Processing of diamond applying femtosecond and nanosecond laser pulses

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Abstract: Diamond array was braze welded on the stainless steel substrate which was processed applying femtosecond and nanosecond laser pulses with pulse duration 40 fs and 5 ns, respectively. The threshold of diamond processed using femtosecond and nanosecond laser pulses was deduced by measuring the relationship between fabricated area and laser power. The processing results show that the threshold of diamond processed by femtosecond laser pulses is lower compared with that processed by nanosecond laser pulses. The morphology of the processed region using differentkinds of laser sources was also compared with microscope. The processing of diamond applying femtosecond was confirmed more effective than that using nanosecond pulses.

Key words: diamond; femtosecond; nanosecond

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利用飞秒激光和纳秒激光脉冲加工金刚石

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摘 要： 分别利用脉宽在 40 fs 和 5 ns 的飞秒及纳秒激光脉冲加工了钎焊在不锈钢底板上的金刚石阵列。通过测量加工区域面积和入射激光功率的关系推断出了飞秒和纳秒激光脉冲加工金刚石材料的阈值。实验结果表明，相比于纳秒激光加工，利用飞秒激光加工金刚石的阈值更低。也利用显微镜比较了利用不同种类光源加工金刚石后加工区域的形貌。研究结果证明了利用飞秒激光加工金刚石相比于纳秒激光更为有效。

关键词： 金刚石； 飞秒； 纳秒

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0 Introduction

With the development of laser technology, ultrafast laser pulses especially femtosecond pulses have been applied in many fields[1-5]. In the field of material processing, machining of super hard materials has met great trouble using traditional method. Laser processing has been found efficient in this kind of materials processing such as silicon carbide and Al_2O_3[6-7]. Laser parameters such as repetition rate and pulse duration have been proven dominate on the effects of processing material such as silica and steel[8-9]. However, there still lack special researches about the interaction effects or morphology of typical superhard materials using different laser pulses duration in the region from nanosecond to femtosecond. In this paper, we report our experimental results of diamond array processing using femtosecond and nanosecond laser pulses. The morphology of diamond array using different kinds of laser sources with output pulse duration in femtosecond and nanosecond region are also researched.

1 Experiments

In our experiments, we use Ti: sapphire(Legend) system with the pulse duration 40 fs as the femtosecond laser source. The repetition rate is set at 1 kHz and the output wavelength is centered around 800 nm[10]. A Q-switched YAG nanosecond laser system (Power Lite Precision II 9010)is used as the nanosecond laser source with the repetition rate 10 Hz and pulse duration 5 ns at 532 nm. Polarizing disks are used to adjust the incident intensity of the femtosecond and nanosecond pulses since the output of the lase beams applied in our experiments are both ploarized. In our processing experiments, in order to improve the quality of the incident laser beam, both the femtosecond and nanosecond laser beam pass through special aperture before incident on the diamond samples.

In order to confirm the smooth surface of the diamond samples used in processing experiments lying in the same level, we braze weld the diamond array on the stainless steel substrate which is shown in Fig.1.

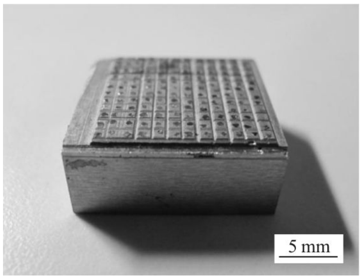

Fig.1 Braze welding diamond array used in the processing experiments

A work station (PI M521.DD) with three-dimension orientation accuracy $2*10^{-7}$ m is used as the processing platform[11]. A microscope(KENYENCE HVX1000) is used to research the morphology of the processing region.

2 Results and discussions

Supposing the incident processing laser beam is Gaussian beam, the power density profile of the incident beam at the surface of the diamond samples agrees with Gaussian distribution. According to Gaussian distribution, the power density decreases with the increasing of L, where L is the distance of the special research place lies from the center of the laser beam. The processing area of the diamond samples is[12]:

$$S=\frac{8\omega_0^2}{\pi}\ln\frac{2P}{\pi\omega_0^2 fF_{th}} \tag{1}$$

Where S is the processing area of diamond samples which equals to $\frac{\pi L}{4}$, ω_0 is the diameter of processing laser beam, F_{th} is the threshold of diamond samples, P is the power of processing laser and f is the pulses number of processing laser pulses per second.

