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L. A. TARSHIS ET AL

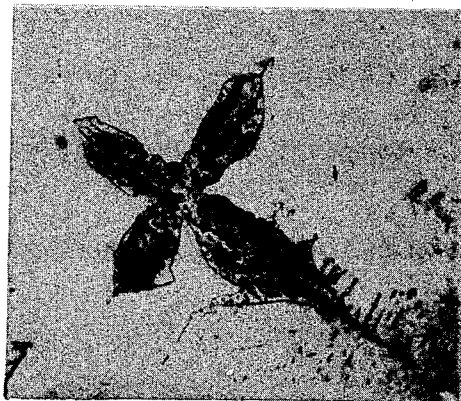
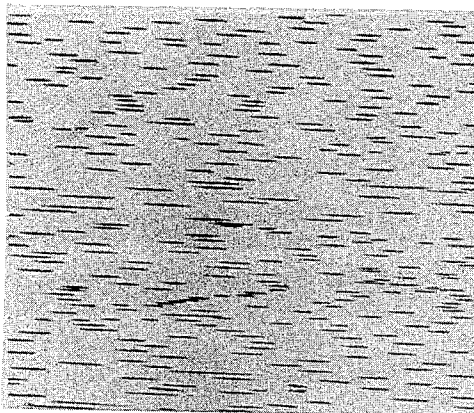
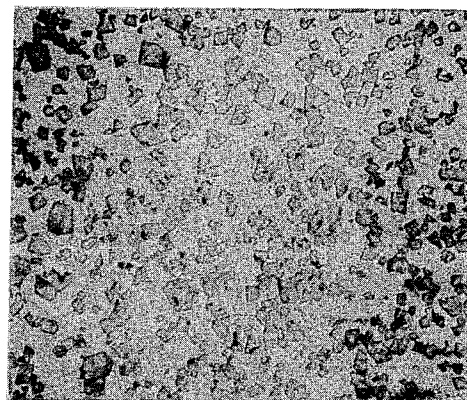
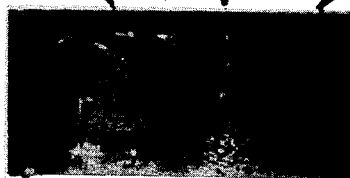
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METHOD OF MAKING MONOCARBIDE FIBER-REINFORCED COBALT-BASE
SUPERALLOY COMPOSITE EUTECTIC CASTINGS

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2 Sheets-Sheet 1

Fig. 1.



