Micromachining of Al_2O_3-TiC ceramics by excimer laser

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Abstract Micromachining of Al_2O_3-TiC ceramic using a KrF excimer laser was studied in the fluence range 2 to 8 J/cm^2. The ablation rate decreases and the roughness increases with the first pulses but after about 200 pulses the process reaches a stationary stage where both roughness and ablation rate become constant. Observation of the processed areas by scanning electron microscopy showed that a globular topography is formed during the first stage and that the surface topography remains unchanged with further pulses. This globular topography is responsible for the variation of roughness and ablation rate observed during the first stage. EDS analysis showed that the globular features present an external region with higher titanium content and a core formed of unaffected material.

Keywords: **Excimer laser. Micromachining. Ablation. Ceramics. Al_2O_3-TiC.**

Micromecanizado de Al_2O_3-TiC mediante láser de excímero

Resumen Se estudia el micromecanizado de cerámicas Al_2O_3-TiC mediante un láser de excímero de KrF con un rango de fluencia de 2 a 8 J/cm^2. La velocidad de ablación disminuye y la rugosidad aumenta con los primeros pulsos. Sin embargo, después de 200 pulsos, el proceso alcanza el régimen estacionario, donde tanto la rugosidad como la velocidad de ablación permanecen constantes. La observación mediante SEM de determinadas áreas mostraban una topografía globular formada durante la primera etapa, mientras que con los siguientes pulsos permanece in cambios. Esta topografía globular es responsable de la variación de rugosidad y de la velocidad de ablación observada durante las primeras etapas del proceso. Los análisis de EDS sobre las zonas globulares mostraron la existencia de una región externa rica en titanio y un núcleo formado por el material sin afectar.

Palabras clave: **Láser de excímero. Micromecanizado. Ablación. Cerámicas. Al_2O_3-TiC.**

1. INTRODUCTION

Laser micromachining presents characteristics that are particularly well adapted to the production of miniaturised components of complex shape, such as magnetic head sliders. In the present paper we report results of a study on laser micromachining of Al_2O_3-TiC using a KrF excimer laser.

2. EXPERIMENTAL

The ceramic composite used in this work was isostatically pressed from a powder mixture containing 66 mass % Al_2O_3 and 34 mass % TiC. The radiation source was a KrF Lambda Physik LPX 305 laser, operating at 248 nm, with pulse length of approximately 20 ns. Details of the experimental procedures were given in previous publications (1 and 2).

After irradiation, the topography of the laser processed areas was investigated by optical profilometry and scanning electron microscopy (SEM). High resolution SEM and chemical analysis were performed using a field emission gun SEM with energy dispersive spectrometry (EDS) attachment.

3. RESULTS

Figure 1 shows the variation of the removal depth per pulse with the number of pulses for laser fluences of 2 and 8 J/cm^2. As can be seen, there is a

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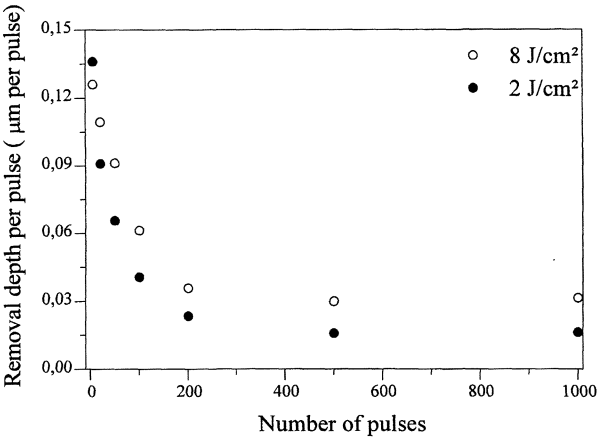

FIG. 1.— Removal rate per pulse vs number of pulses at laser fluences of 2 and 8 J/cm^2.

FIG. 1.— Velocidad de eliminación por pulso frente al número de pulsos para fluencias láser de 2 y 8 J/cm^2.

