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Effects of Carbonation on the Impact Resistance of Old Concrete

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By simulating old concrete through artificial accelerated carbonation, this paper performs the SHPB dynamic impact test and studies the impact resistance of old concrete after carbonation. It obtains the dynamic mechanics performance parameters, including impact compressive strength and dynamic increase factor (DIF), of the concrete of different strength grades at different ages under different strain rates. The results show that: high-strength concrete has better resistance to carbonation than low-strength concrete and that strain rate has some enhancement effects on the impact compressive strength and DIF of concrete.

1. Introduction

Underground cavern protection doors are a very important part of military protection projects and play an important role in ensuring the safety of personnel and military equipment. Most of our military caverns were built in the 1960s and 1970s. (Zhang et al., 2018; Geng et al., 2016; He et al., 2004) How the dynamic performance of the protective doors against strikes and whether they can still serve as protection urgently need to be tested and evaluated. (Guo et al., 2013; Wu et al., 2016) Protective doors are mainly made of concrete materials. (Miao et al., 2015) The carbonation and aging of concrete directly and indirectly affect the efficacy and useful lives of protective works, and even endanger the safety of protective works. Concrete carbonation is a very common phenomenon. It can damage the alkaline passivation films on the surfaces of the reinforcement bars and cause corrosion to them and reduce the effective section areas of the components. (Xiao and Guo, 2010; Yu et al., 2015; Li et al., 2015) As a result, the bearing capacities of the components will decrease, resulting in continuous deterioration of the structural performance, and even structural failures. This phenomenon seriously affects the safety and durability of the structures and needs to be given sufficient attention. (Chen, 2010) With concrete as the research object, this paper simulates old concrete through artificial accelerated carbonation, performs the SHPB dynamic impact test and studies the impact resistance of old concrete after carbonation. It obtains the dynamic mechanics performance parameters, including the stress-strain curve, impact compressive strength and dynamic increase factor (DIF), of the concrete of different strength grades at different ages under different strain rates.

2. Preparation of specimens and carbonation test

2.1 Preparation of specimens

This test included casting of short cylinder specimens in three batches at three concrete mix proportions (different strengths). The short cylinder specimens with a diameter of 70mm and a thickness of 35mm were casted using a PVC mould with a diameter of 75mm and a length of 400mm. Due to the low temperature in winter, the concrete specimens were placed in a semi-ground curing chamber (at a temperature of 19℃ and a relative humidity of 80%) and watered at regular time every day for a total of 28 days. After the long cylinder finished curing, it was cut into short cylinders with a thickness of 38mm and ground and smoothed. Short cylinder specimens were mainly used in the carbonation depth measurement of short cylinders and the impact resistance test.

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2.2 Concrete specimen carbonation test

2.2.1 Carbonation test scheme

The carbonation test equipment used was the concrete carbonation chamber manufactured by Tianjin Huida Test Instrument Factory, with the model number being CCB-70A. The parameters of the carbonation chamber controller were adjusted - the temperature was controlled at 20±3°C, the humidity at 70±5%RH, and the carbon dioxide concentration at 20±3%. The short cylinder specimen only had one circular section, and the remaining surfaces were sealed with heated paraffin to ensure that only one circular section would be in contact with the air as the carbonated plane. Except for the non-carbonated control group, the treated concrete specimens were placed into the carbonation chamber in four batches for an accelerated carbonation period of 7d, 14d, 28d and 56d for the carbonation test.

2.2.2 Conversion relation between the accelerated carbonation time and natural carbonation age of concrete

After 28d of natural curing, the specimens were artificially quickly carbonated. After meeting the intended requirements, they were taken out. The carbonation age under natural conditions can be calculated based on the artificial accelerated carbonation test time. The specific conversion results are shown in Table 1.

