

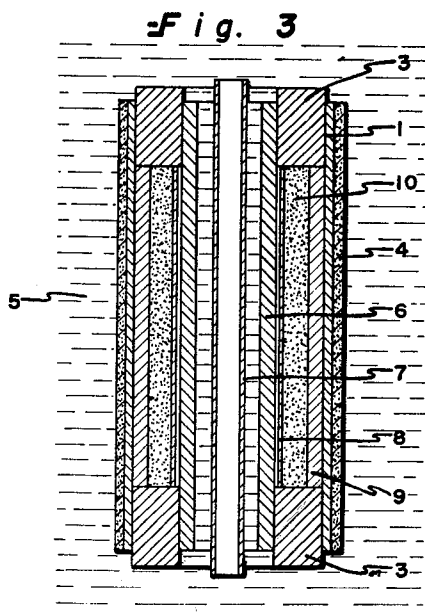
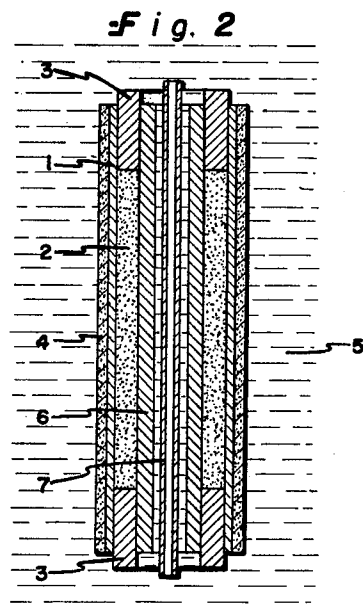
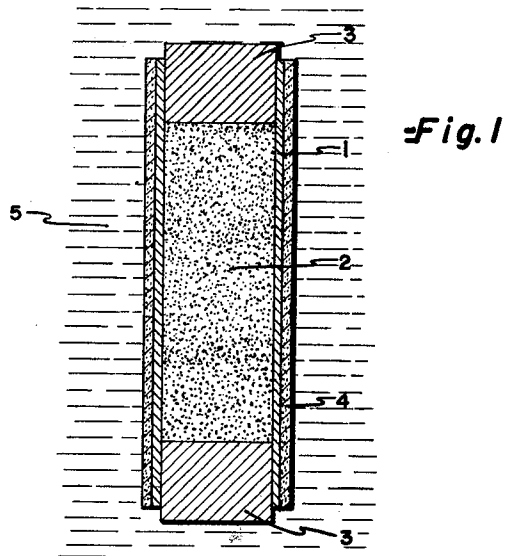
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CERMET OF ALUMINUM WITH BORON CARBIDE OR SILICON CARBIDE

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1

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**CERMET OF ALUMINUM WITH BORON
CARBIDE OR SILICON CARBIDE**

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This invention relates to metal cemented ceramic materials, or cermets, and more particularly to cermets in which the ceramic component is a carbide, and to methods for making such cermets.

Since their development over thirty-five years ago, cemented carbides with appropriate physical properties have had large scale industrial application in services requiring high resistance to wear, oxidation, and corrosion, high strength at elevated temperatures, and high thermal shock resistance.

One method used for producing cemented carbides involves cold pressing and sintering a fine dispersion of carbide and metal powders produced by grinding the components in a ball mill, usually, wet milling. During the milling the metal component tends to react with the milling medium and/or the milling atmosphere to form oxides. To compensate for the above, the dispersion must be dried and subjected to reduction by hydrogen.

The dispersion, either dry or in the presence of a lubricant, is pressed in a die and the resulting compact is subjected to a limited sintering cycle and/or heat treatment to remove the lubricant. The compact is then cut or ground to the desired configuration and subjected to a second and more extensive sintering cycle carried out either in vacuum or in a hydrogen atmosphere.

An alternative method for the production of cemented carbides is hot pressing which involves simultaneous application of heat and pressure to the carbide-metal mixture and produces cermets with superior physical properties, e.g., lower porosity, higher hardness, and improved wear resistance, as compared with the corresponding cermets produced by cold pressing. The mixture of components is pressed, usually by means of hydraulic pressure, into a graphite mold or die and heated either by resistance heating of the die or by induction heating. However, hot pressing is more expensive than cold pressing followed by sintering since the graphite die can rarely be salvaged for reuse. The expense of producing hot-pressed cermets may be reduced by using a graphite mold fabricated in such a manner that two or three articles may be formed during one cycle, but the uniformity of the articles produced is usually inferior to that of singly-produced cermets.

A third process for producing cemented carbides is an infiltration method. In this method, a carbide skeleton, i.e., previously pressed or compacted carbide powder which may or may not have been sintered, is exposed to the desired quantity of molten binder metal, e.g., by superpositioning the molten binder saturated with the carbide on the carbide skeleton. The assembly is heated in a reducing atmosphere until the binder has penetrated the carbide skeleton completely and uniformly, i.e., 1-4 hours.

