Experimental study on rule of radioactive change of red mud concrete

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Abstract. Red mud was used to partially replace cement to prepare red mud concrete, with replacement rate of red mud mass being 0%, 5%, 10%, 15% and 20% respectively, and hydration age being 3d, 28d and 90d. The experiment of cube compressive strength and radioactivity were conducted for 90 cubical test pieces respectively. The results show that with rise of replacement rate of red mud, the cube compressive strength of red mud concrete at the same hydration age first increased and then decreased, leading to increase of content of 226Ra, 232Th, 40K in red mud concrete, and increase of material's radioactivity accordingly; as hydration age was prolonged, with the replacement rate of red mud being the same, the compressive strength increased, and internal and external exposure indices and total specific activity all increased yet with small increase range. Generally the hydration age does not significantly influence the radioactivity of red mud concrete.

1. Introduction

As the solid waste produced in production of alumina, the red mud has high alkali content, leading to severe pollution to the ambience. China, a large producer of aluminium, discharges substantive red mud each year to increasingly cause the problem of red mud treatment [1]. Presently, the main domain treating red mud is the industry of building materials. As red mud is somewhat radioactive [2], applying it to building materials exposes the surrounding environment to radiation for long, thereby influencing the health of people around. The environment with low-dose radiation causes dizziness and tinnitus, hypomnesia and skin injury, while the high dose causes chromosomal variation to be entailed on next generation or several generations, even causes death. Thus, the radiological hazard of red mud has severely hindered its extensive application in the industry of building materials [3]. Some research has been done on the application of red mud to concrete at home and abroad [4-9], yet little research has been done on the rule of radioactivity of red mud concrete. Thus, radioactivity tests were conducted on 90 red mud concrete specimens to explore the influence of radioactivity of radionuclides, especially 226Ra, 232Th, 40K, on specific activity.
2. General situation of experiment

2.1. Experimental materials
Cement: Yatai ordinary Portland cement with strength level of 42.5, its basic performance is in table 1; sand: common natural fluvial sand, its basic performance is in table 2; coarse aggregate: natural continuously graded rubble with maximum particle size of 20mm, as shown in table 3; red mud: red mud produced in the process of bayer method in Shandong Weiqiao Beihai Alumina Factory, its basic chemical composition is in table 4; mixing water: tap water from laboratory.

| Table 1 | Basic properties of cements |
|---------|---------------------------|
| Specific surface area/m².kg⁻¹ | Setting time/min | Compressive strength/MPa | Flexural strength/MPa |
|         | Initial set | Final set | 3d | 28d | 3d | 28d |
| 355     | 255         | 315       | 23.7 | 46.3 | 5.8 | 7.3 |

| Table 2 | Basic properties of fine aggregate |
|---------|----------------------------------|
| Mud content of natural sand % | Apparent density/kg.m⁻³ | Loose density/kg.m⁻³ | alkali-aggregate reaction % | Grading area | Fineness module | Degree of thickness |
| 1.3     | 2650 | 1490 | 0.04 | II | 2.96 | Medium sand |

| Table 3 | Basic properties of coarse aggregate |
|---------|------------------------------------|
| Course aggregate type | Grading /mm | Bulk density/kg.m⁻³ | Apparent density/kg.m⁻³ | Absorption % | Crushing index % |
| Course aggregate I | 5-10 | 1520 | 2740 | 1.1 | — |
| Course aggregate II | 10-20 | 1500 | 2760 | 0.9 | 17.8 |

| Table 4 | Red mud chemical composition |
|---------|------------------------------|
| Chemical components | Al₂O₃ | Na₂Ok | Fe₂O₃ | SiO₂ | TiO₂ | CaO | CO₂ | H₂O | H₂O附 | Loss on ignition | PH | Density/ g.cm⁻³ |
| %       | 23.73 | 7.39 | 28.79 | 24.63 | 2.22 | 2.69 | 0.97 | 8.59 | 1 | 14.94 | 11.3 | 3.2 |

2.2. Preparation of red mud concrete
The red mud concrete was prepared by replacing cement in concrete with equal mass of red mud. Altogether 5 replacement rates of red mud mass were considered: r = 0%, 5%, 10%, 15%, 20%. When r = 0%, the concrete is normal concrete, which was taken as reference concrete. Normal concrete composition was designed as per literature [10]: first defined dosage of different materials, then replaced cement by 5 replacement rates of red mud mass to prepare 45 red mud concrete specimens (150mmx150mmx150mm), which were cured for 3d, 28d, 90d in standard curing conditions respectively, then conducted experiment. The mixture proportion is in table 5.

