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2,783,530

METAL CERAMIC PRODUCT

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This invention relates to metal ceramics and refers more particularly to novel metal ceramic products having improved resistance to failure by thermal shock and very high strength at elevated temperatures.

In the search for materials capable of withstanding very high temperatures the possibility of combining the properties of metals and refractory oxides to advantage has not been overlooked. Materials composed in part of metal and in part of refractory oxides have become available and are known as metal ceramics. Among the more successful of these are combinations of chromium and alumina.

Chromium-alumina metal ceramics are produced commercially by forming desired shapes of a mixture of finely-divided chromium and alumina. The shapes are sintered under controlled atmospheric conditions. Articles so produced are strongly cohesive and have excellent properties under extreme service conditions of heat. For instance, thermocouple protection tubes composed of chromium-alumina metal ceramics have found wide acceptance in industry.

The present invention has for its principal object the provision of metal ceramics having improved high temperature strength and improved resistance to failure from thermal shock.

The invention by means of which this object is attained is based on the discovery that the presence of a relatively small quantity of a partially reducible oxide selected from the group consisting of titanium oxide, tantalum oxide and columbium oxide in the ceramic phase of a metal ceramic greatly enhances the strength of the material at high temperatures and imparts substantial improvement in resistance to thermal shock failure. The invention accordingly comprises a metal ceramic containing oxide of titanium or tantalum or columbium or mixtures thereof in the ceramic constituent and having chromium in the metal constituent.

More specifically, the invention is a metal ceramic composed of 60% to 95% by volume of metal, the remainder ceramic. The metal constituent of the metal ceramic is chromium with which may be alloyed molybdenum or tungsten or both. Because the atomic weight of tungsten is greater than that of molybdenum, expressed on a weight basis molybdenum is more effective than tungsten, but on an atomic basis, molybdenum and tungsten are substantially equivalent in the metal constituent. To point up this equivalency better, the proportions of the elements in the metal constituent are expressed herein in terms of atomic percent. On this basis, molybdenum or tungsten, or both, may be present in the metal constituent up to 50 atom percent of the resulting alloy. The ceramic constituent is composed of at least one oxide of a metal

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selected from the group consisting of titanium, tantalum and columbium (referred to hereinafter as "titanium group metal oxide") and may contain up to 95% by weight of alumina. As will be explained with reference to Table I below, oxide of titanium group metal constitutes at least 0.7% by volume of the metal ceramic.

Chromium in the metal constituent of the metal ceramic of the invention imparts oxidation resistance. By alloying with chromium suitable quantities of molybdenum or tungsten or both, improved strength at high temperatures can be attained without undue sacrifice in oxidation resistance, provided at least 50 atom percent of the metal constituent is chromium. Where the metal phase is an alloy of chromium and molybdenum or tungsten or both, it should contain at least about 5 atom percent of tungsten or molybdenum or both.

As indicated, the ceramic constituent of the metal ceramic of the invention may represent as little as 5% by volume. In such case the ceramic constituent is composed entirely of oxide of titanium, tantalum, or columbium or mixtures thereof. Metal ceramics so constituted have the greatest strength at high temperatures yet achieved. However, such great strength is not required for all purposes, and it may be desirable to include in the ceramic constituent additional oxide so that in the final metal ceramic, oxide will constitute as much as 40% by volume. The additional oxide may be alumina. The metal ceramics containing additional oxide are somewhat easier to form than are those with as little as 5% by volume of oxide.

In the manufacture of metal ceramics of the invention high purity powders of small particle size are desirable. Powders having a particle size of 10 microns and less are preferred but powders which pass through a 300 mesh screen (0.0018 inch openings) may be used. Impurities known to cause embrittlement of the metals should be avoided. Thus, carbon is detrimental and should be kept to a minimum, preferably below 0.03%.

The constituent powders making up a particular composition may be mixed, formed and sintered or the metals may be pre-alloyed before mixing with the oxide. A firing temperature between 1700° C. and 1900° C. in a dry hydrogen atmosphere has been found to produce excellent results in the sintering operation. Other protective atmospheres, such as argon, may be used.

