

Practical experience of construction of concrete pavement using non-conditional aggregates

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Abstract. The ways of involving iron ore tailings in road construction are shown in this paper on example of alkali-activated slag cements used as a binding material. The results of the study showed that in case of the alkali-activated slag cements the compacted concrete mixtures for bases could incorporate up to 40 % of iron ore tailings, and with addition of up to 10 % of fly ash by mass – up to 60 % by mass with providing the required compressive strength (>2 MPa) and coefficient of softening (in water) (not lower than 0.8). The results suggested to show that with increase in quantities of the alkaline component the strength tended to increase, and that addition of fly ash was favourable in terms of consistency of the concrete mixture and time of workability retention. The concrete with 100 % replacement of fine aggregate by iron ore tailings exhibited compressive strength of 30 MPa and the concrete mixture had a consistency of classes S3-S4 as per EN 206-1:2000. This concrete mixture of optimal composition was used as paving in the construction of a pilot road (length 50 m, width 4 m, and thickness 0.3 m) in Qianxi (Tianshan, P.R.China).

1. Introduction

The accumulation of industrial waste requires increased attention in connection with the growing costs for their safe storage. As a rule, mining and processing plants are storing the industrial waste in open-type sludge pool, which leads to increased danger due to contact with the environment.

Iron ore tailings are presented by heavy metals, solids, mill reagents and sulphur compounds. Storing the iron ore tailings in the open area or throwing into the sea and rivers has the potential of causing water pollution [1, 2].

Yellishetty et al. [3] studied the use of iron ore tailings from Goa in India as an aggregate in concrete. The composition of the concrete was in different proportions using mine aggregate (12.5 mm – 20 mm in size), sand and cement as the binder. The results concluded that the aggregate component of the mine wastes conforms to the Indian Standard Specifications for quality standards of aggregates. The use of mine wastes for 100 % replacement for both fine and coarse aggregates will avoid the use of natural sand and natural granite quarry completely. Further study into this will bring much more improvement and economy in concrete production.

Replacement of natural fine aggregate by the iron ore tailings in 100 % quantities significantly decreased the workability and compressive strength of the material [4-6]. Also showed, when the replacement level was no more than 40 %, for 90 days standard cured specimens, the mechanical behaviour of the tailings mixes was comparable to that of the control mix.
Another way of utilization of iron ore tailings in building materials is using waste as a component of green ECC (Engineered Cementitious Composite). Increasing the replacement of cement beyond 40 % replacement ratio reduces the compressive strength, but content TIO in 10–32 % reduction in energy consumption and 29–63 % reduction in carbon dioxide emissions in green ECC compared with typical ECC [7, 8].

However, use of iron ore tailings as a component traditional cements and concretes are complicated due to minor quantities of used waste. Alternative way of utilization of hazardous wastes is using it in alkali-activated cement and concretes on their basis.

Scientific school SRIBM named after V.D. Glukhovsky more than 50 years follows an entirely new concept of the development of cements by modelling the natural processes of mineral formation in order to obtain a durable hardening stone using aluminium silicate raw materials of technogenic origin and compounds of sodium and potassium [9-12]. The obtained cements open up new possibilities for using a large amount of waste of different origin in the composition of both cement and concrete. This is explained by the fact that the alkaline component actively interacts with the waste, forming a series of zeolite-like new formation and low-basic calcium hydrosilicates. The physical-mechanical properties of alkali-activated cements have fairly high values in comparison with traditional cements, as well as immobilizing ability [13-15].

According to obtained results [16-17, 19-20], was investigated using of iron ore tailings as a component of alkali-activated slag foamed concrete and determined that concrete with IOT 35 % by mass can reached 2.56 MPa in standard curing condition. The result demonstrates the effective using of AAC for the production of high-performance structural materials.

Purpose of work. Safety utilization of iron ore tailings as component of alkali-activated cements and concretes on their based for construction of compacted grounds and roads.

2. Raw materials and test methods

Iron ore tailings (IOT), fly ash (FA) and the blast furnace granulated slag (BFGS) with a glass content not less than 85 % by mass and specific surface 450 m$^2$/kg (by Blaine) were used as main components of alkali-activated cement and concretes. The chemical composition of raw materials is given in Table 1.

| Name        | SiO$_2$ | TiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | FeO | MgO | CaO | Na$_2$O | K$_2$O | SO$_3$ |
|-------------|---------|---------|-------------|-------------|-----|-----|-----|--------|-------|-------|
| IOT (China) | 74.2    | 0.3     | 5.3         | 5.7         | 2.8 | 5.8 | 1.2 | 1.5    | -     | -     |
| FA (China)  | 57.8    | 0.7     | 18.6        | 8.4         | 2.2 | 8.0 | 0.9 | 1.9    | 0.4   | -     |
| BFGS (China)| 36.1    | 0.8     | 12.0        | 0.5         | 8.0 | 40.1| 0.3 | 0.5    | 0.5   | -     |

Sodium silicate pentahydrate (TU 2145-001-52257004-2002) and soda ash (GOST 5100-85) were used as alkaline components.

