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Study on damage mechanism of mudstone radiated by high energy laser

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Abstract. As mining resources enter the deep stage, the rock strength is high, the use of traditional mechanical rock breaking technology, easy to cause serious wear of the drill bit, drill replacement costs increase, low rock breaking efficiency problems. Laser rock breaking technology uses the way of non-direct contact with rock mass to cause rock breaking, which greatly improves the speed of deep mining. In this paper, high energy laser experiments are carried out on mudstone. Scanning electron microscopy (SEM) is used to study the mudstone minerals be-fore and after laser radiation, and the Brazilian splitting experiment is carried out on mudstone samples after laser test and he final experimental data and analysis results show that the mudstone mineral particles change from rough surface to smooth surface before and after laser radiation. The tensile strength of saturated mudstone samples is significantly improved after laser radiation.

Keywords: Laser rock breaking technology, Brazilian split, SEM, Mechanism analysis, Mudstone

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1. Introduction

As mining resources at home and abroad have entered the stage of deep min-ing, the hard rock strength of deep rock mass has been significantly improved compared with shallow rock mass. If the traditional mechanical rock breaking technology is continuously used, it is easy to cause serious wear of drill bit, in-crease the cost of drill bit replacement, and low rock breaking efficiency [1]. In recent years, with the continuous development of science and technology, there have been many new technologies in rock breaking, such as hydraulic rock break-ing [2], blasting rock breaking [3], microwave rock breaking [4], laser rock break-ing [5], etc. The emergence of these new technologies has greatly accelerated the speed of rock breaking, and most of these new technologies are caused by non-direct contact with rock rock breaking behavior, perfectly making up for the dis-advantages of traditional rock breaking technology.

Based on the new rock breaking technology, this paper mainly focuses on la-ser rock breaking technology. The principle of laser rock breaking technology is mainly that after the rock is radiated by high-energy laser, the rock in the radiated area will rise sharply to more than 2000°C and undergo physical changes such as thermal crushing, melting and vaporization under the action of high temperature, forming a state of multi-phase coexistence, and significantly reducing the strength of the rock by promoting the generation of cracks [6]. In this paper, high-energy laser is used to radiate mudstone, and mudstone states are divided into dry and saturated states. First, the sintering state and fracture distribution of mudstone samples under two states of laser radiation are observed by naked eye to briefly analyze and compare the damage effects of high-energy laser radiation on dry and saturated mudstone rocks. Secondly, by means of scanning electron microscopy (SEM), Brazil splitting test and high-definition camera recording, the changes of mudstone, rock sample internal structure and splitting characteristics of high-energy laser radiation are accurately recorded and analyzed.

2. Laser Experiment

The size of the mudstone sample used in this paper was selected as a cylinder with a diameter of 50mm and a height of 25mm, which complied with the rec-ommended standards of the International Society of Rock Mechanics and Rock Engineering (ISRM). In order to meet the requirements of the mudstone sample radiated by high-energy laser, the Brazilian splitting test was conducted to test its tensile strength. Dry mudstone samples need to be kept indoors for 7 days to dry naturally, and saturated mudstone samples are treated by soaking in pure water in a sealed container for 7 days. The laser radiation power of the test is selected as 3KW, and the radiation path is designed as a circle that starts from the center of the circle on the surface of the mudstone specimen and travels 20mm in a straight line before rotating counterclockwise.

Before the formal laser radiation, the mudstone sample is horizontally fixed on the operating platform and the high-definition camera is arranged near the la-ser machine tool to record various changes in the process of high-energy laser ra-diation of mudstone. After the arrangement is completed, the laser radiation is carried out according to the radiation path designed in the scheme. When the high-energy laser begins to radiate the surface of the mudstone specimen, sparks will occur in a very short time, and the number of sparks will increase for a peri-od of time in the process of high-energy laser radiation. When radiating mudstone samples, with the increase of laser radiation time, high-temperature molten steam will be generated inside the samples and under the washing action of high-pressure auxiliary air flow accompanied by laser equipment, the molten material produced by sintering inside the samples will be rushed out of the holes of the samples. In addition, a large amount of smoke will be generated during the radia-tion process. Saturated mudstone will make the melting reaction of the rocks more intense. The resulting granular melt shoots out in all directions.

Figure 1 is an image of mudstone radiated by high-energy laser. It can be seen that there are obvious circular laser radiation paths, and a large number of black-gray crystal materials are generated around the paths. The black-gray crystal is translucent and dense glassy, and after testing, the crystal has extremely high strength and most of the crystal components are silica. White traces can be seen on the radiation path, which indicates that the mudstone components in this area have been completely burned.

a) Dry mudstone b) Saturated mudstone

Figure 1 Morphology of mudstone radiated by laser

3. The Brazilian split experiment

In order to compare the strength of the rock samples with that of dry and sat-urated mudstone without laser radiation, the splitting experiment is convenient to observe the perforation in the rock samples after laser radiation. Dry mudstone, saturated mudstone and intact mudstone were successively subjected to the Bra-zilian splitting test. The loading test was carried out by the MTS universal testing machine. The mechanical curves of the splitting test were shown in Figure 2, 3, 4 and 5.

