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Composition Selection and Analysis of Concrete Produced by Utilising Sand from Crushed Concrete Waste

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Abstract. **Normal concrete, produced by using the fine aggregates from the recycled materials, is analysed in the research. Composition selection methodology for the concrete mixture is presented in the research. By employing this methodology, the normal hardened concrete is produced from the natural aggregates and crushed recycled materials. The properties of compressive strength and density of this concrete are not lower than the characteristics of concrete produced only from the natural aggregates. Concrete waste, obtained through the milling, was used for the concrete mixtures described in the research. Concrete waste was used in the concrete mixtures as a fine aggregate together with the fine natural sand. The composition of such mixtures of fine aggregates results in a possibility to use sand, whose module of coarseness is lower or equal to 1, for the concrete production.**

Keywords: **concrete mixture, aggregate from crushed concrete waste, fine aggregate, compressive strength, normal concrete**

I. Introduction

Aggregates from the recycled materials are named aggregates that are produced from inorganic materials earlier used in the construction [1]. Such earlier used inorganic materials can be represented by the crushed construction waste. The amount of concrete in construction waste can reach from 68% to 90% of total amount. Construction waste is created during building construction, restoration, repair or demolition. The term "construction" covers any kind of buildings (residential, as well as non-residential houses) such as roads, bridges etc. Large amounts and volumes of construction waste take a lot of space in the dump areas. The composition of construction waste depends on the type of the building to be built or demolished, as well as on the technologies implemented [2]. The distribution of the quantities of construction waste is provided in Fig. 1. When unexploited buildings are demolished, the distribution of waste quantities slightly differs. After the demolition of these buildings the major part of waste materials consists of wall construction materials: concrete waste and metals.

In accordance with Waste Management Rules, concrete waste belongs to the third group of waste materials [3]. Excavators, stone-breakers, milling machinery are used during demolition of buildings. This equipment is used to implement the initial sorting – local separation of the particular waste materials suitable for recycling and processing [4].

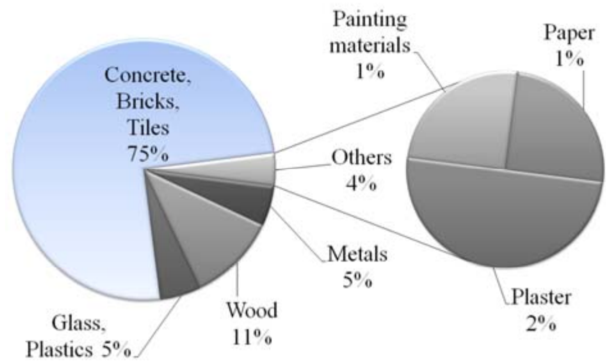

Fig. 1. Quantities of different types of construction waste materials.

As large amounts of construction waste take a lot of space in the dump areas, during the past decade the problems of the reprocessing and utilisation of concrete waste are being resolved intensively worldwide. The major part of construction waste materials belongs to the group of hardly disintegrating materials that pollute 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 used for road construction. In Germany, in 2004 89% of concrete and reinforced concrete waste was returned to the production line of new products [5].

Nowadays in Lithuania crushed concrete is used only for the base of motorways [6]. These materials are called construction materials of repeated usage. The crushed concrete must satisfy the following conditions: ≥ 90% amount of crushed concrete, amount of the crushed masonry material – not higher than 10%, and amount of crushed asphalt – lower than 5%, amount of cohesive material ≤ 1%, amount of organic material ≤ 0.1 %.

Lithuanian companies, which provide reprocessing services of construction waste, produce and supply the following production for the customers: concrete breakstone with the fractions of 0/10, 0/16, 10/22, 16/45, 45/80, 0/22, 0/63 mm. However, fractions of 0.125/16, 0.125/4 mm are not produced, and the particles smaller that 0.125 mm are not separated from waste. Only fractions of the coarse aggregate, i.e., 10/22, 16/45, 45/80 mm, are produced. When prices of the unrefined and refined (without fine particles) mixtures are compared (price for 0/16 mm fraction concrete breakstone is 17.42 Lt/t), it can be noted that the price of unrefined mixtures is 2.5 times lower than the one of 10/22 mm fraction (44.65 Lt/t) [7].

