United States Patent [19]

Niimi et al.

[11] 3,852,063

[45] Dec. 3, 1974

[54] **HEAT RESISTANT, ANTI-CORROSIVE ALLOYS FOR HIGH TEMPERATURE SERVICE**

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[22] Filed: **Oct. 4, 1972**

[21] Appl. No.: **294,981**

[30] **Foreign Application Priority Data**

Oct. 4, 1971 Japan 46-77651

[52] **U.S. Cl.** ..... **75/124,** 75/126 C, 75/126 D

[51] **Int. Cl.** **C22c 37/10,** C22c 39/14

[58] **Field of Search** 75/124

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[57] **ABSTRACT**

The present invention relates to a heat resistant anti-corrosive alloy characterized by good resistance to corrosion at high temperatures and high strength at high temperatures which is suitable as material for re-combustion-type emission gas purifiers such as thermal reactors, after-burners, more specifically to a metal alloy substantially composed of ferrite phase, its major components being:

carbon... below 0.15%
chrome...12–28%
molybdenum...0.2–3.0%
aluminum...0.3–6.0%
vanadium...0.1–3.0%
boron...0.0001–0.0050%
zirconium...0.01–1.0%
iron...balance
at least one of niobium and Tantalum...0.05–3.0%
Titanium...0.05–1.0%
Silicon...below 2.0%

and, if necessary with adequate additions of the following elements:

One or more than two from among rare earth elements such as yttrium, cerium lanthanum, calcium . . . 0.01–1.5%;

tungsten . . . 0.2–3.0 percent; beryllium . . . 0.01–2.0%.

