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ВЛАСТИВОСТІ МАТЕРІАЛІВ РЕЦИКЛІНГУ БУДІВЕЛЬНИХ ВІДХОДІВ ТА МОЖЛИВІСТЬ ЇХ ЗАСТОСУВАННЯ В ДОРОЖНЬОМУ БУДІВНИЦТВІ

PROPERTIES OF RECYCLED CONCRETE AGGREGATE AND THE POSSIBILITY OF THEIR APPLICATION IN ROAD CONSTRUCTION

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The study provides a comprehensive analysis of the properties of materials derived from recycled construction waste. Based on the results, their potential for use in road construction has been assessed, highlighting a more sustainable solution for supporting Ukraine's reconstruction efforts.

У статті досліджено властивості матеріалів рециклінгу будівельних відходів (RCA-Recycled concrete aggregate) та їх потенційне застосування в дорожньому будівництві. В умовах сучасної концепції сталого розвитку, оптимізація використання ресурсів і зменшення впливу на довкілля є ключовими глобальними пріоритетами. Для України ці завдання стали ще актуальнішими через повномасштабну війну. Масштабні руйнування будівель, доріг та інфраструктури призвели до значного накопичення будівельних відходів, що створює як екологічні загрози, так і логістичні труднощі для процесу відновлення.

Використання будівельного сміття як вторинної сировини відкриває нові можливості для ефективного управління відходами. Рециклінг таких матеріалів дає змогу не лише зменшити навантаження на навколишнє середовище, а й посилити потенціал для сталого відновлення. Дорожня інфраструктура відіграє вирішальну роль у забезпеченні мобільності, розвитку торгівлі та зв'язку громад — це один із фундаментальних елементів економічного відновлення України.

У роботі проаналізовано характеристики матеріалів, отриманих із перероблених будівельних відходів, та оцінено їхню доцільність як альтернативи традиційним заповнювачам у дорожньому будівництві. За результатами дослідження встановлено, що одержаний після рециклінгу

заповнювач має подібні до природного характеристики, зокрема насипну густину, вміст пилуватих і глинистих частинок, а також зерен пластинчастої і голчастої форми. Водночас він характеризується суттєво вищим (у 5–7 разів) водопоглинанням, що зумовлено наявністю на поверхні зерен налиплого розчину. Показано, що товщина цього розчину збільшується зі зменшенням розміру фракції, що негативно впливає на міцність заповнювача. Цей фактор є критичним при оцінці довговічності та ефективності використання RCA в дорожньому будівництві.

Ключові слова: Відходи, рециклінг, заповнювачі, матеріали, властивості, бетон, дороги, будівництво.
Waste, recycling, aggregates, materials, properties, concrete, roads, construction.

Introduction. In modern conditions of sustainable development, the efficient use of resources and the minimization of negative environmental impact have become critical priorities for societies worldwide. For Ukraine, these challenges have taken on a heightened significance in light of the ongoing war. The widespread destruction of buildings, roads, and infrastructure has led to an unprecedented accumulation of construction waste, creating both an environmental dilemma and a logistical challenge for the country's recovery. As Ukraine moves forward with rebuilding efforts, recycling construction debris emerges as a vital opportunity to address these issues.

By turning construction waste into usable materials, Ukraine can take a step toward environmental stewardship while bolstering its reconstruction projects. Recycling not only reduces the burden on landfills and conserves natural resources but also aligns with principles of circular economy, offering an innovative approach to sustainability. In this context, the potential application of recycled materials in road construction is particularly noteworthy. Roads are essential for connecting communities, enabling commerce, and supporting mobility - all of which are critical for Ukraine’s recovery and growth.

Properties of materials derived from recycled concrete waste and evaluation of their suitability as substitutes for traditional aggregates in road-building projects are studied in this article. Through scientific analysis and forecasting, the study aims to highlight how recycled materials can contribute to both immediate rebuilding needs and long-term environmental goals. By embracing these practices, Ukraine can leverage innovation to overcome adversity and pave the way toward sustainable reconstruction and development.

Analysis of recent research sources. According to UN calculations, the world's population will exceed the 10 billion mark by 2050. This factor also will push the consumption of building materials. Based on that we can conclude that demand on such materials as concrete will stimulate prices on materials. Therefore, using materials made of building waste recycling could be the one-way solution to

