I BUILDING MATERIALS

INFLUENCE OF VARIOUS SIZE CRUSHED CONCRETE WASTE AGGREGATES ON CHARACTERISTICS OF HARDENED CONCRETE

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ABSTRACT

The characteristics of hardened concrete depend on the raw materials used for the concrete mixture, their characteristics. Therefore, in the research, the variation of characteristics of concrete samples with concrete waste materials was analysed. During the analysis, concrete waste of different fractions was used as coarse and fine aggregate, as well as filler aggregate of crushed concrete waste was used. The research covers the implementation of X-ray analysis of the filler aggregate and identification of the main minerals of the aggregates produced from the concrete waste. The main physical and mechanical characteristics of the samples were determined through the implementation of the standard methodologies: the density of the samples was determined by following the standard LST EN 12390-7, compressive strength – LST EN 12390-3; impregnation – LST 1428.18:1997. It was found that the physical and mechanical characteristics of the concrete, produced by using crushed concrete waste with different particle size, differ from the characteristics of the reference samples. However, these characteristics satisfy the requirements of the designed concrete class C30/37. The obtained results show that crushed concrete waste can be utilised as coarse and fine aggregates for the production of new concrete products.

Keywords: demolition waste, concrete waste, recycled aggregate, filler aggregate, strength

INTRODUCTION

Concrete is one of the oldest and universal construction materials, and is suitable for the production of wide range of products and constructions both, at construction sites and factories. However, the concrete is a multicomponent material of complex structure, and this material consists of different components. These are coarse and fine aggregates with the size of up to few centimetres, binding material with the size of few micrometres, additives and water. Still, the origin of coarse and fine aggregates, used in concrete production, might be different. These can consist of concrete, ceramics and silicate waste, scrap glass, wood waste, pumice of blast-furnaces, volcanic ash, granulated tire rubber and other materials. These materials can substitute the natural aggregates and contribute to the production of the concrete with desirable and specific characteristics.
Concrete waste can be utilised as cheap coarse and fine concrete aggregate. However, special attention should be paid to the production of this aggregate, because after building (when their lifetime ends) demolition, such demolition waste can consist of concrete, silicate or ceramic bricks, wood, roof material, metals, plastic, cardboard and other materials (Fig. 1).
Therefore, it is necessary to carry out the initial sorting of the materials produced during the building demolition, separation of concrete and reinforced concrete products from other materials. Only after the sorting the reprocessing works of reinforced concrete can be implemented: reinforcement separation, shredding of large pieces, crushing and grain sorting into fractions. In this way the coarse, fine and filler aggregate is produced from the concrete waste.

Figure 1. Demolition work of commissioned buildings.

The quality and characteristics of the manufactured production must be constantly monitored, because the crushed constructions may have different strength characteristics. For instance, when ceiling slabs, columns, as well as partition constructions, are crushed. The aggregate mixture, produced from the crushed concrete waste, consists of the particles of cement stone, particles of rock with the cement stone plastered to, and the particles of rock separated during the crushing. In these aggregate particles the pores and micro-cracks, formed during the crushing, dominate. During the analysis, it was determined that the porosity of such aggregate varies and ranges from 5.8 % to 12.5 % (Tam et al., 2008; Zaharieva et al., 2003). As indicated by the researchers (Муртазаев et al., 2008), water absorption of the aggregates increases due to the porous structure of the aggregate produced from concrete waste. As a result, when aggregates of concrete waste are used during the preparation of concrete mixture, the amount of water, necessary to prepare the concrete mixture of the required consistence, increases. (Муртазаев et al., 2008) states that the required amount of water can increase even up to 15 %.

