CRACKING CHARACTERISTICS OF GRANITE UNDER DIFFERENT LASER POWERS

by

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Original scientific paper
https://doi.org/10.2298/TSCI2502313Y

This article explores the crack characteristics and crack propagation laws of granite under different laser power conditions. Research has shown that high energy lasers induce the generation and propagation of cracks in granite by generating local thermal stress. The experimental research object is granite, and the evolution of crack characteristics is observed by irradiating with five laser powers of 250 W, 500 W, 750 W, 1000 W, and 1250 W for 30 seconds. Research has found that as the laser power increases, the crack opening on the granite end face and the diameter of the central melt hole gradually increase. Cracks are distributed radially symmetrically, and transverse through cracks appear when the power is greater than or equal to 750 W, forming small fragments. The side cracks are distributed in a "human" shape, and the depth of the cracks is basically not affected by the laser power, but the opening increases with the increase of power, and the transverse branching cracks gradually appear. The local heating caused by laser irradiation leads to uneven thermal expansion, resulting in significant thermal stress. When the stress exceeds the strength of the rock, cracks are induced. This study provides a theoretical basis and scientific foundation for the application of laser assisted rock breaking technology in deep resource exploitation and complex engineering.

Key words: *laser irradiation, crack propagation, granite*

Introduction

With the rapid development of China's economy, the areas and levels of resource exploitation have long been at the forefront of global exploitation [1-7]. At the same time, due to China's special geological conditions, shallow resources are gradually depleting, and resource exploration and engineering construction are moving towards the deep parts of the earth [8-11]. Deep resource exploitation will become a new norm.

Scholars conducted orthogonal experimental research on laser-induced thermal fracture of rocks, analyzing the effects of laser power, irradiation time, and distance on temperature changes and morphological damage of rocks [12]. Their results demonstrated that localized thermal stress generated by laser irradiation effectively weakens rock strength, inducing and accelerating the generation and propagation of cracks. Ndeda *et al.* [13] showed that when

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thermal stress from laser irradiation exceeds the internal mineral strength of the rock, it leads to microcrack initiation at the mineral level and manifests macroscopically as cracking and spalling of the rock. Li *et al.* [14] reported that the melting zone exhibits the highest temperatures under laser irradiation, with damage characterized by step-like fractures, while the damage and heat-affected zones mainly display crack propagation. Kuang *et al.* [15] investigated the influence of laser power, spot diameter, and scanning speed on the crack distribution in granite using laser irradiation. Their study revealed that the crack angle and the area of cracks at both ends correlate with laser parameters, with cracks primarily concentrated around the grooves created by the laser beam.

In summary, while existing studies have focused on the characteristics of cracks – such as angle, length, and area – formed under laser irradiation, limited attention has been given to the macroscopic crack propagation directions and patterns. Therefore, investigating the cracking behavior of granite end-face fractures under laser irradiation is crucial for advancing the theoretical understanding of laser-assisted rock-breaking. Such research is also essential for meeting the demands of complex deep engineering projects, optimizing operational parameters, improving rock-breaking efficiency, and promoting the development of combined laser-mechanical rock-breaking technologies. The findings will provide a critical scientific basis and theoretical framework for deep engineering construction and resource exploration.

Specimen preparation and experimental programme

The rock sample used in the experiment is granite, and the sample is prepared according to the industry standard Rock Physical and Mechanical Properties Test Procedure Part 18: Rock Uniaxial Compressive Strength Test (DZ/T0276.18-2015). The sample is prepared as a cylindrical body with a height of 100 mm and a diameter of 50 mm.

Table 1 shows the experimental scheme for granite face under different laser powers. Five gradients of laser power were set, namely 250 W, 500 W, 750 W, 1000 W, and 1250 W, with an irradiation time of 30 seconds.

Table 1. Experimental plan for rock crack development under different laser powers

Laser power \ Time	30 seconds
250 W	G-1
500 W	G-2
750 W	G-3
1000 W	G-4
1250 W	G-5