The preparation of a typical material comprises, for example, preparing a charge of powder containing 50% tungsten, 40% chromium and 10% tantalum pentoxide by weight. On an atom percent basis, the metal constituent contains 26.5 atom percent of tungsten and 73.5 atom percent of chromium. The charge is wet ball milled in benzene or toluene for from 24 to 100 hours and dried. A binder such as paraffin or gum arabic is incorporated, and the mixture is compacted at a pressure of between 10,000 and 60,000 pounds per square inch and dried overnight. The compact is then heated at about 1800° C. in a dry hydrogen atmosphere for between one and five hours. Alternatively, the mixed powders, without binder, may be introduced into a graphite die and pressed at between 1700° C. and 1900° C. from 5 to 30 minutes at temperature under a pressure of from 1500 to 3000 pounds per square inch.

The metal ceramics of the invention may be formed by slip-casting if desired, the materials having higher proportions of oxide are more suited to forming by this method. The powdered constituents are mixed and added

to a dilute hydrochloric acid solution to form a suitable slip. If relatively large quantities of molybdenum are used, hydrochloric acid alone is not a satisfactory peptizing agent because of its tendency to attack the molybdenum. For slip-casting metal ceramics containing molybdenum, it is therefore desirable to utilize an organic surface active agent as peptizer as disclosed in the co-pending application of L. A. Conant and D. M. Gillies, Serial No. 140,442, filed January 25, 1950. A preferred peptizing agent of this class is a solution of gum arabic.

Many formulations embodying the invention have been prepared and tested. Table I below sets forth a number of such formulations as specific examples. Of the compositions listed in Table I those containing no alumina were prepared by cold pressing, that is, the first of the three methods explained above, and those containing alumina were slip-cast. All specimens were sintered in accordance with the procedure above described. In the table the compositions of the metal ceramics are given

obtained from Lange's "Handbook of Chemistry," 8th edition.) Thus, on the basis of 100 grams:

Constituent	Weight, g.	Density, g./cc.	Volume, cc.
Cr.....	58	7.1	8.16
Mo.....	19	10.2	1.86
Ta ₂ O ₅	1	8.74	0.11
Al ₂ O ₃	21	4.0	5.25
			15.38

$$\text{Volume percent Ta}_2\text{O}_5 = \frac{0.11}{15.38} \times 100 = 0.7$$

Similar calculations using densities of 19.3 g./cc. for tungsten; 4.26 g./cc. for TiO₂ and 4.60 for Cb₂O₅ show the volume percentage of titanium group oxide in compositions 19 to 29 inclusive to be, respectively: 1.4; 1.5; 3.0; 3.2; 0.7; 1.5; 3.8; 2.3; 7.6; and 3.8.

Table I

No.	Percent composition by weight							Percent VM	Atom percent		
	Cr	Mo	W	TiO ₂	Ta ₂ O ₅	Cb ₂ O ₅	Al ₂ O ₃		Cr	Mo	W
1.....	76	NH	NH	24	NH	NH	NH	65	100		
2.....	60	NH	NH	NH	40	NH	NH	65	100		
3.....	42	NH	NH	52	NH	NH	NH	92.5	74		26
4.....	41	NH	41	18	6	NH	NH	65	73		22
5.....	50	NH	31	19	6	NH	NH	65	85		15
6.....	30	NH	65	NH	5	NH	NH	93	62		38
7.....	30	NH	60	NH	10	NH	NH	87	64		36
8.....	40	NH	50	NH	10	NH	NH	88	74		26
9.....	49	NH	31	NH	NH	20	NH	65	85		15
10.....	53	42	NH	5	NH	NH	NH	90	71	29	
11.....	49	39	NH	11	NH	NH	NH	80	67	33	
12.....	46	36	NH	18	NH	NH	NH	70	70	30	
13.....	73	24	NH	3	NH	NH	NH	95	85	15	
14.....	68	23	NH	9	NH	NH	NH	85	85	15	
15.....	66	22	NH	12	NH	NH	NH	80	85	15	
16.....	58	19	NH	23	NH	NH	NH	65	85	15	
17.....	57	19	NH	NH	24	NH	NH	65	85	15	
18.....	53	9	17	21	NH	NH	NH	65	78	15	7
19.....	NH	NH	NH	1	NH	NH	NH	22	85	100	
20.....	77	NH	NH	1	NH	NH	NH	26	60	100	
21.....	59	20	NH	1	NH	NH	NH	21	65	84	16
22.....	59	20	NH	2	NH	NH	NH	20	65	84	16
23.....	44	35	NH	2	NH	NH	NH	19	65	70	30
24.....	58	19	NH	NH	1	NH	21	65	85	15	
25.....	58	19	NH	NH	2	NH	20	65	85	15	
26.....	57	19	NH	NH	5	NH	19	65	85	15	
27.....	26	NH	60	1	NH	NH	13	65	61		39
28.....	33	NH	42	NH	8	NH	17	65	74		25
29.....	40	16	30	2	NH	NH	13	70	70	15	15

by weight, and the volume percentage of the metal constituent ("percent VM") in the metal ceramics is given. Also reported in the table is the composition of the metal constituent in atom percent.

