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(54) **CEMENTED CARBIDE**

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ABSTRACT

A cemented carbide is a cemented carbide, composed of:
hard phases comprising tungsten carbide as a main ingredi-
ent and binder phases comprising cobalt as a main ingredi-
ent, wherein the hard phases have a ratio D10/D90 of D10
being an area-based 10% cumulative particle size to D90
being an area-based 90% cumulative particle size of 0.30 or
more, the binder phases have a ratio D10/D90 of D10 being
an area-based 10% cumulative particle size to D90 being an
area-based 90% cumulative particle size of 0.23 or more,
wherein the binder phases have an average particle size of
0.25 μm or more and 0.50 μm or less, and wherein the hard
phases have an average particle size of 0.30 μm or more and
0.60 μm or less.

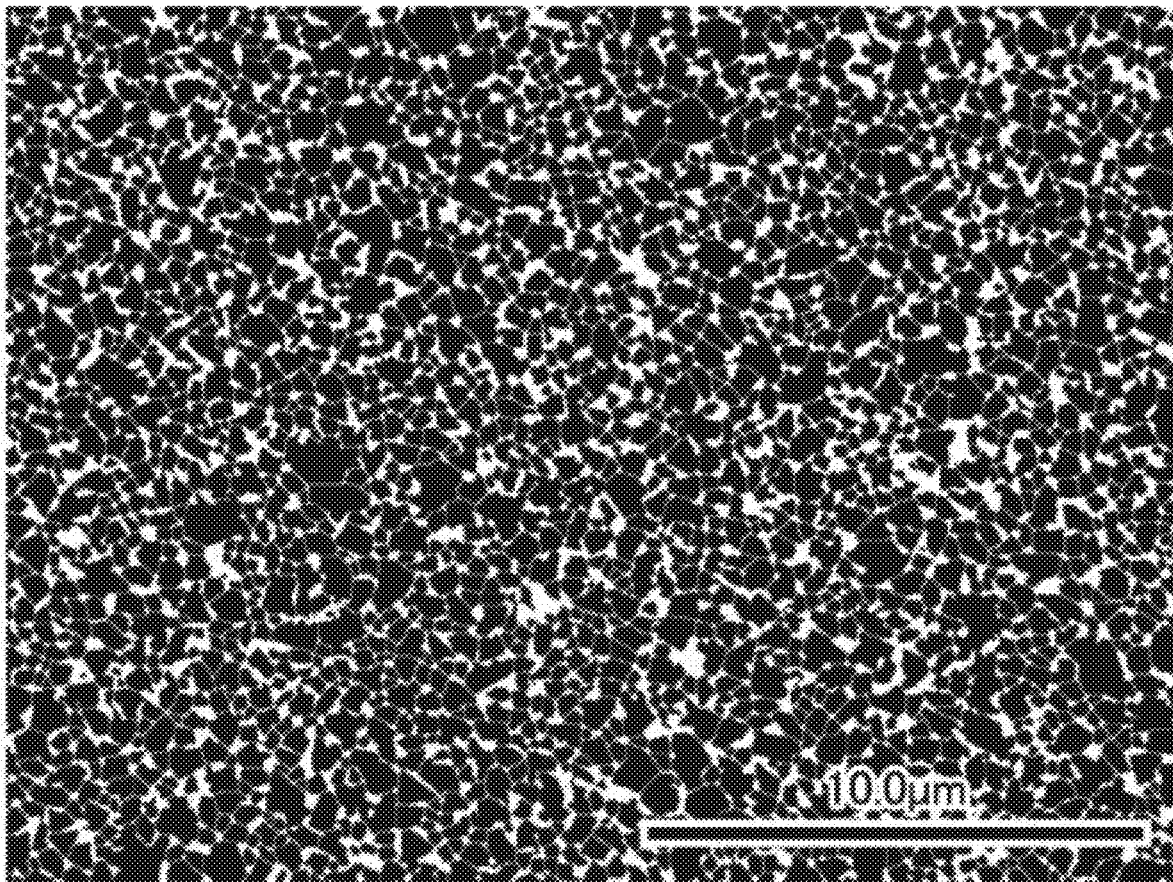
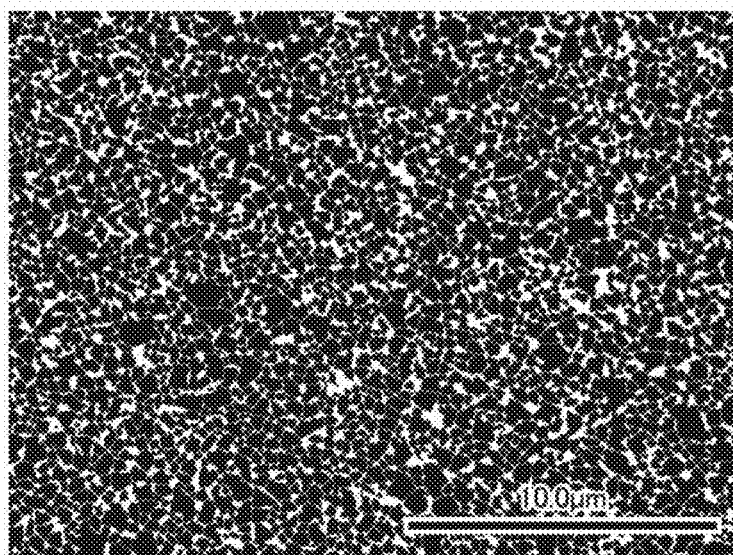


FIG.1



CEMENTED CARBIDE

TECHNICAL FIELD

[0001] The present disclosure relates to a cemented carbide.

BACKGROUND ART

[0002] Cemented carbides comprising hard phases of tungsten carbide (WC) and binder phases of cobalt (Co) have been used as materials for cutting tools conventionally (PTL 1 to PTL 4).

CITATION LIST

Patent Literature

- [0003] PTL 1: Japanese Patent Laying-Open No. 2009-24214
[0004] PTL 2: Japanese Patent Laying-Open No. 2013-60666
[0005] PTL 3: WO 2018/180911
[0006] PTL 4: Japanese Patent Laying-Open No. 2021-134364

SUMMARY OF INVENTION

[0007] A cemented carbide of the present disclosure is a cemented carbide composed of hard phases and binder phases,

- [0008] wherein the hard phases contain tungsten carbide as a main ingredient,
[0009] wherein the binder phases contain cobalt as a main ingredient,
[0010] wherein the hard phases have a ratio D10/D90 of D10 being an area-based 10% cumulative particle size to D90 being an area-based 90% cumulative particle size of 0.30 or more,
[0011] wherein the binder phases have a ratio D10/D90 of D10 being an area-based 10% cumulative particle size to D90 being an area-based 90% cumulative particle size of 0.23 or more,
[0012] wherein the binder phases have an average particle size of 0.25 μm or more and 0.50 μm or less, and
[0013] wherein the hard phases have an average particle size of 0.30 μm or more and 0.60 μm or less.

BRIEF DESCRIPTION OF DRAWING

[0014] FIG. 1 is a FIGURE substituted for a photograph and showing an image obtained by subjecting an image of a cemented carbide of the present embodiment photographed through a scanning electron microscope to binarization processing.

DETAILED DESCRIPTION

Problem to be Solved by the Present Disclosure

[0015] It has been known until now that, in a cemented carbide, uniform dispersion of binder phases or the adjustment of the particle size distributions of hard phases and the binder phases enhances the hardness, the toughness, the abrasion resistance, the plastic deformation resistance, and the breakage resistance of the cemented carbide (for example, PTLs 1 to 4). Merely uniform dispersion of binder phases or merely the adjustment of the particle size distributions

of hard phases and binder phases may have however easily led to welding breakage especially in intermittent processing of titanium-based hard-to-cut materials. A cemented carbide that enables providing a cutting tool having a long tool life even in intermittent processing of titanium-based hard-to-cut materials when used as a tool material has therefore been required.

Advantageous Effect of the Present Disclosure

[0016] According to a cemented carbide of the present disclosure, a cutting tool having a long tool life even in intermittent processing of titanium-based hard-to-cut materials can be provided.