The formation of a mechanically interlocking structure or possibly of a new phase between the carbide and the metal binder indicates formation of a cemented structure. Although a variety of carbides and carbide mixtures have been successfully cemented with a number of metals using one or more of the above described conventional procedures, attempts to prepare aluminum-, titanium-, and magnesium-cemented compositions have met with no success. As reported by Engel (Metal Progress 59, 664 (1951)), no bond is formed between

2

titanium carbide and aluminum, titanium, and magnesium.

One of the criteria for a satisfactory binder material for carbides, as explained by J. T. Norton (Powder Metallurgy Bulletin 6, 75 (1951)) is that the binder form a liquid phase at the sintering temperature which liquid phase "wets" the carbide phase. This "wetting" presupposes intimate contact between the surfaces of the carbide and of the binder. However, the oxide film which so readily forms on aluminum, titanium, and magnesium surfaces prevents the establishment of intimate contact between carbide and metal surfaces and precludes the formation of cemented structures by any of the above-described procedures. Similar problems encountered with other metals such as cobalt and nickel are overcome by sintering in a hydrogen atmosphere, thereby reducing the metal oxide film. However, this scheme is not practical with aluminum, titanium, or magnesium systems since the oxides of these metals are not reduced by hydrogen under convenient operating conditions, i.e., atmospheric pressure and temperatures up to ca. 1500° C.

I have now discovered a method for making cermets in which a carbide is cemented with aluminum, magnesium, titanium, or a mixture of said metals.

The cermets of this invention have various advantages. For example, considering first aluminum and magnesium as the cementing metals, they are considerably less expensive than the corresponding cermets cemented by cobalt and nickel which have commonly been used heretofore. Also because of the dense, adherent oxide layer which forms on aluminum and magnesium surfaces, these metals offer high resistance to destructive oxidation at elevated temperatures. This makes cermets using these metals, particularly the titanium carbide cermets, useful in the construction of components of temperature control instruments, bearings, seals, valve seats, and turbine buckets and blades for jet engines. The titanium carbide-aluminum cermets of this invention, because of the high electrical conductivity and oxidation resistance of the aluminum, are also useful as electrical contact materials under constant exposure to high current and voltage.

Oxidation resistance in air is a factor which must be considered in cutting tool applications which involve edge temperatures of 700-1000° C. Tungsten carbide-cobalt cermets which are widely used in cutting tools have satisfactory oxidation resistance only up to ca. 800° C. while the aluminum-cemented titanium carbide compositions of this invention withstand considerably higher operating temperatures. Similarly, the improved oxidation resistance makes the silicon carbide cermets of the invention particularly useful as heating elements.

The lesser density of a carbide-aluminum or -magnesium composition of porosity comparable to available carbide-cobalt or carbide-nickel cermets provides advantages for applications such as missile components where weight is critical. A boron carbide-aluminum cermet, for example, is useful as a light structural material.

Since, in addition to high oxidation and corrosion resistance, titanium has a higher melting point than cobalt or nickel, a carbide-titanium cermet is useful at higher temperatures than the corresponding cobalt or nickel compositions. A titanium carbide-titanium cermet, for example, is suitable for crucibles used at temperatures up to ca. 1800° C.

The aluminum-, magnesium-, and titanium-cemented carbide cermets of the invention are obtained by placing a finely-divided carbide and a quantity of aluminum, magnesium, or titanium metal at least sufficient to provide from 0.01 to 1 part by weight of the metal per part by weight of the carbide in a tubular container, surrounding the outer wall of the container with a layer of a

detonating explosive, initiating the explosive layer, and thereafter heating the compact thus formed to a temperature above the melting point of the metal.

For a more complete understanding of the method of preparing the novel cermets reference is made to the attached drawings illustrating various assemblies for subjecting the carbide and metal to the action of the detonating explosive wherein

FIGURE 1 represents a longitudinal cross-sectional view of an assembly for use in preparing cermets in solid cylindrical form;

FIGURE 2 represents a longitudinal cross-sectional view of an assembly for use in preparing cermets in tubular form; and

FIGURE 3 represents a longitudinal cross-sectional view of an assembly for use in preparing cermets in which the metal component is provided in non-particulate form.

In the drawings, like numbers indicate similar elements of the three assemblies.

In FIGURE 1, metal tube 1, filled with a mixture of the desired carbide and metal powders 2, is sealed with metal plugs 3. The outside wall of metal tube 1 is surrounded with a layer of a detonating explosive 4 and the assembly is immersed in water 5.

In FIGURE 2, metal tube 6 is positioned essentially concentrically within metal tube 1. The annulus between the adjacent walls of the two tubes is filled with a mixture of the desired carbide and metal powders 2 and the ends of the annulus are sealed with metal plugs 3. An air-filled metal tube 7 closed at both ends is fastened by taping essentially concentrically within metal tube 6 to absorb the energy of shock waves converging in the center of the assembly. The outside wall of metal tube 1 is surrounded with a layer of a detonating explosive 4 and the assembly, immersed in water 5 which flows into the annulus between metal tube 6 and metal tube 7.

