A comparative study on dynamic mechanical performance of concrete and rock

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ABSTRACT. Recently, engineering blasting is widely applied in projects such as rock mineral mining, construction of underground cavities and field-leveling excavation. Dynamic mechanical performance of rocks has been gradually attached importance both in China and abroad. Concrete and rock are two kinds of the most frequently used engineering materials and also frequently used as experimental objects currently. To compare dynamic mechanical performance of these two materials, this study performed dynamic compression test with five different strain rates on concrete and rock using Split Hopkinson Pressure Bar (SHPB) to obtain basic dynamic mechanical parameters of them and then summarized the relationship of dynamic compressive strength, peak strain and strain rate of two materials. Moreover, specific energy absorption is introduced to confirm dynamic damage mechanisms of concrete and rock materials. This work can not only help to improve working efficiency to the largest extent but also ensure the smooth development of engineering, providing rich theoretical guidance for development of related engineering in the future.

KEYWORDS. Concrete; Rock; Dynamic mechanical performance; SHPB.

INTRODUCTION

Studies focusing on dynamic mechanical performance of rock materials, a relatively basic branch in rock mechanics, originate from researches on safety protection of atomic energy plant and earthquake engineering [1]. As engineering construction frequently involves rock materials in the last few years, to be specific, national large-scale energy engineering including water and electricity and nuclear power project, transportation including national railway and highway, engineering including blasting excavation and fixed point blasting or facilities establishment including high-level building, bridge, airport pavement and dam all involves dynamic mechanical performance of rock materials under the impact of medium and high strain-load [2], more and more experts and scholars devote themselves to deep study of dynamic mechanical properties of rock materials. Compared to statics of rock materials, difficulties encountered by works on dynamics are tougher. In the perspective of mechanical analysis alone, knowledge theories of physics and mathematics are more complicated [3]. Consequently, research on mechanics of rock materials has still remained at immature stage, and what is worse, some related areas are just started.
Concrete and rock are two kinds of the most commonly seen materials among rock materials which are usually combined used in engineering practice, such as airport pavement engineering, ground foundation engineering and mine resource

exploitation. Thus to meet the demand of engineering more effectively, the key point lies on the comparative study of mechanical performance of concrete and rock [4]. But scholars tend to focus more on static characteristics of concrete and rock [5, 6] rather than dynamic mechanical performance of them. Furthermore, literatures about comparison of mechanical performance of them together are seldom reported though many scholars have carried out related researches. Through comparing mechanical performance of concrete and rock under impact load, this study further analyzed their damage mechanism, aiming to offer more theoretical reference for dynamic load carrying of practical structural engineering.

OVERVIEW OF MECHANICAL CHARACTERISTICS OF ROCK MATERIALS

Study of dynamic mechanical characteristics of rock materials mainly includes three aspects, i.e., dynamic input, analysis of dynamic mechanical characteristics of materials and dynamic respond analysis of structure of rocks [7]. Study of structural dynamics has acquired substantial breakthrough, because only one experiment is enough to effectively stimulate all influence factors to reflect actual situation of structure, benefiting from the innovation of experimental instruments and test technology, enhancement of dynamic theory and remarkable results of structural mechanical model experiment. Relatively speaking, analysis dynamic input and dynamic mechanical characteristics is weak, as related research is not deep enough and many basic issues are still being explored.

An important research direction exists in study of dynamic mechanical performance of rock materials, i.e., correlation rule of strain rate of dynamic performance of materials. A large amount of previous comparative analysis of dynamic and static experimental results of rock materials [8] suggest that, strain rate is closely correlated with performance of materials, and the correlation has recognized by most experts and scholars. However, issues concerning how strain rate impacts performance of materials and what is the rule have not been unified in academic field, and moreover, related research is still remained at impact of material strength, such as impact on dynamic fracture character and deformation characteristics and sensitivity of micro-structure dynamic characteristics of different materials to strain rate.

COMPARATIVE EXPERIMENT OF DYNAMIC MECHANICAL PERFORMANCE OF CONCRETE AND ROCK

Experimental materials

Concrete used is ordinary silicate concrete composing of water, ordinary Portland cement, coal ash, silica fume, macadam, sand and water reducing agent. Detailed proportion is shown in Tab. 1.

Water	Cement	Coal ash	Silica fume	Macadam	Sand	Water reducing agent
180	375	125	25	690	1030	5

Table 1: Proportion of different components of ordinary silicate concrete (kg/m^3).

