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(54) **METHOD FOR MANUFACTURING A CUTTING TOOL FROM A HIGHLY REFRACTORY COMPOSITE**

(57) The subject matter of the invention is a method of manufacturing a cutting tool from a highly refractory composite obtained from boron carbide and an intermetallic compound of the Ti-Si system, for use in the tool industry.

The method relay on mixing starting powders in the

form of boron carbide (B₄C), titanium silicide TiSi or TiSi₂ as the intermetallic compound of the Ti-Si system, carbon C and boron B in the isopropyl alcohol environment, forming shaped pieces from the mixture of powders and subjecting them to sintering by spark plasma sintering method SPS under the protection of argon.

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Description

[0001] The subject matter of the invention is a method of manufacturing a cutting tool from a highly refractory composite obtained from boron carbide and an intermetallic compound of the Ti-Si system, for use in the tool industry.

[0002] From the Polish description of the application of the invention PL437232 is known a method of obtaining a highly refractory composite from boron carbide and an intermetallic compound of the Ti-Si system, relaying on mixing starting powders in the form of boron carbide B_4C , the intermetallic compound of the Ti-Si system and carbon C in an alcohol environment, forming shaped pieces from the mixture of powders and subjecting them to sintering, in which titanium silicide Ti_5Si_3 and carbon C are added to the boron carbide B_4C powder, in the molar ratio $B_4C:Ti_5Si_3:C$ of 5:2:1. Then, the whole is mixed in the isopropyl alcohol environment for 20-60 minutes and dried until the complete evaporation of the alcohol for 20-120 minutes, after which the shaped pieces are pre-formed and subjected to isostatic pressing under a pressure of 100-200 MPa. The achieved moulded pieces are subjected to the free sintering process in argon atmosphere at a temperature of 1650-1750°C, with a temperature increase of 2-10°C/minute and a holding time of 5-30 minutes at a maximum temperature, achieving the $TiB_2-TiC-SiC-Ti_5Si_3$ composite consisting of 70.0-75.0% of TiB_2 , 0.5-2.5% of TiC , 20.0-27.5% of SiC , and 0.2-1.0% of Ti_5Si_3 by weight. The efficiency of the process is at least 99%.

[0003] It is known from the Polish description of the application of the invention PL425041A1 a ceramic composite of the group of UHTC materials with the matrix of hafnium diboride HfB_2 and a method of manufacturing thereof. The method is characterized in that the additives in the form of silicon carbide SiC and/or boron carbide B_4C in the amount from 8% by volume to 20% by volume and graphene nanoflakes having an average particle size <4 nm in the amount from 2% by volume to 4% by volume are introduced into the powder with hafnium diboride HfB_2 in the amount from 76% by volume to 92% by volume and the starting mixture is subjected to high-pressure sintering using the HPHT method under the pressure of 7.2 GPa at the temperature of $1700 \pm 50^\circ C$.

[0004] It is known from the European patent description EP2021302 B1 a method of manufacturing high-density UHTC composites in the $ZrB_2-SiC-ZrC$ system. This method is characterized in that zirconium powders having a purity higher than 98.5% and a particle size less than 44 μm are dry mixed with boron carbide powder having a purity higher than 99.0% and a particle size less than 44 μm , and then mixed with graphite powder having a particle size ranging from 1 to 2 μm . The mixture thus achieved is subjected to the SHS synthesis, and then sintered using the Electric Current Activated Sintering (ECAS) method at temperatures ranging from 1600 to 1900°C, with a holding for 10 to 20 minutes at a maximum

temperature.

[0005] It is known from the Chinese patent description CN108484171B a method of manufacturing UHTC composites from the B_4C-ZrB_2 system. This method is characterized in that composite powder is produced in the sintering process of the mixture of powders of B_4C , ZrB_2 , carbon black and metallic silicon. The mixture of powders is isostatically pressed under a pressure ranging from 100 to 500 MPa, and then freely sintered at a temperature ranging from 1900 to 2300°C with a holding for 0.5 to 3 hours at a maximum temperature.

[0006] The purpose of the method according to the invention is to increase heat resistance of a cutting tool while maintaining high hardness.

