Theoretical aspects of using fragments of destroyed buildings and structures of Iraq

Ahmed Ahmed Anees Ahmed

1Department of Building Materials Science, Products and Structures, Belgorod State Technological University named after V.G. Shukhov, Kostyukov St., 46, Belgorod, 308012, Russia

E-mail: Civileng85@yahoo.com

Abstract. The relevance of the work is determined with the search for alternative sources of raw materials for the construction industry, associated with the utilization of technogenic waste. The novelty of the paper is to identify the scientific regularities of the influence of concrete scrap from fragments of destroyed buildings and structures on the formation of the microstructure of light and heavy concrete. Concrete scrap was prepared as both fillers of cement materials and small aggregates, based on which concretes with high mechanical properties were created. The compositions were designed from the point of view of geonics (geodaetica), in particular, taking into account the law of affinity of structures. The strength characteristics of concrete mixes were studied in accordance with EN 12390-3. In addition, microstructural, morphological and thermal properties of raw materials and concretes were determined during 28-day of curing. For the first time, a dense microstructure of the composite was provided, both by products of Portland cement and hydration, and, in part, by products of hydration of previously unreacted clinker, whose minerals are present in concrete waste and are activated when they are crushed. The use of fragments of destroyed buildings and structures as a filler of cementing material when replacing Portland cement up to 20% allows getting better compressive strength, both heavy and light concretes.

1. Introduction

Technical progress in the production of concrete and reinforced concrete requires additional sources of raw materials, in particular, the use of high-quality components [1,2]. The solution to this problem is hindered by the constantly growing shortage of mineral and energy resources, as well as increased environmental requirements [3,4]. An alternative source of raw materials for concrete production can be the waste of destroyed buildings [5].

States that have a large number of demolished or destroyed construction sites for various reasons have a great potential for this. The task of recycling these wastes is due to both the high cost of this event, and the need for early commissioning of land plots under these objects [6,7]. In this regard, it is advisable to use fragments of demolished buildings and structures as raw materials for the production of materials for the construction of new buildings, and especially “environment friendly” and “intelligent” composites.

A number of works are devoted to the study of the possibility of using the waste of destroyed buildings: in the EU countries [8], the Netherlands [9], Vienna (Austria) [10], China [11,12], South Korea [13], Lebanon [14], Brazil [15], the United States [11]. However, the results of these studies are very
contradictory, due to the different composition of waste from destroyed buildings in different countries. The general conclusion of these works is that the use of construction debris in newly created composites without reducing the required characteristics of these composites becomes possible only as a result of taking into account the chemical and mineralogical composition of the components, as well as the activation of the raw materials used in various ways. Currently, a number of studies were conducted on the use of concrete scrap in various building materials. Silva et al. [16] developed masonry solutions with aggregates from concrete scrap. Al-Bu-Ali U S et al. [17] used aggregate from concrete scrap to prepare high-density packaging. Amorim Beya and co-authors [18] studied the effect of demolition waste on the formation of microstructure of light and heavy concrete.

The theoretical basis for the design of composites using these raw materials is the transdisciplinary science of geonics (geoaetica), developed by V.S. Lesovik. This science uses the results of research on natural processes to create high-strength concrete and new-generation building structures. In particular, one of the aspects of this science is the law of affinity of structures, which consists in the selection of raw materials for a composite with similar physical and mechanical characteristics. The design of complex composites according to this law is possible only with the system analysis of macro-, micro- and nanoscale levels. These structures must correspond to the base composition as much as possible, in this case, the best adhesion and, consequently, the durability of the composite is ensured. The law is formulated based on the study of natural objects similar to construction composite materials. The results of this paper were obtained using the waste of destroyed buildings and structures of Iraq, which consist mainly of concrete, ceramic bricks and limestone wall blocks. In United Nations reports posted on the website www.un.org it is reported that between 80,000 and 100,000 industrial and residential buildings were completely destroyed as a result of military operations and terrorist acts in Iraq. Meanwhile, the country’s natural resources are rapidly being depleted. Based on these facts, this paper analyzes the potential impact of fine mineral additives (concrete waste) as a filler and fine aggregate for light and heavy concrete.

