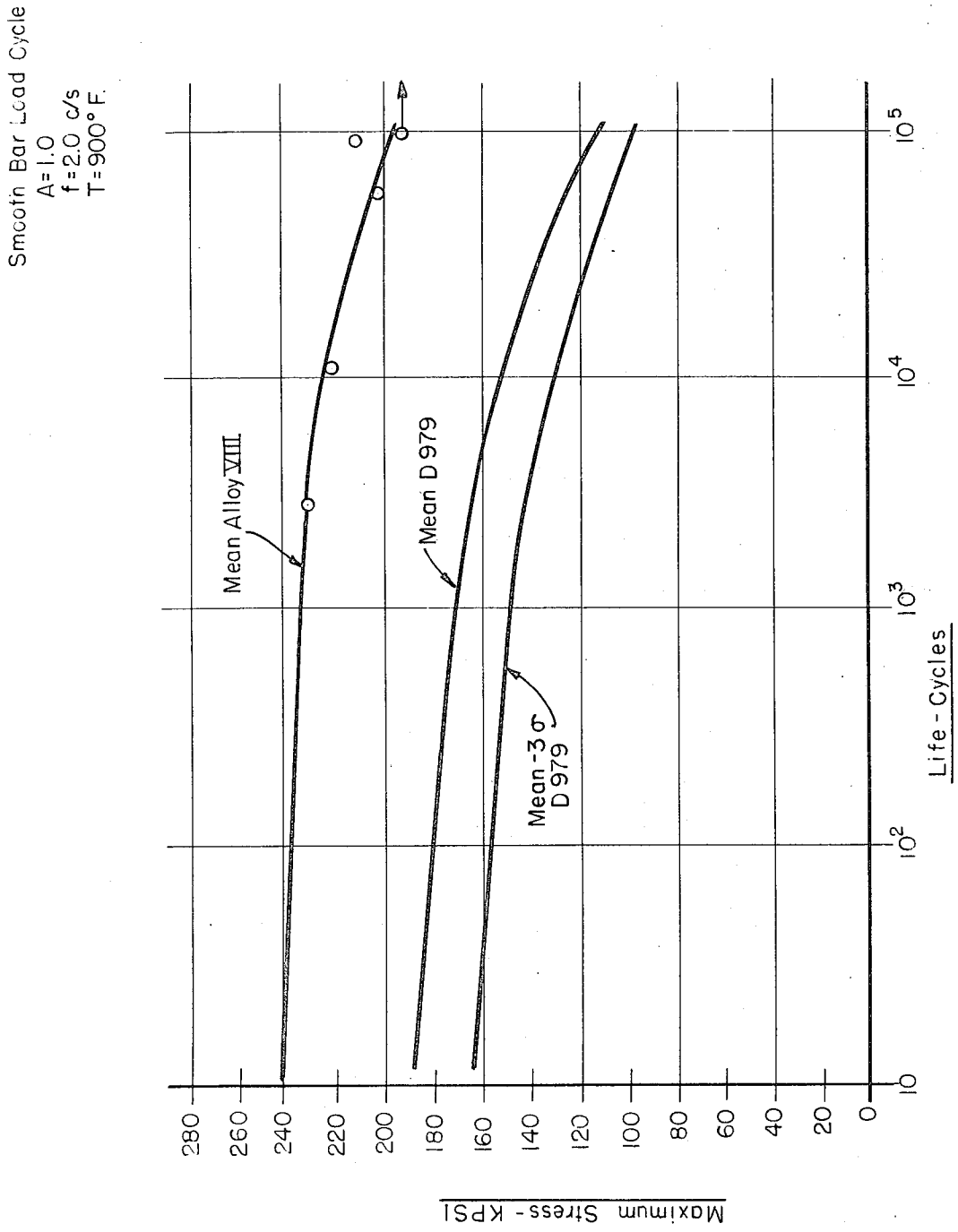
WROUGHT SUPERALLOYS

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WROUGHT SUPERALLOYS

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U.S. Cl. 75—171 9 Claims

ABSTRACT OF THE DISCLOSURE

Wrought superalloy compositions possessing high strength, corrosion resistance and utility at moderate temperatures are produced by atomizing a melt of the desired composition and thereafter consolidating the powders by extrusion and pressforging.

This invention relates to wrought articles exhibiting a desirable combination of physical properties favorable to their use in compressor blade as well as compressor and turbine disc applications where alloy homogeneity, and high strength/density characteristics are of particular importance.

This invention is applicable to the following compositions in percent by weight.