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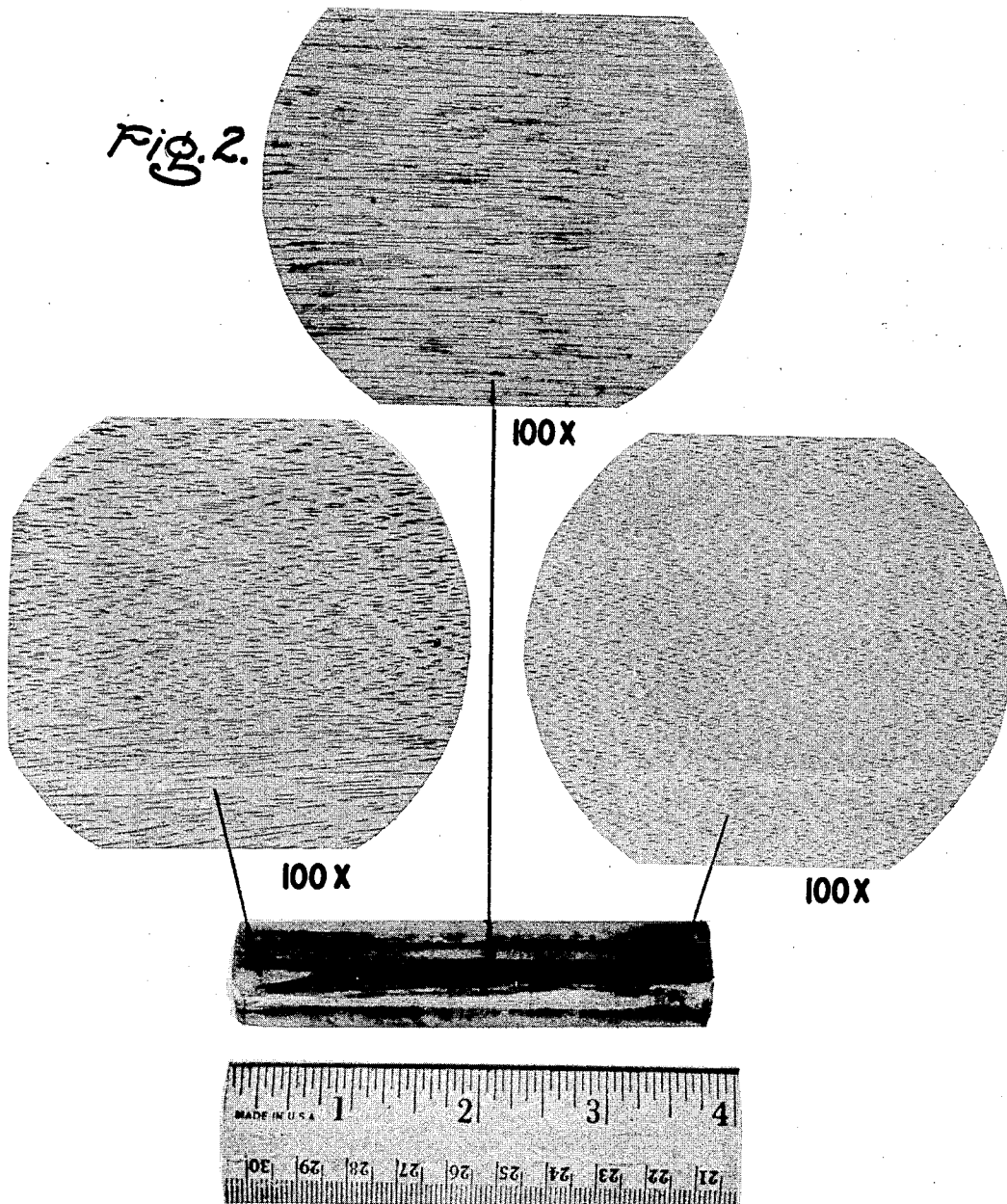
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**METHOD OF MAKING MONOCARBIDE FIBER-
REINFORCED COBALT-BASE SUPERALLOY
COMPOSITE EUTECTIC CASTINGS**

Lemuel A. Tarshis, Latham, and Edward R. Buchanan,
Burnt Hills, N.Y., assignors to General Electric Com-
pany

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5 Claims

ABSTRACT OF THE DISCLOSURE

A high performance eutectic casting comprised of a cobalt-base superalloy matrix reinforced with 5 to 15 volume percent of uniformly aligned fibers of a metal monocarbide extending continuously entirely through the casting is made by directionally solidifying a melt containing the constituents of the monocarbide in amounts corresponding to the monocarbide content of the eutectic. The solidification rate is at least 1/4"/hour.

FIELD OF THE INVENTION

The present invention relates in general to cobalt-base superalloy compositions, and more particularly to novel eutectic castings having cobalt-base superalloy matrices which are reinforced by a fibrous phase of uniformly aligned fibers of a metal monocarbide extending continuously entirely through the castings. This invention is also concerned with a new method by which these novel castings can be produced.

In particular embodiments of this invention, these alloys have utility as directionally solidified castings forming gas turbine engine components.

CROSS REFERENCES

This application is related to copending application Ser. No. 134,235, filed Apr. 15, 1971, of John L. Walter and Harvey E. Cline entitled "Cobalt-Base Tantalum Carbide Eutectic Alloys," assigned to the assignee hereof, now abandoned; and to the continuation-in-part thereof by the same inventors, Ser. No. 182,530, filed on or about Sept. 15, 1971, entitled "Cobalt-Base Tantalum Carbide Eutectic Alloys," also assigned to the assignee hereof.

