PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 :		(11) International Publication Number:
C04B 35/80, 41/87, 35/56, 35/58	A1	WO 97/18177
		(43) International Publication Date: 22 May 1997 (22.05.97)

(21) International Application Number: PCT/US96/15192

(22) International Filing Date: 20 September 1996 (20.09.96)

(30) Priority Data:
08/557,751 13 November 1995 (13.11.95) US

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(81) Designated States: AU, BR, CA, CN, JP, KR, MX, SG, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: WHISKER REINFORCED CERAMIC CUTTING TOOL AND COMPOSITION THEREOF

(57) Abstract

A ceramic composition produced by the consolidation of a blend of starting components. The composition comprises a matrix with one or more of the carbides, nitrides and carbonitrides of hafnium, molybdenum, zirconium, tantalum, niobium, vanadium, tungsten and titanium, and solid solutions thereof in an amount that is greater than 50 volume percent of the matrix. The matrix comprises between 60 and 99.8 volume percent of the composition. Ceramic whiskers are uniformly dispersed throughout the matrix wherein the ceramic whiskers comprises between 0.2 and 40 volume percent of the composition.

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WHISKER REINFORCED CERAMIC CUTTING TOOL AND COMPOSITION THEREOF

BACKGROUND OF THE INVENTION

The present invention pertains to a ceramic cutting tool, and a composition thereof, that has whisker reinforcement. More specifically, the invention pertains to a ceramic cutting tool, and a composition thereof, that has ceramic whisker reinforcement wherein at least 50 volume percent of the ceramic matrix comprises a carbide, nitride and/or carbonitride of titanium, hafnium, molybdenum, zirconium, tantalum, niobium, vanadium and/or tungsten.

In the past, there have been ceramic bodies with whisker reinforcement such as that disclosed in U.S. Patent No. 4,543,345 to Wei. The Wei Patent discloses an alumina matrix with silicon carbide whisker reinforcement, a boron carbide matrix with silicon carbide whiskers, and a mullite matrix with silicon carbide whiskers. According to the Wei patent, the incorporation of silicon carbide whiskers increased the fracture toughness of the substrate.

Japanese Publication No. 63-10758 to Yamagawa et al. pertains to a ceramic composite that comprises alumina as its main component. The balance comprises between 5 to 40 weight TiC and 2 to 40 weight percent silicon carbide whiskers. The combined amount of titanium carbide and silicon carbide whiskers cannot exceed 50 weight percent, i.e., it is 50 weight percent or less. This document also mentions that there can be up to 10 weight percent of an oxide, carbide or nitride

of aluminum, silicon and the Group IVa, Va and VIa elements.

U.S. Patent No. 4,507,224 to Toibana et al. makes general reference to certain nitrides and carbides as suitable matrix material, along with electroconductive powder, for SiC fiber reinforcement. The SiC fibers are present in an amount between 5 and 50 weight percent. The '224 patent makes specific reference to matrices of silicon nitride, aluminum nitride, boron nitride, silicon carbide, boron carbide, and titanium carbide. The '224 Patent recites examples that use alumina, zirconium oxide, silicon nitride as matrices along with silicon carbide fibers. The focus of the '224 Patent is on a ceramic article suitable for electric discharge machining. In this regard, the specification states that the electrical resistance of the substrate must not exceed 10 ohm-cm

The publication "Fiber Reinforced Ceramics: A Review and Assessment of their Potential" by Kpochmal (at pages 9 through 16) mentions ceramics (with fiber reinforcement) having a HfC or ZrC matrix. The filaments include tungsten, molybdenum, tantalum, boron, carbon, silicon carbide, boron carbide, and alumina.

There have also been ceramic cutting tools with whisker reinforcement. In this regard, U.S. Patent No. 4,789,277 to Rhodes et al. discloses the use of ceramic whiskers (the content ranges from 2 volume percent to 40 volume percent) such as alumina, aluminum nitride, beryllia, boron carbide, graphite, silicon carbide (preferably), and silicon nitride in a ceramic matrix. The ceramic matrix is preferably alumina, but includes alumina "doped" with up to 30% zirconia, hafnia and titanium carbide. The alumina remains the dominant component of the matrix.

PCT\US 86\00528 Patent Application to Rhodes et al. entitled HIGH DENSITY REINFORCED CERAMIC BODIES

AND METHOD OF MAKING SAME has as its focus the pressureless sintering of whisker-reinforced ceramic bodies. This document mentions a whisker content of between 0.5 and 21 volume percent. The specific examples teach the use of an alumina matrix with SiC whisker contents from 6.1 volume percent to 29.2 volume percent.

U.S. Patent No. 5,059,564 to Mehrotra et al. for an ALUMINA-TITANIUM CARBIDE-SILICON CARBIDE COMPOSITION pertains to an alumina-based matrix containing a dispersion of SiC whiskers and a TiC phase. The SiC whiskers comprise 1.0 to less than 30 volume percent with the most preferred range being 2.5 to 20 volume percent. The TiC comprises 5 to 40 volume percent, and preferably, with up to 3 volume percent of a sintering aid residue.

U.S. Patent No. 5,427,987 to Mehrotra et al. for a GROUP IVB BORIDE BASED CUTTING TOOLS FOR MACHINING GROUP VIB BASED MATERIALS concerns zirconium boride, hafnium boride and especially titanium boride cutting tools. The addition of W and Co to the boride powder improves the densification of the composition.

The 1969 Air Force Report by Whitney et al. mentions the use of a generally high content of particle reinforcement in ZrN and HfN matrices for use as cutting tools. In this 1969 Report there is no suggestion that whiskers could reinforce these matrices.

U.S. Patent No. 5,231,060 to Brandt teaches using whiskers of the nitride, carbides and borides of Ti, Zr, Hf, V, Nb or Ta to reinforce an oxide-based matrix such as alumina for use as a cutting tool.

U.S. Patent No. 5,439,854 to Suzuki et al. pertains to a cutting tool that contains 40 weight percent or more of TiC, and 5 to 40 weight percent of silicon carbide whiskers (of a length equal to 20 micrometers or less). The cutting tool may also contain

up to 40 weight percent alumina, as well as sintering aids. Up to 40 weight percent of the TiC may be substituted by Ti or a Ti-based compound such as a nitride, boride, or oxide.

Table I set forth below presents certain physical properties of some prior art commercial cutting tools.

Table I
Selected Physical Properties of
Certain Commercial Cutting Tools

Cutting Tool	HRA	VHN (GPa) [18.5 kg load]	K_{IC}(E&C) [$MPam^{1/2}$]
WG-300	94.6	19.4	6.1
HC6	94.6	19.4	5.1
K090	94.8	19.1	4.7

Referring to these commercial cutting tools, the WG-300 cutting tool is sold by Greenleaf Corporation of Saegertown, Pennsylvania and has a composition of about 25 volume percent SiC whiskers and the balance alumina. The HC6 cutting tool is sold by NTK Cutting Tool Division of NGK Spark Plugs (USA), Inc. of Farmington Hills, Michigan, and has a composition of about 70 weight percent TiC and the balance alumina. The K090 cutting tool is made by Kennametal Inc. of Latrobe, Pennsylvania and has a composition of about 70 volume percent alumina and 30 volume percent TiC. Each of these compositions may also contain minor amounts of sintering aid.

SUMMARY OF THE INVENTION

It is an object of the invention to provide an improved ceramic cutting tool, and a composition thereof, that has whisker reinforcement.

It is still another object of the invention to provide an improved ceramic cutting tool, and a composition thereof. that has ceramic whisker reinforcement wherein the ceramic matrix includes about 50 volume percent of one or more of the carbides, nitrides and/or carbonitrides of titanium, hafnium molybdenum, zirconium, tantalum, niobium, vanadium and/or tungsten.