[0007] The gist of the method of manufacturing a cutting tool from a highly refractory composite obtained from boron carbide and an intermetallic compound of the Ti-Si system, relaying on mixing starting powders in the form of boron carbide (B_4C), the intermetallic compound of the Ti-Si system, carbon C and boron B in the isopropyl alcohol environment, forming shaped pieces from the mixture of powders and subjecting them to sintering, relay on that the highly refractory composite contains titanium silicide $TiSi$ or $TiSi_2$ as the intermetallic compound of the Ti-Si system in the molar ratio $B_4C:TiSi/TiSi_2:C:B$ of 1:2:3:1. The obtained $TiB_2-TiC-SiC-TiSi$ composite containing titanium silicide $TiSi$ has 60.0-65.0% by weight of TiB_2 , 20-34% by weight of TiC , 5-14% by weight of SiC and 0.9-1.0% by weight of $TiSi$, while the obtained $TiB_2-TiC-SiC-TiSi_2$ composite containing titanium silicide $TiSi_2$ has 65.0-70.0% by weight of TiB_2 , 9.2-10% by weight of TiC , 19.9-24.1% by weight of SiC and 0.9-1.0% by weight of $TiSi_2$. The sintering process of the formed shaped pieces is carried out by the spark plasma sintering method SPS under the protection of argon at a temperature of 1350-1450°C, with a temperature increase of 200÷300°C per minute, with a holding time of 1÷5 minutes and under the pressure of 50 MPa or by the hot pressing method at a temperature of 1500-1550°C, with the temperature increase of 10°C, with the holding time of 30 minutes and under the pressure of 50 MPa.

[0008] The use of titanium silicide $TiSi$ or $TiSi_2$ as the intermetallic compound of the Ti-Si system in a highly refractory composite made it possible to eliminate unreacted carbon formed as the result of the decomposition of boron carbide (B_4C) during the synthesis, while simultaneously achieving the largest possible amount of the TiB_2 phase having the highest melting point ($T=3325^\circ C$) among the components of the composite and the TiC phase ($T=3140^\circ C$), which improved the refractoriness of the produced composite, while simultaneously increasing its hardness. The preferable phase composition of the composite, i.e. the high content of TiB_2 and TiC phases, compared to the composites known from the state of the art and produced from boron carbide and an intermetallic compound of the Ti-Si system, allows the composite according to the invention to work at high temperatures for a longer time while maintaining preferable me-

chanical properties. On the other hand, the conduction of the sintering process using the spark plasma sintering method SPS under the protection of argon makes it possible to significantly lower the synthesis temperature to 1350°C, and thus reduce the costs of tools manufacturing.

[0009] The obtained shaped pieces of cutting tool obtained by the method according to the invention are characterized by high hardness as measured by the Vickers method and ranging from 25 to 40 (GPa) and can work up to a temperature of 600-800°C at the edge of cutting tool without the use of coolant in the form of water. The proposed shaped pieces can be made with different geometry of the blade shape through mechanical working, and their average density is up to 99.9%. The obtained cutting tools are characterized in that they can be regenerated from 3-5 times by using the additive of boron and carbon to the composition and re-sintering the obtained shaped pieces by using laser treatment under the protection of argon or by mechanical re-working the shaped pieces and removing damaged or deformed surfaces. Due to the high abrasion resistance of the obtained composites, the average friction factor can be determined at the level of 0.4-0.5.

Example 1

[0010] The following powders were prepared to obtain the composite: boron carbide B_4C , titanium silicide $TiSi_2$, carbon C in the form of P-803 technical carbon black (Tuymazy) and amorphous boron, which consisted of three phases: beta boron, boric acid and boron. Commercial boron carbide B_4C powder (Boron carbide B_4C GRADE HS by Höganäs) containing the following phases: $B_{13}C_2$ (99%) and graphite (1%) was used. To produce the $TiSi_2$ powder, the process of self-developing high-temperature synthesis (SHS) was used, as described in the publication by S. Rzepa, L. Chlubny, T. Bucki, "The Ti - Si intermetallic phases synthesis by SHS method", METAL 2018-27th International Conference on Metallurgy and Materials, Conference Proceedings, 2018, p. 1699-1704, according to which the powders of Ti and Si were used in the molar ratio of 1:2. The mixture of powders was placed in a reactor with argon atmosphere under the overpressure of 1.5 atm. The SHS synthesis reaction was initiated locally by the heat released during current flow, through a graphite foil placed in the mixture of powders. The current intensity was 200 A, and the flow time was 1 minute. The produced titanium silicide $TiSi_2$, carbon C in the form of P-803 technical carbon black (Tuymazy) and amorphous boron were added to the boron carbide B_4C powder, in the molar ratio $B_4C:TiSi_2:C:B$ of 1:2:3:1, and the whole mixture was then stirred in a rotary-vibrating mill in the isopropyl alcohol environment for 30 minutes, after which it was dried until the complete evaporation of the alcohol for 30 minutes. The obtained powders were preformed into disks having the diameter of 25 mm and the height of 20 mm and subjected to iso-

