

## Description

This invention relates to a ceramic cutting tool excellent in toughness and wear resistance and a process for the production of the same.

$Al_2O_3$  ceramics are ideal materials for cutting tools, in particular, used at a high speed because of their excellent oxidation resistance, high heat resistance, high hardness, at a high temperature and low reactivity with iron. However,  $Al_2O_3$  ceramics have the fatal disadvantage that the breakage resistance is inferior as a cutting tool because of their insufficient strength and toughness and the application range is considerably limited.

For the development of cutting tools of  $Al_2O_3$  ceramics, it is the most important problem how the breakage resistance is improved. Firstly, it has been proposed to improve the thermal toughness by adding TiC to  $Al_2O_3$  ceramics and the resulting compositions have been put to practical use for cutting castings at high speeds or for cutting high hardness materials such as hardened steels.

Furthermore, in DE-A-2,744,700, it is disclosed that strengthening or toughening of ceramics cutting tools is carried out by utilizing the crack propagation effect of microcracks due to the volume expansion following the modification of tetragonal system to monoclinic system of  $ZrO_2$  dispersed in  $Al_2O_3$  matrix, and in DE-A-2,549,652, it is disclosed that in  $ZrO_2$ -containing ceramics, strengthening of the matrix is carried out by absorbing the crack propagation energy through microcracks previously introduced thereto by the phase modification of  $ZrO_2$ .

It has also been proposed as disclosed in Japanese Patent Publication No. 19391/1987 and Re 32843 to strengthen ceramics by the moderation of stress concentration at the crack points through bridging of the upper and lower surfaces of cracks with crack propagation by SiC whiskers dispersed in  $Al_2O_3$  matrix i.e. by the so-called whisker pull out effect. In Japanese Patent Laid-Open Publication No. 174165/1986 and US Patent No. 4,789,277, use of  $Al_2O_3$ -SiC whisker-ceramics as a cutting tool has been proposed.

Japanese Patent Laid-Open Publication No. 270266/1986 describes that ceramics with a higher strength and higher  $K_{IC}$  can be obtained by adding SiC whiskers and  $ZrO_2$  to  $Al_2O_3$  to result in synergistic strengthening and Japanese Patent Laid-Open Publication No. 45182/1988 discloses higher strength and higher hardness ceramics sintered bodies consisting of  $Al_2O_3$ -SiC whisker- $ZrO_2$  ceramics, in which  $Al_2O_3$  and  $ZrO_2$  are in a proportion by volume of 62 : 38 to 72 : 28 and  $Al_2O_3$  grains have a grain size of at most 1.0  $\mu m$ .

$Al_2O_3$ -TiC ceramics cutting tools are somewhat improved in toughness and, in particular, thermal shock resistance in comparison with  $Al_2O_3$  ceramics cutting tools and at the present time, have been regarded as a standard material for ceramics cutting tools. However, this improvement being insufficient, the  $Al_2O_3$ -TiC ceramics cutting tools can only be used in largely limited fields, i.e. for cutting low cutting resistance materials such as castings or for finish-cutting with a small fluctuation of cut depth in the case of high hardness materials such as heat resisting steels.

$Al_2O_3$ - $ZrO_2$  ceramics cutting tools have much more improved toughness, for example, about 1.5 times large  $K_{IC}$  than  $Al_2O_3$  ceramics cutting tools and accordingly, a part of them has been used for high speed cutting of steels. However, the wear resistance of the  $Al_2O_3$ - $ZrO_2$  ceramics cutting tools is inferior to that of the  $Al_2O_3$ -TiC ceramics cutting tools, because addition of  $ZrO_2$  to  $Al_2O_3$  results in lowering of the hardness thereof, and accordingly, the  $Al_2O_3$ - $ZrO_2$  ceramics cutting tools have found no use for hard-to-cut materials such as heat resisting steels. When  $ZrO_2$  is added, furthermore,  $K_{IC}$  is improved, but the transverse rupture strength is lowered.

On the other hand,  $Al_2O_3$ -SiC whisker-ceramics cutting tools are more improved in hardness,  $K_{IC}$  and transverse rupture strength as compared with the  $Al_2O_3$ -TiC ceramics cutting tools and have been regarded as available for cutting heat resisting materials such as Inconel. When these cutting tools are in fact used for cutting such a heat resisting material as Inconel, in particular, at a high speed such as at least 100 m/min, however, the boundary notch is remarkably progressing in the ceramics, thus resulting in a very short life thereof. This is probably due to that the  $Al_2O_3$ -SiC whisker-ceramics cutting tools are not so improved in  $K_{IC}$  as the  $Al_2O_3$ -TiC ceramics cutting tools.

With respect to this point,  $Al_2O_3$ -SiC whisker- $ZrO$  ceramics cutting tools are surely given a higher hardness and higher  $K_{IC}$  than the  $Al_2O_3$ -TiC ceramics cutting tools, but this is not satisfactory for use under severer conditions, for example, for cutting the heat resisting materials such as Inconel. That is, the progress of the boundary notch is not sufficiently suppressed in the ceramics and their lives are short so that the tools are not put to practical use.

When the  $Al_2O_3$ -SiC whisker-ceramics cutting tools and  $Al_2O_3$ -SiC whisker- $ZrO_2$  ceramics cutting tools are used for cutting castings, they exhibit a sufficient breakage resistance attaining the level, but the wear resistance thereof cannot be rendered optimum.