BACKGROUND OF THE INVENTION

The physical and chemical requirements of materials of construction of gas turbine hot stage components have escalated since the advent of the aircraft jet engine because the engine performance improvements require large operating temperature increases. For a long time, nickel- and cobalt-base alloys have served as the principal high-temperature materials of construction of jet engine buckets and vanes. The continual demand for materials of ever higher temperature capabilities has, however, resulted in the virtual exhaustion of alloying possibilities of the nickel-base and cobalt-base systems and has led to efforts to develop composite materials. While dispersion-strengthening of nickel- and cobalt-base alloys has not been fruitful, directional solidification of pseudobinary eutectics such as Ni₃Al-Ni₃Cb has resulted in somewhat improved high-temperature mechanical strength properties (Thompson and Lemkey, Trans. ASM, vol. 62, page 140, 1969). Good strength properties and in addition usable engineering ductility have been obtained in the Ni-CbC system (Lemkey and Thompson, Metal Trans., vol. 2, page 1537, June 1971) in which the typical directionally-solidified body has a relatively ductile matrix strengthened by an aligned fibrous phase. In fact, the former eutectic has been used in the production of gas turbine buckets, the respective phases in these eutectic products being aligned to maximize physical properties in the desired direction.

Limitations imposed by the simple pseudobinary eutectic alloy upon the properties of these directionally-solidified composites were not avoidable until it was realized that the metal-monocarbide eutectics would withstand additions of alloying elements up to and somewhat beyond the point that the matrix qualifies as a conventional cobalt-base superalloy, i.e., an alloy characterized by deliberate additions of substantial amounts of chromium to improve elevated temperature environmental resistance and optional selective additions of nickel, aluminum, molybdenum, tungsten, niobium, iron, tantalum, titanium and yttrium for additional strengthening capability and improvement of other engineering properties. In these complex matrix chemistry alloys, we have further found that reinforcing monocarbide fibers can be derived from tantalum, titanium, columbium, zirconium, hafnium and vanadium, and from combinations of two or more of these elements with carbon. We provide carbon in these alloys in amount sufficient as a source of the metal monocarbide plus an amount in equilibrium with the monocarbide in solution in the alloy matrix.

Additionally and very importantly, we have discovered that directionally-solidified, monocarbide eutectic superalloy castings which are free from structural inhomogeneity can be consistently produced. Thus, through critical control of the casting melt composition, one can in accordance with this invention make directionally-solidified castings in which the fibrous monocarbide structure extends continuously from one end surface to another of an as-cast body. The necessity for trimming the casting to eliminate non-fibrous portions can thereby be avoided without incurring any offsetting penalty of cost or product performance capability. Moreover, this result can be obtained in castings of a variety of shapes and sizes with the continuous fibrous phase-forming capability being independent of casting dimensions and form. This discovery, then, is the basis for the novel method of this invention related to that disclosed and claimed in copending applications Ser. Nos. 134,235 and 182,530 by which directionally - solidified, metal - monocarbide fiber-reinforced cobalt-base superalloy composite bodies can be consistently produced. The essential difference between the present invention and that of these copending cases is that the fibrous reinforcing phase is coextensive of the casting and not limited as to length by the formation of blocky carbide or other non-fibrous carbide phase.

SUMMARY OF THE INVENTION

This invention in both its method and article of manufacture aspects is predicated upon two basic novel concepts. First, we have found that engineering properties such as oxidation and hot-corrosion resistance can be greatly improved upon relative to those of the simple pseudobinary monocarbide eutectic while retaining the metal-monocarbide fiber-reinforcing effects through additions of alloying elements to levels equivalent to and possibly beyond those of conventional superalloys. Secondly, we have found that the metal-monocarbide fibrous reinforcing phase can be formed so that it is coextensive with a directionally-solidified casting by providing a casting melt containing amounts of the monocarbide constituents corresponding to the monocarbide content of the eutectic.