DESCRIPTION OF EMBODIMENTS

[0017] The embodiments of the present disclosure will be first enumerated and described.

[0018] (1) A cemented carbide of the present disclosure, composed of hard phases and binder phases,

[0019] wherein the hard phases comprise tungsten carbide as a main ingredient,

[0020] wherein the binder phases comprise cobalt as a main ingredient,

[0021] wherein the hard phases have a ratio D10/D90 of D10 being an area-based 10% cumulative particle size to D90 being an area-based 90% cumulative particle size of 0.30 or more,

[0022] wherein the binder phases have a ratio D10/D90 of D10 being an area-based 10% cumulative particle size to D90 being an area-based 90% cumulative particle size of 0.23 or more,

[0023] the binder phases have an average particle size of 0.25 μm or more and 0.50 μm or less, and

[0024] the hard phases have an average particle size of 0.30 μm or more and 0.60 μm or less.

[0025] According to the cemented carbide of the present disclosure, a cutting tool having a long tool life even in intermittent processing of titanium-based hard-to-cut materials can be provided.

[0026] (2) It is preferable that the total of the chromium content and the vanadium content be 0.6% by mass or more and 2.1% by mass or less, the chromium content be 0.4% by mass or more and 1.5% by mass or less, and the vanadium content be 0% by mass or more and 0.6% by mass or less. The generation of coarse deposited particles can be suppressed thereby while the particle growth in the cemented carbide is effectively suppressed. The cemented carbide can therefore have a longer tool life.

[0027] (3) It is preferable that, in a rectangular measurement visual field of 42.3 μm × 29.6 μm set in an image obtained by subjecting a section of the cemented carbide to elemental mapping with an energy dispersive X-ray analyzer, the total number of first vanadium-containing particles and first chromium-containing particles be two or less,

[0028] the first vanadium-containing particles have a particle size of 1 μm or more, and

[0029] the first chromium-containing particles have a particle size of 1 μm or more. The destruction of the cemented carbide starting from the deposited first vanadium-containing particles and the deposited first chromium-containing particles can be suppressed thereby. The cemented carbide can therefore have longer tool life.

DETAILS OF EMBODIMENTS OF THE PRESENT DISCLOSURE

[0030] With referring to the drawing, a specific example of a cutting tool in one embodiment of the present disclosure (hereinafter also described as the “present embodiment”) will be described hereinafter. In the drawing of the present disclosure, the same reference sign indicates the same portion or the corresponding portion. The dimensional relationship between the length, the width, the thickness, the depth, and the like are suitably modified for the clarification and simplification of the drawing, and do not necessarily show actual dimensional relationship.

[0031] The expression “A to B” used herein means the upper limit and the lower limit of the range (namely, A or more and B or less). If a unit is not described on the right of A, but described on the right of only B, the units of A and B are the same.

[0032] If a compound or the like is represented by a chemical formula in which the atomic ratio is not particularly limited herein, all the conventionally well-known atomic ratios are included therein, and the atomic ratio should not be necessarily limited to only the atomic ratio in the stoichiometric range. For example, if a compound is described as “WC”, all the conventionally well-known atomic ratios are included in the ratio between the numbers of atoms constituting WC.

Embodiment 1: Cemented Carbide

[0033] One embodiment of the present disclosure (hereinafter also described as the “present embodiment”) is a cemented carbide composed of hard phases and binder phases,

[0034] the hard phases contain tungsten carbide as a main ingredient,

[0035] the binder phases contain cobalt as a main ingredient,

[0036] in the hard phases, the ratio D10/D90 of D10 being the area-based 10% cumulative particle size to the area-based 90% cumulative particle size D90 is 0.30 or more,

[0037] in the binder phases, the ratio D10/D90 of D10 being the area-based 10% cumulative particle size to D90 being the area-based 90% cumulative particle size is 0.23 or more,

[0038] the average particle size of the binder phases is 0.25 μm or more and 0.50 μm or less, and

[0039] the average particle size of the hard phases is 0.30 μm or more and 0.60 μm or less.

[0040] According to the cemented carbide of the present disclosure, a cutting tool having a long tool life even in intermittent processing of titanium-based hard-to-cut materials can be provided. It is conjectured that the reason is as follows.

[0041] (a) Since, in the hard phases, the ratio D10/D90 of D10 being the area-based 10% cumulative particle size to D90 being the area-based 90% cumulative particle size is 0.30 or more, a difference in grain size among crystal grains constituting the hard phases can be reduced. The hard phases can therefore be uniformly dispersed in the cemented carbide.

[0042] (b) Since the average particle size of the hard phases is 0.30 μm or more and 0.60 μm or less, the above-mentioned hard phases are fine as a whole. The

above-mentioned hard phases can therefore be micronized and uniformly dispersed in the cemented carbide in combination with the above-mentioned (a). A partial loss of the hard phases from the cemented carbide during the use of the tool is suppressed thereby, damage to the cemented carbide that occurs suddenly is suppressed, and the cutting tool can therefore have excellent breakage resistance.

[0043] (c) Since, in the binder phases, the ratio D10/D90 of D10 being the area-based 10% cumulative particle size to D90 being the area-based 90% cumulative particle size is 0.23 or more, a difference in grain size among the crystal grains constituting the binder phases can be furthermore reduced. The binder phases can therefore be uniformly dispersed in the cemented carbide.

[0044] (d) Since the average particle size of the binder phases is 0.25 μm or more and 0.50 μm or less, the above-mentioned binder phases are fine as a whole. The above-mentioned binder phases can therefore be micronized and uniformly dispersed in the cemented carbide in combination with the above-mentioned (c). The welding of the work material to the cemented carbide during the use of the tool is suppressed thereby, and the cutting tool can have excellent welding resistance. The binder phases are fine, a difference in grain size therebetween is small, the occurrence of damage from the presence of coarse particles during the use of the tool is suppressed, and the tool can have excellent breakage resistance.

[0045] That is, in the cemented carbide of the present disclosure according to the present embodiment, the hard phases and the binder phases are fine, and the hard phases and the binder phases are uniformly dispersed, so that the cemented carbide can have both excellent welding resistance and excellent breakage resistance. According to the cemented carbide of the present disclosure, a cutting tool having a long tool life even in intermittent processing of titanium-based hard-to-cut materials can therefore be provided.

<Composition of Cemented Carbide>

[0046] The cemented carbide of the present embodiment is composed of the hard phases and the binder phases. That is, the total content of the hard phases and binder phases of the cemented carbide is 100% by mass. The expression “the cemented carbide is composed of the hard phases and the binder phases” used herein means that as long as the effect of the present disclosure is exhibited, the cemented carbide can contain inevitable impurities besides the hard phases and the binder phases. Examples of the inevitable impurities include iron, molybdenum, and sulfur. The content of the inevitable impurity in the cemented carbide (the total of the contents of two or more impurities in the case wherein the impurities are two or more) is preferably 0% by mass or more and less than 0.1% by mass. The content of the inevitable impurities in the cemented carbide is measured by ICP (inductively coupled plasma) emission spectrometry (measuring apparatus: SHIMADZU CORPORATION “ICPS-8100” (TM)).

[0047] It is preferable that the lower limit of the content of the hard phases in the cemented carbide of the present embodiment be 84% by mass or more, 85% by mass or more, or 86% by mass or more. It is preferable that the upper limit of the content of the hard phases in the cemented carbide of the present embodiment be 92% by mass or less, 91% by mass or less, or 90% by mass or less. It is preferable

that the content of the hard phases in the cemented carbide of the present embodiment be 84% by mass or more and 92% by mass or less, 85% by mass or more and 91% by mass or less, or 86% by mass or more and 90% by mass or less.

[0048] It is preferable that the lower limit of the content of the binder phases in the cemented carbide of the present embodiment be 8% by mass or more, 9% by mass or more, or 10% by mass or more. It is preferable that the upper limit of the content of the binder phase in the cemented carbide of the present embodiment be 16% by mass or less, 15% by mass or less, or 14% by mass or less. It is preferable that the content of the binder phases in the cemented carbide of the present embodiment be 8% by mass or more and 16% by mass or less, 9% by mass or more and 15% by mass or less, or 10% by mass or more and 14% by mass or less.