Rock used is unweathered natural sandstone taken from Qinling Mountains with field sampling method. It is mainly composed of quartz and calcite and shows up white color. Detailed components are presented in Tab. 2.

Components	Quartz	Calcite	Plagioclase	Potassium feldspar	Montmorillonite	Chlorite	Illite	Dolomite
Content (%)	52	27	8	6	1	2	3	1

Table 2: Component of sandstone.

Experimental equipment and method

Split Hopkinson pressure bar (SHPB) (diameter 100 mm) made up of three parts, main equipment, energy system and test system is the main equipment for dynamic compression test [9]. Sample of concrete and rock is obtained through several professional procedures. First, samples are taken using ZS-100 upright core drilling machine, then cut by DQ-1 cutting machine. (The machine can be applied in fields like petroleum, geology, metallurgy, coal and exploration; diameter of blade: 450 mm or 500 mm; cutting scope: single blade (diameter 500 mm) can cut cylindrical rock core with a diameter of

25~180 mm as well as original rock with a size of 180 mm×180 mm×350 mm, while double blade (diameter 450 mm) can cut square (50 mm×50 mm) or rectangle (50 mm×120 mm); power of main motor: 2.2 kilowatt; power of longitudinal motor: 0.75 kilowatt) and finally polished by SHM-200 double-end face stone mill. After sampling, a cylinder (diameter 100 mm×50 mm, length-diameter ratio 1:2) is used for experiment combining with literatures related to dynamic compression test performed with SHPB. Five different levels of impact load are designed for two materials. Every impact load is corresponding to one strain rate and every experiment is repeated thrice under the same strain rate. The most reasonable group of data is selected for analysis after comparing experimental data in every group.

Experimental results

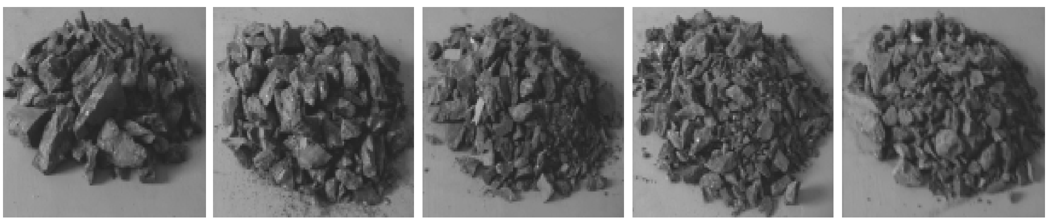
Tab. 3 and 4 are impact test results of concrete and sandstone obtained under five different strain rates respectively. Dynamic damage forms corresponding to two materials is shown in Fig. 1 and 2 respectively and they rank based on the strain ratio from low to high.

Number of samples	Diameter of reshaper (mm)	Blow speed (m/s)	Strain rate $\bar{\dot{\varepsilon}}$, s^{-1}	Dynamic compressive strength $f_{c,d}$ MPa	Peak strain ε_p ,10^{-3}	Specific energy absorption (KJ/m^3)	Damage form of sample
A1	20	5.29	40.95	76.60	6.30	555.89	Blocky fragmentation
B1	22	6.40	60.79	84.08	6.45	827.55	Blocky fragmentation
C1	25	7.53	86.42	95.82	7.14	1174.38	Severe fragmentation
D1	27	8.29	95.01	107.57	7.21	1344.52	Severe fragmentation
E1	30	9.99	125.70	130.75	8.60	1558.67	Severe fragmentation

Table 3: SHPB test results of concrete.

Number of samples	Diameter of reshaper (mm)	Blow speed (m/s)	Strain rate $\bar{\dot{\varepsilon}}$, s^{-1}	Dynamic compressive strength $f_{c,d}$ MPa	Peak strain ε_p , 10^{-3}	Specific energy absorption (KJ/m^3)	damage form of sample
A2	30	11.0	93.1	173.5	18.32	1059.87	Large block
B2	33	12.58	123.5	179.4	19.02	2490.25	Medium block
C2	35	13.49	135.2	203.7	19.48	2830.33	Small block
D2	40	14.39	154.9	218.9	20.37	3050.47	Blocky fragmentation
E2	45	15.53	166.0	226.8	21.70	3320.12	Severe fragmentation

Table 4: SHPB experiment results of sandstone.



(a1) (b1) (c1) (d1) (e1)

Figure 1: Damage form of concrete samples.