Table 1: Relationship between artificial accelerated carbonization and natural carbonation age

Artificial accelerated carbonization time (day)	7	14	28	56
Corresponding natural carbonation age (year)	5.8	11.6	23.2	46.5

3. Impact resistance test on carbonated concrete and results analysis

3.1 Test design

In the concrete impact resistance test, concrete was studied at three strength grades – C30, C40 and C50. In order to reduce the errors caused by the radial and longitudinal inertia and end-face friction effects in the test, the specimens designed had an aspect ratio of 0.5. Short cylinder specimens that met the 74mm diameter requirement for the SHPB test were made, with a diameter of 70mm, a thickness of 35mm, an end surface non-parallelism of 0.05mm, and a end face flatness of 0.02mm. After carbonation for 7d, 14d, 28d, and 56d, impact compression tests were carried out at five different rates on a Split Hopkinson Pressure Bar (SHPB) device. In order to obtain five different strain rates, the pressure of the output gas on the barometric pressure controller were set at 0.3MPa, 0.4MPa, 0.5MPa, 0.6MPa, and 0.7MPa, respectively. After calculation, the corresponding bullet impact rates were 9.1m/s, 10.5m/s, 12.3m/s, 13.8m/s and 15.1m/s, respectively. A total of 345 short cylinder specimens were designed for the control test.

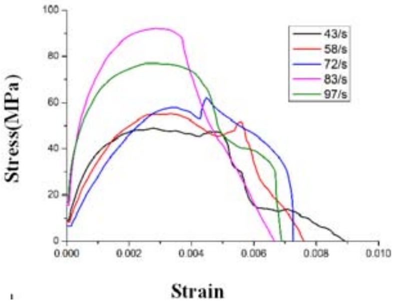
3.2 Phenomena and analysis in the test

The SHPB test lasted for a very short time. When a bullet was fired from the barrel, the bullet, the input bar, the concrete specimen, and the transmission bar collide in sequence, producing harsh impact sounds, and the destruction of the concrete specimen could be observed, with small grain powder splashing out. After the end of the test, the broken particles of the concrete specimen were collected and the failure form of the concrete specimen was obtained. Through analysis, it can be found that due to different strength grades, carbonation ages and impact pressure, the concrete specimens had different failure forms, but they also exhibited certain patterns. At the same carbonation age and impact pressure, with the increase of strength grade, the destruction was gradually weakened. This means that, under the same conditions, the higher the strength grade is, the lower the deformability of the concrete will be and the better impact resistance it will have. At the same carbonation age and strength grade, with the increase of the impact pressure, the destruction became more serious. The impact pressure determines the impact velocity of the bullet and thus plays a very important role in the destruction of the concrete. Where other conditions are constant, the higher the impact pressure is, the higher the level of concrete destruction will be.

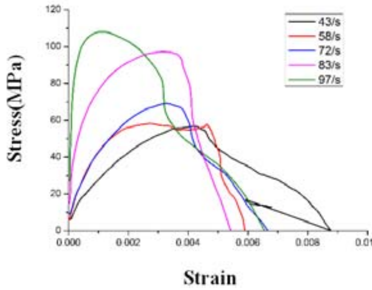
3.3 Stress-strain curve in the SHPB test

The SHPB compression test was performed on old concrete. Considering three concrete grades, five carbonation ages, and five bullet impact speeds, a total of 75 groups of tests were designed to test the impact compression performance of concrete.

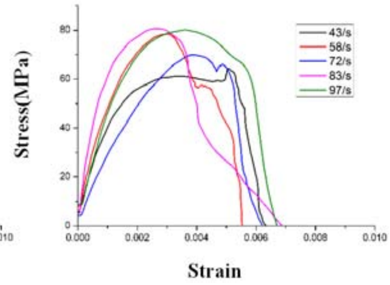
After accelerated carbonation for 0d, 7d, 14d, 28d and 56d, the stress-strain curves of the concrete specimens of different strength grades under the average strain rate of $43s^{-1}$, $58s^{-1}$, $72s^{-1}$, $83s^{-1}$ and $97s^{-1}$ were shown in Figure 2, 3 and 4, respectively.



