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Laser Dressing of Alumina Grinding Wheels

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High-power lasers are being explored as a non-contact-type dressing tool for alumina grinding wheels. The alumina grinding wheel surface underwent melting and/or vaporization on the surface when laser-dressed, forming a modified layer on the surface. Refinement of the grain size took place. The individual particles that formed on the surface had well-defined faceted structures. Microcutting edges were generated on the individual grains and particles, which can act as cutting edges for efficient grinding. The results of x-ray diffraction and pole figure analysis suggested that the formation of these faceted structures was due to the preferential orientation of the grains after dressing.

Keywords alumina, grinding, lasers, surface preparation

1. Introduction

The loss of grinding efficiency due to a reduction in the number of cutting edges on the grinding wheel surface is one of the most common problems associated with the grinding operation. The abrasive particles on the grinding wheel surface get worn out, and also the porous nature of the wheel results in the clogging of metal chips in the wheel surface (Ref 1) during grinding, which results in a reduction of grinding efficiency. To maintain a high efficiency in the process, the cutting face of the wheel has to be restored. This is done by dressing, which is a sharpening operation that is designed to generate a particular surface topography on the cutting face of the wheel. The modification of the surface topography strongly influences the wheel performance and improves the grinding efficiency (Ref 2).

Dressing affects the quality of the ground product significantly, as characterized by its size, shape, surface roughness, and integrity (Ref 3). The conventional contact-type methods, like mechanical dressing using a diamond dresser, results in excessive material loss from the grinding wheel (Ref 4). Mechanical dressing induces stresses causing deep cracks that undercut the grinding wheel. These factors eventually cause loosening of the chunks of grains and reduce the number of effective cutting edges (Ref 1). The laser is an efficient tool to process ceramic materials due to its high intensity and directionality. Laser dressing can be performed on a grinding wheel to generate surfaces with sharp cutting edges, either by locally modifying the worn-out particles and/or by dislodging the loaded metal chips. Focused laser radiation produces enormous power densities in a very small region of the wheel surface and thus can cause a localized modification of either the exposed grain or the bond. Some of the major advantages of the use of a laser for dressing operation are:

- Control over the spot size
- Fast processing and easy automation
- Ease of beam delivery to the workpiece via an optical fiber cable, thus making remote dressing possible
- Selective removal of the clogged material alone is possible
- Consistent dressing conditions, by which grinding reproducibility is expected

2. Experimental Work

Commercially available 0.25 wt.% chromia-doped alumina grinding wheel pieces were laser-dressed with varying laser power. Abrasive grains have Fe_2O_3 and Na_2O in small amounts, whereas the bonding system was made up of SiO_2 and Al_2O_3 as major components (~85 wt.%) and Na_2O, K_2O, P_2O_5, and CaO as minor components. A 2.5 kW Hobart (Rochester, Kent, U.K.) continuous-wave Nd:YAG laser equipped with a fiberoptic beam delivery system was used for dressing an Al_2O_3 grinding wheel. The laser beam was focused at a height of 0.5 mm above the surface of the wheel. The lenses within the output-coupling module of the fiberoptic delivery system were configured to provide a 3.5 mm × 600 μm rectangular beam in spatial distribution onto the sample surface. Such a configuration provides rapid processing speed and limits the overlap between the laser passes to less than 20%. Laser power intensities of 500, 750, and 1000 W were used. Dressing of the entire surface was done by scanning the laser beam in parallel tracks at a linear speed of 50 cm/min on the surface, as shown by the schematic diagram in Fig. 1.