US-A-4657877 discloses ceramic articles for heat engine components made of  $\text{Al}_2\text{O}_3$  and SiC whiskers with  $\text{ZrO}_2$ . Above 12 vol%  $\text{ZrO}_2$ , typically 20 vol%, is said to be required to show increase in fracture toughness.

US-A-4749667 teaches ceramic articles made of  $\text{Al}_2\text{O}_3$  and SiC whiskers with  $\text{ZrO}_2$ , in which there must be between 35 and 45 vol% SiC whiskers for good hardness and toughness.

EP-A-0208910 discloses a wide range of formulations of alumina ceramic materials reinforced with SiC whiskers for cutting tools.  $\text{ZrO}_2$  is disclosed as one of a wide range of possible additives to materials comprising essentially SiC whiskers,  $\text{Al}_2\text{O}_3$  and a sintering assistant. In particular one example is disclosed consisting of 60wt%  $\text{Al}_2\text{O}_3$ , 25wt%  $\text{MgO}$  and 1wt%  $\text{YB}_6$ . More generally, this document discloses compositions with additives in addition to sintering assistants, these additives comprising any of B, C, AlN,  $\text{B}_4\text{C}$  and boride of Si, Al, Y, lanthanide, a transition metal belong to Group IVa Va and VIa of the Periodic Table of the Elements or oxide, carbide, nitride, boride thereof including solid solution thereof.

EP-A-0295228 discloses a  $\text{Al}_2\text{O}_3$ -SiC whisker-  $\text{ZrO}_2$  cutting tool with a possible further addition of  $\text{Cr}_2\text{O}_3$ .

It is an object of the present invention to provide a ceramics cutting tool excellent in toughness as well as wear resistance.

Examples of the present invention provide an  $\text{Al}_2\text{O}_3$ -SiC whisker- $\text{ZrO}_2$  ceramics cutting tool having excellent properties, in which the ceramics is rendered as compact as possible in a range wherein  $\text{Al}_2\text{O}_3$  is not subject to grain growth by adjusting the amounts of SiC whiskers and  $\text{ZrO}_2$  to optimum and controlling precisely the producing conditions.

The present invention provides an  $\text{Al}_2\text{O}_3$  - SiC whiskers -  $\text{ZrO}_2$  ceramic cutting tool comprising 27 to 32% by volume of SiC whiskers, 3 to 7 % by volume of partially stabilised  $\text{ZrO}_2$ , at least one sintering aid selected from the group consisting of  $\text{MgO}$ ,  $\text{Y}_2\text{O}_3$  and  $\text{NiO}$  and the balance of  $\text{Al}_2\text{O}_3$ , said  $\text{Al}_2\text{O}_3$  having a mean grain diameter of at most 1.5  $\mu\text{m}$ .

The accompanying drawings are to illustrate the merits and principle of the present invention in detail.

Fig. 1 is a graph showing the relationship between the boundary notch  $V_N$  and the amount of  $\text{ZrO}_2$  in a ceramics cutting tool of  $\text{Al}_2\text{O}_3$ -SiC whiskers- $\text{ZrO}_2$  system containing 30 vol % of SiC whiskers when cutting Inconel 718.

Fig. 2 is a graph showing the relationship between the hot pressing temperature and boundary notch  $V_N$  when cutting Inconel 718 using a ceramics cutting tool of 32 vol % of SiC whiskers, 5 vol % of  $\text{ZrO}_2$  containing 3wt% of  $\text{Y}_2\text{O}_3$  and the balance of  $\text{Al}_2\text{O}_3$ .

The inventors have made various efforts to provide an improved  $\text{Al}_2\text{O}_3$ -SiC whisker- $\text{ZrO}_2$  ceramics cutting tool, whereby the disadvantages of the ceramics cutting tool of the prior art can be overcome and consequently, have found that such an improved ceramics cutting tool can be produced by controlling precisely the producing conditions.

Accordingly, an  $\text{Al}_2\text{O}_3$ -SiC whisker- $\text{ZrO}_2$  ceramic cutting tool should comprise 27 to 32 vol % of SiC whiskers, 3 to 7 vol % of partially stabilised  $\text{ZrO}_2$  and the balance of  $\text{Al}_2\text{O}_3$  having a mean grain diameter of at most 1.5  $\mu\text{m}$ . This ceramics cutting tool can be produced by hot pressing a mixed powder of  $\text{Al}_2\text{O}_3$ , SiC whiskers  $\text{ZrO}_2$  and sintering aid(s) at a temperature of 1500 to 1750 °C under a pressure of 150 to 500  $\text{kg/cm}^2$  for a period of time of 30 minutes to 5 hours, or by hot pressing a mixed powder of  $\text{Al}_2\text{O}_3$ , SiC whiskers  $\text{ZrO}_2$  and sintering aid(s) at a temperature of 1450 to 1750 °C under a pressure of 10 to 500  $\text{kg/cm}^2$  for a period of time of 30 minutes to 5 hours and then subjecting the mixture to a hot hydrostatic pressure treatment at a temperature of 1500 to 1800 °C under a pressure of 10 to 3000 atm ( $1 \times 10^6$  to  $3 \times 10^8$  Pa) for a period of time of 30 minutes to 5 hours. Preferably, the SiC whiskers have an aspect ratio of 3 to 200.