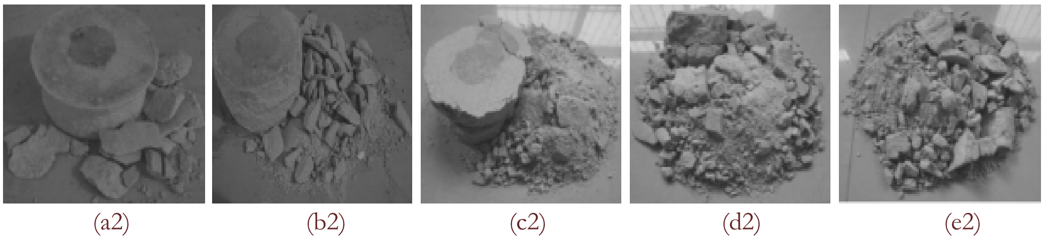


Figure 2: Damage form of sandstone samples

Result analysis

It can be seen from Fig. 3 described based on Tab. 3 and 4 that, dynamic mechanical performance of two materials is closely correlated to strain rate. To be specific, dynamic compressive strength of two materials increases linearly with strain rate; dynamic compressive strength of concrete is lower than sandstone. Through linear regression, we can conclude a formula of the relationship of dynamic compressive strength and strain rate of two materials (C stands for concrete, S stands for sandstone and R^2 stands for correlation coefficient).

$$\begin{cases} f_{c,d}(C) = 46.40 + 0.64\bar{\dot{\varepsilon}} & R^2 = 0.95067 \\ f_{c,d}(S) = 94.56 + 0.79\bar{\dot{\varepsilon}} & R^2 = 0.87914 \end{cases} \tag{1}$$

Comparing the formula, we can conclude that, dynamic compressive strength of rock varies more obvious as strain rate changes.

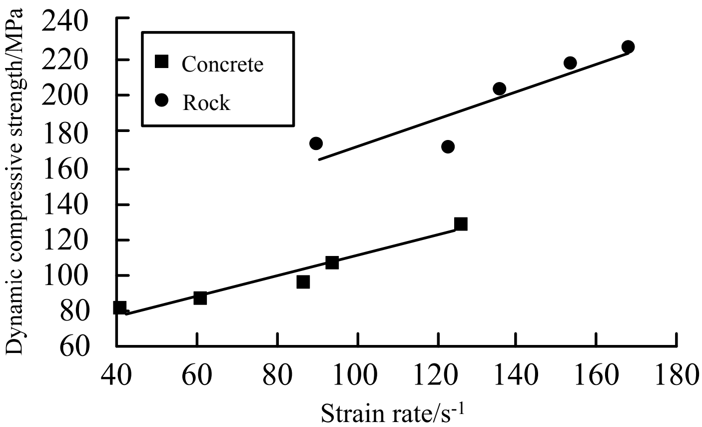


Figure 3: Correlation between dynamic compressive strength and strain rate.

Fig. 4 shows the correlation between peak strain and strain rate of concrete and sandstone under the effect of impact load. It can be observed from the figure that, peak strain of two materials tends to be higher as strain rate increases and moreover, this corresponding relationship is quadratic. Formula regarding to the correlation between strain rate and peak strain of two materials can be obtained after linear regression, as follows (C stands for concrete, S stands for sandstone and R^2 stands for correlation coefficient).

$$\begin{cases} \varepsilon_p(C) = 6.60 - 0.019\bar{\dot{\varepsilon}} + 2.76\times10^{-4}\bar{\dot{\varepsilon}}^2 & R^2 = 0.99756 \\ \varepsilon_p(S) = 23.37 - 0.108\bar{\dot{\varepsilon}} + 5.87\times10^{-4}\bar{\dot{\varepsilon}}^2 & R^2 = 0.96554 \end{cases} \tag{2}$$

It can be known that, under the effect of impact load, both concrete and rock changes their forms, and the variation degree is positively correlated to strain rate, i.e., peak value increases with the increase of strain rate.