Thus, broadly and generally, in its method aspect, this invention comprises the steps of preparing a cobalt-base superalloy casting melt containing, in addition to the superalloy matrix chemistry, the metal-monocarbide constituents in amounts corresponding to the monocarbide content of the eutectic, and directionally-solidifying the melt at the rate of at least 1/4"/hour. Determination of the amounts of the monocarbide constituents to be used in the formulation of the casting melt in accordance with

this invention can be made experimentally, as will be subsequently described.

Likewise, broadly and generally, in its article aspect, this invention takes the form of an aligned composite cast eutectic body comprising a cobalt-base superalloy matrix and a metal-monocarbide fibrous phase within the matrix providing reinforcement for the cast body. The fibrous phase consists essentially of aligned metal-monocarbide fibers about one to ten millimeters in length extending continuously through the cast body from one surface to the other of the body in its original cast condition.

DETAILED DESCRIPTION OF THE INVENTION

The melt compositions provided according to this invention are cobalt-base superalloys containing 10.0 to 16.0 percent chromium and 5 to 14.0 percent of monocarbide-forming metals and 0.4 to 0.9 percent carbon. These compositions, as indicated above, may also contain substantial amounts of other metals as follows:

	Percent
Nickel	Trace to 16.0
Molybdenum	Trace to 6.5
Aluminum	Trace to 4.0
Tungsten	Trace to 6.5
Iron	Trace to 1.0
Titanium	Trace to 1.0
Yttrium	Trace to 1.0

The volume fraction of metal monocarbide fiber in a composite eutectic casting of this invention depends upon the kinds and amounts of optional constituents of the superalloy matrix such as aluminum. Additionally, the metal-monocarbide content of the fibers eutectic will be governed by the total composition, and particularly by the complexities of the influences of constituents of the superalloy on the composition of the eutectic. For these reasons, it is necessary to determine in some manner rather precisely the composition of the eutectic and the amounts of the monocarbide constituents of the eutectic so that the casting melt can be formulated.

One procedure which has been employed successfully involves preparation of a cobalt-base superalloy casting melt in which the carbon and monocarbide-forming metal contents are well into the hypereutectic range. Directional solidification of this melt at a suitable rate such as 1/4"/hour results in an ingot or casting containing in some increment of its length the metal monocarbide fibers aligned parallel to the growth direction in the superalloy matrix. This portion of the ingot corresponds to the eutectic composition. Then, chemical analysis of that segment of the casting will yield the eutectic composition and consequently the formulation of another casting melt of this analyzed eutectic composition to be provided for directional solidification in accordance with the method of this invention to produce a new article of this invention.

The differences between the products of this invention and those resulting from the use of such hypereutectic casting melt are apparent from the drawings accompanying and forming a part of the specification, in which:

FIG. 1 comprises a photograph of a directionally-solidified ingot corresponding to the composition of a hypereutectic melt, and three photomicrographs (150 dia.) of microstructures in three different portions of one ingot as indicated; and,

FIG. 2 comprises a photograph array corresponding to that of FIG. 1 in which the picture ingot was produced in accordance with this invention by directional solidification of a casting melt containing the eutectic amounts of the monocarbide constituents.

One article or product of the present invention is produced by directional solidification of a casting melt consisting essentially of about: 15.7 percent chromium, 9.5 percent nickel, 12.0 percent tantalum, 0.77 percent carbon, 6.4 percent tungsten and 55.63 percent cobalt.

Another such article is produced by directional solidification of a casting melt of about: 15.7 percent chromium, 9.5 percent nickel, 12.0 percent tantalum, 0.77 percent carbon and 62.03 percent cobalt.

