JOURNAL OF MATERIALS SCIENCE 6 (1971) 126-129

The Machining of Oxides Using Gas Lasers

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The use of CO_2-N_2-He gas lasers in the cutting and engraving of oxide materials is demonstrated. The materials investigated were vitreous silica, zirconia, alumina, magnesium aluminate spinel, magnesia and aluminous porcelain.

1. Introduction

The coherent 10.6 μm radiation emitted by CO_2-N-He gas lasers is almost completely absorbed by oxide materials. Such lasers are therefore potentially useful as a heat source in processes which involve the melting or evaporation of oxides. This capability has been demonstrated recently in the single crystal growth [1-3] and spheroidisation of refractory oxides [4]. The present work describes a further development which demonstrates the use of gas lasers for cutting and engraving various oxide materials. In particular, the machining of helical grooves for containing resistance heater windings is examined.

2. Experimental Details

A 50 Hz AC-energised CO_2-N_2-He gas laser supplied by Ferranti Ltd was used in these experiments. The output power of the laser could be varied within the range 50 to 500 W. For machining, the laser beam was directed and converged normal to the surface of cylindrical test specimens by using a mirror system attached to an extension table on the saddle of a metal working lathe. The test specimens were positioned in the lathe chuck. The essential features of the apparatus are illustrated in fig. 1 for both cutting and engraving configurations. A mirror with a long focal length ($f = 50$ cm) was used to converge the laser beam so that the diameter of

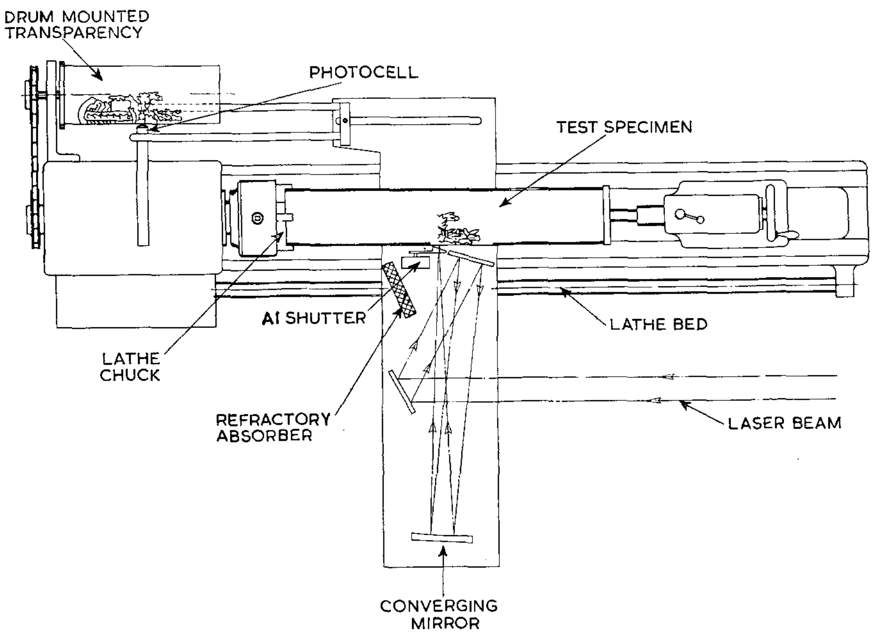

Figure 1 A schematic arrangement of the optical system and lathe used in the engraving process. In direct cutting and grooving the aluminium shutter, photocell and synchronous drum motion are not used.

the beam incident upon slightly oval shaped or eccentrically mounted specimens remained essentially unaltered during rotation in the lathe.

Commercially available oxide ceramics in the form of tube, bar or crucibles were used for the investigation. The materials examined were vitreous silica, zirconia, alumina, magnesium aluminate spinel, magnesia and aluminous porcelain.

3. Results

3.1. Grooving and Cutting

Grooving and cutting operations were most readily performed on vitreous silica because this material has a high vapour pressure when molten and is therefore easily evaporated by a focused laser beam. Furthermore, the material has a good thermal shock resistance and does not readily crack under the steep temperature gradient