In FIGURE 3, metal tube 6 is inserted through the bore of metal tube 8 which metal tube 8 comprises the metal to be incorporated into the novel cermet. Metal tube 9, also comprising the metal to be incorporated into the novel cermet, is inserted within the bore of metal tube 1 and the first set of tubes 6 and 8 is positioned essentially concentrically within the second set of tubes 9 and 1. The annulus between the adjacent walls of tubes 8 and 9 is filled with the desired carbide powder 10 and sealed with metal plugs 3. An air-filled metal tube 7 closed at both ends is fastened by taping essentially concentrically within metal tube 6 as in FIGURE 2. The outside wall of metal tube 1 is surrounded with a layer of a detonating explosive 4 and the assembly, immersed in water 5 which flows into the annulus between tubes 6 and 7.

The composition of tubes 1 and 6 is not critical since these tubes merely serve to contain the carbide and metal of the novel cermets during detonation; however, these tubes obviously must have sufficient strength to withstand the detonation pressure. In the assemblies of FIGURES 1 and 2 a lining of paper, or of another suitable material, interposed between the walls of the tubes and the carbide-metal mixture prevents infiltration of metal from the tubes into the mixture.

Although I do not intend to be limited by any theory of the mechanism by which the novel aluminum-, magnesium-, and titanium-cemented cermets are formed, I believe that a brief discussion of the probable mechanism of the preferred method of preparation will elucidate the value of various modifications and the reasons for the inefficacy of conventional procedures.

In each of the assemblies illustrated above in FIGURES 1 and 2, the surfaces of carbide powder particles are initially in contact with the surfaces of metal, i.e., aluminum, magnesium, or titanium, powder particles which surfaces are coated, as would be expected, with an oxide film. The pressure of the shock waves generated by the detonation of the layer of explosive surrounding the assembly constricts the metal tube(s) thereby mechani-

cally increasing the density of the powder mixture. At the same time, this pressure effectively reduces the particle size of the powders and mechanically ruptures the oxide film thus bringing the increased surface area of carbide powder into intimate contact with oxide-free metal within a few microseconds. Similarly, in the assembly illustrated in FIGURE 3, the surfaces of carbide powder particles are in contact with the oxide-coated, adjacent surfaces of the metal, i.e., aluminum, magnesium, or titanium, tubes 8 and 9. As described above the oxide film is ruptured by the pressure of the shock waves and the increased surface area of carbide powder is brought into intimate contact with oxide-free metal within microseconds.

In either case, the carbide-metal system is heated to a temperature at which the metal melts to form a liquid phase which "wets" the carbide particles and, under the influence of high surface forces, flows into the pores in the carbide skeleton.

The type of interaction between the carbide and metal phases is dependent upon the properties of the carbide and the metal, and upon the conditions under which the carbide-metal system is compacted and sintered. Simple mechanical interaction or formation of an interlocking structure between the carbide and the metal in which the metal penetrates and essentially fills the pore volume of the carbide skeleton is essential to the formation of the novel cermets. Among the additional phenomena which may be associated with the formation of the novel compositions are surface reaction between carbide and metal resulting in the formation of a new phase, i.e., an intermetallic compound or alloy, mutual solution and reprecipitation, etc.

Evacuation of the assembly prior to explosive treatment minimizes the porosity of the cemented compositions. The additional precaution of sintering the remaining tube assembly unopened precludes the possibility of the reformation of metal oxide as the metal infiltrates the carbide skeleton. However, the need for this precaution is more urgent when using the assembly illustrated in FIGURE 3 than when using the assemblies illustrated in FIGURES 1 and 2. In the latter cases, the metal is provided in finely divided form and the pressure of the shock waves which disrupts the oxide film establishes many more areas of intimate contact between carbide and oxide-free metal than can be achieved in the assembly of FIGURE 3 in which the metal is provided in the form of a sheath for a centrally disposed mandrel (metal tube 6) and in the form of a liner for metal tube 1. Furthermore, since the carbide and metal powders are thoroughly blended prior to compaction, during sintering a given quantity of metal has to flow only a relatively short distance before the carbide skeleton is completely penetrated by the metal binder which factor reduces the probability of the reformation of oxides.

As explained above, the effect of the shock waves is to disrupt the metal oxide film and bring the carbide into intimate contact with the oxide-free metal. The conventional infiltration process fails in this respect since no pressure is applied and the oxide film remains intact. Although cold pressing and hot pressing disrupt the oxide film, the pressure is applied over a relatively long time, e.g., longer than $\frac{1}{2}$ second, as compared with the pressure of the shock waves which is applied over a short time, e.g., up to 10 microseconds. Thus there is sufficient time during cold or hot pressing for the oxide to reform as compression proceeds with the result that no intimate contact between carbide and free metal is established.

The composition, means of initiation, loading, velocity of detonation, and confinement of the detonating explosive layer used in the preferred method of preparation of the novel cermets are not critical. It will be apparent to one skilled in the art that a sufficient quantity of explosive to effect the destruction of the oxide film without damaging the assembly should be used. A layer of a flexible explosive

composition is conveniently wrapped around the outer tubes of the preferred assemblies as illustrated in the attached drawings. The layer of detonating explosive may be initiated by means of a line-wave generator (as described in U.S. Patent No. 2,943,571 issued July 5, 1960) which in turn may be initiated by means of a conventional electric blasting cap.