C ---------- max	0.30
Cr	11–15
Co	8–12
Mo	1–2.5
W	3–10
Ta	3.5–10
Hf	Up to 3
Ti	3.5–4.6
Al	3.0–4.0
Ti+Al	7–8
B	0.005–0.025
Zr	0.05–0.4

containing not more than 200 p.p.m. oxygen, less than 0.089% nitrogen and less than 0.75% Fe, the balance being essentially Ni.

A more preferred range of compositions is as follows:

C	0.02–.25
Cr	11.5–13.75
Co	8–9.5
Mo	1.5–2.0
W	3.25–5.5
Ta	3.5–8
Hf	Up to 2.25
Ti	3.75–4.6
Al	3.0–4.0
Ti+Al	7–8
B	0.010–0.016
Zr	0.08–0.16

O_2, N_2, Fe as above, the balance being Ni.

Hafnium is an optional constituent in these alloys. When present, the benefits conferred by the HF are obtained when the hafnium content is between about 0.75% and 2.0% by weight.

Cast alloys of these or closely related compositions are described in our copending United States Patent Applications.

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189,733	Oct. 15, 1971.
196,799	Nov. 5, 1971.
243,418	Apr. 10, 1972.

The compositions of this invention when suitably processed into wrought articles achieve fine grain sizes and complete alloy homogeneity and exhibit uniform mechanical properties. A fine dispersion of gamma prime Ni_3 (Al, Ti) phase contributes to the excellent tensile and fatigue properties exhibited by the alloys in their wrought form which are significantly superior to these properties in the same articles when cast from a melt of the alloy.

In order to produce articles which exhibit higher tensile strength and better fatigue properties than those of the cast superalloys of the above noted applications, wrought articles of similar compositions may be produced by the following procedure:

(1) Form a melt of desired alloy composition;
(2) Atomize the melt to produce powder particles;
(3) Consolidate the particles to form a billet;
(4) Work the billet to to produce a wrought article.

Preferred procedures for effecting each of these steps are as follows:

1. Atomization

The molten compositions are atomized with gas or by other suitable known techniques in which the material is protected from the atmosphere to produce powder particles. In the examples which follow, the atomization process consisted of vacuum induction melting, back-filling of the melting chamber with a positive pressure of argon and atomizing by gravity feeding liquid metal through a ceramic nozzle. As the metal passed out the bottom of the nozzle a jet of argon impinged on the molten stream and atomized the material which was collected in an argon filled chamber below.

After atomization, the powder was classified according to particle size. Analysis showed that about 20 percent of the entire powder yield was +100 mesh size, 45 percent −100 +325 mesh size and 35 percent −325 mesh size. Typical oxygen contents of the powders produced were 50 p.p.m. for the −20 +100 mesh particles, 80 p.p.m. for the −100 +325 mesh particles.

2. Consolidation

Following atomization, the powder particles are consolidated to wrought form. Consolidation can be performed by a number of different techniques which include vacuum hot pressing, hot isostatic compaction, extrusion and combinations thereof.

Extrusion is a preferred technique for the consolidation of the powders and was utilized in the Examples described in this application.

Of the alloy powder produced, only the −100 mesh particles were used for canning preliminary to extrusion. The cans utilized consisted of stainless steel tubes, typically 4¾ inches inside diameter and 5⅝ inches outside diameter, each of which had a stainless steel plug approximately two inches thick electron beam welded to one end. The cans were vibrated as the powder was added to achieve the greatest possible tap density (e.g., 65 to 70 percent). Once the cans were filled with powder, two inch thick stainless steel plugs containing hollow stems for evacuation were electron beam welded to the open ends. The cans were evacuated to 10^{-4} microns. During evacuation they were induction heated to approximately 1000° F. to remove adsorbed gases. Sealing was performed by peening the evacuated tube and TIG welding. Extrusion of the cans was performed at temperatures of 2000° F. to 2050° F. and ratios of from 4:1 to 10:1.

Oxygen analysis showed the extruded billets to contain generally less than 100 p.p.m. Examination of the specimens representative of these bars revealed a uniform structure; small MC-type carbides were randomly distributed throughout and a large amount of gamma prime precipitate was present. Grain size was extremely fine being between two and four microns in diameter (ASTM No. 14).

3. Forging

The strength capabilities of the alloys of this invention are best developed by forging subsequent to extrusion. The powder alloy forgings described in this application ranged from three inches in diameter by ⅝ inch thickness to ten inches in diameter by one inch thickness. They were produced on a 1500 ton press in a one step upsetting operation employing temperatures between 2050° F. and 1850° F. During forging of these compositions it was noted that excellent workability was demonstrated in that the alloy responded to deformation smoothly and uniformly with no evidence of cracking. Grain sizes for all forgings were extremely fine, being smaller than ASTM 12.

