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Study on the Breaking Law of Different Rocks by Moving Linearlaser

Rong Deng, Xiaorui Tang, Wenting Zhang, Wenling Zhang, Ke Chen, Qiuyang Li

School of Mechanical and Electrical Engineering, Southwest Petroleum University, Chengdu 610500, China

Abstract

The combination of laser technology and traditional drilling technology to achieve efficient rock breaking technology has extremely important value and prospects in the field of oil and gas exploitation. At present, there are some researches on the interaction and fragmentation of static spot and rock However, the research on the fragmentation of rock by different motion spots and different shapes of light spots is carried out. In this paper, the actual situation of laser-mechanical combined drilling is considered to be a linear spot. The number of irradiation times and the moving speed are parameter variables, and the physical and mechanical properties and thermal sensitivity of linear laser spot and different rock action are studied. It provides a reference for the development of laser-mechanical combined drilling experiments and the selection of experimental parameters. The experimental results show that with the increase of the number of irradiation times and the decrease of the moving speed, the density and compressive strength of the two rocks are decreasing, the porosity is increasing, and the average temperature of the line is significantly improved. The maximum values of density increment of granite and sandstone are -0.207g/cm3 and -0.0519g/cm3, respectively. The maximum values of compressive strength increment are -61Mpa and -23Mpa, respectively. The maximum porosity increments are 0.0228 and 0.0304 respectively. The average line temperature is 314°C and 414°C, respectively. The change of laser spot velocity is more sensitive to the influence of granite density. The influence of laser spot irradiance on granite density, porosity and compressive strength is more sensitive than sandstone.

Keywords

LaserTechnology; Movinglightspot; Numberofirradiation; Sensitivelaw; Rockbreakage.

1. Introduction

With the rapid development of the world economy, people's demand for oil and gas resources has increased sharply, and the contradiction between supply and demand has become increasingly serious. However, due to the depletion of conventional oil and natural gas resources, the rapid development of the human economy has been suppressed. Therefore, increasing the development of oil and gas resources in complex and difficult to drill formations will alleviate or even resolve the contradiction between supply and demand of oil and gas resources. The application of conventional drilling tools to oil and gas exploration in complex, difficult-to-drill formations will result in significant reductions in rock crushing efficiency and significant increases in drilling costs. Therefore, how to improve rock breaking efficiency and reduce drilling cost in complex and difficult to drill formations will be the main problem to solve the problem of oil and gas supply and demand.

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From the rise of laser technology in the 1960s, people gradually realized the important strategic significance of combining laser technology with drilling technology. The application of laser technology in oil exploitation will provide a new idea for efficient rock breaking and drilling [1]. And method. Many scholars at home and abroad have proved the feasibility of laser rock breaking after a lot of theoretical and experimental analysis, and can achieve efficient and clean rock breaking without changing the traditional drilling technology [2]. At present, research on the interaction between laser and rock is mainly to change the laser power, irradiation time, defocusing amount, laser incident angle and other parameters, to act on the rock with static spot, to study the rock breaking law and heat sensitivity [3]. However, high-power lasers are expensive and costly to maintain, and their direct application to the drilling industry will double the cost of drilling. In order to effectively improve the rock-breaking efficiency and reduce the drilling cost, the kilowatt-class laser is combined with the traditional mechanical drilling process, and the rock is subjected to impact damage and thermal damage by the laser, resulting in pre-crushing, which releases the internal stress of the rock and reduces the rock. Strength, improve the drill ability of rock, and then use mechanical rock breaking to achieve high efficiency and economy of drilling technology. Therefore, under the condition of laser mechanical coupling, the laser-to-rock fracture law will become an important research topic in oil drilling technology [4].

The existing laser rock breaking and perforating experiments are mainly to study the action law of the static spot on the rock sample under different laser process parameters, and the research content is limited to the result of laser action on rock [5]. When the laser is combined with the machine and applied to the drilling project, the spot will produce a certain speed of movement as the bit rotates. The laser beam will not be limited to a spot [6]. In order to improve the coverage of the spot, the shape of the spot will be linear and move at a certain speed [7]. This paper mainly studies the movement of different linear samples by moving the linear laser spot, by changing the movement of the line beam. The speed and number of irradiations reveal the thermal sensitivity of moving linear laser spots to sandstone and granite. Provide some data support for laser mechanical combined drilling technology.

