MACHINING OF CERAMICS

Ceramics have a unique combination of mechanical, physical and chemical properties:

- High strength
- Hardness
- Low density
- High stiffness (modulus of elasticity)
- Good tribological properties (e.g., excellent resistance to different types of wear}
- Very low electric conductivity
- Very low thermal conductivity
- High refractoriness and thermal stability
- Good corrosion resistance

The techniques of manufacturing ceramics (shape forming, sintering) allow to produce the parts of different sizes and shapes with good cost efficiency.
However the machining of ceramics is very expensive and time consuming operation representing from 50 to 90% of the total cost of the part.

The main parameter of the efficiency of a machining operation is the **Material Removal Rate (MRR)** indicating the volume of the material removed from the workpiece surface for 1 min.

The methods of ceramics machining:

- **Machining of ceramics in the presintered state**
- **Grinding of ceramics**
- **Ultrasonic machining of ceramics**
- **Rotary ultrasonic machining of ceramics**
- **Laser assisted machining of ceramics**
- **Laser machining of ceramics**

Machining of ceramics in the presintered state

Sintered ceramics are very hard and therefore their machining is an expensive, difficult and time consuming process.

Ceramic parts may be effectively machined before the final sintering stage either in the “green” (non-sintered powder) compact state or in the presintered “bisque” state.

Conventional machining methods (milling, drilling, turning) may be applied for the ceramic parts in the presintered state.
Titanium nitride (TiN) coated high speed steel tools, tungsten carbide tools and polycrystalline diamond (PCD) tools are used in machining of presintered ceramics.

The material removal rate (MRR), which may be achieved in machining of ceramics in the bisque (presintered) state is 0.6 in^3/min (9832 mm^3/min). This value is similar or even higher than MRR of Tool and die steels.

Shrinkage and warping of the ceramic part occurring during its sintering does not allow to achieve tight dimensional tolerances and high quality surface finish in the presintered state.
However machining of bisque ceramics allows to reduce the cost of the final machining of the parts in the sintered state.

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Grinding of ceramics

Grinding is the most widely used method of machining of Ceramics in the sintered state.

Grinding operation involves a rotating abrasive wheel removing the material from the surface of the workpiece. The grinding zone is continuously flushed with afluid coolant, which cools the grinding zone, lubricates the contact between the wheel and the part surfaces, removes the micro-chips (debris) produced in the grinding process.

Resin-bond wheels with either synthetic or natural diamond of different grit size pressed at different concentrations in polymer (resin) matrices are commonly used for grinding ceramics.

Electrolytic in-process dressing (ELID) technique of dressing metal-bonded grinding wheels is used for fine (nano) finish grinding.

The Material Removal Rate (MRR) of grinding ceramics is maximum 0.0006 in^3/min (9.832 mm^3/min).

Ultrasonic machining of ceramics

Ultrasonic machining (UM) of ceramics is the machining method using the action of a slurry containing abrasive particles flowing between the workpiece and a tool vibrating at an ultrasonic frequency.

The vibration frequency is 19 ~ 25 kHz.
The amplitude of vibration 0.0005 - 0.002” (13 – 50 µm).
During the operation the tool is pressed to the workpiece at a constant load.
As the tool vibrates, the abrasive particles (grits) dispersed in the slurry strike the ceramic workpiece and remove small ceramic debris fracturing from the surface.

Conventional ultrasonic machining (UM) is characterized by low material removal rates: up to 0.003 in^3/min (49 mm^3/min).
Other disadvantages of the conventional ultrasonic machining method are low accuracy and high tool wear.

Ultrasonic machining is used commonly for drilling operation.

Rotary ultrasonic machining of ceramics

Rotary ultrasonic machining (RUM) of ceramics combines grinding operation with the method of ultrasonic machining.

A core drill tool made of a metal bonded diamond grits is used in the rotary ultrasonic machining (commonly drilling).
The tool is rotating and simultaneously vibrating at an ultrasonic frequency. The tool is continuously fed and pressed at a load towards the ceramic workpiece causing abrasive action performed by the rotating-vibrating diamond grits.

A fluid coolant is continuously flowing through the core of the tool to the grinding zone cooling it and removing the debris produced in the grinding process.

Rotary ultrasonic machining is much more effective than conventional ultrasonic machining.
The RUM material removal rate is up to 0.03 in^3/min (492 mm^3/min).

Laser assisted machining of ceramics

Laser assisted machining (LAM) is the method of machining ceramics using a laser beam directed to the workpiece area located directly in front of the conventional cutting tool.

The laser beam heats and softens (not melts) the ceramic material at the surface just prior the cutting action.
As a result the cut material becomes ductile and it may be removed much faster than in conventional cutting operation without a laser assistance.

The LAM material removal rate is up to 0.06 in^3/min (983 mm^3/min).

Titanium nitride coated tools are used for the laser assisted machining of ceramics.

Traditional machining operations (milling, turning) may be performed by the method of the laser assisted machining.

Laser machining of ceramics

Laser machining of ceramics is the machining operation performed by a high power laser melting the material, which is blown away by a supersonic gas jet.

The laser energy density required for melting alumina ranges from 4.6 BTU/in^2 to 6.1 BTU/in^2 (750 J/cm^2 to 1000 J/cm^2).

The following machining operation may be performed by laser:

- Drilling
- Cutting
- Scribing and marking

Residual stresses and micro-cracks may form at the cut edge as a result of the shrinkage of the solidified molten material.

Preheating of the ceramic workpiece to 2550ºF (1399ºC) prior to the laser machining allows to minimize micro-cracking due to reduction of the temperature gradients and thermal stresses.

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