Structure and properties of recycled concrete aggregate

O A Larsen¹, I V Komoleva¹, P D Tobolev¹, V V Naruts¹, and S O Badamshin²
¹Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia
²LafargeHolcim, 29, Serebryanicheskaya embankment, 109028, Moscow, Russia

E-mail: larsen.oksana@mail.ru

Abstract. The problem of waste reuse from building industry is acute around the civilized world. The construction of infrastructure in large cities increases the amount of building waste. This study presents the possibility of using concrete waste of residential buildings included in the renovation program of the Moscow. The use of recycled aggregates obtained from demolished concrete allows saving the content of natural aggregates in concrete and significantly reducing the amount of waste that pollutes the environment. Their use is possible in structures with the proper concrete mix content with maintenance of the same properties. Recycled concrete aggregates differ from natural aggregates as the former aggregate contain adhered mortar. The content of the adhered mortar in coarse recycled concrete aggregate was determined on fraction of 5-10 mm. In this study, limestone aggregate was used as initial in structure of recycled concrete aggregate. The quantitative content of crushed concrete components was carried out using quantitative analysis. The main characteristics including specific gravity and water absorption of recycled aggregate were determined. The specific gravity and density of aggregate were 2.59 g/cm³ and 1.9 g/cm³, respectively. The water absorption and mortar content were 3.8% and 39.9%, respectively.

1. Introduction

The Government of Moscow has started housing renovation program in 2017. The program is aimed at demolition of dilapidated low-rise residential buildings and new construction on the exempted territories. The program is designed for 15 years and includes more than 5 thousand houses.

After the demolition of one five-store residential building consisting of four porches, 10 thousand tons of wastes are formed. All these wastes are taken to landfills, which are already overloaded. Therefore, the problem of waste recycling from demolition of houses arises [1]. Possible way to handle this problem is to use recycled concrete fillers in concrete production. Firstly, recycling technology was applied in Germany after World War II. This approach was applied in other countries as a method of construction waste recycling [2].

Recycled aggregate is the main component of concrete waste. The recycling of old concrete reduces the wastes [3-5]. The technology of wastes usage for concrete production consists of the following steps [6]:
- demolition;
- removal;
- crushing of existing concrete.

Materials separation technology has evolved considerably in the last few years. This allows automatic separation of all contaminants from concrete aggregates such as paper and cardboard, glass,
gypsum, ferrous and nonferrous metals, wood and plastics with 98% efficiency [7]. Some methods, such as air and eddy current magnetic separation, dry density separation are usable in concrete demolition waste recycling which allows to turn traditionally landfilled mixed materials into valuable products and give important environmental benefits [8].

The simplest crushing plant is used to recycle concrete and reinforced concrete wastes. Wastes feed to the crusher via hopper, apron feeder and presort station. Concrete is crushed and fed into magnetic separator in order to separate metal inclusions. The obtained mass enters the screening machine and sieves it into certain fractions [9].

Recycled concrete contains a large amount of binder [10]. The interfacial transition zone between the coarse aggregate and cement paste is a weak place in concrete. Recycled concrete aggregate reduces physical and mechanical properties of concrete due to high porosity and low frost resistance [11]. Despite these disadvantages it is possible to obtain the material with high strength [12]. Recycling of concrete helps to support sustainability. Recycling technology reduces the amount of waste disposal of old concrete and protects the environment.

2. Materials and Methods

2.1. Recycled concrete
The internal wall panel of a residential building in Moscow was used in this study. Demolished concrete waste of residential building with series of 1605-AM-5 in Kuntsevo district of Moscow was built in 1961 in the course of renovation program. The initial panel was 5600x2700x140 mm in size. Panel was crushed and fractioned to a coarse aggregate with size of 5-10 mm (Figure 1). Coarse aggregate contained adhered mortar on its surface.

2.2. Water absorption
Water absorption ability of recycled concrete was obtained by methods of Russian standard 8269.0-97. Water absorption was determined by saturation of the samples in water and dried later to a constant mass. Five samples with size of 5-10 mm were saturated in water for 48 hours. Before test the samples were cleaned from loose particles and dust by metal brush and then dried to a constant mass. The laboratory balance, drying chamber, container for saturating and metal brush were used. The crushed stone samples were placed in water tank at room temperature. Samples were kept in reservoir in 20 mm below water level. Samples were removed from the container dried and weighed.

![Figure 1. Recycled concrete samples after selection and drying.](image)
2.3. Components of recycled concrete

In this study the quantitative analysis of crushed concrete components was used. The sample of recycled aggregate with fractions of 5-10 mm was calcined at 400 °C for 4 hours (Figure 2 and 3). During mechanical destruction of the granules the adhered mortar was separated with a spatula from original coarse aggregate. Concrete is disintegrated by mechanical impact of rubber or wooden pestle into constituent parts. The material passes through the sieves 5; 2.5; 1.25; 0.63; 0.315; 0.16 mm. The residue on the sieve was weighed and mass of coarse aggregate was obtained. The material passed through the sieve 0.16 mm is considered as a binder and component of adhered mortar.