2. Experimental scheme

2.1 Experimental materials and equipment

The rock samples used in this experiment are sandstone and granite. The rock specifications are: 100mm × 100mm × 30mm, as shown in Figure 1. The main components of sandstone are quartz and clay, and the main components of granite are quartz, plagioclase and albite.

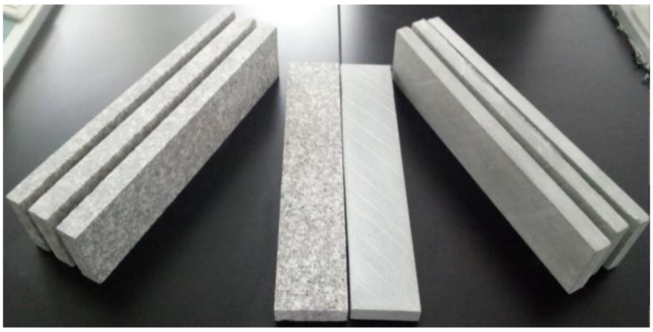

Figure 1 Experimental rock sample

In this experiment, MFSC1000w fiber laser is used to provide light energy; a circular spot with a diameter of 10mm is formed into a rectangular line spot of 100mm × 0.8mm through a shaping mirror group, and the power density is 12.5w/mm2 to ensure sufficient damage to the rock Energy [8]; The rock sample is fixed by mechanical horizontal moving gantry and the rock sample is driven to reciprocate. The thermal imager was used to monitor the experimental process and collect data, as shown in Figure 2.

After the rock sample was irradiated by laser, the core was obtained by the ZS200 core automatic coring machine. The surface of the sample was observed with a SZN stereo microscope, and the

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appearance of the sample was collected. The rock sample density and porosity data were collected using a SCMS-E high temperature and high pressure core multi-parameter measuring system_ gas pore permeation measuring instrument. The core compressive strength data was measured using a WDW-100 electronic universal testing machine.

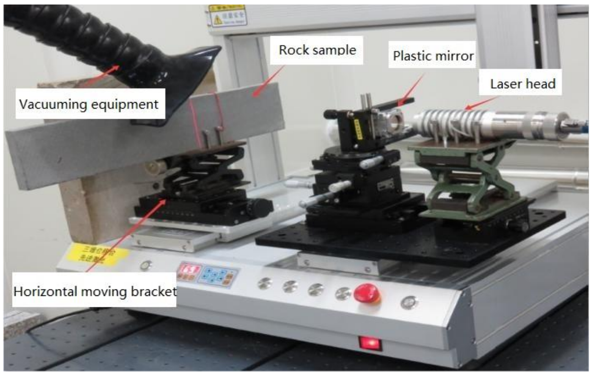

Figure 2 Experimental device diagram

2.2 Experiment procedure

The laser process parameters of this experiment are: laser power is 1000w, spot size is: 100mm × 0.8mm rectangular line focusing spot, the spot moving distance is 80mm. The process parameter variables are: the moving speed of the linear spot, and the number of repeated irradiation of the linear spot. As shown in Table 1 Experiment alparametersTable 1. During the experiment, the laser head remains stationary, and a beam spot is emitted on the shaping mirror group to shape the spot into a linear spot, so that it is vertically focused on the rock sample. Fix the rock sample by moving the gantry and drive the rock sample to make a linear motion in the horizontal direction to ensure that the acceleration of the linear spot is consistent. As shown in Figure 3. A dust suction device is fixed next to the rock sample to prevent the debris from splashing and damaging the plastic mirror group.