When coarse aggregate, produced from the strong concrete waste, is used, it is possible to produce the concrete the class thereof would satisfy the strength class requirements of the typical concrete (Бибик, 2010). Scientists (Evangelista et al., 2010) state that the compressive strength of the concrete, produced from concrete waste is close to the strength of the concrete produced from natural materials. These scientists determined that after the substitution of 30 % of coarse aggregate by concrete waste, the strength of hardened concrete decreases only by 3.6 %. In addition, the scientists also determined that, when 100 % of coarse aggregate was substituted by the aggregate, produced from the concrete waste, the compressive strength decreases by 7.6 %.

Concrete waste can be also used for the production of fine aggregate, which can replace a part or whole amount of sand required for concrete production. Scientists (Kou et al., 2009) analysed the utilisation of fine aggregate, produced from concrete and reinforced concrete waste, for the concrete production. During the investigation 25 % and 100 % amount of sand was replaced by concrete waste. After 28 days of hardening the strength of concrete decreased by 3.2 % and 8.4 %, comparing to the strength of the reference concrete samples. After proper reprocessing of concrete and reinforced concrete waste, it can be utilised for manufacturing of products of the required quality. Large amounts of construction waste occupy a lot of space in dump areas. During the past decades, the problems of reprocessing and utilisation of concrete waste are being resolved intensively, because every year huge amounts of construction waste are accumulated in the world, and this waste does not fragment and contaminate the environment in the course of time.

In Finland strict laws are employed to ensure that all demolition waste is recycled. In Japan, almost all reprocessed concrete and reinforced concrete waste is utilised for road construction. In Germany, in 2004 89 % of concrete and reinforced concrete waste was returned to the production line of new products (Klee, 2009).

In Lithuania, according to the waste records of 2007, 67 % of construction waste was reprocessed. On 19-11-2008 the directive 2008/98/EB of the European Parliament and Board was confirmed. In this directive it is stated that till 2020 at least 70 % of non-hazardous construction and demolition waste must be prepared for recycling and reprocessing.

Hence, the target of the research is to investigate the possibilities of secondary utilisation of concrete waste in concrete mixtures, and analyse the variation of characteristics of hardened concrete, for the production thereof the concrete waste aggregates with different particle sizes were utilised.

MATERIALS AND METHODS

Research materials

The following raw materials were utilised in the research:

Coarse aggregate: gravel breakstone and crushed concrete waste.

Fine aggregate: natural sand and crushed concrete waste. The main characteristics of coarse and fine aggregates are shown in Table 1.

Table 1

Characteristics of coarse aggregate

Coarse aggregate	Parameter and its value		
	Bulk density, g/cm^3	Particle density, g/cm^3	Hollowness, %
Crushed gravel 4/16 mm	1.44	2.45	41
Concrete waste 4/16 mm	1.16	2.10	45
Crushed gravel 0.125/4 mm	1.64	2.41	32
Concrete waste 0.125/4 mm	1.21	2.30	47

Filler aggregate: crushed concrete waste, the particle size of which is smaller than 0.125 mm. The main characteristics of the filler aggregate are shown in Table 2.

Cement: Composite Portland limestone cement CEM II/A-L 42.5 N, satisfying the requirements of the standard LST EN 197-1. The chemical composition of this cement is provided in Table 3, and mineral composition – in Table 4. The physical-mechanical characteristics of the utilised cement are shown in Table 5.

Table 2

Characteristics of filler aggregate

Filler aggregate	Parameter and its value		
	Bulk density, g/cm^3	Particle density, g/cm^3	Specific surface, cm^2/g
Crushed concrete waste 0/0.125mm	0.95	2.50	2904

Table 3

Chemical composition of the cement

Chemical composition, %						
SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	Other
20.6	63.4	5.45	3.36	3.84	0.80	0.34

Table 4

Mineral composition of the cement

Mineral composition, %			
C_3S	C_2S	C_3A	C_4AF
57.26	15.41	8.68	10.15

Table 5

Physical-mechanical characteristics of the cement

Parameter	Value
Size of particles	5–30 μm
Early compressive strength after 2 days, N/mm^2	21
Standard compressive strength after 28 days, N/mm	47
Initial set, min.	190
Final set, min	230
Specific surface, cm^2/g	3950
Specific particle density, g/cm^3	2.75
Bulk density, g/cm^3	1.02

Composition of the mixtures analysed

Four concrete mixtures were prepared during the research. Their compositions are provided in Table 6. Concrete compositions K, C1, C2, C3 were selected depending on the characteristics of raw materials, by implementing computational - experimental methodology and by using tables, diagrams and nomograms. The selected class of the concrete compressive strength was C30/37, mobility – 3 cm.