4 Claims, 5 Drawing Figures

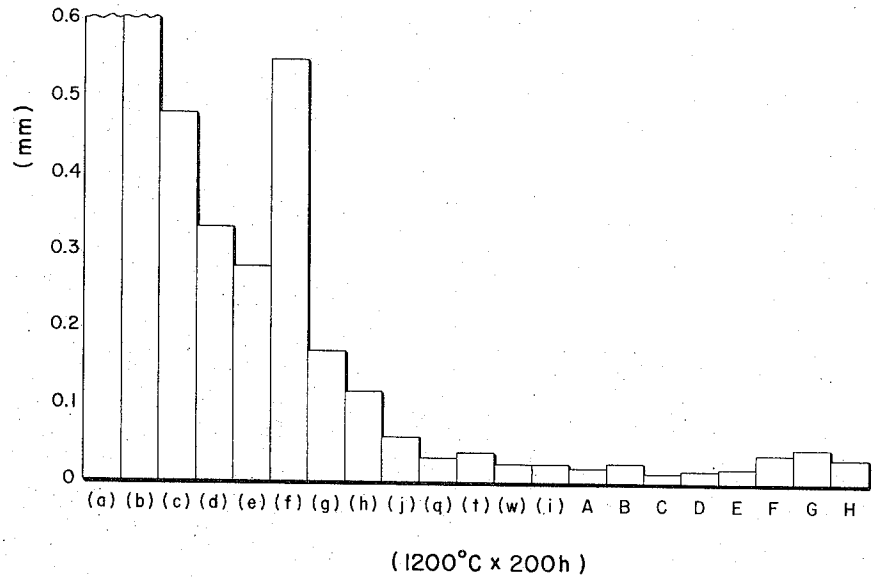


FIG. 1

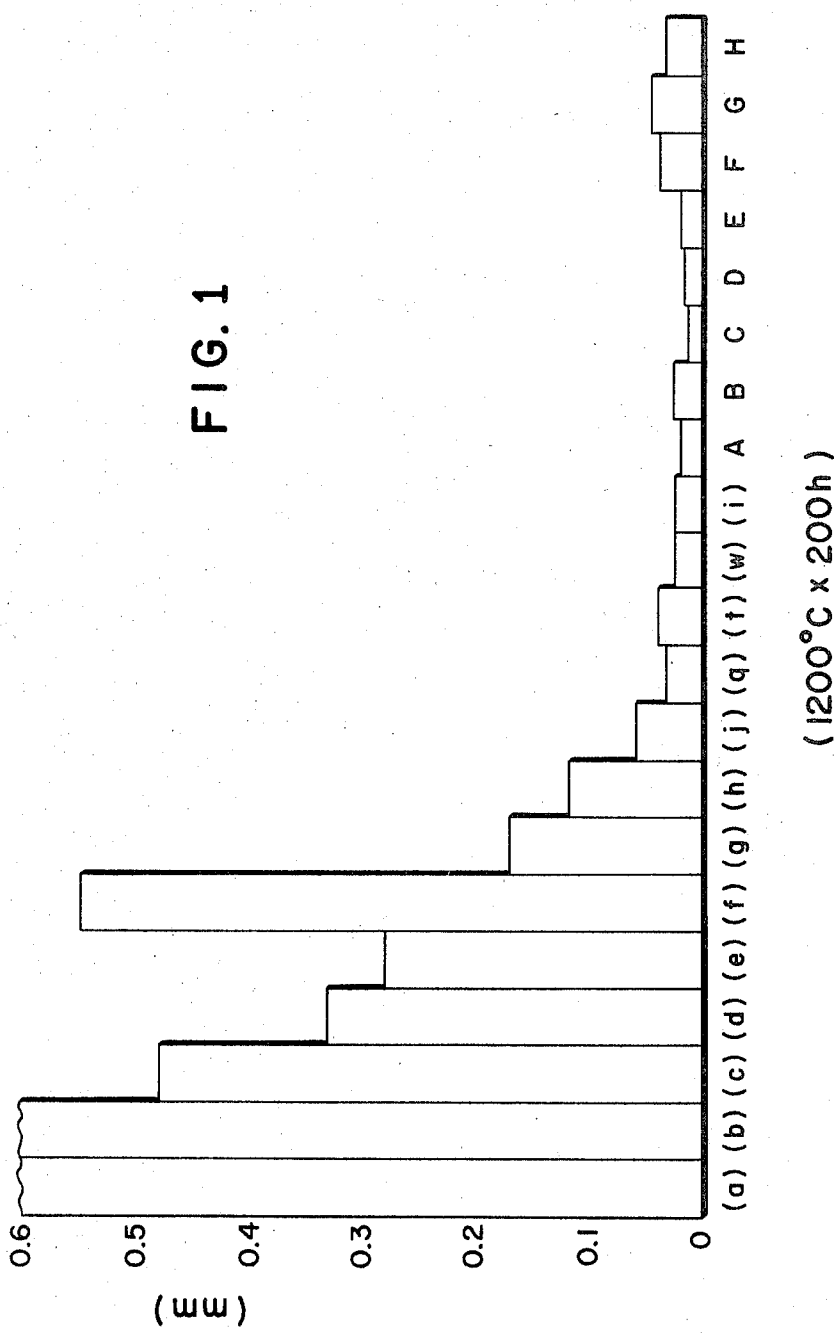


