Influence of Aggregate Type on Properties of Geopolymer Concrete

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Abstract. The results of comparative studies of geopolymer concrete strength made with coarse aggregate based on granite, limestone, concrete scrap were given. It is found that the use of granite aggregate instead of limestone and concrete scrap reduces the strength flexural 2-2.5 times, as on impact - 2.5-3.5 times; the compressive strength decreases by 10-30%. It concluded that the main item that reduces the strength of the investigated geopolymer concrete when using granite aggregate, its low creep is observed, which, with high autogenous shrinkage of the geopolymer binder, leads to concrete cracking. The established features of the influence of the type of aggregate on the properties of concrete substantiate the use of crushed limestone and concrete scrap as a coarse aggregate of geopolymer concrete.

1. Introduction

Geopolymer concretes are considered as an environmentally friendly alternative to Portland cement concretes [1, 2]. Thus the development and study of properties of this new kind of concrete occurs in comparison with the achievements of the science Portland cement concrete.

For a long time the influence of coarse aggregate on the properties of concrete was considered as an insignificant factor. This is due to the fact that the strength and durability of the coarse aggregate is much higher than the properties of hardened cement paste, therefore, the properties of concrete are much more dependent on the characteristics of hardened cement paste.

The development of concrete technology has ensured that its strength is comparable to the strength of rocks, which are used as a material for an aggregate. Besides high strength concrete [3], and geopolymer concrete are characterized [4-7] by high values of autogenous shrinkage and it increases the risk of cracking in the early stages of hardening. In this regard in recent years the studies of the influence of coarse aggregate on various properties of concrete have been activated [8-12].

Shrinkage deformations in concrete lead to internal stresses, which can cause cracking [5-7]. Cracking is influenced not only by the degree of shrinkage, but also by the creep of the hardened geopolymer paste, its ability to relax stresses, as well as the creep of the coarse aggregate.

The mechanism of autogenous shrinkage of geopolymer concretes is poorly studied, which does not allow its reliable prediction [7, 13-15]. Autogenous shrinkage is of great importance for concrete structure formation at the macro level. It determines the strength and durability of geopolymer concrete. Many works study the influence of a binder composition and curing conditions on shrinkage and concrete cracking [14-16]. At the same time, the properties of the aggregate, primarily its...
deformability, surface topography, adhesion of geopolymer paste hardening can have a significant effect on concrete cracking [2, 17, 18].

In this paper, we studied the effect of three types of coarse aggregates and their consumption on the flexural strength and compression, impact resistance of concrete.

2. Materials and research methods
Concretes produced with 3 kinds of aggregates: granite, limestone and scrap concrete structures were investigated. The properties of the aggregates are shown in table 1. All the investigated coarse aggregates have particle size 5-10 mm.

| Type of coarse aggregate | Strength grade according to GOST 8267-93 | Density (kg/m³) | Bulk density (kg/m³) | Water absorption (%) |
|-------------------------|------------------------------------------|-----------------|----------------------|----------------------|
| Granite                 | 1400                                     | 2692            | 1444                 | 0.2                  |
| Limestone               | 1000                                     | 2359            | 1270                 | 3.4                  |
| Concrete scrap          | 600                                      | 2263            | 1154                 | 6.9                  |

To prepare the binder, we used granulated blast-furnace slag with a specific surface area 3800 cm²/g and grinding granite with a specific surface area 3500 cm²/g. Sodium water glass with a silicate modulus of 2.54 and a density of 1.48 g / cm³ and sodium hydroxide (NaOH) were used as activator of hardening.

In all investigated concretes, the ratio of fine aggregate, binder components, hardening activator and water was constant. During the experiment, the ratio between the coarse aggregate and the geopolymer paste was changed. This ratio (α) was expressed by the ratio of the volume of the mortar component of concrete to the volume of the intergranular space of the coarse aggregate.

\[ \alpha = \frac{V_m}{V_{isa}}. \]

where \( V_m \) – the volume of the mortar component of concrete, m³;

\( V_{isa} \) – volume of intergranular space of coarse aggregate, m³.

The consumption of coarse aggregate in the investigated concrete compositions was calculated by the formula [19]

\[ CA = \frac{1}{(\alpha \Pi_{ca}/\rho_b + 1/\rho)} \]

where \( \Pi_{ca} \) – voidness of coarse aggregate = 1 – \( \rho_b / \rho \);

\( \rho_b \) – bulk density of coarse aggregate, kg/m³;

\( \rho \) – density of coarse aggregate, kg/m³.

Designing concrete compositions, which are shown in table 2, the coefficient \( \alpha \) changed from 1.32 to 1.5. While the bulk concentration of a coarse aggregate of granite, limestone, concrete scrap depends not only on the coefficient \( \alpha \), but also on rock density of coarse aggregate and bulk density ratio.

From compositions listed in table 2, samples of size 40 × 40 × 160 mm were prepared, which after curing at normal temperature for 12 hours hardened at heat treatment in the regime: 3 hours temperature rise, 12 hours isothermal curing at 80 °C and 6 hours cooling.
Table 2. Concrete compositions (kg/m³).

