JMEPEG (2006) 15:247-250
DOI: 10.1361/105994906X95968

1059-9495/$19.00

Laser Surface Preparation of Vitrified Grinding Wheels

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(Submitted November 4, 2005; in revised form December 22, 2005)

A new method for surface cleaning loaded grinding wheels is introduced by applying CO_2 laser irradiation onto the grinding wheel surface. It was demonstrated that effective cleaning can be achieved by selection of the laser power flux and the duration of the irradiation. Fusion and evaporation of clogged metal chips play important roles in the laser cleaning process. It is suggested that high laser power irradiance and short irradiation duration are essential for effective grinding wheel cleaning.

Keywords grinding wheels, laser cleaning, surface engineering, vitrification

1. Introduction

Wheel loading is one of the most common problems in grinding operations, particularly for grinding aerospace materials. As grinding continues, removed chips may accumulate in the space between abrasive grains and deteriorate the wheel's cutting ability. A common method to prevent wheel loading is to deliver a large amount of high-pressure coolant to the grinding zone. However, this consumes huge amounts of energy in coolant delivery, especially for high-speed grinding processes. Maintaining and disposing of coolant is also an environmental issue and the costs involved are substantial. Another method that is often used is removing loaded materials by dressing the wheel, thus restoring a sharp wheel surface. However, dressing of grinding wheels with diamond not only causes excessive wheel loss but also interrupts grinding during dressing. In addition, the dresser wears away with time owing to its physical contact with the wheel surface, thus limiting the degree of automation. Frequent use of dressing is also not acceptable for superabrasive wheels, the cost of which is considerable.

Lasers have been successfully applied to material removal processes such as laser cutting and drilling. Laser cleaning techniques have been used in removing oxide layers from valuable artefacts without damaging the delicate patina of the substrate (Ref 1, 2). This suggests that a laser cleaning technique may provide a solution to prevent or minimize wheel loading and maintain a sharp wheel surface.

Research on using lasers to dress grinding wheel surfaces has been reported (Ref 3-5). The results demonstrated that the use of a laser could be an option used in grinding wheel dressing. However, laser dressing did not show a great advantage over conventional dressing. The possible reason is that a high-powered laser not only removes bonding materials but also damages the abrasive grains that lead to higher grinding forces and higher wheel wear. A large degree of wheel wear introduces large grinding errors and is not acceptable for superabrasive grinding. It should be noted that the research has also pointed out that clogged chips can be removed through evaporation caused by laser radiation (Ref 3, 5). This suggests that a laser cleaning technique may be used to prevent or minimize wheel loading and maintain the sharp wheel surface created by touch dressing. By continually irradiating the loaded wheel surface with a particular degree of laser energy, it is possible to remove clogged chips without deteriorating the wheel surface.

In this paper, results from a series of experiments are compared, which demonstrated that vaporization and fusion of the chips are important mechanisms in removing debris from the wheel surface. The success of laser cleaning relies on the balance of an adequate energy flux and the duration of laser irradiation. This paper also discusses different phenomena associated with wheel cleaning and problems faced in the ability to clean the surfaces of grinding wheels.

2. Thermal Behavior of the Laser Cleaning Process

Laser cleaning a grinding wheel surface relies on a sufficient amount of energy irradiated on the wheel surface, cleaning clogged debris without damaging the wheel. Different melting points of different materials may provide an opportunity to achieve effective cleaning. Furthermore, other differential factors related to the interaction of the laser beam with the constituent parts of the loaded wheel should also be considered. The wheel grain, bonding material, and the embedded metal, in addition to their melting points, will have other properties that vary between them. These include optical reflectivity, thermal and optical conductivity, and specific heats. Understanding in detail how the laser reacts to these variations could be exploited to optimize the cleaning process.

When a laser beam irradiates on the wheel surface, it may be considered that energy flows in only one direction in a semi-infinite body. If there is no convection or heat generation, the basic equation becomes:

$$\frac{\partial^2 T}{\partial z^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \qquad \text{(Eq 1)}$$

This paper was presented at the fourth International Surface Engineering Congress and Exposition held August 1-3, 2005 in St. Paul, MN.