FIG. 2

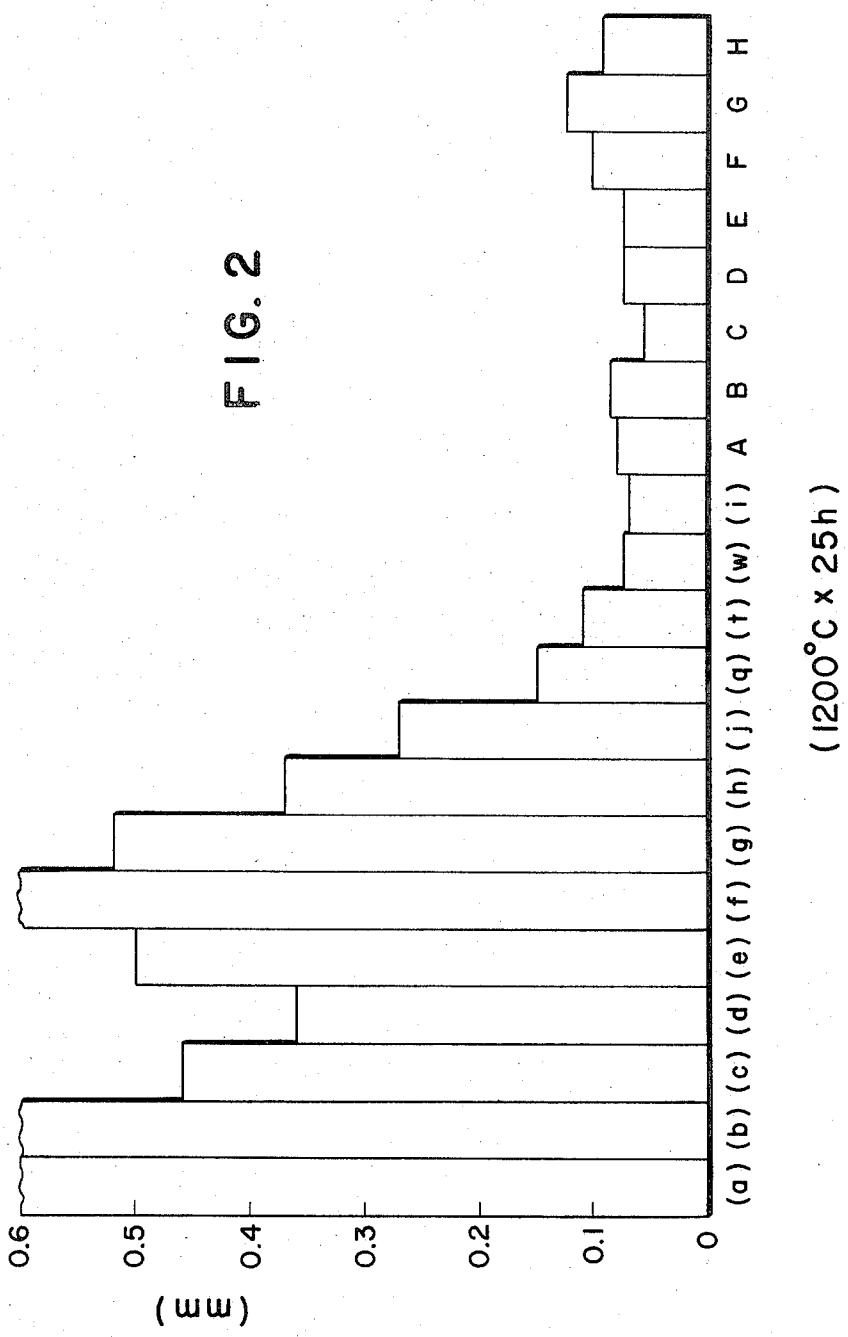
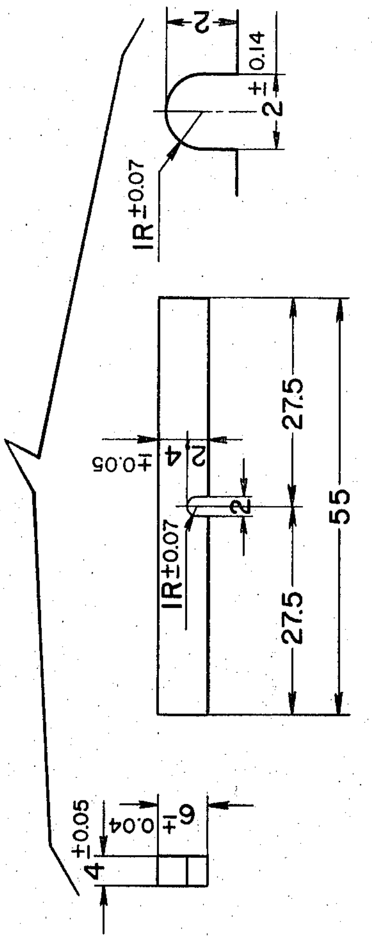


