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Research on the Dynamic Mechanical Properties of Magnetite Concrete under Impact Load

Ting Xie, Zhenfu Chen

School of Civil Engineering, University of South China, Hengyang, 421001, China

Email: profczf@qq.com

Abstract. In order to investigate the dynamic compression characteristics of magnetite concrete under impact load, the large-diameter $\Phi 100\text{mm}$ Hopkinson pressure bar test device was used to test the impact compression of magnetite concrete specimens under different strain rates, whose the experimental results were valid and consistent, and the stress-strain curves of magnetite concrete were obtained at different strain rates. The results show that: (1)the stress-strain relationship of magnetite concrete materials is nonlinear; (2)that magnetite concrete materials are obvious rate sensitive materials, whose strain rate sensitivity is lower than that of plain concrete, and the compressive strength of concrete increasing with the strain rate's increasing; (3)the failure pattern of specimen appears the splitting damage at low strain rate and the block destroy at high strain rate.

1. Introduction

Radiation-proof concrete has been employed to many fields such as nuclear power, military, education, scientific research and medical treatment. As a common radiation-proof concrete, magnetite concrete has attracted increasing attention.

In recent years, an increasing number of terrorist bombings, earthquakes, tsunamis and mudslides have been threatening the lives and property of our country, society and people. Concrete is the most important and the most widely used in civil engineering, and which has a good development prospect. Because of lacking of researches on traditional concrete structure dynamic response by the impact, explosion, and impact and other non-design load[5, 6], it leads to a series of continuous collapse problem[7] which brought great harm to people's life and property. The study of the dynamic characteristics of concrete materials will be the basis for the impact resistance design and the continuous collapse resistance design of building structures, as well as the basis for the evaluation of the explosion resistance and impact resistance of existing structures. However, previous studies on radiation-proof concrete were mostly limited to material properties and quasi-static properties[1-3], and rarely involved in dynamic properties. In this paper, a 100-mm-diameter Split Hopkinson pressure bar(SHPB)[4] was used to carry out the impact resistance test of magnetite concrete under different strain rates, so as to provide experimental basis for reasonable impact resistance evaluation and design of magnetite concrete structure.

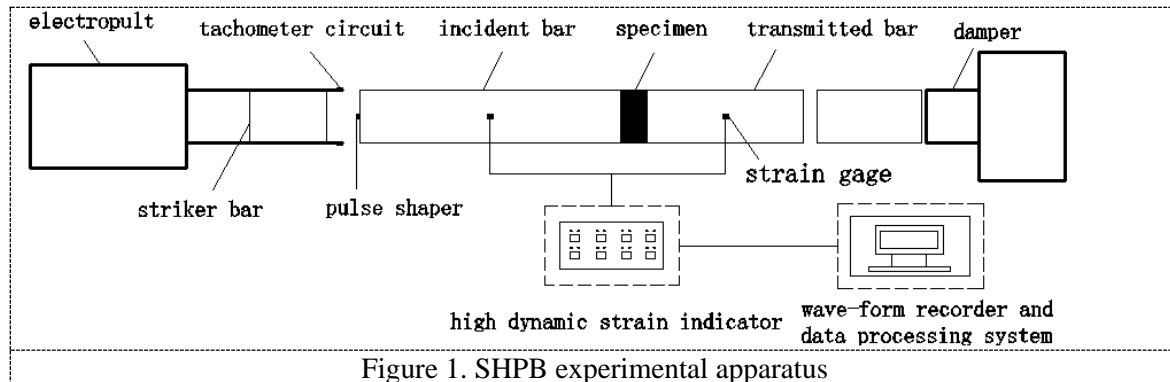
2. Overview of test

2.1 Main test equipment



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In this paper, adopting a 100-mm-diameter SHPB apparatus, its incident bar length is 5000 mm, transmission rod length is 3000 mm, its elastic modulus is 190.3 GPa, density of rod is 7.65 g/mm³ and its bullet length is 600 mm. The SHPB experimental apparatus diagram is shown in figure 1.