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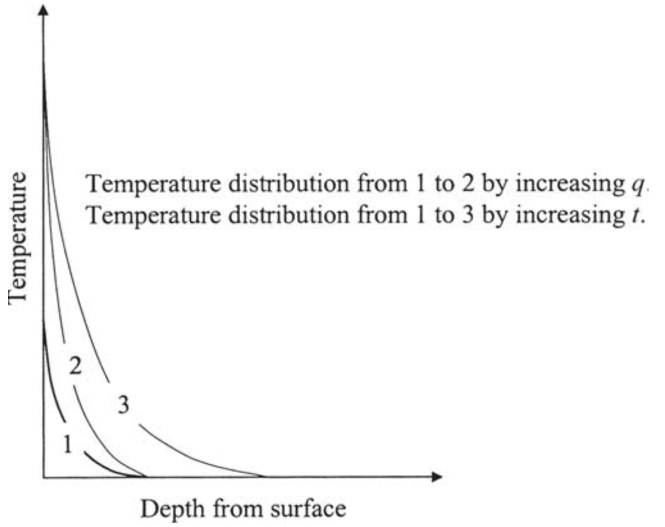

Fig. 1 Increase of surface temperature under different laser irradiation conditions

where T is the temperature in the wheel, z is the depth from the wheel surface, α is the thermal diffusivity of the wheel and t is the time after laser irradiation begins. If it is assumed that the laser power flux absorbed by the wheel is q, with no radiant heat loss, or melting, then the solution of Eq. 1 is:

$$T_{z,t} = \frac{2q}{K}\left\{\alpha\sqrt{t}\,\mathrm{ierfc}\left(\frac{z}{2\sqrt{\alpha t}}\right)\right\} \qquad \text{(Eq 2)}$$

where K is thermal conductivity and ierfc is an integral of the complimentary error function. Equation 2 indicates both q and t contribute the temperature elevation in the surface. The depth the laser energy penetrated into the wheel surface is constrained by the duration of the laser irradiation. Increasing irradiation time will allow the laser energy to penetrate deeper so as to raise the wheel substrate temperature. For a simple analysis, the temperature elevation on the surface can be simplified as:

$$T_{0,t} = \frac{2q}{K}\sqrt{\frac{\alpha t}{\pi}} \qquad \text{(Eq 3)}$$

Figure 1 illustrates the different effects of laser power flux and irradiation duration on the temperature elevation in the material. For the purpose of laser cleaning, higher surface temperatures are desirable for the removal of machining debris. However, the elevation of temperature under the wheel surface may damage the wheel structure, which should be prevented. Therefore, high power flux and short irradiation laser pulses are likely to be optimum for laser cleaning purposes.

3. Experimental Apparatus

A Ferranti CO_2 laser machine (Ferranti Photonics Ltd, Dundee, U.K.) was used to explore the effects of laser irradiation on the wheel surface and clogged metal chips. The laser wavelength is 10.6 μm. The laser beam diameter at the exit aperture in the cover is 11 mm. The maximum peak power is 2000 W with a pulse half-width of at least 0.1 ms when the preceding off time is longer than 3 ms. The laser output from the machine can be continuous wave or pulsed. For the investigation of laser energy transfer, pulsed output mode was used.

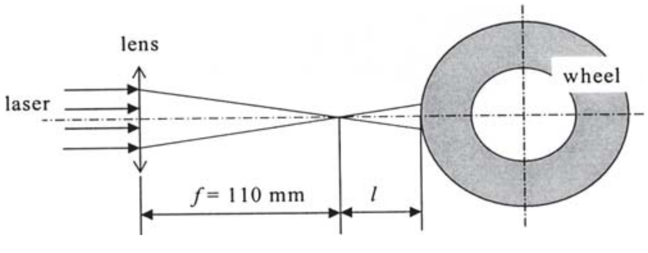

Fig. 2 Laser cleaning arrangement

As illustrated in Fig. 2, the laser beam passes through a convex lens and irradiates on a moving grinding wheel surface. The velocity of the wheel is 25.4 mm/s. A focused laser with high power density will cut through the wheel removing both cutting grains and clogged chips. Such a case can be considered as laser dressing. For laser cleaning however, the aim is for the laser beam to only remove clogged metal chips without damaging the wheel surface. This may be achieved by controlling the laser irradiation on the wheel surface. Two important parameters are the laser beam energy flux and the duration of laser irradiation. By adjusting the focal offset, l, between the lens focus point and the wheel surface, the laser irradiation energy flux can be controlled. A large focal offset will provide a large laser spot on the wheel surface. Hence, the laser power flux will be lower. Control of laser pulse duration and pulse frequency can also adjust the laser irradiation power level.