An equal ratio of water and binding materials W/B – 0.43 was used in all concrete mixtures. This ratio influences the structure, strength, durability and quality of the hardened concrete. The water amount selection is a very important stage, because this amount is related to the concrete composition, characteristics of its components. Minimal amount of water shall ensure the production of the concrete mixture of the required consistence.

During the research natural coarse aggregate, the particle size of which was 4/16 mm, was used. Only in C2 mixture the coarse aggregate, produced from crushed concrete waste, was utilised. The size of the particles of this aggregate was 4/16 mm. The aggregate, produced from concrete waste, replaced the overall amount of coarse aggregate. The amount of fine aggregate in this mixture was increased, because the selection of the concrete mixture composition, where the overall amount of coarse aggregate is replaced by crushed concrete waste, results in the lack of fine fraction aggregate. In mixture C3 the overall natural fine aggregate was replaced by concrete waste.

During the selection of concrete compositions, the cement part in C1 mixture was replaced by filler aggregate. In accordance with the standard LST 1577:1999, the mass ratio between the filler aggregate and Portland cement CEM II A cannot exceed 15 %. After the designing of the concrete composition, it was decided to add a half of this amount and 8 % of cement mass was replaced by the filler aggregate.

Table 6

Compositions of concrete mixtures

Concrete marking	Composition							
	Cement, kg/m^3	Coarse aggregate, kg/m^3		Fine aggregate, kg/m^3		Filler aggregate, kg/m^3	Water, l/m^3	W/B
		Crushed gravel	Concrete waste	Sand	Concrete waste			
K	395	1277	–	372	–	–	170	0.43
C1	363	1277	–	372	–	32	170	0.43
C2	410	–	930	690	–	–	180	0.43
C3	415	1280			420	–	180	0.43

The filler aggregate was produced by crushing concrete waste with alligator and by sifting out the produced material with laboratory separators into fractions belonging to coarse aggregates, fine aggregates and filler aggregates.

All concrete mixtures were prepared manually in the laboratory. The prepared concrete mixture of the required consistence was poured to 100×100×100 mm size moulds. The samples were thickened by vibration on the laboratory vibrating platform for approximately 1 min. The samples were hardened in the moulds for 24 hours, and then stored in 20ºC±2ºC temperature water (according to LST EN 12390-2) until the tests for the assessment of the characteristics were performed. Five samples were chosen from three concrete lots produced in laboratory conditions.

Research methodology

After 28 days of hardening in water, the density of the concrete cubes was estimated in accordance with the standard LST EN 12390-7, impregnation – in accordance with LST 1428.18:1997 and the compressive strength of the concrete – in accordance with LST EN 12390-3. The samples were compressed by using the press "ALPHA 3-3000", complying with the requirements of the standard LST EN 12390-4.

The concrete compressive strength was calculated by employing formula (1).

$$f_{cm} = \frac{F_b}{A_b}, \tag{1}$$

where : F_b – fragmenting compressive force, kN; A_b – sample cross-section area, mm^2.

During the investigation the mineral composition of the filler aggregate X-ray analysis of the filler aggregate was implemented by using the diffraction meter DRON-2 (Cu anode, Ni filter, monochromator, cracks with the size of 1:8:0.5 mm). The 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/I0 values of the lines with the corresponding values in ASTM file.