Concrete waste can also be used for the production of fine aggregate, which can replace the part or whole amount of sand required for concrete production. Scientists have analysed the use 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 compressive strength of concrete decreased by 3.2% and 8.4%, comparing to the strength of reference concrete samples [8].

In Poland, crushed concrete was used for the construction of the new concrete road covering layer. During the restoration of the concrete covering layer (approximately 20 km) of A4 type highway, built 70 years ago, the concrete covering layer was disassembled, concrete was milled out and 20–30% of the milled out concrete waste was used to replace the new aggregates during the preparation of concrete covering layer of the highway.

The research was conducted to select the mixture of concrete produced by utilising fine aggregates from the recycled materials, such as crushed concrete waste (obtained through the milling), and to analyse the properties of hardened concrete produced from these materials.

II. Methodology for the Selection of Concrete Mixture Composition

During the selection of the composition of concrete mixture it was decided to follow the experience of scientists, who analysed the influence of crushed particles on the properties of concrete mixture. Russian researchers, who put forward the recommendations on the utilisation of sand produced from crushed rock, noted that when crushed particles less than 0.14 (0.16) mm in size were used, water demand increased in the concrete. Therefore, during the preparation of sand from crushed rock, these fine dispersive particles are not used. It is recommended that the crushed particles of fine aggregate together with very fine sand are used for concrete production. The utilisation of such complex fine aggregate can save 7% of cement, comparing to the case when only fine sand is used for the concrete production. In addition, less amount of natural material, 0.07–0.21 m^3, is required for every m^3 of concrete being prepared. When such complex fine aggregate is used (one part of the aggregate is composed from fine sand, the other – from the crushed particles), the crushed part should be characterised (in respect to the module of coarseness) as coarse or very coarse fine aggregate. The amount of flat particles in the crushed material shall not be higher than 60%, and the amount of dust and clay particles shall not exceed 5%. However, when complex fine aggregate is used, the amount of dust and clay particles must fulfil the requirements applicable to concrete [9].

For the selection of concrete composition, where complex fine aggregate is used, the optimal ratio m is defined through experiments and by employing the following equation:

$$m = \frac{S_{sm}}{T_{sm}}, \qquad (1)$$

S_{sm} – amount of natural fine sand, kg; T_{sm} – amount of the crushed particles that belong to the group of fine aggregates, kg.

In addition, for the concrete mixtures discussed the ratio r is calculated in accordance with the following equation:

$$r = \frac{S_m}{S_t}, \qquad (2)$$

S_m – amount of fine aggregate in the mixture, kg/m^3; St – amount of coarse aggregate in the concrete mixture, kg/m^3.

The optimal amount of the crushed particles in the mixture of fine aggregate and r value depend on the fineness of natural sand. The dependence of these values on sand fineness is provided in Table I [9].

TABLE I

THE OPTIMAL AMOUNT OF THE CRUSHED PARTICLES AND ΔR VALUES

Module of coarseness of natural sand	Amount of the crushed particles in mixture, %	Δr
1.0 – 1.4	40 – 60	+0.20
1.5 – 1.8	25 – 40	+0.15
1.9 – 2.1	10 – 20	+0.10

The calculated composition of concrete mixture is verified experimentally, the strength of concrete mixture is determined, and water/cement ratio is revised.

III. Characteristics of Raw Materials, Composition of Concrete Mixture and Test Methodologies

Cement, fine aggregate – sand and crushed concrete waste, coarse aggregate – gravel and crushed concrete waste were used for the tests.

Cement: composite Portland limestone cement CEM II/A-L 42.5 N, satisfying the requirements of standard LST EN 197-1 "Cement. Part 1 [10]. Composition, technical requirements and conformity criteria of regular cements".

Coarse aggregate: natural 4/16 mm gravel and crushed concrete waste with the fractions of 4/16 mm. Crushed concrete waste was obtained through the milling of concrete base layer of Šiauliai (Lithuania) viaduct, and after drying and sieving of the obtained material. Coarse fractions were used as coarse aggregate, and fine fractions were refined and used for the production of fine aggregate.