Longer laser pulse duration and higher pulse frequency will place more laser energy onto the wheel surface. Grinding wheel cutting surfaces were examined using a microscope with video camera fixed in position to observe the surface of the grinding wheel. Images were taken with an original magnification of 20×

4. Experimental Results and Discussion

A grinding experiment was carried out on the Jones & Shipman 540 surface grinder (Jones & Shipman, Farmington, CT) to obtain a loaded wheel surface for further laser cleaning experiments. A grinding wheel with specification, WA46JV6G, was used to grind Inconel 718 samples. Figure 3 shows Inconel material (bright areas) clogged in the wheel surface after a sample has been ground. Grains of the grinding wheel are transparent under normal light.

Different control parameters were selected for the laser cleaning experiments. Figure 4 shows an effective laser cleaning to the loaded wheel surface, where laser pulse duration is 20×10^{-5} s and laser pulse frequency is 19.9 Hz. When the laser is irradiated on the wheel surface, the clogged metal chips were melted and the wheel material was not damaged. The melted chips became dark spheres due to oxidation, scattering under the surface, and would tend to be expelled from the wheel when it rotated. This demonstrated that wheel cleaning could be achieved through chip fusion, or evaporation. For the focal offset $l = 10$ mm, the laser radiation power flux of the test was 2.5 kW/mm^2. For Al_2O_3 abrasives (Ref 6), the melting temperature is 2323 °C, thermal conductivity, K, is 0.360 W/cm °C, and thermal diffusivity, α, is 0.119 cm^2/s. Equation