If the amount of SiC whiskers is less than 27 vol %, increase of the strength is not sufficient, in particular, when cutting heat resisting materials such as Inconel, while if more than 32 vol %, the amount of  $\text{Al}_2\text{O}_3$  is decreased relatively to lower the wear resistance. This should be avoided. If the amount of  $\text{ZrO}_2$  is less than 3 vol %, increase of  $K_{IC}$  is not sufficient in comparison with the  $\text{Al}_2\text{O}_3$  ceramics, while if more than 12 vol %, the strength of the ceramics is lowered and the wear resistance during cutting is also deteriorated. More preferably,  $\text{ZrO}_2$  is in the range of 3 to 7% by volume.

In the ceramic composition of the present invention,  $\text{Al}_2\text{O}_3$  grains have a mean grain diameter of at most 1.5  $\mu\text{m}$ , since if the grain diameter exceeds 1.5  $\mu\text{m}$ , the wear resistance is largely decreased when it is used as a cutting tool. The sintering property of the  $\text{Al}_2\text{O}_3$ -SiC whisker ceramic with low sintering property can be improved by adding  $\text{ZrO}_2$  to render it possible to lower the sintering temperature. Thus, the mean grain diameter of  $\text{Al}_2\text{O}_3$  can be controlled to at most 1.5  $\mu\text{m}$  to improve the wear resistance to a greater extent.

In the ordinary sintering at normal pressure, compacting of such ceramics is not sufficient enough to resist practical use as a cutting tool. On the other hand, in preferred embodiments of the present invention, a mixture of  $\text{Al}_2\text{O}_3$  powder, SiC whiskers,  $\text{ZrO}_2$  powder and sintering aid(s) is hot pressed, or after the hot pressing, it is subjected to a hot isostatic press (HIP) treatment.

When the hot pressing is carried out without the hot isostatic press treatment, at a temperature of lower than  $1500^\circ\text{C}$ , compacting is insufficient, while at a temperature of higher than  $1750^\circ\text{C}$ ,  $\text{Al}_2\text{O}_3$  is subject to excessive grain growth to lower the wear resistance. When the sintering is carried out for a time of longer than 5 hours,  $\text{Al}_2\text{O}_3$  is also subject to excessive grain growth to lower the wear resistance, while when shorter than 30 minutes, compacting is insufficient. If the pressure for the hot pressing is less than  $150\text{ kg/cm}^2$ , compacting is insufficient and even if more than  $500\text{ kg/cm}^2$ , the effect is not so increased and this is meaningless on commercial scale.

The hot isostatic press treatment should be carried out after converting pores in the ceramics sintered compact into cellular pores by the compressing and sintering. To this end, the hot pressing should be at a temperature of  $1450^\circ\text{C}$  or higher, since if lower than  $1450^\circ\text{C}$ , pores in the ceramics sintered compact are not converted into cellular pores, but are retained as open pores. Thus, compacting cannot sufficiently be obtained by the hot isostatic press treatment. If the hot pressing is carried out at a temperature of higher than  $1750^\circ\text{C}$ ,  $\text{Al}_2\text{O}_3$  is subject to excessive grain growth. This is not preferable. If the time is shorter than 30 minutes, pores in the ceramics sintered compact are not converted into cellular pores, but are retained as open pores and compacting cannot sufficiently be obtained by the hot isostatic press treatment, while if longer than 5 hours,  $\text{Al}_2\text{O}_3$  is subject to excessive grain growth.

For the purpose of converting pores in the ceramics sintered compact into cellular pores by the hot pressing, a pressure of less than  $10\text{ kg/cm}^2$  is insufficient and even a pressure of more than  $500\text{ kg/cm}^2$  does not result in more effects. This is meaningless on commercial scale.

As to the hot isostatic press treatment, a temperature of lower than  $1500^\circ\text{C}$ , a pressure of less than  $1 \times 10^6\text{ Pa}$  (10 atm) and a time of less than 30 minutes are insufficient for compacting of the ceramics, while a temperature of higher than  $1800^\circ\text{C}$  and a time of longer than 5 hours result in excessive growth of  $\text{Al}_2\text{O}_3$  and a pressure of more than  $3 \times 10^6\text{ Pa}$  (3000 atm) does not result in more effects.

Furthermore, sintering aids well known as those of the  $\text{Al}_2\text{O}_3$  ceramics, such as  $\text{MgO}$ ,  $\text{Y}_2\text{O}_3$  and  $\text{NiO}$ , are added.  $\text{ZrO}_2$  partially stabilized with  $\text{Y}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{HfO}_2$ , etc. is used as a starting powder.

The following examples are given in order to illustrate the present invention in detail without limiting the same, in which parts and percents are to be taken as those by weight unless otherwise indicated.