From the above equation, the processing area of diamond samples decreases with the decrease of incident laser power. If we define the threshold of processing diamond the corresponding power when the processing area decreases to zero, the threshold of processing diamond samples can be expressed as follows:

$$F_{th}=\frac{2P_0}{\pi\omega_0^2 f} \tag{2}$$

Figure 2 is the experimental and fitting results of fabricated area under different femtosecond laser power. From this figure, it can be found that the fabricated area of diamond increases together with the increase of incident femtosecond laser power. Experimental and fitting results of fabricated area under different nanosecond laser power are shown in Fig.3, which is similar as the processing experiments using femtosecond laser pulses. Both the processing experimental results using femtosecond and nanosecond laser agree quite well with the fitting results according to Eq.1, which proves the reasonableness of function (1).

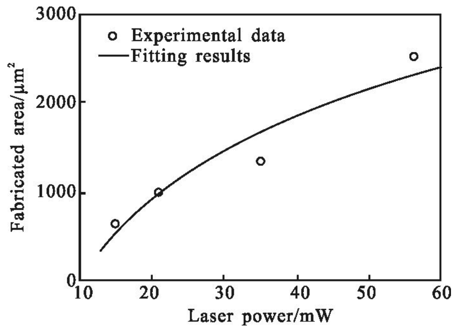

Fig.2 Experimental and fitting results of fabricated area under different femtosecond laser power

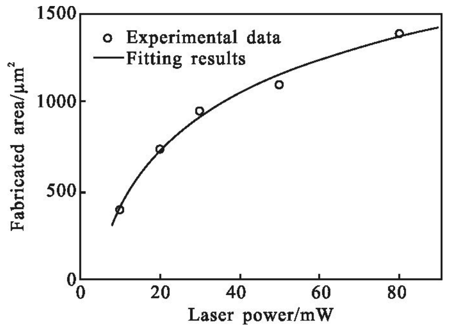

Fig.3 Experimental and fitting results of fabricated area under different nanosecond laser power

We can also get the threshold of processing diamond using femtosecond and nanosecond laser pulses 0.75 J/cm^2 and 0.90 J/cm^2, respectively, if we extend the fitting curve to the place where fabricated area equals to zero according to function (2). Our experimental results are quite close to those reported by D. H. Reitzeetal[13].

The processing results show that the threshold of diamond processed by femtosecond laser pulses is lower compared with that processed by nanosecond laser pulses. This means that the processing of diamond applying femtosecond is more effective compared with that using nanosecond pulses although the photon energy of femtosecond (1.55 eV) is much lower than that of nanosecond laser pulses (2.33 eV). We attribute this to the suppressed thermal effects of femtosecond laser processing.

We also take the photos of processed groove on diamond applying femtosecond and nanosecond pulses which are shown in Fig.4(a) and Fig.4(b), respectively, to investigate the morphology of the processed region. The power of incident laser is adjusted to 80 mW and the processing velocity is fixed at 0.1 mm/s. Under the same processing parameters, clear groove can be seen in Fig.4(a) with some cracks around the processing region applying femtosecond laser pulses. However, only a thin groove is found and regelation region lies around the processing position when processing diamond using nanosecond laser pulses as shown in Fig.4(b). This confirms our above conclusion that the processing of diamond using ultrafast laser is more effective than that applying nanosecond laser. The emergence of cracks in Fig.4(a) and regelation region in Fig.4 (b) indicates that the stress induced by processing laser pulses is much smaller applying femtosecond laser pulses.

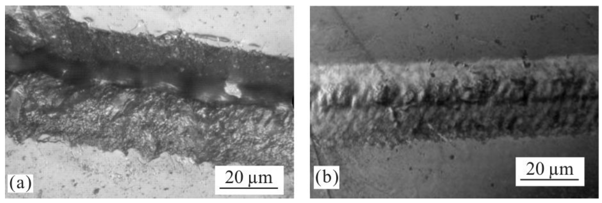

Fig.4 Morphology of fabricated groove on diamond using femtosecond pulses (a) and nanosecond pulses (b)

3 Conclusion

In this paper, diamond arraybraze welded on the stainless steel substrate was processed using femtosecond and nanosecond laser pulses with pulse duration 40 fs and 5 ns, respectively. The processing threshold of diamond applying femtosecond and nanosecond laser pulses was deduced to be 0.75 J/cm^2 and 0.90 J/cm^2 respectivelyby measuring the relationship between fabricated area and laser power, which is quite close to those reported in relative literature. The stress induced by femtosecond laser is found much lower than that by applying nanosecond laser by investigating the morphology of the fabricated regions. The processing of diamond applying femtosecond was confirmed more effective than that using nanosecond pulses.

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