The mix composition of raw materials under study have prepared in mixer with supplementary addition of 8-9 % of water. Specimens of compacted soils have moulded according to STO 26233397 MOSAVTODOR.1.1.1.01-2013 in metal molds (Figure 1).

For sandy and clayey soils with the largest grain size and aggregates less than 5 mm, the shape of the specimens is taken as a cylinder with diameter $d = 50$ mm and height $h = 50$ mm. The load on the compaction sample to 30 MPa is lifted for 5-10 seconds. Moulding is carried out for 3 minutes under static pressure $(30 \pm 0.3)$ MPa. The compressive strength test was carried out on the 28 days age in normal conditions ($t = 20 \pm 2$ °C, humidity $95 \pm 5$ %).
After 7 days of normal hardening the specimens were fully saturated with water for 2 days. The softening coefficient was determined by the formula:

$$K_{sc} = \frac{R_w}{R_d}$$  \hspace{1cm} (1)

where $R_w$ is compressive strength of saturated specimen, MPa; $R_d$ – compressive strength of normal hardening specimen, MPa.

Mix composition of compacted soils and alkali-activated concretes are represented in Table 2 and Table 3, respectively.

![Figure 1. Moulding of specimens for tests by pressing method.](image)

**Table 2. Mix composition of compacted soils using of iron ore tailings**

| Marking | Cement composition, % by mass | IOT, % by mass | Soil, % by mass | FA, % by mass | Crushed stone 0-5 mm, % by mass | Water content, % by mass |
|---------|-------------------------------|----------------|----------------|----------------|--------------------------------|------------------------|
| S - 1   | 9.6                           | 40             | 50             | -              | -                             | 9                      |
| S - 2   | 9.6                           | 50             | 40             | -              | -                             | 8                      |
| S - 4   | 9.6                           | 70             | 20             | -              | -                             | 8                      |
| S - 5   | 9.6                           | 40             | 25             | -              | 25                            | 9                      |
| S - 6   | 9.6                           | 50             | 15             | 25             | -                             | -                      |
| S - 7   | 9.6                           | 60             | 5              | 25             | -                             | -                      |
| S - 8   | 9.2                           | 40             | 25             | -              | 25                            | 8                      |
| S - 9   | 19.2                          | 40             | 40             | -              | -                             | 9                      |
| S - 10  | 19.2                          | 40             | 30             | 10             | -                             | 9                      |
| S - 11  | 19.2                          | 40             | 30             | 10             | -                             | 9                      |
| S - 12  | 9.2                           | 40             | 15             | 10             | 25                            | 8                      |
| S - 13  | 19.2                          | 60             | 10             | 10             | -                             | 8                      |
| S - 14  | 19.2                          | 40             | 15             | -              | 25                            | 8                      |
Table 3. Mix composition high volume iron ore tailings alkali-activated concretes

| Name | Concrete mix composition, kg/m³ | Cement composition | Crushed stone | IOT | 5-10 | 10-20 | H₂O |
|------|---------------------------------|-------------------|---------------|-----|------|-------|-----|
|      |                                 | BFGS  | FA  | Soda Ash | Sodium silicate | LST |       |     |      |
| DF-3 | 407                             | -     | 17.7| 17.7     | 2.2             | 904 | 816   | -   | 165  |
| DF-4 | 390                             | -     | 17.7| 35.5     | 2.2             | 907 | 818   | -   | 157  |
| DF-5 | 296                             | -     | 13.5| 36.7     | 1.7             | 889 | 314   | 584 | 191  |
| DF-6 | 305                             | 76    | 17.4| 34.8     | 2.1             | 888 | 280   | 520 | 155  |
| DF-7 | 285                             | -     | 6.0  | 9.0      | 1.5             | 894 | 316   | 588 | 220  |
| DF-8 | 280                             | -     | 12.3 | 12.3     | 1.5             | 924 | 834   | -   | 227  |

3. Results and discussion

At the first stage of the studies mix compositions of compacted soils using iron ore tailings were developed and their physical-mechanical characteristics were determined. The results are shown in Table 4.

Table 4. Physical-mechanical properties of high volume iron ore tailings alkali-activated concretes

| Marking | Average density, kg/m³ | Softening coefficient | Compressive strength (normal condition), MPa, after days |
|---------|------------------------|-----------------------|--------------------------------------------------------|
|         |                        |                       | 7           | 28                               |
| S - 1   | 2181                   | 0.83                  | 1.45        | 2.87                             |
| S - 2   | 2111                   | 0.76                  | 0.78        | 1.33                             |
| S - 3   | 2117                   | -                     | 0           | 0                                |
| S - 4   | -                      | -                     | -           | -                                |
| S - 5   | 2280                   | 0.49                  | 1.20        | 2.40                             |
| S - 6   | -                      | -                     | -           | -                                |
| S - 7   | -                      | -                     | -           | -                                |
| S - 8   | 2193                   | 0.58                  | 1.43        | 3.29                             |
| S - 9   | 2264                   | 0.43                  | 1.14        | 2.62                             |
| S - 10  | 2136                   | 1.10                  | 0.90        | 2.07                             |
| S - 11  | 2136                   | 0.57                  | 0.90        | 2.07                             |
| S - 12  | 2188                   | 1.00                  | 1.10        | 2.53                             |
| S - 13  | 2057                   | 1.10                  | 1.50        | 3.10                             |
| S - 14  | 2227                   | 1.23                  | 1.30        | 2.99                             |