| Compositions          | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   |
|-----------------------|------|------|------|------|------|------|------|------|------|------|------|------|
| Granite               | 1257 | 1227 | 1199 | 1172 | –    | –    | –    | –    | –    | –    | –    | –    |
| Limestone             | –    | –    | –    | –    | 1106 | 1080 | 1055 | 1032 | –    | –    | –    | –    |
| Concrete scrap        | –    | –    | –    | –    | –    | –    | –    | 1106 | 1080 | 1055 | 1032 | –    |
| Slag                  | 114  | 116  | 118  | 120  | 113  | 116  | 118  | 120  | 119  | 122  | 124  | 126  |
| Grinding granite      | 266  | 272  | 277  | 282  | 265  | 271  | 276  | 281  | 279  | 285  | 290  | 295  |
| Sand                  | 569  | 581  | 592  | 603  | 567  | 579  | 591  | 601  | 598  | 609  | 620  | 631  |
| Water glass           | 106  | 109  | 111  | 113  | 106  | 108  | 110  | 112  | 112  | 114  | 116  | 118  |
| NaOH                  | 9.47 | 9.67 | 9.86 | 10.04| 9.44 | 9.64 | 9.83 | 10.01| 9.94 | 10.14| 10.32| 10.50|
| Water                 | 101  | 103  | 105  | 107  | 101  | 103  | 105  | 107  | 106  | 108  | 110  | 112  |
| α                     | 1.32 | 1.38 | 1.44 | 1.5  | 1.32 | 1.38 | 1.44 | 1.5  | 1.32 | 1.38 | 1.44 | 1.5  |
| Coarse aggregate, %   | 46.7 | 45.6 | 44.5 | 43.5 | 46.9 | 44.7 | 45.8 | 43.7 | 44.1 | 41.9 | 43.0 | 40.9 |

Flexural strength, compressive strength, as well as strength on impact were investigated.

The flexural strength was determined as the arithmetic mean of the tests of 4 samples, and the compressive strength was determined as the average value of 8 samples. Small beams size 40 × 40 × 160 mm were cut into 4 sample 38 mm long, for which the strength was determined on the impact tester (figure 1).

![Figure 1. Impact tester.](image)

Impact resistance \( (R_f) \) was determined by the destruction energy, which was calculated by the formula

\[
R_f = m \cdot g \cdot (1+2+3+\ldots+n) \cdot 10^{-2}/S,
\]

где \( m \) – the mass of the moving part of impact testing machine (2 kg);

\( g \) – free fall acceleration, (9.81 m/s²);
3. Results and their discussion
The analysis of the dependences of flexural strength, compressive strength and impact force from the volume content of coarse aggregate in concrete (figure 2 and 3) indicates that this characteristic of concrete has a significant influence on these properties.

Figure 2. The influence of coarse aggregate volume on flexural strength (a), compressive strength (b) (1 – granite, 2 – limestone, 3 – concrete scrap).

Figure 3. The influence of coarse aggregate volume on fracture energy (1 – granite, 2 – limestone, 3 – concrete scrap).

The properties of coarse aggregate have even greater influence on the strength. Calculations show that replacement of the limestone aggregate by granite aggregate (despite the fact that the strength of the granite is higher than strength of limestone and concrete scrap (table 1)), reduces the flexural strength in 2-2.5 times and at impact in 2.5-3.5 times. At the same time, the decrease in the strength of concrete at compression is much less significant - only 10-30 %. Replacement of crushed limestone by coarse aggregate from concrete scrap does not lead to a significant decrease of strength, despite the fact that the strength of concrete scrap is much less than the strength of limestone.
Various authors noted [8, 20] that the use of limestone aggregate allows to obtain a higher concrete strength in comparison with other aggregates. As reasons for increasing the strength are higher roughness of limestone and adhesion cement and geopolymer to limestone surface [8, 11]. We can state [2, 8, 9, 10] that the dimensions, shape and structure of aggregates surface affect the strength, shrinkage, stiffness, creep, density, permeability and durability of concrete.

Besides the concrete strength increase may be caused by water absorption of the aggregate. When the geopolymer paste is in a plastic state, water is adsorbed by porous of aggregate. At the stage of hardening, the adsorbed water transforms into geopolymer stone (the effect of internal care, by analogy with cement concrete).

Higher creep of this rock in comparison with granite can influence increase of strength using limestone, its it is evidences by a higher creep of different types of concrete made with limestone aggregate [17, 20]. High creep provides a decrease of stress concentration in the contact area caused by shrinkage deformation of hardened geopolymer paste. In favor of this hypothesis we can the indicate absence of cracks in the specimens, manufactured using limestone coarse aggregate or concrete scrap, while on granite aggregate samples shrinkage cracks up to 0.2 mm were stated (figure 4).

Figure 4. Cracks on the surface of geopolymer concrete made using coarse granite aggregate.

Shrinkage cracks in samples with granite aggregate explain the significant decrease in flexural and impact strength. At the same time, as seen in figure 3, the compressive strength decreases significantly less, which indicates that the main reason for the decrease in strength when using coarse granite aggregate is the formation of cracks in the geopolymer, but not the low adhesion of the coarse aggregate with this component of concrete. The effect of the form of coarse aggregate on its adhesion to the hardened geopolymer paste, and water absorption of the porous aggregate and the value of these factors for concrete properties such as: durability, cracking and durability requires extensive experimental study.

4. Conclusion
The research of geopolymer concrete strength, made using granite and limestone coarse aggregate, and aggregate based on concrete scrap has shown that the type of aggregate has a significant influence on the strength properties.

It is found that the use of granite aggregate in comparison with other investigated coarse aggregate leads to significant reduction of flexural and impact strength. At the same time, the decrease in the strength of concrete at compression is much less than at flexural and impact action. Higher strength of concrete made with limestone aggregate or concrete scrap can be explained by higher creep of these
materials and stress relaxation in the contact zone. This is confirmed by lower cracking of geopolymer concretes prepared with the use of such coarse aggregates in comparison with granite crushed stone.

The determined features of the influence of the type of aggregate on the properties of concrete justify the use of crushed limestone and concrete scrap as a coarse aggregate of geopolymer concrete.

5. References
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