It will be observed that in Table I compositions numbered 1 through 18 contain in the ceramic phase only oxide of titanium, tantalum or columbium, no alumina being present. Since the proportion of metal in the metal-ceramic composition is reported in terms of percent by volume (percent VM) the proportion of titanium group metal oxide in volume percentage is readily obtained by subtraction from 100%. Thus in composition 13 with 95% by volume of metal, the proportion of titanium oxide in the metal ceramic is 5% by volume, whereas in compositions 1, 2, 4, 5, 9 and 16 to 18 inclusive titanium group metal oxide constitutes 35% by volume of the metal ceramic. The other compositions of this group are intermediate of these extremes.

In compositions numbered 19 to 29 inclusive in Table I, the ceramic phase contains alumina in addition to titanium group metal oxide, and to determine the proportion of the latter requires different calculation. For example, composition No. 24 contains by weight, 58% chromium; 19% molybdenum; 1% tantalum pentoxide and 21% alumina. The volume of each constituent is determined by dividing the weight of each in grams by the density of the constituent. (In the following calculation the densities were

Metal ceramics embodying the invention have been thoroughly tested to determine their capabilities. Typical results of some of the tests conducted on the specific compositions listed in Table I are tabulated below in Table II. These include hardness as measured on the Rockwell A scale ("RA"), bend strength at 1000° C. and creep test results. In the last mentioned test, a specimen is subjected to a predetermined stress in bending at 1000° C., the stress is applied for the number of hours indicated, and the deflection of the specimen is measured in inches. In the tests reported in Table II, the specimens used in No. 1 through 18 were 1/8 inch by 1/4 inch by 1 inch in span. In the tests of specimens No. 19 through 29, specimens were 1/8 inch by 1/4 inch by 3 inches in span. In all cases the load was applied at the center of the span. Deflection is expressed in inch per inch ("In./in.") span. As a measure of oxidation resistance, specimens are exposed for 200 hours at temperatures of 1000° C. or 1200° C. in air, cooled and then subjected to a bend test at 1000° C. The strength of the specimen after this treatment compared to its original strength at 1000° C. gives some indication of the extent of oxidation suffered by the specimen. Results of such tests are included in Table II. Also included in Table II are the results of tests designed to show the resistance of the materials to thermal shock. In such tests the specimen is heated to 1000° C. and quenched in oil or water as

indicated, the heating and quenching cycle being repeated a number of times (indicated by "Cy." in the table), and the strength of the specimen is then determined at 1000° C. Comparison with the original strength of a similar specimen indicates resistance to damage by thermal shock.

tain alumina in the ceramic phase are not so strong as those materials containing about 90% by volume of metal and having only titanium, tantalum, or columbium oxide in the ceramic phase, their creep resistance is better and their strength is superior to the conventional straight chromium-alumina materials.

Table II

No.	Hardness, RA	Bending strength at 1,000° C. p. s. i.*	Creep in bending at 1,000° C.			Strength at 1,000° C. after 200 hrs. at temperature—		Strength at 1,000° C. after quench	
			Stress p. s. i.*	Time hrs.	Defl., In./in.	p. s. i.*	Temp.	p. s. i.*	Cy.
1	57	33				40	1,000		
2		103	20	800	0.13	84	1,000		
3	80	210				140	1,000		
4		180	35	240	0.25	143	1,200	185	¹ 10
4		180	35	240	0.25	143	1,200	43	² 10
5		136				50	1,200		
		209							
6		211				80	1,000		
7		250				200	1,000		
8	78	220	35	125	0.1	200	1,000		
9		87							
10	75	155	35	110	0.09	50	1,200		
		183							
11	77	151	35	291	0.12	130	1,200	47	² 10
		206							
12		150	35	532	0.09	126	1,200	55	² 10
		166							
13		124				92	1,200		
14		132							
		141				119	1,200		
15	71	132							
	77	147				120	1,200	41	² 10
16	71	120	35	140	0.16	100	1,200	83	² 10
	75	125							
17		103				103	1,200		
18		160				117	1,200	73	² 10
19	67	45	15	168	0.008	43	1,200	31	² 8
20	70	45	15	168	0.008			25	² 6
21	78	75	30	168	0.112	55	1,200	39	² 10
22	79	80	30	168	0.200	66	1,200	49	² 10
23	79	105				81	1,200	105	² 10
24	79	62	30	168	0.065	52	1,200	49	² 8
25	79	65	30	168	0.023	61	1,200	49	² 7
26	80	84	30	168	0.145			51	² 8
27	80	126						98	² 10
28	83	122				92	1,000		
29		100				98	1,200		

