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Study on Mechanical Properties of Barite Concrete under Impact Load

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Abstract. In order to research the mechanical properties of Barite concrete under impact load, a group of concrete compression tests was carried out under the impact load by using the drop test machine. A high-speed camera was used to record the failure process of the specimen during the impact process. The test results show that:with the increase of drop height, the loading rate, the peak load, the strain under peak load, the strain rate and the dynamic increase factor (DIF) all increase gradually. The ultimate tensile strain is close to each other, and the time of impact force decreases significantly, showing significant strain rate effect.

1. Introduction

With the development of nuclear technology and the implementation of the long-term development plan of national nuclear power, the research and application of anti radiation concrete have been widely concerned.Barite concrete is a newly emerging special material in recent years and belongs to one kind of radiation-proof concrete. It has the functions of shielding some harmful rays such as α, β, X and neutrons produced by natural radiation and artificial radiation [1], Therefore often used in national defense, nuclear power plants and other projects requiring radiation protection materials. Because of the wide distribution and low price of barite, the application of barite in special engineering is becoming more and more extensive. The research on the damage and mechanical properties of Barite Concrete is beneficial to its further application and popularization.

In recent years, the frequent international terrorist attacks and earthquakes, tsunamis, debris flows and other natural disasters have posed a great threat to society and people's lives and property. The incident of the ship's impact on the pier that endangering the safety of bridges are also frequently reported.

Concrete is the most important and the most widely used structural material today. The possibility of facing non-design loads such as impact, explosion and impact is getting more and more attention. It is necessary to carry out the research on the mechanical properties[2-4]and the constitutive properties of concrete under impact load.

Study on dynamic mechanical properties of concrete as early as began in early 20th Century, Since Abrams DA first made a compressive test under dynamic and static loading in 1917, and found the rate correlation between the compressive strength of concrete, a large number of scholars began to carry out dynamic test on various mechanical properties of concrete materials. Yan Dongming et al.[5] studied the dynamic uniaxial tensile properties of two kinds of strength concrete in the strain rate 10-5/ s ~ 10-0.3/s by MTS testing machine. Xiao Shiyun, Zhang Jian et al.[6] investigated the dynamic uniaxial direct compression properties of ordinary concrete compression specimens in the strain rate range of 10-5/s ~10-2/s through a large static and dynamic electro-hydraulic servo test. Hu Shisheng et al. used split Hopkinson pressure bar (SHPB) test technique to study the mechanical properties of concrete in the strain rate range of 101/s~102/s. Ross et al.[7] used the SHPB rod carried out experimental research and numerical simulation on tension-compression performance of concrete members, the strain rate up to the range $1s^{-1}$~$300s^{-1}$ was obtained and studied the mechanical properties of concrete in this range. However, since the dynamic loading test is much more complicated than the static loading test, the existing test results can not fully describe the dynamic performance of the concrete, and the test device used, the test method is different and subject to the specifications and age of the specimen preparation and other factors, the results obtained by different testers are very different. In this context, a series of prismatic barite concrete specimens using a drop-weight impact test machine for $1s^{-1}$～$4s^{-1}$ strain rate range of impact test, measured the impact of different impact height and strain of the time-history curve, recorded the destruction of the specimen morphology and high-speed photography information.

2. Test contents and methods

2.1 Preparation of Specimen

According to GB/T 50081-2002"Standard for Test Method of Mechanical Properties of Ordinary Concrete", the specimen is a concrete prism with a length of 100 mm and a height of 300 mm (as shown in FIG. 1)[8]. Using ordinary 425 Portland cement, the coarse aggregate is continuous graded barite with a maximum particle size of 20mm. The fine aggregate is barite sand, the fineness modulus of 2.59, belonging to the medium sand. Water is a common tap water. The match ratio is shown in Table 1. After 28 days of standard curing, the compressive strength of the cube is 36.2MPa, and the axial compression strength of prism is 22.8 MPa.