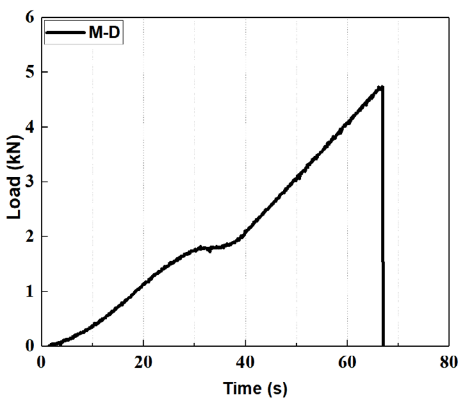

Figure 2 Tensile strength results of dry mudstone in Brazil after radiation

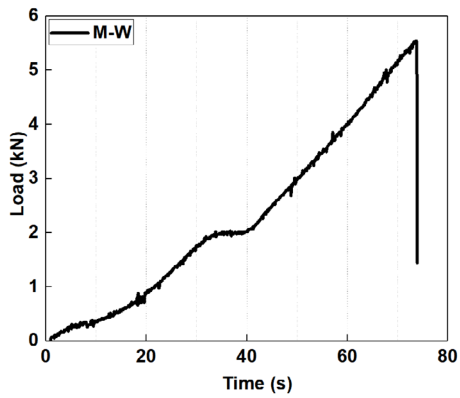

Figure 3 Tensile strength results of saturated mudstone in Brazil after ra-diation

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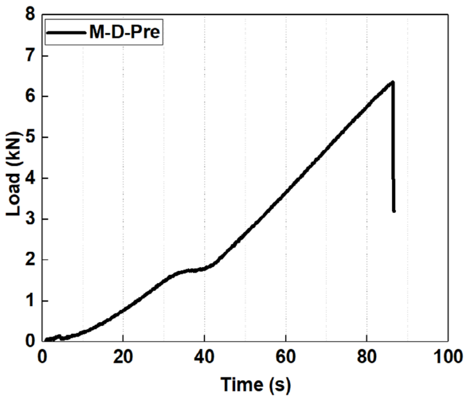


Figure 4 Complete dry mudstone Brazilian tensile strength results

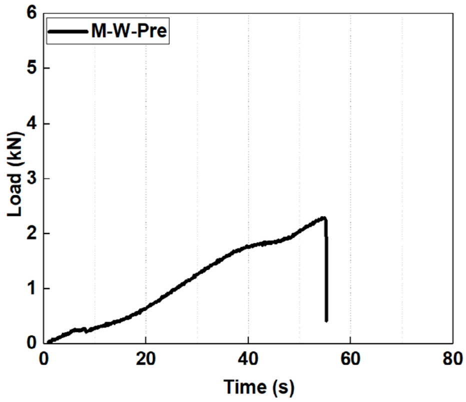


Figure 5 Complete saturated mudstone Brazilian tensile strength results

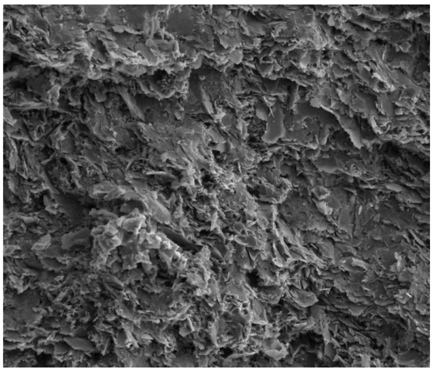
According to the mechanical data curve of the Brazilian splitting experiment of mudstone in two states after laser radiation,figure 2 and figure 3,indicate that the peak load of the dry mudstone specimen is lower than that of the saturated mudstone specimen, and the tensile strength of the saturated mudstone specimen after laser radiation is higher than that of the dry mudstone specimen. As can be seen in figure 4 and figure 5, the Brazilian tensile strength of intact mudstone specimen shows that the tensile strength of intact dry mudstone is significantly higher than that of saturated mudstone. It is worth noting that the tensile strength of radiated dry mudstone is lower than that of intact mudstone. The tensile strength of the specimen after high energy laser irradiation was significantly im-proved. After the end of the splitting experiment, the internal perforation of the specimen was analyzed. Figure 6 shows the morphology of mudstone after split-ting.

Figure 6 Fracture morphology of mudstone specimen

Figure 6 shows the characteristics of mudstone perforation. It can be seen from the figure that the perforation caused by laser is mainly reflected in the pen-etrating perforation at the axial position. At the same time, because the laser stays on the circular path for a short time, the perforation marks are shallow. The size of laser perforation gradually decreases from the surface of the rock sample, and the breakdown position is trumpet shaped after breakdown. Accord-ing to the abnormal sound heard at the scene and the shape of the perforation, it is speculated that this phenomenon occurred because the rock collapse occurred in the final stage of the perforation under the action of high pressure gas and strong thermal stress. According to the details of the image, it can be seen that the radiation inside the hole presents a round-walled layered porous structure. Ac-cording to the high temperature conditions and the composition of mudstone, it is inferred that this structure is formed by the gradual cooling of the radiation product under the action of pressure, and the silicon in the radiation product is not the main element component, the main components are calcium silicate and aluminate.