The containing tubes, i.e., metal tubes 1 and 6 can be removed mechanically before or after sintering, or melted off. Sintering can be effected with any of the several conventional modifications with respect to temperature, rate of heating and cooling atmosphere, etc.

The carbide and metal components used can be provided in a number of forms. Generally powders of particle size less than 200 mesh are desirable; however, cermets have been successfully prepared using 20 mesh metal powder. If the diameter of the tubular container of FIGURE 3 is very small, a sufficient quantity of the metal component can be provided in the form of a liner for the container thus obviating the need for the metal-sheathed centrally disposed mandrel. The metal can also be in the form of wires or rods extending through a mass of the carbide powder.

Mixtures of aluminum, magnesium, or titanium, e.g., alloys, with one or both of the other metals, as well as in combination with other materials, can be used. Any of the conventional additives used in the preparation of cemented carbides, e.g., wetting agents, and any single carbide or any mixture or other combination of carbides can be incorporated into the cermets within the sense and scope of this invention.

Using the assemblies illustrated in FIGURES 1 and 2, the composition of the cermets is controlled by blending the carbide and metal in any desired proportion. The only upper limit on the amount of metal binder which can be incorporated into the novel cermets using the assembly illustrated in FIGURE 3 is the initial pore volume of the carbide skeleton. The relative amounts of metal and carbide used can be varied to obtain specific physical properties in the cermets. In general, the metal to carbide ratios used will be in the range of about 0.01–1 part by weight metal to 1 part by weight carbide; for cutting tool applications the preferred range is about 0.01–0.2 part by weight metal to 1 part by weight carbide. The cermets produced as described have porosity comparable to commercially available cemented carbides, and have the metallic luster, and thermal and electrical conductivity characteristic of these compositions.

The following examples illustrate some of the aluminum-, magnesium-, and titanium-cemented carbide cermets of the present invention and methods for their preparation. They are intended as illustrative only, however, and are not to be considered as exhaustive or limiting. In the examples, parts are by weight.

The explosives employed in these examples were in the form of extruded flexible sheets of compositions designated as compositions A and B.

Composition A contains 20% very fine pentaerythritol tetranitrate (PETN), 70% red lead, and, as a binder, 10% of a 50/50 mixture of butyl rubber and a thermoplastic terpene resin [mixture of polymers of β -pinene of formula $(C_{10}H_{16})_n$], commercially available as "Piccolyte" S-10 (manufactured by the Pennsylvania Industrial Chemical Corporation). This composition is readily extruded into sheet and detonates at a velocity of about 4100 meters per second. Complete details of the composition and a suitable method for its manufacture are described in co-pending application Serial No. 65,012 filed October 26, 1960 in the name of Cyril J. Breza and having a common assignee with the present application.

Composition B is a modification of composition A containing 8%, rather than 10%, of the butyl rubber-thermoplastic terpene resin binder, and 2% polybutene

(Polybutene No. 24 manufactured by Oronite Chemical Company).

Example 1

A cermet containing titanium carbide and aluminum combined in such a manner that voids in the carbide skeleton were filled with an aluminum-titanium alloy of variable composition was prepared as follows:

A solid cylindrical aluminum plug having diameter of $1\frac{3}{4}$ inches and a length of $1\frac{1}{4}$ inches was inserted 1 inch into the end of a seamless aluminum tube having an outside diameter of 2 inches, a wall thickness of $\frac{1}{8}$ inch and a length of 7 inches and welded in place thus sealing one end of the tube. The bore of the tube was lined with paper and vibrator-packed to within 1 inch of the open end of the tube with a mixture of 88 parts of less than 325 mesh titanium carbide powder and 12 parts of less than 325 mesh aluminum powder prepared by mixing the constituent powders in a twin-cone blender for one hour. The titanium carbide-aluminum powder mixture thus packed had a bulk density of about 2.15 grams per cubic centimeter. A second aluminum plug $1\frac{1}{4}$ inches in length was inserted 1 inch into the open end of the tube assembly and welded in place to form an assembly substantially as illustrated in FIGURE 1 of the attached drawings.