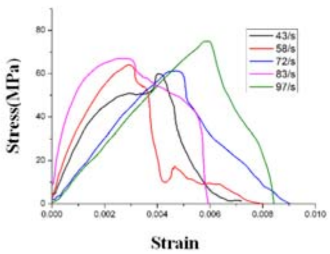
(a) Concrete carbonated for 0d



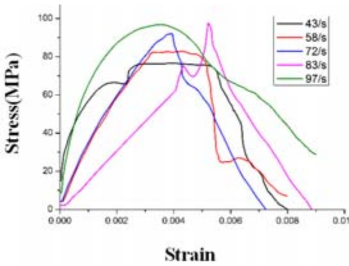
(b) Concrete carbonated for 7d



(c) Concrete carbonated for 14d

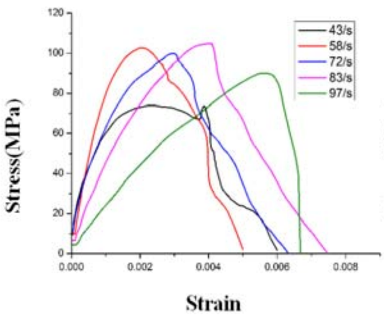


(d) Concrete carbonated for 28d

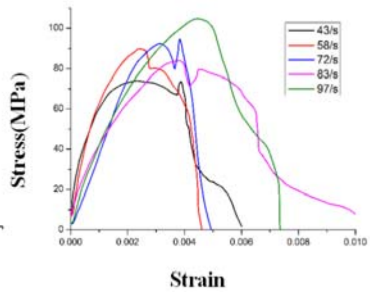


(e) Concrete carbonated for 56d

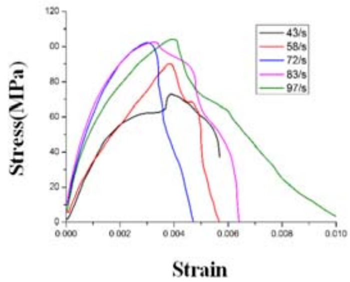
Figure 1: Stress-strain curves of C30 concrete at different carbonation ages under different strain rates



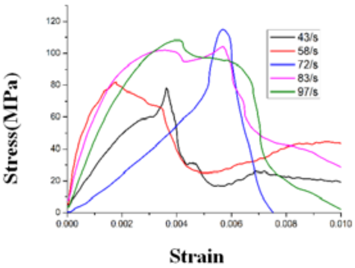
(a) Concrete carbonated for 0d



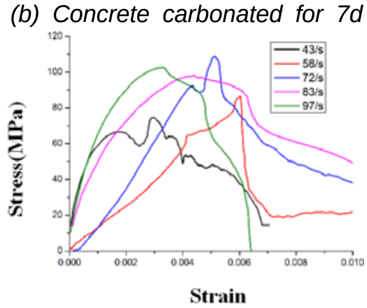
(b) Concrete carbonated for 7d



(c) Concrete carbonated for 14d

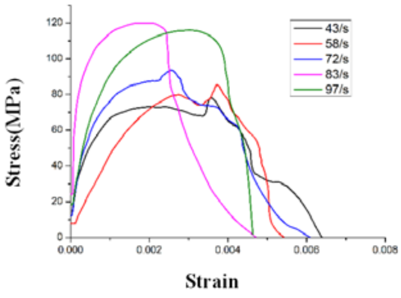


(d) Concrete carbonated for 28d

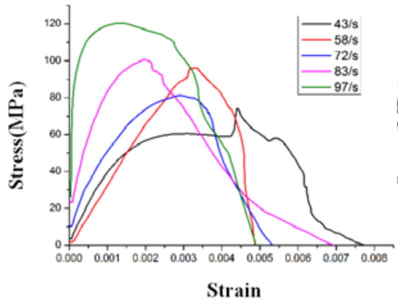


(e) Concrete carbonated for 56d

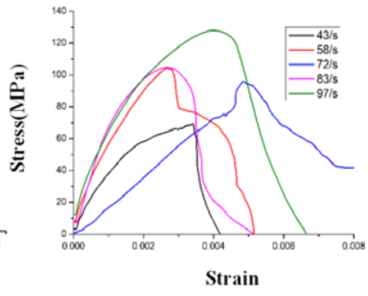
Figure 2: Stress-strain curves of C40 concrete at different carbonation ages under different strain rate



