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Test and analysis of blast wave in mortar test block

Fei Liu[a,*], Ziru Guo[b], Huayong Lv[a], Zhanbo Cheng[c]

[a] College of Resources & Safety Engineering, China University of Mining & Technology, Beijing, China
[b] School of Chemical Engineering, Anhui University of Science and Technology, Huainan, China
[c] School of Engineering, University of Warwick, Coventry, United Kingdom

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ABSTRACT

A strain gauge system poured in a mortar test block was used to study the propagation of blast waves generated by explosive charges. The shock waves were recorded with a super dynamic strain test system using strain gauges. The measured wave-forms were analyzed. The results show that the propagation of the blast wave in the experiment is mainly manifested by the joint action of the shock wave and the reflected tensile wave, and the action time is about 6 μs and 15 μs, respectively. At the same measuring point, the peak value of strain wave reaches 10^4 με, and the peak strain rate reaches 10^6 s^{-1}. The attenuation of radial strain wave is faster than that of tangential strain wave, while the attenuation of gas is not obvious, and the compression strain on rock is greater than the tensile strain. Within the scope of the study, the loading of the blast wave is greater than that of the unloading. In the radial direction, with the increase of distance, the loading and unloading of shock wave on rock all showed a declining trend. The loading effect of the reflected tensile wave did not decay, and the unloading effect attenuated weakly. In the tangential direction, the loading effect of the shock wave on the rock first decreases and then increases, and the unloading damage of rock increases slightly. The loading effect of the reflected tensile wave on the rock first decreases and then increases, while the unloading damage nearly unchanged.

1. Introduction

Blasting plays a crucial role in various human activities such as construction (bridges, tunnels), extraction of minerals (mines) and in urban development and dismantling. The understanding of how to use the energy efficiently of the explosives to break rocks or concrete is of particular importance for blasting engineering. The research on the propagation of explosive waves in rocks and concrete has always been a complex and difficult task in blasting engineering. Some of the difficulties arise due to the speed of the phenomena (the explosion) making the measurement of the involved variables a very complicate task. Among all physical phenomena generated due to the detonation of the explosives, it is accepted that the strain rate, the high temperature and gas pressure have an important influence in the fragmentation generated by the blast. The mechanism of explosion is extremely complex, and it has been estimated pressures up to 10 GPa and above and peak strain rates as high as 10^6 s^{-1} in the rock closed to the walls of the borehole.[1–3] On the other hand, the rising edge of the explosive wave only has a fraction of a microsecond. Such extreme conditions and fast development of the phenomena demands specialized testing equipment and technologies, and provide a challenge for new and improved means to measure the effect of the explosives.

Currently, the measurement of the propagation of blast waves in rocks can be grouped in; electric, optical, high-speed photography and others.[4,5] Among them, the electrical measurement is used more often. In the electrical measurement, the sensors commonly used are the manganese-copper sensor, the quartz piezoelectric sensor, the resistance sensor and the PVDF sensor. The resistance sensor is most of the times the preferable choice because of its repeatability, low costs, and the capability of measuring the tensile and compressive strain simultaneously.[6]

Based on the review of the available technology and the results from previous experiments, in this research the super dynamic strain test system using strain gauges[7,8] was adopted to measure the shock waves in the mortar test blocks. Strain gauges were attached to a strain brick in the radial and tangential directions along the propagation direction of the blast wave, and then the strain brick was installed in the mortar test block.[9,10] The blasting waves were measured at distances of 50 mm, 100 mm and 150 mm away from the explosive source. The collected waveforms were then analyzed and the results are included next.

* Corresponding author.
E-mail address: feiliu182@163.com (F. Liu).

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2. Mortar block preparation and description of the sensor system

2.1. Mortar block preparation

The mortar blocks were prepared using ordinary Portland cement (PC32.5), and fine yellow sand passing the 24-mesh sieve. The ratio of cement, sand, and water was 1:2:0.5 and the density of the mortar block is 2100 kg m^{-3}.

The mortar blocks were prepared in a cylindrical mold of steel, composed by two semi-cylindrical steel shells with a diameter of 400 mm and a height of 450 mm. The strain bricks were removed after 48 h of pouring and curing the mortar. Each strain brick size used was 180 mm × 20 mm × 10 mm. Then the radial and tangential strain gauges were installed on the surface of the strain bricks along the propagation direction of the blast wave. To protect the strain bricks from water, one anti-corrosion insulation treatment was applied.