A rectangular sheet of the above-described explosive composition B having a weight distribution of 16 grams per square inch was glued around the outside wall of the aluminum tube, encircling the tube for its entire length. A triangular line-wave generator (as described in U.S. Patent No. 2,943,571 issued July 5, 1960) was glued to the edge of the sheet explosive which conformed to the upper periphery of the aluminum tube. A No. 8 electric blasting cap was fastened to the apex of the line-wave generator and the assembly was immersed in water. The blasting cap was actuated by application of an electric current thus initiating the line-wave generator which, in turn, initiated the sheet of explosive. After the detonation, the end-plugs were cut off and the remaining assembly was heated for 2 hours at 800° C. in a carbon dioxide atmosphere. The heat treatment melted and thus removed the constricted aluminum tubes. X-ray diffraction of a sample of the cemented carbide gave the following pattern of lattice spacings, d , A , and relative intensities, I/I_1 :

d, A -----	2.78	2.69	2.51	2.40	2.31	2.17	1.93	-----
I/I_1 -----	<5	<5	>5	<5	10	100	<5	-----
d, A -----	1.53	1.31	1.25	1.08	.994	.968	.883	.833
I/I_1 -----	45	25	10	5	5	15	15	10

The observed lattice spacing and relative intensities correspond to those for titanium carbide and aluminum-titanium alloys AlTi and Al_3Ti in the A.S.T.M. card file, establishing that a reaction had taken place between the penetrating aluminum and the titanium carbide skeleton with formation of a true metallurgical bond.

The cemented carbide thus produced had a density of 4.20 grams per cubic centimeter, or approximately 90% of the theoretical density, a transverse rupture strength of 27,850 pounds per square inch, and diamond pyramid hardness number under a 1000-gram load of 1030. The oxidation resistance of the novel composition was very good; e.g., a sample cut from the cermet gained less than 3.1 milli-grams per square centimeter of surface area per hour at 1100° C. in air.

Example 2

A composition comprising titanium carbide and aluminum combined as in Example 1 was prepared by mixing 95 parts of less than 325 mesh titanium carbide powder and 5 parts of less than 325 mesh aluminum powder. The assembly was arranged and detonation and sintering carried out as in Example 1. Prior to detonation the bulk density of the titanium carbide-aluminum

powder mixture as packed in the aluminum tube was 2.77 grams per cubic centimeter. The explosive employed in this example was a sheet of explosive composition B having a weight distribution of 14 grams per square inch.

The titanium carbide and aluminum were metallurgically bonded as indicated by the following lattice spacings, d , A , and relative intensities, I/I_1 , which correspond to those for titanium carbide, aluminum, and aluminum-titanium alloys AlTi and Al₃Ti in the A.S.T.M. card file.

d , A	2.58	2.50	2.40	2.30	2.17	1.53	-----
I/I_1	<5	90	<5	5	100	45	-----
d , A	1.31	1.25	1.08	.993	.968	.884	.833
I/I_1	25	10	15	10	15	15	10

Example 3

A composition comprising titanium carbide and aluminum combined as in Example 1 was prepared according to the following procedure:

A seamless aluminum tube having an outside diameter of 1 inch, a wall thickness of $\frac{1}{4}$ inch, and a length of 8 inches was positioned concentrically within a second seamless aluminum tube having an outside diameter of 2 inches, a wall thickness of $\frac{1}{8}$ inch, and a length of 7 inches. An aluminum plug $\frac{1}{4}$ inches in length was inserted 1 inch into one end of the annulus between the adjacent walls of the two tubes and welded in place thus sealing one end of the annulus. The adjacent walls of the aluminum tubes were lined with paper and the annulus between the walls, vibrator-packed to within 1 inch of the open end of the annulus with a mixture of 88 parts of less than 325 mesh titanium carbide powder and 12 parts of less than 325 mesh aluminum powder prepared as in Example 1. The titanium carbide-aluminum powder mixture thus packed had a bulk density of about 2.1 grams per cubic centimeter. A second aluminum plug $\frac{1}{4}$ inches in length was inserted 1 inch into the open end of the annulus and welded in place. An air-filled copper tube sealed at both ends having an outside diameter of $\frac{1}{4}$ inch, a wall thickness of $\frac{1}{32}$ inch, and a length of about $7\frac{3}{4}$ inches was positioned concentrically within the inner aluminum tube in such a manner that a portion of the copper tube about $\frac{1}{8}$ inch in length extended beyond each end of the compaction assembly and taped in place to form an assembly substantially as illustrated in FIGURE 2 of the attached drawings.

A sheet of explosive composition B having a weight distribution of 22 grams per square inch was glued to the outside wall of the outer aluminum tube. A line-wave generator and a No. 8 electric blasting cap were attached as in Example 1 and the assembly was immersed in water which flowed into the annulus between the outside wall of the copper tube and the inside wall of the inner aluminum tube. The explosive was initiated, and after the detonation the end plugs were cut off and the copper tube was removed. The remaining assembly was subjected to heat treatment as in Example 1 during which process the constricted aluminum tubes were melted off.

Metallographic examination of the compact produced revealed that the titanium carbide skeleton was completely penetrated by aluminum. Photomicrographs of polished and etched sections of the new material showed that the aluminum binder had formed a mechanically interlocking structure around each titanium carbide particle and that small carbide precipitates had formed in the aluminum veins. X-ray diffraction of a sample of the cemented carbide gave the following pattern of lattice spacings, d , A , and relative intensities, I/I_1 :

d , A	2.50	2.34	2.29	2.16	2.02
I/I_1	80	10	5	100	5
d , A	1.92	1.53	1.43	1.30	1.25
I/I_1	1	40	1	20	10

The observed lattice spacings and relative intensities correspond to those for titanium carbide, aluminum-titanium alloy Al₃Ti, and free aluminum in the A.S.T.M. card file, establishing that a reaction had taken place between the penetrating aluminum and the titanium carbide skeleton with formation of a true metallurgical bond.