Table 1 Experiment alparameters

Eequipment	Variable	Variable value
Horizontal mobile gantry	Spot movement speed : v（mm/s)	5, 10, 15
Fiber-optic laser	Spot irradiation times ： n（Times)	1, 3, 5

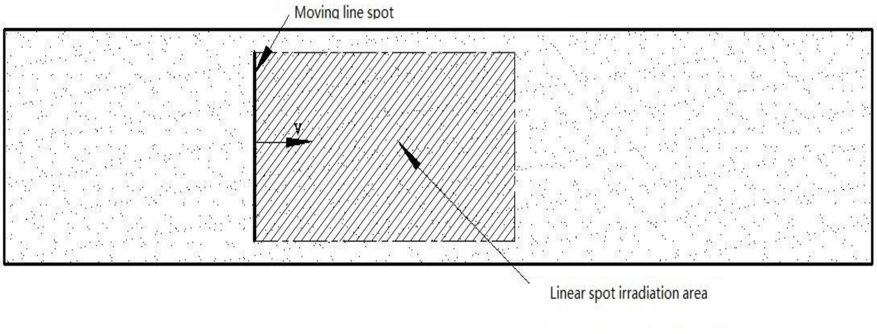

Figure 3 A schematic diagram of laser acting rock

3. Experimental results and analysis

3.1 Macroscopic morphology analysis of linear spot irradiation area44

When the linear spot acts on the rock sample, black enamel glass bodies appear on both the granite and sandstone surfaces, and the black enamel glass body on the granite surface is denser than the sandstone. When the laser power is P=1000w, the linear spot moving speed V=5mm/s, and the irradiation times N=5, the linear spot reacts strongly with the granite, and the experimental process is

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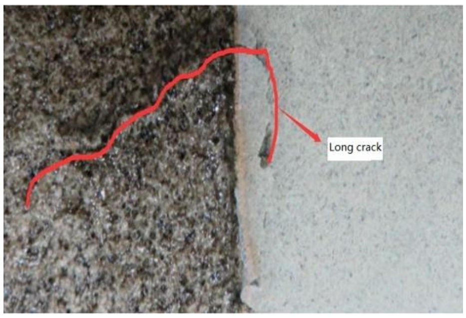
accompanied by a sharp popping sound accompanied by cuttings. The exfoliated line shape, the original light black material turns into a dark black enamel vitreous under laser irradiation [9]. The linear spot reacts smoothly with the sandstone, and the squeaking sound is generated during the experiment. A clear long crack appears on the rock sample, extending from the irradiated area to the non-irradiated area, causing a large piece of rock to be lifted and thin and brittle broken. An orange-yellow boundary line is formed between the laser irradiated area and the unlased laser irradiated area [10]. The rock fragments are more frequently warped on the boundary line, and the visible cracks are more concentrated than other irradiated areas, as shown in **错误!未找到引用源。**.

After laser irradiation Before laser irradiation

(a)Granite

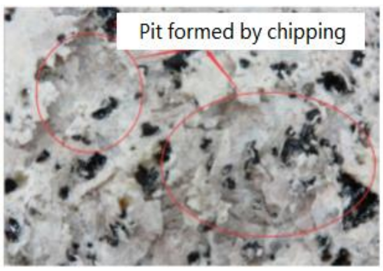


After laser irradiation Before laser irradiation

(b)Sandstone

Figure 4 Contrast map of macroscopic appearance before and after action of linear spot

When the moving speed of the spot is 10mm/s and the number of irradiation is 3, the surface of the granite begins to peel off, and as the laser moving speed decreases, the number of irradiation increases, and the chipping is progressively intense. When the spot moving speed is 5 mm/s and the number of irradiation is 5, the surface of the granite rock forms a large number of pits due to the chipping of the cuttings. When the spot moving speed is 10 mm/s and the number of irradiation is 5, cracks visible to the naked eye appear on the surface of the sandstone. When the spot moving speed is 5mm/s and the number of irradiation is 5, the rock surface is lifted up on the surface of the sandstone [11]. As shown in Figure 5.



(a)Granite v=15mm/s n=1

(b) Granite v=5mm/s n=5

(c)Sandstone v=15mm/s n=1

(d)Sandstone v=5mm/s n=5

Figure 5 Macroscopic profile of rock samples with different moving speeds and times of irradiation

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3.2 Analysis of physical and mechanical properties of rocks

3.2.1 Comparison of rock sample density before and after experiment

Before the experiment, the average density of the granite samples was 2.5850 g/cm3. After the experiment, the average density of the granite samples was 2.5315 g/cm3, which was reduced by 0.0535 g/cm3, and the percentage increase was -2.07%. Before the experiment, the average of the sandstone samples was The density was 2.3036 g/cm3. After the experiment, the average density of the sandstone samples was 2.2711 g/cm3, which was reduced by 0.0325 g/cm3, and the percentage increase was -1.41%. Table 2 and Table 3Table 3 are the comparison tables of the effects of different irradiation times and moving speeds on the density of two types of rock samples before and after the laser spot action. It can be seen from the data in the table that the density of the two rock samples after laser irradiation is lower than that before irradiation, and the influence of the laser spot moving speed and the number of irradiation times on the granite porosity is more significant than that of sandstone [11].