#### Example 1

A mixed powder of 63 % by volume of  $\alpha\text{-Al}_2\text{O}_3$  with a mean grain diameter of  $1\text{ }\mu\text{m}$  or less, 5 % by volume of  $\text{ZrO}_2$  partially stabilized with 3 % of  $\text{Y}_2\text{O}_3$  and 32 % by volume of SiC whiskers with a mean diameter of  $0.6\text{ }\mu\text{m}$  and an aspect ratio of 5 to 50 was adequately and uniformly dispersed in ethanol using ultrasonic wave and dried. The resulting mixed powder was shaped in about  $100\text{ mm}$  (diameter)  $\times 6\text{ mm}$  using a dry bag and then hot pressed for 1 hour at a temperature of  $1650^\circ\text{C}$  and a pressure of  $400\text{ kg/cm}^2$  in a vacuum of  $1\text{ Pa}$  using a hot pressing metal mold of C/C composite. From the thus resulting sintered body was got a cutting insert (Sample A) of Form No. SNGN 120408 and then subjected to polishing. For comparison, there were used a commercially available  $\text{Al}_2\text{O}_3\text{-TiC}$  ceramics cutting tool (NB 90S -commercial name-, manufactured by X Co., Sample B),  $\text{Al}_2\text{O}_3\text{-ZrO}_2$  ceramics cutting tool (SN 60 -commercial name-, manufactured by Y Co., Sample C),  $\text{Si}_3\text{N}_4$  ceramics cutting tool (NS 130 -commercial name-, manufactured by Sumitomo Electric Industries, Ltd., Sample D) and  $\text{Al}_2\text{O}_3\text{-SiC}$  whisker-ceramics cutting tool (WG 300 -commercial name-, manufactured by Z Co., Sample E).

These samples were subjected to cutting tests under the following conditions:

Cutting Conditions 1

|                     |                                                              |
|---------------------|--------------------------------------------------------------|
| Workpiece to be cut | Inconel 718 (commercial name, aged after solution treatment) |
| Cutting Speed       | 100 m/min                                                    |
| Feed                | 0.15 mm/rev                                                  |
| Cutting Depth       | 2 mm                                                         |
| Insert Form No.     | SNGN 120408                                                  |
| Holder              | FN 11R-44A                                                   |
| Cutting Agent       | no                                                           |

The results are as follows:

Sample B: boundary breakage when cutting for 12 seconds

Sample C: melt down of insert edge when cutting for 21 seconds

Sample D, E and A were resistant to cutting for 1 minute to give the following results:

|          | Flank Wear Width ( $V_B$ ) (mm) | Boundary Notch ( $V_N$ ) (mm) |
|----------|---------------------------------|-------------------------------|
| Sample D | 0.38                            | 0.52                          |
| Sample E | 0.12                            | 0.55                          |
| Sample A | 0.13                            | 0.18                          |

Similarly, the above described samples were subjected to cutting tests under the following conditions:

Cutting Conditions 2

|                 |                       |
|-----------------|-----------------------|
| Workpiece       | FC 30                 |
| Cutting Speed   | 350 m/min             |
| Feed            | 0.15 mm/tooth         |
| Cutting Depth   | 2 mm                  |
| Insert Form No. | SNGN 120408           |
| Cutter          | DNF 4160 R (one edge) |
| Cutting Agent   | no                    |

The results are summarized below:

Sample A:  $V_B$  (mean value) 0.13 mm after cutting for 30 minutes

Sample B: broken when cutting for 4 minutes 38 seconds

Sample C: melt down of insert edge when cutting for 4 min 18 sec

Sample D:  $V_B$  (mean value) 0.31 mm after cutting for 30 min

Sample E:  $V_B$  (mean value) 0.23 mm after cutting for 30 min

Example 2

Ceramics cutting tools shown in Table 1 were prepared by the same method as that of obtaining Sample A in Example 1 and then subjected to cutting tests under Cutting Conditions 1 of Example 1.

Table 1

| Sample | Al <sub>2</sub> O <sub>3</sub> (vol %) | SiC Whisker (vol %) | ZrO <sub>2</sub> (vol%) | Flank Wear Width V <sub>B</sub> (mm) | Boundary Notch V <sub>N</sub> (mm) |
|--------|----------------------------------------|---------------------|-------------------------|--------------------------------------|------------------------------------|
| F      | 70                                     | 25                  | 5                       | 0.20                                 | 0.79                               |
| G      | 60                                     | 35                  | 5                       | 0.14                                 | 0.20                               |
| H      | 58                                     | 37                  | 5                       | 0.25                                 | 0.27                               |
| I      | 70                                     | 30                  | 0                       | 0.23                                 | 0.98                               |
| J      | 63                                     | 30                  | 7                       | 0.14                                 | 0.17                               |
| K      | 56                                     | 30                  | 14                      | 0.31                                 | 0.41                               |
| L      | 63                                     | 27                  | 10                      | 0.14                                 | 0.25                               |
| M      | 58                                     | 32                  | 10                      | 0.15                                 | 0.19                               |
| N      | 95                                     | 0                   | 5                       | life: at most 1 sec                  |                                    |
| O      | 40                                     | 50                  | 10                      | life: at most 1 sec                  |                                    |

Note: Sample J according to Present Invention

### Example 3

Ceramics cutting tools having the same composition as Sample A obtained in Example 1 were prepared by the conditions shown in Table 2 and then subjected to cutting tests under Cutting Conditions 1 of Example 1, thus obtaining results shown in Table 2.

To examine the effect of the hot hydrostatic pressure treatment, a ceramics cutting tool having the same composition as Sample A was compressed and sintered at 1600 °C and 100 kg/cm<sup>2</sup> for 40 minutes and then subjected to hot hydrostatic pressure treatments under various conditions. The treatment conditions and test results under Cutting Conditions 1 are shown in Table 3.