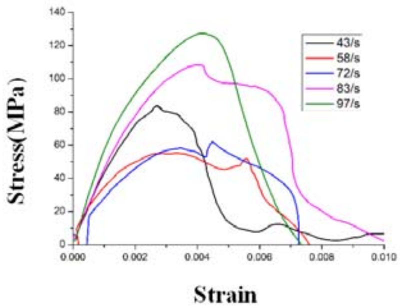
(a) Concrete carbonated for 0d



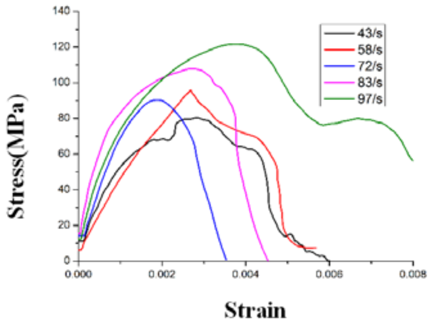
(b) Concrete carbonated for 7d



(c) Concrete carbonated for 14d



(d) Concrete carbonated for 28d



(e) Concrete carbonated for 56d

Figure 3: Stress-strain curves of C50 concrete at different carbonation ages under different strain rates

From Figure 1-3, it can be seen that the concrete stress-strain curves in the impact compression test process can be roughly divided into three stages: the first stage was the rising period, where initially the impact compressive strength of the concrete rapidly increased with the increase of the strain; the second stage was the plateau stage, where the concrete stress increased very slowly after reaching a certain level while the strain dramatically increased and after that the concrete reached the stress peak; the third stage is the falling period, where the stress started to drop sharply after the stress peak. From the above figure, it can also be seen that the strain rate and the carbonation age have very significant effects on the concrete strength. The compressive strength of concrete increases to different extents with the increase of the strain rate, and the amplitude of the change of the concrete compressive strength varies with the carbonation age.

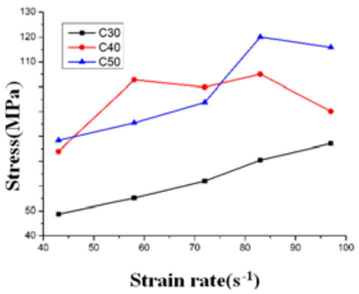
3.4 Strain rate effect on the impact compressive strength

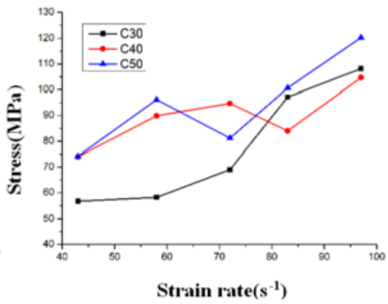
The impact compressive strength of concrete varied with the carbonation age and the strain rate. Figure 4 shows the trend of the impact compressive strength of the concrete at five carbonation ages with the strain rate.

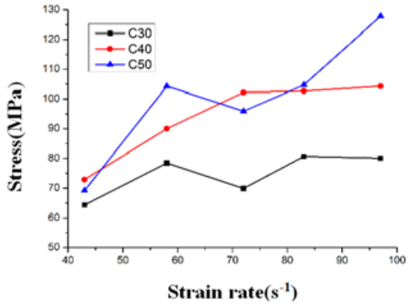
From Figure 4, it can be found that the impact compressive strength of concrete had a significant strain rate effect and exhibited a certain trend. For the concrete of the same strength grade, after the same carbonation time, the impact compressive strength generally increased to different extents with the increase of the strain rate. From this, it can be concluded that the strain rate has a certain enhancement effect on the impact compressive strength of concrete. After 7d of carbonation, the impact compressive strength of C30 concrete under an average strain rate of $97s^{-1}$ was 108.2MPa, far higher than the static compressive strength 31.7 MPa. The enhancement effect was very obvious.

The dynamic increase factor (DIF) refers to the ratio of the impact compressive strength to the static compressive strength of concrete at a high strain rate. It can be used to study the increase magnitude of the concrete impact compressive strength at high strain rates. The DIF trends of the concrete of three strength grades at five carbonation ages with the strain rate are obtained, as shown in Figure 5.

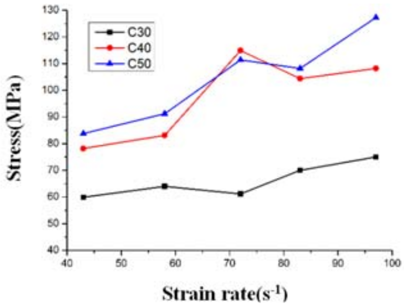
Figure 5 shows the effect of the strain rate on the DIF of concrete. With some discrete data eliminated, it can be seen that the DIF of the concrete at the same carbonation age increased to different extents ranging from 1.2 to 3.5 with the increase of strain rate. On the whole, the DIF of the C30 concrete increased the most. After some concrete specimens reached a certain age, the DIF value decreased slightly, but the overall DIF value increased.

