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PROPERTIES OF RECYCLED COARSE AGGREGATES MADE OF CONCRETE WASTE

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During the post-war reconstruction, Ukraine will face the challenge of dealing with a large number of buildings and structures that will be subject to partial dismantling and demolition. According to the Kyiv School of Economics as of January 2024, the losses from the destruction and damage of buildings and structures amount to at least 75 billion dollars [1]. The issue of the general level of physical depreciation of buildings and structures is also relevant for Ukraine, both in the industrial and civil-residential sectors. The development of construction contributes to an increase in the volume of demolishing old buildings and structures, which, in turn, leads to the emergence of a large amount of construction waste. On the other hand, there will be a need for a large amount of materials for renewal, the share of which can account for up to 50 % of the construction cost. To reduce the cost of projects, it is advisable to reuse materials from waste generated after dismantling. In 2022 new standard was implemented regulating the handling of waste resulting from armed conflicts [2]. Now contractors carrying out the liquidation of the consequences of armed aggression are required to take measures to reuse construction waste.

Taking into account the presence of natural crushed stone in concrete scrap, the question arises about the possibility of using crushed concrete during new construction. The most obvious option is the use of crushed concrete waste as a coarse aggregate for the production of new concrete.

Concrete is a heterogeneous composite material, the mechanical properties of which are determined by the interaction of its components. In the mesoscopic model, concrete with natural aggregate is represented as a two-phase system consisting of coarse aggregate and a mortar matrix, which are connected by a layer of the interphase transition zone (ITZ) along the boundary of the coarse aggregate. Recycled coarse aggregate (RCA) is obtained by crushing and processing used concrete. Thus RCA consists of two main phases – original natural aggregate (NA) and residual mortar (RM). Therefore concrete with RCA is more complex system due to the presence of additional phases – RM and ITZ between it and NA.

During the design a concrete mixture it is necessary to know such characteristics of aggregates as grain size composition, bulk density, specific density, voids, strength. To determine the specified characteristics of RCA obtained from crushed concrete on local materials, three mixtures of concrete were designed and a series of cube samples were made from them. Each mixture was produced in 3 series for testing and grinding at the age of 28, 90 and 180 days. Materials with the characteristics given below were used to design concrete mixtures:

– cement: portland cement by Heidelbergcement, Kryvyy Rih; specific density (SD) $\rho_c = 3{,}1\ g/cm^3$; bulk density (BD) $\rho_{b.c} = 1{,}2\ g/cm^3$;

– fine aggregate: sand; fineness modulus M_k=1,39; SD $\rho_{fa} = 2{,}65\ g/cm^3$; BD $\rho_{b.fa} = 1{,}61\ g/cm^3$

– coarse aggregate (origin virgin aggregate): granite crushed stone; grain size composition according to DSTU B V.2.7-75-98; SD $\rho_{ca} = 2{,}6\ g/cm^3$; BD $\rho_{b.ca} = 1{,}51\ g/cm^3$; aggregate crushing value (in cylinder) 9 %.

At the appropriate age after the hardening in normal conditions, the samples were tested for compressive strength. The results of compressive strength tests are represented in the Table 1.

The samples of origin concrete were crushed using a laboratory jaw crusher with complex rotation. Since the size of the crusher's inlet is 70 mm, the samples were initially split into fragments with a maximum size of 50−60 mm. For further testing, precisely the split samples were used, based on the consideration that this method of fragmentation, in terms of its impact on the material's structure, is closest to real demolition methods of buildings.