According to the obtained results, using iron ore tailings in quantity of 60 % by mass of the compacted soil does not allow achieving of the hardening stone with the required water resistance. However, it was found that the optimal amount of waste in the mix composition is 40 % by mass achieving the compressive strength of the hardening stone to 3 MPa. The addition of crushed stone (composition S-8) in an amount of 25 % by mass increased the strength to 3.29 MPa which corresponds to the requirements of [9] for stratum of compacted soil in the lower layer. The addition of fly ash allowed increasing the water resistance of the hardening stone from 0.49 to 1.1 due to the compaction of the structure of the hardening stone and the reduction in the number of pores capable of passing into the water, which also affects its strength. The increasing of compressive strength was possible due to using mixture of alkaline components (sodium silicate and soda ash). The compressive strength and water resistance of specimens on the early stages of hardening were significantly increased.

However, using iron ore tailings in large quantities is possible not only in the basis of the road, but also into the roadway. The nature of the waste allows us to use it as a full-fledged component instead
of river sand. In the course of the work, concrete mix compositions with high content of waste (40 % by mass) were developed. The composition of the developed concrete is given in Table 5.

Table 5. Physical-mechanical properties of high volume iron ore tailings alkali-activated concretes

| Name | Slump., cm | Density of concrete, kg/m³ | Compressive strength, MPa, days |
|------|-----------|----------------------------|---------------------------------|
|      |           |                            | 3     | 7    | 14   | 28   |
| DF-3 | 7         | 2330                       | 19.3  | 23.3 | 29.4 | 32.3 |
| DF-4 | 3         | 2307                       | 26.1  | 28.6 | 33.7 | 38.0 |
| DF-5 | 4         | 2329                       | 18.6  | 22.7 | 27.5 | 29.0 |
| DF-6 | 7         | 2282                       | 20.0  | 26.1 | 30.1 | 32.6 |
| DF-7 | 5         | 2322                       | 10.0  | 11.9 | 17.3 | 16.7 |
| DF-8 | 5         | 2293                       | 11.1  | 15.5 | 18.4 | 21.3 |

The analysis of the obtained results showed that using of TOI waste in concrete composition up to 40 % (by mass per 1 m³ of concrete mix) allows to reach strength of 38 MPa for 28 days, while the plasticity of the concrete mixture is P1, P2, which is quite good an indicator. Adding fly ash in quantity up to 20 % (by mass) reduces the consumption of slag and allows achieving a similar plasticity of the mixture with less water.

According to the obtained results, the composition of alkali-activated concrete (DF-6) was recommended for the construction of a roadway in industrial conditions in Qianxi (Tangshan, China). In the process of approbation, a roadway with a length of 50 m, a width of 4 m and a height of 0.3 m were made. The process of preparation of the concrete mixture was carried out on the basis of the existing concrete mixing plant (CMP) is shown in Figure 2.

The components of the alkali-activated concrete were mixed with a two-shaft impeller forced action mixer with a working capacity of 1.2 m³. The finished concrete mixture was transported to the construction site by means of concrete mixers with a drum capacity of 12 m³. The time of transporting the concrete mixture to the construction site was 20-30 minutes. However, the mobility of the concrete mix (DF-6 composition) is 4 hours, which allows to significantly increase the distance between the CMP and the construction site. The concrete mix was consolidated with the deep-seated vibrators (Figure 3), and the surface was levelled with a screed (Figure 4).
Figure 3. Vibration of concrete mix

Figure 4. Surface leveling

The surface of concrete was grouted to eliminate defects using a trowel machine (Figure 5). This process was possible after 24-36 hours depending on the slump of the concrete mix. Trowelling at early age led to large deformations of the surface.

At night, a “greenhouse” type covering was used which heated the concrete with electric lamps (Figure 6) to maintain the temperature and creating optimal conditions for hardening. The temperature at the surface of the concrete was in the range 15-18 °C.

Figure 5. Trowelling of concrete mix surface

Figure 6. Normal hardening of alkali-activated concrete at night

The compressive strength of finished roadway on 28 days is 28-30 MPa taking into account the fact that slump of concrete mix was P4-P5.

4. Conclusion
1) Compacted soils were developed which contain 40 % IOT by mass to be used for road basis. The compressive strength of hardening stone is 3.29 MPa that meets the requirement of the standard.
2) Possibility if utilization of iron ore tailings in alkali-activated concretes including 40 % waste by mass (full sand replacement) and preparation of concrete mix in industrial condition was investigated. The compressive strength of concrete to 30 MPa is achieved using concrete mix with high mobility (P5-P5).
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