When the hot pressing conditions prior to the hot isostatic pressing treatment were examined with respect to various points, at a temperature of lower than 1500 °C the same result was obtained as in the case of Sample 10 and at a pressure of less than 10 kg/cm<sup>2</sup> or in a time of shorter than 30 minutes, the lives of the tools were at most 30 seconds. When the temperature was higher than 1800 °C or the time was longer than 5 hours, the lives of the tools were at most 30 seconds, because Al<sub>2</sub>O<sub>3</sub> was subject to excessive grain growth after the hot hydrostatic pressure treatment.

Table 2

| Hot Pressing Conditions and Cutting Test Results |                               |                                             |                        |                                      |                                    |
|--------------------------------------------------|-------------------------------|---------------------------------------------|------------------------|--------------------------------------|------------------------------------|
| Sample                                           | Hot Pressing Temperature (°C) | Hot Pressing Pressure (kg/cm <sup>2</sup> ) | Hot Pressing Time (hr) | Flank Wear Width V <sub>B</sub> (mm) | Boundary Notch V <sub>N</sub> (mm) |
| P                                                | 1400                          | 400                                         | 1                      | life: 8 sec                          |                                    |
| Q                                                | 1600                          | 400                                         | 1                      | 0.12                                 | 0.29                               |
| R                                                | 1750                          | 400                                         | 1                      | 0.17                                 | 0.24                               |
| S                                                | 2100                          | 400                                         | 1                      | life: 19 sec                         |                                    |
| T                                                | 1750                          | 400                                         | 0.25                   | life: at most 1 sec                  |                                    |
| U                                                | 1750                          | 400                                         | 7                      | life: 11 sec                         |                                    |
| V                                                | 1750                          | 100                                         | 1                      | life: 58 sec                         |                                    |
| W                                                | 1750                          | 600                                         | 1                      | 0.17                                 | 0.37                               |
| X                                                | 1700                          | 400                                         | 1                      | 0.13                                 | 0.15                               |

Note: Samples Q, R and X according to Present Invention

Table 3

| Hot Isostatic Press Treatment Conditions and Cutting Test Results |                  |                        |           |                             |                           |
|-------------------------------------------------------------------|------------------|------------------------|-----------|-----------------------------|---------------------------|
| Sample                                                            | Temperature (°C) | Pressure (Pa)(Atm)     | Time (hr) | Flank Wear Width $V_B$ (mm) | Boundary Notch $V_N$ (mm) |
| 1                                                                 | 1400             | $1 \times 10^8$ (1000) | 1         | life: at most 1             |                           |
| 2                                                                 | 1700             | $1 \times 10^8$ (1000) | 1         | 0.10                        | 0.13                      |
| 3                                                                 | 1800             | $1 \times 10^8$ (1000) | 1         | 0.25                        | 0.29                      |
| 4                                                                 | 1700             | $5 \times 10^5$ (5)    | 1         | life: 5 seconds             |                           |
| 5                                                                 | 1700             | $1 \times 10^8$ (1000) | 0.25      | life: 11 seconds            |                           |
| 6                                                                 | 1700             | $1 \times 10^8$ (1000) | 7         | life: 19 seconds            |                           |
| 7                                                                 | 1900             | $1 \times 10^8$ (1000) | 1         | life: 21 seconds            |                           |
| 8                                                                 | 1500             | $1 \times 10^8$ (1000) | 1         | 0.14                        | 0.21                      |
| 9                                                                 | no treatment     |                        |           | life: at most 1 sec         |                           |
| Note: Samples 2, 3 and 8 according to Present Invention           |                  |                        |           |                             |                           |

Example 4

Sample A and Samples F to X were further subjected to cutting tests under the following conditions:

Cutting Conditions 3

|                 |               |
|-----------------|---------------|
| Workpiece       | FC 25         |
| Cutting Speed   | 300 m/min     |
| Feed            | 0.4 mm/rev    |
| Cutting Depth   | 1.5 mm        |
| Insert Form No. | SNGN 120408   |
| Holder          | FN 11 R - 44A |
| Cutting Oil     | dry           |
| Cutting Time    | 10 minutes    |

The results are shown in Table 4:

Table 4

| Sample | Flank Wear Width $V_B$ (mm) | Boundary Notch $V_N$ (mm) | $Al_2O_3$ Mean Grain Diameter ( $\mu m$ ) |
|--------|-----------------------------|---------------------------|-------------------------------------------|
| A      | 0.13                        | 0.18                      | 0.8                                       |
| F      | 0.14                        | 0.19                      | 0.8                                       |
| G      | 0.14                        | 0.23                      | 0.8                                       |
| H      | 0.20                        | 0.22                      | 0.8                                       |
| I      | 0.21                        | 0.37                      | 0.8                                       |
| J      | 0.14                        | 0.18                      | 0.8                                       |
| K      | 0.22                        | 0.20                      | 0.8                                       |
| L      | 0.14                        | 0.19                      | 0.8                                       |
| M      | 0.15                        | 0.18                      | 0.8                                       |
| N      | 0.17                        | 0.55                      | 0.8                                       |
| O      | 0.24                        | 0.48                      | 0.8                                       |
| P      | 0.22                        | 0.35                      | 0.6                                       |
| Q      | 0.15                        | 0.22                      | 0.7                                       |
| R      | 0.16                        | 0.20                      | 1.4                                       |
| S      | 0.20                        | 0.38                      | 3.0                                       |
| T      | 0.17                        | 0.35                      | 0.7                                       |
| U      | 0.19                        | 0.33                      | 2.1                                       |
| V      | 0.17                        | 0.37                      | 1.4                                       |
| W      | 0.17                        | 0.20                      | 1.4                                       |
| X      | 0.13                        | 0.19                      | 1.0                                       |

Note: Samples J, Q, R and X according to Present Invention;  $Al_2O_3$  Mean Grain Diameter: measured by observation of SEM.