It is another object of the invention to provide an improved ceramic cutting tool, and a composition thereof, that has ceramic whisker reinforcement wherein the ceramic matrix includes about 50 volume percent of one or more of the carbides, nitrides and/or carbonitrides of titanium, hafnium, molybdenum, zirconium, tantalum, niobium, vanadium and/or tungsten, and optionally, the substrate further includes one or more particulates of alumina, silicon carbide or the borides of titanium, zirconium or hafnium.

It is still another object of the invention to provide an improved ceramic cutting tool, and a composition thereof, that has ceramic whisker reinforcement wherein the whiskers include one of alumina, silicon carbide, or the carbides, nitrides, borides or carbonitrides of titanium, zirconium or hafnium.

It is another object of the invention to provide an improved ceramic cutting tool, and a composition thereof, that has ceramic whisker reinforcement wherein the ceramic matrix includes about 50 volume percent of one or more of the carbides, nitrides and/or carbonitrides of titanium, hafnium,

molybdenum, zirconium, tantalum, niobium, vanadium and/or tungsten, and optionally, the substrate further includes one or more particulates of alumina, silicon carbide or the borides of titanium, zirconium or hafnium. The ceramic whiskers include one or more of alumina, silicon carbide, silicon nitride, boron carbide, or the carbides, nitrides, borides, or the carbonitrides of titanium, zirconium or hafnium, or the oxides of zirconium or hafnium.

In one form thereof, the invention is a composition produced by the consolidation of a blend of starting components. The composition comprises a matrix which comprises one or more of the carbides, nitrides and carbonitrides of hafnium, molybdenum, zirconium, tantalum, niobium, vanadium, titanium, tungsten and solid solutions thereof in an amount that is greater than 50 volume percent of the matrix. The matrix further includes sintering aid residue present from the use of one or more sintering aids as a starting component in an amount of less than or equal to 1 weight percent of the starting components. The matrix comprises between 60 and 99.8 volume percent of the composition. The composition further includes ceramic whiskers uniformly dispersed throughout the matrix wherein the ceramic whiskers comprises between 0.2 and 40 volume percent of the composition.

In another form thereof, the invention is a ceramic cutting tool that comprises a rake face and a flank face. There is a cutting edge at the juncture of the rake face and the flank face. The tool includes a ceramic composition that has a matrix comprising between about 45 volume percent and less than 50 volume percent of titanium molybdenum carbide, and less than about 55 volume percent alumina. The matrix comprises between about 60 volume percent and about 90 volume percent of the ceramic composition. The composition further includes ceramic whiskers uniformly dispersed

throughout the matrix wherein the ceramic whiskers comprise about 2 volume percent to about 35 volume percent of the ceramic composition.

BRIEF DESCRIPTION OF THE FIGURES

The following is a brief description of the figures that comprise a part of this patent application:

FIG. 1 is an isometric view of a cutting insert that comprises a specific embodiment of the cutting tool of the present invention; and

FIG. 2 is a scanning electron microscopy (SEM) secondary electron image photomicrograph (5000X magnification) of a hot-pressed composite in accordance with the present invention corresponding to Example 2 herein showing a polished plane perpendicular to the hot pressing axis;

FIG. 3 is a scanning electron microscopy (SEM) secondary electron image photomicrograph (2000X magnification) of a hot-pressed composite in accordance with the present invention corresponding to Example 4 herein showing a polished plane perpendicular to the hot pressing axis;

FIG. 4 is a scanning electron microscopy (SEM) secondary electron image photomicrograph (2000X magnification) of a hot-pressed composite in accordance with the present invention corresponding to Example 6 herein showing a polished plane perpendicular to the hot pressing axis;

FIG. 5 is a graph of depth of cut notch wear as a function of cutting time for embodiments of the present invention as well as a prior art composition;

FIG. 6 is a graph of flank wear as a function of cutting time for embodiments of the present invention as well as a prior art composition; and

FIG. 7 is a graph of nose wear as a function of cutting time for embodiments of the present invention as well as a prior art composition.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

The invention pertains to ceramic compositions, and especially, such ceramic compositions that include ceramic whisker reinforcement. Generally speaking the ceramic cutting tool comprises a ceramic matrix and ceramic whiskers which reinforce the matrix. The combination of the matrix and the whiskers comprises a substrate. The substrate may be coated with a hard material. Examples of such hard materials include alumina, titanium carbide, titanium nitride, titanium carbonitride, titanium aluminum nitride, cubic boron nitride and diamond and their combinations. The coating may be applied by chemical vapor deposition (CVD) [see U.S. Patent No. 4,801,510 to Mehrotra et al. for ALUMINA COATED SILICON CARBIDE WHISKER-ALUMINA COMPOSITION] or physical vapor deposition (PVD) [see U.S. Patent No. 5,264,297 to Jindal et al. for PHYSICAL VAPOR DEPOSITION OF TITANIUM NITRIDE ON A NONCONDUCTIVE SUBSTRATE] or a scheme where some layers are applied by PVD and some layers are applied by CVD (see U. S. Patent No. 5,232,318 to Santhanam et al. for COATED CUTTING TOOLS). The substrates that have a high titanium carbide or titanium carbonitride content, i.e., at least 25 to 30 volume percent titanium carbide or titanium carbonitride, are electrically conductive to such an extent that they are particularly suitable for PVD coating and EDM machining.

The specific matrix of the present invention comprises a carbide, carbonitride and/or nitride of one or more of titanium, hafnium, molybdenum, zirconium, tantalum, niobium, vanadium and/or tungsten so that this component is about 50 volume percent or more of the matrix.

The reason that the preferable content for the carbide, nitride, carbonitride component is over 50 volume percent of the matrix is that this provides for higher hardness and a higher fracture toughness. In this regard, when the carbide, nitride, carbonitride component is over 50 volume percent of the matrix, the fracture toughness is greater than or equal to 6.3 $MPam^{1/2}$ K_{IC}, and more preferably greater than or equal to 6.6 $MPam^{1/2}$ K_{IC}, and the hardness is greater than or equal to 94.7 Rockwell A. The combination of the high hardness and the high fracture toughness makes these combinations suitable for use as cutting tools, bearings, seal rings, wear plates and nozzles,

In addition, the matrix may include particulates of silicon carbide, titanium boride, zirconium boride, chromium boride, hafnium boride, alumina, zirconium oxide, and hafnium oxide along with sintering aid residues. The preferred content of the sintering aids is less than or equal to 1 weight percent, and the more preferable sintering aid content is less than or equal to .5 weight percent. The preferred sintering aids include yttria, magnesia and zirconia either alone or in combination.

The matrix comprises between 60 and 99.8 volume percent of the complete ceramic cutting tool composition.

In regard to the ceramic whiskers, these whiskers are selected from any of the following materials: silicon carbide, titanium carbide, titanium carbonitride, titanium nitride, titanium boride, zirconium carbide, zirconium carbonitride, zirconium nitride, zirconium boride, hafnium carbide, hafnium nitride, hafnium carbonitride, hafnium boride, alumina, silicon nitride and boron carbide. The ceramic whiskers comprise between 0.2 and 40 volume percent of the complete ceramic cutting tool composition.

To maximize fracture toughness in the present invention, it is preferred that a Group IVB (titanium, hafnium or zirconium) nitride or carbonitride-based matrix, more preferably a titanium nitride or titanium carbonitride-based matrix, be reinforced with one or more whiskers of the group consisting of Al_2O_3, Si_3N_4, TiB_2, SiC, TiC, and B_4C. The TiC, TiB_2, SiC or B_4C whiskers should provide the best fracture toughness in a titanium nitride or titanium carbonitride-based matrix.