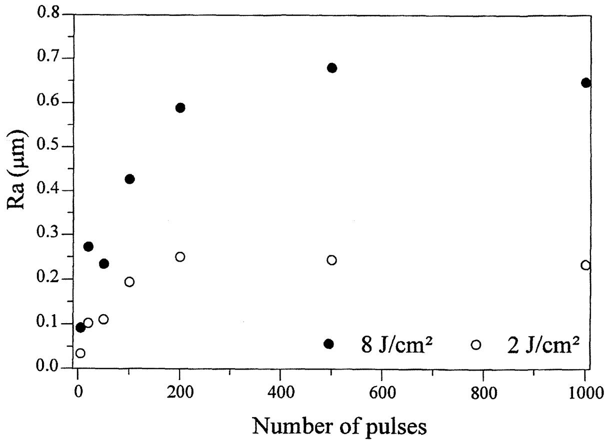

FIG. 2.— Surface roughness versus number of pulses at laser fluences of 2 and 8 J/cm^2.

FIG. 2.— Rugosidad superficial frente al número de pulsos para fluencias láser de 2 y 8 J/cm^2.

significant fall in the removal rate with increasing number of pulses, until it reaches a constant value after 200 pulses. This value increases with higher laser fluence.

The roughness of the machined surfaces first increases with increasing number of pulses and then reaches a constant value after approximately 200 pulses (Fig. 2). The roughness also increases with increasing laser fluence.

The SEM micrograph in figure 3 shows the surface morphology of areas irradiated with 50 and 200 pulses at 6 J/cm^2. After processing with 50 laser pulses, globular features appear at the processed surface. After 200 laser pulses the surface is completely covered by these globules and the mean globule size increases. A further increase in the number of pulses up to 1.000 does not change the surface morphology significantly. The growth of this laser modified layer is certainly responsible for the variation observed in both removal rate and roughness.

The microstructure of the surface layer, revealed in fractured globules (Figs. 4-8), consists of an unaltered internal (core) region (Fig. 5), and a featureless titanium rich outer layer (Fig. 7).

4. DISCUSSION

It was shown in a previous paper (3) by AES and EPMA analysis, that the globules which formed after laser irradiation are rich in titanium, carbon and oxygen, and that the region between globules is

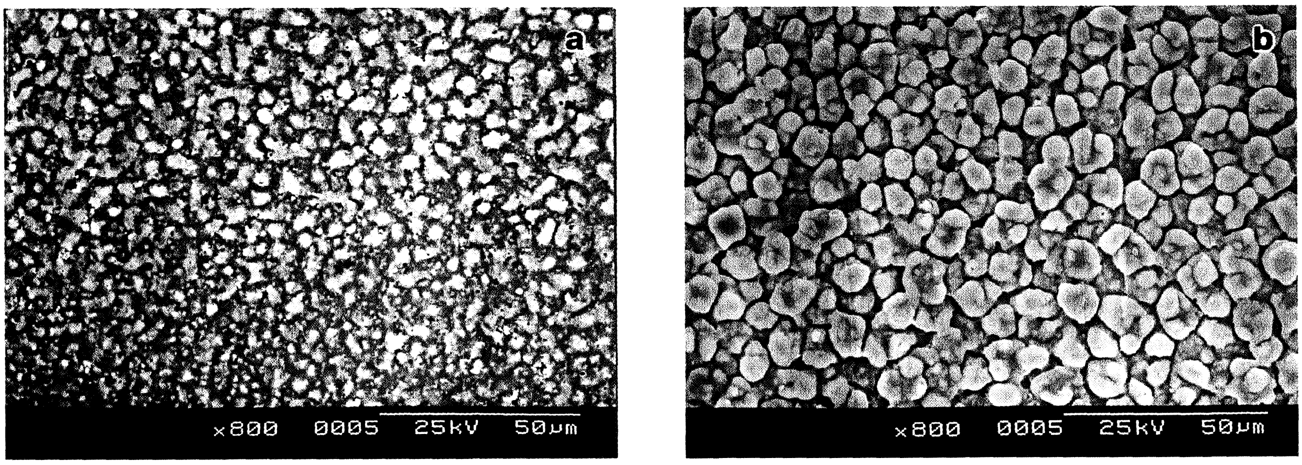

FIG. 3.— SEM micrograph of surface areas irradiated with 6 J/cm^2 and a) 50 pulses, b) 200 pulses.