Macroscopic crack characteristics of granite under laser irradiation

Mechanism of laser-induced thermal fracturing in rock

The mechanism of laser-induced thermal fracturing in rock explores the principles governing crack formation and damage processes in rocks under thermal effects during laser-rock interaction. The phenomenon of laser-induced thermal fracturing arises from the highly concentrated energy of the laser, which rapidly heats the rock surface, creating temperature gradients and thermal stresses. When a laser beam irradiates the rock surface, the energy is absorbed and converted into heat. Due to the high energy density of the laser, the temperature of the rock surface rises sharply. Different rock components, such as mineral composition and crystal structure, absorb laser energy at varying rates, leading to localized uneven heating. As laser irradiation continues, the heated surface layer of the rock undergoes thermal expansion, while the cooler interior restricts this expansion. This disparity generates significant thermal stress concentrated on the rock surface, making it susceptible to microcrack formation. When the thermal stress exceeds the rock's strength, initial cracks form on the surface, typically originating at micro-defects such as grain boundaries or micro-voids. As laser heating persists, these cracks propagate further. Crack growth generally follows the direction of maximum thermal stress, often perpendicular to the rock surface. When the energy input from the laser balances the energy dissipation of the rock, a thermal equilibrium state is reached, and crack propagation ceases. At this stage, the high temperature induced by the laser may cause phase transitions and melting of mineral components in the rock. The entire process of laser-induced thermal fracturing is influenced by factors such as rock type, laser power, irradiation duration, and environmental conditions. This mechanism provides a fundamental understanding of laser-assisted rock-breaking technologies and their application in engineering.

Development characteristics of rock end face cracks under laser irradiation

Figure 1 shows the characteristics of crack development in rock cross-sections under different laser powers, exhibiting different crack cracking patterns. After laser irradiation, a large number of cracks appeared on the granite end face, mainly in the form of central dissolution pores distributed symmetrically along the radial direction of the light spot, extending to the edge of the sample. As the laser power increases, the crack opening and hole diameter gradually increase. Under lower laser power irradiation conditions, the energy absorbed by the rock is less. At this time, the crack opening is smaller and the central molten hole is smaller. The molten material accumulated outside the hole gradually increases with the increase of laser irradiation power. This molten material is formed by heating the rock with high energy laser to melt the rock and form lava. When the laser power increases to 1250 W, the molten material in the hole reacts violently and cools on the surface of the rock to form enamel. As the laser power increases, the amount of molten material outside the central hole continues to increase, and it cools down on the surface of granite into irregular serrated edge enamel bodies. When the laser power increases to 750 W, transverse through cracks appear around the hole, connecting two or more cracks, forming a small fracture block around the central hole.

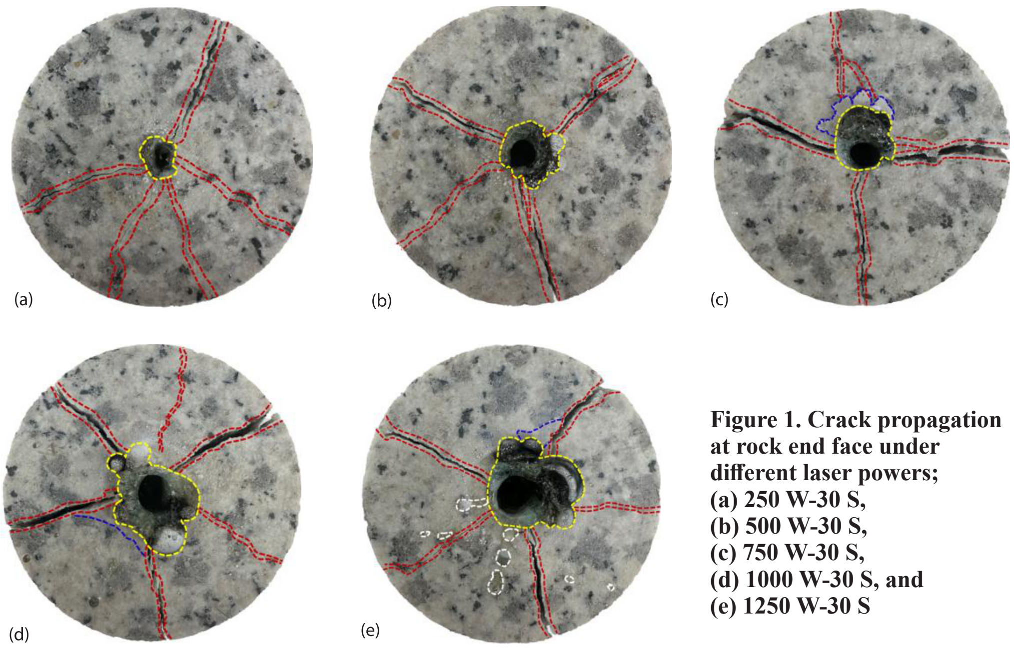

Figure 1. Crack propagation at rock end face under different laser powers; (a) 250 W-30 S, (b) 500 W-30 S, (c) 750 W-30 S, (d) 1000 W-30 S, and (e) 1250 W-30 S

Characteristics of crack development on rock side under laser irradiation

To investigate the cracking characteristics of rock side cracks under different laser parameter conditions, two variable factors of different laser irradiation power and irradiation time were set to explore the cracking characteristics of rock under different laser parameter conditions, reveal the development law of rock side cracks under laser power and irradiation time, and qualitatively describe the development characteristics of rock side cracks.