static pressing under the pressure of 200 MPa. The achieved moulded pieces were subjected to the sintering process by the spark-plasma method SPS in argon (Ar) atmosphere under the protection of argon, at the temperature of 1450°C, with the temperature increase of 300°C per minute, with the holding time of 5 minutes and under the pressure of 50 MPa. The $TiBz-TiC-SiC-TiSi_2$ composite containing titanium silicide $TiSi_2$, obtained by the method according to the invention, had the following phase composition: 70.0 % by weight of TiB_2 , 9.2 % by weight of TiC , 19.9 % by weight of SiC , and 0.9 % by weight of $TiSi_2$. The thus obtained moulded pieces of the composite having the composition as above in the form of the cylinder having the diameter of 20 mm and the height of 6 mm were subjected to mechanical working.

[0011] The manufactured tool in the form of a multi-blade plate having the RNGN1204 geometry, intended for use in a cutting device, had high hardness of 40 (GPa) as measured by the Vickers method, wherein during the test it worked at the temperature of 650°C without the use of coolant in the form of water. The obtained cutting tools are characterized in that they can be regenerated by using the additive of boron and carbon to the composition and re-sintering the obtained shaped pieces, it is possible to use laser treatment under the protection of argon or by mechanical re-working the shaped pieces and removing damaged or deformed surfaces. Due to the high abrasion resistance of the obtained composites, the average friction factor can be determined at the level of 0.5. The use of intermetallics and starting products in the form of boron carbide (B_4C), boron (B) and carbon (C) confirms the occurrence of the reaction sintering during the synthesis, which makes it possible to achieve a density of the obtained composites at the level of 99.9%.

Example 2

[0012] The following powders were prepared to obtain the composite: boron carbide B_4C , titanium silicide $TiSi$, carbon C in the form of P-803 technical carbon black (Tuymazy) and amorphous boron, which consisted of three phases: beta boron, boric acid and boron. Commercial boron carbide B_4C powder (Boron carbide B_4C GRADE HS by Höganäs) containing the following phases: $B_{13}C_2$ (99%) and graphite (1%) was used. To produce the $TiSi$ powder, the process of self-developing high-temperature synthesis (SHS) was used, as described in the publication by S. Rzepa, L. Chlubny, T. Bucki, "The Ti - Si intermetallic phases synthesis by SHS method", METAL 2018-27th International Conference on Metallurgy and Materials, Conference Proceedings, 2018, p. 1699-1704, according to which the powders of Ti and Si were used in the molar ratio of 1:1. The mixture of powders was placed in a reactor with argon atmosphere under the overpressure of 1.5 atm. The SHS synthesis reaction was initiated locally by the heat released during current flow, through a graphite foil placed in the mixture of powders. The current intensity was 200 A, and the flow