Fine aggregate: 0/1 mm natural sand and fine fractions (0.125/4 mm) of crushed concrete waste. Crushed concrete sand was obtained through the sieving of the remaining particles after the sorting out of the coarse fractions. The finest particles less than 0.125 mm in size were not used, because in the analysis, carried out earlier, it was noted that these particles decreased the strength of concrete considerably [11].

The main characteristics of coarse and fine aggregates are provided in Table II.

TABLE II
CHARACTERISTICS OF COARSE AND FINE AGGREGATES

Aggregate	Title and value of the parameter		
	Bulk density, g/cm^3	Particle density, g/cm^3	Hollowness, %
4/16 mm gravel	1.44	2.48	42
0/1 mm sand	1.60	2.43	34
0.125/4 mm crushed concrete waste	1.21	2.31	48
4/16 mm crushed concrete waste	1.30	2.31	44

The granulometric composition of fine aggregate, produced from crushed concrete waste, is shown in Fig. 2, and the granulometric composition of fine sand used during the research is depicted in Fig. 3.

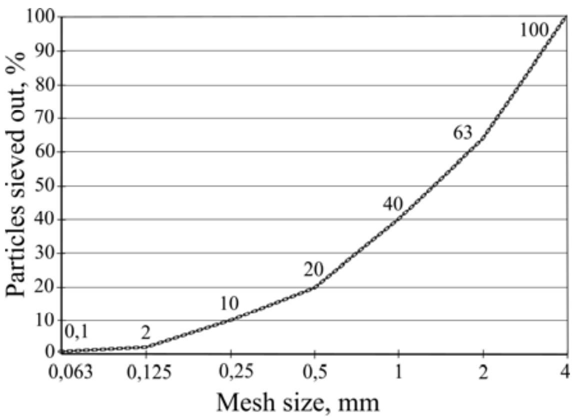

Fig. 2. Granulometric composition curve of fine aggregate from crushed concrete waste.

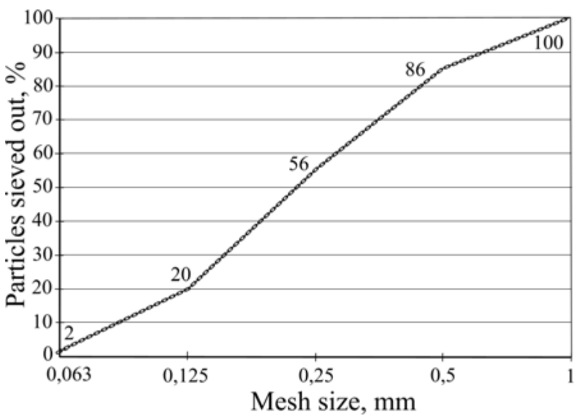

Fig. 3. Granulometric composition curve of fine aggregate from crushed concrete waste.

During the investigation of crushed concrete of various fractions it can be noticed that the amount of flat and oblong particles depends on the fraction size and equipment used for concrete crushing. The major part of the coarse fractions of crushed concrete consists of triangular or quadrangle particles with irregular shape. The amount of oblong and flat particles is larger in the fractions of smaller particles. However, this amount depends on the equipment used for crushing. Crushed concrete particles, obtained by employing alligator and milling equipment, were compared. As can be seen in Figures 4 and 5, fine concrete aggregate, obtained through the milling of a concrete layer with milling equipment, has less oblong particles. However, it can also be seen that this aggregate is contaminated by asphalt concrete insertions. These insertions were created after the mixing of residues of old milled asphalt concrete layer with concrete.

