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Research on the application of transparent rock blasting test in "engineering blasting" teaching

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Abstract: *In order to help students deeply understand the process of rock blasting failure and crack propagation mechanism, it is proposed to introduce transparent rock blasting model test into the teaching of engineering blasting course. In this paper, a teaching and experimental platform based on transparent rock-like blasting is designed, and the ultra-high speed camera and digital speckle technology are combined to visualize the ultra-dynamic failure process of rock blasting. Compared with the traditional rock blasting test, the transparent rock blasting test can directly show the blasting process of centralized charge and reveal the crack propagation law in the near, middle and far areas of blasting, which is helpful to improve the teaching effect of rock blasting and students' scientific research and innovation ability.*
Key words: *Transparent rock; Rock blasting; Crack propagation mechanism; Experimental teaching*

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I. Introduction

Engineering blasting technology is a kind of technology that makes use of the energy produced by the explosion of industrial explosives to deform, destroy and throw the exploded medium, and then achieve the expected engineering purpose. At present, China has become a leading geotechnical engineering country, and marching to the deep earth is a new journey for China to enter the powerful geotechnical engineering country [1]. As an efficient means of rock breaking in deep ground, blasting is widely used in deep geotechnical engineering [2]. In many colleges and universities, applied engineering majors such as bomb and explosion engineering, mining engineering and civil engineering have widely offered "engineering blasting" as a core professional course, which has trained a large number of professional and technical talents in blasting engineering for our country [3].

Traditional engineering blasting teaching mostly explains some formulas and pictures to students in class with the help of multimedia courseware, which cannot clearly and intuitively present the entire blasting process and detailed blasting details, and is far from meeting the requirements of expanding students' innovative thinking in science and technology [4]. On the other hand, the teaching process is boring and boring, it is difficult to mobilize students' learning enthusiasm, and cannot achieve the expected teaching effect.

How to fully stimulate students' learning interest and enthusiasm in the teaching process, and enable students to deeply understand and firmly grasp the professional knowledge, and effectively achieve the teaching purpose and training objectives of the course is an urgent problem to be solved in the teaching of engineering blasting course. Engineering practice is an important link in the teaching process of engineering majors in universities. Model tests can deepen students' understanding of theoretical knowledge and improve their ability to solve problems.

Therefore, this paper proposes to apply the transparent rock blasting model test to the teaching of engineering blasting course. By using the characteristics of transparent rock visualization after explosion, the crack growth and failure law of the model after explosion are presented. The evolution process of rock super-dynamic strain field can be captured by combining ultra-high-speed photography and digital image speckle technology, and the instantaneous failure process of rock blasting can be digitally visualized. Then, the model test results are combined into the course teaching of the corresponding chapters, and the effect of its teaching application is analyzed, and the role of transparent rock blasting model test in the teaching of engineering blasting is clarified.

II. Test device

A self-developed model test device with plane stress loading system, data measurement system and high-speed photography system was used to simulate the in-situ stress constraint on deep rock mass[5]. The device mainly includes stress loading platform, oil pressure station, high-speed camera suspension, etc., as shown in Fig. 1.

Fig. 1 Device for plane stress loading on model specimen

The maximum size of model specimen applied to stress loading platform is 500×500×100(mm) (length×width×height). The rated power and extreme power of the oil pressure station used in the loading platform are 5MPa and 7MPa respectively, and the piston area of a single oil cylinder is 7.065cm^2. If the device is used to load the model specimen with the size of 300×300×20(mm), the rated load concentration and ultimate load concentration that can be reached inside the specimen are 1.1775Mpa and 1.6485Mpa respectively, which basically satisfy the uniform condition of stress field in the model.

III. Model preparation

3.1 Raw materials

(1) Epoxies resin

The appearance of epoxy resin is colorless and highly transparent, which mainly has the following characteristics:

a. Excellent mechanical properties. Epoxy resin has strong cohesion and dense molecular structure, so its mechanical properties are better than phenolic resin and unsaturated polyester and other general thermosetting resin.

b. Easy curing. Choosing a variety of different curing agent, epoxy resin system can almost cured at 0 ~ 180 ℃ temperature range.

c. Small curing shrinkage. The reaction of epoxy resin with the curing agent used is carried out by direct addition reaction or ring-opening polymerization of epoxy groups in the resin molecules without water or other volatile by-products being released. Compared with unsaturated polyester resin and phenolic resin, they show low shrinkage during curing, generally 1% ~ 2%.

d. Good manufacturability. Epoxy resin curing hardly produce low molecular volatiles, so it can be formed by low pressure or contact.

(2) Curing agent

Epoxy resin itself is a thermoplastic polymer prepolymer, showing viscous liquid or brittle solid. Pure resins are of little use value. Only after the addition of substances called curing agents for curing reaction to generate three-dimensional crosslinked network structure, insoluble polymer, can it present a series of excellent performance and become useful.