2.3. Experiment method
The compression test for all the samples was conducted on 200t microcomputer controlled compression testing machine. The test set is as shown in fig.2. The radiation test on red mud concrete utilized CIT-3000F low-background multi-channel gamma spectrometer produced by Sichuan
Xinxianda Measurement and Control Technology Co., Ltd. to determine the compressive strength for concrete at 3d, 28d and 90d of hydration age and radioactive specific activity of $^{226}$Ra, $^{232}$Th, $^{40}$K.

Table 5 The mixture proportion of red concrete

| No.  | Red mud | Cement | Fine aggregate | Course aggregate I | Course aggregate II | Water | Water-reducing admixture |
|------|---------|--------|----------------|---------------------|---------------------|-------|------------------------|
| RMC-0 | 0       | 360    | 780            | 216                 | 862                 | 162   | 3.6                    |
| RMC-5 | 18      | 342    | 780            | 216                 | 862                 | 162   | 3.6                    |
| RMC-10 | 36     | 324    | 780            | 216                 | 862                 | 162   | 3.6                    |
| RMC-15 | 54     | 306    | 780            | 216                 | 862                 | 162   | 3.6                    |
| RMC-20 | 72     | 288    | 780            | 216                 | 862                 | 162   | 3.6                    |

Figure 1. Several specimens after fabricating. Figure 2. Test device

3. Result and discussion

3.1. Influence of replacement rate of red mud on compressive strength of red mud concrete

Under different replacement rates of red mud, the cube compressive strength of red mud concrete at different hydration ages is as shown in fig.3. With increase of replacement rate of red mud, the cube compressive strength of red mud concrete at 3d, 28d and 90d first increased and then decreased, being the largest when the replacement rate of red mud $r=5\%$: 20.66MPa, 41.83MPa, 47.12MPa respectively, with strength improved by 9.54%, 46.93% and 31.51% compared with normal concrete whose replacement rate of red mud $r=0\%$; When the replacement rate of red mud $r=20\%$, the compressive strength was the smallest, being 18.48MPa, 28.32MPa and 30.90MPa respectively, with strength reduced by 2.05%, 0.50% and 13.77% compared with normal concrete whose replacement rate of red mud $r=0\%$. Thus, the longer the hydration age was, the more obvious the improvement on strength of red mud concrete was. When $r=20\%$, the compressive strengths of red mud concrete in all the hydration ages was basically equal compared with that of normal concrete, indicating the red mud can deliver significant effect when replacing the cement.

3.2. Influence of replacement rate of red mud on radioactivity of red mud concrete

The detection result of radioactivity of red mud concrete under different replacement rates of red mud is as shown in fig.4. The internal and external exposure indices and total specific activity at all hydration ages and under all replacement rates are in table 6. Fig.4 and table 6 show that with increase of replacement rate of red mud, the internal and external exposure indices and total specific activity of red mud concrete at 3d, 28d and 90d all increased, with increase ranges at 3d being respectively 188.5%, 156.1% and 142.5%; increase ranges at 28d being respective 197.3%, 163% and 152.2%,
increase ranges at 90d being 200.2%, 165.5% and 154.8%. The reason is that the more the red mud in red mud concrete is, the higher the content of $^{226}$Ra, $^{232}$Th and $^{40}$K in red mud concrete is, and the stronger the radioactivity of material is.