FIG. 5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2
2 ± 0.14
4 ±0.05
2
27.5
27.5
55
9 ± 0.04

FIG. 3

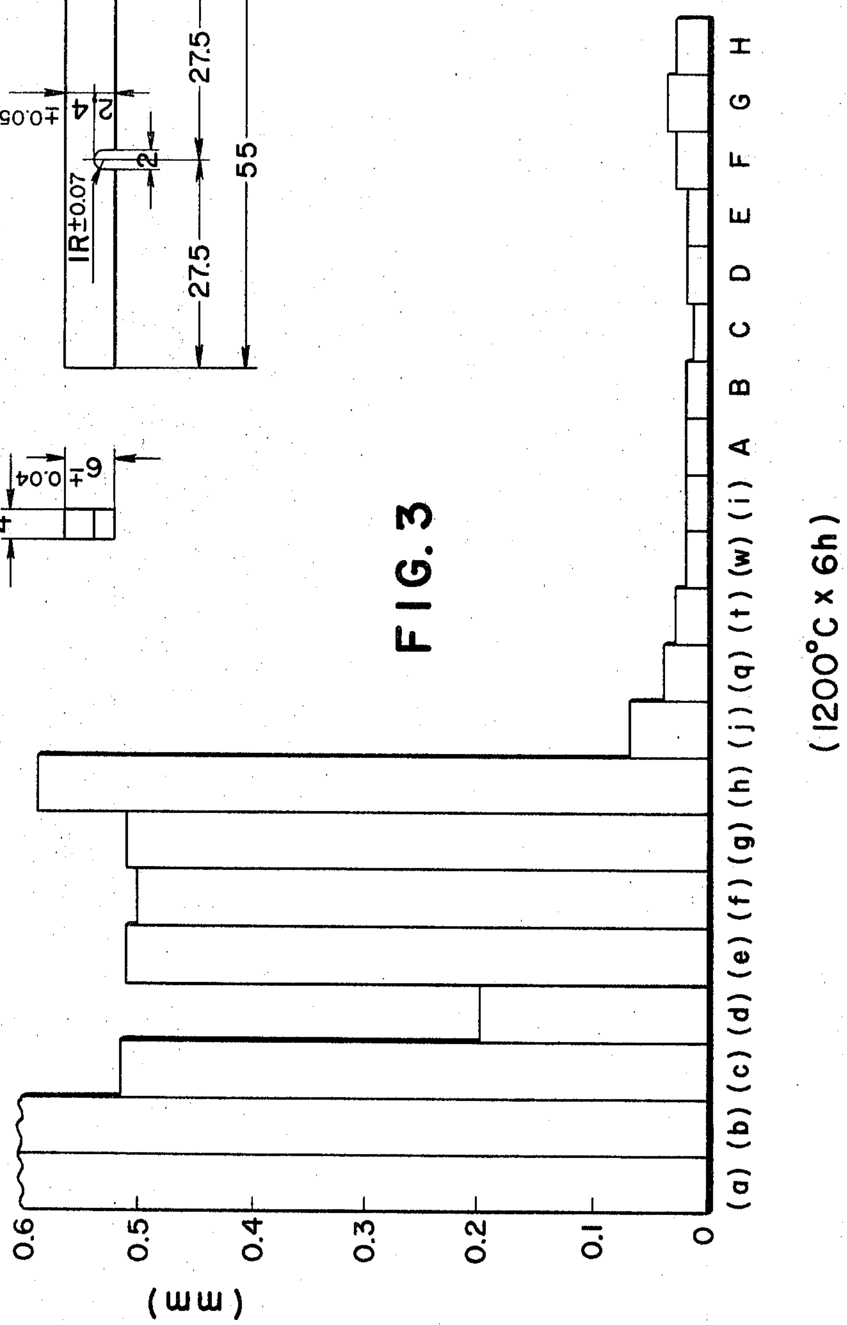
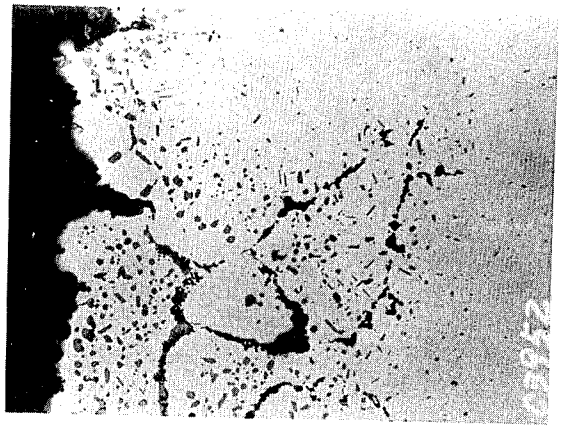