reduce prices and also provide a sustainable solution. First of all, understanding the life cycle of materials could determine the way those materials could be reused in future [1]. In the next two- or three-decades world consumption of materials for construction will overtake 106 billion tons. Recycled construction waste materials are increasingly recognized for their potential in road construction due to their environmental and economic benefits [2]. In Europe, approximately 200 million tons of construction and demolition waste are produced annually [3-5]. A comprehensive study highlights the use of recycled aggregates, industrial by-products, and natural fibres in sustainable pavement applications. These materials, such as geopolymer-stabilized recycled aggregates and cement-stabilized waste materials, demonstrate superior mechanical properties, durability, and environmental suitability compared to traditional aggregates [2]. The use of recycled construction and demolition (C&D) waste in unbound pavement layers was discussed and the engineering properties of recycled aggregates with natural ones were compared highlighting their long-term performance in road applications [6]. The importance of the interfacial transition zone in the recycled aggregate concrete is undeniable. It was shown that the integration of pozzolanic additions at the micro- and ultra-dispersed level, using "fly ash-silica fume" system combined with polycarboxylate superplasticizers, enhances the strength and reduces the porosity of the interfacial transition zone in such concrete [3]. This plays a crucial role in ensuring the durability of concrete structures.

Setting the goal and objectives of research. Study on the properties of recycled construction waste materials and the possibility of their application in road construction.

Research methodology

Concrete waste from the demolition of a building's floor slab was used in the study (Fig. 1).

Fig. 1. Crushed concrete waste from the demolition of a precast slab

Cube specimens were cut, and the compressive strength was determined to be 32.6 MPa, which corresponds to the compressive strength class of concrete C20/25. The microstructural analysis was carried out using an MBS–9 optical microscope combined with an LCMOS14000KPA digital camera and processed with ToupView imaging software.

The properties of the fine and coarse aggregates obtained after crushing were determined in accordance with DSTU B V.2.7-232 and DSTU B V.2.7-71, respectively.

Research results. Properties of recycled concrete aggregates obtained after crushing in jaw crusher were determined. The humidity of RCA was 2,1%. The content of dust and clay particles is 3%. The bulk density of 5-10 mm fraction is 1110 kg/m^3. Flakiness of 5-10 and 10-20 mm fraction of RCA is 22,1 and 32,4%, respectively.

Granite shows significantly lower water absorption compared to RCA (Fig. 2). The lower water absorption of granite is expected due to its dense, non-porous nature. Both size fractions of RCA exhibit substantially higher water absorption percentages than the corresponding size fractions of granite. The water absorption of granite for the 5-10 mm fraction is slightly higher than that for the 10-20 mm fraction. The similar tendency is observed for RCA, but the values are significantly higher.

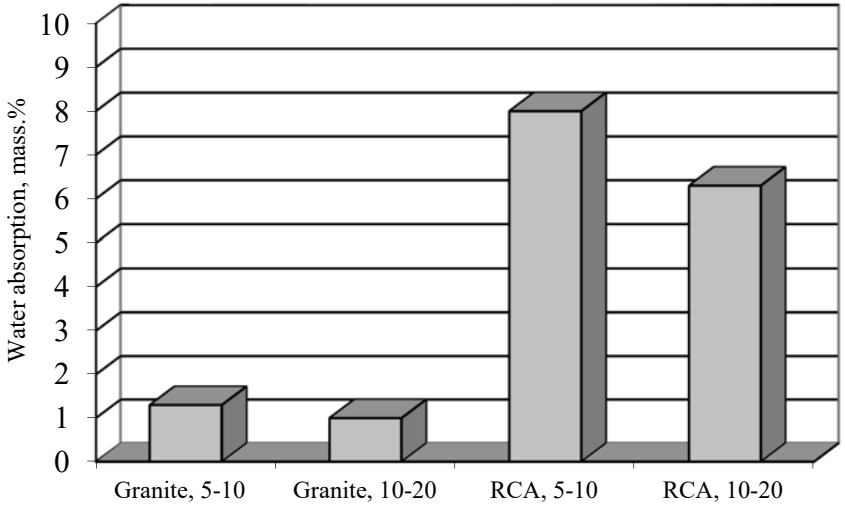

Fig. 2. Water absorption of coarse aggregate

The higher water absorption of RCA (the 5-10 mm fraction) is due to a more porous structure and potentially the presence of a thicker layer of adhered cement mortar. The trend of smaller particle sizes (5-10 mm) exhibiting slightly higher water absorption could be attributed to a more porous cement mortar around smaller particles of the coarse aggregates (Fig. 3). Al-Janabi et al. [5] observed the same tendency. This higher absorption could have implications for the performance of RCA in construction applications, potentially affecting properties like workability, strength, and durability of concrete.