Referring to FIG. 1 and the geometry of the specific embodiment, there is illustrated a cutting tool generally designated as 10. Cutting tool 10 has a rake face 12 and a flank face 14. The rake face and the flank face intersect to form a cutting edge 16. The specific configuration is a SNGN-453T style of cutting insert with a T land according to the American National Standard for Cutting Tools-Indexable Inserts-Identification System, ANSI B212.4-1986 (cutting edge preparation: .002-.004 inch x 20° chamfer). Other styles of cutting inserts and edge preparations are acceptable and are contemplated to be within the scope of this invention.

As demonstrated from the examples below, ceramic cutting tools within the above definition have excellent density, hardness and fracture toughness. These properties provide for excellent cutting tools, especially in the high speed machining of steels, cast irons, and nickel-base super alloys.

In machining applications where abrasive wear resistance is more of a concern than chemical wear resistance, a titanium carbide-based matrix is preferable. If, however, chemical wear resistance is more important than abrasive wear resistance, then a hafnium carbide-based or titanium carbonitride-based matrix is preferable. Chemical wear resistance may also be improved by applying a hard coating to the insert

such as, for example, titanium nitride, titanium carbonitride, titanium aluminum nitride, titanium carbide, and alumina.

For machining of nickel base super alloys, or for any workpiece in which a combination of high hardness and high chemical inertness is desired, it is preferred that a titanium carbonitride ($TiC_x N_y$) based matrix be used in which x is greater that 0 but less than 0.95 and y + x = 1. More preferably, y is greater than or equal to 0.5. For x = 0, that is titanium nitride, hardness may be reduced and there may be a reaction between the titanium nitride and the SiC whiskers during the high temperature fabrication of these materials. Therefore, y should be less than 0.95. Another range for x and y for titanium carbonitride [$Ti(C_XN_y)$] is y is less than 0.90 and greater than or equal to 0.55, and x + y = 1. Still another range for x and y for titanium carbonitride [$Ti(C_XN_y)$] is y is less than 0.75 and greater than or equal to 0.6, and x + y = 1. Optionally, titanium carbonitride may be replaced by hafnium carbonitride or zirconium carbonitride.

The following examples, as described in Tables II through IV below, are exemplary of the invention and were made according to the following method. For all of the examples, the silicon carbide whiskers were ultrasonically dispersed in isopropanol for one hour.

For Examples Nos. 1 through 7, 9 and 10, the silicon carbide whiskers were made by Tokai Carbon Co. of Tokyo, Japan under the designation Grade No. 1. The Tokai whiskers had an average length of 20 to 50 micrometers and an average diameter of .3 to 1 micrometers. The crystalline structure of these Tokai SiC whiskers was mostly beta silicon carbide.

For Examples Nos. 11 and 12, the silicon carbide whiskers were obtained from Advanced Composite

Materials Corporation of Greer, South Carolina under the grade designation SC-9. The SC-9 whiskers had an average length of 10 to 80 micrometers and an average diameter of 0.6 micrometers. The crystalline structure of these SC-9 SiC whiskers was alpha silicon carbide.

In regard to the method of preparation for Examples Nos. 1 through 7 and 9 through 12, the balance of the components were blended in a mill with isopropanol for one hour. The ultrasonicated silicon carbide whiskers were then blended with the blend of the balance of the components in a mill for 20 minutes. This blend was then discharged through a 200 mesh screen, dried in a rotary evaporator, and then passed through a 100 mesh screen. The dried blend was uniaxially hot pressed in a temperature range of 1750°C to 1850°C at 4500 psi for 60 minutes under an argon atmosphere to essentially full density. The resulting product was ground into a SNGN-453T style of cutting insert having a T land, (cutting edge preparation of .002 to .004 inches and 20 degrees chamfer) as described above.

Tables II through IV below includes in parenthesis the identification of the supplier if there was more than one supplier of the component. The Y_2O_3 for all of the examples was supplied by Hermann C. Strack Berlin GmbH & Co, KG, P O Box 1229, D-7887 Lauterburg, Baden, Germany.

In Tables II through IV the silicon carbide whiskers supplied by Tokai carry the designation "(T)". The silicon carbide whiskers supplied by Advanced Composite Materials Corporation carry the designation "(A)".

For some of the examples, the Al_2O_3 was supplied by Nanophase Technologies Corporation of Darien, Illinois under the designation Nanotek Al_2O_3 Gamma/Delta. In Tables II through IV, the designation "(N)" shows that the Al_2O_3 powder was obtained from

Nanophase. The Nanotek Al_2O_3 powder had a BET specific surface area of 56.2 square meters/gram. The Al_2O_3 was greater than 99.9% pure. The phases present were delta and gamma. For the example (Example No. 2) that used the Nanotek Al_2O_3 powder, an addition of .05 volume percent MgO was added to the blend. The Nanotek Al_2O_3 powder was substantially equiaxed.

The balance of the examples used Al_2O_3 from several lots of Al_2O_3 powder that were supplied by Ceralox (a division of Vista Chemical Company) under the designation HPA-0.5. In Tables II through IV the designation "(C)" shows that the Al_2O_3 was from Ceralox. The Ceralox powder had a BET specific surface area of 10.0 to 11.5 square meters/gram. The as-received Ceralox Al_2O_3 contained an addition of .05 volume percent MgO. The Ceralox Al_2O_3 powder was substantially equiaxed.

The TiC supplied by Biesterfeld U.S. Inc., Advanced Materials Department of New York, New York carried the designation Furukawa TiC, and had a BET specific surface area of 8.52 square meters/gram. In Table II the designation "(F)" shows that the TiC was Furukawa TiC. The Furukawa TiC powder was substantially equiaxed.

The TiC particles supplied by the Macro Division of Kennametal Inc. under the designation Grade A had a BET specific surface area of 5.9 square meters/gram. In Table II the designation "(M)" shows that the TiC came from the Macro Division of Kennametal. The Macro Division TiC powder was substantially equiaxed.

The $Ti_{.8}Mo_{.2}C$ solid solution powder supplied by the Macro Division of Kennametal Inc. of Port Coquitlam, British Columbia, Canada had a BET specific surface area of 4.6 square meters/gram. The $Ti_{.8}Mo_{.2}C$ solid solution powder was substantially equiaxed.

The titanium carbonitride powder supplied by the Macro Division of Kennametal Inc. had a BET specific surface area of 5.2 square meters/gram. This component has a formula of $TiC_{.7}N_{.3}$. The Macro Division titanium carbonitride powder was substantially equiaxed.

Tables II through IV below set forth the compositions (and suppliers where indicated) and the hot pressing temperature. The compositions are set forth in volume percent of the entire composition. For those components that are a part of the matrix, the volume percentage of the matrix for that component is set forth in brackets. For all of Examples 1 through 7 and 9 through 12 the alumina component contained about .05 volume percent magnesia.

In addition, Tables II through IV below set forth the results of tests to ascertain the following properties of the examples: the density (grams/cc), the Rockwell A hardness, the Vickers hardness, and the fracture toughness ($MPam^{1/2}$) as measured by Evans & Charles (Evans & Charles, "Fracture Toughness Determination by Indentation", J. American Ceramic Society, Vol. 59, Nos. 7-8, pages 371-372 using a 18.5 kg load).

