Presented in ACerS'02, St. Louis, May 2002. Published in *Ceramic Bulletin* **82** (2003) 35

MICROWAVE DRILL FOR CERAMICS

E. Jerby, V. Dikhtyar, and O. Aktushev
Faculty of Engineering, and *Ramot* Ltd.
Tel Aviv University, Ramat Aviv 69978 Israel
e-mail: jerby@eng.tau.ac.il Tel/Fax + 972 3 640 8048

ABSTRACT

The paper introduces a method for drilling into hard non-conductive materials by localized microwave radiation (US patent 6,114,676). The microwave drill utilizes a conventional microwave source (2.45-GHz magnetron) to form a portable and relatively simple drilling tool. The drilling head consists of a coaxial feed with a near-field concentrator. The latter focuses the microwave radiation into a small volume under the drilled-material surface. The concentrator itself penetrates into the hot spot created in a fast thermal runaway process. The drilling debris is removed mechanically. This microwave device can be used to drill into concrete, silicon, ceramic, rocks, glass, plastic, and even wood. Hole diameters obtained so far range from 0.5 mm to 13 mm. The larger holes are produced with a slight mechanical assistance. The paper presents recent experimental results of the microwave-drill in various ceramics.

INTRODUCTION

The microwave-drill concept has been introduced recently in a US patent[1], and in consequent conceptual[2] and theoretical[3] papers. The microwave-drill operation is based on the concentration of microwave energy into a small hot spot, much smaller than the microwave wavelength itself. This is done by a near-field microwave concentrator, which is brought in contact with the material to be drilled, as shown in Fig. 1. The microwave energy localized underneath the material surface generates a small hot spot in which the material becomes soften or even molten. The concentrator pin itself is then inserted into the molten hot spot and shapes its boundaries. The hole can be shaped other than circular. Finally, the concentrator is pulled out from the drilled hole, and the material cools down in its new shape. The process does not require fast rotating parts, and it makes no dust, and no noise.

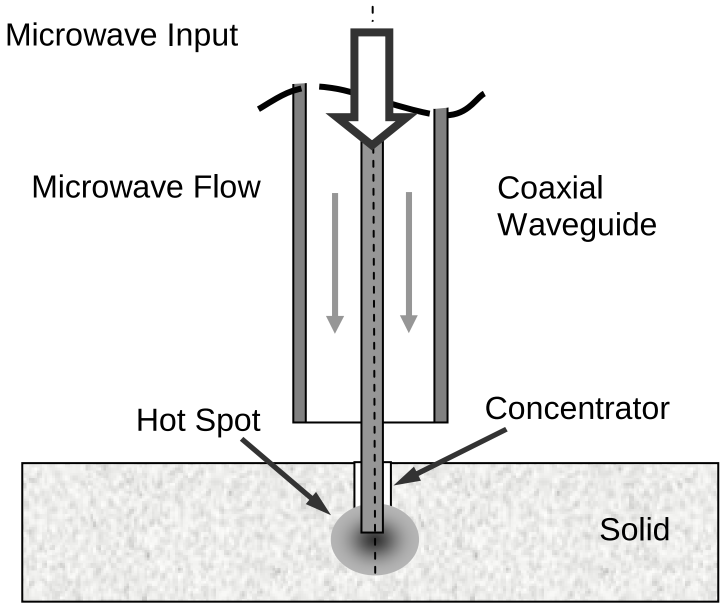

Fig. 1: A principle scheme of the microwave drill.

The microwave drill is effective for drilling and cutting in a variety of hard non-conductive dielectric materials, but not in metals. The latter reflect the radiation and therefor are almost not affected by the microwave drill. Hence, the microwave drill enables a distinction between different materials, and in particular between dielectrics and metals. Specifically, the microwave drill can be implemented to make holes and grooves in dielectric coatings on metallic substrates with no damage to the underlying metallic substrate. This selectivity feature can be used also as a sensor to detect the combined materials and their geometry, and to guide the drilling bit accordingly.

The microwave drill can be implemented in relatively simple instruments, but safety and RFI considerations may limit its public usage. Hence, the microwave drill is proposed first for professional tools, and for embedded drilling and cutting equipment in automatic industrial manufacturing processes. The microwave drill may provide a low-cost solution for drilling (or cutting) in diameters larger than 0.1 mm in non-conductive materials.

2. MICROWAVE-DRILL APPARATUS

An experimental laboratory setup of a microwave drill operating at 2.45GHz is shown for instance in Fig. 2. This setup consists of a 2.45 GHz magnetron fed by a switched power supply (0-2kW adjustable); an isolator; a directional coupler; an E-H tuner for impedance matching; a transition from a WR340 waveguide to the coaxial microwave drill; and a shielded chamber for a safe microwave-drill operation. The microwave-drill head illustrated schematically in Fig.1 consists of an open-end coaxial waveguide with a movable center conductor sustaining high temperatures.