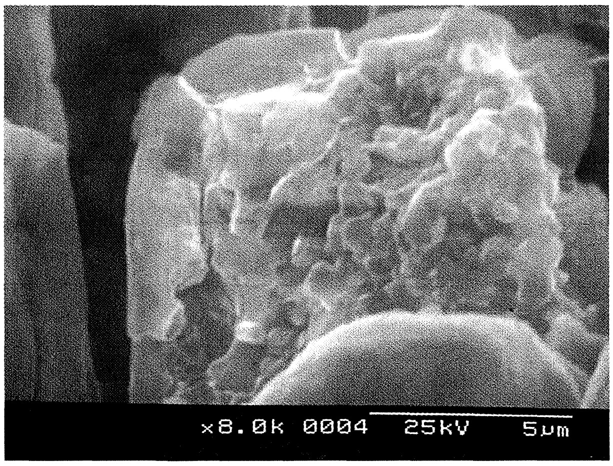

FIG. 4.— SEM micrograph revealing microstructure of the surface layer.

FIG. 4.— Microestructura superficial de las capas obtenidas.

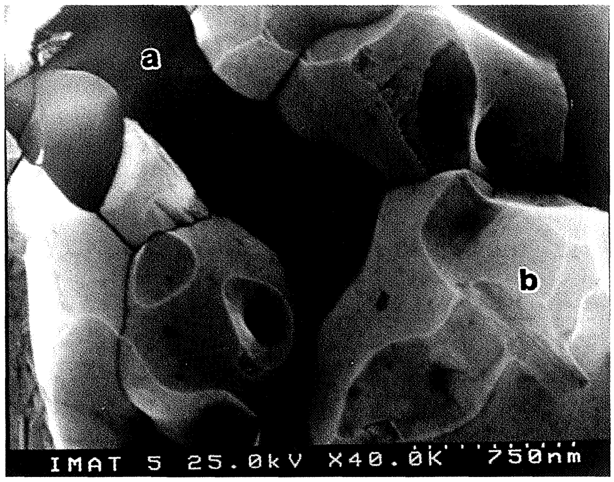

FIG. 5.— FE-SEM micrograph showing the internal region of a globule.

FIG. 5.— Micrografía de la zona globular.

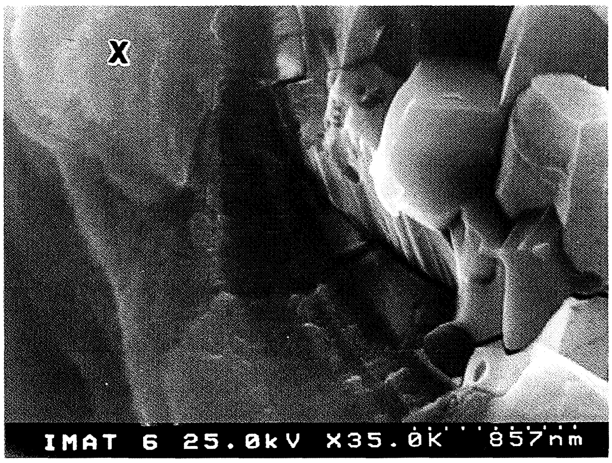

FIG. 7.— FE-SEM micrograph showing the external layer of a globule

FIG. 7.— Micrografía de la capa externa de un globulo.