Table II
$TiC-Al_2O_3-SiC$ Whisker Compositions and
Physical Properties of Examples Nos. 1-3, 9 and 10

Ex./Comp & Physical Properties	Example 1	Example 2	Example 3	Example 9	Example 10
TiC	39.75(F) [53]	39.75(F) [53]	39.75(M) [53]	40(M) [62]	50(M) [59]
$TiC_{.7}N_{.3}$	-	-	-	-	-
$Ti_{.8}Mo_{.2}C$	-	-	-	-	-
Al_2O_3	35(C) [46.7]	35(N) [46.7]	35(C) [46.7]	24.75(C) [37.7]	34.75(C) [40.7]
Y_2O_3	0.25 [.3]	0.25 [.3]	0.25 [.3]	0.25 [.3]	0.25 [.3]
SiC_W	25(T)	25(T)	25(T)	35(T)	15(T)
Temp (^oC)	1750	1750	1775	1800	1800
Density (g/cc)	4.147	4.147	4.137	4.069	4.318
HRA	95.0	95.1	94.9	94.9	94.7
VHN (Gpa) [18.5 kg load]	21.0	20.8	19.7	21.1	20
K_{IC} (E&C) $MPam^{1/2}$	6.3	6.3	6.6	7.2	6.7

Table III
$TiC_{.7}N_{.3}$-Alumina-SiC Whisker Compositions and Physical Properties of Examples Nos. 4, 7, 11 and 12

Ex./Comp. & Physical Properties	Example 4	Example 7	Example 11	Example 12
TiC	-	-	-	-
$TiC_{.7}N_{.3}$	39.03 [52.5]	39.75 [53]	39.75 [53]	39.75 [53]
$Ti_{.8}Mo_{.2}C$	-	-	-	-
Al_2O_3	35.43(C) [47.4]	35(C) [46.7]	35(C) [46.7]	35(C) [46.7]
Y_2O_3	0.25 [.3]	0.25 [.3]	0.25 [.3]	0.25 [.3]
SiC_W	25.29(T)	25(T)	25(A)	25(A)
Temp (^oC)	1800	1800	1800	1850
Density (g/cc)	4.214	4.228	4.223	4.241
HRA	95.0	95.0	94.8	94.9
VHN (Gpa) [18.5 kg load]	20.7	21.1	19.8	20.1
K_{IC} (E&C) $MPam^{1/2}$	6.3	6.6	7.5	7.5

Table IV
$Ti_{.8}Mo_{.2}C$-Alumina-SiC Whisker Composites
Compositions and Physical Properties
of Examples Nos. 5 and 6

Ex./ Comp. & Physical Properties	Example 5	Example 6
TiC	--	--
$TiC_{.7}N_{.3}$	--	--
$Ti_{.8}Mo_{.2}C$	34.7 [47.6]	39.75 [53]
Al_2O_3	38(C) [52]	35(C) [46.7]
Y_2O_3	0.27 [.4]	0.25 [.3]
SiC_w	27.03(T)	25(T)
Temp. (^oC)	1800	1800
Density (g/cc)	4.371	4.473
HRA	95.2	95.0
VHN (Gpa) [18.5 kg load]	20.7	21.3
K_{IC} (E&C) $MPam^{1/2}$	6.3	6.5

A review of the physical properties of the examples reveals that these compositions present physical properties that should make excellent cutting tools.

For example, referring to the physical properties of the composites of Table II, Examples Nos. 1 through 3, 9 and 10 present compositions of TiC, alumina and SiC whiskers. The densities for these compositions ranged from 4.069 g/cc to 4.318 g/cc. The Rockwell A hardness (HRA) ranged from 94.7 to 95.1 and the Vickers Hardress ranged from 19.7 to 21.1. The fracture toughness K_{IC} (E&C) ranged from 6.3 to 7.2 $MPam^{1/2}$.

A comparison of Example 10 with Example 9 shows that an increase in the TiC content (from 40 vol.% to 50 vol.%) and the alumina content (from 24.75 vol.% to 34.75 vol.%) coupled with a decrease in the SiC whisker content (from 35 vol.% to 15 vol.%) results in an increase in the density of the sintered composite from 4.069 g/cc to 4.318 g/cc.

Referring to all of the examples of Table II, there does not appear to be any discernible trend in the hardness parameters (Rockwell A and Vickers).

A comparison between Examples Nos. 1 and 2 shows that the coarseness of the alumina powder does not significantly impact the physical properties.

Still referring to the composites in Table II, a comparison between Example 9 and Examples Nos. 1 through 3 reveals that the fracture toughness (K_{IC}) appears to significantly increase when the alumina content decreases and the silicon carbide whisker content increases. More specifically, with the TiC content remaining the same, a decrease in alumina from about 35 vol.% to about 25 vol.% coupled with an increase in the silicon carbide whisker content from about 25 vol.% to about 35 vol.% results in an increase

in the fracture toughness (K_{IC}) from between 6.3 and 6.6 to 7.2 $MPam^{1/2}$.

A comparison of Example 9 with Example 10 reveals that fracture toughness [K_{IC}] increases from 6.7 to 7.2 $MPam^{1/2}$ when the TiC and alumina contents decrease and the SiC whisker content increases.

Referring to the physical properties of the $TiC_{.7}N_{.3}$-alumina-SiC whisker composites in Table III, it becomes apparent that the use of the SC-9 silicon carbide whiskers from Advanced Composite Materials Corporation provides for an increase in the fracture toughness of this TiCN-alumina-SiC whisker composite from between 6.3 and 6.6 to 7.5 $MPam^{1/2}$. Although the compositions are somewhat similar, the increase in fracture toughness appears to be due to the nature of the SC-9 whiskers as compared to the Tokai silicon carbide whiskers.

Referring to the examples (Examples Nos. 5 and 6) of Table IV that present the physical properties of the $Ti_{.8}Mo_{.2}C$-alumina-SiC whisker composites, a comparison between Examples Nos. 5 and 6 shows that a decrease of 5 volume percent in the $Ti_{.8}Mo_{.2}C$ coupled with a 3 volume percent increase in the alumina and a 2 volume percent increase in the SiC whiskers does not make a significant impact on the properties of the $Ti_{.8}Mo_{.2}C$-Al_2O_3-SiC whisker composite.

Overall, it can be seen that the above composites in accordance with the present invention possess a combination of hardness and fracture toughness which are unequaled by the prior art cutting tool compositions shown in Table I.

Photomicrographs which are representative of examples of the compositions in accordance with the present invention are shown in FIGS. 2, 3, and 4. In FIG. 2, which corresponds to Example 2, the lightest phase is alumina, the gray phase is titanium carbide, the elongated (or darkest) phase are silicon carbide

whiskers. In FIG. 3, which corresponds to Example 4, the lightest phase is also alumina and the darkest phase is also silicon carbide whiskers, however, the gray phase is titanium carbonitride. In FIG. 4, which corresponds to Example 6, the lightest and darkest phases are respectively alumina and silicon carbide whiskers, however, the gray phase is titanium molybdenum carbide.

In accordance with the present invention, the compositions of Examples 1, 3, 4, 6, and 7 shown in Tables II were ground into SNGN-453T indexable cutting inserts and used to machine Inconel 718 (hardness 38 Rockwell C) in a turning test under the conditions of 800 surface feet/minute speed, 0.006 inch per revolution, feed rate, and 0.050 inch depth of cut, flood coolant, and a 45 degree lead angle. The end of life criteria used was: flank wear (FW) = .030 inch; maximum flank wear (MW) = .040 inch; nose wear (NW) = .040 inch; depth of cut notch (DN) = .080 inch; and crater wear (CR) = .004 inch. Included in the tests were samples of WG-300 (Example No. 8) in the same insert geometry for comparison purposes. The results of these tests are shown in Table V below and in FIGS. 5, 6, and 7. Each example is identified in FIGS. 5, 6 and 7 by its identical reference numeral. These results indicate that the tools having a matrix based on titanium carbonitride or titanium molybdenum carbide had the best cutting edge life time under the above conditions. The most rapid wear mechanism and the wear mechanism which lead to failure was depth of cut notching on all the materials shown in Table V.