[0049] The cemented carbide of the present embodiment preferably comprises the hard phases at 84% by mass or more and 92% by mass or less and the binder phases at 8% by mass or more and 16% by mass or less. The cemented carbide of the present embodiment preferably comprises the hard phases at 85% by mass or more and 91% by mass or less and the binder phases at 9% by mass or more and 15% by mass or less. The cemented carbide of the present embodiment preferably comprises the hard phases at 86% by mass or more and 90% by mass or less and the binder phases at 10% by mass or more and 14% by mass or less.

[0050] The contents of the hard phases and the binder phases in the cemented carbide are measured by ICP emission spectrometry (measuring apparatus: SHIMADZU CORPORATION “ICPS-8100” (TM)).

<<Hard Phases>>

[0051] The hard phases of the present embodiment contains tungsten carbide as a main ingredient. Here, the expression “containing tungsten carbide as a main ingredient” means that as long as the effect of the present disclosure is exhibited, the hard phases can contain a component other than tungsten carbide. If the hard phases contain a component other than tungsten carbide, the hard phases may contain tungsten carbide at 80% by mass or more. The hard phases may contain tungsten carbide at 85% by mass or more, 90% by mass or more, or 95% by mass or more. The tungsten (W) content measured by ICP emission spectrometry (measuring apparatus: SHIMADZU CORPORATION “ICPS-8100” (TM)) is converted into the tungsten carbide (WC) content to determine the content of tungsten carbide in the hard phases.

[0052] As long as the effect of the present disclosure is exhibited, the above-mentioned hard phases can contain a carbide, a nitride, a carbonitride, and an oxide of at least one element selected from the group consisting of Ti, Cr, V, Mo, Ta, Nb, and Zr, an inevitable impurity element mixed in the process for producing WC; a very small amount of an impurity element; and the like besides tungsten carbide. Examples of these impurity elements include molybdenum (Mo) and chromium (Cr). It is preferable that the content of the impurity element (total content two or more impurity elements in the case of the two or more impurity elements) in the hard phases be less than 0.1% by mass. The content of the impurity element in the hard phases is measured by ICP emission spectrometry (measuring apparatus: “ICPS-8100” (TM), manufactured by SHIMADZU CORPORATION). Subjecting a section of the cemented carbide to

elemental mapping with an energy dispersive X-ray spectrometer (EDS) enables determining that the hard phases contain a carbide, a nitride, a carbonitride, and an oxide of at least one element selected from the group consisting of Ti, Cr, V, Mo, Ta, Nb, and Zr; an inevitable impurity element mixed in the process for producing WC; a very small amount of an impurity element; and the like.

<Ratio of 10% Cumulative Particle Size D10 to 90% Cumulative Particle Size D90 D10/D90 (Hard Phases)>

[0053] In the above-mentioned hard phases, the ratio D10/D90 of D10 being the area-based 10% cumulative particle size to D90 being the area-based 90% cumulative particle size is 0.30 or more. The hard phases can be uniformly dispersed in the cemented carbide thereby. In the above-mentioned hard phases, the lower limit of D10/D90 is preferably 0.31 or more and more preferably 0.32 or more. In the above-mentioned hard phases, the upper limit of D10/D90 is preferably 0.50 or less, more preferably 0.45 or less, and further preferably 0.40 or less. In the above-mentioned hard phases, D10/D90 is preferably 0.31 or more and 0.50 or less, more preferably 0.31 or more and 0.45 or less, and further preferably 0.32 or more and 0.40 or less.

[0054] In the above-mentioned hard phases, D10/D90 is measured in a procedure comprising the following (A1) to (E1).

[0055] (A1) Any surface or any section of the cemented carbide is mirror-finished. Examples of the method for mirror finishing include a method for polishing with diamond paste, a method using a focused ion beam apparatus (FIB apparatus), a method using a cross section polisher (CP apparatus), and a method for performing these in combination.

[0056] (B1) The processed surface of the cemented carbide is photographed with a scanning electron microscope (“S-3400N” manufactured by Hitachi High-Tech Corporation). Three photographed images are prepared. The photographic regions of the three images are different. The photographic areas can be freely set. The conditions are an observation magnification of 3000 times, an acceleration voltage of 10 kV, and reflected electron images.

[0057] (C1) The three reflected electron images obtained in the above-mentioned (B1) are captured into a computer by image analysis software (ImageJ, version 1.51j8: <https://imagej.nih.gov/ij/>) and subjected to binarization processing. The images are captured, and the display “Make Binary” on the computer screen is then pressed to execute the binarization processing under the conditions set in the above-mentioned image analysis software beforehand. Furthermore, Despeckle is performed once for removing noise, and Watershed is then performed to also distinguish the grain boundary of the crystal grains under the conditions set in the above-mentioned image analysis software beforehand. Particles of 0.002 μm^2 or more are measured by Analyze Particle. Although the thresholds in the binarization processing can also be set by manual regulation, the manual regulation is not adopted in the present procedure. As described above, the binarization processing is executed by pressing the display “Make Binary” in the present procedure.

[0058] The hard phases can be discriminated from the binder phases based on the shade of color in the images subjected the binarization processing. For example, in the images subjected to the binarization processing, the hard

phases are shown as black regions, and the binder phases are shown as white regions. FIG. 1 shows an image obtained by subjecting one of the above-mentioned reflected electron images to binarization processing by the above-mentioned image analysis software (ImageJ).

[0059] (D1) Rectangular measurement visual fields of 960 pixels in length×1280 pixels in width are set in the three images subjected to the binarization processing. All the hard phases (black regions) in the three measurement visual fields are measured for equivalent circle diameter (Heywood diameter, namely equal area equivalent circle diameter) with the above-mentioned image analysis software.

[0060] (E1) The area-based 10% cumulative particle sizes (equivalent circle diameters) D10 and the area-based 90% cumulative particle sizes (equivalent circle diameters) D90 of all the hard phases in the three measurement visual fields are calculated. D10/D90 (hard phases) is then found by dividing the D10 by the D90.

[0061] As long as the applicant measured, it was confirmed that even though the identical sample was subjected to the above-mentioned measurement multiple times with the selected areas in the measurement visual fields changed, the results of the measurement varied slightly, and even free setting of the measurement visual fields did not make the results arbitrary.

<Average Particle Size of Hard Phases>

[0062] The average particle size of the above-mentioned hard phases is 0.30 μm or more and 0.60 μm or less. The hard phases can be micronized in the cemented carbide as a whole thereby. The lower limit of the average particle size of the above-mentioned hard phases is preferably 0.35 μm or more and more preferably 0.40 μm or more. The upper limit of the average particle size of the above-mentioned hard phase is preferably 0.55 μm or less and more preferably 0.50 μm or less. The average particle size of the above-mentioned hard phases is preferably 0.35 μm or more and 0.55 μm or less, and further preferably 0.40 μm or more and 0.50 μm or less. The average particle size of the above-mentioned hard phases is measured in a procedure comprising the following (A2) to (B2).

[0063] (A2) According to the procedure comprising (A1) to (D1) in the above-mentioned method for measuring D10/D90 (hard phases), all the hard phases in the three measurement visual fields (black regions) are measured for equivalent circle diameter (Heywood diameter, namely equal area equivalent circle diameter).

[0064] (B2) The area-based 50% cumulative particle size (equivalent circle diameter) D50 of all the hard phases in the three measurement visual fields is calculated. The D50 corresponds to the average particle size of the hard phases.

[0065] As long as the applicant measured, it was confirmed that even though the identical sample was subjected to the above-mentioned measurement multiple times with the selected areas in the measurement visual fields changed, the results of the measurement varied slightly, and even free setting of the measurement visual fields did not make the results arbitrary.