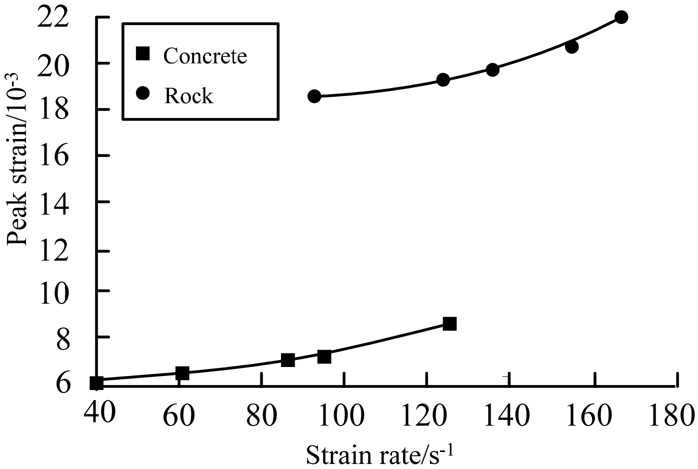


Figure 4: Correlation between peak strain and strain rate.

ANALYSIS OF DYNAMIC DAMAGE MECHANISM

It has been found from Fig. 1 and 2 that, two materials obviously change their forms under the effect of impact load, and concrete is broken to even blocks no matter strain rate is high or low, while sandstone changes into different forms under impact load with different strain rate, relatively large block under low strain rate and relatively small and powdered block under high strain rate [10]. To present dynamic damage mechanism of two materials more clearly, we use specific energy absorption to describe toughness of materials. In the view of physics, it means the stress wave energy absorbed by sample material in unit volume. Fig. 5 demonstrates the correlation between specific energy absorption and strain rate of concrete and sandstone.

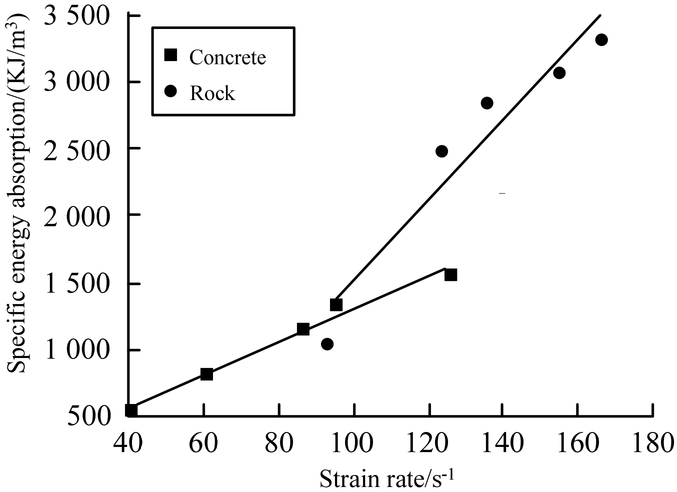


Figure 5: Correlation between specific energy absorption and strain rate.

The figure above showed that specific energy absorption increases linearly with the increase of strain rate and the fitted formula is as follows:

$$\begin{cases} SEA(C) = 94.28 + 12.20\bar{\dot{\varepsilon}} & R^2 = 0.96849 \\ SEA(S) = -1473.45 + 29.91\bar{\dot{\varepsilon}} & R^2 = 0.88962 \end{cases} \tag{3}$$

Energy absorption ability of sandstone is more significant than concrete. When strain rate becomes higher, specific energy absorption of sandstone varies more obviously. Taking dynamic damage forms of two materials into account, we can summarize that, dynamic forms of materials is correlated to specific energy absorption value. To be specific, dynamic damage materials varies more significant, leading to smaller pieces, when specific absorption value becomes higher. Hence we confirm that, the dynamic damage mechanism of concrete and rock materials is that, two materials are in a dynamic instability state when carrying impact load; large energy absorbed by unit volume of material will result in severe damage. As energy absorption ability is determined by properties and strain rate of material, sandstone has a stronger energy absorption ability than concrete.

CONCLUSIONS

Three points can be summarized from the test results. Firstly, dynamic mechanical performance of concrete and sandstone is in a close correlation with strain rate and dynamic compressive strength and peak strain is positively correlated to strain rate, i.e., the former increase with the increase of the latter. Secondly, dynamic compressive strength of two materials is approximately in linear correlation with strain rate, and peak strain and strain rate has a second order correlation, concrete is more obvious than rock. The last point is that, dynamic damage mechanism of two materials is actually a dynamic instability process produced after absorbed impact load and damage becomes severer as energy increases; the ability of energy absorption is usually determined by characteristics and strain rate of materials. We conclude from the above three points that, concrete is more suitable to be used as building material than rock materials. However, selection of material is affected by multiple factors in the process of engineering construction; therefore, construction material should be chosen according to local conditions.

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