Table1. Mix Ratio of Barite Concrete

Water/binder ratio	Mix ratio（kg/m³）			
	Water	Cement	Sand	Rock
0.55	185	336	899	1745

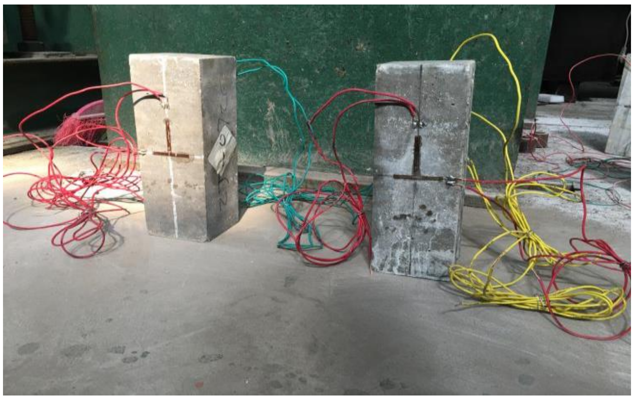

Figure1. The barite concrete test block has been attached to the strain gauge.

2.2 Test Device

This test is completed on the drop hammer impact testing machine (shown in Figure2.) in the structural laboratory of the Civil Engineering College of University of South China. The basic technical indexes of the test machine:the maximum drop hammer impact height is 5m, and the drop weight is 70kg to 200kg. In this test, the aluminum hammer was used and the quality of the hammer was 170kg. Test by lifting the hammer to a certain height, free fall has a dynamic impact on the concrete specimen. By changing the drop height of the hammer, the dynamic compression tests under different strain rates were completed.

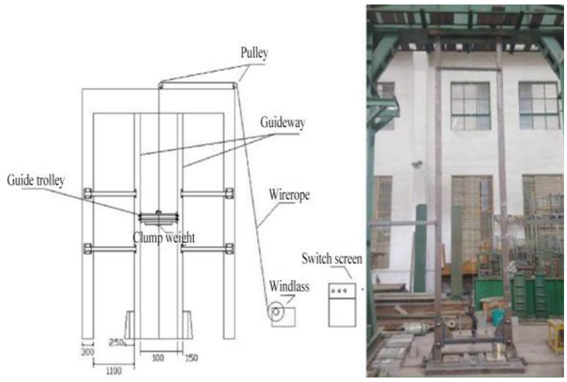

Figure2. Site figure of drop hammer device in University of South China.

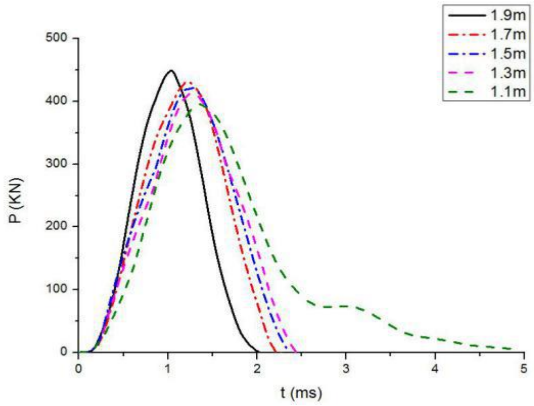

Figure 3. The Impact force time curve under different impact height.

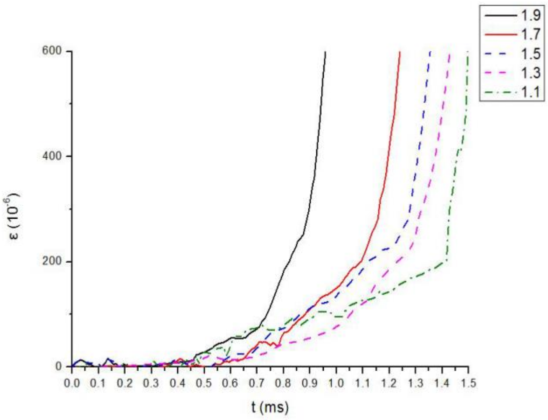

Figure 4. The history curve of tensile strain at at different impact height.