*In thousands.

¹ Quenched in oil.² Quenched in water.

The average bend strength of commercially available chromium-alumina metal ceramics is of the order of 50,000 pounds per square inch. These materials have excellent oxidation resistance and exhibit substantially the same strength after exposure to temperatures of 1200° C. in air. However, the chromium-alumina materials are susceptible to thermal shock to the extent that they exhibit only about half their original strength after two or three cycles of heating and quenching. Also, they tend to exhibit considerable deflection under creep test conditions, for instance having a deflection of greater than 0.033 inch per inch under stress of 15,000 pounds per square inch at 1000° C. in 168 hours.

With the properties of the chromium-alumina materials in mind, it will be seen from the data in Table II that the metal ceramics of this invention are far stronger and generally much less subject to failure by thermal shock. Their creep properties are also much better in that they show less deflection under heavier loads applied for longer times. The oxidation resistance of the metal ceramics of the invention is generally very good, but, not unexpectedly, varies with the chromium content of the metal constituent, the higher the chromium content, the better the oxidation resistance. The data also show that the greater strength and greatest resistance to thermal shock are generally attained with the higher proportions of metal and that of the materials listed in the table those containing tungsten or molybdenum alloyed with chromium generally have the greatest strength. While those materials of about 65% by volume of metal which con-

For greatest strength, therefore, a preferred range of composition for metal ceramics embodying the invention is about 85% to 95% by volume of metal, the remainder ceramic, the metal being composed of chromium with which may be alloyed up to 50 atom percent of molybdenum or tungsten or both, the ceramic being oxide of titanium, tantalum or columbium or mixtures thereof. For easier fabrication, a preferred range of composition of metal ceramics embodying the invention is about 60% to 85% by volume of metal, the remainder ceramic, the metal being composed of chromium with which may be alloyed up to 50 atom percent of molybdenum or tungsten or both, the ceramic being oxide of titanium, tantalum or columbium or mixtures thereof and having associated therewith up to 95% by weight of alumina in the ceramic phase, the oxide of titanium group metal constituting at least 0.7% by volume of the metal ceramic.

The reasons for the greatly improved physical properties of the metal ceramics of the invention as compared with the conventional chromium-alumina products are not entirely understood. However, it is believed that the improvement may be due to the partial reduction of titanium, tantalum, or columbium oxides during sintering. In chromium-alumina metal ceramics one has essentially a physical mixture of an oxide phase and a metal phase. It has been postulated that the Al₂O₃ reacts by solid solution formation with a thin layer of Cr₂O₃ on the surface of the chromium particles to form a bond between metal and oxide. This postulate is reasonable

since Al_2O_3 and Cr_2O_3 are isostructural, but the importance of the effect in determining the properties of the product has not been established and in any case the amount of such chemical interaction must be small. Also, under the sintering conditions used the aluminum oxide is irreducible. In the materials of this invention, on the other hand, one purposely uses an oxide which is fairly easily reduced to a lower oxide (or oxides) but not easily reduced to the metal. During sintering, lower oxides may be formed in one or more of the following ways:

- (1) by thermal decomposition of the oxide,
- (2) by reaction of the oxide with metallic chromium to form chromium oxide and the lower oxide,
- (3) by reduction of the oxide by hydrogen in the furnace atmosphere.

It is apparent that the final composition of the oxide phase may be complex, comprising the original oxide plus its reduction products plus chromium oxide and possibly the oxides of tungsten and/or molybdenum which may have been present on the original tungsten and molybdenum powders. Furthermore, these oxides may combine to form solid solutions, eutectic structures or simple mixtures in the final oxide phase.