time was 1 minute. The produced titanium silicide TiSi_2 , carbon C in the form of P-803 technical carbon black (Tuymazy) and amorphous boron were added to the boron carbide B_4C powder, in the molar ratio $\text{B}_4\text{C}:\text{TiSi}:\text{C}:\text{B}$ of 1:2:3:1, and the whole mixture was then stirred in a rotary-vibrating mill in the isopropyl alcohol environment for 30 minutes, after which it was dried until the complete evaporation of the alcohol for 30 minutes. The obtained powders were preformed into disks having the diameter of 25 mm and the height of 20 mm and subjected to isostatic pressing under the pressure of 200 MPa. The achieved moulded pieces were subjected to the sintering process by the spark-plasma method SPS in argon (Ar) atmosphere under the protection of argon, at the temperature of 13 50°C, with the temperature increase of 300°C per minute, with the holding time of 5 minutes and under the pressure of 50 MPa. The $\text{TiB}_2\text{-TiC-SiC-TiSi}$ composite containing titanium silicide TiSi , obtained by the method according to the invention, had the following phase composition: 60.0% by weight of TiB_2 , 34% by weight of TiC , 5% by weight of SiC and 1% by weight of TiSi . The thus obtained moulded pieces of the composite having the composition as above in the form of the plate with the square base having the side of 20 mm and the height of 6 mm were subjected to mechanical working.

[0013] The manufactured tool in the form of a multi-blade plate having the RNGN1204 geometry, intended for use in a cutting device, had high hardness of 38 (GPa) as measured by the Vickers method, wherein during the test it worked at the temperature of 650°C without the use of coolant in the form of water. The obtained cutting tools are characterized in that they can be regenerated by using the additive of boron and carbon to the composition and re-sintering the obtained shaped pieces, it is possible to use laser treatment under the protection of argon or by mechanical re-working the shaped pieces and removing damaged or deformed surfaces. Due to the high abrasion resistance of the obtained composites, the average friction factor can be determined at the level of 0.5. The use of intermetallics and starting products in the form of boron carbide (B_4C), boron (B) and carbon (C) confirms the occurrence of the reaction sintering during the synthesis, which makes it possible to achieve a density of the obtained composites at the level of 99.9%.

Example 3

[0014] The following powders were prepared to obtain the composite: boron carbide B_4C , titanium silicide TiSi_2 , carbon C in the form of P-803 technical carbon black (Tuymazy) and amorphous boron, which consisted of three phases: beta boron, boric acid and boron. Commercial boron carbide B_4C powder (Boron carbide B_4C GRADE HS by Höganäs) containing the following phases: B_{13}C_2 (99%) and graphite (1%) was used. To produce the TiSi_2 powder, the process of self-developing high-temperature synthesis (SHS) was used, as described in the publication by S. Rzepa, L. Chlubny, T. Bucki, "The

Ti - Si intermetallic phases synthesis by SHS method", METAL 2018-27th International Conference on Metallurgy and Materials, Conference Proceedings, 2018, p. 1699-1704, according to which the powders of Ti and Si were used in the molar ratio of 1:2. The mixture of powders was placed in a reactor with argon atmosphere under the overpressure of 1.5 atm. The SHS synthesis reaction was initiated locally by the heat released during current flow, through a graphite foil placed in the mixture of powders. The current intensity was 200 A, and the flow time was 1 minute. The produced titanium silicide TiSi_2 , carbon C in the form of P-803 technical carbon black (Tuymazy) and amorphous boron were added to the boron carbide B_4C powder, in the molar ratio $\text{B}_4\text{C}:\text{TiSi}_2:\text{C}:\text{B}$ of 1:2:3:1, and the whole mixture was then stirred in a rotary-vibrating mill in the isopropyl alcohol environment for 30 minutes, after which it was dried until the complete evaporation of the alcohol for 30 minutes. The obtained powders were preformed into disks having the diameter of 25 mm and the height of 20 mm and subjected to isostatic pressing under the pressure of 200 MPa. The achieved moulded pieces were subjected to the sintering process by the hot pressing method at the temperature of 1550°C, with the temperature increase of 10°C, with the holding time of 30 minutes and under the pressure of 50 MPa. The $\text{TiB}_2\text{-TiC-SiC-TiSi}_2$ composite containing titanium silicide TiSi_2 , obtained by the method according to the invention had, the following phase composition: 65.0% by weight of TiB_2 , 10% by weight of TiC , 24.1% by weight of SiC and 0.9% by weight of TiSi_2 . The thus obtained moulded pieces of the composite having the composition as above in the form of the cylinder having the diameter of 20 mm and the height of 6 mm were subjected to mechanical working.