## Example 5

Ceramics cutting tools each having a composition comprising 30 % by volume (as constant amount) of SiC whiskers with a mean with a mean diameter of 0.6  $\mu m$  and an aspect ratio of 5 to 50, 0 to 20 % by volume of  $ZrO_2$  partially stabilized with 3 % of  $HfO_2$  and the balance of  $\alpha-Al_2O_3$ , as shown in Table 5, were prepared under the same conditions as those of Example 1, and then subjected to cutting tests under Cutting Conditions 1 of Example 1, thus obtaining results shown in Fig. 1 in which there is given a relationship between the amount of  $ZrO_2$  and boundary notch.

Table 5

| Sample | SiC Whiskers (vol %) | $ZrO_2$ (vol %) | $Al_2O_3$ (vol %) | Boundary Notch $V_N$ (mm) |
|--------|----------------------|-----------------|-------------------|---------------------------|
| 10     | 30                   | 0               | 70                | 0.98                      |
| 11     | 30                   | 3               | 67                | 0.20                      |
| 12     | 30                   | 5               | 65                | 0.15                      |
| 13     | 30                   | 7               | 63                | 0.17                      |
| 14     | 30                   | 12              | 58                | 0.25                      |
| 15     | 30                   | 14              | 56                | 0.41                      |
| 16     | 30                   | 20              | 50                | 0.81                      |

Note: Samples 11 to 13 according to Present Invention

## Example 6

Ceramics cutting tools having the same compositions as Sample A obtained in Example 1 were prepared by the conditions shown in Table 6 and then subjected to cutting tests under Cutting Condition 1 of Example 1, thus obtaining results shown in Fig. 2, in which there is given a relationship between the hot pressing temperature and boundary notch  $V_N$ .

Table 6

| Sample | Hot Pressing Temperature (°C) | Hot Pressing Pressure (kg/cm <sup>2</sup> ) | Hot Pressing Time (hr) | Mean Grain Size of Al <sub>2</sub> O <sub>3</sub> (μm) | Boundary Notch $V_N$ (mm) | Boundary Notch $V_N$ After HIP (mm) |
|--------|-------------------------------|---------------------------------------------|------------------------|--------------------------------------------------------|---------------------------|-------------------------------------|
| 17     | 1400                          | 400                                         | 1                      | 0.6                                                    | tool life 8 sec           |                                     |
| 18     | 1550                          | 400                                         | 1                      | 0.6                                                    | 0.48                      | 0.2                                 |
| 19     | 1600                          | 400                                         | 1                      | 0.7                                                    | 0.29                      | 0.15                                |
| 20     | 1650                          | 400                                         | 1                      | 0.8                                                    | 0.18                      | 0.10                                |
| 21     | 1700                          | 400                                         | 1                      | 1.0                                                    | 0.15                      | 0.13                                |
| 22     | 1750                          | 400                                         | 1                      | 1.4                                                    | 0.24                      | 0.24                                |
| 23     | 1800                          | 400                                         | 1                      | 1.7                                                    | 0.88                      | 0.88                                |
| 24     | 1900                          | 400                                         | 1                      | 2.3                                                    | tool life 29 sec          | tool life 21 sec                    |

Note: Samples 18 to 22 Present Invention

The thus resulting sintered bodies were subjected to a HIP treatment in Ar at 1600 °C and 1500 atm for 1 hour to prepare cutting inserts, which were then subjected to cutting tests in an analogous manner to Example 1 for comparison with those before the HIP treatment. The results are shown in Table 6 and Fig. 2.

It will clearly be understood from the results of Examples that the ceramics cutting tools of the present invention are excellent in toughness as well as wear resistance.

## Claims

1. An Al<sub>2</sub>O<sub>3</sub> - SiC whiskers - ZrO<sub>2</sub> ceramic cutting tool comprising 27 to 32% by volume of SiC whiskers, 3 to 7 % by volume of partially stabilised ZrO<sub>2</sub>, at least one sintering aid selected from the group consisting of MgO, Y<sub>2</sub>O<sub>3</sub> and NiO and the balance of Al<sub>2</sub>O<sub>3</sub>, said Al<sub>2</sub>O<sub>3</sub> having a mean grain diameter of at most 1.5 μm.
2. A process for the production of the Al<sub>2</sub>O<sub>3</sub>-SiC whisker-ZrO<sub>2</sub> ceramic cutting tool as claimed in Claim 1, which comprises hot pressing a mixed powder of the Al<sub>2</sub>O<sub>3</sub>, SiC whiskers, ZrO<sub>2</sub> and sintering aid at a temperature of 1500 to 1750 °C under a pressure of 150 to 500 kg/cm<sup>2</sup> for a period of time of 30 minutes to 5 hours.
3. A process for the production of the Al<sub>2</sub>O<sub>3</sub>-SiC whiskers-ZrO<sub>2</sub> ceramic cutting tool as claimed in Claim 1, which comprises hot pressing a mixed powder of the Al<sub>2</sub>O<sub>3</sub>, SiC whiskers, ZrO<sub>2</sub> and sintering aid at a temperature of 1450 to 1750 °C under a pressure of 10 to 500 kg/cm<sup>2</sup> for a period of time of 30 minutes to 5 hours and then subjecting the mixture to a hot isostatic press treatment at a temperature of 1500 to 1800 °C under a pressure of 10 to 3000 atm for a period of time of 30 minutes to 5 hours.
4. The process as claimed in either of Claims 2 or 3, wherein ZrO<sub>2</sub> is partially stabilized with at least one compound selected from the group consisting of Y<sub>2</sub>O<sub>3</sub>, CaO and HfO<sub>2</sub>.