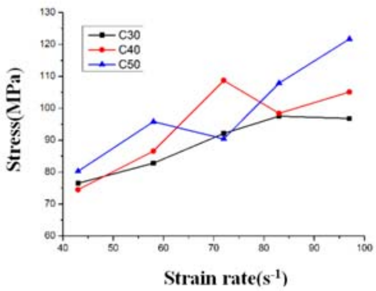






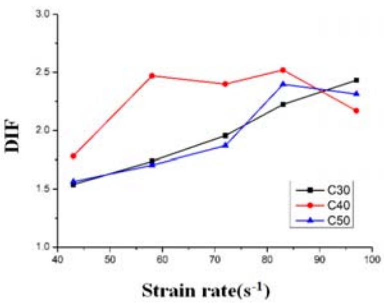
(a) Concrete carbonated for 0d *(b) Concrete carbonated for 7d* *(c) Concrete carbonated for 14d*

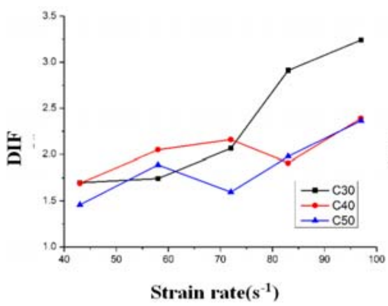


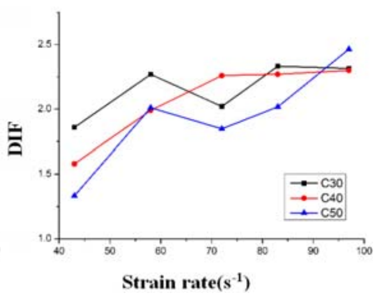


(d) Concrete carbonated for 28d *(e) Concrete carbonated for 56d*

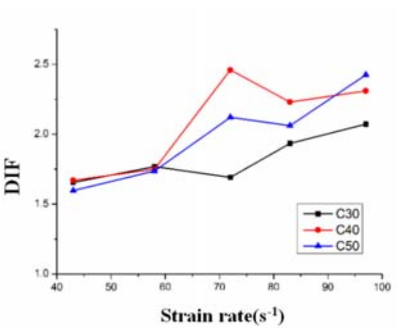
Figure 4: Changes in the impact compressive strengths of the concrete of the three strength grades at different carbonation ages with the strain rate

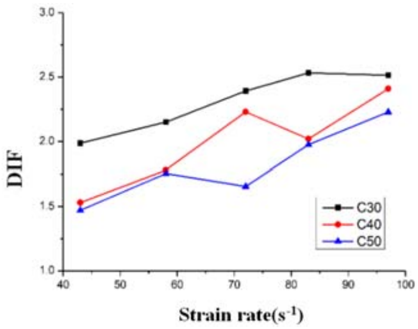






(a) Concrete carbonated for 0d *(b) Concrete carbonated for 7d* *(c) Concrete carbonated for 14d*





(d) Concrete carbonated for 28d *(e) Concrete carbonated for 56d*

Figure 5: Changes in the DIFs of the concrete of the three strength grades at different carbonation ages with the strain rate

3. Conclusions

(1) From the failure form of the concrete specimens after the SHPB impact test, it can be seen that the failure form of the concrete is significantly positively correlated with the strain rate. However, under the same strain rate, with the increase of the concrete strength, the failure form of the concrete is mitigated, indicating that high-strength concrete has better resistance against carbonation than low-strength concrete.
(2) For the concrete of the same strength grade, after the same carbonation time, the impact compressive strength and dynamic increase factor generally increase to different extents with the increase of the strain rate, showing that the strain rate has some enhancement effects on the impact compressive strength and dynamic increase factor of concrete.
(3) Carbonation age has some impacts on the dynamic performance of concrete, mainly shown in that: under the same strain rate, it has very obvious increase effect on the impact compressive strength of C30 concrete while it brings the least change to that of C50 concrete; under the same strain rate, the DIF of C30 concrete increases more than that of C50 concrete.

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