In the setup shown in Fig. 2 the drilling process is controlled and operated manually. These controls include (1) adjusting the magnetron power by the switched power supply, (2) matching the impedance by the E-H tuner according to the microwave incident and reflected power measurements, and (3) pushing or pulling the concentrator pin according to the drilling process evolution. This manual operation has been essential in early stages of the concept development. Currently, an advanced automatic setup is being developed in our laboratory. The new setup will enable real-time data measurements, and the development of automatic microwave-drill procedures for various materials and hole sizes.

Fig. 2: The experimental microwave-drill apparatus.

A practical tool version of the microwave drill is shown in Fig. 3. The telescopic coaxial concentrator is fed directly by the 600W, 2.45GHz-magnetron output, and two electrical actuators function as stubs to maintain the impedance matching. This tool is much more compact than the experimental setup of Fig. 2, but is not less effective.

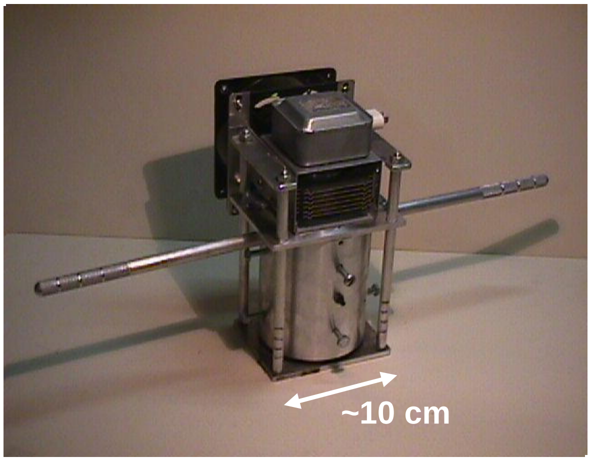

Fig. 3: The manual microwave-drill tool version.

3. EXPERIMENTAL DEMONSTRATIONS

The microwave drills presented in the previous section have been tested on a variety of materials and hole sizes. Materials penetrated successfully[2] by the microwave drills include concrete, alumina and glass-ceramics, silicon, glass, basalt, and softer materials such as wood and plastic. The microwave drill failed to penetrate into quartz and sapphire plates, though melting signs were observed on their surfaces.

The microwave drill utilizes the thermal-runaway and hot spot phenomena[3], which occur during microwave heating of most non-conductive materials. The temperature grows first gradually up to a certain level from which an explosive increase of the temperature occurs. This sudden rise of the local microwave heating temperature causes a local hot spot and melts the heated material, thus enabling its drilling. Fig. 4 shows for instance the hot spot generated by the microwave drill in a glass plate during the penetration.

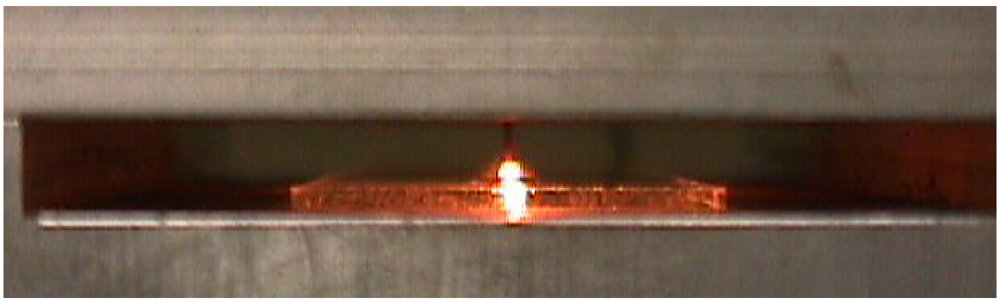

Fig. 4: A hot spot generated by the microwave drill in a glass plate while drilling a 1-mm diameter hole (the plate width is 26 mm).

Ref.[2] shows several examples including a 1-mm-diameter hole in a silicon wafer. The accuracy of the hole shape is not satisfying (note that much narrower and accurate holes are required in practice) but this preliminary result shows the principle feasibility of the process. Similar results are presented in glass plates but yet a more careful operation is needed there to prevent cracks. Typically, a 600W microwave-drill penetrates easily into a concrete slab to form hole of ~2mm diameter and ~2cm within one minute[2]. The debris are compressed to the wall and partly evaporated or converted to a glossy material. A widening of this basic size requires a further microwave radiation to soften or to melt the remaining volume bound in the required (larger) diameter. The glossy material is formed around the concentrator pin as fragile debris that can be easily removed mechanically.

The microwave drill has been tested also on various ceramics. Fig. 5 shows for instance a 1-mm hole made in a plate of glass ceramic (502-600). The glossy debris were not removed in this example, in order to demonstrate the effect.