## Patentansprüche

1. Spanabhebendes Al<sub>2</sub>O<sub>3</sub> - SiC-Whiskers - ZrO<sub>2</sub> - Keramikwerkzeug, welches 27 bis 32 Vol.-% SiC-Whiskers, 3 bis 7 Vol.-% teilweise stabilisiertes ZrO<sub>2</sub> und mindestens ein aus der aus MgO, Y<sub>2</sub>O<sub>3</sub> und NiO bestehenden Gruppe sowie der zu ergänzenden Restmenge von Al<sub>2</sub>O<sub>3</sub> ausgewähltes Sinterhilfsmittel umfaßt, wobei das Al<sub>2</sub>O<sub>3</sub> einen mittleren Korngrößendurchmesser von höchstens 1,5 μm aufweist.



## Example 6

Ceramics cutting tools having the same compositions as Sample A obtained in Example 1 were prepared by the conditions shown in Table 6 and then subjected to cutting tests under Cutting Condition 1 of Example 1, thus obtaining results shown in Fig. 2, in which there is given a relationship between the hot pressing temperature and boundary notch  $V_N$ .

Table 6

| Sample | Hot Pressing Temperature (°C) | Hot Pressing Pressure (kg/cm <sup>2</sup> ) | Hot Pressing Time (hr) | Mean Grain Size of Al <sub>2</sub> O <sub>3</sub> (μm) | Boundary Notch $V_N$ (mm) | Boundary Notch $V_N$ After HIP (mm) |
|--------|-------------------------------|---------------------------------------------|------------------------|--------------------------------------------------------|---------------------------|-------------------------------------|
| 17     | 1400                          | 400                                         | 1                      | 0.6                                                    | tool life 8 sec           |                                     |
| 18     | 1550                          | 400                                         | 1                      | 0.6                                                    | 0.48                      | 0.2                                 |
| 19     | 1600                          | 400                                         | 1                      | 0.7                                                    | 0.29                      | 0.15                                |
| 20     | 1650                          | 400                                         | 1                      | 0.8                                                    | 0.18                      | 0.10                                |
| 21     | 1700                          | 400                                         | 1                      | 1.0                                                    | 0.15                      | 0.13                                |
| 22     | 1750                          | 400                                         | 1                      | 1.4                                                    | 0.24                      | 0.24                                |
| 23     | 1800                          | 400                                         | 1                      | 1.7                                                    | 0.88                      | 0.88                                |
| 24     | 1900                          | 400                                         | 1                      | 2.3                                                    | tool life 29 sec          | tool life 21 sec                    |

Note: Samples 18 to 22 Present Invention

The thus resulting sintered bodies were subjected to a HIP treatment in Ar at 1600 °C and 1500 atm for 1 hour to prepare cutting inserts, which were then subjected to cutting tests in an analogous manner to Example 1 for comparison with those before the HIP treatment. The results are shown in Table 6 and Fig. 2.

It will clearly be understood from the results of Examples that the ceramics cutting tools of the present invention are excellent in toughness as well as wear resistance.

## Claims

1. An Al<sub>2</sub>O<sub>3</sub> - SiC whiskers - ZrO<sub>2</sub> ceramic cutting tool comprising 27 to 32% by volume of SiC whiskers, 3 to 7 % by volume of partially stabilised ZrO<sub>2</sub>, at least one sintering aid selected from the group consisting of MgO, Y<sub>2</sub>O<sub>3</sub> and NiO and the balance of Al<sub>2</sub>O<sub>3</sub>, said Al<sub>2</sub>O<sub>3</sub>, having a mean grain diameter of at most 1.5 μm.
2. A process for the production of the Al<sub>2</sub>O<sub>3</sub>-SiC whisker-ZrO<sub>2</sub> ceramic cutting tool as claimed in Claim 1, which comprises hot pressing a mixed powder of the Al<sub>2</sub>O<sub>3</sub>, SiC whiskers, ZrO<sub>2</sub> and sintering aid at a temperature of 1500 to 1750 °C under a pressure of 150 to 500 kg/cm<sup>2</sup> for a period of time of 30 minutes to 5 hours.
3. A process for the production of the Al<sub>2</sub>O<sub>3</sub>-SiC whiskers-ZrO<sub>2</sub> ceramic cutting tool as claimed in Claim 1, which comprises hot pressing a mixed powder of the Al<sub>2</sub>O<sub>3</sub>, SiC whiskers, ZrO<sub>2</sub> and sintering aid at a temperature of 1450 to 1750 °C under a pressure of 10 to 500 kg/cm<sup>2</sup> for a period of time of 30 minutes to 5 hours and then subjecting the mixture to a hot isostatic press treatment at a temperature of 1500 to 1800 °C under a pressure of 10 to 3000 atm for a period of time of 30 minutes to 5 hours.
4. The process as claimed in either of Claims 2 or 3, wherein ZrO<sub>2</sub> is partially stabilized with at least one compound selected from the group consisting of Y<sub>2</sub>O<sub>3</sub>, CaO and HfO<sub>2</sub>.