Table I presents chemical analyses for compositions prepared and processed to wrought articles in accordance with this invention.

TABLE I.—Chemical Composition for Alloys in Weight Percent

Heat number	C	Co	Mo	Cr	W	Ta	Hf	Al	Ti	B	Zr	O_2	N_2	Fe	Ni
I	0.20	9.1	1.85	11.5	3.6	4.1	1.90	3.23	4.21	0.010	0.15	83	0.07	0.71	Bal
II	0.20	9.2	1.89	12.1	3.7	3.9	------	3.29	4.12	0.011	0.12	85	0.02	0.68	Bal
III	0.23	9.06	1.89	12.40	3.90	4.07	------	3.40	4.00	0.012	0.12	99	0.02	0.07	Bal
IV	0.21	8.56	1.82	11.85	4.33	4.13	1.88	3.30	4.10	0.014	0.12	79	0.02	0.07	Bal
V	0.16	8.9	1.90	11.9	5.1	7.5	------	3.2	3.86	0.013	0.10	97	0.02	0.08	Bal
VI	0.14	9.1	1.92	11.8	3.99	4.0	------	3.0	4.44	0.013	0.10	73	0.02	0.08	Bal
VII	0.15	9.1	1.95	12.8	3.95	3.9	------	3.7	4.18	0.013	0.11	120	0.02	0.08	Bal
VIII	0.02	9.2	1.91	13.4	3.80	3.7	------	3.4	4.14	0.015	0.13	90	0.02	0.01	Bal
IX	0.15	9.1	1.90	12.6	3.90	4.10	------	3.4	3.90	0.013	0.10	80	0.02	0.08	Bal
X	0.18	8.25	1.70	11.9	4.01	3.81	.85	3.2	4.3	0.013	0.10	124	0.02	0.12	Bal

The alloys exhibit excellent room temperature tensile properties as indicated by the results shown in Table II and retain these properties when tested at 900° F. as shown by the results in Table III.

TABLE II.—Room Temperature Tensile Test Results for PA-100 Series Alloys

Heat number	Heat treatment	UTS (K s.i.)	0.2% YS (K s.i.)	Percent EL	Percent RA
I	H	266.8	214.7	12.3	19.6
	H	266.8	217.1	12.5	12.6
	I	276.2	229.4	11.5	14.0
	I	261.0	210.3	10.3	13.8
	A	242.7	192.3	7.5	12.6
II	A	258.9	196.8	11.4	12.8
	H	269.2	211.5	17.9	21.0
	H	271.0	214.0	5.6	21.0
	I	277.3	225.2	20.0	25.9
	I	270.0	203.5	18.6	19.6
III	H	254.4	215.2	14.2	12.7
	H	254.4	213.9	16.0	13.9
	I	266.9	230.5	11.6	15.2
	I	260.1	230.0	12.0	10.5
	A	253.0	188.5	13.4	12.7
	A	253.0	191.0	5.1	12.7
IV	H	259.7	226.0	10.0	10.0
	H	258.5	220.9	11.1	12.7
	I	260.1	216.1	11.4	15.2
	I	260.8	215.2	11.5	12.5
	A	250.0	180.4	11.5	10.0
	A	240.5	177.2	15.8	10.0
V	I	277.2	253.1	8.0	8.8
	I	272.1	254.4	6.7	7.5
	I	275.0	256.4	3.5	10.2
	I	272.5	256.2	6.4	10.0
	A	238.1	198.6	6.8	9.2
	A	232.0	202.5	4.7	6.4
VI	I	274.6	246.8	12.6	15.1
	I	274.0	243.2	12.6	13.7
	I	270.0	242.5	11.6	16.2
	A	240.7	196.0	8.3	7.8
	A	237.5	190.7	8.0	7.8
VII	I	275.0	240.0	16.6	16.2
	I	273.7	240.6	15.3	17.5
	I	268.7	236.2	13.2	16.2
	I	270.0	237.5	15.0	16.2
VIII	I	274.6	239.2	15.3	16.4
	I	273.7	237.5	18.3	17.5
	I	273.1	243.5	12.1	14.1
	I	272.7	237.3	14.0	16.4
IX	I	273.7	238.7	14.1	16.2
	I	270.3	233.3	16.4	17.2
	I	272.5	236.2	18.0	17.5
	I	272.5	236.2	17.7	18.7
	A	254.1	197.3	10.9	10.6
	A	252.5	197.4	11.1	11.5

TABLE II—Continued

Heat number	Heat treatment	UTS (K s.i.)	0.2% YS (K s.i.)	Percent EL	Percent RA
X	I	262.5	227.5	10.0	13.0
	I	256.2	230.0	8.0	12.5
	I	271.7	240.3	9.7	11.5
	I	267.5	238.8	9.4	13.7
INCO 718	J	208.0	172.0	21.0	--------
D979	K	205.0	145.0	15.0	--------

Corresponding values for two presently known commercial alloys are appended in this and subsequent Tables for comparison.