<<Binder Phases>>

[0066] The binder phases of the present embodiment contain cobalt as a main ingredient. Here, the expression "containing cobalt as a main ingredient" means that the

cobalt content in the binder phases is 80% by mass or more and 100% by mass or less. The cobalt content in the binder phases is determined by ICP analysis.

[0067] The above-mentioned binder phases can contain iron (Fe), nickel (Ni), and a dissolved substance in the alloy (chromium (Cr), tungsten (W), vanadium (V), or the like) besides cobalt. The binder phases can comprise cobalt and at least one selected from the group consisting of iron, nickel, chromium, tungsten and vanadium. The binder phases can comprise cobalt; at least one selected from the group consisting of iron, nickel, chromium, tungsten, and vanadium; and inevitable impurities. Examples of the inevitable impurities include manganese (Mn), magnesium (Mg), calcium (Ca), molybdenum (Mo), sulfur (S), titanium (Ti), and aluminum (Al). It can be determined by subjecting a section of the cemented carbide to elemental mapping using an energy dispersive X-ray spectroscopy (EDS) that the binder phases contain iron (Fe); nickel (Ni); & dissolved substance in the alloy (chromium (Cr), tungsten (W), vanadium (V), or the like); and inevitable impurities.

<Ratio of 10% Cumulative Particle Size D10 to 90% Cumulative Particle Size D90 D10/D90 (Binder Phases)>

[0068] In the above-mentioned binder phases, the ratio D10/D90 of D10 being the area-based 10% cumulative particle size to D90 being the area-based 90% cumulative particle size is 0.23 or more. The binder phases can therefore be uniformly dispersed in the cemented carbide. In the above-mentioned binder phases, D10/D90 is preferably 0.24 or more and more preferably 0.25 or more. In the above-mentioned binder phases, D10/D90 is preferably 0.5 or less, more preferably 0.45 or less, and further preferably 0.4 or less. In the above-mentioned binder phases, D10/D90 is preferably 0.23 or more and 0.5 or less, more preferably 0.24 or more and 0.45 or less, and further preferably 0.25 or more and 0.4 or less.

[0069] In the above-mentioned binder phases, D10/D90 is measured in a procedure comprising the following (A3) to (C3).

[0070] (A3) Images of sections of the cemented carbide subjected to the binarization processing are obtained in a procedure identical to (A1) to (C1) described in the method for measuring D10/D90 of the hard phases.

[0071] (B3) Rectangular measurement visual fields of 960 pixels in length×1280 pixels in width are set in the three images subjected to the binarization processing. All the binder phases (white regions) in the three measurement visual fields are measured for equivalent circle diameter (Heywood diameter, namely equal area equivalent circle diameter) using the above-mentioned image analysis software.

[0072] (C3) The area-based 10% cumulative particle sizes (equivalent circle diameters) D10 and the area-based 90% cumulative particle sizes (equivalent circle diameters) D90 of all the binder phases in the three measurement visual fields are calculated. D10/D90 (binder phases) is then found by dividing the D10 by the D90.

[0073] As long as the applicant measured, it was confirmed that even though the identical sample was subjected to the above-mentioned measurement multiple times with the selected areas in the measurement visual fields changed, the results of the measurement varied slightly, and even free setting of the measurement visual fields did not make the results arbitrary.

<Average Particle Size of Binder Phases>

[0074] The average particle size of the above-mentioned binder phases is 0.25 μm or more and 0.50 μm or less. The binder phases can therefore be micronized in the cemented carbide as a whole. The average particle size of the above-mentioned binder phases is preferably 0.23 μm or more and more preferably 0.25 μm or more. The average particle size of the above-mentioned binder phases is preferably 0.47 μm or less and more preferably 0.45 μm or less. The average particle size of the above-mentioned binder phases is preferably 0.23 μm or more and 0.47 μm or less and more preferably 0.25 μm or more and 0.45 μm or less.

[0075] The average particle size of the above-mentioned binder phases is measured in a procedure comprising the following (A4) to (B4).

[0076] (A4) According to the procedure comprising (A3) to (B3) in the above-mentioned method for measuring D10/D90 (binder phases), all the identification phases in the three measurement visual fields (white regions) are measured for equivalent circle diameter (Heywood diameter, namely equal area equivalent circle diameter).

[0077] (B4) The area-based 50% cumulative particle size (equivalent circle diameter) D50 of all the binder phases in the three measurement visual fields is calculated. The D50 corresponds to the average particle size of the binder phases.

[0078] As long as the applicant measured, it was confirmed that even though the identical sample was subjected to the above-mentioned measurement multiple times with the selected areas in the measurement visual fields changed, the results of the measurement varied slightly, and even free setting of the measurement visual fields did not make the results arbitrary.

<<Chromium Content and Vanadium Content>

[0079] The total of the chromium content and the vanadium content is preferably 0.6% by mass or more and 2.1% by mass or less. Here, as long as the total of the chromium content and the vanadium content is 0.6% by mass or more and 2.1% by mass or less, the ratio of the chromium content to the vanadium content may be any ratio. The total of the chromium content and the vanadium content is more preferably 0.8% by mass or more and 1.9% by mass or less and further preferably 1.0% by mass or more and 1.7% by mass or less.

<Chromium Content>

[0080] The chromium content in the cemented carbide of the present embodiment is preferably 0.4% by mass or more and 1.5% by mass or less. Chromium has the action of suppressing the grain growth of tungsten carbide particles. If the chromium content is in the range, the generation of coarse particles can be effectively suppressed, and the welding resistance and the breakage resistance of the cemented carbide can be further improved. The chromium content is preferably 0.4% by mass or more, more preferably 0.5% by mass or more, and further preferably 0.6% by mass or more. The chromium content is preferable 1.5% by mass or less, more preferably 1.4% by mass or less, and further preferably 1.3% by mass or less. The chromium content is more preferably 0.5% by mass or more and 1.4% by mass or less and further preferably 0.6% by mass or more and 1.3% by mass or less. The above-mentioned chromium can exist as solid solution in the binder phases. The above-mentioned

chromium is deposited as Cr_3C_2 and can exist as the hard phases. The above-mentioned chromium preferably exists as solid solution in the binder phases.

[0081] The chromium content in the cemented carbide is measured by ICP emission spectrometry.

<Vanadium Content>

[0082] The vanadium content is preferably 0% by mass or more and 0.6% by mass or less. The vanadium has the action of suppressing the grain growth of tungsten carbide particles. If the vanadium content is in the range, the generation of coarse particles can be effectively suppressed, and the welding resistance and breakage resistance of the cemented carbide can be further improved. The vanadium content is preferably 0.1% by mass or more and more preferably 0.2% by mass or more. The vanadium content is preferably 0.55% by mass or less and more preferably 0.5% by mass or less. The vanadium content is more preferably 0.1% by mass or more and 0.55% by mass or less and further preferably 0.2% by mass or more and 0.5% by mass or less. The above-mentioned vanadium can exist as solid solution in the binder phases. The above-mentioned vanadium is deposited as VC, and can exist as the hard phases. The above-mentioned vanadium preferably exists as solid solution in the binder phases.

[0083] The content of vanadium in the cemented carbide is measured by ICP emission spectrometry.

<<Particle Number of First Chromium-Containing Particles of First Vanadium-Containing Particles>>

[0084] It is preferable in a rectangular measurement visual field of 42.3 μm ×29.6 μm set in an image obtained by subjecting a section of the cemented carbide of the present disclosure to elemental mapping with an energy dispersive X-ray analyzer that the total number of first vanadium-containing particles and first chromium-containing particles is two or less, the particle size of the first vanadium-containing particles be 1 μm or more, and the particle size of the first chromium-containing particles be 1 μm or more.

[0085] The first vanadium-containing particles exist as the hard phases in the cemented carbide. The first vanadium-containing particles mainly comprise vanadium and carbon, and can further contain impurities. Examples of the impurities include W, Ti, Mo, Ta, Nb, Cr, N, and O. The content of the impurities in the first vanadium-containing particles can be 30% by mass or less. The content of the impurities is measured by ICP emission spectrometry.