RESULTS AND DISCUSSION

After the X-ray analysis of the filler aggregate implemented during the research, its mineral composition was determined. The X-ray pattern is shown in Fig. 2. 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, 0.18 7, 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).

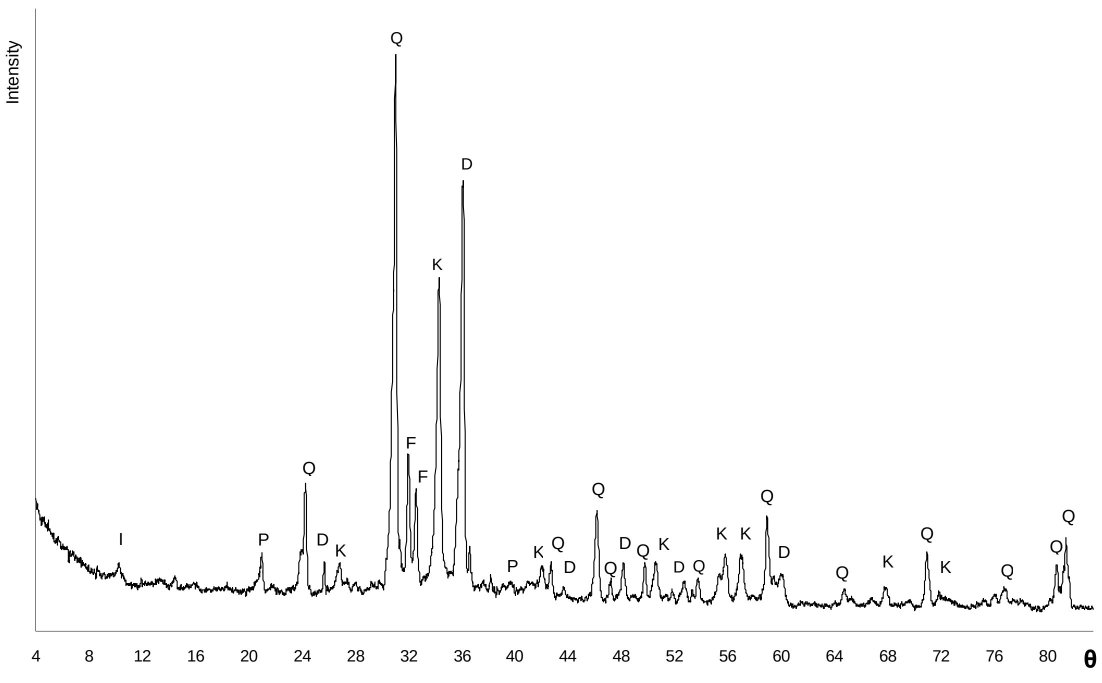

Figure 2. X-ray pattern of filler aggregate: Q – quartz; K – calcite; D – dolomite; F – feldspars; P – portlandite; I – illite.

Considering the results of the 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.

80 % of the concrete volume is occupied by concrete aggregates. They have a large influence on the concrete characteristics and durability, and the strength of the concrete depends very much on the mineral composition, quality, strength, hollowness, cleanness and granulometric composition of the aggregates.

During the research the compressive strength values of the concrete samples were estimated. It was noticed that the compressive strength depends on the size of the particles of the aggregate utilised. As scientists assume (Naujokaitis, 2007) strength of the concrete depends on the characteristics of the coarse aggregates, because their particles form the concrete framework and have an influence on the nature of the distribution of the concrete stresses, deformations, as well as on the formation of cracks due to various loads applied. The amount of water required for the preparation of the concrete mixture is related to the fine aggregates. In addition, the granulometric composition of the fine aggregate, characteristics, shape and amount of the particles influence the concrete macrostructure, and this is the structure of cement grout (with sand aggregate) existing in the concrete.

The results of the estimation of the compressive strength of hardened concrete are provided in Fig. 3.