INCO 718 has the following nominal composition (weight percent)

C	0.05
CR	18
Mo	3
Cb	5
Ti	1
Al	0.5
Fe	20
Ni	Balance

D979 has the following nominal composition (weight percent)

C	.05
Fe	27
Cr	15
Mo	4
W	4
Ti	3
Al	1
Ni	Balance

In Table II and in succeeding Tables, A, H, I, J and K, represent the following heat treatments:

A: 2175° F./4 hours/OQ+1200° F./24 hours/AC+1400° F./16 hours/AC

H: 1950° F./4 hours/OQ+1500° F./4 hours/AC+1300° F./16 hours/AC

I: 1300° F./50 hours/AC

J. 1750° F./1 hour/OQ+1325° F./8 hours Fce Cool to 1150° F./8 hrs./AC

K: 1850° F./4 hours/WQ+1550° F./6 hours+1300/6 hours/AC

TABLE III.—900° F. Tensile Test Results

Heat number	Heat treatment	UTS (K s.i.)	0.2% YS (K s.i.)	Percent EL	Percent RA
V	I	249.3	226.6	11.6	16.0
	I	249.3	221.3	12.1	16.0
	I	246.7	217.9	12.3	16.6
	I	247.3	218.4	16.7	18.4
	A	232.0	200.0	5.0	6.6
	A	233.3	193.3	7.8	12.9
VI	I	238.6	210.6	14.2	25.3
	I	237.9	212.0	15.8	21.5
	I	246.1	215.3	20.0	19.2
	I	241.7	170.8	16.8	17.7
	A	209.2	182.8	5.5	7.0
	A	223.6	184.2	8.0	14.4

TABLE III—Continued

Heat number	Heat treatment	UTS (K s.i.)	0.2% YS (K s.i.)	Percent EL	Percent RA
VII	I	234.6	204.0	19.2	22.6
	I	234.2	203.9	18.7	26.6
	A	236.3	193.5	9.5	10.3
	A	231.5	197.3	7.0	7.3
IX	I	234.1	205.0	16.0	21.5
	I	233.3	203.8	16.2	25.6
	A	226.6	188.0	7.7	13.3
	A	219.7	190.7	7.8	13.1
INCO 718	J	190.0	160.0	15.0	------
D979	K	190.0	137.0	18.0	------

When tested for stress rupture the results reported in Table IV were obtained.

TABLE IV

Heat number	Heat treatment	Stress rupture results: 1,200° F./150 K s.i. Life (hrs.)	1,200° F./150 K s.i. EL (percent)	1,400° F./85 K s.i. Life (hrs.)	1,400° F./85 K s.i. EL (percent)
III	H	37.5	4.0	------	------
	H	49.5	4.5	------	------
	I	93.1	4.5	------	------
	I	109.8	6.8	------	------
	I	89.2	7.5	------	------
	I	68.1	6.8	------	------
	A	------	------	58.6	2.4
	A	------	------	81.3	1.4
IV	H	119.2	3.6	------	------
	H	226.7	4.0	------	------
	I	276.9	6.5	------	------
	I	262.0	8.2	------	------
	I	271.0	4.5	------	------
	A	------	------	137.3	3.2
	A	------	------	94.6	2.5
V	I	4.17	5.8	------	------
	I	46.7	6.6	------	------
	I	20.8	4.4	------	------
	I	42.5	8.6	------	------
	A	------	------	80.9	3.5
	A	------	------	135.2	3.0
VI	I	65.4	7.5	------	------
	I	70.6	8.0	------	------
	I	76.0	8.0	------	------
	I	58.3	3.3	------	------
	A	------	------	159.5	2.0
	A	------	------	177.7	1.8
VII	I	59.4	7.3	------	------
	I	38.9	6.0	------	------
	I	39.3	8.0	------	------
	I	45.5	5.3	------	------
	A	------	------	35.2	1.2
	A	------	------	49.6	2.6
VIII	I	66.8	5.2	------	------
	I	62.2	4.8	------	------
	I	56.7	7.3	------	------
	I	52.5	8.9	------	------
	A	------	------	36.4	2.2
	A	------	------	213.2	(1)
IX	I	61.1	7.7	------	------
	I	52.0	1.0	------	------
	I	66.4	5.5	------	------
	I	72.3	6.0	------	------
	A	------	------	77.8	2.4
	A	------	------	94.6	1.4
X	I	44.9	5.0	------	------
	I	54.3	11.2	------	------
	I	55.8	7.3	------	------
	I	53.3	6.0	------	------
INCO 718	J	<5	------	------	------
D979	K	<5	------	------	------