[0086] The first chromium-containing particles exist as the hard phases in the cemented carbide. The first chromium-containing particles mainly comprise chromium and carbon, and can further contain impurities. Examples of the impurities include W, Ti, Mo, Ta, Nb, V, N, and O. The content of the impurities in the first chromium-containing particles can be 30% by mass or less. The content of the impurities is measured by ICP emission spectrometry.

[0087] It is preferable in a rectangular measurement visual field of 42.3 μm ×29.6 μm set in an image obtained by subjecting a section of the cemented carbide of the present disclosure to elemental mapping with an energy dispersive X-ray analyzer that the total number of first vanadium-containing particles and first chromium-containing particles be two or less. It is because the breakage resistance of the cemented carbide tends to decrease in the case where many

first chromium-containing particles or many first vanadium-containing particles exist in the cemented carbide. It is more preferable that the total particle number of the first vanadium-containing particles and the first chromium-containing particles be one or less, and it is further preferable that the total number be zero, namely that the first vanadium-containing particles or the first chromium-containing particles does not exist.

[0088] In a rectangular measurement visual field of $42.3\ \mu\text{m} \times 29.6\ \mu\text{m}$ set in an image obtained by subjecting a section of the cemented carbide to elemental mapping with an energy dispersive X-ray analyzer (EDS), the number of the first vanadium-containing particles and the number of the first chromium-containing particles is measured in the following procedure. That is, an observed image at a magnification of 3000 times is obtained using an electron microscope for any section of the cemented carbide. In any one rectangular visual field of $42.3\ \mu\text{m} \times 29.6\ \mu\text{m}$ in an observed image, the number of the first vanadium-containing particles and the amount of the first chromium-containing particles can then be counted to obtain the number of the first chromium-containing particles and the number of the first vanadium-containing particles.

[0089] Five visual fields freely set in the above-mentioned observed image are subjected to the above-mentioned measurement to determine the total numbers of the first vanadium-containing particles and the first chromium-containing particles in the visual fields. The average of the total numbers in the five visual field is calculated. The average thereof is defined as the total number of the first vanadium-containing particles and the first chromium-containing particles in the present embodiment.

[0090] As long as the applicant measured, it was confirmed that even though the identical sample was subjected to the above-mentioned measurement multiple times with the selected areas in the measurement visual fields changed, the results of the measurement varied slightly, and even free setting of the measurement visual fields did not make the results arbitrary.

Embodiment 2: Method for Manufacturing Cemented Carbide

[0091] As a method for micronizing the hard phases contained in the cemented carbide as a whole, the use of hard particle powder having a small particle size as a raw material and the mixing of chromium particle powder and vanadium particle powder besides hard particle powder and cobalt particle powder in the mixing step described below are devised. Since merely the use of hard particle powder having a small particle size as a raw material and merely the mixing of chromium particle powder and vanadium particle powder did not enable fully reducing spaces among the hard phases in the cemented carbide, the binder phases however tended to easily become coarse grains. In such a case, since the chromium particles and the vanadium particles were deposited in the cemented carbide, the binder phases contained in the cemented carbide may have been difficultly dispersed. The present inventors have earnestly examined manufacturing conditions for obtaining cemented carbide of the present embodiment and consequently and newly found the optimal manufacturing conditions. Hereinafter, details about the method for manufacturing the cemented carbide of the present embodiment will be described.

[0092] The cemented carbide of the present embodiment can be typically manufactured by performing a step of preparing raw material powders, a mixing step, a molding step, a sintering step, and a cooling step in the order. Hereinafter, the steps will be described.

<<Preparation Step>>

[0093] In the preparation step, all the raw material powders of materials constituting the cemented carbide are prepared. Examples of the raw material powders include tungsten carbide powder that is a raw material of the hard phases, cobalt (Co) powder that is a raw material of the binder phases, and chromium carbide (Cr_3C_2) powder and vanadium carbide (VC) powder as a grain growth suppressant. The grain growth suppressant can reduce the particle size of the hard phases constituted of the ultraparticulate tungsten carbide particles. Commercial tungsten carbide powder, cobalt powder, chromium carbide powder, and vanadium carbide powder are available.

[0094] As tungsten carbide powder (hereinafter also described as “WC powder”), particulate WC powder (average particle size: $0.5\ \mu\text{m}$ or more and $1.0\ \mu\text{m}$ or less) and ultraparticulate WC powder (average particle size: $0.2\ \mu\text{m}$ or more and $0.4\ \mu\text{m}$ or less) are prepared. The hard phases in the cemented carbide can therefore be formed into particulates as a whole. Since ultraparticulate tungsten carbide particles fills spaces among particulate tungsten carbide particles, the mean free path of cobalt can be decreased, and the particle size of the binder phases can therefore be reduced as a whole. The present inventors have earnestly examined and consequently and newly found that the preparation of the two WC powders as described above enables forming the hard phases in the cemented carbide into particulates as a whole and reducing the particle sizes of the binder phases as a whole.

[0095] The average particle sizes of the raw material powders used herein mean average particle sizes measured by the FSSS (Fisher Sub-Sieve Sizer) method. The average particle sizes are measured with a “Sub-Sieve Sizer model 95” (TM), manufactured by Fisher Scientific K.K. The particle sizes of WC particles contained in the WC powders is measured with a particle size distribution measuring apparatus (trade name: MT3300EX) manufactured by MicrotracBEL Corp.

[0096] The average particle size of the cobalt powder can be $0.5\ \mu\text{m}$ or more and $1.5\ \mu\text{m}$ or less. The average particle size of the chromium carbide powder can be $0.7\ \mu\text{m}$ or more and $3.5\ \mu\text{m}$ or less. The average particle size of the vanadium carbide powder can be $0.1\ \mu\text{m}$ or more and $1.2\ \mu\text{m}$ or less. These average particle sizes are measured with a “Sub-Sieve Sizer model 95” (TM), manufactured by Fisher Scientific K.K.

<<Mixing Step>>

[0097] In the mixing step, the raw material powders prepared in the preparation step are mixed. Mixed powder in which the raw material powders are mixed is obtained by the mixing step. The blended amounts of the raw material powders in the mixed powder are suitably adjusted in view of the contents of the components such as the hard phases and the binder phases of the cemented carbide.

[0098] For example, the blended amount of the particulate WC powder in the mixed powder can be 50.0% by mass or more and 71.0% by mass or less.

[0099] For example, the blended amount of the ultraparticulate WC powder in the mixed powder can be 10% by mass or more and less than 29% by mass.

[0100] For example, the blended amount of the cobalt powder in the mixed powder can be 6% by mass or more and 16% by mass or less. The blended amount of the cobalt powder in the mixed powder is preferably more than 8% by mass and 16% by mass or less.

[0101] For example, the blended amount of the chromium carbide powder in the mixed powder can be 0.4% by mass or more and 1.5% by mass or less.

[0102] For example, the blended amount of the vanadium carbide powder in the mixed powder can be 0% by mass or more and 0.7% by mass or less. The blended amount of the vanadium carbide powder in the mixed powder is preferably 0% by mass or more and 0.6% by mass or less. The total of the blended amount of the chromium carbide powder in the mixed powder and the blended amount of the vanadium carbide powder in the mixed powder is preferably 0.6% by mass or more and 2.1% by mass or less.

[0103] As the mixing method, a mixing method in which pulverization is controlled is used for maintaining the particles having different particle sizes (particulate tungsten carbide particles and ultraparticulate tungsten carbide particles) as they are. Specifically, a ball mill, an attritor, a Karman mixer, or the like is used. Especially in the mixing method using a media-free mixer such as a Karman mixer, the pulverization of WC particles in the WC powders is easily suppressed. The mixing time can be suitably adjusted depending on the mixed method. In the case of strong pulverization, the advantage of the above-mentioned composition is scarcely exhibited.

[0104] Cobalt is highly expandable, and becomes thin plate-like in the mixing step. In order to maintain the shapes of the above-mentioned particulate cobalt, it is desirable to feed cobalt after an elapse of at least half of the mixing time.