The installation of the strain bricks was done simultaneously with the process of pouring the mortar in the mold. First, the mortar was poured to a height of 150 mm in the steel model, and it was vibrated to densify the mortar with a vibrating rod. Then, the strain bricks were inserted 80 mm deep into the compacted mortar and the next layer of mortar was added slowly and vibrating the mixture up to the designed height (450 mm) when the first layer has a certain intensity. It can maintain the consistency of the mortar, reducing the impact of wave propagation due to the stratification of the interface. To create the borehole for the explosives, a 7 mm diameter steel rod was located with a depth of 200 mm from the upper face of the sample in the center. Three sets of the mortar sample were poured and were cured to 28 days. Figs. 1 and 2 show the schematic and the picture of the prepared mortar blocks including the location of the strain bricks.

At the same time of the mortar sample preparation three sets of cubic blocks of 150 mm × 150 mm × 150 mm were poured with the same mixture. The cubic samples were used to measure the physical and the mechanical parameters of the mortar. P-wave velocities of the mortar were measured using a CTS-25 non-metallic ultrasonic detector. Compressive strength and elastic modulus were measured using the CSS-YAW3000 electro-hydraulic servo pressure frame and the DH3816 static strain test system. The Poisson's ratio μ and the shear wave velocity C_s were calculated using the elastic relationships in Eqs. (1) and (2).[7]

$$C_p = \sqrt{\frac{E(1-\mu)}{\rho(1+\mu)(1-2\mu)}} \tag{1}$$

Fig. 2. Mortar test block pouring mold.

$$C_s = \sqrt{\frac{E}{2\rho(1+\mu)}} \tag{2}$$

The compressive stress and the axial strain were calculated using Eqs. (3) and (4) from the uniaxial compression test:

$$\sigma = \frac{F}{A} = \frac{F}{l^2} \tag{3}$$

$$\varepsilon = \frac{\Delta l}{l} \tag{4}$$

In Eqs. (3) and (4), where σ is the compressive strength in MPa, F is the specimen failure load in N, A is the area of the specimen in m^2, and l is the side length of the specimen in m. Fig. 3 shows the curve stress strain for one of the tests.

The measured data from the three mortar cubic blocks were averaged. The compressive strength Fc is 40.05 MPa and the elastic modulus E is 29.30 GPa. Poisson's ratio μ is 0.28. The longitudinal wave velocity C_p is 4231 ms^{-1} and the transverse wave velocity C_s is 2339 ms^{-1}.

2.2. Sensor system

The sensor system consists of strain gauges, a TST3406 dynamic data logger, a SDY2107A dynamic strain gauge (frequency response up to 2.5 MHz), and a desktop computer.[11] To avoid noise in the collected signal, a magnetic shielding circuit was implemented. The strain gauge used in the test was a 120 Ω foil epoxy phenolic strain gauge with a sensitive grid size of 2.0 mm × 4.0 mm, a substrate size of 3.5 mm × 6.5 mm and a sensitivity coefficient of 2.08 ± 0.01. The strain gauges

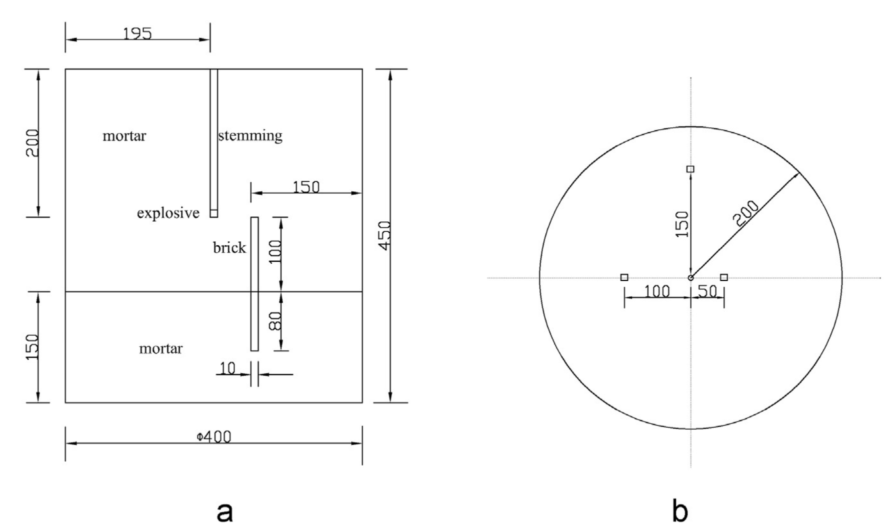

Fig. 1. Schematic diagram of blast hole and strain brick layout (mm). (a) Sectional view. (b) Top view.