By studying sintering behavior and by examining microstructures and physical properties the following conclusions have been drawn as to the functions of these partially reducible oxides in the formation of these materials:

(1) A liquid phase is formed during sintering even though the sintering temperature may be well below the melting points of any of the original constituents of their mixtures. This is presumably due to formation of lower melting oxide mixtures.

(2) This liquid phase promotes sintering and densification of the metal phase. Lower oxide melts are known to wet and dissolve metals more effectively than normal oxide melts and hence might be expected to provide a recrystallization medium for metal as well as for oxide.

(3) Chromium oxide, which normally occurs as an intergranular impurity in sintered chromium and sintered chromium alloys, is dissolved in the liquid phase and becomes part of the mixed oxide phase. This mixed oxide phase occurs in the final structure as more or less discrete grains so located as to be effective in stiffening the structure and imparting creep resistance to it.

(4) The final structure contains a somewhat larger proportion of oxide than would be expected on the basis of the original composition, due, presumably, to reaction between the added oxide and metallic chromium to form chromium oxide and the lower oxide.

Whether or not the foregoing theoretical explanation is correct, the fact remains that metal ceramics embodying the invention have strength at high temperature approaching the highest attained at room temperature by other materials. These properties endow these materials with great potential value for use in applications involving high stress at high temperature, for example, for turbine blades, rocket engine parts, extrusion dies and the like.

While a number of specific compositions embodying the invention have been given herein by way of example, the invention is not limited to those examples. Other metals which may be present in the metal constituent of metal ceramics according to the invention include columbium and tantalum which tend to improve toughness of the product.

Certain compositions embodying this invention are disclosed in my copending application Serial No. 360,453, filed June 9, 1953.

I claim:

1. A metal ceramic composed of 60% to 95% by volume of metal, the remainder ceramic, the metal constituent of said metal ceramic being composed of chromium having alloyed therewith 0 to 50 atom percent of at least one metal selected from the group consisting of molybdenum and tungsten; the ceramic constituent of said metal ceramic being composed of oxide of at least one metal selected from the group consisting of titanium,

columbium, and tantalum and having associated therewith 0% to 95% by weight of alumina, said oxide of said titanium group metal constituting at least 0.7% by volume of said metal ceramic.

2. A metal ceramic composed of 60% to 95% by volume of metal, the remainder ceramic, the metal constituent of said metal ceramic being composed of chromium having alloyed therewith 0 to 50 atom percent of at least one metal selected from the group consisting of molybdenum and tungsten; said ceramic being oxide of at least one metal selected from the group consisting of titanium, columbium, and tantalum.

3. A metal ceramic composed of 60% to 95% by volume of metal, the remainder ceramic, said metal being chromium; the ceramic constituent of said metal ceramic being composed of oxide of at least one metal selected from the group consisting of titanium, columbium, and tantalum and having associated therewith 0% to 95% by weight of alumina, said oxide of said titanium group metal constituting at least 0.7% by volume of said metal ceramic.

4. A metal ceramic composed of 60% to 95% by volume of metal, the remainder ceramic, said metal being chromium; said ceramic being oxide of at least one metal selected from the group consisting of titanium, columbium and tantalum.

5. A metal ceramic composed of 85% to 95% by volume of metal, the remainder ceramic, the metal constituent of said metal ceramic being composed of chromium having alloyed therewith 0 to 50 atom percent of at least one metal selected from the group consisting of molybdenum and tungsten; said ceramic being oxide of at least one metal selected from the group consisting of titanium, columbium, and tantalum.

6. A metal ceramic composed of 85% to 95% by volume of metal, the remainder ceramic, said metal being chromium; said ceramic being oxide of at least one metal selected from the group consisting of titanium, columbium and tantalum.

7. A metal ceramic composed of 85% to 95% by volume of metal, the remainder ceramic, said metal being chromium having alloyed therewith 5 to 50 atom percent of molybdenum; said ceramic being oxide of at least one metal selected from the group consisting of titanium, columbium, and tantalum.

8. A metal ceramic composed of 85% to 95% by volume of metal, the remainder ceramic, said metal being chromium having alloyed therewith 5 to 50 atom percent of tungsten; said ceramic being oxide of at least one metal selected from the group consisting of titanium, columbium and tantalum.