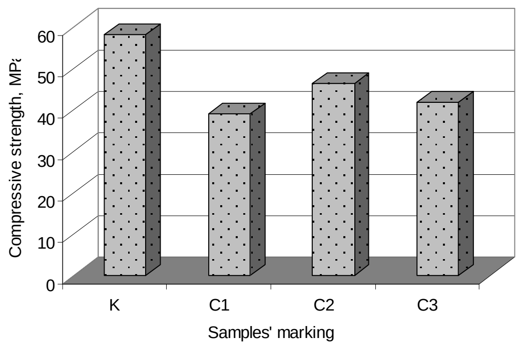

Figure 3. Results of estimation of compressive strength of concrete samples.

Fig. 3 shows that the compressive strength of the concrete samples with concrete waste aggregates with the particles of different sizes reaches 67–80 % of the strength of the reference samples (K). The lowest strength was achieved when a part of the cement of concrete mixture was replaced by the filler aggregate produced from crushed concrete waste. The compressive strength of the concrete samples, where 100 % of natural coarse or fine aggregates were replaced by the aggregate produced from concrete waste, varies depending on the size of the particles of the new aggregate. The compressive strength of the sample C2, where the coarse aggregate was replaced by crushed concrete waste, decreased by 20 %, and, when natural sand was replaced (sample C3), the compressive strength decreased by 28 %. However, the strengths of the concrete samples C2 and C3 reach their compression class requirements. As scientists (Evangelista et al., 2010) state, when concrete waste is utilised as fine aggregate, the strength of the newly hardened concrete can decrease by up to 30 %.

The compressive strength is a very important characteristic of concrete. In addition to this, concrete is the most resistant to the compression stresses. As it is stated by (Naujokaitis, 2007), concrete, that is influenced by compression loads, disintegrates according to three models: the first – when disintegration occurs through the cement stone, the second – when disintegration occurs through the aggregate and the third – when concrete disintegrates through both, cement stone and aggregate. It was noticed that during the compression process, when the concrete samples were disintegrating, the disintegration occurred not only through the cement stone, but also through the aggregates produced from concrete waste.

In Fig. 4 a view of a cut concrete sample, in the production thereof the concrete waste was used as the coarse aggregate, is showed.

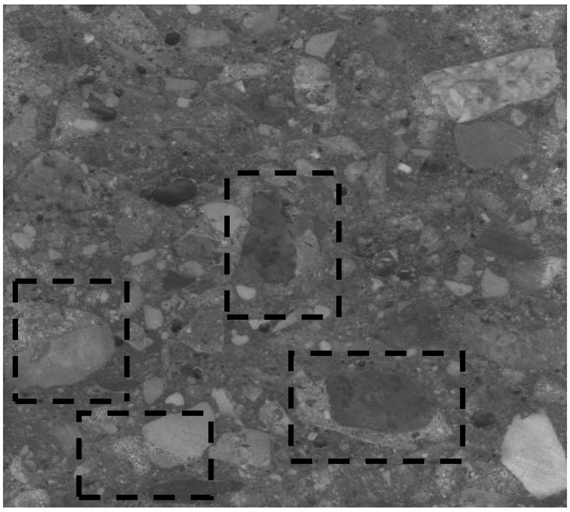

Figure 4. View of cut concrete sample.

Newly created cement stone, coarse and fine aggregates can be noticed in this view. Newly created aggregate from the concrete waste is marked in the figure, and it is clear that this aggregate is formed from the natural aggregate and the adhered cement stone, which remained uncrushed during the crushing process. In addition, it can be seen how this aggregate adheres to the newly formed cement stone.

The concrete density, as well as the compressive strength, are one of the main quality parameters of hardened concrete. The variation of the density of hardened concrete, depending on concrete composition, is shown in Fig. 5.