[0105] After the mixed step, the mixed powder may be granulated as necessary. The granulation of the mixed powder facilitates filling a die or a metal mold with the mixed powder during the molding step described below. A well-known granulation method is applicable to the granulation, and for example, a commercial granulator such as a spray dryer is usable.

<<Molding Step>>

[0106] In the molding step, the mixed powder obtained in the mixing step is molded into a predetermined shape to obtain a compact. As the molding method and the molding conditions in the molding step, a common method and common conditions only have to be adopted, and may be any method and any conditions. Examples of the predetermined shape include the shape of a cutting tool (for example, the shape of a small-diameter drill).

<<Sintering Step>>

[0107] In the sintering step, the compact obtained by the molding step is sintered to obtain a sintered material. In the method for manufacturing the cemented carbide of the present disclosure, the sintering temperature is 1400° C. or more. The flowing of the binder phases is promoted thereby,

the rearrangement of the hard particles is also promoted, and the binder phases can therefore be uniformly dispersed in the cemented carbide. If the sintering temperature is less than 1400° C., the binder phases tend to be scarcely uniformly dispersed. The present inventors have earnestly examined and consequently and newly found that the binder phases are uniformly dispersed in the cemented carbide by performing the sintering step at the sintering temperature as described above.

[0108] The sintering temperature is preferably 1500° C. or less. If the sintering temperature exceeds 1500° C., the grains of the hard phases tend to grow easily. In the method of for manufacturing the cemented carbide of the present disclosure, the sintering time can be 0.5 hours or more and 2 hours or less after the heating and holding.

<<Cooling Step>>

[0109] In the cooling step, the above-mentioned sintered material is cooled. In the method for manufacturing the cemented carbide of the present disclosure, the cooling step is performed at a temperature decreasing rate of 5° C./minute or more. Since the amounts of Cr and V dissolved in the binder phases can be highly maintained thereby, the deposition of Cr and V can be suppressed thereby. Here, the expression “the temperature decreasing rate is 5° C./minute” means that the temperature decreases at a rate of 5° C. per minute. The present inventors have earnestly examined and consequently and newly found that the deposition of Cr and V can be suppressed by performing the cooling step at the temperature decreasing rate as described above. The temperature decreasing rate is preferably 15° C./minute or more.

[0110] Examples of the atmosphere during the cooling step include, but are not limited to, a N₂ gas atmosphere or an inert gas atmosphere such as Ar. The pressure during the cooling is not particularly limited, and may be increased or reduced. For example, Examples of the pressure in the case of increasing the pressure as mentioned above include 100 kPa or more and 7000 kPa or less. In one aspect of the present embodiment, examples of the above-mentioned cooling step include a cooling step in which the above-mentioned sintered material is cooled to normal temperature in an Ar gas atmosphere.

EXAMPLE

[0111] The present embodiment will be described by the Examples further specifically. The present embodiment is not, however, limited by these Examples.

<<Manufacturing of Cemented Carbide>>

<Preparation Step>

[0112] In order to manufacture cemented carbides of Sample Nos. 1 to 21, 25, and 27 to 34, raw material powders (namely tungsten carbide (WC) powders, cobalt (Co) powder, chromium carbide (Cr₃C₂) powder, and vanadium carbide (VC) powder) having average particle sizes shown in the “Composition of mixed powder” column in Table 1 were prepared as the raw material powders.

<Mixing Step>

[0113] The raw material powders were mixed in the blended amounts shown in Table 1 and Table 2 to prepare mixed powders. The “Blended amount [% by mass]” in

Table 1 and Table 2 indicates the ratio of each raw material powder to the total mass of the mixed powder. The mixing was performed with a ball mill for the mixing time described in Table 1 and Table 2. The obtained mixed powders were spray-dried to prepare granulated powders.

<Molding Step>

[0114] The obtained granulated powders were press-molded to produce round rod-shaped compacts having a diameter of 6 mm.

<Sintering Step>

[0115] The compacts were placed in a sintering furnace and sintered in vacuum under the conditions of temperatures

shown in the “Sintering temperature [° C.]” columns in Table 1 and Table 2 and times shown in the “Sintering time [h]” column in Table 1 to obtain sintered materials.

<Cooling Step>

[0116] After the sintering step, the sintered materials were cooled in an argon (Ar) gas atmosphere at temperature decreasing rates described in Table 1 and Table 2 to obtain cemented carbides.

Table 1

[0117]

TABLE 1

Sample No.	Composition of mixed powder										Mixing time [h]	Sintering temperature [° C.]	Sintering time [h]	decreasing rate [° C./min]
	WC powder (particulate)		WC powder (ultraparticulate)		Co powder		Cr ₃ C ₂ powder		VC powder					
	Average particle size [μm]	Blended amount [% by mass]	Average particle size [μm]	Blended amount [% by mass]	Average particle size [μm]	Blended amount [% by mass]	Average particle size [μm]	Blended amount [% by mass]	Average particle size [μm]	Blended amount [% by mass]				
1	0.5	65.0	0.2	21.7	1.2	12.0	1.5	1.0	0.8	0.3	8	1450	1	30
2	0.5	64.9	0.3	21.7	1.2	12.0	1.5	1.0	0.8	0.4	8	1450	1	30
3	0.5	64.9	0.2	21.7	1.2	12.0	1.5	1.0	0.8	0.4	8	1470	1	30
4	0.8	65.0	0.2	21.7	1.2	12.0	1.5	1.0	0.8	0.3	8	1450	1	30
5	0.5	65.7	0.2	21.7	1.2	12.0	1.5	0.3	0.8	0.3	8	1450	1	30
6	0.5	65.5	0.2	21.7	1.2	12.0	1.5	0.5	0.8	0.3	8	1450	1	30
7	0.5	64.6	0.2	21.7	1.2	12.0	1.5	1.4	0.8	0.3	8	1450	1	30
8	0.5	64.3	0.2	21.7	1.2	12.0	1.5	1.7	0.8	0.3	8	1450	1	30
9	0.5	65.3	0.2	21.7	1.2	12.0	1.5	1.0	—	0	8	1450	1	30
10	0.5	65.1	0.2	21.7	1.2	12.0	1.5	1.0	0.8	0.2	8	1450	1	30
11	0.5	64.8	0.2	21.7	1.2	12.0	1.5	1.0	0.8	0.5	8	1450	1	30
12	0.5	64.6	0.2	21.7	1.2	12.0	1.5	1.0	0.8	0.7	8	1450	1	30
13	0.5	65.0	0.2	21.7	1.2	12.0	1.5	1.0	0.8	0.3	8	1450	1	5
14	0.5	65.0	0.2	21.7	1.2	12.0	1.5	1.0	0.8	0.3	8	1400	1	30
15	0.5	65.0	0.2	21.7	1.2	12.0	1.5	1.0	0.8	0.3	8	1360	1	30
16	—	0	0.2	86.7	1.2	12.0	1.5	1.0	0.8	0.3	8	1450	1	30
17	0.8	86.7	—	0	1.2	12.0	1.5	1.0	0.8	0.3	8	1450	1	30
18	0.5	71.0	0.2	21.7	1.2	6.0	1.5	1.0	0.8	0.3	8	1450	1	30
19	0.5	68.0	0.2	21.7	1.2	9.0	1.5	1.0	0.8	0.3	8	1450	1	30
20	0.5	62.0	0.2	21.7	1.2	15.0	1.5	1.0	0.8	0.3	8	1450	1	30

Table 2

[0118]

