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Deterioration behavior of reinforced concrete beam under compound effects of acid-salt mist and carbon dioxide

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HIGHLIGHTS

- Compound effects of acid-salt mist and carbon dioxide on RC beams were studied.
- The failure mode of deteriorated beams changed from crushing of concrete to yielding of rebar.
- Neutralization depth increased with the time linearly whiles the corrosion of rebar changed nonlinearly.
- The expansive cracks increased nonlinearly under the effects of deteriorated concrete and rebar.
- Relationship between the experimental time and the service time was achieved.

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ABSTRACT

An experimental investigation on the deterioration behavior of reinforced concrete (RC) beams under compound effects of acid-salt mist and carbon dioxide was conducted. The changes of failure mode, neutralization depth, strength loss of concrete, corrosive rate of rebar and the expansive crack width were tested. And then the relationship between the experimental time and service time was achieved with theoretical analysis. Results indicated that neutralization depth of concrete increased with time linearly while corrosion of rebar changed nonlinearly. When the concrete cracked, the corrosion increased rapidly. The bond between the corroded rebar and deteriorated concrete decreased, and then the failure mode of RC beams under flexural load change from crushing of compression concrete to yielding of rebar. The relationship between the service time and investigation time was achieved, according to the neutralization ratio of concrete and corrosion ratio of rebar respectively. It was found between the calculation results and the calculation of corrosion ratio was closer.

1. Introduction

RC structures are widely used in the mine, where they are deteriorated by the compound effects of acid-salt mist and carbon dioxide. The fragile safety of RC structures hinders the normal production of coal. As betrayed in the investigation, RC structures deteriorated heavily after the service of 10 years [1]. The concrete loosened and the compressive strength reduced, and then the surface cracked and even peeled off. The sectional area of corroded rebar decreased and the tensile capacity reduced. The cohesion between the deteriorated concrete and corroded rebar degraded along with the increase of crack width. And then the carrying capacity and ductility of the RC beam decreased. The RC structure will be destroyed because of the redistribution of the internal force and the decrease of the reliability. Some photos about the deterioration of RC beams in the mines are illustrated in Fig. 1.

The effects of corrosive mediums existed in the colliery ground environment are coupled. The hydrogen ions (H^+) produced by the acid mist consisted of hydrogen chloride and chlorine deteriorated the concrete together with the sulfate radical (SO_4^{2-}), and then the gypsum or other more expansive crystal produced [2,3]. Friedel salt was formed when the SO_4^{2-} corroded the concrete with the chloride (Cl^-) [4]. The expansive force enlarged the micro cracks inside the concrete, resulting in concrete cracked. The diffusion coefficient of Cl^- reduced slightly under the effect of carbonization, and the carbonization resistance increased vividly for the corrosion of Cl^- conversely [4]. In addition, the carbonization destroyed the original filtering mechanism of the concrete matrix and promoted the resolution of Friedel salt, so that an increase in content of Cl^-

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[5]. Sulfate hindered the corrosion of Cl^- at the initial stage and gave promotion finally [6]. Cl^- penetrated into the internal concrete easily through the enlarged cracks and corroded the rebar. Much more cracks enlarged by the corrosion and then the deterioration alternately repeated, the RC beam damaged [7,8].

The researches above gave the mechanism of concrete deterioration and rebars corrosion qualitatively. And the coupling effects corrosive mediums on the RC beams were discussed. But the time-dependent property of the deterioration was not considered, which just the chief gauge of prevention and treatment in the future. The experimental investigation was taken on the basis of measuring data and similarity theory. The neutralization depth and compressive strength loss of concrete, the corrosion ratio of rebar and the flexural capacity of the RC beam were tested, and the time-dependent regularity was got. On this basis, the relationship between the test time and service time was discussed for the application of the results.

2. Experimental program

2.1. Materials and beam specimen

The ordinary Portland cement of 32.5 grade, with the specific gravity of 3.18 and specific surface area of 350 m^2/kg, was used in this investigation. Coarse aggregate was crushed stone with a maximum size of 16 mm. Natural river sand, medium sand with the fineness modulus of 2.42, was used as fine aggregate in the study. The ratio of fine aggregate to coarse aggregate was fixed at 35%. Concrete mixtures were designed according to the Chinese Standard of JGJ55 [9]. The mixture proportion by weight was water: cement: Fine aggregate: Coarse aggregate = 192:343:576:1063, with 28-day cubic compressive strength of 35.2 MPa.

The beam specimens had a length of 1500 mm and a rectangular cross-section of 100 mm × 200 mm (breadth × width). The sectional dimensions of specimen and cross-section of the beam specimen was shown in Fig. 2. Two round bars with the diameter of 8 mm were placed on the top of the beam as hangers and two 12-mm-diameter ribbed bar were placed on the bottom of the beam as tensile rebar. The thickness of protective layer concrete was taken 15 mm. The yield and ultimate strengths of rebar were 380 MPa and 552 MPa, respectively.

2.2. Test design

As the hydrogen chloride and chlorine deteriorated the concrete by dissolving in the water and producing hydrochloric acid, so they can be replaced by hydrochloric acid mist in the experiment. For the RC beams were not soaked in the corrosive liquid, and then the salt mist consist of NaCl, $MgCl_2$ and Na_2SO_4 was sprayed to the cover of the beams to realize the simulation. The alternation of wetting and drying and freeze–thaw cycle were out of consideration. The design of simulation environment was illustrated in Table 1.

A total of eight beam specimens were made for the investigation, in which one beam was taken as control specimens and the other seven were under the environment attacked. All the test specimens were cast by the same batch. After being cured for 28 days in the laboratory air, the beam specimens were placed in the laboratory for 7 months, and then been removed into the simulation environment the same time. The deterioration behavior of the beam specimens were detected at intervals of 3 months. The beams were flexural loaded in batches, and then the concrete cores were drilled from the ends of the beams and the corroded rebar were got when the concrete outside crushed. One percent phenolphthalein alcohol solution was sprayed on the surface of the core as a pH indicator of neutralization. The maximum and minimum values and somewhere between position were tested and the average value was taken as the neutralization depth. The concrete cores were axially loaded for testing the compressive strength. The rebar were loaded for the tensile strength after the corrosive ratio tested.

（a)Cracks in the bottom surface（after 13 years service） （b)Side concrete peeled off（after 21 years service）

Fig. 1. Photos about deterioration of RC beams.

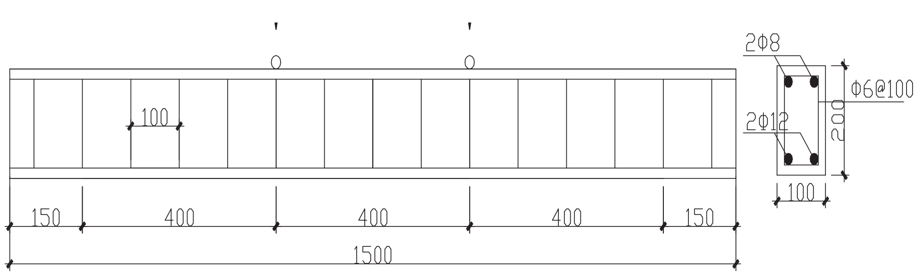

Fig. 2. Sectional dimensions of specimen and cross-section (unit: mm).