Table 2 The influence of the number of irradiated spots on the density of rock samples

	Average density before irradiation (g/cm3)		Average density after irradiation (g/cm3)		Average density increase before and after irradiation (g/cm3)	
	granite	sandstone	granite	sandstone	granite	sandstone
n=1	2.5839	2.2964	2.5792	2.2879	-0.0047	-0.0085
n=2	2.5887	2.3169	2.5472	2.274	-0.0415	-0.0429
n=3	2.5825	2.2976	2.4682	2.2514	-0.1143	-0.0462

Table 3 The influence of the velocity of spot movement on the density of rock samples

	Average density before irradiation (g/cm3)		Average density after irradiation (g/cm3)		Average density increase before and after irradiation (g/cm3)	
	granite	sandstone	granite	sandstone	granite	sandstone
v=5	2.5482	2.3482	2.4589	2.3108	-0.0893	-0.0374
v=10	2.5888	2.2744	2.5339	2.2424	-0.0549	-0.032
v=15	2.6182	2.2884	2.6018	2.2601	-0.0164	-0.0283

3.2.2 Porosity porosity comparison before and after experiment

The porosity test uses Boyle's law. When the temperature is constant, the ideal gas volume of a certain mass is inversely proportional to the absolute pressure of the gas:

$$\frac{V_1}{V_2} = \frac{P_2}{P_1} \text{ or } P_1V_1 = P_2V_2 \quad (2-1)$$

In the formula:

P_1 is the initial pressure of the system, the unit is Mp_a

P_2 is the system equilibrium pressure, the unit is Mp_a;

V_1 is the volume at the initial pressure P_1, and the unit is cm^3;

V_2 is the volume under the equilibrium pressure P_2, and the unit is cm^3.

In order to ensure the accuracy of the test, considering the temperature change and non-ideal gas characteristics, the expansion formula is as follows:

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$$\frac{P_1V_1}{Z_1T_1}=\frac{P_2V_2}{Z_2T_2} \quad (2-2)$$

In the formula: Z_1 and Z_2 are the gas compression factors under pressures P_1 and P_2, respectively. During the test, the test gas is first filled into the pores of the rock sample, and after the equilibrium, the gas is diffused into the standard chamber V_1, and the porosity is calculated by the pressure twice.

$$V_{x1}=V_1\frac{\frac{P_2}{Z_2T_2}}{\frac{P_1}{Z_1T_1}-\frac{P_2}{Z_2T_2}}-V_0 \quad (2-3)$$

$$\phi=\frac{V_{x1}}{V_d} \quad (2-4)$$

In the formula:

V_0—system dead volume, cm^3;

V_{x1}—rock sample pore volume, cm^3;

V_d—rock sample apparent volume, cm^3;

Φ—rock sample porosity,

Before the experiment, the average porosity of the granite samples was 0.0396. After the experiment, the average porosity of the granite samples was 0.0451, the average porosity was increased by 0.0055, and the increment percentage was 14%. The average porosity of the sandstone samples before the experiment was 0.1446. The average porosity of the post-sandstone sample was 0.1605, the average porosity was increased by 0.0159, and the percentage increase was 10%. When the number of irradiations is n=5 and the spot moving speed is v=5mm/s, the maximum increments of porosity of granite and sandstone are 0.0228 and 0.0304, respectively. Table 4 and Table 5 are the comparison tables of the effects of different irradiation times and moving speeds on the porosity of the two types of rock samples before and after the laser spot effect. It can be seen from the data in the table that the porosity of the two rock samples after laser irradiation is improved compared with that before irradiation [12]. The effect of the laser spot moving speed and the number of irradiation times on the porosity of the granite is more significant than that of the sandstone.

