure of the aggregate, produced from concrete waste is porous. Due to this, water impregnation of the aggregates increases. As a result, when concrete’s composition is prepared, water amount has to be increased in order to prepare concrete mixture of the required consistence;

3. Hollowness of the coarse aggregate produced from the concrete waste is rather large. As a result, during the selection of concrete composition, it is necessary to ensure that hollows, created between the coarse aggregates, are filled by the filler aggregates. Therefore, the larger amount of fine fraction is required in the concrete composition. In the mixtures, the amount of 0.25–2 mm size particles has to be increased, and the amount of 4–8 mm size particles are decreased;

4. Considering the obtained characteristics, chemical compositions as well as surface areas of the cement and filler aggregate from concrete waste, it can be stated that the filler aggregate can replace a part of the cement and can be used as an additive in cement production. However, the replacement of a cement part is possible only when the cement, with strength class higher than recommended, or the cement with lower amount of additives is used;

5. After the aggregates are produced from the concrete waste, all characteristics of the raw materials are determined and optimal concrete mixture's compositions are selected, it is possible to replace a part of concrete mixture’s components by the materials obtained after the proper reprocessing of concrete and reinforced concrete waste;

6. From an ecological viewpoint, in order to protect our surrounding environment against the pollution and to save natural resources, construction and demolition waste can be returned to the production of new products of the required quality.

References

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