WATER JET MILLED RIBBED SILICON CARBIDE MIRRORS

Inventor: R. Kyle Webb, Escondido, CA (US)

Correspondence Address:
TREX ENTERPRISES CORP.
10455 PACIFIC COURT
SAN DIEGO, CA 92121 (US)

Appl. No.: 11/543,174
Filed: Oct. 2, 2006

Related U.S. Application Data
Continuation-in-part of application No. 11/249,860, filed on Oct. 12, 2005.
Provisional application No. 60/722,305, filed on Sep. 30, 2005.

Publication Classification
Int. Cl. B24C 5/04 (2006.01)
U.S. Cl. 451/102

ABSTRACT

Water jet milled ribbed silicon carbide mirrors and a method of making the mirrors. In a preferred embodiment the component is a light weight silicon carbide mirror fabricated with water jet milling from a solid silicon carbide work piece. A prior art water jet cutting process has typically cuts edges, slots, and holes is utilized in a controlled-depth application where the jet does not pass all the way through the silicon carbide work piece. In preferred embodiments the silicon carbide material is a product of a chemical vapor composite process such as that described in U.S. Pat. Nos. 5,154,862 and 5,348,765.
WATER JET MILLED RIBBED SILICON CARBIDE MIRRORS

[0001] This application claims the benefit of provisional application Ser. No. 60/722,305 and is a continuation-in-part application of utility application Ser. No. 11/249,860 which is incorporated by reference herein.

[0002] The present invention relates to silicon carbide components and in particular to silicon carbide mirrors and to processes for machining the mirrors. This invention was made in the course of the performance of Contract No. FA9451-05-C-0019 with the United States Airforce Research Laboratory and the United States Government has rights in the invention.

BACKGROUND OF THE INVENTION

Silicon Carbide

[0003] Silicon carbide was discovered by Edward Goodrich Acheson around 1893, and he not only developed the electric batch furnace by which SiC is still made today, but also formed The Carbonundum Company to manufacture it in bulk, initially for use as an abrasive. Purser silicon carbide can be made by the more expensive process of chemical vapor deposition (CVD). Applicant's employer is the assignee of two patents (U.S. Pat. Nos. 5,154,862 and 5,348,765, both of which are incorporated by reference herein) covering a CVD-type process for making silicon carbide in which tiny particles are entrained in the chemical vapor. This silicon carbide made with this process possess improved properties such as increased toughness and reduced stress. Commercial large single crystal silicon carbide is grown using a physical vapor transport commonly known as modified Lely’s method. Purser silicon carbide may also be made by the thermal decomposition of a polymer, poly(methylsilane), under an inert atmosphere at low temperatures. This has certain advantages over the CVD process in that the polymer may readily formed into various shapes prior to thermalization into a silicon carbide ceramic. Naturally occurring silicon carbide is called “moissanite” and is extremely rare, as it is not formed naturally in any quantity within the Earth, and thus is found only in tiny quantities in certain types of meteorite and as microscopic traces in corundum deposits and kimberlite.

[0004] Alpha silicon carbide (α-SiC) is most common, and is formed at temperatures greater than 2000° C. Alpha SiC has the typical hexagonal crystal structure. Beta modification (β-SiC), with a face-centered cubic crystal structure, is formed at temperatures below 2000° C., but has relatively fewer commercial uses. Silicon carbide has a specific gravity of 3.2, and its high melting point (approximately 2700° C.) makes silicon carbide useful for bearings and furnace parts. It is also highly inert chemically. SiC also has very low thermal expansion coefficient and no phase transitions that would cause discontinuities in thermal expansion. Pure SiC is clear. As a gemstone, silicon carbide is similar to diamond in several important ways: it is transparent and extremely hard (9.25 on the Mohs scale, compared to 10 for diamond), with an index of refraction between 2.65 and 2.69 (compared to 2.42 for diamond). SiC has a hexagonal crystal structure.

[0005] In the 1980s and 1990s, silicon carbide was studied on several research programs for high-temperature gas turbines in the United States, Japan, and Europe. The components were intended to replace nickel superalloy turbine blades or nozzle vanes. However, none of these projects resulted in a production quantity, mainly because of its low impact resistance and its low fracture toughness. Silicon carbide’s hardness and rigidity make it a desirable mirror material for astronomical work, although they also make manufacturing and figuring such mirrors quite difficult.

