

April 3, 1973

E. RUDY

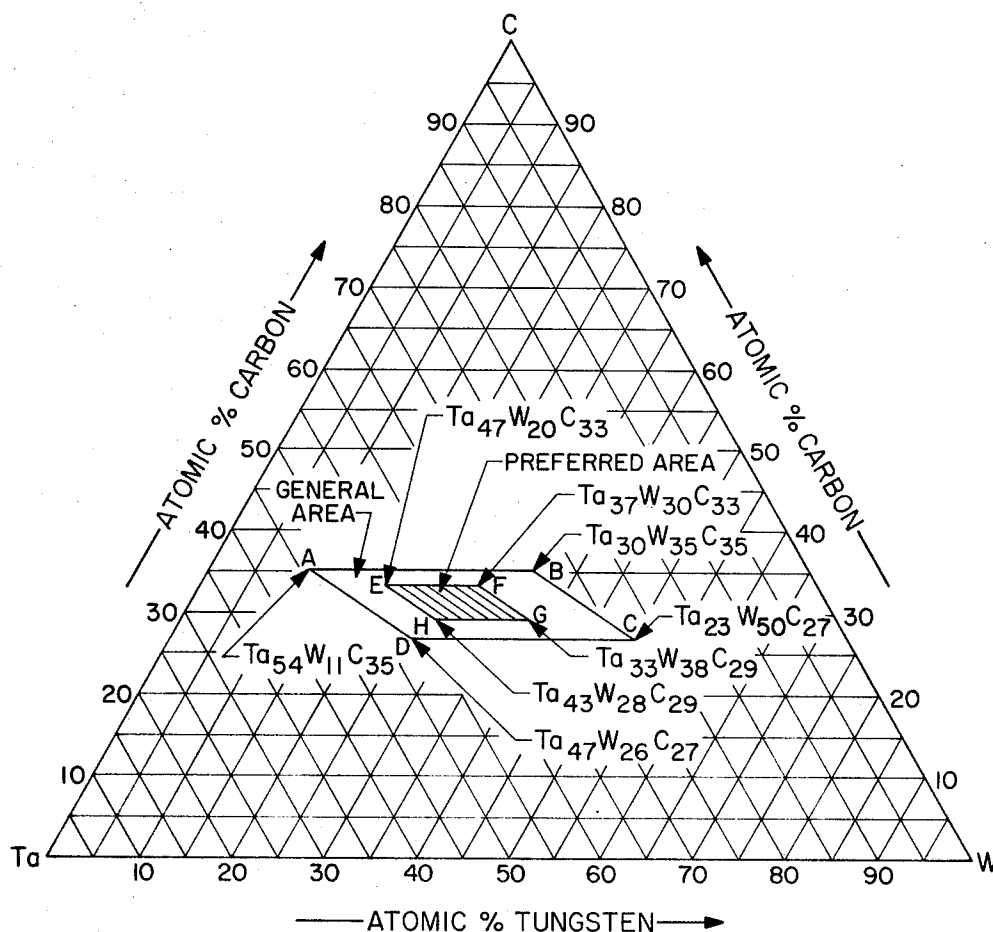
3,725,055

CARBIDE-METAL COMPOSITES

Filed July 29, 1970

2 Sheets-Sheet 1

FIG. 1



ERWIN RUDY INVENTOR,

BY *Edward O. Ansell*

ATTORNEYS

April 3, 1973

E. RUDY

3,725,055

CARBIDE-METAL COMPOSITES

Filed July 29, 1970

2 Sheets-Sheet 2



Fig. 2.

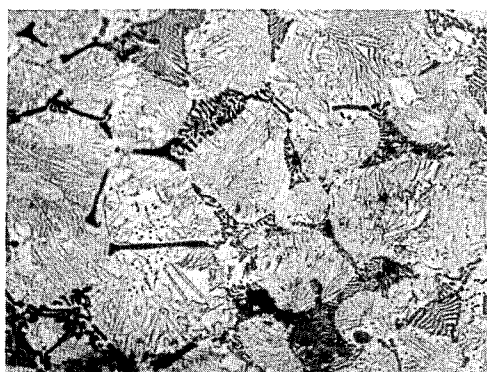


Fig. 3.



Fig. 4.

INVENTOR
ERWIN RUDY
BY *Edward O. Ansell*
ATTORNEY

1

3,725,055

CARBIDE-METAL COMPOSITES

Erwin Rudy, Beaverton, Oreg., assignor to Aerojet-

General Corporation, El Monte, Calif.