Still another such article is produced by directional solidification from a nominal melt composition consisting essentially of: 15.7 percent chromium, 9.5 percent nickel, 3.0 percent tungsten, 12.0 percent tantalum, 0.77 percent carbon and 59.03 percent cobalt.

A fourth such article is produced by directional solidification of a casting melt of composition as follows: 15.0 percent chromium, 10.0 percent nickel, 11.51 percent niobium, 1.49 percent carbon and 62.0 percent cobalt.

These four articles, like articles of this invention in general, contain from about 5 to about 15 volume percent of a metal monocarbide in the form of fibers aligned and distributed uniformly throughout the superalloy matrix of the composite structure of the articles in their directionally solidified condition as shown in FIG. 2. They are also free from blocky carbides and other non-fibrous forms of carbide which are characteristic of hypereutectic superalloy composite castings of this type, as illustrated in FIG. 1.

The compositions of four typical products of this invention described in Examples I, II and III below are set out in Table I.

TABLE I.—COBALT BASE-MONOCARBIDE-REINFORCED ALLOY CASTINGS

Alloy designation	Composition						
	Co	Cr	Ta	Nb	C	Ni	W
Co50B-LT	55.63	15.7	12.0	-----	0.77	9.5	6.4
Co50B-LT-0W	62.03	15.7	12.0	-----	0.77	9.5	-----
Co50B-LT-3W	59.03	15.7	12.0	-----	0.77	9.5	3.0
Co50B-EB	62.0	15.0	-----	11.51	1.49	10.0	-----

EXAMPLE I

Two castings designated in Table I as Co50B-LT were produced by directional solidification in a Bridgeman crystal growth vessel of a melt of identical composition at the substantially constant rate of 1/4"/hour in a temperature gradient of 250° C. per inch. Practically no segregation was found in the resulting ingot, the microstructure of which was a matrix containing throughout substantially uniformly distributed and aligned monocarbide fibers, making up approximately 12 volume percent of the ingots. The fibers were essentially single crystal monocarbides each containing essentially carbon and tantalum. The matrix was a cobalt-base superalloy containing chromium, essentially in equilibrium with the fibers. Data gathered in tests performed on these ingots are set forth with comparable data on the nickel-base superalloy René 80 in Tables II and III. The tensile tests were conducted at a strain rate of 4×10⁻²/min.

EXAMPLE II

A casting of the alloy designated in Table I as Co50B-LT-3W was produced as described in Example I with results substantially as stated therein. The volume fraction of the aligned tantalum monocarbide fibers in the ingot was about 12 percent. Again, the matrix was a cobalt-base superalloy containing chromium, nickel, tungsten and small amounts of tantalum and carbon in equilibrium with the tantalum and carbon of the fibrous phase extending uniformly from end to end of the untrimmed casting. Data gathered in tests performed on this ingot like those of Example I are likewise set out in Tables II and III.

EXAMPLE III

Two castings of the Co50B-LT-0W alloy were prepared as described in Example I. These ingots, like those of Examples I and II, exhibited essentially no segregation and the microstructure in each instance consisted of a matrix containing throughout substantially uniformly distributed and aligned fibers of tantalum monocarbide as illustrated in FIG. 2. This fibrous phase constituted about

12 volume percent of each of these ingots in which the matrix was a cobalt-base superalloy containing chromium, nickel and small equilibrium amounts of tantalum and carbon. Again, data obtained in tests of these ingots as described in Example I are contained in Tables II and III.

EXAMPLE IV

Again, following the procedure of Example I, a casting of the above alloy Co50B-EB was produced, examined and tested with the results set forth in Tables II and III. Like the ingots of the foregoing examples, this one was of substantially uniform, non-segregated microstructure with a niobium monocarbide fibrous phase constituting about 10 volume percent extending from end to end of the ingot. The individual monocarbide crystals were again of fiber-like form and uniformly aligned along the longitudinal axis of the ingot. The matrix was a cobalt-base superalloy containing chromium, nickel and relatively small amounts of niobium and carbon in equilibrium with the niobium and carbon of the fibers. The results of the Example I tests carried out on this product are set out in Tables II and III.