The density of the cemented carbide thus produced was 4.23 grams per cubic centimeter, or approximately 91% of the theoretical density, and the transverse rupture strength, 33,250 pounds per square inch. The hardness of the composition, as indicated by a diamond pyramid hardness number of 1050 under a 1000-gram load, was in the range of that of commercial cutting tools, and a drill bit ground from the new material was effectively used to cut steel, brass, and aluminum. The oxidation resistance of the titanium carbide-aluminum composition at high temperatures was very good; e.g., a specimen gained less than 8 milligrams per square centimeter of surface area after 12 hours in air at 1025° C.

Example 4

A composition comprising titanium carbide and aluminum combined as in Example 1 was prepared by mixing 51.1 parts of less than 325 mesh titanium carbide powder and 48.9 parts of less than 325 mesh aluminum powder. The assembly was arranged and detonation and sintering carried out as in Example 3. X-ray diffraction of a sample of the cemented carbide product gave the following pattern of lattice spacings, d , A , and relative intensities, I/I_1 :

d , A	2.50	2.34	2.31	2.17
I/I_1	50	55	10	100
d , A	2.08	2.03	1.53	1.44
I/I_1	5	35	35	20

The observed lattice spacings and relative intensities correspond to those for titanium carbide, aluminum-titanium alloy Al₃Ti, and free aluminum, establishing that a reaction had taken place between the penetrating aluminum and the titanium carbide skeleton with formation of a true metallurgical bond.

The cermet was of a quality comparable to that of the cemented carbide of Example 1 and had, for example, a transverse-rupture strength of 55,700 pounds per square inch.

Example 5

A composition comprising titanium carbide and aluminum combined as in Example 1 was prepared by mixing 88 parts of less than 325 mesh titanium carbide and 12 parts of approximately 20 mesh aluminum. The assembly was arranged and detonation and sintering carried out as in Example 3. Prior to detonation the titanium carbide-aluminum powder mixture, as packed between the adjacent walls of the aluminum tubes, had a bulk density of 2.02 grams per cubic centimeter. The explosive employed in this example was an extruded sheet of the above-described explosive composition A having a weight distribution of 14 grams per square inch.

Metallographic examination of this composition revealed a relatively porous microstructure as compared to that of the cermets made with less than 325 mesh aluminum as described in the previous examples. The density of the cermet was 3.75 grams per cubic centimeter; the diamond pyramid hardness number was 765, and the transverse rupture strength, 20,600 pounds per square inch. The following observed pattern of lattice spacings, d , A , and relative intensities, I/I_1 , indicate that the aluminum reacted with the titanium carbide skeleton to form a metallurgically bonded cemented structure:

d , A	3.39	2.50	2.34	2.30	2.16	2.01
I/I_1	<5	85	10	5	100	<5
d , A	1.53	1.43	1.30	1.25	1.22	-----
I/I_1	40	<5	20	10	<5	-----

Example 6

A composition comprising titanium carbide and aluminum combined as in Example 1 was prepared as follows:

A seamless mild steel tube having an outside diameter of $1\frac{1}{2}$ inches, a wall thickness of $\frac{1}{4}$ inch, and a length of 7 inches was inserted through the bore of a seamless aluminum tube having an outside diameter of $1\frac{5}{8}$ inches, a wall thickness of $\frac{1}{32}$ inch, and a length of 5 inches in such a manner that a portion of the mild steel tube 1 inch in length extended beyond each end of the aluminum tube. A second seamless aluminum tube having an outside diameter of 2.95 inches, a wall thickness of $\frac{1}{4}$ inch, and a length of 5 inches was inserted within the bore of a second seamless mild steel tube having an inside diameter of 3 inches, a wall thickness of $\frac{1}{8}$ inch, and a length of 7 inches in such a manner that a portion of the mild steel tube 1 inch in length extended beyond each end of the aluminum tube. The first set of tubes was positioned concentrically within the second set of tubes and a steel plug $1\frac{1}{4}$ inches in length, inserted 1 inch into one end of the annulus between the adjacent walls of the aluminum tubes sealing one end of the annulus. The annulus between the adjacent walls of the aluminum tubes was vibrator-packed to within 1 inch of the open end of the tube assembly with less than 325 mesh titanium carbide powder. The powder thus packed had a bulk density of approximately 2.3 grams per cubic centimeter. A second steel plug $1\frac{1}{4}$ inches in length was inserted 1 inch into the open end of the tube assembly and welded in place.

The compaction assembly was evacuated to 2.5×10^{-4} mm. of mercury by conventional means through a piece of copper tubing inserted into a hole drilled in one plug. An air-filled copper tube sealed at both ends having an outside diameter of $\frac{1}{2}$ inch, a wall thickness of $\frac{1}{32}$ inch, and a length of about $7\frac{3}{4}$ inches was positioned concentrically within the inner mild steel tube and taped in place as in Example 3.