Table V
Tool Life & Failure Mode for
Examples Nos. 1, 3, 4, 6, 7 and WG-300

Example	Rep. 1 (Minutes)	Rep. 2 (Minutes)	Tool Life Average (Minutes)	Relative % Tool Life vs. WG-300
1	5.8 DN	1.5 DN	3.7	78%
3	4.3 DN	1.3 DN	2.8	60%
4	9.7 DN	8.8 DN	9.3	197%
6	7.3 DN	6.4 DN	6.9	146%
7	4.7 DN	6.9 DN	5.8	123%
8	4.3 DN	5.1 DN	4.7	100%

However, the flank wear resistance of the present invention was less than that of the prior art grade tested. It is believed that flank wear resistance may be improved by increasing the nitrogen content of the titanium carbonitride forming the matrix or increasing the molybdenum content of the titanium molybdenum carbide used in the matrix. Flank wear resistance of the present invention may also be improved by applying a hard coating to the cutting insert composed of compositions in accordance with the present invention. Preferred hard coatings include titanium nitride, titanium carbonitride, titanium aluminum nitride, and alumina coatings applied by PVD and/or CVD techniques.

The flank wear resistance of the prior art grade tested (Example No. 8/ WG-300) appeared to be better than Examples Nos. 1, 3, 4, 6 and 7. This may be due to the greater alumina content in the prior art grade. More specifically, the prior art grade (Example No. 8/ WG-300) has an alumina content of about 75 volume percent as compared with about 35 to 40 volume percent for Examples Nos. 1, 3, 4, 6 and 7. The flank wear resistance of the present invention may be improved by the use of greater amounts of alumina or by decreasing the amount of silicon carbide whiskers

present and increasing one or more of the matrix phases, e.g., titanium carbonitride or alumina.

All applications, patents and other documents referred to herein are hereby incorporated by reference herein.

Other embodiments of the invention will be apparent to those skilled in the art from a consideration of the specification or practice of the invention disclosed herein. It is intended that the specification and examples be considered as illustrative only, with the true scope and spirit of the invention being indicated by the following claims.

WHAT IS CLAIMED IS:

1. A composition produced by the consolidation of a blend of starting components, the composition comprising:

a matrix comprising one or more of the carbides, nitrides and carbonitrides of hafnium, molybdenum, tungsten, zirconium, tantalum, niobium, vanadium, titanium, and solid solutions thereof in an amount that is greater than 50 volume percent of the matrix, the matrix further includes sintering aid residue present from the use of one or more sintering aids as a starting component in an amount less than .5 weight percent of the starting components wherein the sintering aid comprises one or more of yttria, magnesia and zirconia, the matrix comprising between 60 and 99.8 volume percent of the composition; and

ceramic whiskers uniformly dispersed throughout the matrix, the ceramic whiskers comprising between 0.2 and 40 volume percent of the composition.

2. The composition of claim 1 wherein the ceramic whiskers are selected from one or more of the following: alumina, silicon carbide, boron carbide, silicon nitride, and the carbides, nitrides, borides and carbonitrides of titanium, zirconium and hafnium.

3. The composition of claim 1 wherein the matrix further includes ceramic particulates selected from one or more of the group consisting of silicon carbide, titanium boride, zirconium boride, hafnium boride, alumina, zirconium oxide and hafnium oxide.

4. The composition of claim 1 wherein the matrix comprises greater than 50 volume percent titanium carbonitride, and the balance of the matrix comprising at least 40 volume percent alumina.

5. The composition of claim 5 wherein the ceramic whiskers comprise silicon carbide whiskers, and the silicon carbide whiskers comprises about 2 volume percent to about 35 volume percent of the composition.

6. The composition of claim 5 wherein the ceramic whiskers comprise silicon carbide whiskers, and the silicon carbide whiskers comprises between 10 volume percent and 30 volume percent of the composition.

7. The composition of claim 1 wherein the matrix comprises greater than 50 volume percent titanium carbonitride, and the balance of the matrix comprising less than 50 volume percent alumina.

8. The composition of claim 1 wherein the matrix comprises greater than 50 volume percent of titanium molybdenum carbide, and the balance of the matrix comprising at least 40 volume percent alumina.

9. The composition of claim 8 wherein the ceramic whiskers comprise silicon carbide whiskers, and the silicon carbide whiskers comprise about 2 volume percent to about 35 volume percent of the composition.

10. The composition of claim 1 wherein the matrix comprises greater than 50 volume percent of titanium molybdenum carbide, and the balance of the matrix comprising less than 50 volume percent alumina.

11. A ceramic cutting tool comprising:

a rake face; and a flank face, a cutting edge at the juncture of the rake face and the flank face;

a ceramic composition having a matrix comprising at least 50 volume percent of one or more of the carbides, nitrides and carbonitrides of hafnium, molybdenum, zirconium, tantalum, niobium, vanadium, tungsten, titanium, and solid solutions thereof, the

matrix further includes sintering aid residue present from the use of one or more sintering aids as a starting component in an amount less than .5 weight percent of the starting components wherein the sintering aid comprises one or more of yttria, magnesia and zirconia, wherein the matrix comprises between 60 and 99.8 volume percent of the ceramic composition; and

ceramic whiskers uniformly dispersed throughout the matrix wherein the ceramic whiskers comprise between 0.2 and 40 volume percent of the ceramic composition.

12. The ceramic cutting tool of claim 12 wherein the ceramic whiskers are selected from one or more of the following alumina, silicon carbide, silicon nitride, boron carbide, or the carbides, nitrides, borides or carbonitrides of titanium, zirconium or hafnium.

13. The ceramic cutting tool of claim 12 wherein the matrix further includes ceramic particulates selected from one or more of the group consisting of silicon carbide, titanium boride, zirconium boride, hafnium boride, alumina, zirconium oxide, and hafnium oxide.

14. The ceramic cutting tool of claim 12 further including a coating on the rake face and the flank face.

15. The ceramic cutting tool of claim 15 wherein the coating comprises a layer selected from the group consisting of alumina, TiC, TiN, TiCN and TiAlN.

16. The ceramic cutting tool of claim 16 wherein the layer is applied by chemical vapor deposition.

17. The ceramic cutting tool of claim 16 wherein the layer is applied by physical vapor deposition.

18. A ceramic composition produced by the consolidation of a blend of starting components wherein the ceramic composition comprises:

a matrix comprising one or more of titanium nitride, titanium carbonitride, the carbides, nitrides and carbonitrides of hafnium, molybdenum, niobium, and tungsten, and solid solutions thereof in an amount that is greater than 50 volume percent of the matrix, and the matrix comprising between 60 and 99.8 volume percent of the composition; and

ceramic whiskers uniformly dispersed throughout the matrix, the ceramic whiskers comprising between 0.2 and 40 volume percent of the composition.

19. The composition of claim 19 wherein the ceramic whiskers are selected from one or more of the following alumina, silicon carbide, silicon nitride, boron carbide, and the carbides, nitrides, borides and carbonitrides of titanium, zirconium and hafnium.

20. The composition of claim 19 wherein the matrix further includes ceramic particulates selected from one or more of the group consisting of silicon carbide, titanium boride, zirconium boride, hafnium boride, chromium boride, alumina, zirconium oxide and hafnium oxide.

21. The composition of claim 19 wherein the matrix further includes titanium carbide and the carbide, carbonitrides and nitrides of zirconium, tantalum and vanadium; and the matrix further includes sintering aid residue present from the use of one or more sintering aids as a starting component in an amount of less than or equal to 1 weight percent of the starting components

22. The composition of claim 22 wherein the matrix comprises greater than 50 volume percent titanium carbide, and the balance of the matrix comprising at least 40 volume percent alumina and sintering aid residues.

23. The composition of claim 23 wherein the ceramic whiskers comprise silicon carbide whiskers, and the silicon carbide whiskers comprises between about 10 volume percent and about 40 volume percent of the composition.