2.2 Preparation of test sample

The cement is ordinary Portland cement which code is P.O 32.5R, and the magnetite material adopt the magnetite sand which produced by Henan Li Zhixing metallurgical materials co., LTD. The magnetite crushed stone used as coarse aggregate has a particle size of 5-15mm, the magnetite sand is measured by the average fineness modulus of 3.10, indicating the grade is well, and the water is ordinary running water. Magnetite concrete mix design is shown in table 1. Adopting the double end face grinding machine which manufactured in Jiangyan Xianke instrument factory, to smooth the top and bottom surface of the specimens of standard curing 28 days, the results show that the flatness of specimens is not less than 0.02 mm, geometry size is about $\Phi 100 \text{ mm} \times 50 \text{ mm}$.

Table 1. Magnetite concrete mix ratio

Name	Cement	Fine aggregate	Coarse aggregate	Water
Component	420	1469	2728	185

2.3 Preparation of test sample

By using pressure tester (TYE - 2000) to test the specimen cube static compressive strength of 28 days, the magnetite and ordinary concrete strength are the same which code is C50, impact test were conducted eight groups of 40 times, which divided into four conditions and its load pressure is 0.3 MPa, 0.4 MPa, 0.6 MPa, 0.9 MPa respectively, the test got magnetite concrete and ordinary concrete in the stress-strain curve under different working conditions. This paper use the wave form shaping technology, choosing 2 mm thickness corrugated plastic materials, whose diameter is 20 mm, 25 mm, 30 mm, 35 mm respectively, rounding rubber pad, the wave shaper measured before and after the incident bar, typical transmission rod gauge pulse waveform signal recorded respectively as shown in figure 2 and 3, Adopting three-wave method[8] to process the signal, the typical curve between the strain rate and time was obtained, which is shown in figure 4.