[0015] The manufactured tool in the form of a multi-blade plate having the RNGN1204 geometry, intended for use in a cutting device, had high hardness of 40 (GPa) as measured by the Vickers method, wherein during the test it worked at the temperature of 500°C without the use of coolant in the form of water. The obtained cutting tools are characterized in that they can be regenerated by using the additive of boron and carbon to the composition and re-sintering the obtained shaped pieces, it is possible to use laser treatment under the protection of argon or by mechanical re-working the shaped pieces and removing damaged or deformed surfaces. Due to the high abrasion resistance of the obtained composites, the average friction factor can be determined at the level of 0.5. The use of intermetallics and starting products in the form of boron carbide (B_4C), boron (B) and carbon (C) confirms the occurrence of the reaction sintering during the synthesis, which makes it possible to achieve a density of the obtained composites at the level of 99.9%.

Example 4

[0016] The following powders were prepared to obtain the composite: boron carbide B_4C , titanium silicide TiSi ,

carbon C in the form of P-803 technical carbon black (Tuymazy) and amorphous boron, which consisted of three phases: beta boron, boric acid and boron. Commercial boron carbide B_4C powder (Boron carbide B_4C GRADE HS by Höganäs) containing the following phases: $B_{13}C_2$ (99%) and graphite (1%) was used. To produce the TiSi powder, the process of self-developing high-temperature synthesis (SHS) was used, as described in the publication by S. Rzepa, L. Chlubny, T. Bucki, "The Ti - Si intermetallic phases synthesis by SHS method", MET-AL 2018-27th International Conference on Metallurgy and Materials, Conference Proceedings, 2018, p. 1699-1704, according to which the powders of Ti and Si were used in the molar ratio of 1:1. The mixture of powders was placed in a reactor with argon atmosphere under the overpressure of 1.5 atm. The SHS synthesis reaction was initiated locally by the heat released during current flow, through a graphite foil placed in the mixture of powders. The current intensity was 200 A, and the flow time was 1 minute. The produced titanium silicide $TiSi_2$, carbon C in the form of P-803 technical carbon black (Tuymazy) and amorphous boron were added to the boron carbide B_4C powder, in the molar ratio $B_4C:TiSi:C:B$ of 1:2:3:1, and the whole mixture was then stirred in a rotary-vibrating mill in the isopropyl alcohol environment for 30 minutes, after which it was dried until the complete evaporation of the alcohol for 30 minutes. The obtained powders were preformed into disks having the diameter of 25 mm and the height of 20 mm and subjected to isostatic pressing under the pressure of 200 MPa. The achieved moulded pieces were subjected to the sintering process by the hot pressing method at the temperature of 1500°C, with the temperature increase of 10°C, with the holding time of 30 minutes and under the pressure of 50 MPa. The TiBz-TiC-SiC-TiSi composite containing titanium silicide TiSi, obtained by the method according to the invention, had the following phase composition: 60.0% by weight of TiB_2 , 25% by weight of TiC, 14% by weight of SiC and 1% by weight of TiSi. The thus obtained moulded pieces of the composite having the composition as above in the form of the square having the side of 20 mm and the height of 6 mm were subjected to mechanical working.

[0017] The manufactured tool in the form of a multi-blade plate having the RNGN1204 geometry, intended for use in a cutting device, had high hardness of 37 (GPa) as measured by the Vickers method, wherein during the test it worked at the temperature of 600°C without the use of coolant in the form of water. The obtained cutting tools are characterized in that they can be regenerated by using the additive of boron and carbon to the composition and re-sintering the obtained shaped pieces, it is possible to use laser treatment under the protection of argon or by mechanical re-working the shaped pieces and removing damaged or deformed surfaces. Due to the high abrasion resistance of the obtained composites, the average friction factor can be determined at the level of 0.5. The use of intermetallics and starting products in

the form of boron carbide (B_4C), boron (B) and carbon (C) confirms the occurrence of the reaction sintering during the synthesis, which makes it possible to achieve a density of the obtained composites at the level of 99.9%.