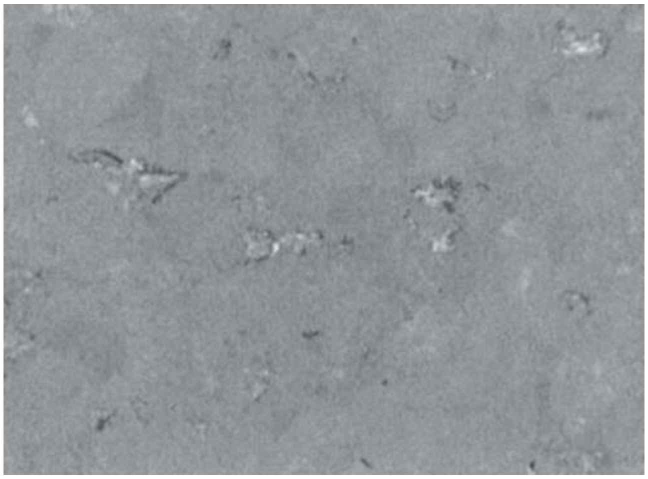

Fig. 3 Grinding wheel surface clogged with Inconel

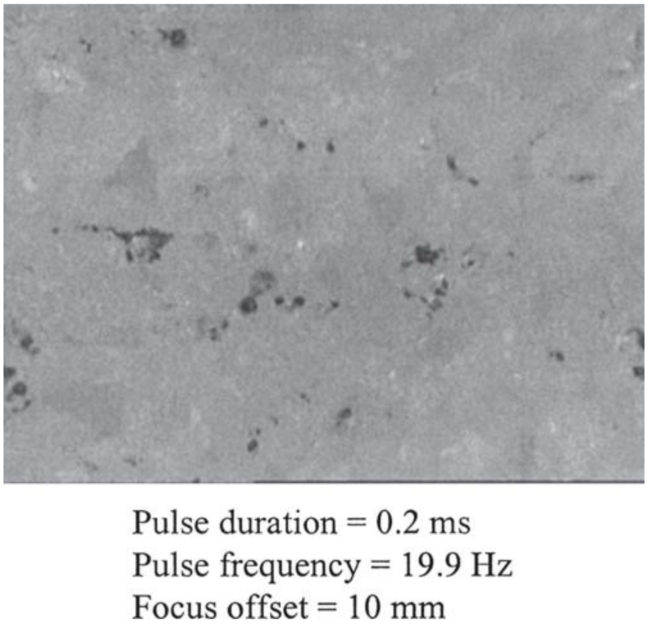

Fig. 4 Effective laser cleaning achieved by applying adequate laser power flux

3 shows that it requires 1.5 kW/mm^2 to allow the surface temperature to reach its melting point within 0.2 ms. Experimental observation shows there was no evidence of wheel surface damage, the laser absorption ratio of Al_2O_3 abrasives should therefore be less than 61%. The melting point of the IN718 is 1350 °C. Assuming the thermal conductivity of IN718 is 0.1016 W/cm °C and the thermal diffusivity of the IN718 is 0.0284 cm^2/s, then it requires 0.51 kW/mm^2 to allow the surface temperature to reach its melting point within 0.2 ms. Therefore, the ratio of the laser energy that went into Inconel was over 20%. For the IN718, the vaporization temperature is 2700 °C, therefore it only requires 1.02 kW/mm^2 to evaporate the metal within 0.2 ms. If there is more than 41% laser energy absorbed by the Inconel, then the clogged chips may be cleaned by evaporation. Therefore, loaded chip cleaning by laser may include fusion and evaporation.

By shortening the focal offset distance to 5 mm, the laser radiation power flux of the experiment became 10 kW/mm^2.

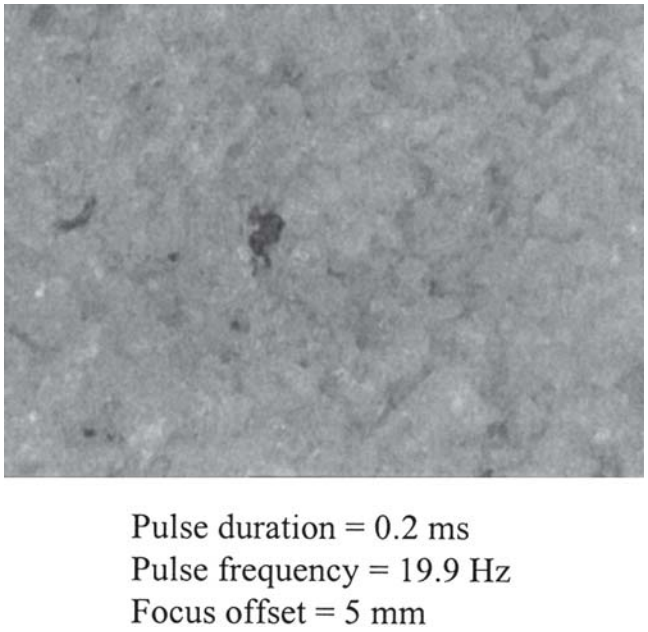

Fig. 5 Damaged wheel surface after laser cleaning

The higher density laser power flux removed the chips but also damaged the wheel surface, as indicated in Fig. 5. This also indicated that the absorption ratio of Al_2O_3 is higher than 15%.

Changing the laser pulse frequency, which means changing the number of laser pulses on the same wheel surface, can also control the level of laser irradiance. Damage to the wheel surface material could occur if the laser pulse frequency is too high. This indicated that too much energy was irradiated on the wheel surface.

Some interesting phenomena were observed during the experiments. Clogged debris chips remained in the wheel if a longer laser pulse length was used but with a low power flux. This was due to the heating process being much more gradual. The long pulse duration could, however, ultimately lead to a high overall temperature on the wheel surface, which may harm the wheel structure. Some metal chips clogged in the surface of the wheel are difficult to clean with low laser power flux, even using longer pulse duration. Longer laser irradiation may run more risk of wheel damage rather than contribute to chip removal.

Therefore, selection of correct parameters for laser irradiation is very important for an effective and reliable cleaning process. As demonstrated in Fig. 4 and 5, chip fusion could play an important role in wheel cleaning.

5. Conclusions

A feasibility study has been carried out to investigate the application of laser technology in the grinding process. By irradiating an infrared (IR) laser on the loaded wheel surface using carefully set control parameters, it is possible to remove clogged metal chips without deteriorating the wheel's cutting surface. Both fusion and evaporation of metal chips are important for the laser cleaning process. Effectiveness of laser cleaning relies on the different material melting temperatures and other thermal properties. Suitable laser parameters are identified through process thermal analysis and it was suggested that high power flux and short irradiation laser pulse would be ideal for the laser cleaning purpose. Precise control of laser irradiation is important for an effective and reliable laser cleaning process.

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