A slow-speed diamond-laced wheel was used for the stress-free cutting of the dressed wheel samples for further characterization. Microstructural analysis was done using scanning electron microscopy (SEM). To minimize charging during SEM, a low vacuum (~30 Pa air) was maintained in the SEM chamber. A Philips Norelco X-Ray diffractometer (Amsterdam, The Netherlands) with CuK_α radiation operating at 40 kV and 15 mA was used to characterize the dressed wheel surface in terms of the phases present. Furthermore, pole figure measurements were made to identify the texture in the grinding

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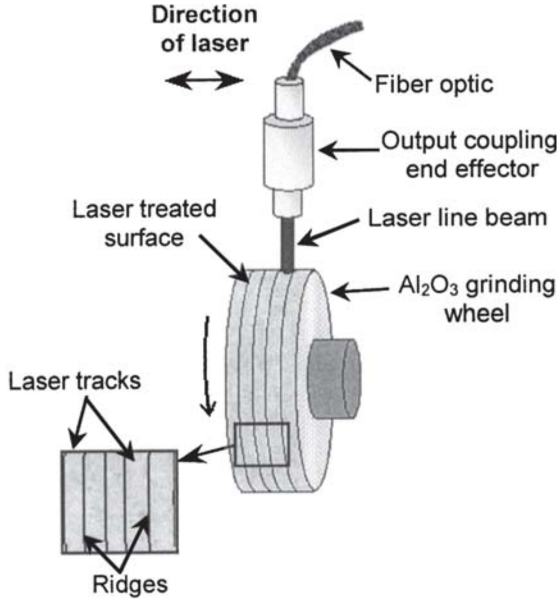

Fig. 1 Schematic of the laser dressing of the Al_2O_3 grinding wheel

wheel using a Philips X'Pert Analytical Diffractometer (Sunnyvale, CA). The instrument was operated at 45 kV and 40 mA, using CuK_α radiation through a point source. The reflection method was used for pole figure analysis, with ϕ varying between 0 and 360°, and ψ varying between 0 and 85°. Planes with higher relative intensity in the normal x-ray diffraction (XRD) plots (2θ vs. intensity) were analyzed for their pole figures.

3. Experimental Results and Discussion

Figure 2(a) shows the as-received grinding wheel surface when observed using SEM, and Fig. 2(b) shows the change in the surface structure after dressing. The as-received wheel surface has relatively large particles (100–150 µm) with considerable porosity in between. The particles are irregular in shape with a few bonding bridges between them. The addition of Cr_2O_3 gives the grinding wheel its characteristic pink color. Depending upon the laser-processing parameters used, the high thermal energy produced during laser processing caused melting and/or vaporization of the grinding wheel material on the surface. Thus, both melting (followed by resolidification) and/or vaporization resulted in the modification of the surface topography (i.e., morphology and composition). The melted material resolidified very fast, as a layer on the surface. Using different laser-processing parameters (i.e., beam focus, power, and transverse speed), the extent of the modified layer on the surface can be controlled for various surface topographies. Dressing of the grinding wheel was accomplished by well-defined laser-generated grooves/tracks on the wheel surface. Microstructural analysis also revealed microcracks and refinement of the grain structure.

Laser dressing produced microcutting edges on the worn-out grains in the wheel. Grains in the newly formed and resolidified layer were of modified geometry and were characterized by multifaceted surfaces. The particles were symmetric with well-defined vertices and edges on each particle. One such particle is shown in Fig. 3. The vertices and edges are expected to provide cutting facets for improved grinding efficiency.