Example 5

[0018] The following powders were prepared to obtain the composite: boron carbide B_4C , titanium silicide TiSi, carbon C in the form of P-803 technical carbon black (Tuymazy) and amorphous boron, which consisted of three phases: beta boron, boric acid and boron. Commercial boron carbide B_4C powder (Boron carbide B_4C GRADE HS by Höganäs) containing the following phases: $B_{13}C_2$ (99%) and graphite (1%) was used. To produce the TiSi powder, the process of self-developing high-temperature synthesis (SHS) was used, as described in the publication by S. Rzepa, L. Chlubny, T. Bucki, "The Ti - Si intermetallic phases synthesis by SHS method", MET-AL 2018-27th International Conference on Metallurgy and Materials, Conference Proceedings, 2018, p. 1699-1704, according to which the powders of Ti and Si were used in the molar ratio of 1:1. The mixture of powders was placed in a reactor with argon atmosphere under the overpressure of 1.5 atm. The SHS synthesis reaction was initiated locally by the heat released during current flow, through a graphite foil placed in the mixture of powders. The current intensity was 200 A, and the flow time was 1 minute. The produced titanium silicide $TiSi_2$, carbon C in the form of P-803 technical carbon black (Tuymazy) and amorphous boron were added to the boron carbide B_4C powder, in the molar ratio $B_4C:TiSi:C:B$ of 1:2:3:1, and the whole mixture was then stirred in a rotary-vibrating mill in the isopropyl alcohol environment for 30 minutes, after which it was dried until the complete evaporation of the alcohol for 30 minutes. The obtained powders were preformed into disks having the diameter of 25 mm and the height of 20 mm and subjected to isostatic pressing under the pressure of 200 MPa. The achieved moulded pieces were subjected to the sintering process by the hot pressing method at the temperature of 1550°C, with the temperature increase of 10°C, with the holding time of 30 minutes and under the pressure of 50 MPa. The TiBz-TiC-SiC-TiSi composite containing titanium silicide TiSi, obtained by the method according to the invention, had the following phase composition: 65.0% by weight of TiB_2 , 20% by weight of TiC, 14% by weight of SiC and 1% by weight of TiSi. The thus obtained moulded pieces of the composite having the composition as above in the form of the square having the side of 20 mm and the height of 6 mm were subjected to mechanical working.

[0019] The manufactured tool in the form of a multi-blade plate having the RNGN1204 geometry, intended for use in a cutting device, had high hardness of 35 (GPa) as measured by the Vickers method, wherein during the test it worked at the temperature of 400°C without the use of coolant in the form of water. The obtained cutting

tools are characterized in that they can be regenerated by using the additive of boron and carbon to the composition and re-sintering the obtained shaped pieces, it is possible to use laser treatment under the protection of argon or by mechanical re-working the shaped pieces and removing damaged or deformed surfaces. Due to the high abrasion resistance of the obtained composites, the average friction factor can be determined at the level of 0.5. The use of intermetallics and starting products in the form of boron carbide (B_4C), boron (B) and carbon (C) confirms the occurrence of the reaction sintering during the synthesis, which makes it possible to achieve a density of the obtained composites at the level of 99.9%.

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Claims

1. method of manufacturing a cutting tool from a highly refractory composite obtained from boron carbide and an intermetallic compound of the Ti-Si system, relaying on mixing starting powders in the form of boron carbide (B_4C), the intermetallic compound of the Ti-Si system, carbon C and boron B in the isopropyl alcohol environment, forming shaped pieces from the mixture of powders and subjecting them to sintering and mechanical working, **characterized in that** the highly refractory composite contains titanium silicide TiSi or $TiSi_2$ as the intermetallic compound of the Ti-Si system, in the molar ratio $B_4C:TiSi/TiSi_2:C:B$ of 1:2:3:1, wherein the obtained TiBz-TiC-SiC-TiSi composite containing titanium silicide TiSi has 60.0-65.0% by weight of TiB_2 , 20-34% by weight of TiC, 5-14% by weight of SiC and 0.9-1.0% by weight of TiSi, while the obtained TiB_2 -TiC-SiC-TiSi₂ composite containing titanium silicide $TiSi_2$ has 65.0-70.0% by weight of TiB_2 , 9.2-10% by weight of TiC, 19.9-24.1% by weight of SiC and 0.9-1.0% by weight of $TiSi_2$, and the sintering process of the formed shaped pieces is carried out by spark plasma sintering method SPS under the protection of argon, at a temperature of $1350=1450^\circ C$, with a temperature increase of $200\div 300^\circ C$ per minute, with a holding time of $1\div 5$ minutes and under the pressure of 50 MPa or by the hot pressing method at a temperature of $1500-1550^\circ C$, with the temperature increase of $10^\circ C$, with the holding time of 30 minutes and under the pressure of 50 MPa.