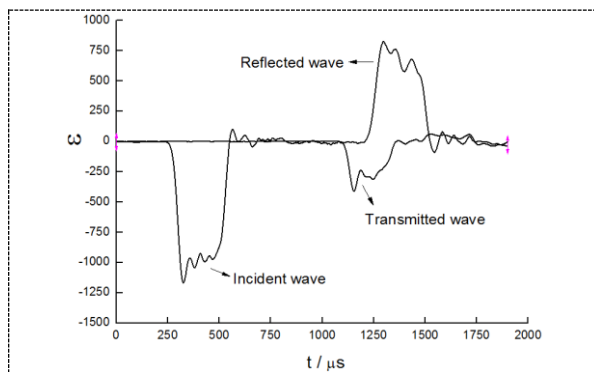


Figure 2. Unshaped pulse waveform

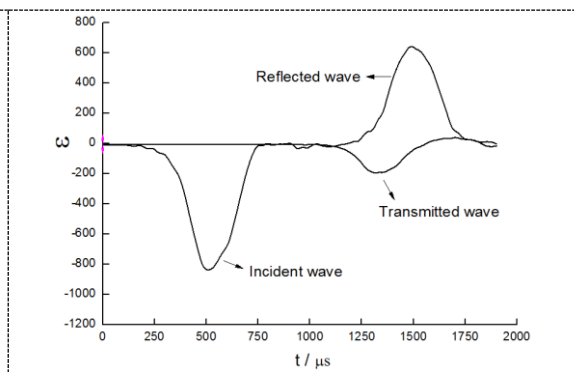


Figure 3. Shaped pulse waveform

3. Analysis of test results

3.1 Effectiveness analysis of the test

The SHPB test technology is applied to concrete quasi-brittle materials[9], which is based on the one-dimensional stress wave elasticity theory and assumed to be uniform distribution of the specimen stress. The validity and reliability of the test results should ensure that the stress is evenly distributed and the approximate constant strain rate loading is maintained as far as possible before the specimen reaches the peak stress[10]. For the SHPB impact compression test, when the specimen is loaded to failure, the stress on its front and rear ends is inconsistent, and the stress is not uniform. The stress balance in the sample needs a certain number of times for the stress wave to travel back and forth in the sample, which Ravichandran G et al. [11] believe that the stress wave can travel back and forth for two times to achieve the approximate stress uniformity. In this paper, the rubber waveform shaper is effective obviously, after joining dresser, the rise of input pulse wave along the extension, the stress wave propagation time, specimen to uniform stress time is enough, from the figure 2, 3, it can be seen that no truer, when the incident pulse rising along the rise is 77 us, only after joining dresser, present half sinusoidal pulse, when the incident pulse rising along the rise which increase 191 up to 319 us, when rising along the rise is not in front of the dresser 2 to 4 times, when rising along the rise of the incident pulse increased from 25% to 42% - 53%, It can be approximately considered that the specimen reaches the stress uniformity state before failure. As we can know in the figure 4, the curve of strain rate-time shows that as the bullet loading velocity increases, the approximate constant strain rate effect time shorten, followed by 154 us, 129 us, 103 us, 56us before the specimen destruction, and constant strain rate effect time of loading process between 16% to 52%, the average time rate is 34%, which can approximate consider that specimen keep approximate constant strain rate in the process of loading. In conclusion, owing to meeting the effective conditions of conventional SHPB impact compression test, the results of this test are reliable.

3.2 Consistency verification of test results

This article selects five magnetite concrete samples used to verify the test result consistency, each load to ensure the same 0.6 MPa loading pressure and length of bullets, the bullet position is consistent, and the circular rubber cushion thickness and, diameter is 2 mm, 30 mm respectively, which are placed in the middle of the incident bar ends, ensure the surrounding air, noise and humidity are the same. The test results are shown in table 2.

As can be seen from table 2, the five groups of experimental data are relatively similar, and the fluctuations of individual data are also within the allowable range of the experiment. It also shows that even in the same firing conditions, also won't get exactly the same shells hit rate, compared with other sample statistics found that the test data of the C1-3 have certain difference, the factors might be such a phenomenon: first a projectile is slightly long, between the projectile and the mortar tubes and the frictional resistance between the input and output shaft and bearing, loading pressure stability is not

enough, which leads to unable accurately control the impact speed of load; Second, the concrete material itself is very discrete. Due to the randomness of its sample composition distribution and the initial defect of structure, it is sensitive to impact loading and compression. Third, the machining accuracy of concrete samples and waveform shaper is not easy to control, and the paste material and position of waveform shaper will also cause the fluctuation of test data. To sum up, the test results in this paper can be considered to have a good consistency.

Table 2. Verification of consistency of experimental results

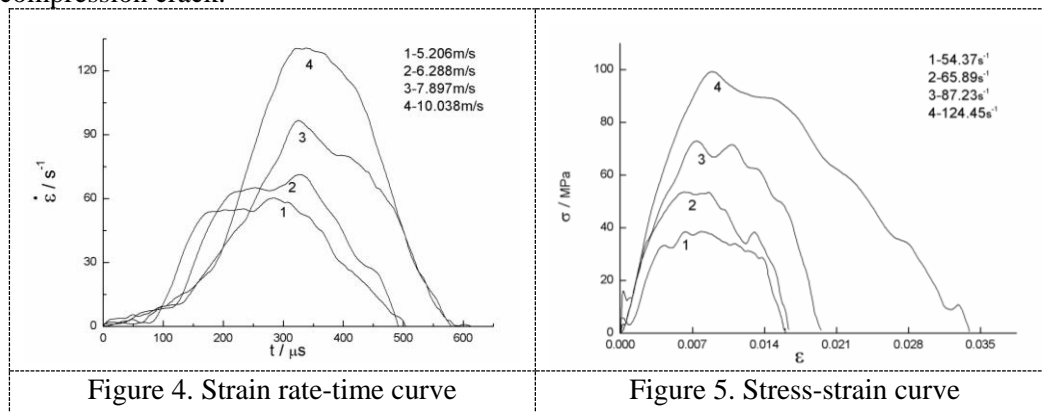
Specimen Number	Specimen Size		Bullet Velocity /($\text{m}\cdot\text{s}^{-1}$)	Incident wave		Reflected wave		Transmission wave	
	diameter /mm	Thickness/mm		Amplitude / μe	Time/ μs	Amplitude / μe	Time/ μs	Amplitude / μe	Time/ μs
C1-1	100.01	49.72	7.897	720.9	590	324.8	606	307.6	579
C1-2	100.02	48.63	7.713	710.1	596	472.6	587	287.8	577
C1-3	100.01	48.31	7.787	660.7	617	371.9	630	275.6	609
C1-4	100.05	48.97	7.629	671.6	610	388.1	609	282.3	583
C1-5	100.11	49.30	7.683	682.3	599	392.4	592	291.1	581