Filed July 29, 1970, Ser. No. 59,064

Int. Cl. C22c 29/00

U.S. Cl. 75-134 F

23 Claims

ABSTRACT OF THE DISCLOSURE

This patent describes a refractory metal-bonded carbide alloy for use in cutting tools and in other applications where high hardness and abrasion resistance are required. The desired fine-grained composite structure is obtained by the disproportionation of a precursor $(Ta,W)_2C$ -based subcarbide phase into a monocarbide and a metal alloy phase. The precursor subcarbide phase originates from ternary or higher order alloys of refractory transition metals and carbon. Consolidation of the composites can be accomplished by melting and casting or powder metallurgy techniques.

DISCUSSION OF THE PRIOR ART

Conventional sintered carbide tooling materials consist of a mechanically-pulverized, hard carbide phase dispersed in a matrix (binder) of an iron group metal, usually cobalt or nickel. The binder phase contributes toughness to the composite and also serves as an aid in sintering. The loss of strength of iron group metal-based binder phases at relatively low temperatures can cause thermal wear to become the dominant wear mechanism at high cutting speeds and on worn tools, and the low melting temperatures of these binder phases also precludes their use as abrasion-resistant materials at temperatures above about 800° to 1000° C.

DESCRIPTION OF THE INVENTION

The carbide-metal composites of the invention have mechanical shock resistance characteristics favorably comparable to the conventional cobalt-bonded carbide tools but contain a significantly higher melting metal phase. The good shock resistance is obtained by the formation of a fine-grained, lamellar microstructure having hard monocarbide phase and a refractory metal phase.

The carbide-metal composites of the invention comprise base alloy combinations of tantalum, tungsten and carbon and have a fine-grained, lamellar microstructure which is derived from a pseudobinary eutectoid disproportionation of a precursor subcarbide phase. The lamellar structure consists of a monocarbide and a metal phase with the metal phase being rich in tungsten and contributing toughness to the composite. The monocarbide phase of the composite is rich in tantalum. The carbide composite of the invention, in one of its embodiments, has grains of primary carbide dispersed throughout the lamellar eutectoid structure. It is thought that the interspersed primary carbide grains improve the cutting action of the carbide composite when employed as a machine tool.

The carbide composite cutting tool of this invention has a complex composition of refractory metals and carbon with the base composition being tantalum-tungsten-carbon, optionally, alloyed with certain beneficial materials, for example, niobium, vanadium, titanium, zirconium hafnium and chromium singly or in combination. Molybdenum may be substituted in part for the tungsten in the base composition. The carbide composite, in addition to its lamellar microstructure, may, in certain compositions, contain small quantities (5 to about 25 vol. percent) of a primary monocarbide phase, metal phase and/or some subcarbide phase; the former two phases are

2

formed along with the precursor subcarbide phase which yields, by disproportionation, the desired lamellar microstructure. Quantities of either tantalum-or tungsten-rich subcarbide may be present as a result of the bivariant disproportionation in alloys with off-eutectoid compositions.

Other advantages of the invention will be apparent from the following detailed description and drawings in which:

FIG. 1 is a composition ternary showing desired compositional areas for the Ta-W-C base alloys of the invention;

FIG. 2 is a photomicrograph of a typical tantalum-tungsten-carbon alloy $[Ta(37)-W(30)-C(33)$ atomic percent] taken at a magnification of 2500 $\times$ and falling within the preferred area E, F, G, H of the composition diagram of FIG. 1, wherein the subcarbide is essentially completely disproportionated;

FIG. 3 is a photomicrograph at a magnification of 1000 of a second tantalum-tungsten-carbon alloy of somewhat different composition $[Ta(38)-W(34)-C(28)$ atomic percent] falling within area A, B, C, D but below the area E, F, G, H of the composition of FIG. 1, wherein there is a metal alloy/carbide eutectic dispersed throughout the lamellar microstructure; and

FIG. 4 is a photomicrograph at a magnification of 1800 times of a third tantalum-tungsten-carbon alloy of a somewhat different composition $[Ta(38)-W(27)-C(35)$ atomic percent] falling within the area A, B, C, D but above the area E, F, G, H of the composition diagram of FIG. 1, wherein there are primary monocarbide grains dispersed throughout the lamellar eutectoid microstructure.

The carbide in the photomicrographs, FIGS. 2, 3 and 4, is light and the metal alloy dark.