2. Materials and methods

Portland cement CEM I 42.5 N (Belgorod cement, Russia) was used as a binder. The chemical and mineralogical composition as well as the main technical characteristics are given in tables 1 and 2. The specific surface area of Portland cement was 300 - 350 m²/kg.

| Chemical composition, % wt. | Mineralogical composition, % wt. |
|---------------------------|---------------------------------|
| CaO          | SiO₂        | Al₂O₃     | Fe₂O₃     | MgO      | SO₃      | Alkalis  | 3S       | 2S       | 3A       | 2AF      |
| 65.73        | 22.19       | 4.37      | 4.30      | 0.67     | 0.18     | 0.70     | 60.3     | 16.8     | 6.9      | 13.3     |

| Setting time, h:min | Tensile strength in bending, MPa | Tensile compressive strength, MPa |
|---------------------|---------------------------------|-----------------------------------|
| beginning 2:30       | ending 3:35                      | 3 day 5.8                        |
|                      |                                 | 28 day 8.1                      |
|                      |                                 | 3 day 33.6                      |
|                      |                                 | 28 day 46.6                     |

The following raw materials were used as control natural aggregates: sand from the Kursk Deposit (Russia), granite crushed stone from the Erkilya Deposit (Russia), and expanded clay of the 10-20 fraction of the Aleksinsky plant (Russia). Characteristics of sand, crushed stone and expanded clay are presented in tables 3-5.

| Characteristics       | Values |
|-----------------------|--------|
| Bulk density, kg/m³   | 1400   |
| Fineness modulus      | 1.8    |
Table 4. Properties of used crushed stone.

| Characteristics                     | Value  |
|-------------------------------------|--------|
| Specific weight, kg/m³              | 2600   |
| Porosity, % vol.                    | 4.1    |
| Compressive strength, MPa:          |        |
| dry                                 | 168    |
| damp                                | 156    |
| Microcline, % wt.                   | 156    |
| Plagioclase, % wt.                  | 15-20  |
| Quartz, % wt.                       | 25-35  |
| Biotite, % wt.                      | 2-5    |

Table 5. Properties of expanded clay.

| Characteristics                      | Value  |
|--------------------------------------|--------|
| Compressive strength, MPa            | 0.3-6  |
| Frost resistance, cycles             | 15     |
| Water absorption, %                  | 10-25  |
| Density, kg/m³                       | 800    |

Table 6 shows the composition of construction and demolition waste from Iraqi buildings and structures (figure 1). As it can be seen from table 6, construction and demolition waste resulting from military operations in Iraqi cities is 99.88% of crushed stone and cement. The appearance of crushed demolition waste is shown in Fig. 1, here they can see that the resulting technogenic large aggregate contains layers of cement mortar. Where such a layer is absent, film sections of hydrate phases are observed. There is every reason to believe that such inclusions will improve the adhesion of technogenic aggregate to the cement matrix. This assumption is based on the fact that the adhesion of various materials to the cement matrix decreases in the following sequence: clinker > limestone> granite > quartz.

Table 6. Composition of destroyed buildings.

| Material | Portland cement | Crushed stone | Fibre | Wood | Metal | Plastic | Gypsum |
|----------|-----------------|---------------|-------|------|-------|---------|--------|
| Content, % | 39.48         | 60.4         | 0.04  | 0.02 | 0.04  | 0.01    | 0.01   |

Figure 1. Appearance of crushed demolition waste.

Demolition waste was crushed in a jaw crusher to obtain fractions 2.5-5; 1.25-2.5; 0.63-1.25; 0.315-0.63; 0.16-0.315 and 0-0. 16. This raw material was used as a fine aggregate in further research. To study the demolition waste as a cement binder filler, they were further crushed at a VM-20 ball mill (Russia) to a size comparable to that of Portland cement.

The features of the microstructure and composition of raw materials and products used in the synthesis of Iraqi materials were studied by theoretical and empirical methods. The morphology of raw
materials and small concrete samples with a size of 15 mm × 15 mm × 4 mm was studied using a scanning electron microscope (MIRA3 TESCAN, Brno, Czech Republic) operating at an accelerating voltage of 8.0 kV. The chemical composition of raw materials and small concrete samples was determined using an ARL 9900 WorkStation x-ray spectrometer (Thermo Fisher Scientific, Waltham, USA) with a built-in diffraction system. Differential thermal analysis (DTA) and thermal gravimetry (TG) were performed using a Shimadzu DTG-60H thermogravimetric analyzer (Japan).

The mixture was poured into a cone 30 cm high, then, after removing the cone, the sediment was measured. The average density of concrete was determined on samples-cubes 10 × 10 × 10 cm, dried to a constant weight at 105°C. The compressive strength of concrete samples was produced on 10 × 10 × 10 cm samples using a 200 kN Shimadzu test machine (Kyoto, Japan), in accordance with EN 12390-3.