Water Jet Cutting

[0006] Water jet cutting is a well known technology. There are currently more than 400 abrasive water jet machine shops performing basic loose tolerance 2-D machining in the US. Waterjet cutting can be as much as 10 times faster than electron discharge machining (EDM) machines but conventional water jets are not as precise as EDM machines. Special water jet tooling is available for producing production quantities of components numbering in the thousands and machined with 2-axis to 5-axis tolerances of +/-0.001 inches (+/-0.025 mm). Application of water jet cutting include:

[0007] Nuclear Decommissioning and Decontamination applications
[0008] Nuclear Cleaning Applications
[0009] Deep Underwater Cutting Applications
[0010] High Pressure Waterjet and Cryojet Atomization of Metals
[0011] High Volume Cutting Applications
[0012] Thick Glass Cutting Applications
[0013] Vision Assisted Cutting Applications
[0014] Tube Cleaning Applications
[0015] Rust, Paint, and Coating Removal Applications
[0016] Custom Waterjet Machining Applications

[0017] The ultrahigh-pressure pump technology used to create high-velocity water jets was developed in the 1970s. Water is pumped at pressures up to 55,000 psi and expelled through a sapphire orifice to form a fine, coherent cutting jet. At this pressure, the water is traveling at about 2500 feet/second when it emerges from the orifice. Water jets typically have diameters from 0.003 to 0.020 inch, requiring 2 to 90 Hp at 55,000 psi.

Pure and Abrasive Water Jets

[0018] Pure water jets are generally used to cut only soft materials such as food, paper products, cloth, leather, wood, fiberglass, and some aerospace composites. It is a valued technology in many applications due to the fact that it is easily automated and because of its ability to cut very thin kerf widths with little material loss. The capability of the ultra-high pressure water jets was extended in the early 1980s by adding abrasives to form the abrasive water jet (AWJ). The abrasive particles are entrained in the water jet and transported at supersonic velocities to cut virtually any material. The AWJ has been shown to produce surfaces that are free from adverse mechanical, thermal, or metallurgical effects, and have found acceptance in cutting applications such as aerospace sheet metals and composites.
The water jet flows through a mixing tube where abrasive particles are entrained in the jet. The high-velocity water flow in the mixing tube creates a vacuum that serves to draw air, which is used to transport abrasives from a hopper into the nozzle via a supply hose. The primary function of the mixing tube is to force a transfer of energy from the water jet to the particles, while holding the accelerated abrasive particles in a narrow collimated stream. Garnet abrasives are commonly used as the AWJ cutting medium.

The AWJ has advantages over other machining methods in many areas:

- The AWJ easily machines titanium, nickel alloys and very hard brittle materials
- It is a cold cutting process, machining without creating thermal distortions or thermally driven changes to the metallurgical and crystal structure (no brittle recast or micro-cracks as left by laser and EDM)
- The workpiece sees very low tool loads with the abrasive-waterjet and machining delicate part features is an option
- Glass and ceramic materials can be machined to complex shapes without the sub-surface flaws created during grinding
- Drilling small, deep holes is easily performed with the AWJ
- AWJ cuts more materials and is faster than EDM
- AWJ cuts more materials and is faster than laser with thick materials

The AWJ has many advantages over other machining technologies, but has remained a niche market in part because of limitations involved in machining to close tolerances and therefore competing effectively with the much larger laser and EDM markets.

SUMMARY OF THE INVENTION

The present invention provides water jet milled ribbed silicon carbide mirrors and a method of making the mirrors. In a preferred embodiment the component is a lightweight silicon carbide mirror fabricated with water jet milling from a solid silicon carbide work piece. A prior art water jet cutting process has typically cut edges, slots, and holes is utilized in a controlled-depth application where the jet does not pass all the way through the silicon carbide work piece. In preferred embodiments the silicon carbide material is a product of a chemical vapor deposition process such as that described in U.S. Pat. Nos. 5,154,862 and 5,348,765, referred to in the Background section of this specification. Preferably the abrasive powder used in the water jet process is silicon carbide.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an isometric view of a ribbed mirror made in accordance with the teachings of the present invention.

FIG. 2 is a drawing showing in detail the rib structure.

FIG. 2A is a section of FIG. 2.

FIG. 2B is a section of FIG. 2A.