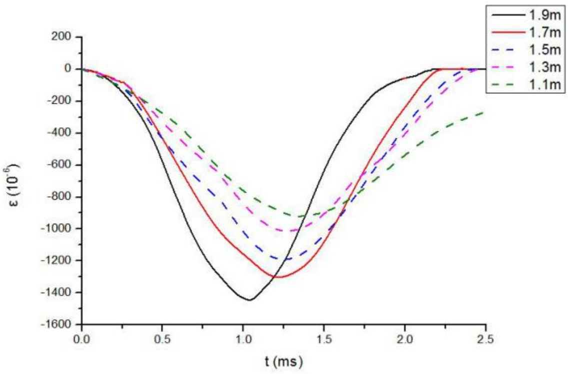

Figure 5. The history curve of compressive strain different impact height.

The mean of all the results in this test are summarized in Table 2. The peak value of the longitudinal strain is the value of the recording signal of each strain piece corresponding to the peak moment of the impact force. The ultimate tensile strain is the strain value corresponding to the starting time of the specimen in the history curve of tensile strain. Through the numerical derivation of the tension strain time history curve, the abrupt point of the tensile strain is taken as the cracking time of the specimen.

As can be seen from table 2 and figure 3, with the increase of the impact height, the peak of the impact force is increasing and the increase of the amplitude is about 2%~5%.The loading and unloading slope of the force time curve becomes steeper, the load rate becomes larger and the impact time is shorter.Among them, the three working conditions of 1.3~1.7m are relatively close, the increase of impact peak is only about 2%, and the loading and unloading slope in time history curve and impact force are similar.

The data in Table 2 and Figure 4 show that barite concrete specimens are subjected to compressive deformation under impact loading. When the compressive strength is reached, the tensile area produces cracks, and it becomes a sharp increase in tensile strain value.Under the effect of different impact height, the ultimate tensile strain is similar, and all of them are around 200~270 micro strain.

After analyzing the results of the test, Bischoff[9] found that the peak pressure strain increased with the increase of strain rate, and the increase range was in the range of 0~40%. Table 2, 3 and Figure 4 show that the peak pressure strain of the specimen increases with the increase of the impact height. This phenomenon is usually considered to be related to the strain rate effect.Among them, the strain rate in the table refers to the shear strain rate before the cracking time of the specimen. On average, in the range of $1.02S^{-1}$ to $3.02S^{-1}$ strain rate, the peak pressure strain increases by 10%~20%.

Figure 6 gives the relationship between dynamic increase factor (DIF) and strain rate of barite concrete material, and compares it with the previous scholar's [10-11]study. As can be seen from the diagram, with the increase of the strain rate, the dynamic increase factor(DIF) also shows an increasing trend.

Figure 7 shows the failure mode of the specimen under 5 kinds of impact heights. From the chart, we can see that under the condition of 1.1m, the failure mode is mainly caused by tiny cracks in the middle part of the test piece, partial cracks are produced, and a small amount of debris is found around them.Under the working condition of 1.3m, the cracks in the middle part of the specimen increased significantly compared with the 1.1m working conditions, and the concrete exfoliation at some edges and corners. Under the working condition of 1.5m, in the middle of the specimen, the vertical penetration cracks are produced, and some of the specimens are split. Under the working conditions of 1.7m and 1.9m, the failure modes are all radial splitting, especially under the 1.9m condition, some of the specimens are destroyed and a large amount of debris is produced. According to figure 3, we can see that there is a certain relationship between the impact time of different working conditions and the damaged form of the specimen. At the height of 1.1m, small cracks appear only in the surface and central pulling area of the test block, and the impact time is significantly higher than that of other working conditions. The damage morphology of 1.3m~1.7m is similar, and the impact time is almost the same. At the height of 1.9m, the damage is the most serious and the impact time is the smallest because the specimen is not only split and partially destroyed.