The base alloy compositions which provide the desired microstructure are designated in the ternary composition diagram of FIG. 1. The preferred carbide alloys of the invention have base alloy compositions falling within the smaller blocked area E, F, G, H of FIG. 1. The carbide compositions formed in alloys of area E, F, G, H are characterized by essentially complete disproportionation of the forerunner subcarbide phase that exists above the eutectoid decomposition temperature. The preferred carbide alloy compositions, tungsten, tantalum and carbon in the atomic percentages of area E, F, G, H of FIG. 1 are prepared by melting and rapidly cooling the alloys. The primary product of crystallization is a substantially homogeneous, solid metal subcarbide phase, which upon further cooling disproportionates into the desired lamellar microstructure comprising the aforementioned metal and monocarbide phase. The monocarbide phase derived from the disproportionation typically has 45% to 55% tantalum, 2% to 10% tungsten and about 45% carbon. The refractory metal phase of the lamellar microstructure contains 80% to 98% tungsten, 2% to 20% tantalum and about 0.5% carbon; with percentages given in atomic percent.

The larger blocked area A, B, C, D, more specifically the annulus area lying between the outer box A, B, C, D and the inner box E, F, G, H, includes compositions having a predominantly lamellar microstructure, but may contain some primary monocarbide on the carbon-rich side (top), primary metal alloys on the metal-rich side (bottom), and subcarbides to the right and left sides. It has been mentioned that carbide composites having compositions within the inner boxed area E, F, G, H will have an essentially 100% lamellar structure. A carbide composite produced from a melt having an atomic percentage composition outside the inner area E, F, G, H and immediately thereabove, but within the larger area A, B, C, D, will possess a different microstructure. The initial freezing results in the formation of primary monocarbide dispersed throughout a metal subcarbide matrix. Upon further cool-

ing, the subcarbide phase (but not the primary monocarbide) disproportionates to form the desired lamellar microstructure consisting of refractory metal and monocarbide phases. The primary monocarbide resulting from the initial solidification of the melt is unaffected by the disproportionation and is interspersed throughout the lamellar microstructure. If the selected compositions fall beneath the inner area E, F, G, H, but within the larger area A, B, C, D, the final microstructure will contain the familiar lamellar aggregates dispersed in a metal and carbide eutectic microstructure. If the atomic percentages of the compositions are located either to the right or left sides of the inner area E, F, G, H and within the larger area A, B, C, D, the first product of solidification of the melt will be the familiar solid metal subcarbide phase. As the decomposition temperature of the subcarbide is reached upon further cooling, the typical lamellar structure is formed, which, however, for these compositions, does not consist solely of metal and monocarbide phase, but also contains subcarbide; i.e., at compositions not coinciding with, or located in the immediate vicinity of, the eutectoid composition, the decomposition is temperature-concentration dependent (bivariant) and does not result in complete consumption of the subcarbide by disproportionation.

The carbide-metal composite of the invention is preferably prepared by melting and casting to obtain the fine-grained, lamellar microstructure. A typical fine-grained, completely disproportionated, lamellar microstructure without any primary constituent is illustrated in FIG. 2. In the photomicrograph, the metal phase is dark and the carbide phase appears light. The carbide composite shown in the photomicrograph of FIG. 2 was a composition of tantalum, tungsten and carbon falling within the inner area E, F, G, H of the composition diagram of FIG. 1. The photomicrograph of FIG. 3 is typical of carbide composites of the invention falling below the inner area E, F, G, H, but within the outer area A, B, C, D, of the ternary composition diagram of FIG. 1. The photomicrograph of FIG. 4 is typical of metal-carbide composites of the invention falling above the inner area E, F, G, H, but within the outer area of the composition of FIG. 1. This photomicrograph, FIG. 4, shows primary monocarbide interspersed throughout the disproportionated fine-grained lamellar eutectoid of monocarbide and metal alloy phases; again the carbide is light and the metal alloy appears dark.

The carbide-metal composite of the invention can also be prepared from powdered material by hot pressing, or by cold pressing and sintering, preferably with the addition of sintering aids. The starting powders may be carbides and metals, which are mixed in the desired quantities, but preferably consist of pre-alloyed material prepared by comminution of melted and rapidly-cooled alloys of the desired composition.

It is important to whatever manner of fabrication employed that the alloys of the invention be cooled rapidly enough during fabrication, typically at least 20° C. per second, to obtain the desired small grain size. Cooling at too slow a rate gives a coarse grain product, while, dependent on the metal alloy composition, too rapid cooling may suppress the disproportionation.