Figure 2 shows the development characteristics of rock side cracks under different laser powers. The laser powers are set to 250 W, 500 W, 750 W, 1000 W, and 1250 W, and the laser irradiation time is 30 seconds. After 30 seconds of laser irradiation, the cracks on the side of the rock developed in a "人" shape. As the end face cracks developed to the edge of the rock sample end face, the rock side cracks began to develop vertically downward, and at the end of the crack, they began to split into two. The two cracks at the bottom developed in two left and right directions, and at the end of the development, they showed a *human* shape distribution. As the laser power gradually increases, the opening of cracks on the rock side also increases. From the figure, it can be observed that the crack depth of the rock sample is not affected by the laser power. During the process of laser power ranging from 250-1000 W, the depth of the side cracks does not change much, and the height remains at the same horizontal line. The branching cracks develop horizontally, and the transverse crack opening gradually increases with the increase of irradiation power.

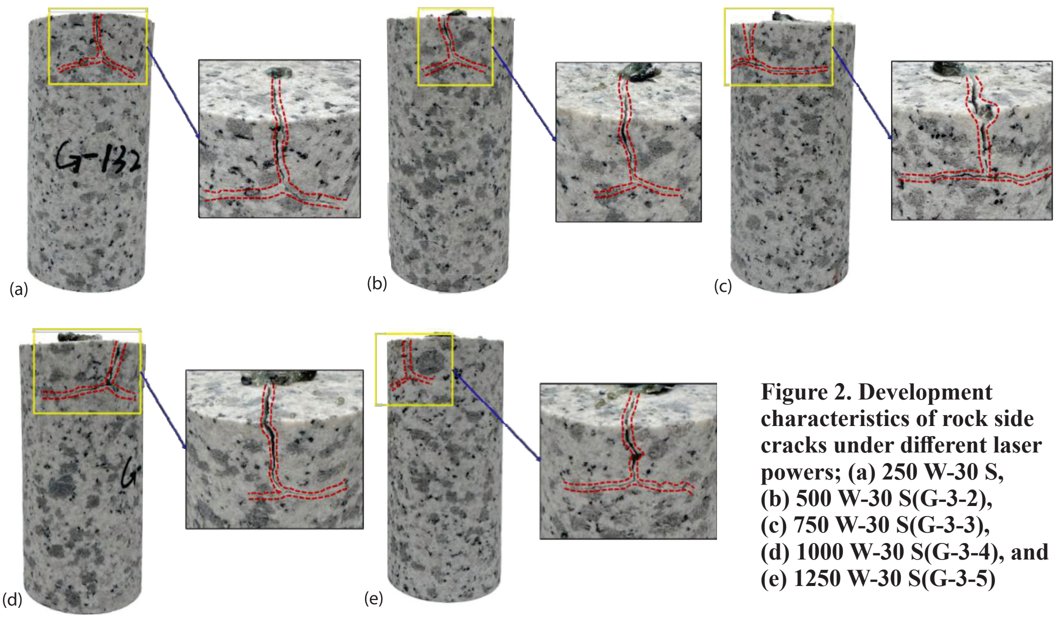

Figure 2. Development characteristics of rock side cracks under different laser powers; (a) 250 W-30 S, (b) 500 W-30 S(G-3-2), (c) 750 W-30 S(G-3-3), (d) 1000 W-30 S(G-3-4), and (e) 1250 W-30 S(G-3-5)

Conclusion

Under the action of laser irradiation, thermal stress is generated in granite, leading to the generation and propagation of cracks. Increasing the laser power enhances the characteristics of crack opening and melting zone, and shows obvious crack propagation patterns on the end and side surfaces. The end face cracks are radially symmetrical and form transverse through cracks when the laser power is high, while the side cracks develop into a sharp-type shape with consistent depth, but the opening width increases with the increase of laser power.

The law of induced rock thermal cracking under laser action has been revealed, providing theoretical support and scientific basis for optimizing laser assisted rock breaking parameters in deep resource mining and complex engineering applications.

Acknowledgment

This work was financially supported by Project (52225403) supported by the National Natural Science of China, National Key Research and Development Program of China (2023YFF0615401) and Project(2023NSFSC0004、2024NSFSC0097) supported by Sichuan Science and Technology Program and National Natural Science Foundation of China (U2013603).

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Paper submitted: October 4, 2024
Paper revised: November 13, 2024
Paper accepted: November 22, 2024