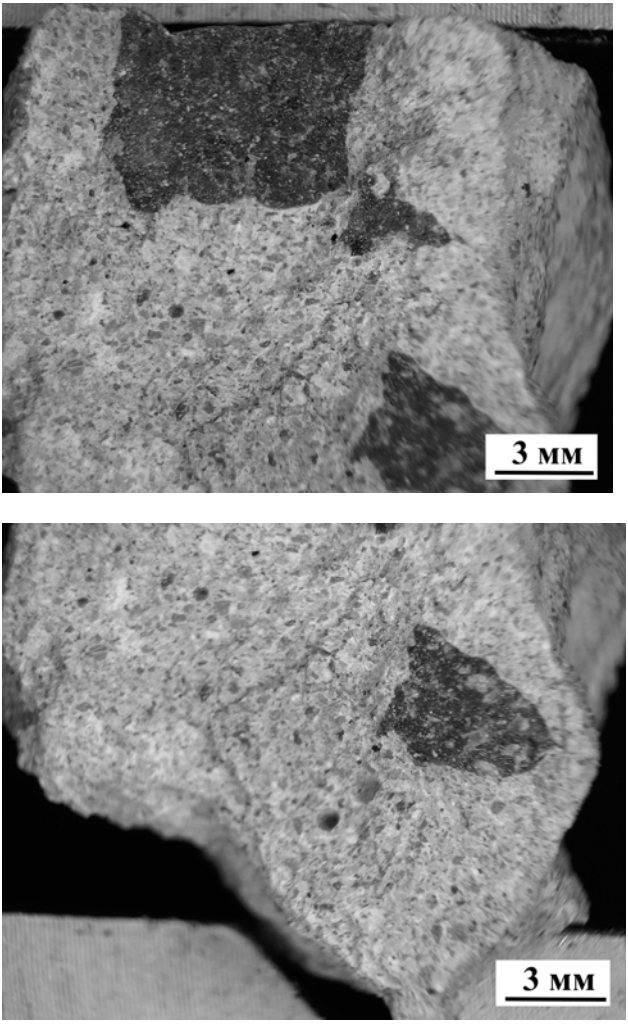

Fig. 3. Particles of RCA

As can be seen from Fig. 4, thicker layer of the adhered cement mortar results in the increase of the crushability of the 10-20 mm fraction (38,5%) of RCA compared to 20-40 mm fraction (18,7%). At the same time, the abrasion of the construction and demolition waste does not differ significantly, and is 17,7 and 21,5% for 5-10 and 10-20 mm fraction, respectively.

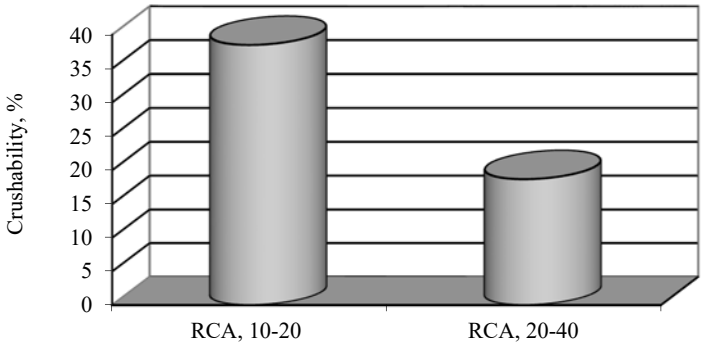

Fig. 4. Crushability of coarse aggregate

The grading curve of the RCA is shown in Fig. 5. The results show that RCA is the most suitable for fine-grained concrete, because its grading curve lays between A and B ones and such recycled concrete aggregate has to be enriched with the coarser fraction to produce ordinary concrete (fraction higher than 15 mm).

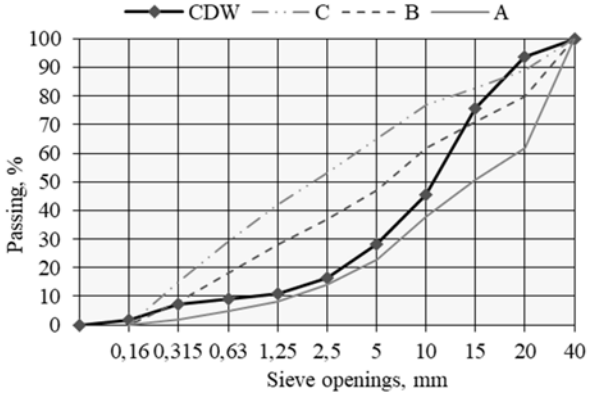

Fig. 5. RCA grading curve in comparison with standard curves from DSTU B V.2.7-299:2013

According to Ukrainian standard DSTU B V.2.7-299:2013, if the grading curve of aggregates is located between A and B curves, such aggregate mix is considered optimal and can be used to produce high quality concrete for the road construction.

Conclusions. The established patterns and the rational, efficient selection of concrete constituents allow for the design of a concrete mix that includes both natural aggregates and recycled concrete aggregates, while taking into account the peculiarities of their properties. This ensures the production of concrete for road construction with durability that is not inferior to that of concrete containing only natural aggregates.

Recommendations. RCA can be used in concrete production technology, but their properties must be considered during the concrete mix design process.

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