[1] Not measured—Specimen stuck in grips.

When tested for low cycle fatigue strength, the results reported in Table V were obtained.

TABLE V

900° F. Low Cycle Fatigue Properties* for Alloy VIII

Load (P.s.i.)	Cycles To Failure
230	2,760
220	9,590
210	90,630
200	57,660
190	268,030

*Conditions of Tests:
I: Heat treatment
Load controlled
A: Ratio=1.0
Frequency=2.0 c.p.s.
K_t=1.0

The superiority of the powder alloy over the conventional D979 alloy is apparent in FIG. 1.

The properties of the wrought alloys of this invention are superior to the properties of otherwise similar alloys which were cast rather than wrought. This can be seen by comparing the properties reported in Table II, with similar tests in the above noted applications, the disclosures of which are intended to be incorporated by reference, and the results in Table VI.

TABLE VI.—COMPARISON OF ROOM TEMPERATURE TENSILE PROPERTIES

Alloy	Tensile strength (K s.i.)	0.2% yield strength (K s.i.)	Percent elong.
X [1] (With hafnium)	264.5	234.1	9.3
Prior art (cast) [2]	172.7	159.1	4.0
III [1] (without hafnium)	263.5	230.2	11.8
Prior art (cast) [2]	172.6	157.3	4.0

[1] Wrought alloys (X and III) heat treated—1,300° F. (50) AC.
[2] Cast alloys heat treated—2,050° F. (2) AC +1550° F. (4) AC +1400° F. (16) AC

We claim:

1. A wrought superalloy exhibiting high strength/density characteristic and excellent tensile and fatigue properties produced by powder metallurgy processing from particles of an alloy consisting essentially of the following composition in weight percent

C	maximum	0.30
Cr		11–15
Co		8–12
Mo		1–2.5
W		3–10
Ta		3.5–10
Hf		Up to 3
Ti		3.5–4.6
Al		3.0–4.0
Ti+Al		7–8
B		0.005–0.025
Zr		0.05–0.4

containing not more than 200 p.p.m. oxygen, less than 0.089% nitrogen and less than 0.75% Fe, the balance being essentially Ni; said powder metallurgy processing comprising at least the following:

consolidating particles of said alloy composition to form a billet; and

thereafter hot forging said billet to produce said wrought article.

2. A compressor disc formed of the alloy of Claim 1.

3. A turbine disc formed of the alloy of Claim 1.

4. A compressor blade formed of the alloy of Claim 1.

5. The wrought alloys of Claim 1 wherein the originally powdered composition comprises:

C	0.02–.25
Cr	11.5–13.75
Co	8–9.5
Mo	1.5–2.0
W	3.25–5.5
Ta	3.5–8
Hf	Up to 2.25
Ti	3.75–4.6
Al	3.0–4.0
Ti+Al	7–8
B	0.010–0.016
Zr	0.08–0.16

O_2, N_2, Fe as above, the balance being Ni.

6. A compressor disc formed of the alloy of Claim 5.

7. A turbine disc formed of the alloy of Claim 5.

8. A compressor blade formed of the alloy of Claim 5.

9. Articles formed by extrusion and subsequent forging of the powder alloys of Claim 1.

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WAYLAND W. STALLARD, Primary Examiner

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

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Inventor(s) Bruce A. Ewing and Frank J. Rizzo, Jr.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In column 5, Table III - Continued, Heat number VII, the second item in column "RA" should be changed from "26.6" to --- 26.3 ---, the fourth item should be changed from "7.3" to --- 7.8 ---, and the fifth item "8" should be deleted.

Column 6, line 44, after "superalloy" insert --- turbine or compressor component ---;

Column 6, line 72, delete "article" and substitute --- turbine or compressor component from said billet ---.

Column 7, line 1, delete "alloys" and substitute --- articles ---.

Signed and sealed this 5th day of November 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

PO-1050
(5/69)

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