3.3 Effect of strain rate on dynamic mechanical properties

3.3.1A Effect of strain rate on dynamic mechanical properties

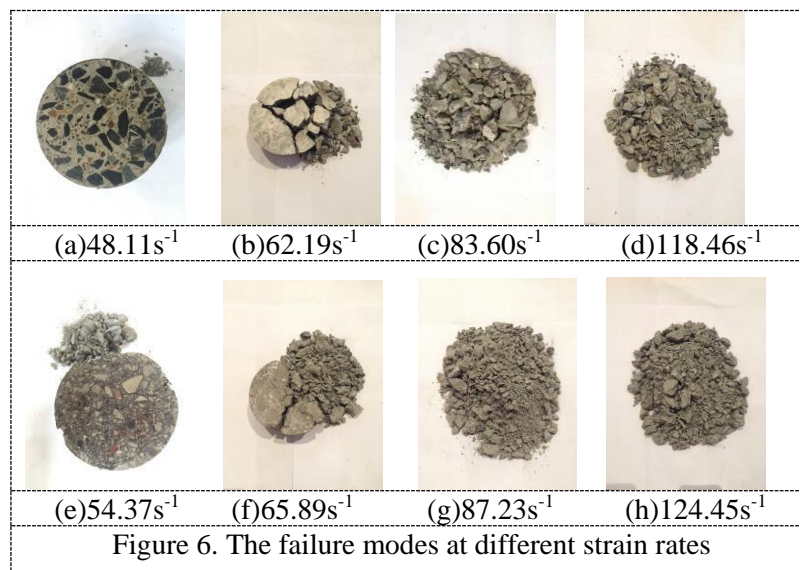
The stress-strain relationship curve of magnetite concrete specimens under different strain rates is shown in figure 5. Which shows that the stress-strain curve of the specimen have the following characteristics:

The relationship between stress-strain curves is nonlinear, and the rising section of the curve is the elastic deformation stage of the material. With the increase of strain rate, the tangent slope of each curve is approximately parallel, which indicate the dynamic elasticity of magnetite concrete modulus basically did not change, but increased slightly with the increase of strain rate. Curve as platform from peak stress reached the first stress concussion, entered the stage of elastic-plastic deformation of concrete, specimens under uniform load is already at this time, the micro cracks in concrete and microvoid hole began to be squeezed, irreversible plastic deformation specimen was going on, until the peak stress, the micro cracks in concrete and microvoid holes squeezed close-grained, specimen to reach the ultimate compressive strength, at the same time, the portion of the crack to expand rapidly, thereby brittle failure occurs, which shows the curve drops rapidly it is the concrete strain softening stage. The highest points of curve 3 and curve 4 in figure 5 appear in the first stress peak. The reason is that at high strain rate, the concrete cannot dissipate the huge energy which generated only by squeezing the initial crack, and a large number of new cracks and broken aggregate are needed to bear the energy consumption. Therefore, the compressive strength of the specimen is greatly increased and reaches its peak in the first peak valley. It can also be found that the increased impact velocity causes the platform segment to become shorter and the descending segment to occur in advance due to the faster compression crack.