2.4. Specific gravity of recycled concrete aggregate

Specific gravity of recycled concrete aggregate is determined by measuring the mass per unit volume of dried and crushed powder of material with Le Chatelier flask (Figure 4). The prepared powder is poured into a container for weighing. The sample is dried to a constant mass and cooled to room temperature. The device is filled with water to the lower mark and the water level is determined by the lower meniscus. Through the funnel of the device, the suspension is poured in small portions until the liquid level in the device, determined by the lower meniscus, rises to a level with a division of 20 ml or with another division within the upper graded part of the device. It is recommended to shake the device to remove air bubbles.

2.5. Density of recycled concrete aggregate in cement paste

The recycled concrete aggregate with volume of 3.5 l was dried and weighed. Then the aggregate was mixed on a pre-moistened baking tray with 1.7 kg of cement and 3.4 kg of natural sand. The determined necessary amount of water was gradually added to the mixture to obtain hard concrete mixture of 5-10 sec according to Russian standard 7473. The mixture was kept in a baking tray for 15 minutes and completely placed in 5 l vessel. The vessel with mixture was vibrated in 30-60 sec and weighed.
3. Results

3.1. Water absorption
High water absorption of recycled coarse aggregates influences on fresh-state properties of concrete. Water absorption ($W_{abs}$) by weight was calculated:

$$W_{abs} = \frac{m_1 - m}{m} \cdot 100\%$$  \hspace{1cm} (1)

$m_1, m$ - weight of the sample in saturated and dry state, g.

$$W_{abs} = \frac{4.61 - 4.44}{4.44} \cdot 100\% = 3.8\%.$$ 

3.2. Recycled concrete components
The weight loss of aggregate during calcination from 434 g to 411 g was determined. The content of adhered mortar was determined in accordance with Russian standard 8269.0-97 with the use of sieve analysis (Table 1).

| Sieve size, mm | Percent of mass retained on each sieve, % | Cumulative retained, % |
|---------------|------------------------------------------|------------------------|
| 5             | 60.10                                    | 60.10                  |
| 2.5           | 9.00                                     | 69.10                  |
| 1.25          | 5.60                                     | 74.70                  |
| 0.63          | 4.62                                     | 79.32                  |
| 0.315         | 5.60                                     | 84.91                  |
| 0.16          | 6.57                                     | 91.48                  |
| >0.16         | 8.52                                     | 100.00                 |
It has been concluded that the adhered mortar content is 39.9%. This rate is very important and can be used to specify the application of the recycled aggregate. The presence of adhered mortar with evolved network of capillary pores in recycled aggregate increases water absorption. The aggregate with high water absorption can increase the loss of flowability of concrete mixtures in first minutes after their production.

3.3. Specific gravity of recycled concrete aggregate
The powder remains that is not included in the device is weighed. The specific gravity $\rho$ of the powder is determined, g/cm$^3$:

$$\rho = \frac{m - m_i}{V}$$  \hspace{1cm} (2)

$m$ - weight of dried powder, g;
$m_i$ - weight of the powder remains, g;
$V$ - volume of water displaced by the powder, determined on a graduated scale, cm$^3$.

$$\rho = \frac{50.0 - 1.2}{18.8} = 2.59 \text{ g/cm}^3.$$  \hspace{1cm} (3)

3.4. Density of recycled concrete aggregate in cement paste
Density of recycled concrete aggregate $\rho^{rc}$ in cement paste was calculated, g/cm$^3$:

$$\rho^{rc} = \frac{\rho^\nu_m w_{ra}}{w_i - \rho^\nu_m \left(\frac{w_{cem}}{\rho_c} + \frac{w_{qs}}{\rho_{qs}} + w_w\right)}$$

$\rho^\nu_m$ - density of vibrated mix, g/cm$^3$;
$w_{ra}$ - weight of recycled aggregate;
$w_i$ - total batch consumption of materials, kg;
$w_{cem}$ - weight of cement, kg;
$\rho_c$ - specific gravity of cement, g/cm$^3$;
$w_{qs}$ - weight of quarts sand, kg;
$\rho_{qs}$ - specific gravity of quarts sand, g/cm$^3$;
$w_w$ - water content in the mixture, kg.

Density of aggregate grains in a cement test is determined as the arithmetic mean of the results of two parallel tests. It was found that the average density was 1.9 kg / m$^3$.

4 Conclusion
Recycled concrete aggregates differ from natural aggregates and show less performance. They have lower density and higher water absorption. The specific gravity and average density of aggregate were 2.59 g/cm$^3$ and 1.9 g/cm$^3$ respectively. It was determined that the water absorption and mortar content were 3.8% and 39.9% respectively. According to Japanese research, the use of recycled aggregate from concrete mixed with natural aggregate in an amount of up to 30% does not reduce the properties of concrete. The use of recycled aggregate is limited in concrete load-bearing structures. They can be effectively used as a starting material for the manufacture of non-structural concrete or for other
purposes. The use aggregates in structural concrete elements is noted when the content of the mortar component in the aggregate is up to 44%. Use of recycled aggregates in concrete production gives a great environmental benefit in saving of natural resources.

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