TABLE 2

Composition of mixed powder															Temperature
WC powder (particulate)		WC powder (ultraparticulate)		Co powder		Cr ₃ C ₂ powder		VC powder		Mixing time	Sintering temperature	Sintering time	de- creasing rate		
Sample No.	Average particle size [μm]	Blended amount [% by mass]	Average particle size [μm]	Blended amount [% by mass]	Average particle size [μm]	Blended amount [% by mass]	Average particle size [μm]	Blended amount [% by mass]	Average particle size [μm]					Blended amount [% by mass]	
21	0.5	59.0	0.2	21.7	1.2	18.0	1.5	1.0	0.8	0.3	8	1450	1	30	
25	0.5	65.0	0.2	21.7	1.2	12.0	1.5	1.0	0.8	0.3	8	1450	1	30	
27	0.5	65.5	0.2	21.7	1.2	12.0	1.5	0.4	0.8	0.4	8	1450	1	30	
28	0.5	64.5	0.2	21.7	1.2	12.0	1.5	1.5	0.8	0.3	8	1450	1	30	
29	0.5	64.7	0.2	21.7	1.2	12.0	1.5	1.0	0.8	0.6	8	1450	1	30	
30	0.5	64.2	0.2	21.7	1.2	12.0	1.5	1.5	0.8	0.6	8	1450	1	30	
31	0.5	65.8	0.2	21.7	1.2	12.0	1.5	0.5	—	0	8	1450	1	30	
32	0.5	64.0	0.2	21.7	1.2	12.0	1.5	1.6	0.8	0.7	8	1450	1	30	

TABLE 2-continued

Sample No.	Composition of mixed powder											Sintering temperature [° C.]	Sintering time [h]	decreasing rate [° C./min]
	WC powder (particulate)		WC powder (ultraparticulate)		Co powder		Cr ₃ C ₂ powder		VC powder					
	Average particle size [μm]	Blended amount [% by mass]	Average particle size [μm]	Blended amount [% by mass]	Average particle size [μm]	Blended amount [% by mass]	Average particle size [μm]	Blended amount [% by mass]	Average particle size [μm]	Blended amount [% by mass]				
33	—	0	0.2	91.7	1.2	6.0	1.5	1.6	0.8	0.7	8	1450	1	30
34	0.8	65.1	0.2	21.7	1.2	12.0	1.5	1.0	0.8	0.2	8	1450	1	30

[0119] The above-mentioned steps were performed to manufacture round rod-shaped cemented carbides of Sample Nos. 1 to 21, 25, and 27 to 34 having compositions shown in Table 2.

<<Evaluation>>

[0120] The cemented carbides of each sample were measured for the compositions of the cemented carbides (the content of hard phases and the content of binder phases), the contents of tungsten carbide particles in the hard phases, the cobalt contents in the binder phases, D10/D90 in the hard phases, the average particle sizes of the hard phases, D10/D90 in the binder phases, the average particle sizes of the binder phases, the chromium contents, the vanadium contents, and the total area percent of the area of first vanadium-containing particles and the area of first chromium-containing particles in images obtained by photographing sections of the cemented carbides with a scanning electron microscope.

<Determination of Compositions of Cemented Carbides (Contents of Hard Phases and Contents of Binder Phases)>

[0121] The contents of the hard phases in the cemented carbides of Sample Nos. 1 to 21, 25, and 27 to 34 were determined by the method described in Embodiment 1. The “Content of hard phases [% by volume]” columns in Table 3 and Table 4 describe the obtained results. The contents of the binder phases in the cemented carbides of Sample Nos. 1 to 21, 25, and 27 to 34 were determined by the method described in Embodiment 1. The “Content of binder phases [% by volume]” columns in Table 3 and Table 4 describe the obtained results.

<Measurement of Contents of Tungsten Carbide Particles in Hard Phases and Cobalt Content in Binder Phases>

[0122] The contents of the tungsten carbide particles in the hard phases of the cemented carbides of Sample Nos. 1 to 21, 25, and 27 to 34 were determined by the method described in Embodiment 1. The “WC particles content in hard phases [% by mass]” columns in Table 3 and Table 4 describe the obtained results. The cobalt contents in the binder phases of the cemented carbides of Sample Nos. 1 to 21, 25, and 27 to 34 were determined by the method described in Embodiment 1. The “Co content in binder phases [% by mass]” columns in Table 3 and Table 4 describe the obtained results.

<Measurement of D10/D90 in Hard Phases and D10/D90 in Binder Phases>

[0123] D10/D90 in the hard phases of the cemented carbides of Sample Nos. 1 to 21, 25, and 27 to 34 were

determined by the method described in Embodiment 1. The “D10/D90 (hard phases)” columns in Table 3 and Table 4 describe the obtained results. D10/D90 in the binder phases of the cemented carbides of Sample Nos. 1 to 21, 25, and 27 to 34 were determined by the method described in Embodiment 1. The “D10/D90 (binder phases)” columns in Table 3 and Table 4 describe the obtained results.

<Measurement of Average Particle Size of Hard Phases and Average Particle Size of Binder Phases>

[0124] The average particle sizes of the hard phases in the cemented carbides of Sample Nos. 1 to 21, 25, and 27 to 34 were determined by the method described in Embodiment 1. The “Average particle size of hard phases [μm]” columns in Table 3 and Table 4 describe the obtained results. The average particle sizes of the binder phases of the cemented carbides of Sample Nos. 1 to 21, 25, and 27 to 34 were determined by the method described in Embodiment 1. The “Average particle size of binder phases [μm]” columns in Table 3 and Table 4 describe the obtained results.

<Measurement of Chromium Content and Vanadium Content>

[0125] The chromium contents in the cemented carbides of Sample Nos. 1 to 21, 25, and 27 to 34 were determined by the method described in Embodiment 1. The “Cr content [% by mass]” columns in Table 3 and Table 4 describe the obtained results. The vanadium contents in the cemented carbides of Sample Nos. 1 to 21, 25, and 27 to 34 were determined by the method described in Embodiment 1. The “V content [% by mass]” columns in Table 3 and Table 4 describe the obtained results.

<Measurement of Total of Particle Number of First Vanadium-Containing Particles and Particle Number of First Chromium-Containing Particles>

[0126] The total of the particle number of the first vanadium-containing particles and the particle number of the first chromium-containing particles in the cemented carbides of Sample Nos. 1 to 21, 25, and 27 to 34 were determined by the method described in Embodiment 1. The “area percent of first V particles+first Cr particles [%]” columns in Table 3 and Table 4 describe the obtained results.

Table 3

[0127]

TABLE 3

Sample No.	Content of hard phases [% by mass]	Content of binder phases [% by mass]	WC content in hard phases [% by mass]	D10/D90 (hard phases)	Average particle size of hard phases [μm]	Co content in binder phases [% by mass]	D10/D90 (binder phases)
1	88	12	100	0.31	0.40	100	0.25
2	88	12	100	0.33	0.40	100	0.27
3	88	12	100	0.31	0.40	100	0.29
4	88	12	100	0.32	0.60	100	0.25
5	88	12	100	0.26	0.52	100	0.22
6	88	12	100	0.30	0.48	100	0.23
7	88	12	100	0.31	0.37	100	0.25
8	88	12	100	0.32	0.29	100	0.21
9	88	12	100	0.30	0.43	100	0.23
10	88	12	100	0.30	0.43	100	0.24
11	88	12	100	0.31	0.36	100	0.25
12	88	12	100	0.32	0.31	100	0.25
13	88	12	100	0.31	0.37	100	0.25
14	88	12	100	0.31	0.38	100	0.23
15	88	12	100	0.32	0.35	100	0.22
16	88	12	100	0.34	0.24	100	0.23
17	88	12	100	0.30	0.68	100	0.20
18	94	6	100	0.32	0.36	100	0.26
19	91	9	100	0.31	0.38	100	0.25
20	85	15	100	0.30	0.43	100	0.24

Sample No.	Average particle size of binder phases [μm]	Cr content [% by mass]	V content [% by mass]	Cr content + V content [% by mass]	Particle number of first V particles + first Cr particles [number of particles]	Breakage resistance [m]	Welding resistance [μm]
1	0.35	1.0	0.3	1.3	0	210	20
2	0.35	1.0	0.3	1.3	0	230	17
3	0.35	1.0	0.3	1.3	0	250	15
4	0.48	1.0	0.3	1.3	0	160	34
5	0.53	0.3	0.3	0.6	0	90	41
6	0.42	0.5	0.3	0.8	0	170	26
7	0.32	1.4	0.3	1.7	2	200	18
8	0.31	1.7	0.3	2.0	8	100	9
9	0.40	1.4	0	1.4	0	170	31
10	0.37	1.0	0.2	1.2	0	180	28
11	0.33	1.0	0.5	1.5	2	190	19
12	0.31	1.0	0.7	1.7	4	120	11
13	0.33	1.4	0.3	1.7	6	130	14
14	0.36	1.0	0.3	1.3	0	170	23
15	0.39	1.0	0.3	1.3	0	100	31
16	0.27	1.0	0.3	1.3	0	90	4
17	0.57	1.0	0.3	1.3	0	80	52
18	0.26	1.0	0.3	1.3	0	110	7
19	0.31	1.0	0.3	1.3	0	150	17
20	0.37	1.0	0.3	1.3	0	170	29