Table 4 The effect of the number of irradiated spots on the porosity of rock samples

	Average porosity before irradiation		Average porosity after irradiation		Average porosity increment before and after irradiation	
	granite	sandstone	granite	sandstone	granite	sandstone
n=1	0.0374	0.1431	0.0382	0.1577	0.0008	0.0146
n=3	0.0391	0.1401	0.0438	0.16	0.0047	0.0199
n=5	0.043	0.1492	0.0535	0.1637	0.0105	0.0145

Table 5 The effect of the velocity of spot movement on the porosity of rock samples

	Average porosity before irradiation		Average porosity after irradiation		Average porosity increment before and after irradiation	
	granite	sandstone	granite	sandstone	granite	sandstone
v=5	0.0384	0.141	0.0452	0.157	0.0068	0.016
v=10	0.0413	0.144	0.0457	0.1583	0.0044	0.0143
v=15	0.00381	0.15	0.0446	0.166	0.0065	0.016

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3.2.3 comparison of compressive strength of rock samples before and after the experiment

Before the experiment, the average compressive strength of the granite samples was 152 Mpa. After the experiment, the average compressive strength of the granite samples was 127 Mpa, which was reduced by 25 Mpa, and the percentage increase was -16%. Before the experiment, the average compressive strength of the sandstone samples was 53 Mpa, After the experiment, the average compressive strength of the sandstone sample was 46 Mpa, which was reduced by 7 Mpa, and the percentage increase was -13%. Table 6 and Table 7 show the comparison of the effects of different irradiation times and moving speeds on the compressive strength of the two types of rock samples before and after the laser spot effect. It can be seen from the data in the table that the compressive strength of the two rock samples after laser irradiation is lower than before irradiation [13]. The effect of the laser spot moving speed and the number of irradiation times on the compressive strength of granite is more significant than that of sandstone.

Table 6 The influence of the number of irradiated spots on the compressive strength of rock samples

	Average compressive strength before irradiation（Mpa）		Average compressive strength after irradiation（Mpa）		Average compressive strength increment before and after irradiation（Mpa）	
	granite	sandstone	granite	sandstone	granite	sandstone
n=1	151	53	143	49	-8	-4
n=3	156	51	134	45	-22	-6
n=5	149	54	105	43	-44	-11

Table 7 The influence of the velocity of spot movement on the compressive strength of rock samples

	Average compressive strength before irradiation(Mpa)		Average compressive strength after irradiation(Mpa)		Average compressive strength increment before and after irradiation(Mpa)	
	granite	sandstone	granite	sandstone	granite	sandstone
v=5	146	54	118	40	-28	-14
v=10	152	51	128	45	-24	-6
v=15	149	56	136	52	-13	-4

3.3 Thermal imaging analysis

The linear moving spot repeatedly acts on the rock surface, causing the temperature of a certain area of the rock sample to change several times in a certain period of time. The sharply varying temperature difference causes the rock sample to repeatedly expand in a short time, generating thermal stress at a sudden temperature change, when the thermal stress After the ultimate strength of the rock sample is exceeded, cracks will crack. When the spot repeatedly acts on the rock sample, the crack will gradually expand and the number will gradually increase, and even the small rock fragments will be peeled off from the rock sample. As shown in Figure 6 , the phenomenon of debris splashing on the surface of the granite appears, and as the number of irradiation increases, the phenomenon of chipping on the surface of the rock sample is more severe. After repeated irradiation of sandstone, there is no phenomenon of debris spalling, and energy accumulates slowly on the surface of the rock sample.