The explosive employed in this example was an extruded sheet of explosive composition A having a weight distribution of 22 grams per square inch. The sheet of explosive was glued around the outside wall of the outer mild steel tube and a line-wave generator and a No. 8 electric blasting cap were attached as in Example 1. The assembly was immersed in water which flowed into the annulus between the adjacent walls of the copper tube and the inner mild steel tube, and the explosive, initiated as in Example 1.

After the detonation the copper tube was removed. The remaining assembly was heated unopened for two hours at 800° C. in a muffle furnace and furnace cooled. The end plugs were cut off and the inner mild steel tube, slit and mechanically removed. It was found that the titanium carbide compact had been penetrated by aluminum from the aluminum tubes. The remnants of the aluminum tubes were melted off by heating the assembly at 800° C. in a carbon dioxide atmosphere and the outer mild steel tube was mechanically removed.

Metallographic examination and photomicrographs of the cermet thus produced revealed a microstructure similar to that of the cemented carbide described in Example 1. X-ray diffraction of a sample of the cemented carbide gave the following pattern of lattice spacings, d , A and relative intensities, I/I_1 :

d, A	2.51	2.31	2.18	1.93	1.68	1.53	1.43
I/I_1	85	20	100	10	5	45	5
d, A	1.81	1.25	1.17	1.08	.996	.969	-----
I/I_1	25	20	6	10	10	15	-----

The observed lattice spacings and relative intensities correspond to those for titanium carbide and aluminum-titanium alloys $AlTi$ and Al_3Ti in the A.S.T.M. card file giving proof a reaction had taken place between the pen-

trating aluminum and the titanium carbide skeleton with formation of a true metallurgical bond.

The density of the cemented carbide thus produced was 4.44 grams per cubic centimeter, or approximately 95.3% of the theoretical density, and the transverse rupture strength, 52,600 pounds per square inch. The hardness of the composition, as indicated by a diamond pyramid hardness number of 1160 under a 1000-gram load, was in the range of commercial cutting tools, and a bit ground from the new material was effectively used to cut steel, brass, and aluminum. The oxidation resistance at high temperatures of the composition was very good; e.g., a specimen gained less than 7 milligrams per square centimeter of surface area after 12 hours at 1025° C.

It should be noted at this point that alloys of the approximate composition $AlTi$ have melting points above 1200° C., good oxidation resistance, and a higher hardness than other titanium alloys. The novel titanium carbide-aluminum cermets exhibited high strength at elevated temperatures and superior thermal shock resistance which enabled them to withstand repeated cycles of heating to 900° C. and quenching without cracking. The cermets generally had a transverse-rupture strength of above 45,000 pounds per square inch under which stress a uniform, metallic fracture, rather than a chalky crumbling, developed.

Reduced, uniform crystallite size contributed to the hardness of the novel cermets which is in the range of that of commercial cutting tools, e.g., diamond pyramid hardness number 850-1700. The cemented carbides could be cut slowly on a silicon carbide cutoff wheel, preferably prior to sintering, and the ground material, used to cut steel, brass, and aluminum as shown above.

A comparison with data in the literature showed that the titanium carbide-aluminum cermets had only one-half the oxidation rate of the corresponding nickel and cobalt compositions under similar conditions.

Example 7

A composition comprising tungsten carbide and aluminum was prepared by mixing 95 parts of less than 325 mesh tungsten carbide powder and 5 parts of less than 325 mesh aluminum powder prepared by blending the constituent powders in a twin-cone blender for one hour. The assembly described in Example 3 was used. The bulk density of the powder mixture as packed between the adjacent walls of the aluminum tubes prior to detonation was approximately 3.0 grams per cubic centimeter.

The explosive used in this example was an extruded sheet of above-described explosive composition B having a weight distribution of 14 grams per square inch, initiated as in Example 1.

After detonation the aluminum tubes were mechanically stripped, and the copper tube was removed. A piece cut from the powder compact was heated for one hour at 800° C. in a vacuum furnace.

The density of the heat-treated tungsten carbide-aluminum cermet was 7.61 grams per cubic centimeter, or approximately 51% of the theoretical density, and the diamond pyramid hardness number was 517. Metallographic examination and microphotographs of polished and etched samples of this composition showed a cemented structure similar to that of the compositions described in the previous examples. However, X-ray diffraction indicated that no substantial reaction had taken place between the components.

Example 8

A composition comprising silicon carbide and aluminum was prepared from a mixture of 80 parts of less than 325 mesh silicon carbide powder and 20 parts of less than 325 mesh aluminum powder prepared as in Example 1. The assembly, explosive, and compaction technique described in Example 3 were used. The bulk density of the powder mixture as packed between the ad-

jacent walls of the aluminum tubes prior to detonation was approximately 1.38 grams per cubic centimeter.

After detonation, the end-plugs were cut off, and the copper tube was removed. The remaining assembly was heated for one hour at 800° C. in a carbon dioxide atmosphere. During heating the aluminum tubes were melted and thus removed.