(3) Rosin saturated solution

Rosin is a non-volatile natural resin. The rosin made from turpentine is a transparent and hard brittle solid material, broken surface of which likes shells and has glass luster. Rosin has a dense ring structure, which can be added to the epoxy resin system to improve the rigidity of the solidified material and further reduce its bending strength. Since rosin blocks or rosin powders are solid materials that cannot be added directly to the epoxy resin system, they need to be dissolved into a liquid state before the test.

Since the mechanical properties of epoxy resin after curing are greatly affected by curing agent, colorless transparent epoxy resin #618 and colorless transparent modified curing agent are selected as the basic raw materials according to the requirements of developing transparent hard rock-like similar materials. Meanwhile, the RSS was made of optimal rosin. Fig.2 shows the physical pictures of three raw materials.

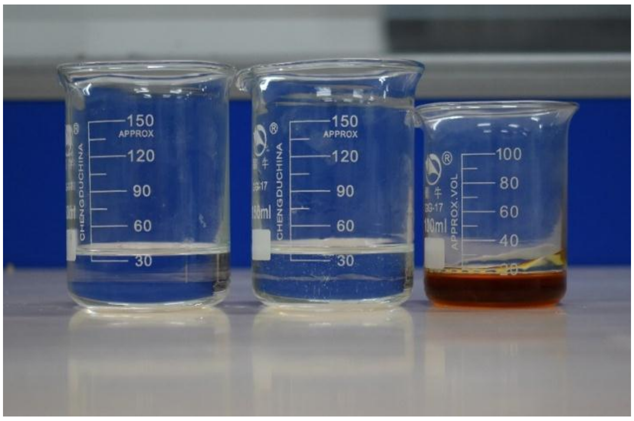

Fig. 2 Raw materials formaking transparent hard rock-like materials. From left to right: modified curing agent, epoxy resin #618 and RSS[6].

3.2Specimen preparation

The detailed making steps are as follows[6]:

(1) Pre-made solution. Unlike epoxy resins and curing agents, RSS cannot be purchased directly and need to be made. Firstly, the optimal rosin blocks were breaked into powders, which were screened through a 100-mesh screen. Then, 100-mesh of rosin powder was melted into an appropriate amount of anhydrous alcohol solution until the solution reached a saturated state.

(2) Sticking film in mold. According to the exploratory test, it was found that pouring the mixed solution directly into the mold would make it difficult to disassemble the mold, so it was necessary to pretreat the mold before pouring. Firstly, a thin layer of vaseline was applied to the surface of the mold, and then an anti-stick film was applied to the surface.

(3) Pouring specimen. Firstly, epoxy resin, curing agent and RSS were weighed according to the designed experimental proportion and placed in beaker. Then, epoxy resin and curing agent were heated in an oven at 50℃, and RSS was heated in a water bath at 50℃. When all the bubbles in epoxy resin and curing agent were removed, they were mixed and stirred evenly. At this time, the bubbles inevitably appeared again in the mixed solution, and they were still heated in the oven at 50℃ until the bubbles were removed. Finally, the RSS from the water bath was taken out and poured into the epoxy resin system. After the mixture was stirred evenly, it was poured into the mold. It is concluded by many experiments that no bubbles will occur as long as the mixture of three solutions is stirred slowly and uniformly, when the preheated RSS is mixed with the non-bubbled thermal epoxy resin system.

(4) Maintenance and polishing ofspecimen. The mold filled with resin mixture solution was smoothly placed in a constant temperature room for maintenance. After the specimen was fully cured, the mold was removed and the uneven places ofspecimen were polished with sandpaper or a small grinder.

IV. Experiments

4.1 Design

According to the specimen production method in section 3.2, a flat specimen with a ratio of ER: CA: RSS = 1:1:0 was made in the laboratory, the size of which is $300 \times 300 \times 20\text{mm}^3$. In view of the small amount of explosives used in the model test, a relatively safe and stable small detonator was selected as the explosive in this test. The charge hole was located in the center of the specimen with a radius of 5mm, the two ends of which were bonded with 1mm thick plastic discs for fixing the special small detonator. The detailed charging structure is shown in Fig. 3:

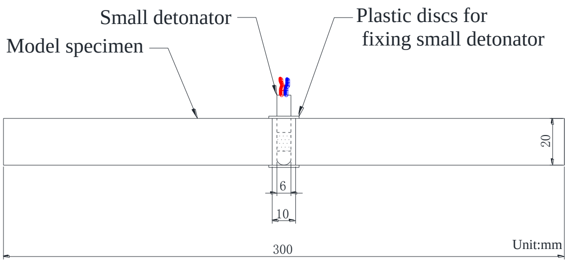

Fig. 3 Charging structure diagram of transparent model specimen

4.2. Results and analysis

The effect of model specimen made of transparent hard rock-like materials after blasting is shown in Fig. 4.