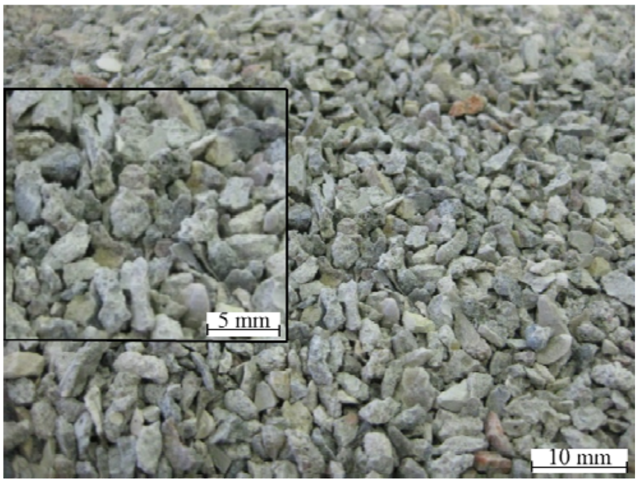

Fig. 4. Fine aggregate produced from crushed concrete by using alligator equipment.

Fig. 5. Fine aggregate produced from crushed concrete by using milling equipment.

5 concrete mixtures were prepared. Composition of concrete mixtures is provided in Table III.

TABLE III
COMPOSITION OF CONCRETE MIXTURES

Concrete marking	Cement, kg/m^3	Coarse aggregate, kg/m^3		Fine aggregate, kg/m^3 (% from overall amount of fine aggregate)		Water, l/m^3
		Gravel	Crushed concrete waste	Fine sand	Crushed concrete waste	
DK	463	783	–	527 (100 %)	–	214
D1	463	783	–	105 (20 %)	422 (80 %)	214
D2	463	783	–	211 (40 %)	316 (60 %)	214
D3	463	783	–	316 (60 %)	211 (40 %)	214
D4	463	–	783	–	527 (100 %)	214

The selected class of concrete compressive strength – C30/37, slumping factor 3 cm (it belongs to the slumping factor – S1 in accordance with LST EN 206-1 "Concrete - Part 1: Specification, performance, production and conformity") [12]. Concrete composition was selected depending on the characteristics of raw materials, by implementing computational and experimental methodology and by using tables, diagrams and nomograms [13]. This composition was corrected according to Table 1, by increasing r from 0.473 to 0.673. Marking DK stands for the reference concrete composition that is prepared by using natural aggregates – gravel and sand. Other compositions D1, D2, D3 of concrete mixture were prepared by employing the concrete composition selection methodology described earlier. The largest amount of the crushed particles of concrete waste was used in mixture D1, and this amount was equal to 80% compared to the overall amount of fine aggregate. The lowest amount of crushed particles of concrete waste was in concrete mixture D3 – 40%, and average amount in mixture D2 – 60%. The described ratio m in concrete mixtures was equal to the following: D1 – 0.25; D2 – 0.67; D3 – 1.50. In addition, for the purpose of comparison, the concrete mixture D4 was prepared. In this mixture only concrete waste was utilised – coarse and fine aggregates, without natural materials.

Equal ratio of water and cement W/C – 0.5 was used in all concrete mixtures. The slumping factor of the concrete mixture was verified against LST EN 12350-2 "Testing of fresh concrete. Part 2. Slump test"; it was equal to 3 cm [14].

The prepared concrete mixture of the required consistence was poured into the moulds (100×100×100 mm). Samples were thickened by vibration on a laboratory vibrating platform for approximately 1 min. Samples were hardened in accordance with LST EN 12390-2 "Testing of hardened concrete. Part 2. Making and curing specimens for strength tests" [15]. After 28 days of hardening, concrete samples were dried out in a laboratory dryer. Density of the concrete samples was determined according to LST EN 12390-7 "Testing of hardened concrete. Part 7. Density of hardened concrete" [16]. Impregnation was found by soaking samples for 72 hours in 20±1°C temperature water. Capillary rate of mass flow g1 was determined by saturating the samples, whose bottom surface was immersed into water, and by using the following equation:

$$g_1 = \frac{m_2 - m_1}{S}, \ \frac{g}{cm^2} \cdot 0{,}5h \tag{3}$$

m_1 – the mass of dry sample, g; m_2 – the mass of the sample, saturated by implementing 0.5 h capillary method; S – the surface area, through which the saturation of the sample was carried out, cm^2.