## Patentansprüche

1. Spanabhebendes Al<sub>2</sub>O<sub>3</sub> - SiC-Whiskers - ZrO<sub>2</sub> - Keramikwerkzeug, welches 27 bis 32 Vol.-% SiC-Whiskers, 3 bis 7 Vol.-% teilweise stabilisiertes ZrO<sub>2</sub> und mindestens ein aus der aus MgO, Y<sub>2</sub>O<sub>3</sub> und NiO bestehenden Gruppe sowie der zu ergänzenden Restmenge von Al<sub>2</sub>O<sub>3</sub> ausgewähltes Sinterhilfsmittel umfaßt, wobei das Al<sub>2</sub>O<sub>3</sub> einen mittleren Korngrößendurchmesser von höchstens 1,5 μm aufweist.



2. Verfahren zur Herstellung des spanabhebenden  $\text{Al}_2\text{O}_3$  - SiC-Whiskers -  $\text{ZrO}_2$  - Keramikwerkzeugs gemäß Anspruch 1, welches die Warmpressung eines Pulvergemisches aus  $\text{Al}_2\text{O}_3$ , SiC-Whiskers,  $\text{ZrO}_2$  sowie einem Sinterhilfsmittel bei einer Temperatur von 1500 bis 1750 °C und einem Druck von 150 bis 500 kg/cm<sup>2</sup> für eine Zeitspanne von 30 Minuten bis 5 Stunden umfaßt.
3. Verfahren zur Herstellung des spanabhebenden  $\text{Al}_2\text{O}_3$  - SiC-Whiskers -  $\text{ZrO}_2$  - Keramikwerkzeugs gemäß Anspruch 1, welches die Warmpressung eines Pulvergemisches aus  $\text{Al}_2\text{O}_3$ , SiC-Whiskers,  $\text{ZrO}_2$  sowie einem Sinterhilfsmittel bei einer Temperatur zwischen 1650 °C und 1750 °C und einem Druck von 10 bis 500 kg/cm<sup>2</sup> über eine Zeitspanne von 30 Minuten bis 5 Stunden sowie die daran anschließende Maßnahme umfaßt, daß man das Gemisch einer isostatischen Warmpreßbehandlung bei einer Temperatur zwischen 1500 °C und 1800 °C und einem Druck von 10 bis 3000 Atmosphären über eine Zeitspanne von 30 Minuten bis 5 Stunden unterwirft.
4. Verfahren gemäß einem der Ansprüche 2 oder 3, bei dem das  $\text{ZrO}_2$  teilweise mit mindestens einer Verbindung stabilisiert ist, welche aus der aus  $\text{Y}_2\text{O}_3$ , CaO und  $\text{HfO}_2$  bestehenden Gruppe ausgewählt ist.

#### Revendications

1. Outil de coupe en céramique à base de  $\text{Al}_2\text{O}_3$  - whiskers de SiC -  $\text{ZrO}_2$  comprenant 27 à 32% en volume de whiskers de SiC, 3 à 7% en volume de  $\text{ZrO}_2$  partiellement stabilisé, au moins adjuvant de frittage choisi dans le groupe comprenant MgO,  $\text{Y}_2\text{O}_3$  et NiO et le restant en  $\text{Al}_2\text{O}_3$ , ladite  $\text{Al}_2\text{O}_3$  ayant un diamètre de grain moyen de tout au plus 1,5 µm.
2. Procédé de production de l'outil de coupe en céramique à base de  $\text{Al}_2\text{O}_3$  - whiskers de SiC -  $\text{ZrO}_2$  suivant la revendication 1, qui comprend la compression à chaud d'une poudre mixte des  $\text{Al}_2\text{O}_3$ , whiskers de SiC,  $\text{ZrO}_2$  et adjuvant de frittage à une température de 1500 à 1750 °C sous une pression de 150 à 500 kg/cm<sup>2</sup> pendant une période de 30 minutes à 5 heures.
3. Procédé de production de l'outil de coupe en céramique à base de  $\text{Al}_2\text{O}_3$  - whiskers de SiC -  $\text{ZrO}_2$  suivant la revendication 1, qui comprend la compression à chaud d'une poudre mixte des  $\text{Al}_2\text{O}_3$ , whiskers de SiC,  $\text{ZrO}_2$  et adjuvant de frittage à une température de 1450 à 1750 °C sous une pression de 10 à 500 kg/cm<sup>2</sup> pendant une période de temps de 30 minutes à 5 heures et ensuite le traitement du mélange par une presse isostatique chaude à une température de 1500 à 1800 °C sous une pression de 10 à 3000 atm pendant une période de temps de 30 minutes à 5 heures.
4. Procédé suivant l'une ou l'autre des revendications 2 et 3, dans lequel le  $\text{ZrO}_2$  est partiellement stabilisé avec au moins un composé choisi dans le groupe comprenant  $\text{Y}_2\text{O}_3$ , CaO et  $\text{HfO}_2$ .