24. The composition of claim 22 wherein the matrix comprises greater than 50 volume percent titanium carbide, and the balance of the matrix comprising less than 50 volume percent alumina and sintering aid residues.

25. A ceramic cutting tool comprising:

a rake face; and a flank face, a cutting edge at the juncture of the rake face and the flank face;

a ceramic composition having a matrix comprising between about 45 volume percent and less than 50 volume percent of titanium molybdenum carbide, and less than about 55 volume percent alumina, wherein the matrix comprises between about 60 volume percent and about 90 volume percent of the ceramic composition; and

ceramic whiskers uniformly dispersed throughout the matrix wherein the ceramic whiskers comprise about 2 volume percent to about 35 volume percent of the ceramic composition.

26. The ceramic cutting tool of claim 26 wherein the matrix comprises between about 55 volume percent and greater than about 50 volume percent of alumina.

27. The ceramic cutting tool of claim 26 wherein the ceramic whiskers comprise about 10 volume percent to about 30 volume percent of the ceramic composition.

28. The composition of claim 1 wherein one or more of the sintering aids comprises an amount of less than or equal to .3 weight percent of the starting components.

29. The composition of claim 5 wherein the titanium carbonitride has the formula $Ti(C_xN_y)$ wherein y is less than .95 and greater than 0.5, and $x + y = 1$.

30. The composition of claim 5 wherein the titanium carbonitride has the formula $Ti(C_xN_y)$ wherein y is less than 0.90 and greater than or equal to 0.55, and $x + y = 1$.

31. The composition of claim 5 wherein the titanium carbonitride has the formula $Ti(C_xN_y)$ wherein y is less than 0.75 and greater than or equal to 0.6, and $x + y = 1$.