The high speed camera photographed the whole process of the block at a rate of 10000 frames per second. Figure 8 is a high-speed photography screenshot of the specimen subjected to pressure damage under the 1.9m condition. As we can see from the diagram, the hammer begins to contact the specimen at 0ms. At 0.48ms, the middle and upper parts of the test parts produce oblique shear fracture and extend development successively. At1.1ms, a large number of vertical penetration cracks are generated and broadened. In 2.02ms, some of the test blocks have been fragmental and shedding, the main body part of the specimen has become a mobile system and the rigid body movement occurs, the width of the crack is increasing and the bearing capacity of the specimen has been completely lost.

Table2. Dynamic test results of different impact height of 170kg drop hammer

NO.	Quality（kg）	Height（m）	Peak Force（kn）	Moment of Peak Force（ms）	Impact Time（ms）	Ultimate Tensile ($\varepsilon max/10^{-6}$)	Longitudinal Peak Strain ($\varepsilon max/10^{-6}$)
ZJ1711	170	1.1	391.8	1.47	5.18	202.2	-926.8
ZJ1713	170	1.3	412.2	1.28	2.47	226.3	-1012.2
ZJ1715	170	1.5	424.9	1.25	2.35	270.4	-1189.7
ZJ1717	170	1.7	433.6	1.18	2.25	212.9	-1299.9
ZJ1719	170	1.9	456.2	1.02	2.07	252.6	-1437.4

Table3. Dynamic Increase Factor（DIF）calculation table

Impact Condition	Static cracking load（kn）	Dynamic cracking load（kn）	DIF	strain rates (s^{-1})
ZJ1711	259.7	360.3	1.39	1.02
ZJ1713	259.7	383.5	1.48	1.15

ZJ1715	259.7	391.2	1.51	1.38
ZJ1717	259.7	410.3	1.56	2.18
ZJ1719	259.7	418.1	1.61	3.02

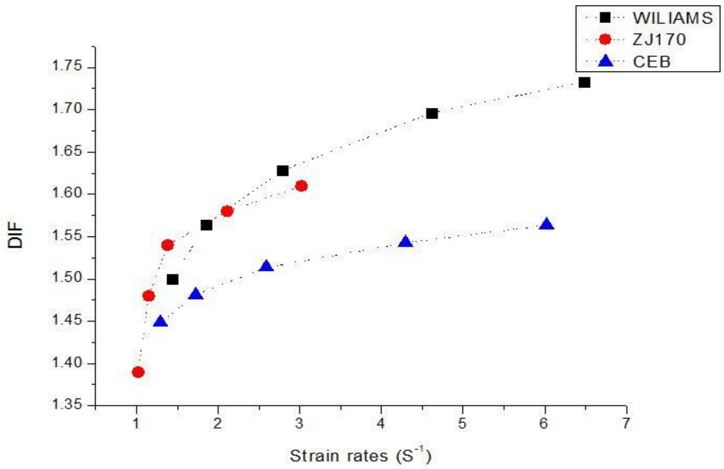

Figure6. Curves of relationship between DIF and strain rate in this test.

Figure7. Failure mode of specimen under different working conditions.

3. Conclusion

The following conclusions can be obtained through the analysis of the mechanical properties and deformation characteristics of barite concrete specimens under drop hammer impact test: when the drop weight is constant, the impact force peak and loading rate increase with the increase of impact height, and the impact time becomes shorter and the strain rate increases; Under the impact load, the similar ultimate tensile strain of Barite under different working conditions is not affected by the impact height, while the longitudinal peak strain increases with the increase of impact height; The relationship between the dynamic increase factor (DIF) and strain rate obtained from this experiment is between [10and11]. It shows that the dynamic enhancement coefficient (DIF) of Barite Concrete is basically the same with the trend of strain rate growth.

Acknowledgments

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