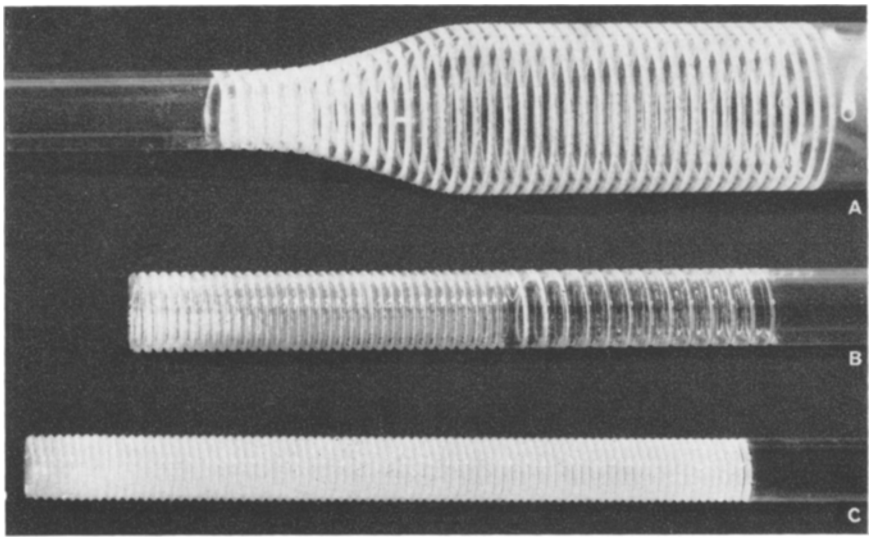

Figure 2 Helically grooved vitreous silica: (a) variable section tube (2.8 cm—1.2 cm diameter). (b) 1.2 cm diameter tube. (c) 0.9 cm diameter rod.

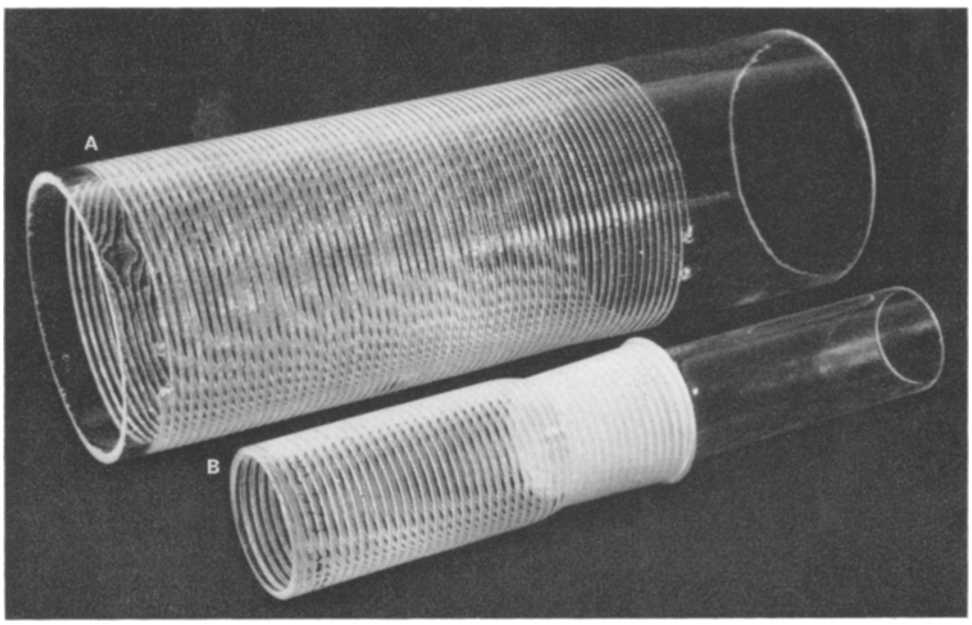

Figure 3 Helically grooved vitreous silica: (a) 8 cm diameter. (b) 3.8 cm diameter.

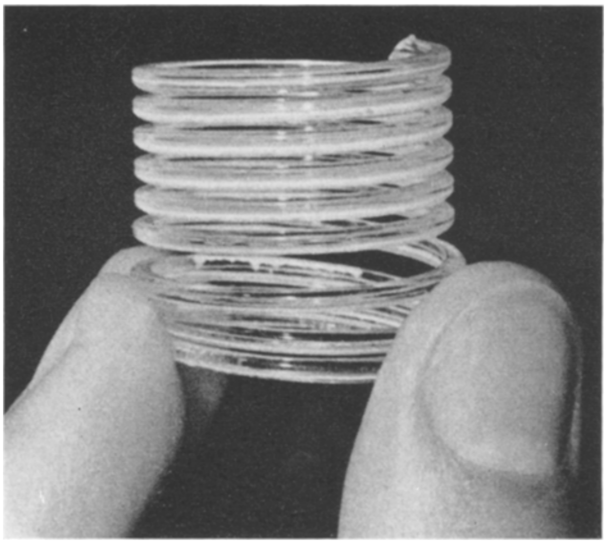

Figure 4 A vitreous silica spring cut from 2.8 cm diameter tube.

conditions which exist in regions adjacent to the cutting zone. Figs. 2 and 3 show rods and tubes on which helical threads have been grooved by a laser beam of 100 to 150 W power focused to approximately 0.5 mm diameter. Normal rotational and translational movements of the lathe were employed to produce the helix. Figs. 2a and 3b particularly, show the uniformity of grooves cut in tubes of uneven section whilst keeping the focusing mirror at a fixed distance from the test specimen.

An increase in laser output power to 200 W with a beam diameter slightly less than 0.5 mm, causes complete penetration of the tube wall and produces springs of the type shown in fig. 4. Springs up to 5 cm long with an elasticity of 50% have been made in this way.