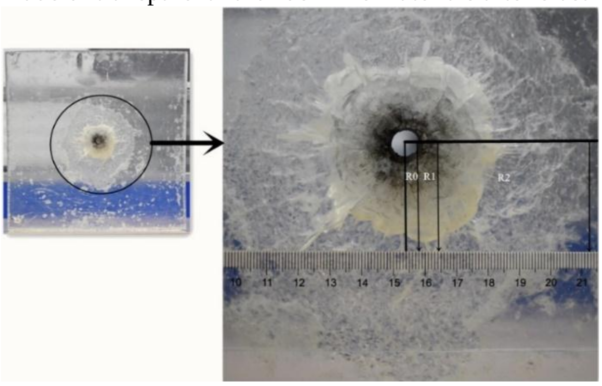

Fig. 4 Transparent model specimen after explosion[6]

As can be seen from Fig. 4, the characteristics of blasting fracture observed directly after blasting of transparent model specimens were very similar to those observed in real rocks, which can be divided into crushing zone (R_1), fissure zone (R_2) and elastic vibration zone (beyond R_2). Therefore, according to the mechanism of rock blasting fracture, the failure process of transparent model specimens under blasting load can be inferred as follows: firstly, the detonation waves acted on the transparent rock wall around the detonator, which generated shock wave in the specimen and quickly attenuated to stress waves. Shock waves caused "crushing" in the transparent rock near the detonator, and stress waves caused radial fractures in the transparent rock outside the crushed zone. Subsequently, the detonation gas products continue to compress the transparent rock crushed by the shock wave, and the detonation gas "wedges" into the cracks generated by the stress wave, so that it continues to extend and further open.

5Analysisforteaching effect

The experimental results of the above transparent rock blasting model are integrated into the practical course teaching of "Engineering blasting" to explain the relevant course content of "Physical process of rock destruction under the action of explosives".

(1) When the explosive explodes, the detonation wave impacts the four walls of the chamber, and the rocks in the four walls move outward, pressing the outer rock mass, forming a shock wave in the rock mass. Under the action of the rock shock wave, the stress state of a layer of rock near the wall of the chamber exceeds the compressive limit, and the rock structure is destroyed, forming a crushing ring (also known as the crushing ring); Outside the ring, the rock element body is under pressure in the direction of shock wave propagation, and the element body obtains the speed of movement in the direction of propagation and begins to move outward. As a result of movement, the element body is subjected to tension in the direction of vertical wave propagation. As a result, the maximum shear stress appears in the direction of line 45^0, and the rock mass in this range is damaged by the action of tensile stress and shear stress, forming a fracture ring.

(2) The rock in the wall of the chamber moves outward, the chamber expands, the blast gas transmits sparse waves from the wall of the chamber, the pressure of the chamber decreases, the rock's outward movement is blocked by the outer rock, and the movement speed slows down. When the pressure in the rock is greater than the pressure on the wall of the chamber, the force direction of the rock unit is toward the chamber, and thus accelerates toward the chamber until it moves toward the chamber. The movement of rock elements towards the chamber is similar to the bubble pulsation of water explosion. The deceleration and reverse of rock movement propagates sparse waves in the rock mass and generates radial tensile stress. The dispersion in the crushing ring around the chamber moves towards the chamber, which causes the explosion gas to wedge into radial cracks

(tensile cracks), shear cracks, circumferential cracks and primary cracks in rock mass to expand and form fracture rings.

After class, a survey of students found that the process of rock blasting was visually presented with the teaching experiment platform of transparent rock model blasting, which made the previously boring course teaching lively and interesting, and made it easier for students to understand and master professional knowledge about the external action of explosive explosion, the reflection and stretching effect of stress waves, and the formation process of blasting funnel. In addition, in the learning process, students realized the important significance of model experiment for engineering blasting design, construction and innovation research and development, and stimulated their interest in engineering blasting.

V. Conclusions

The teaching experiment platform based on transparent rock-like model blasting can promote students' intuitive understanding of rock blasting technology and enhance students' ability of quantitative analysis of rock explosion dynamics. The practice shows that the model experiment can intuitively show the morphology and law of rock blasting crack growth. The non-contact measurement method based on high-speed photography and digital speckle technology can capture the evolution process of rock dynamic strain field and visualize the process of rock blasting failure. This not only helps students to deeply understand and firmly grasp the professional knowledge of engineering blasting course, but also can enhance students' learning interest in engineering blasting course and stimulate students' learning enthusiasm for rock blasting theory.

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