During the experimental work, we used the system-structural foundations of the material science approach in “composition design – technology development – microstructure research – properties study”.

3. Results
After crushing the demolition waste, the fractions were eliminated 2.5-5; 1.25-2.5; 0.63-1.25; 0.315-0.63; 0.16-0.315 and 0-0.16. Micrographs of the resulting dropouts are shown in Fig. 3. The mineral composition of various fractions of demolition waste is shown in table 7.

![Figure 2. Micrographs of screening fractions: a) 0-0.16, b) 0.16-0.315, c) 0.315-0.63, d) 0.63-1.25, e) 1.25-2.5, f) 2.5-5.](image)

**Table 7.** The mineral composition of various fractions of demolition wastes.

| Fraction | SiO₂  | Ca(OH)₂ | CaCO₃ | CSH  | C₃S | C₂S |
|----------|-------|---------|-------|------|-----|-----|
| 0.00-0.16| 48.4  | 11.5    | 10.0  | 5.8  | 12.0| 12.3|
| 0.16-0.315| 55.2  | 7.4     | 11.0  | 4.4  | 11.0| 11.0|
| 0.315-0.63| 56.4  | 11.0    | 3.9   | 12.0 | 6.7 | 10.0|
| 0.63-1.25| 65.1  | 12.0    | 6.0   | 5.9  | 5.0 | 6.0 |
| 1.25-2.5  | 64.4  | 10.5    | 6.9   | 3.0  | 7.6 | 7.6 |
| 2.5-5     | 62.8  | 11.0    | 0     | 6.0  | 9.2 | 11.0|
Tests were carried out to replace natural sand with concrete scrap dropout in C8/10 class expanded clay concrete and C16/20 class heavy concrete. The tests were carried out with partial and complete replacement of sand with destruction waste with a particle size of 1.8 mm. In this case, the concrete mixtures were prepared on natural sand (control composition) and artificial sand with partial substitution (30% range of variation) to complete replacement (table 8-9).

Table 8. Compositions and properties of expanded clay concretes.

| Number of content | Cement content, kg/m³ | Quartz sand, kg/m³ | Claydite, kg/m³ | Demolition waste, kg/m³ | Water, cm | Cone draft, cm | Average density, kg/m³ | Compressive strength, MPa |
|-------------------|-----------------------|--------------------|----------------|--------------------------|-----------|---------------|------------------------|---------------------------|
| LW-1              | 225                   | 800                | 410            | -                        | 270       | 3-4           | 1670                   | 16                        |
| LW-2              | 225                   | 560                | 410            | 240                      | 255       | 4-5           | 1600                   | 17.2                      |
| LW-3              | 225                   | 400                | 410            | 400                      | 226       | 3-4           | 1625                   | 19.8                      |
| LW-4              | 225                   | 240                | 410            | 560                      | 243       | 3-4           | 1562                   | 17.9                      |
| LW-5              | 225                   | -                  | 410            | 800                      | 246       | 3-4           | 1564                   | 17.7                      |

Table 9. Compositions and properties of heavyweight concretes.

| Number of content | Cement content, kg/m³ | Sand, kg/m³ | Crushed stone, kg/m³ | Demolition waste, kg/m³ | Water, cm | Cone draft, cm | Average density, kg/m³ | Compressive strength, MPa |
|-------------------|-----------------------|-------------|----------------------|--------------------------|-----------|---------------|------------------------|---------------------------|
| HW-1              | 475                   | 600         | 1350                 | -                        | 237       | 4             | 2360                   | 27                        |
| HW-2              | 475                   | 450         | 1350                 | 150                      | 237       | 4             | 2340                   | 26.9                      |
| HW-3              | 475                   | 300         | 1350                 | 300                      | 237       | 4             | 2365                   | 26.5                      |
| HW-4              | 475                   | 150         | 1350                 | 450                      | 237       | 4             | 2344                   | 27.2                      |
| HW-5              | 475                   | -           | 1350                 | 600                      | 237       | 4             | 2350                   | 26                        |

As the research results showed (table 8), the compressive strength of expanded clay concrete using demolition waste increases, which is explained by an increase in the adhesion of the aggregate to the cement matrix. Table 9 shows the results of similar studies for heavy concrete. Tests to replace natural sand with artificial crushed sand in heavy concrete also showed that the strength of concrete does not decrease, but even exceeds the control composition. It is obvious that the artificial crushed sand obtained as a result of classification of crushed fragments of destroyed buildings and structures has a good potential for use as a fine aggregate in concrete.