FIG. 3 is a side view of the mirror.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Abrasive water jet cutting processes typically cut edges, slots, and drill holes through work pieces. Applicant has discovered that abrasive water jet technology can be adapted to mill silicon carbide parts with very precise accuracy of 0.01 inch or better. So the technique can also be used in controlled-depth applications. Prior art water jet milling tools are used. The preferred abrasive powder is silicon carbide powder. Milling with water jet involves moving the work piece past the nozzle or the nozzle past the work piece at a controlled feed rate that allows precise amounts of silicon carbide material to be removed. This generally means the work piece is mounted on some spinning or translating surface while the nozzle moves in a straight line or the nozzle is connected to a multi-axis motion control mechanism and the work pieces moves in a straight line. Milling depth control is determined by the number of passes the work piece makes under the jet. Milling feature sizes can be held to an accuracy of ±0.001 inch. In preferred embodiments a silicon carbide work piece is moved at a speed of about 600 feet per minute under the abrasive water jet resulting in a milling depth of cut of about 0.010 inch per pass. Work piece positioning and movements are computer controlled.

Abrasive water jet machining can be thought of as a water-driven grinding process. A narrow, high-pressure jet of water (approximately 55,000 psi) carries particles of very hard abrasive particles at speeds ranging from 1,000 to 2,800 feet per second. These particles do the cutting. There are few materials, metal or non-metal, which cannot be cut in this way. Water jet milling of silicon carbide offers other advantages over classical grinding and lapping process of fabricating silicon carbide material in that it is a cool process. Because there is no heat-affected zone, water jet is a candidate for applications where thermal-induced micro-fractures or distortions in the part are unacceptable. There are also important advantages of water jet milling of silicon carbide over chemical milling processes. Chemical milling typically is environmentally-unfriendly, water jet milling is environmentally friendly. With water jet milling it is much easier to control the milling depth for different regions of the work piece. Still another advantage over chemical milling is that water jet milling provides better surface finish.

FIG. 1 is an isometric view of the rib side of an approximately one foot diameter light weight silicon carbide mirror currently being fabricated in accordance with the teachings of this invention. The dimensions of the rib pattern are shown in FIGS. 2, 2A, 2B and 3. With the water jet machining and milling depths are controlled to a tolerance of 0.01 inch and all other dimensions are controlled to 0.005 inch. Surface roughness is controlled to 0.1 micron. Machining thin ribs from solid piece is one application in which abrasive water jet milling provides a distinct advantage over classical milling processes. Unlike the more conventional milling, water jet milling poses no risk of deflecting a delicate rib during machining. The water jet transmits no lateral force.
Variations

Persons skilled in the art of silicon carbide parts will recognize that the water jet milling techniques described above can be applied in a wide variety of applications. For example, silicon carbide mirrors vary very widely in size and this technique can be applied to virtually any size mirror. Many other silicon carbide components can be made using the present invention. Some examples are: secondary mirror supports, called spiders, optical benches, blank silicon carbide wafers and other silicon carbide components used in integrated circuit lithography, rocket nozzles, projectile heads and wing leading edges.

Therefore the reader should determine the scope of the present invention by the appended claims and not of the examples that have been described above.

What is claimed is:

1. A method of making a silicon carbide mirror structure, said method comprising the steps of:
   A) producing a silicon carbide blank having at least one approximately smooth surface defining a front surface with an opposite surface defining a rear surface,
   B) milling the rear surface using an abrasive water jet process to create a rib structure supporting the front surface,
   C) polishing said approximately smooth front surface to achieve a mirror finish.

2. The method as in claim 1 wherein the silicon carbide blank is a silicon carbide composite blank.

3. The method as in claim 2 wherein the silicon carbide blank is produced in a process of the type described in U.S. Pat. Nos. 5,154,862 and 5,348,765.

4. The method as in claim 1 wherein abrasive material used in said water jet process is silicon carbide.

5. A silicon ribbed carbide mirror fabricated using an abrasive water jet method, said method comprising the steps of:
   A) producing a silicon carbide blank having at least one approximately smooth surface defining a front surface with an opposite surface defining a rear surface,
   B) milling the rear surface using an abrasive water jet process to create a rib structure supporting the front surface,
   C) polishing said approximately smooth front surface to achieve a mirror finish.

6. The mirror as in claim 5 wherein the silicon carbide blank is a silicon carbide composite blank.

7. The mirror as in claim 6 wherein the silicon carbide blank is produced in a process of the type described in U.S. Pat. Nos. 5,154,862 and 5,348,765.

8. The mirror as in claim 5 wherein abrasive material used in said water jet process is silicon carbide.

* * * * *