Table 4

[0128]

TABLE 4

Sample No.	Content of hard phases [% by mass]	Content of binder phases [% by mass]	WC content in hard phases [% by mass]	D10/D90 (hard phases)	Average particle size of hard phases [μm]	Co content in binder phases [% by mass]	D10/D90 (binder phases)
21	82	18	100	0.28	0.47	100	0.20
25	88	12	100	0.31	0.40	80	0.23
27	88	12	100	0.30	0.49	100	0.23
28	88	12	100	0.31	0.34	100	0.23
29	88	12	100	0.31	0.36	100	0.25

TABLE 4-continued

30	88	12	100	0.30	0.30	100	0.24
31	88	12	100	0.26	0.55	100	0.21
32	88	12	100	0.31	0.25	100	0.24
33	94	6	100	0.32	0.20	100	0.24
34	88	12	100	0.31	0.60	100	0.24

Sample No.	Average particle size of binder phases [μm]	Cr content [% by mass]	V content [% by mass]	Cr content + V content [% by mass]	Particle number of first V particles + first Cr particles [number of particles]	Breakage resistance [m]	Welding resistance [μm]
21	0.54	1.0	0.3	1.3	0	70	48
25	0.37	1.0	0.3	1.3	0	140	14
27	0.48	0.4	0.4	0.8	0	140	34
28	0.32	1.5	0.3	1.8	3	160	14
29	0.33	1.0	0.6	1.6	3	150	15
30	0.29	1.5	0.6	2.1	8	120	10
31	0.55	0.5	0	0.5	0	80	48
32	0.27	1.6	0.7	2.3	12	80	6
33	0.20	1.6	0.7	2.3	18	40	3
34	0.50	1.0	0.3	1.3	0	150	37

<Cutting Test>

[0129] A cutting test was performed using cutting tools made of the cemented carbides of Sample Nos. 1 to 21, 25, and 27 to 34 under the following cutting conditions to evaluate the breakage resistance and the welding resistance. The breakage resistance was evaluated based on the cutting length (m) when the breakage reached 100 μm. If the cutting length is more than 100 m, it is meant that the breakage resistance is excellent. The welding resistance was evaluated based on the average welding width (μm) at the time of breakage. If the welding width is 40 μm or less, it is meant that the welding resistance is excellent. The “Breakage resistance [m]” columns and the “Welding resistance [μm]” columns in Table 3 and Table 4 describe the obtained results (namely the cutting lengths and the welding widths).

(Cutting Conditions)

- [0130]** Work material: Ti-6Al-4V (titanium alloy (titanium-based hard-to-cut material))
[0131] Cutting rate: 120 m/min
[0132] Feed: 0.1 mm/blade
[0133] Axial cutting: 2 mm
[0134] Radial cutting: 0.5 mm
[0135] Presence or absence of water-soluble coolant: Present

Results

[0136] The cemented carbides of Sample Nos. 1 to 4, 6 to 7, 9 to 14, 18 to 20, 25, 27 to 30, and 34 correspond to Examples. Meanwhile, Sample Nos. 5, 8, 15 to 17, 21, and 31 to 33 correspond to Comparative Examples. It was confirmed that the cutting tools made of the cemented carbides of Sample Nos. 1 to 4, 6 to 7, 9 to 14, 18 to 20, 25, 27 to 30, and 34 (Examples) were excellent in breakage resistance, and had long tool lives even in intermittent processing of titanium-based hard-to-cut materials as compared with the cutting tools made of the cemented carbides of Sample Nos. 5, 8, 15 to 17, 21, and 31 to 33 (Comparative Examples).

[0137] Furthermore, it was confirmed that the cutting tools made of the cemented carbides of Sample Nos. 1 to 4, 6 to 7, 9 to 14, 18 to 20, 25, 27 to 30, and 34 (Examples) were excellent in welding resistance, and had long tool lives especially and even in intermittent processing of titanium-based hard-to-cut materials as compared with the cutting tools made of the cemented carbides of Sample Nos. 5, 8, 15 to 17, 21, and 31 to 33 (Comparative Examples).

[0138] It was therefore found that the cemented carbides of Sample Nos. 1 to 4, 6 to 7, 9 to 14, 18 to 20, 25, 27 to 30, and 34 had long tool lives even in intermittent processing of titanium-based hard-to-cut materials.

[0139] Although the embodiments and Examples of the present disclosure were described above, it is also expected from the first that the configurations of the above-mentioned embodiments and Examples are optionally combined or variously modified.

[0140] It should be considered that the embodiments and Examples disclosed this time are illustrations in all respects, and are not limitative. The scope of the present invention is shown by CLAIMS rather than the above-mentioned embodiments or Examples. It is intended that all the modifications within meaning and scope equivalent to CLAIMS are included therein.

REFERENCE SIGNS LIST

[0141] D10 10% cumulative particle size; D50 50% cumulative particle size; D90 90% cumulative particle size

1. A cemented carbide composed of hard phases and binder phases,
 - wherein the hard phases comprise tungsten carbide as a main ingredient,
 - wherein the binder phases comprise cobalt as a main ingredient,
 - wherein the hard phases have a ratio D10/D90 of D10 being an area-based 10% cumulative particle size to D90 being an area-based 90% cumulative particle size of 0.30 or more,

wherein the binder phases have a ratio **D10/D90** of **D10** being an area-based 10% cumulative particle size to **D90** being an area-based 90% cumulative particle size of 0.23 or more,

wherein the binder phases have an average particle size of 0.25 μm or more and 0.50 μm or less, and

wherein the hard phases have an average particle size of 0.30 μm or more and 0.60 μm or less.

2. The cemented carbide according to claim 1,

wherein the total of chromium content and vanadium content is 0.6% by mass or more and 2.1% by mass or less,

wherein the chromium content is 0.4% by mass or more and 1.5% by mass or less, and

wherein the vanadium content is 0% by mass or more and 0.6% by mass or less.

3. The cemented carbide according to claim 1,

wherein, in a rectangular measurement visual field of 42.3 μm ×29.6 μm set in an image obtained by subjecting a section of the cemented carbide to elemental mapping with an energy dispersive X-ray analyzer, the total number of first vanadium-containing particles and first chromium-containing particles is two or less,

wherein the first vanadium-containing particles have a particle size of 1 μm or more, and

wherein the first chromium-containing particles have a particle size of 1 μm or more.

4. The cemented carbide according to claim 2, wherein the chromium content is 0.5% by mass or more and 1.4% by mass or less.

5. The cemented carbide according to claim 2, wherein the vanadium content is 0.1% by mass or more and 0.55% by mass or less.

6. The cemented carbide according to claim 1, wherein a content of the hard phases in the cemented carbide is 84% by mass or more and 92% by mass or less.

7. The cemented carbide according to claim 1, wherein the hard phases have the ratio **D10/D90** of **D10** being the area-based 10% cumulative particle size to **D90** being the area-based 90% cumulative particle size of 0.50 or less.

8. The cemented carbide according to claim 1, wherein the binder phases have the ratio **D10/D90** of **D10** being the area-based 10% cumulative particle size to **D90** being the area-based 90% cumulative particle size of 0.5 or less.

9. The cemented carbide according to claim 1, wherein an average particle size of the binder phases is 0.25 μm or more and 0.45 μm or less.

10. The cemented carbide according to claim 1, wherein an average particle size of the hard phases is 0.35 μm or more and 0.55 μm or less.

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