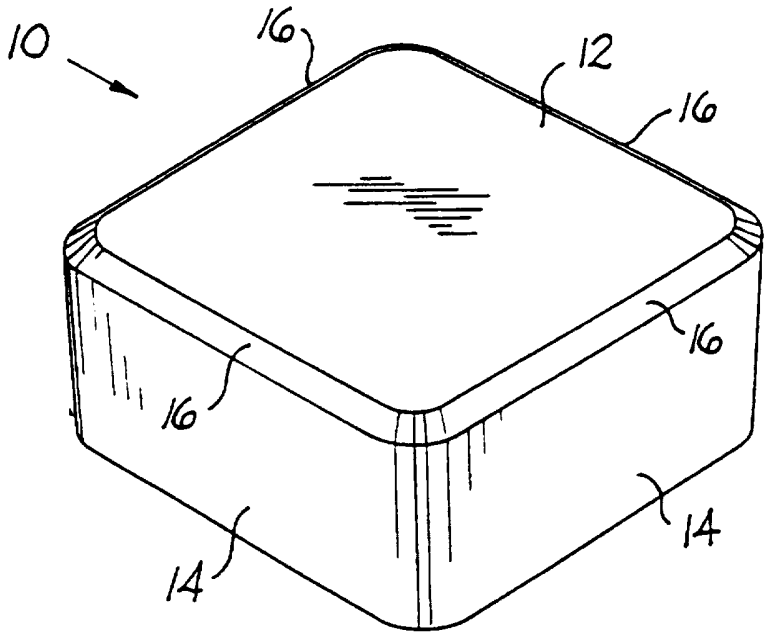


FIG. 1

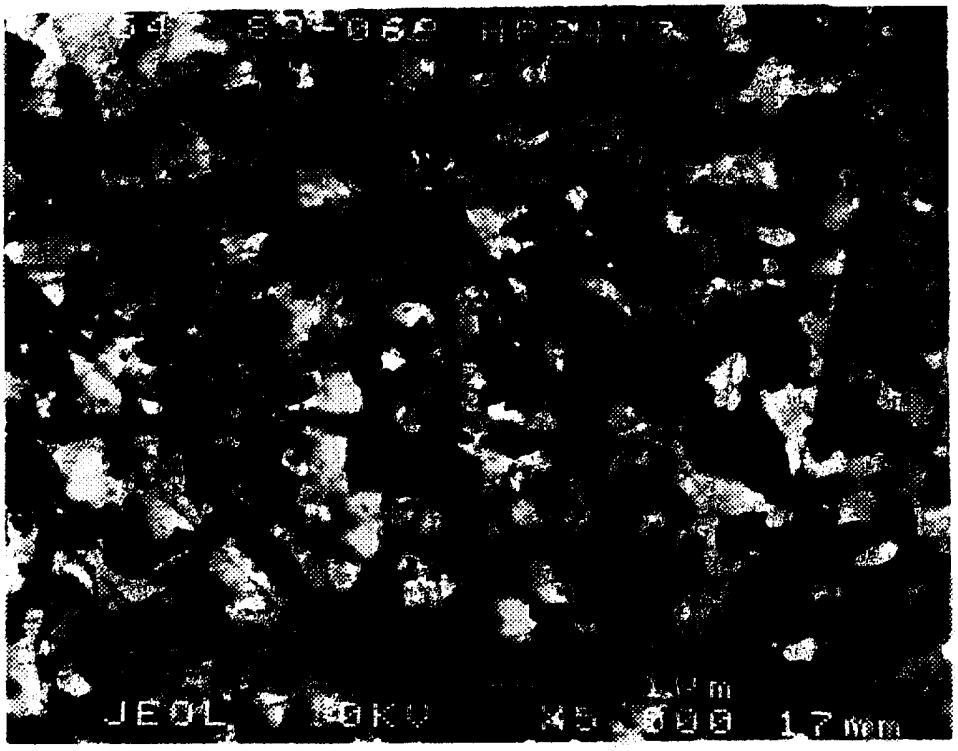


Fig. 2

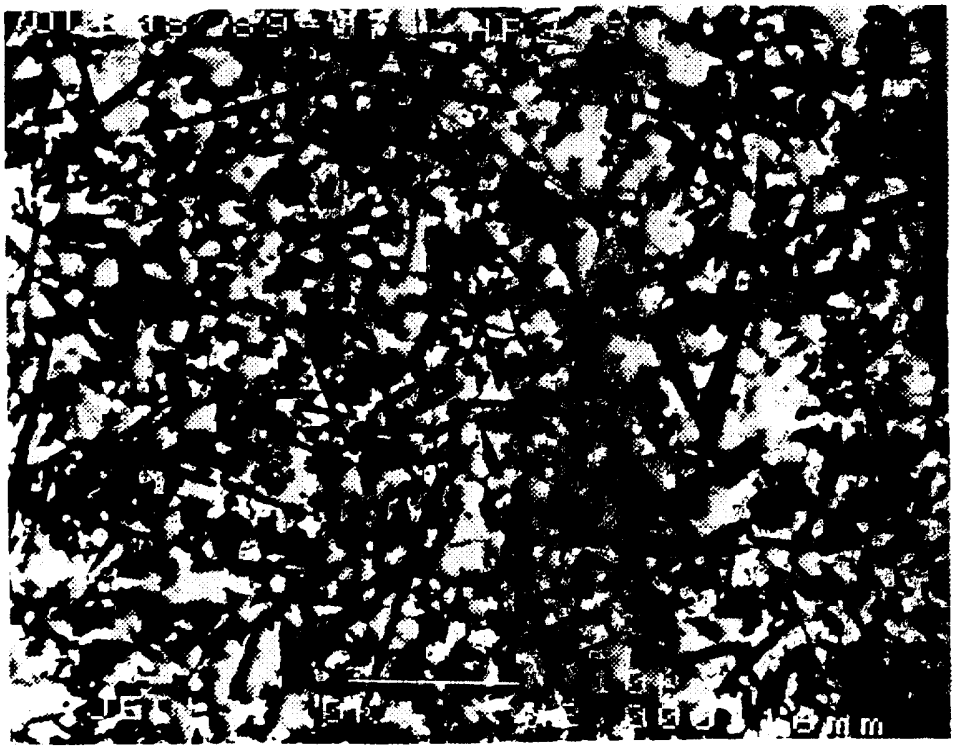


Fig. 3

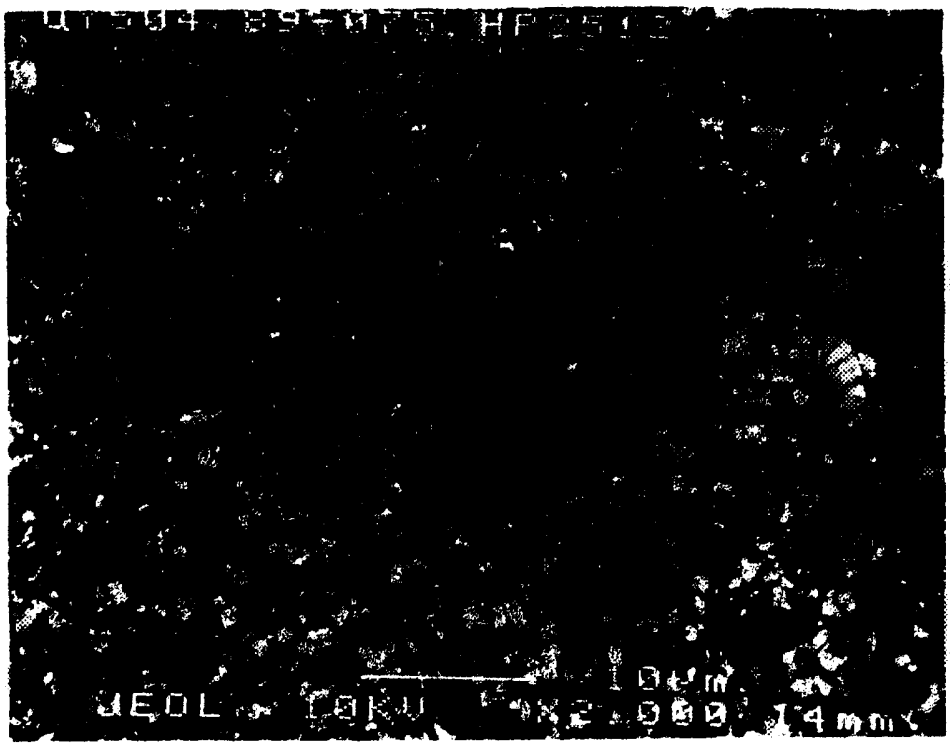
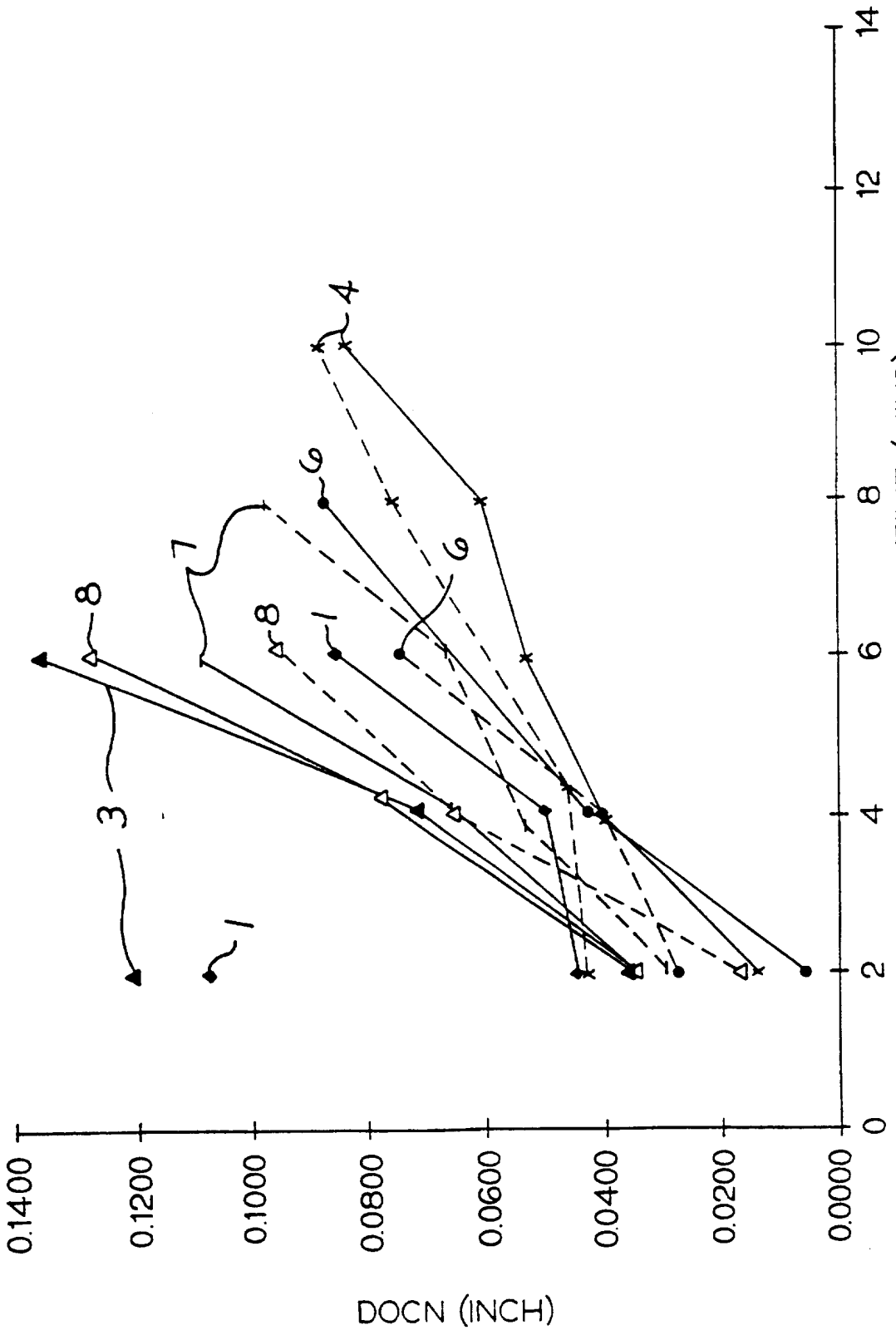


Fig. 4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0.0000
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6
8
10
12
14
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3
4
6
7
8