(mm)
0.6
0.5
0.4
0.3
0.2
0.1
0
(a) (b) (c) (d) (e) (f) (g) (h) (j) (q) (t) (w) (i) A B C D E F G H
(1200°C x 6h)

FIG. 4



HEAT RESISTANT, ANTI-CORROSIVE ALLOYS FOR HIGH TEMPERATURE SERVICE

BACKGROUND OF THE INVENTION

Both abroad and at home, the control of auto emission gases has come to be enforced with increasing stringency year after year. To accomplish such control effectively, it is necessary to equip the conventional internal combustion gasoline engine with new devices for emission gas purification such as thermal reactors, after burners, catalyst muffers or E.G.R. (exhaust gas recirculation) or to try engine modifications.

In the re-combustion type emission gas purifier which has to work at a maximum temperature of 1,200°C, its component members, which are exposed to high temperature combustion gases, must be able to satisfactorily withstand the oxidation due to CO_2, H_2O and residual O_2 contained in these gases and the high temperature corrosion due to PbO, S, SO_2 or P contained in them. Besides, to assure ample durability of the apparatus itself, its members have to be strong enough at high temperatures.

As materials for thermal reactors and after burners, Fe-Cr-Al alloys conventionally employed in furnace heaters or various heat-resistant stainless alloys are conceivable. The conventional Fe-Cr-Al alloys excel in high temperature corrosion resistance, but they have the drawbacks that they are liable to become brittle in high temperature service through coarsening of crystals and they lack high temperature strength. Meanwhile, austenitic stainless alloys and nickel base heat-resistant alloys, characterized by excellence high temperature strength, lack in high temperature corrosion resistance and accordingly they need surface treatment; or they are so expensive that they are found unfit for mass production.

The present inventors, setting an eye on the excellence of Fe-Cr-Al alloys in their high temperature corrosion resistance, investigated how to improve these alloys in the coarsening of their crystals and consequently from their investigation have successfully perfected the present invention of an alloy with remarkably better characteristics of high temperature corrosion resistance than that of the conventional austenitic stainless alloy or nickel base heat-resistant alloy, and better characteristics of high temperature strength, crystal coarsening and moldability than those of the conventional Fe-Cr-Al alloys.