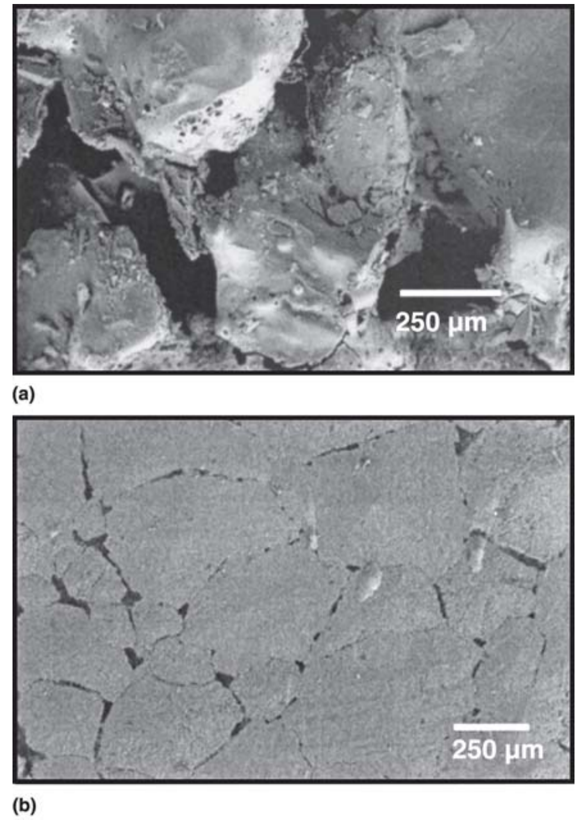

Fig. 2 Microstructure of the grinding wheel surface (a) as-received and (b) post-laser-dressed (500 W)

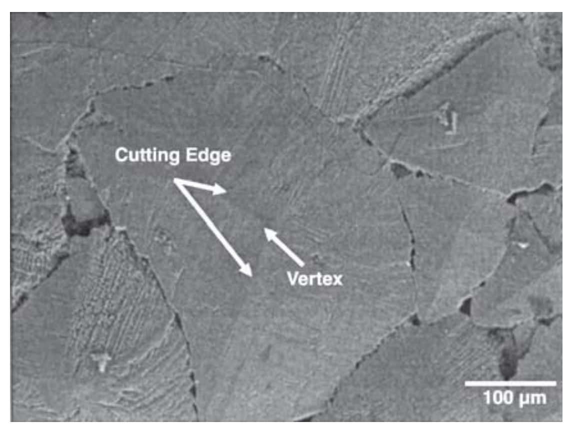

Fig. 3 Morphological features on a laser-dressed sample (1000 W). An individual particle with cutting edges is shown.

XRD analysis of the as-received samples, as well as the laser-dressed samples, showed corundum (αAl_2O_3) as a primary phase. However, the intensity of the few individual peaks was significantly higher than that of others in the laser-dressed samples, indicating preferential orientation. Pole figure analysis was done for selective 2θ angles chosen from the XRD plots, corresponding to the peaks with higher relative intensity. Table 1 indicates the poles and the corresponding planes that were analyzed. Also, the data in Table 1 qualitatively compare the nature of the pole figures obtained for these poles at different laser powers as well as for those in the undressed sample.

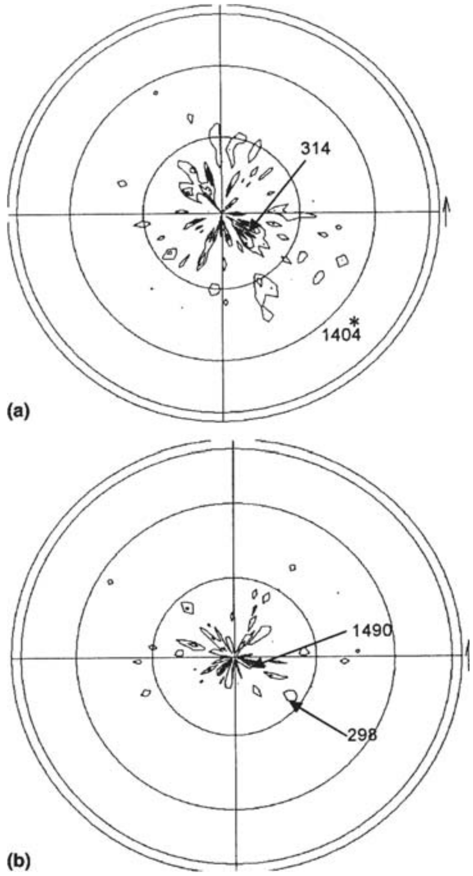

Fig. 4 Pole figure for the (012) plane in (a) the as-received sample and (b) the laser-dressed sample. *, intensity on an arbitrary scale