4. Microanalysis

The original mudstone before the laser radiation experiment and the mud-stone after the laser radiation were analyzed by scanning electron microscopy (SEM). Figure 7 shows the SEM images before and after the laser radiation.


before laser treatment

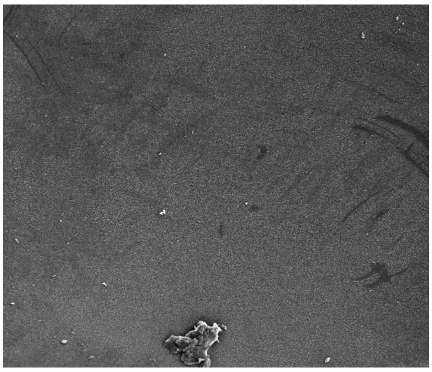

after laser treatment

Figure 7 SEM images before and after laser radiation

In Figure 7, the surface of the SEM image before laser radiation is uneven, and the mineral particles are sliced and arranged in an irregular manner similar to ocean waves, numerous porous structures can be seen. After radiation, the SEM image is black and translucent, and the surface is dense and smooth without any holes and cracks. The SEM morphology indicates that laser irradiation helps in melting the rock mass where it passes and then exhibits a dense and smooth mi-croscopic structure, it can be inferred that the strength of the rock mass can be el-evated to some kind due to such an irradiation process.

5. Conclusion

Through the use of high-energy laser radiation drying and saturated mudstone samples, Brazil splitting test and SEM microscopic analysis, this paper studies the damage mechanism of high-energy laser radiation mudstone and the influence of water content conditions on the laser radiation effect of mudstone samples. According to the experimental phenomena and data analysis, the following con-clusions can be drawn:

(1) High-energy laser radiation mudstone will produce very high intensity black gray translucent crystal material in the laser radiation path.

(2) The Brazilian splitting experiment shows that the tensile strength of satu-rated mudstone after laser radiation is higher than that of dry mudstone, and the tensile strength of saturated mudstone is significantly improved after laser radia-tion.

(3) The radiation inside the hole after laser radiation presents a round-walled layered porous structure, and it is found under SEM observation that the surface of the mudstone particles in the radiation area is smooth, without any holes and cracks.

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Исследование механизма повреждения аргиллита излучением высокоэнергетического лазера

Аннотация. По мере того, как добыча полезных ископаемых выходит на глубокую стадию, прочность породы повышается, использование традиционной механической технологии разрушения породы легко приводит к серьезному износу бурового долота, увеличению затрат на замену сверла, проблемам с низкой эффективностью разрушения породы. Технология лазерного разрушения горных пород использует метод непрямого контакта с горным массивом для разрушения породы, что значительно повышает скорость глубокой разработки. В данной статье проводятся эксперименты с использованием высокоэнергетического лазера на аргиллите. Сканирующая электронная микроскопия (СЭМ) используется для изучения минералов аргиллита до и после лазерного облучения, а бразильский эксперимент по расщеплению проводится на образцах аргиллита после лазерного испытания, и окончательные экспериментальные данные и результаты анализа показывают, что минеральные частицы аргиллита меняют шероховатую поверхность на гладкую до и после лазерного облучения. Прочность на разрыв насыщенных образцов аргиллита значительно повышается после лазерного облучения.

Ключевые слова: Технология лазерного разрушения горных пород, бразильский раскол, СЭМ, анализ механизма, аргиллит.

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Жоғары энергиялы лазердің сәулеленуімен саздың зақымдану механизмін зерттеу

Аңдатпа. Тау-кен өндірісі терең сатыға көтерілгендіктен, тау жыныстарының беріктігі артады, тау жыныстарын жоюдың дәстүрлі механикалық технологиясын қолдану Бұрғылау қашауының қатты тозуына, бұрғылауды ауыстыру шығындарының өсуіне және тау жыныстарын жоюдың төмен тиімділігіне әкеледі. Тау жыныстарын лазермен жою технологиясы тау жыныстарын жою үшін тау жыныстарымен жанама байланыс әдісін қолданады, бұл терең игеру жылдамдығын едәуір арттырады. Бұл мақалада жоғары энергиялы балшық лазерін қолдану арқылы эксперименттер жүргізіледі. Сканерлеуші электронды микроскопия (СЭМ) лазерлік сәулеленуге дейін және одан кейінгі сазды минералдарды зерттеу үшін қолданылады, ал Бразилиялық ыдырау эксперименті лазерлік сынақтан кейінгі сазды сынамаларда жүргізіледі және соңғы эксперименттік деректер мен талдау нәтижелері сазды минералды бөлшектердің өрескел бетті лазерлік сәулеленуге дейін және одан кейін тегіс бетке ауыстыратынын көрсетеді. Лазерлік сәулеленуден кейін қаныққан аргиллит үлгілерінің созылу күші айтарлықтай артады.

Түйін сөздер: Лазерлік тау жыныстарын жою технологиясы, бразилиялық сплит, СЭМ, механизмді талдау, аргиллит.

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