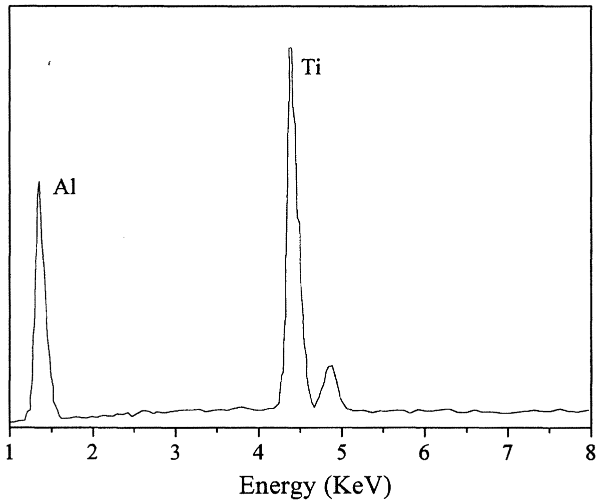

FIG. 8.— EDS spectrum taken at the point indicated in the micrograph of figure 7.

FIG. 8.— Espectro de EDS en la zona globular de la figura 7.

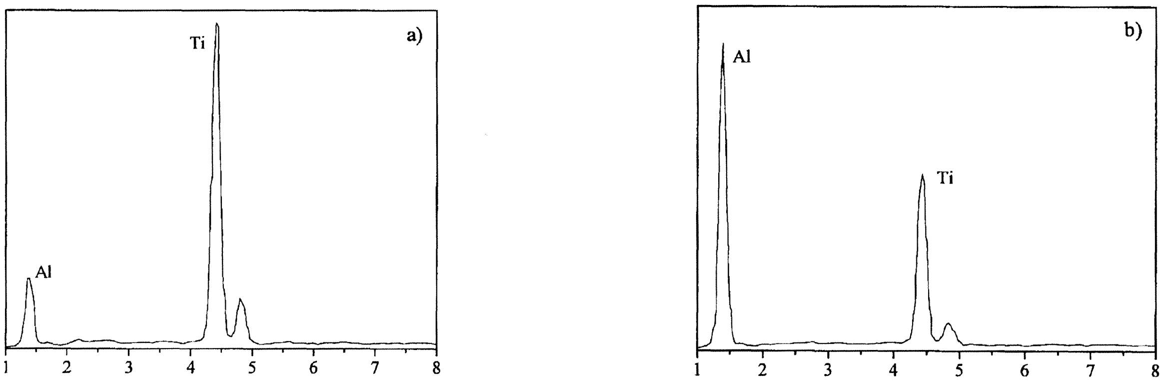

FIG. 6.— EDS spectra taken at the regions marked in the micrograph of figure 5.

FIG. 6.— Espectro de EDS en la zona globular de la figura 5.

rich in aluminium. It was suggested that a differential ablation mechanism was responsible for the formation of the globules. In the present paper it is shown that each globule presents two different regions: an external layer rich in titanium, in agreement with the results obtain by EPMA and AES, and an internal region or core consisting of two different phases, one rich in titanium and another rich in aluminium, similar to the material in pristine condition.

These new results reinforce the conclusion that a differential ablation mechanism is responsible for the observed topography. A higher ablation rate for alumina, possibly because of an electronic ablation mechanism for excimer laser ablation of alumina, as suggested by other authors (4-6), would leave a TiC rich layer behind, and a lower ablation rate of this phase would act as a shield for the underlying material. A differential mechanism of this kind would accordingly explain the external layer rich in titanium, and the unaltered core.

5. CONCLUSIONS

1. The roughness and the removal rate of $A1_2O_3$-TiC ceramic samples irradiated in air with 2 to 8 J/cm^2 KrF excimer laser light depend strongly on the number of laser pulses up to 200 pulses, then become constant. The ablation rate in stationary regime is 0.015 and 0.032 µm/pulse at 2 and 8 J/cm^2 respectively.
2. Removal rate and roughness increase with laser fluence. The limiting roughness increases in the range 0.12 to 0.65 mm when the fluence increases from 2 to 8 J/cm2.
3. The variation of roughness and removal rate is due to the formation of a globular surface layer. Each globule of this layer presents an external layer rich in titanium and an internal region presenting two different phases, one rich in titanium and another rich in aluminium.
4. The observed topography can be explained by differential ablation, alumina being rapidly laser sputtered by an electronic mechanism, and titanium carbide being ablated through a predominantly thermal effect.

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