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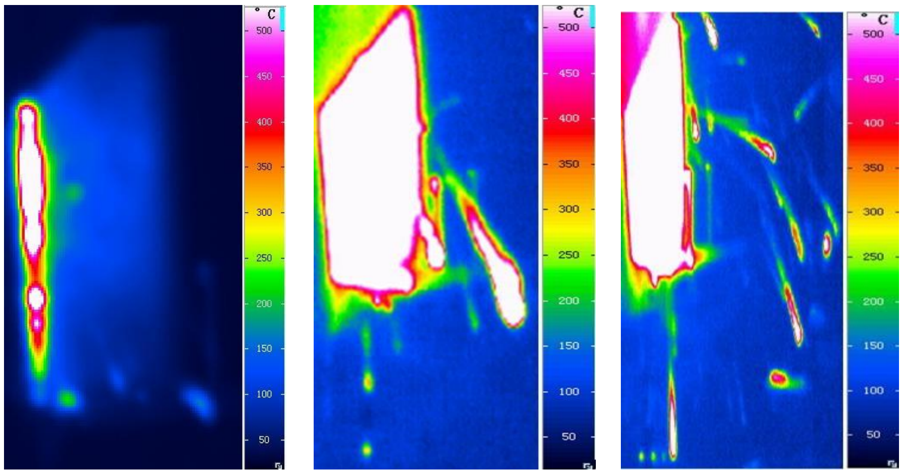
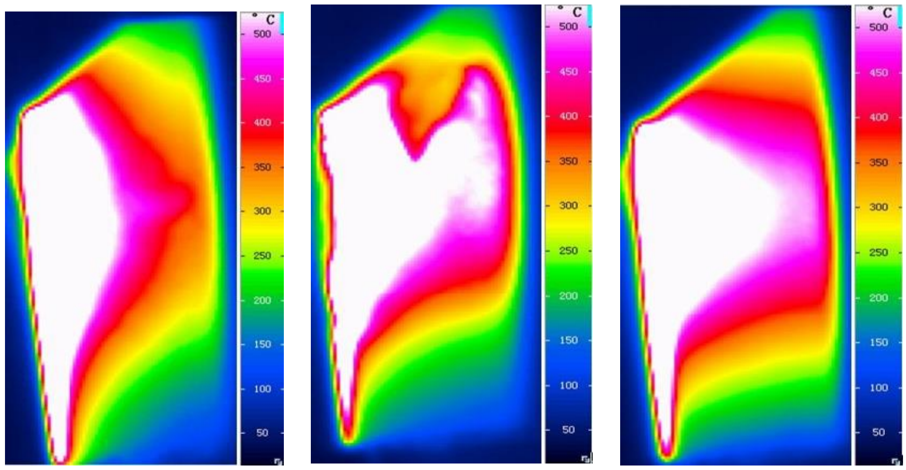


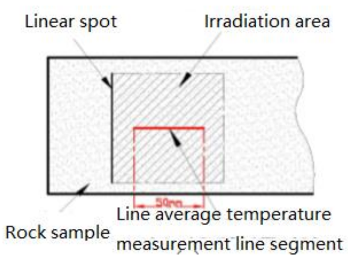
(a)Granite n=1 (b)Granite n=3 (c)Granite n=5



(d)Sandstone n=1 (e)Sandstone n=3 (f)Sandstone n=5

Figure 6 Thermal imaging of rock samples under different irradiation times

When the moving speed of the linear spot is v=10mm/s, the average temperature of the line increases continuously and is approximately linear as the number of times of spot irradiation increases, and the length of the line along the moving direction of the spot is 50 mm. When the number of irradiations is n=5, the average temperature of the granite and sandstone lines reaches a maximum value of 314 ℃ and 414 ℃, respectively. As shown in Figure 7(b). When the number of linear spot irradiations is n=3, the average temperature of the line decreases with the increase of the moving speed of the spot. When the moving speed of the spot is v=5mm/s, the average temperature of the granite and sandstone lines reaches the maximum, which is respectively 237 ℃ and 340 ℃. As shown in Figure 7(c). And the average temperature of the granite line under the same parameters is lower than that of sandstone. This is due to the spalling of the cuttings during the irradiation of the granite, which causes some of the thermal energy to be lost with the stripping of the cuttings, which makes the surface temperature distribution of the granite uneven, the heat accumulation ability is weaker than the sandstone, and the thermal energy distribution is not as uniform as the sandstone. as shown in Figure 8.