3.3.2 Failure pattern analysis of specimen bisection.

It shows from Figure 6 that the failure modes of plain concrete and magnetite concrete. It can be seen from the figure that the failure modes of the specimen are relatively consistent. With the increase of air pressure, the speed of the bullet, it shows in figure 4 that the average strain rate of increase in test, in the operation condition of the loading rate is low ($\dot{\epsilon}_{mag} = 54.37s^{-1}, \dot{\epsilon}_{pla} = 48.11s^{-1}$), which presenting axial splitting cracks and appeared only Angle slightly damaged, under the condition of the increase of strain rate, the damage form specimens show the massive damage, and obviously increase the number of pieces, pieces of gradually decreases, and showed a strong strain rate correlation, these phenomena from the perspective of energy dissipation can be made a good explanation.



4. Conclusion

In this paper, SHPB test equipment is used to research the dynamic compression performance of magnetite concrete under multiple strain rate conditions, and the dynamic compression stress-strain curve is obtained. The main conclusions are as follows:

(1) using $\Phi 100$ mm SHPB compressibility mechanics experiment device was carried out on the sample test, rubber plastic shaping effect is obvious, the incident pulse rising along the rise before plastic 2 to 4 times, which basic meet the requirements of uniform stress condition, it realized that the constant strain rate loading, the experimental results have good consistency to ensure the test reliable and effective.

(2) the magnetite by the rising period of concrete stress strain curve, platform and decline of the nonlinear curve, to clear the rate sensitivity of materials, with the increase of strain rate, rising curve segment steepening lengthen, platform period shorter, the decline occurred ahead of time, the dynamic compressive strength of concrete has been significantly improved, the brittle failure more obvious with the increase of strain rate.

(3) with the increase of strain rate, magnetite concrete transits from splitting damage to block failure, and the number of blocks obviously increases, the fragmentation degree gradually decreases, and the strain rate continues to increase, finally causing the specimen crushing failure.

Acknowledgments

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References

- [1] Sun B, Jiao Ch J. (2017) Research status and development trend of radiation shielding concrete. In: Concrete, 12: 143-146. (in Chinese)
- [2] Wu Ch M, Ding D X, et al. (2009) Performance test on shielding concrete. In: Nuclear Power Engineering, 30: 141-144.(in Chinese)
- [3] Wu Ch M, Ding D X, Zhang H C. (2007) Methods for the design of shielding concrete mix ratio. In: Nuclear Power Engineering, 28: 124-127. (in Chinese)
- [4] Kolsky H. (1949) An investigation of the mechanical properties of materials at very high rates of loading. In: Proc Phys Soc London, 62: 676-700.
- [5] Tian L,Zhu C, et al. (2013) Dynamic Response and failure modes of RC columns under impact. In: Engineering Mechanics, 30: 150-155. (in Chinese)
- [6] Yan S, Liu L, Qi B X, et al. (2011) Dynamic response and failure mode analysis of concrete infilled rectangular steel tube columns under blasting loading. In: Journal of Disaster Prevention and Mitigation Engineering, 31: 477-482. (in Chinese)
- [7] Shi Y ch, Li Zh X. (2010) State-of-the-art in damage and collapse analysis of RC structures under blast loading. In: China Civil Engineering Journal, 43: 83-92. (in Chinese)
- [8] Song L, Hu S S. (2005) Two-wave and three-wave method in SHPB data processing. In: Explosion and Shock Waves, 25: 368-373. (in Chinese)
- [9] Fang Q, Hong J, et al. (2014) Issues of SHPB test on concrete-like material. In: Engineering Mechanics. 31: 1-14+26. (in Chinese)
- [10] Li W M,Xu J Y, et al. (2008) Study on 100-mm-Diameter SHPB techniques of dynamic stress equilibrium and nearly constant strain rate loading. In: Journal of Vibration and Shock. 27: 129-132. (in Chinese)
- [11] Ravichandran G, Subhash G. (1994) Critical appraisal of limiting strain rates for compression testing ceramics in a split Hopkinson pressure bar. In: JAm Ceram Soc, 77: 263-267.