![Figure 3. Relationships between $f_{cu}$ and $r$](image)

**Table 6** Influence of red mud on radioactivity of red mud concrete

| No.  | $I_{Ra}$ | $I_{r}$ | Total specific activity /Bq.kg$^{-1}$ |
|------|----------|---------|--------------------------------------|
| RMC-0-3d | 0.2965   | 0.2088  | 82.8                                 |
| RMC-5-3d | 0.5220   | 0.3426  | 131                                 |
| RMC-10-3d | 0.7440   | 0.4630  | 175.5                                |
| RMC-15-3d | 0.7865   | 0.4898  | 185                                 |
| RMC-20-3d | 0.8555   | 0.5348  | 200.8                                |
| RMC-0-28d | 0.2965   | 0.2084  | 81.1                                 |
| RMC-5-28d | 0.5400   | 0.3512  | 133                                 |
| RMC-10-28d | 0.7650   | 0.4736  | 178.2                                |
| RMC-15-28d | 0.8100   | 0.5026  | 188.4                                |
| RMC-20-28d | 0.8815   | 0.5481  | 204.5                                |
| RMC-0-90d | 0.2965   | 0.2083  | 80.8                                 |
| RMC-5-90d | 0.5505   | 0.3572  | 134.8                                |
| RMC-10-90d | 0.7725   | 0.4784  | 179.5                                |
| RMC-15-90d | 0.8250   | 0.5106  | 191                                 |
| RMC-20-90d | 0.8900   | 0.5530  | 205.9                                |

![image](a)

![image](b)
3.3. Influence of hydration age on radioactivity of red mud concrete

The detection result of radioactivity of red mud concrete at different hydration ages is as shown in Fig. 5 and Table 6. With prolonging of hydration age, the internal and external exposure indices and total specific activity all increased yet with small increase range, which indicates that generally the hydration age does not significantly influence the radioactivity of red mud concrete.

3.4. Analysis on mechanism of radioactive shielding

The coarse aggregate in raw material and red mud replacing cement are all materials with certain natural radioactivity [11]. The radioactivity is mainly from the α, β and γ rays released when nuclear decay occurs to $^{226}$Ra, $^{232}$Th and $^{40}$K [12-13]. In the process of hydration of red mud concrete, on the one hand, the clinker minerals incessantly release radionuclide ions to lead to rise of radioactive specific activity; on the other hand, the C-S-H gel produced in hydration process absorbs and envelops the radionuclide to some extent, thereby sealing the radionuclide ions released by clinker minerals into solidified body to lead to drop of radioactive specific activity.

With replacement rate of red mud being fixed, with the increase of hydration age, the internal and external exposure indices and total specific activity increased slightly, which was caused by joint effect of above two aspects. Analysis on test data shows that in hydration process, the $^{226}$Ra in clinker minerals was incessantly released, while $^{226}$Ra is instable in water and prone to be absorbed into C-S-H gel. But the alite structure cannot block the γ rays released by $^{226}$Ra; $^{232}$Th is very stable in nature, with little change in radioactive specific activity in hydration; $^{40}$K can be rapidly fused into hydration liquidoid, while water can shield the radioactivity of $^{40}$K to some extent. In the hydration process, $^{40}$K was enveloped in hydrated product of Si-OK [14-15], with little change in radioactive specific activity. To sum up, with replacement rate of red mud being fixed, with prolonging of hydration age, the internal and external exposure indices and total specific activity all increased yet with small increase range.
Figure 5. Influence of hydration ages on radioactivity of red mud concrete

4. Conclusion
After experimental study on radioactivity of red mud concrete, the paper preliminarily draws following conclusions:

(1) Under the same replacement rate, the longer the hydration age is, the more obvious the improvement on strength of red mud concrete is. When r=20\%, the compressive strengths of red mud concrete at all the hydration ages are basically equal compared with that of normal concrete.

(2) With increase of replacement rate of red mud, the cube crushing strength of red mud concrete first increases and then decreases, being the highest when r=5\%, and lowest when r=20\%.

(3) The more the red mud in red mud concrete is, the higher the content of 226Ra, 232Th and 40K in red mud concrete is, and the stronger the radioactivity of material is.

(4) With prolonging of hydration age, the internal and external exposure indices and total specific activity all increased yet with small increase range, indicating generally the hydration age does not largely influence the radioactivity of red mud concrete.

(5) Table 6 shows that the internal and external exposure indices all meet the requirements of literature [16].

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