Table 1

Origin concrete. Test results

Mixture	Age of test, days	Density, g/cm^3	Compressive strength, $f_{c.cube}$, MPa	Coefficient of variation, %	Strength f_c, MPa
C1/28/K	28	2,33	22,1	5,8	20,7
C2/28/K	28	2,36	30,7	3,7	28,7
C3/28/K	28	2,28	26,2	5,0	24,4
C1/90/K	90	2,38	29,4	13,0	23,0
C2/90/K	90	2,31	30,6	5,0	28,6
C3/90/K	90	2,32	36,0	8,2	32,9
C1/180/K	180	2,36	29,5	2,1	27,5
C2/180/K	180	2,32	34,8	2,8	32,5
C3/180/K	180	2,34	36,6	8,0	33,6

Grain size composition of each mixture was determined by sieve analysis. The results of tests are represented as sieving curves (Fig. 1, 2). As we can see from Figure 1 ungraded mixtures of fine (less than 5 mm) and coarse fractions (more than 5 mm) do not meet the requirements of [3] due to the large content of fine fractions (they are not between curves A and B). At the same time, in general, the grain size composition of only coarse fractions meets the requirements of standards in Ukraine (Fig. 2): in the two-fraction mixture, the content of the 5−10 mm fraction is up to 31 %, the 10−20 mm fraction is 63−70 %, the larger fraction is 1−6 %.

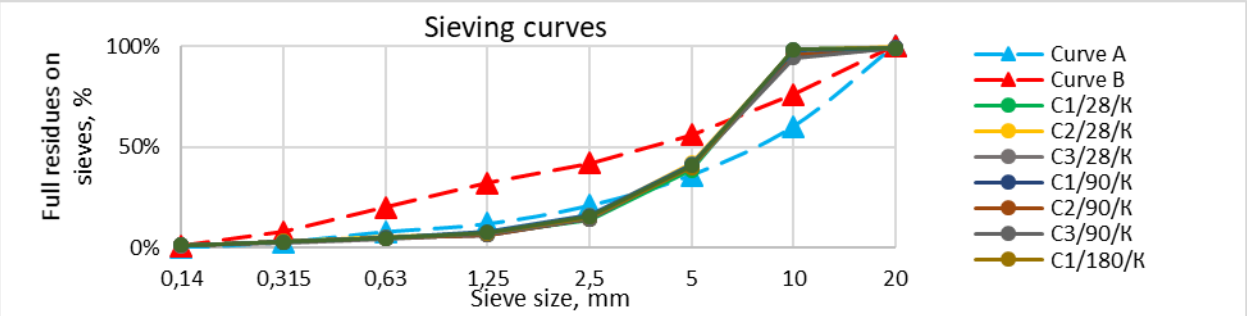

Fig. 1. Sieving curves of a mixture of fine and coarse fractions

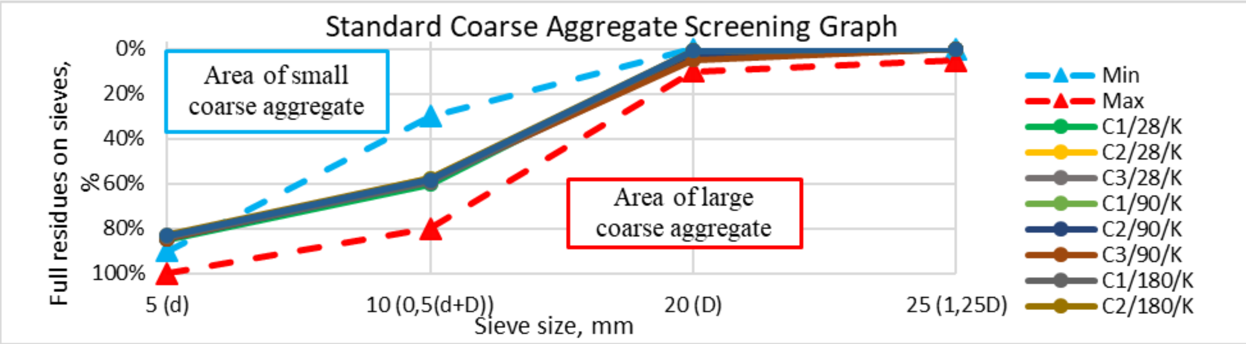

Fig. 2. Sieving curves of only the coarse fractions on the standard graph

A visual inspection of individual grains of fractionated RCA showed that the content of RM on the grains of different fractions differs significantly. Almost 100 % of grains in the 10−20 mm fraction contain both natural crushed stone and RM. In the vast majority, the content of the RM is less than 50 %. In the fraction of 5−10 mm, a certain amount of grains does not have natural crushed stone at all, in a large number of grains the content of RM significantly exceeds 50 %. Therefore, to determine the specific and bulk densities, each fraction was tested separately.