9. A metal ceramic composed of 60% to 85% by volume of metal, the remainder ceramic, said metal being chromium having alloyed therewith 0 to 50 atom percent of at least one metal selected from the group consisting of molybdenum and tungsten; the ceramic constituent of said metal ceramic being composed of alumina and oxide of at least one metal selected from the group consisting of titanium, columbium, and tantalum, said oxide of said titanium group metal constituting at least 0.7% by volume of said metal ceramic.

10. A metal ceramic composed of 60% to 85% by volume of metal, the remainder ceramic, said metal being chromium; the ceramic constituent of said metal ceramic being composed of alumina and oxide of at least one metal selected from the group consisting of titanium, columbium, and tantalum, said oxide of said titanium group metal constituting at least 0.7% by volume of said metal ceramic.

11. A metal ceramic composed of 60% to 85% by volume of metal, the remainder ceramic, said metal being chromium having alloyed therewith 5 to 50 atom percent of tungsten; the ceramic constituent of said metal ceramic being composed of alumina and oxide of at least one metal selected from the group consisting of titanium,

columbium, and tantalum, said oxide of said titanium group metal constituting at least 0.7% by volume of said metal ceramic.

12. A metal ceramic composed of 60% to 85% by volume of metal, the remainder ceramic, said metal being chromium having alloyed therewith 5 to 50 atom percent of molybdenum; the ceramic constituent of said metal ceramic being composed of alumina and oxide of at least one metal selected from the group consisting of titanium, columbium, and tantalum, said oxide of said titanium group metal constituting at least 0.7% by volume of said metal ceramic.

13. A metal ceramic composed of 60% to 95% by volume of metal, the remainder ceramic, said metal being chromium having alloyed therewith 0 to 50 atom percent of at least one metal selected from the group consisting of molybdenum and tungsten; the ceramic constituent of said metal ceramic being composed of oxide of titanium having associated therewith up to 95% by weight of alumina, said oxide of titanium constituting at least 0.7% by volume of said metal ceramic.

14. A metal ceramic composed of 60% to 95% by volume of metal, the remainder ceramic, said metal being chromium; the ceramic constituent of said metal ceramic being composed of oxide of titanium having associated therewith up to 95% by weight of alumina, said oxide of titanium constituting at least 0.7% by volume of said metal ceramic.

15. A metal ceramic composed of 60% to 95% by volume of metal, the remainder ceramic, said metal being chromium having alloyed therewith 5 to 50 atom percent of tungsten; the ceramic constituent of said metal ceramic being composed of oxide of titanium having associated therewith up to 95% by weight of alumina, said oxide of titanium constituting at least 0.7% by volume of said metal ceramic.

16. A metal ceramic composed of 60% to 95% by volume of metal, the remainder ceramic, said metal being chromium having alloyed therewith 5 to 50 atom percent of molybdenum; the ceramic constituent of said metal

ceramic being composed of oxide of titanium having associated therewith up to 95% by weight of alumina, said oxide of titanium constituting at least 0.7% by volume of said metal ceramic.

17. A metal ceramic composed of 60% to 85% by volume of metal, the remainder ceramic, said metal being chromium having alloyed therewith 0 to 50 atom percent of at least one metal selected from the group consisting of molybdenum and tungsten; the ceramic constituent of said metal ceramic being composed of alumina and oxide of titanium, said oxide of titanium constituting at least about 0.7% by volume of said metal ceramic.

18. A metal ceramic composed of 60% to 85% by volume of metal, the remainder ceramic, said metal being chromium; the ceramic constituent of said metal ceramic being composed of alumina and oxide of titanium, said oxide of titanium constituting at least about 0.7% by volume of said metal ceramic.

19. A metal ceramic composed of 60% to 85% by volume of metal, the remainder ceramic, said metal being chromium having alloyed therewith 5 to 50 atom percent tungsten; the ceramic constituent of said metal ceramic being composed of alumina and oxide of titanium, said oxide of titanium constituting at least about 0.7% by volume of said metal ceramic.

20. A metal ceramic composed of 60% to 85% by volume of metal, the remainder ceramic, said metal being chromium having alloyed therewith 5 to 50 atom percent of molybdenum; the ceramic constituent of said metal ceramic being composed of alumina and oxide of titanium, said oxide of titanium constituting at least about 0.7% by volume of said metal ceramic.

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