Compressive strength of concrete was determined in accordance with LST EN 12390-3 "Testing of hardened concrete. Part 3. Compressive strength of test specimens" [17]. Samples were compressed by using press "ALPHA 3000", complying with the requirements of LST EN 12390-4 "Testing of hardened concrete. Part 4" [18].

Strength analysis of the concrete samples was carried out by employing non-destructive methodology and by estimating the speed of ultrasound impulse with device UK-14P. Propagation speed (V) of ultrasound impulse of contrary transfer was calculated by using the following equation:

$$V = \frac{l_1}{\tau \cdot 10^{-6}}; \ \frac{m}{s} \tag{4}$$

τ – the propagation period of ultrasound impulse, ms; l – the sample length, m, 10^{-6} – the conversion factor.

IV. Test Results

Density results of the samples are provided in Fig. 6.

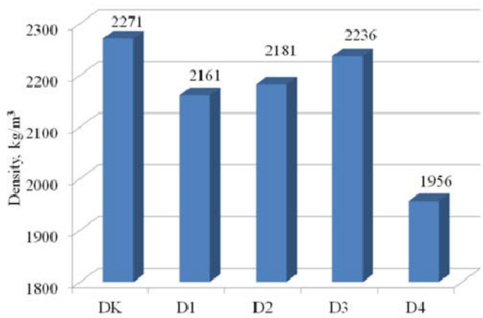

Fig. 6. Density results of concrete samples.

Concrete cubes of the reference samples DK, prepared without using crushed concrete waste, have the largest density. Densities of other concrete samples (D1–D3) differ from the reference samples by only 4.8%, and the smallest density of the samples was achieved when only crushed concrete waste was used for the concrete mixture. Density of these samples is lower by 14% compared to the reference density.

Compressive strength of concrete samples was estimated after 2, 7, and 28 days of hardening. The obtained results of compressive strength are shown in Fig. 7.

It can be seen that compressive strength of the samples depends on the amount of the crushed concrete waste used for the concrete mixture.

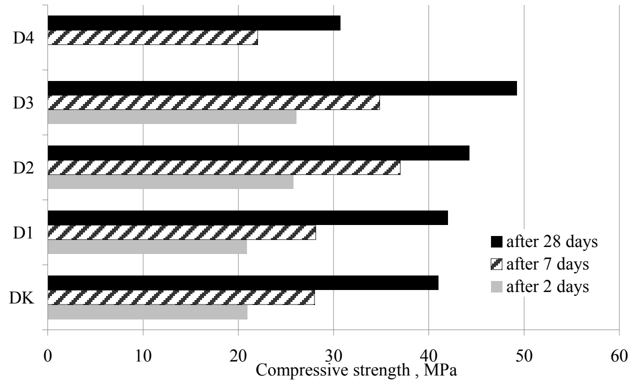

Fig. 7. Compressive strength results of concrete samples.

After the standard hardening period, the largest compressive strength was achieved for the samples that had 40% of crushed concrete waste in the composition (D3). Compressive strength of these samples is larger than that of the reference samples by even 20%. Based on the test results of compressive strength, it can be concluded that the optimal amount of fine aggregate (sand) in the mixture prepared with concrete waste is 60%. However, it has to be considered that crushed concrete waste is used only with very fine sand, whose module of coarseness does not exceed 1. Compressive strengths of the samples of all four sets (DK, D1–D3) reached values required by the specified concrete class C30/37.

The smallest strength of the concrete samples was achieved when only crushed concrete samples were used – samples D4. Compressive strength of these samples reaches only 31 MPa. In the previously published articles it was also identified that, when the natural concrete aggregates were replaced by crushed concrete waste, the compressive strength of the samples decreased by approximately 25–30% [19].

Propagation speed of the ultrasound impulse was determined. Average values of this parameter are provided in Fig. 8. As can be seen in Fig. 8, the most even structure belongs to D3 samples, where the propagation speed of ultrasound impulse is the highest. After the calculation of the dependence of compressive strength on the propagation speed of ultrasound impulse it was determined that the relation of these values was medium – correlation coefficient was 0.893, and determination coefficient – 0.798. Mathematical expression of the relation – y=0.0188x-28.726.