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EUROPEAN SEARCH REPORT

Application Number

EP 23 15 5356

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A,D,P	EP 4 056 540 A1 (AKADEMIA GORNICZO HUTNICZA IM STANISLAWA STASZICA W KRAKOWIE [PL]) 14 September 2022 (2022-09-14) * claim 1 * * abstract * * paragraphs [0015], [0022], [0024] * -----	1	INV. C04B35/58 C04B35/626 C04B35/645 C04B35/65
A	ZHAO GUOLONG ET AL: "Microstructure and mechanical properties at room and elevated temperatures of reactively hot pressed TiB ₂ -TiC-SiC composite ceramic tool materials", CERAMICS INTERNATIONAL, ELSEVIER, AMSTERDAM, NL, vol. 42, no. 4, 22 December 2015 (2015-12-22), pages 5353-5361, XP029388012, ISSN: 0272-8842, DOI: 10.1016/J.CERAMINT.2015.12.068 * abstract * * paragraph [02.1] * * table 2 *	1	TECHNICAL FIELDS SEARCHED (IPC)
A	GRIGORIEV SERGEY N. ET AL: "Processing and Characterization of Spark Plasma Sintered SiC-TiB ₂ -TiC Powders", MATERIALS, vol. 15, no. 5, 5 March 2022 (2022-03-05), page 1946, XP055912973, DOI: 10.3390/ma15051946 * abstract * * paragraph [02.1] * * paragraph [0004] * -----	1	C04B
A	JP H10 101433 A (KAGAKU GIJUTSU SHINKO JIGYODAN) 21 April 1998 (1998-04-21) * abstract * * claims 1, 6 * ----- -/--	1	
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 11 October 2023	Examiner Buffet, Noemie
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document	



EUROPEAN SEARCH REPORT

Application Number

EP 23 15 5356

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	<p>RAJU G B ET AL: "Temperature dependent hardness and strength properties of TiB₂ with TiSi₂ sinter-aid", JOURNAL OF THE EUROPEAN CERAMIC SOCIETY, ELSEVIER, AMSTERDAM, NL, vol. 29, no. 10, 1 July 2009 (2009-07-01), pages 2119-2128, XP026099718, ISSN: 0955-2219, DOI: 10.1016/J.JEURCERAMSOC.2008.11.018 [retrieved on 2009-01-14]</p> <p>* abstract *</p> <p>* paragraph [5.Conclusions] *</p> <p>* paragraph [2.Experimental_procedure] *</p> <p>* table 1 *</p>	1	
A,D	<p>-----</p> <p>RZEPA SYLWIA ET AL: "The Ti- Si intermetallic phases synthesis by SHS method", METAL 2018; 7TH INTERNATIONAL CONFERENCE ON METALLURGY AND MATERIALS, METAL 2018, 23-25, MAY, 2018, BRNO, CZECH REPUBLIC, EU, 23 May 2018 (2018-05-23), pages 1699-1704, XP009535055, Retrieved from the Internet: URL:https://www.confer.cz/metal/2018/read/1298-the-ti-si-intermetallic-phases-synthesis-by-using-shs-method.pdf</p> <p>* abstract *</p> <p>* examples 7-10; table 1 *</p> <p>-----</p>	1	
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
The Hague		11 October 2023	Buffet, Noemie
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>			

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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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11-10-2023

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 4056540 A1	14-09-2022	EP 4056540 A1	14-09-2022
		PL 243571 B1	11-09-2023
JP H10101433 A	21-04-1998	NONE	

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- PL 437232 [0002]
- EP 2021302 B1 [0004]
- CN 108484171 B [0005]

Non-patent literature cited in the description

- **S. RZEPA ; L. CHLUBNY ; T. BUCKI.** The Ti - Si intermetallic phases synthesis by SHS method. *MET-AL 2018-27th International Conference on Metallurgy and Materials, Conference Proceedings*, 2018, 1699-1704 [0010] [0012] [0014] [0016] [0018]