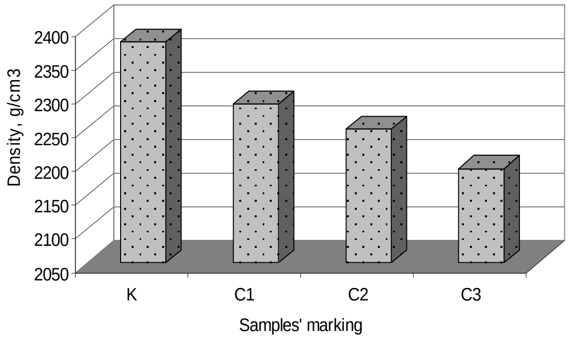

Figure 5. Results of density estimation of concrete samples.

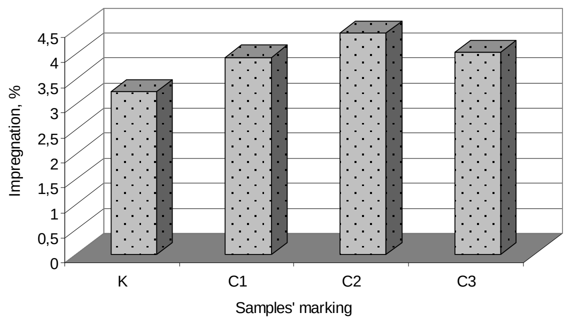

Figure 6. Results of the estimation of sample impregnation.

It can be noticed that concrete C1, where only natural aggregates were used and 8 % part of the cement was replaced by the filler aggregate produced during the crushing of the building concrete constructions, density reached the highest value – 2286 kg/m^3. Comparing with the reference concrete samples, the density decreased by only 4 %, even though the concrete strength decreased by 33 %. The density decreases when concrete waste replaces coarse or fine aggregates. The density of the concrete, produced by utilising coarse aggregates from crushed concrete waste, is 2249 kg/m^3, i.e., this value is by 3 % higher than the one of concrete, produced by utilising concrete waste instead of fine aggregate. However, the density of all samples satisfies the density requirements applicable for normal concrete, the density of which after 28 days of hardening and drying must be in the range of 2000–2600 kg/m^3.

The concrete density is not fixed, and it depends on the characteristics of the raw materials utilised. Therefore, it is necessary to constantly analyse the main characteristics of the aggregates produced from concrete and reinforced concrete waste, because these characteristics influence the properties of the hardened concrete.

Water impregnation of the hardened concrete samples was estimated after 72 hours of soaking. The results of impregnation are shown in Fig. 6.

CONCLUSIONS

1) Waste reprocessing problems are very important in the world and are being resolved intensively, because more and more new buildings are built and old, unused constructions are demolished. In respect to the ecological safety and in order to save natural resources, concrete waste can be utilised for the production of high quality products by returning this waste to the production technological cycle.
2) After analysis of the influence of the size of particles of the aggregates utilised in concrete production, it was noticed that the compressive strength values vary. The compressive strength decreases by 20 % when coarse aggregates are replaced by concrete waste, and, after fine aggregate is replaced by the crushed concrete waste, the concrete compressive strength decreased by 28 %. However, when natural aggregates are replaced by concrete waste, the strengths of the newly produced hardened concrete samples reach the compression strength value of the class C30/37 of the designed concrete.
3) The results of the analysis show that, when natural coarse and fine aggregates are utilised and 8 % of the amount of cement is decreased by replacing it with the filler aggregate from crushed concrete waste, the compressive strength decreases significantly, density increases by 21 % and impregnation decreases only by 4 %.
4) According to the density results of the concrete samples it can be assumed that the density values of the produced concrete samples satisfy the requirements applicable for normal concrete, because the obtained values vary from 2190 to 2286 kg/m^3.
5) The results of the analysis showed that, when crushed concrete waste is used for the concrete, the characteristics of the hardened concrete worsen, comparing to the reference concrete sample where waste was not utilised. However, during further analysis it is possible to estimate the optimal compositions of concrete mixtures and to monitor the characteristics of the produced products.

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