The microphotographs shown in Fig. 3 show the interfacial transition zone of the technogenic aggregate and the cement matrix. The dense contacts of cement stone and large aggregate are clearly visible that form a single formed composite. Dense contact structure is formed due to the fact that in the early stages of hardening of the concrete mix crushed stone obtained from construction waste, absorbs part of the closing water, and then during solidification of the cement stone this water is given away by the pores of technogenic crushed stone to bind clinker minerals into high-strength new formations. As a result, the activity of the binder increases, while the rheological characteristics of the mixture do not decrease. If the concrete waste is small, and the technology does not involve thermal water treatment, they are able to provide hydration of previously unreacted particles of clinker minerals and Ca(OH)$_2$, the total amount of which is approximately 15-25% in the concrete mix.

Figure 3. Contact zone between the cement matrix and the aggregate.
Thus, it was revealed that the composites obtained from active fillers of Portland cement binders and crushed stone from demolition waste have good adhesion between the components. Accordingly, this makes it possible to obtain building materials of a wide profile with reduced deformability, good crack resistance, durability, etc. These conclusions, based on the law of affinity of structures, have been proven earlier [19].

In Fig. 4 shows the compressive strength versus the amount of Portland cement replaced with crushed drift waste. At the same time, in accordance with the law of affinity of structures, concrete waste was crushed until the specific surface area of Portland cement (300-350 m² / kg) was reached.

**Figure 4.** Effect of the amount of Portland cement replaced by crushed demolition waste on compressive strength of heavyweight and lightweight concrete.

The introduction of additives of various genesis into the binder entails a transformation of the mechanism and speed of hydration processes of clinker minerals in interaction with the closing water. It is possible that these additives can react with new formations of the Portland cement matrix, respectively, forming new phases that affect the characteristics of the concrete composite in various ways. Therefore, to achieve the goal of the paper, it was necessary to study the hydration mechanisms depending on the presence of waste in buildings. Differential thermal and x-ray phase analysis were used for this purpose.

Fig. 5 shows the results of DTA of 28-day-old solidified cement with the introduced concrete additives. There is a complex endothermic effect, reaching a maximum at a temperature of about 102°C. The peak at 448°C characterizes the endothermic effect resulting from the dehydroxylation of portlandite. This endoeffect shows that the secondary concrete, acting as an active filler of cement binders, did not react with all the calcium hydroxide, respectively, the liquid phase of the hardening mixture was saturated with this Ca(OH)₂. According to fundamental concepts, in a saturated solution of Ca(OH)₂, high-base C-S-H (II), as opposed to low-base C-S-H (I) remain stable. Accordingly, the most important component of cement materials modified with thin-ground concrete scrap is the C-S-H (II) fiber structure.

**Figure 5.** DTA patterns of HW-1 specimen.

Small endothermic effects at temperatures of 689°C and 713°C are mainly characterized by decarbonization of weakly crystallized metastable forms of CaCO₃ formed due to partial carbonation Ca(OH)₂.
X-ray diffraction analysis of the HW-1 sample (Fig. 6) correlates with the above differential thermal studies. In particular, in addition to the reflections of non-hydrated clinker minerals (d = 4,343; 4,270; 3,357 and 3,198 Å), a relatively small reflection of 2,637 Å attracts attention as identified portlandite.

![Figure 6. XRD results of specimen HW-1.](image)

The same is confirmed by microphotography obtained with the help of SEM developed for concrete at the age of 28 days (Fig. 7). There is a dense microstructure provided by both Portland cement products and hydration products of previously unreacted clinker minerals present in concrete waste and activated during its grinding.

![Figure 7. Microstructure of new growths in heavy concrete HW-1 at the age of 28 days.](image)

4. Summary
This article presents the possibility of recycling construction waste, which leads to the solution of a number of problems: waste disposal and improving the physical and mechanical properties of concrete by adding recycled waste as a filler or fillers. Based on the results of a set of studies, the following conclusions are offered for further discussion:

The use of demolition waste as a fine aggregate gives similar results in the mechanical characteristics of heavy and light concrete, as when using natural sand. This is due to the compaction of the struc-
ture and the fusion of concrete waste with the surface of the cement matrix, as a result of which they look like a single whole.

Demolition waste as a cement binder filler when replacing Portland cement up to 20% allows getting a better compressive strength, both heavy and light concrete, due to the compaction of the microstructure by products of hydration of previously unreacted clinker minerals present in concrete waste, and activated during grinding.

5. References

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