TABLE II.—ELEVATED TEMPERATURE STRESS-
RUPTURE PROPERTIES

Alloy	Test temp. (° F.)	Stress (p.s.i.)	Life (hrs.)	Percent elongation
Co50B-LT-----	1,950	30,000	2.7	9.1
	1,832	35,000	8.4	6.4
	2,000	25,000	9.9	5.9
	1,700	40,000	0.5	5.6
	2,000	20,000	61.9	12.8
Co50B-LT-OW-----	1,700	40,000	3.6	4.0
	2,000	20,000	119.2	6.7
Co50B-LT-3W-----	2,000	25,000	9.6	8.3
	1,950	30,000	4.4	3.7
	2,150	15,000	61.1	6.4
	1,832	35,000	6.8	2.4
	1,700	40,000	48.8	3.9
Co50B-EB-----	2,000	20,000	335.0	3.2
	1,700	40,000	4.9	6.4
René 80-----	2,000	20,000	139.8	5.9
	2,000	20,000		

TABLE III.—MECHANICAL PROPERTIES OF ELEVATED TEMPERATURE

Alloy	Test temp. (° F.)	Ultimate tensile strength (p.s.i.)	Percent elongation
Co50B-LT-----	1,800	57,000	9.8
	2,000	47,800	6.6
Co50B-LT-OW-----	1,800	60,100	10.6
	2,000	48,800	6.6
Co50B-EB-----	1,832	49,700	(*)
René 80-----	1,832	48,000	13.0
	2,012	28,000	15.0

* Not measured.

As shown by the above data, the metal monocarbide-reinforced cobalt-base superalloy bodies of this invention have comparable or superior high-temperature physical properties to René 80 which is recognized as one of the

best commercially-available high-temperature metallic structural material.

Herein and in the appended claims, proportions and percentages are stated on the weight basis unless otherwise expressly specified.

It will be obvious to those skilled in the art upon reading the foregoing disclosure that many modifications and alterations in the specific compositions and microstructures disclosed as non-limiting examples may be made within the general context of the invention, and that numerous modifications, alterations and additions may be made thereto within the true spirit and scope of the invention as set forth in the appended claims.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. The method of forming a high performance eutectic casting comprising a cobalt-base superalloy matrix with 5 to 15 volume percent of a fibrous phase consisting essentially of aligned fibers of tantalum monocarbide and extending continuously entirely through the casting in its as-cast condition, which comprises the steps of preparing a cobalt-base superalloy casting melt containing constituents of the monocarbide in amounts corresponding to the monocarbide content of the eutectic, and directionally solidifying said melt at a rate of at least ¼"/hour.

2. The method of claim 1 in which the casting melt consists essentially of about 55.6 percent cobalt, 9.5 percent nickel, 15.7 percent chromium, 12.0 percent tantalum, 0.77 percent carbon and 6.4 percent tungsten.

3. The method of claim 1 in which the casting melt consists essentially of approximately: 15.7 percent chromium, 9.5 percent nickel, 12.0 percent tantalum, 0.77 percent carbon and 62.0 percent cobalt.

4. The method of claim 1 in which the said casting melt consists essentially of about: 15.0 percent chromium, 10.0 percent nickel, 11.5 percent niobium, 1.49 percent carbon, and 62.0 percent cobalt.

5. The method of claim 1 in which the casting melt is of composition within the following percentage ranges:

Chromium -----	10.0-16.0
Nickel -----	Trace-16.0
Molybdenum -----	Trace-6.5
Aluminum -----	Trace-4.0
Titanium -----	Trace-1.0
Carbon -----	0.4-0.9
Monocarbide forming metal -----	5.0-14.0
Yttrium -----	Trace-1.0
Iron -----	Trace-1.0
Tungsten -----	Trace-6.5

References Cited

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