FIG. 5

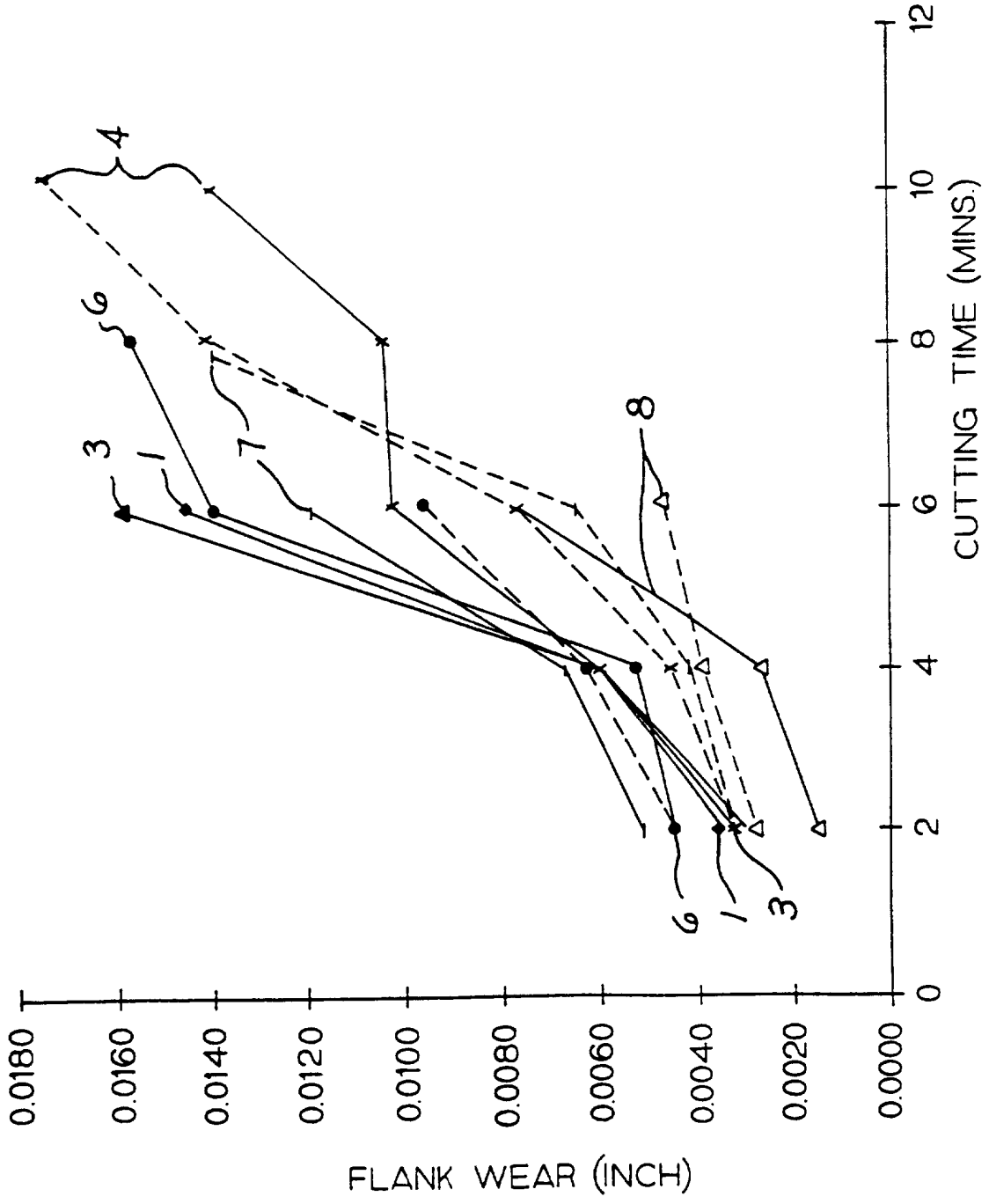
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FIG. 6

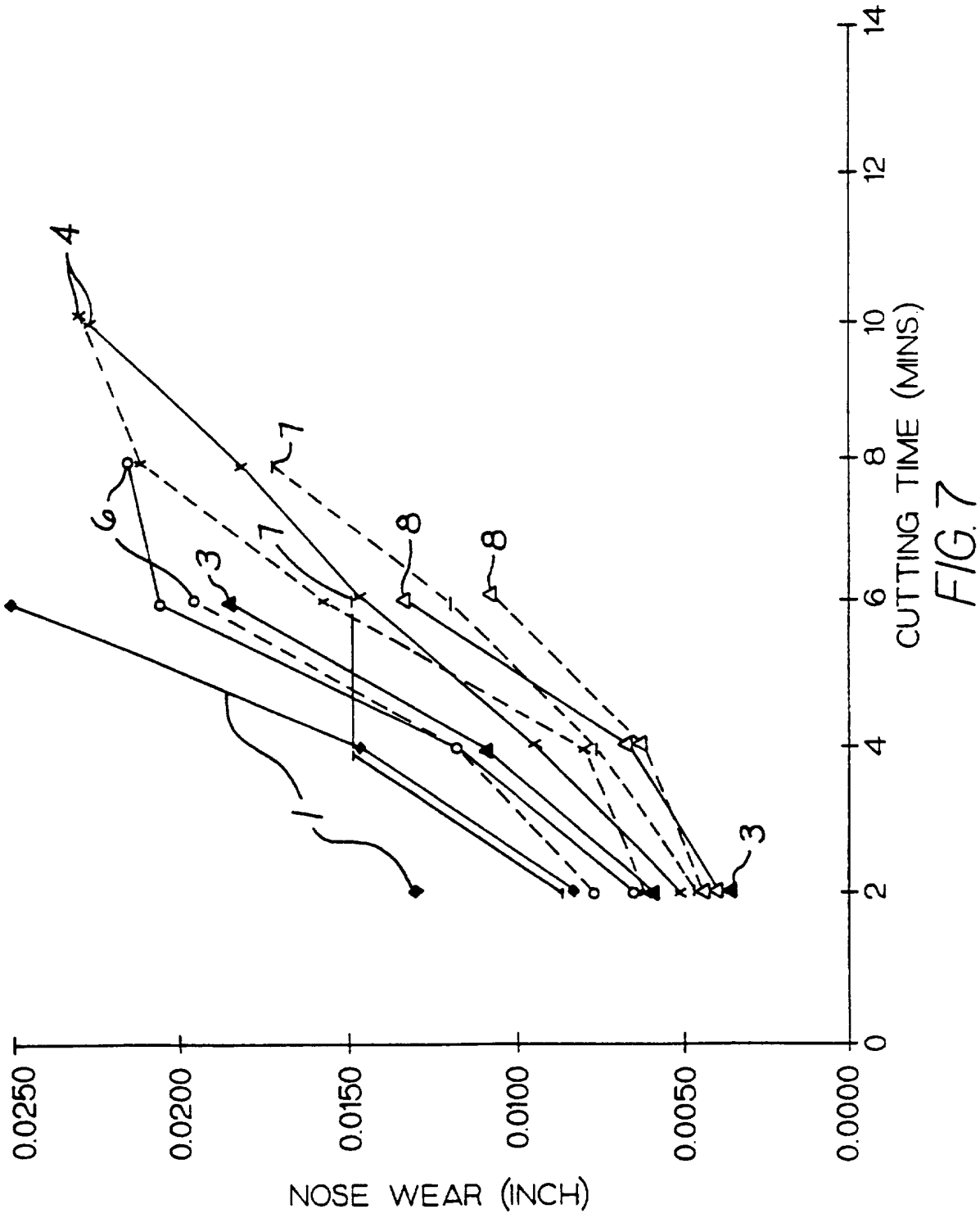
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FIG. 7

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 96/15192

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 C04B35/80 C04B41/87 C04B35/56 C04B35/58

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 C04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US,A,5 439 854 (J. SUZUKI ET AL.) 8 August 1995 cited in the application see claims 1,4-8,22,23; tables 1,4 ---	1-13, 18-24,28
X	CHEMICAL ABSTRACTS, vol. 114, no. 4, 28 January 1991 Columbus, Ohio, US; abstract no. 28933, A. NISHIYAMA ET AL.: "Coated ceramic cutting tools having high wear resistance" XP002022981 see abstract & JP,A,02 116 691 (MITSUBISHI METAL CORP., JAPAN) 1 May 1990 --- -/--	1-4,7, 11-14, 16-22,24

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
17 January 1997	07.02.97

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax (+ 31-70) 340-3016	Hauck, H

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 96/15192

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 014, no. 417 (C-0756), 10 September 1990 & JP,A,02 157176 (MITSUBISHI METAL CORP.), 15 June 1990, see abstract -----	11-17

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

Intern... ...nal Application No
PCT/US 96/15192

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-5439854	08-08-95	JP-B- 8016028	21-02-96
		JP-A- 63225579	20-09-88