The ternary alloys of the invention may be modified and improved by alloying with certain other metals. Thus, the tungsten may be partially replaced by molybdenum (for instance, up to one-half of the atomic percentage of the tungsten, e.g., 20 atomic percent of the base alloy) without objectionably impairing performance as a machine tool. Smaller quantities of chromium, up to 5 atomic percent, also may be substituted for tungsten. Niobium, vanadium, titanium, zirconium and hafnium may be substituted for tantalum, either singly, or in combination, in quantities up to approximately 20 atomic percent of the base alloy. The base alloy composition of the invention, including the foregoing beneficial alloying metals, will

typically comprise at least 90 atomic percent of the carbide-metal composite of the invention. Other elements which are essentially inert in respect to cutting performance may be added to the base compositions in quantities which do not affect the basic disproportionation reactions necessary to form the lamellar microstructure. The total concentration of these inert elements may be as much as 10 atomic percent of the carbide-metal composite; however, in general, the amount of such inert ingredients is held to less than 3 atomic percent.

The carbide-metal alloy composite of the invention typically has melting temperatures around 3000° C. These melting temperatures are considerable improvements over the 1400° C. melting temperatures of conventional cobalt cutting tools.

EXAMPLES

In the preparation of the carbide-metal composite of the invention, the starting materials, which may consist, for example, of TaC, W₂C, W, Ti, Nb, V and C in powder form, are mixed to provide the desired composition and charged into the crucible of an electric arc furnace. Under helium and reduced pressure, the powders are then arc melted, and cooled rapidly below the disproportionation temperature producing the lamellar structure. Typically, disproportionation occurs in the range of 2700° C. to about 1800° C. The cast alloys are then machine ground to the desired configuration of the cutting tool and utilized in tests to establish the rate of metal removal in a conventional machining operation. The test material cut by the carbide alloys of the invention was type 347 stainless steel in the form of 3 inch diameter and 18 inch long cylindrical bars. The surface was removed to a depth of 0.050 inch prior to testing the experimental alloys. In the standard test, the steel bar was cut at 400 surface feet per minute (s.f.m.), using a depth of cut of 50 mils (.050 inch) and a feed rate of 10 mils per revolution. The tool geometry for the standard test was as follows: back rake, 0°, side rake, 5°, side relief, 5°, end relief, 5°, side clearance end angle, 25°.

Cutting tools formed from the carbide metal composite of the invention, prepared in the foregoing manner by furnace casting and shaping into a specified tool configuration, were compared with commercial, top grade, C-2 and C-50 type commercial cutting tools. The results of the tests are reported in Table I, along with the specific compositions of the various carbide alloys of the invention tested. The machining tests on the respective test and comparison tools were carried out until a wear depth .016 inch was reached, except as otherwise noted in Table I.

TABLE I.—CUTTING TOOL COMPOSITIONS AND CUTTING TEST RESULTS

Composition (atomic percent)										Tool life	
Ti	Zr	Hf	V	Nb	Ta	Cr	Mo	W	C	Min.	Wear, inches ¹
12	-----	4	-----	28	-----	21	35	-----	-----	42	.012
6	-----	2	-----	34	-----	27	29	-----	-----	36	-----
18	-----	5	-----	23	-----	25	29	-----	-----	26	-----
4	-----	-----	6	31	-----	3	28	28	-----	30	.017
Commercial C-50 carbide										40	-----
Commercial C-2 carbide										4	-----

¹ Standard tests on 347 stainless steel at 400 surface feet/min., .050" depth of cut, .010" feed/revolution, and .016" wear land (standard tool life), except as noted.

I claim:

1. A carbide-metal composite comprising a base alloy composition of tantalum, tungsten and carbon having a fine-grained, lamellar microstructure derived from the disproportionation of a metal subcarbide phase, said lamellar microstructure characterized in having a monocarbide phase and a metal phase, with the metal phase being rich in tungsten and contributing toughness to the composite and said monocarbide phase having tantalum as its base metal.

2. A carbide-metal composite in accordance with claim 1, having tantalum-tungsten-carbon base alloy compositions selected from within the area A, B, C, D of the ternary composition diagram of FIG. 1.

3. A carbide-metal composite in accordance with claim 1, having tantalum-tungsten-carbon base alloy compositions selected from within the area E, F, G, H of the ternary composition diagram of FIG. 1.

4. A carbide-metal composite in accordance with claim 1 with a microstructure generally similar to that shown in the photomicrograph of FIG. 2.