The obtained BDs ranged from 1,05 g/cm^3 to 1,1 g/cm^3 of fractions 5−10 mm and from 1,20 g/cm^3 to 1,27 g/cm^3 of fractions 10−20 mm.

Given the presence of porous RM on the grains paraffin was used to determine the SD. Randomly selected and pre-weighed grains were immersed for 1−2 s in melted paraffin and then cooled in air. After that, the grains with paraffin were weighed and placed in a flask with a predetermined volume of water in it. Knowing the density of paraffin, the SD of RCA was determined. The obtained SDs ranged from 2,29 g/cm^3 to 2,38 g/cm^3 of fractions 5−10 mm and from 2,44 g/cm^3 to 2,55 g/cm^3 of fractions 10−20 mm.

a *b*

Fig. 3. Fractions 5−10 mm (a) and 10−20 mm (b)

To determine the strength of RCA, a crushing test in a steel cylinder was carried out. Based on the test results graphs of the dependence of crushing value on SD were constructed (Fig. 3). It can be seen that the strength of the RCA decreases with a decrease in density.

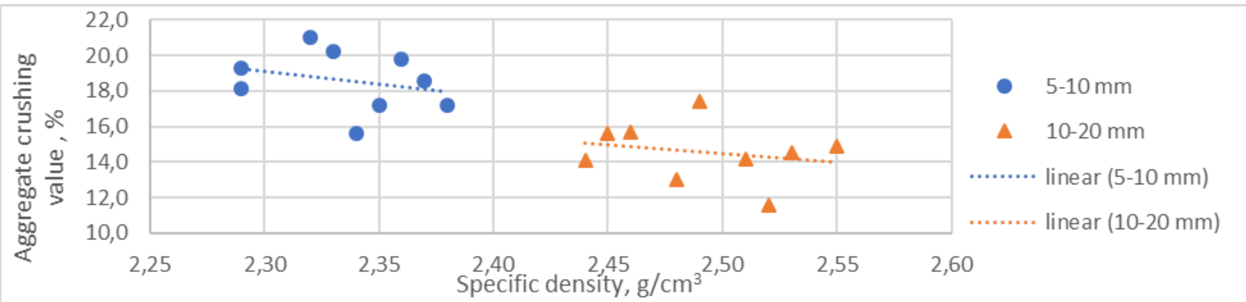

Fig. 3. Dependence of aggregate crushing value on SD

Conclusions. The main factor that has a decisive influence on the properties of RCA and concrete with their use is the presence of RM. During experiment, due to the known information about the characteristics of the components of the original concrete mixtures, it was established that the content of the RM by mass in fractions of 5−10 mm was 20−30 %, in fractions of 10−20 mm − 5−15 %. The presence of RM is the reason for the diversity of densities even within the same fraction, which significantly complicates the correct design the concrete mixture. It also causes the higher water absorption. Therefore, one of the methods of improving the properties of RCA is to reduce the content of the RM. Obviously this content is determined at the stage of crushing concrete scrap. Due to the features of the crushing process in the jaw crusher, the structure of the mortar matrix is disturbed. As a result, some grains, even maintaining their shape, become very weak − their destruction is possible even by hand. It is advisable to apply additional grinding in a hammer crusher, in which the weakened fragments will be separated from the grains under impact. And that will generally lead to an increase in the strength of the entire RCA mixture, as well as to an increase in the density of its packaging.

References

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