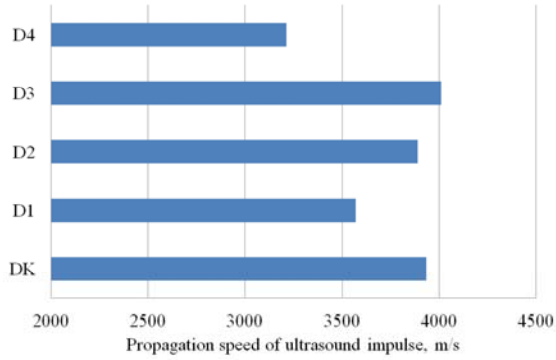

Fig. 8. Propagation speed of ultrasound impulse in the concrete samples.

Impregnation results of the hardened concrete samples after 3 days of soaking in water are provided in Fig. 9. It can be noticed that the highest sample impregnation, reaching 10.3%, was achieved after soaking of D4 samples, and the lowest impregnation – 4.8 % was achieved for D3 samples. In addition, it can be noticed that the impregnation values of DK, D2 and D3 samples are very similar.

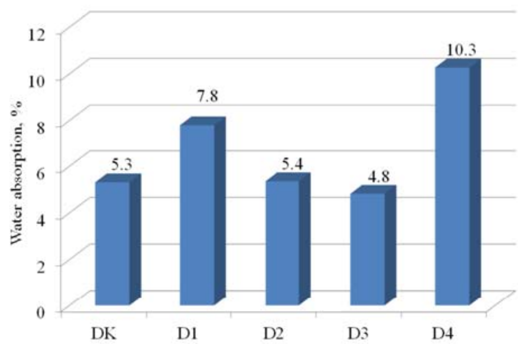

Fig. 9. Concrete impregnation results.

After the determination of capillary rate of mass flow in concrete samples, it can be noticed (Fig. 10) that it is the lowest one for the reference samples – 0.08 g/cm^2•0.5h, and for D4 samples it is two times higher – 0.21 g/cm^2•0.5h. The obtained results of the analysis show that, when for the preparation of concrete mixtures the fine sand is used together with the crumbs of concrete waste, all hollows are filled better, and more dense and even structure of the concrete samples is achieved.

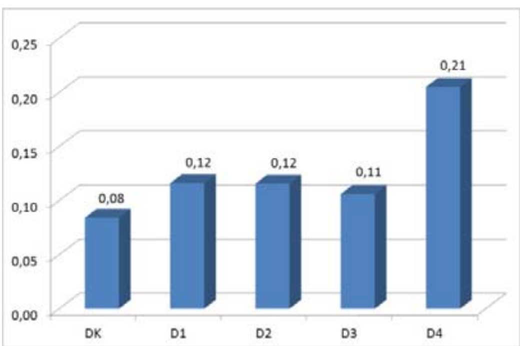

Fig. 10. Capillary rate of mass flow of the concrete samples.

During the selection of an optimal value of the ratio m, it can be noticed that, after considering the results of compressive strength, the propagation speed of ultrasound impulse, density, impregnation, capillary rate of mass flow, it is equal to 1.50. For this ratio of fine sand and crushed concrete waste (fine fraction) the best results of physical and mechanical characteristics are achieved.

V. Conclusions

1. Concrete mixtures can be prepared by utilising crushed concrete waste that is reprocessed by implementing various methodologies. One of the ways to produce waste is the milling of the concrete layer. Waste obtained in such a way can be utilised as a fine aggregate in the concrete production, and especially when this waste is used in the mixtures together with fine sand. The composition of such mixtures results in a possibility to use sand, whose module of coarseness is lower or equal to 1, for the concrete production. When fine sand is used together with fine concrete waste it is possible to produce concrete, whose properties are not worse that the ones of concrete prepared by using natural gravel and sand.

2. Optimal ratio m of sand and crushed concrete waste is equal to 1.50. For this ratio the best results of physical and mechanical characteristics are achieved: compression strength 49 MPa, propagation speed of ultrasound impulse 4010 m/s, impregnation 4.8%, sample density 2236 kg/m^3, capillary rate of mass flow 0.11 g/cm^2•0.5h.

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