5. A carbide-metal composite in accordance with claim 1 with a microstructure generally similar to that shown in the photomicrograph of FIG. 3.

6. A carbide-metal composite in accordance with claim 1 with a microstructure generally similar to that shown in the photomicrograph of FIG. 4.

7. A carbide-metal composite in accordance with claim 1, wherein the tantalum-tungsten-carbon base alloy composition including beneficial alloying substituents or additions, comprise at least 90 atomic percent of the composite.

8. A carbide-metal composite in accordance with claim 2, wherein molybdenum in amounts from about 0 up to 20 atomic percent of the base alloy composition is substituted for tungsten, but for never more than the total amount of tungsten present in said composition.

9. A carbide-metal composite in accordance with claim 2, wherein an alloying element selected from the group consisting of niobium, vanadium, titanium, zirconium and hafnium, or combination thereof, is substituted at least in part for tantalum, said alloying elements comprising up to 20 atomic percent of the base alloy composition, but for never more than the total amount of tantalum present in said composition.

10. A cutting tool comprising a carbide-metal composite comprising a fine-grained, lamellar microstructure comprising a mono-carbide phase and a metal phase formed from a base alloy composition of tantalum, tungsten and carbon and derived from disproportionation of a metal subcarbide phase, said metal phase being rich in tungsten and contributing toughness to the composite and said monocarbide phase having tantalum as its base metal.

11. A cutting tool in accordance with claim 10 wherein the microstructure of the metal-carbide is generally similar to that shown in the photomicrograph of FIG. 2.

12. A cutting tool in accordance with claim 10 wherein the microstructure of the metal-carbide composite is generally similar to that shown in the photomicrograph of FIG. 3.

13. A cutting tool in accordance with claim 10 wherein the microstructure of the metal-carbide composite is generally similar to that shown in the photomicrograph of FIG. 4.

14. A cutting tool in accordance with claim 10 having a tantalum-tungsten-carbon base alloy composition selected from within the area A, B, C, D of the ternary diagram of FIG. 1.

15. A cutting tool in accordance with claim 10 having a tantalum tungsten-carbon base alloy composition se-

lected from the area E, F, G, H of the ternary composition diagram of FIG. 1.

16. A cutting tool in accordance with claim 14 wherein the tantalum-tungsten-carbon base alloy composition, including beneficial alloying substituents, comprise at least 90 atomic percent of the carbide-metal composite.

17. A cutting tool in accordance with claim 15 wherein the tantalum-tungsten-carbon base alloy composition including beneficial alloying substituents comprise at least 90 atomic percent of the carbide-metal composite.

18. A cutting tool in accordance with claim 14 wherein molybdenum in amounts from 0 up to 20 atomic percent of the base alloy composition is substituted for tungsten, but for never more than the total amount of tungsten present in said composition.

19. A cutting tool in accordance with claim 14, wherein an alloying element selected from the group consisting of niobium, vanadium, titanium, zirconium and hafnium, or combination thereof, is substituted at least in part for tantalum, said alloying elements comprising up to 20 atomic percent of the base alloy composition, but for never more than the total amount of tantalum present in said composition.

20. A carbide-metal composite which comprises a base alloy composition of tantalum-tungsten and carbon, said composition yielding a fine-grain lamellar microstructure derived from the disproportionation of a precursor subcarbide, said composition lying within the quadrilateral area A, B, C, D, of the ternary compositional diagram of FIG. 1.

21. The composite of claim 20, wherein the composition lies within the quadrilateral area E, F, G, H, of the ternary compositional diagram of FIG. 1.

22. A cutting tool in accordance with claim 15 wherein molybdenum in amounts from 0 to up to 20 atomic percent of the base alloy composition is substituted for tungsten, but for never more than the total amount of tungsten present in said composition.

23. A cutting tool in accordance with claim 15 wherein an alloying element selected from the group consisting of niobium, vanadium, titanium, zirconium and hafnium, or combination thereof, is substituted at least in part for tantalum, said alloying elements comprising up to 20 atomic percent of the base alloy composition, but for never more than the total amount of tantalum present in said composition.

References Cited

UNITED STATES PATENTS

1,774,849	9/1930	Schroter	75—176
2,977,225	3/1961	Wlodek	75—176
3,116,145	12/1963	Semchysen	75—176
3,528,808	9/1970	Lemkey	75—135 X
3,554,737	1/1971	Foster	75—134

L. DEWAYNE RUTLEDGE, Primary Examiner

J. E. LEGRU, Assistant Examiner

U.S. Cl. X.R.

75—174, 176