Metallographic examination of the novel composition revealed a cemented structure and the cermet was easily polished to a dark, metallic luster. The density of the cermet was 3.07 grams per cubic centimeter, or approximately 98.7% of the theoretical density, and X-ray diffraction revealed the presence of α -SiC(III), α -SiC(VI), and aluminum. There was no indication of significant reaction between the components.

Example 9

A composition comprising boron carbide and aluminum was prepared from a mixture 80 parts of less than 20 μ particle size boron carbide powder and 20 parts of less than 325 mesh aluminum powder using the assembly and technique of Example 8. The bulk density of the powder mixture prior to detonation was approximately .85 gram per cubic centimeter.

The cermet thus produced had a density of 2.42 grams per cubic centimeter, or approximately 95.3% of the theoretical density, and a microstructure similar to that of the novel compositions of the previous examples. X-ray diffraction gave the following observed pattern of lattice spacings, d , A , and relative intensities, I/I_1 , the majority of which correspond to those for boron carbide and aluminum in the A.S.T.M. card file:

d , A	4.48	4.00	3.76	3.34	2.92	2.80	2.68	2.56	2.36	2.34	2.09	2.03
I/I_1	5	10	30	5	25	10	20	45	100	25	10	20
d , A	1.94	1.84	1.81	1.75	1.71	1.62	1.55	1.50	1.46	1.44	1.40	1.34
I/I_1	5	10	<5	45	5	<5	<5	10	10	10	10	5
d , A	1.32	1.31	1.30	1.28								
I/I_1	5	5	5	<5								

There were a number of unidentified lines which indicate some limited reaction between the components. However, there was no significant change in volume such as often accompanies the reaction of boron carbide and other metals to form borides. Such a change in volume would lead to a weak, chalky composite structure.

Example 10

A composition comprising titanium carbide and magnesium was prepared from a mixture of 95 parts of less than 325 mesh titanium carbide powder and 5 parts of less than 325 mesh magnesium powder using the assembly, explosive, and compaction technique of Example 8. The bulk density of the powder mixture as packed prior to detonation was 2.43 grams per cubic centimeter. After detonation the copper tube was removed, and the aluminum tubes were mechanically stripped. The compact was then heated for 2 minutes at 700° C. in air.

The density of the cemented carbide was 3.94 grams per cubic centimeter or approximately 82.6% of the theoretical density and the diamond pyramid hardness number was 970. The microstructure of the cermet was similar to that of the cermets described in the previous examples and the following observed pattern of lattice spacings, d , A , and relative intensities, I/I_1 , indicate formation of a new phase, i.e., magnesium carbide, between the components:

d , A	3.22	2.60	2.50	2.45	2.16	1.53	1.30	1.25	1.08	.993	.968	.884
I/I_1	<5	<5	80	5	100	50	25	15	10	10	15	25
d , A	.883											
I/I_1	10											

Example 11

A composition comprising titanium carbide and titanium was prepared from a mixture of 45.4 parts of less than 325 mesh titanium carbide powder and 54.6 parts of less than 325 mesh titanium powder using the assembly, explosive, and compaction technique described in Example 8. The bulk density of the powder mixture as packed prior to detonation was approximately 1.56 grams per cubic centimeter.

After detonation the copper and aluminum tubes were mechanically removed from the compact. The compact was then heated for 10 seconds at 1100° C. in air by means of an acetylene torch.

This cermet had a density of 4.4 grams per cubic centimeter, or approximately 93.5% of the theoretical density, hardness on the Rockwell A scale of 79, and a transverse rupture strength of 21,050 pounds per square inch. X-ray diffraction revealed no new phase formation; however, the titanium lines shifted toward higher lattice spacing values than for the pure metal indicating mutual solubility of the components and the formation of a solid solution. The following is the observed pattern of lattice spacings, d , A , and relative intensities, I/I_1 :

d , A	2.57	2.50	2.36	2.26	2.17	1.74
I/I_1	10	55	45	50	100	15

Metallographic examination of the cermet revealed that the carbide grains were completely surrounded by the metallic matrix.

The invention has been described in detail in the foregoing. However, it will be apparent to those skilled in the art that many variations are possible without departure from the scope of the invention. I intend therefore to be limited only by the following claims.

I claim:

1. A cermet consisting essentially of a finely-divided ceramic component selected from the group consisting of boron carbide, silicon carbide and mixtures thereof cemented by metallurgical bonding by elemental aluminum.

2. A cermet of claim 1 containing from 0.01 to 1 part by weight of elemental aluminum for each part by weight of ceramic component.

3. A cermet consisting essentially of a finely-divided ceramic component selected from the group consisting of boron carbide, silicon carbide and mixtures thereof cemented by metallurgical bonding by elemental aluminum, the aluminum coating the particles of said finely-divided ceramic component and filling the spaces between said particles.

4. A cermet of claim 3 containing from 0.01 to 1 part by weight of elemental aluminum for each part by weight of ceramic component.

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