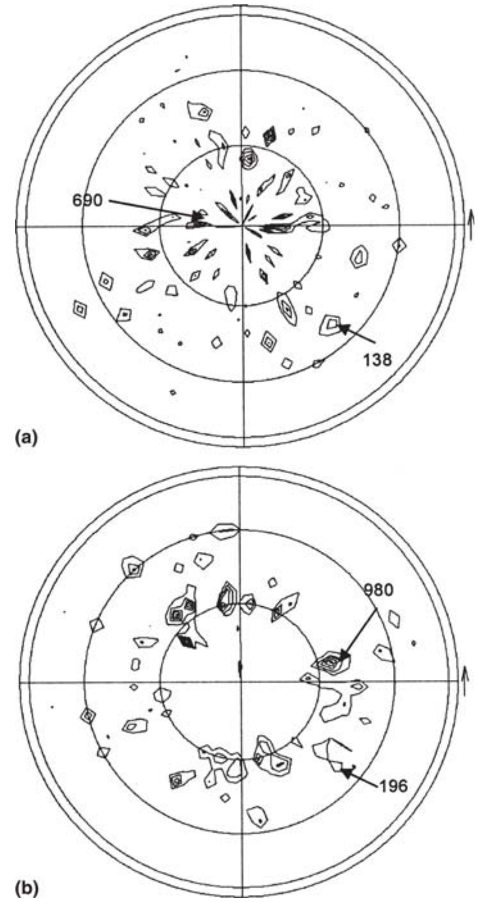

Fig. 5 Pole figure for the (214) plane in (a) the as-received sample and (b) the laser-dressed sample

Table 1 Qualitative comparison for the pole figure analysis at different 2θ angles for the undressed and laser dressed samples at different powers

2θ°	Plane	Undressed sample	500 W	750 W	1000 W
25.57	(012)	S	CC	CC	CC
57.50	(116)	CC	S	S	S
37.76	(110)	S	CC	CC	CC
66.50	(214)	S	R	R	R
35.15	(104)	S	CC	CC	CC

CC, concentrated about the center in a symmetric way; R, poles are arranged in a concentric ring about the center; S, scattered

The scattered peaks in the pole figure indicate the absence of any preferential orientation, whereas if the peaks are concentrated symmetrically about the center, then the sample has a preferential orientation for that plane. For the planes analyzed during the experiments, the (012), (104), and (110) planes were scattered in the undressed sample. After laser dressing, they were concentrated about the center. Figure 4 is an example of this. The labels on the pole figures indicate the intensity of the line profiles of the peaks on an arbitrary scale. The (116) plane, which was the most prominent peak in the as-received sample, was reduced in intensity in the laser-dressed material. For this plane, the corresponding pole figure after laser dressing had all the poles scattered. For the (214) plane, the poles were scattered in the undressed condition, but, after dressing most of them, the poles were arranged in a concentric ring about the center (Fig. 5), indicating an orientation of the peaks at an angle to the sample surface. The (110) plane, which was almost in the background in the undressed sample, became the plane with the highest intensity after laser dressing. Thus, the (110) plane appeared to have the highest preferential orientation after dressing. The faceted structure on the surface of the particles is possibly a result of such preferred orientation. This gives an indication of texture formation on the surface as a result of laser dressing. The identification of planar textures due to laser dressing is important as the (atomic) planar density is expected to influence the grinding characteristics, the grinding performance, and the lifetime of these grinding surfaces.

4. Conclusions

Laser dressing can be developed as a dressing tool with precise control over the processing parameters. A very narrow zone is processed at any given time, thus reducing the grinding wheel material loss. Refinement in the microstructure is seen after laser dressing. Densification of the surface and the subsurface structure took place. The particles formed on the surface after dressing are of a specific geometry, with multifaceted surfaces having well-defined cutting edges and vertices on them. Particles on the surface have a preferential orientation after laser dressing.

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