(a)Position diagram of line average temperature measurement

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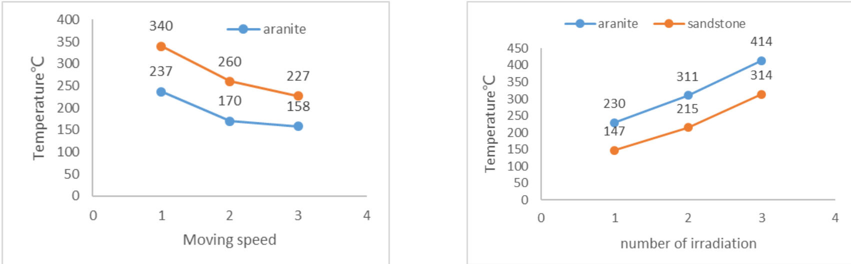
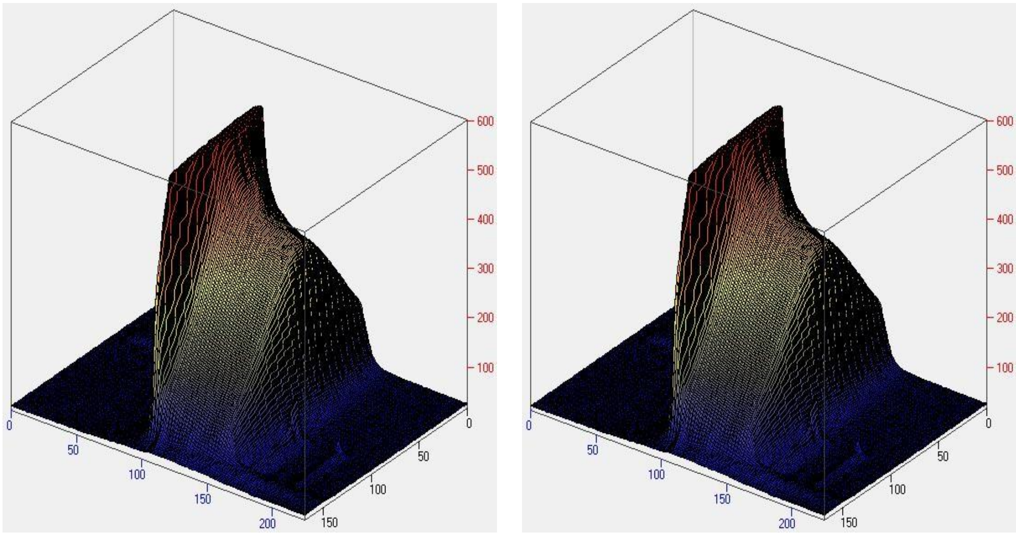


(b) rock sample under different irradiation times (c) rock samples at different moving speeds

Figure 7 Line average temperature



(a) Granite (b) Sandstone

Figure 8 Thermal distribution diagram

4. Conclusion

1) After the linear moving laser spot acts on the two kinds of rock samples, the surface of the granite has spalled off, and pits and gully cracks are formed on the surface of the rock sample, and the number of irradiation increases as the moving speed of the spot decreases. The phenomenon of rock sample spalling is more severe, and the gully cracks generated on the surface of the rock sample are more obvious and denser.

2) After the spot irradiance of the rock sample, the enamel vitreous body appeared on both rock samples, and the density was lower than that of the sandstone. After laser irradiation of the rock sample, the enamel body reflects light more strongly than other irradiated areas, absorbs less heat energy, and changes the temperature difference at the edge of the enamel body more, causing the edge crack and wrinkle concentration of the glaze. The enamel body on the sandstone surface is small and dense, and the position not covered by the enamel body is vaporized at a high temperature, and a large number of tiny cracks are formed between the enamel body and the enamel body. With the increase of the number of irradiations, the gasification phenomenon is intensified, and many micro-cracks gradually expand and eventually merge into the growth cracks. These cracks cause the rock sample to rise under the action of thermal stress.

3) After laser irradiation, the density and compressive strength of granite and sandstone are reduced, and the porosity is increased. The effects of laser spot movement speed and irradiation times on granite density, porosity and compressive strength are more significant than sandstone.

4) When the linear spot moving speed v=10mm/s, the average temperature of the granite and sandstone lines increases linearly with the increase of the number of spot irradiations. When the number of irradiations is n=5, the maximum value is reached, which is respectively 314°C and 414°C; when the number of linear spot irradiation is n=3, the average temperature of the line decreases with

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the increase of the moving speed of the spot. When the moving speed of the spot is v=5mm/s, the average temperature of the granite and sandstone lines reaches the maximum. Values were 237°C and 340° C, respectively. Under the same parameters, the average temperature of the granite line is lower than that of the sandstone and the thermal energy distribution is not as uniform as the sandstone.

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