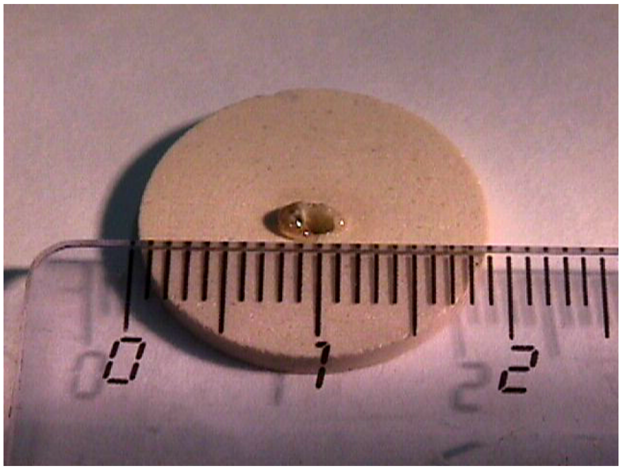

Fig. 5: A 1-mm via hole made by the microwave drill in glass ceramic (the debris remained for demonstration).

The microwave drill was found useful not only to drill into low-purity alumina and glossy ceramics, but also to insert and joint metallic or ceramic nails into these materials. Fig. 6 shows an example of a 0.5-mm diameter tungsten nail inserted by the microwave drill into a plate of a zirconium phosphate (502-1550). Fig. 7 shows an alumina tube inserted and joined by the microwave drill into a plate of aluminum silicate (502-1100).

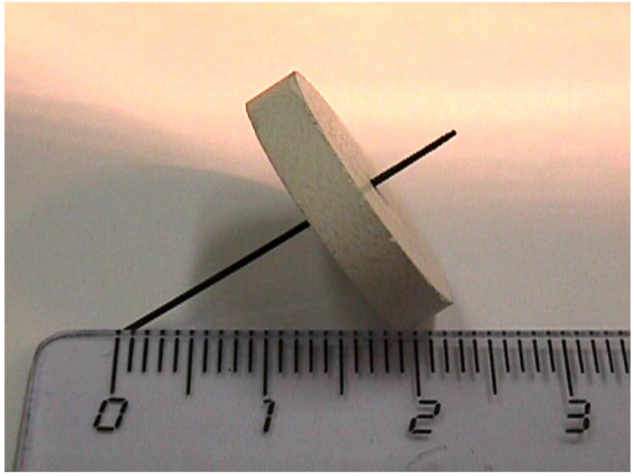

Fig. 6: A tungsten nail (0.5mm^{Ø}) inserted into a zirconium-phosphate plate

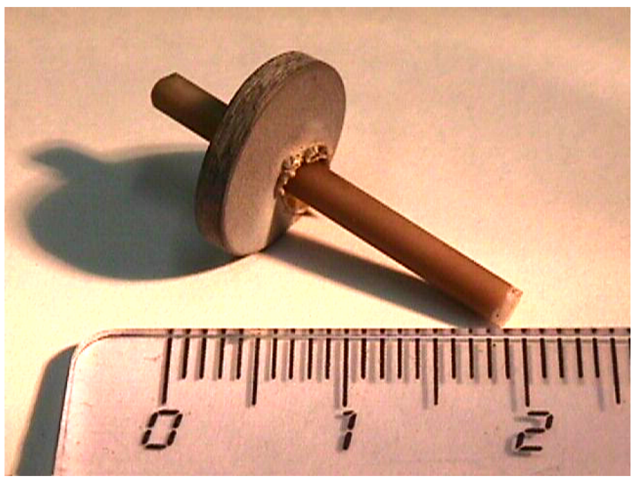

Fig. 7: A plate of aluminum silicate in which an alumina tube (2.5mm^{Ø}) is inserted and joined by the microwave drill

The microwave drill is found useful for other cutting operations in addition to drilling and nailing. Fig. 8 shows for instance a basalt stone drilled by microwaves, whereas in the bottom of the ~2cm deep hole, a cross is impressed. Hence, the microwave drill can be used to impress marks and to cut grooves in the materials mentioned above.

Fig. 8: A basalt stone drilled and coined by microwaves (note the cross-coined in the bottom of the 2-cm deep, 0.5-cm diameter hole)

4. SUMMARY

The preliminary results of the microwave-drill operation on various ceramics demonstrate a principle feasibility of this concept for machining of ceramics, and in particular for drilling, cutting, and nailing in these materials. In view of the progress achieved in the conceptual and practical developments[2] and in the theoretical analysis[3] of the microwave-drill method, the next stages should be a microstructure analysis of the microwave-drill impact on a wide range of ceramic materials.

The objective of these studies is to incorporate the microwave-drill with other manufacturing processes as a tool for shaping ceramic structures. In particular, the microwave drill can be used as an "inner-sintering furnace" to provide both shaping and hardening of complex ceramic products.

REFERNCES

[1] E. Jerby and V. Dikhtyar, "Method and device for drilling, cutting, nailing and joining solid non-conductive materials using microwave radiation," US Patent 6,114,676.

[2] E. Jerby and V. Dikhtyar, "Drilling into hard non-conducting materials by a localized microwave radiation," 8th Ampere Microwave-Heating Conference Proc., Sept. 2001 Bayreuth, Germany.

[3] U. Grosglick, V. Dikhtyar, and E. Jerby, "Coupled thermal-electromagnetic model for microwave drilling", JEE'02 European Symposium on Numerical Methods in Electromagnetics Proc., Toulouse, 6-8 March 2002.