Grooving can also be carried out on pressed and sintered materials which are substantially below their theoretical density because localised heating in the laser beam produces further densification. This is very useful for non-volatile materials. A typical example is given in fig. 5 which shows a zirconia crucible, originally sintered to 75% of the theoretical density, grooved by further densification using a 2 mm diameter laser beam at a power of 300 W. Grooves separated by as little as 1 mm have been produced by a 0.5 mm diameter beam. Similar effects have been obtained with magnesia where machining occurs by a combination of evaporation and a localised increase in density. The depth of the groove becomes difficult to control when the density of the material is less than approximately 60% of the theoretical value.

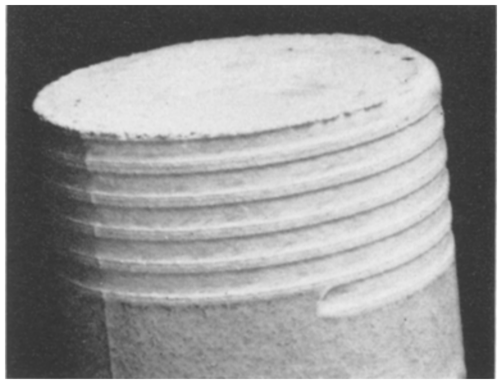

Figure 5 A helically grooved zirconia crucible (5.3 cm diameter).

Fully recrystallised or highly dense materials which have a low vapour pressure at the melting point, such as alumina and spinel, cannot be machined readily to give accurate smooth grooves. However, a limited amount of material can be removed by spalling. In this case, a laser beam focused to 0.5 mm diameter at a power of 300 W has been used to melt the surface of the material and form a trail of small recrystallised spheres which are easily abraded to leave a shallow groove. Attempts to produce deeper cuts by reprocessing the same groove have usually resulted in the development of cracks and have therefore generally been unsuccessful.

The mode of operation of an AC-laser, which is energised for only a portion of each half cycle [2], limits the speed at which the item being machined passes through the beam. Continuous and relatively smooth grooves can be cut at peripheral speeds up to 5 cm sec^{-1} for a laser beam diameter of 0.5 mm. At greater speeds, or a smaller beam diameter, the machining effect of each pulse begins to be resolved as a series of separate indentations in the surface of the test specimen.

3.2. Engraving

Engraving has been carried out on cylindrical specimens by arranging for a high speed motor-driven aluminium shutter either to intercept or pass the laser beam on to the specimen surface in response to signals from a photocell (fig. 1). The photocell detects black lines on a picture transparency fastened to a drum rotating synchronously with the lathe chuck. The system is so arranged that the occurrence of a black line in the transparency causes the shutter to rotate and thereby allows the laser beam access to the specimen surface. When the line has been traversed the shutter returns to the original position and deflects the beam into a refractory capable of absorbing 10.6 μm radiation. Fig. 6 shows the results of preliminary engraving experiments on vitreous silica, aluminous porcelain and recrystallised alumina. Engraving has been effected by evaporation, sintering and spalling processes respectively, for the three materials. These results were obtained by scanning the transparency and test specimens with a resolution of 20 lines cm^{-1}, using a beam power of 50 W, a beam diameter of 0.5 mm and a peripheral speed of 5 cm sec^{-1}.

4. Discussion and Conclusions

The present work clearly demonstrates the feasibility of using a CO_2-N-He gas laser as a tool for machining oxide laboratory items which are generally difficult to obtain by normal cutting and grinding procedures. These include items of uneven section (e.g. silica ware) and mechanically hard materials (e.g. zirconia). The speed at which machining can be carried out should be improved by using DC energisation although the higher peak powers associated with AC energisation assist material removal by evaporation [2]. The process is most adaptable to fully densified materials with a high vapour pressure or to pressed and sintered materials which can be further densified under the action of the heat generated by the laser beam.

Acknowledgements

The authors wish to thank Mr G. A. Roberts for his assistance in this work. This paper is published by permission of the Controller, HMSO.

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Received 2 November and accepted 7 November 1970.

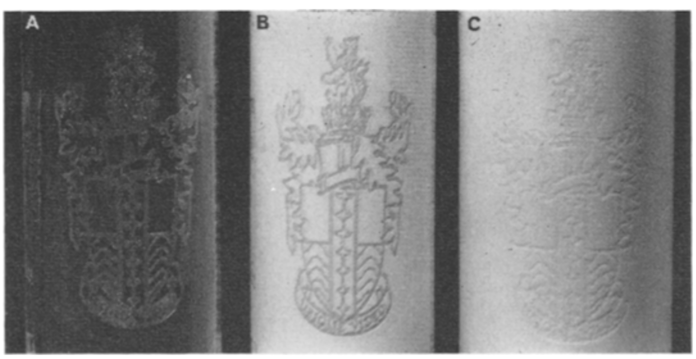

Figure 6 Engraved ceramic tubes. (a) vitreous silica (8.0 cm diameter). (b) aluminous porcelain (7.4 cm diameter). (c) alumina (8.6 cm diameter).