SUMMARY OF THE INVENTION

The object of the present invention is to provide an alloy suitable as material for component members of a re-combustion-type emission gas purifier which is characterized by excellence in high temperature corrosion resistance, high temperature strength, crystal coarsening characteristics and moldability, the major alloying elements to constitute this alloy to attain this object being:

carbon	below 0.15%	zirconium	0.01–1.0%
chrome	12–28%	iron	balance
molybdenum	0.2–3.0% at least one of niobiam and		
tantalum	0.05–3.0%		
titanium	0.05–1.0%		
silicon	below 2.0%		
aluminum	0.3–6.0%		
vanadium	0.1–3.0%		
boron	0.0001–0.0050%		

and, if necessary, the following elements being adequately added:

One or more than two from among rare earth elements such as yttrium, cerium, lunthanum, calcium 0.01–1.5%;

tungsten 0.2–3.0 percent; beryllium 0.01–2.0%.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram showing the results of comparison in anti-oxidization characteristics between the invented alloy and various conventional heat-resistant anti-corrosive alloys,

FIG. 2 is a diagram showing the results of comparison in corrosion resistance in a hot atmosphere of lead oxide between the invented alloy and various conventional heat-resistant anti-corrosive alloys,

FIG. 3 is a diagram showing the results of comparison in corrosion resistance in a hot atmosphere of sulphur between the invented alloy and various conventional heat-resistant anti-corrosive alloys,

FIG. 4 is a micrograph showing an intercrystalline corrosion recognized in an austenitic alloy (SUS 41) which has been etched by hot sulphur,

FIG. 5 schematically illustrates a specimen used in a Charpy test of the invented alloy.

DETAILED ACCOUNT OF THE INVENTION

The present invention relates to an alloy characterized by excellence in high temperature oxidation resistance, high temperature corrosion resistance in an atmosphere of lead oxide or sulphur and high temperature strength which can be applied as material for heat-resistant members in various re-combustion-type emission gas purifiers and for vessels in a catalyst muffler, for engine parts exposed to hot emission gases, for components of gas turbine combustion chambers and for furnace heaters.

The invention alloy is substantially constituted by a ferrite phase, its chemical composition being broadly as follows

carbon	below 0.15%	silicon	below 2.0%
chrome	12–28%	aluminum	0.3–6.0%
molybdenum	0.2–3.0%	vanadium	0.1–3.0%

at least one of niobium and

tantalum	0.05–3.0%	boron	0.0001–0.0050%
titanium	0.05–1.0%	zirconium	0.01–1.0%
		iron	balance

and if necessary, the following elements being added in adequate quantities:

One or more than two from amoung rare earth elements such as yttrium, cerium, lanthanum, calcium . . . 0.01–1.5%;

tungsten . . . 0.2–3.0 percent; beryllium . . . 0.01–2.0%

The invented alloy is substantially a ferrite base alloy with major additions of Cr and Al. Its high temperature strength has been improved mainly through solid solution treatment with Mo, V, Ta, B, Be and partially through precipitation. Moreover, improvements on crystal coarsening characteristics, elongation at room temperature, tonghness and high temperature corro-

sion resistance have been attained through addition of Ti, Zr as well as the above-mentioned elements.

Table 1 summarizes the functional effects of the various elements chosen as additives in the course of developing the invented alloy.

As seen from Table 1, B, Be, Mo, Ta, Nb and V are found particularly effective for enhancing the high temperature strength and B, Be, Mo, Ta, Ti and Zr are for preventing the crystals from being coarsened. Meanwhile, room temperature elongation can be effectively improved by addition of Ta in a small amount, but it is markedly reduced by addition of Si or excessive addition of B. Addition of Y greatly improves the impact withstanding characteristics. Addition of Cr, Al, Y is effective for improving the anti-oxidation, anti-lead oxide, and anti-sulphur characteristics, but excessive addition of B is harmful.

TABLE 1

Effects of various additives in the invented alloy on various characteristics.

TABLE 1.—EFFECTS OF VARIOUS ADDITIVES IN THE INVENTED ALLOY ON VARIOUS CHARACTERISTICS

Characteristics	Elements												
	C	Si	Cr	Al	Mo	Ta	Nb	V	Ti	Zr	B	Be	Y
High temperature strength	○	△	○	○	ⓞ	ⓞ	ⓞ	ⓞ	□	□	ⓞ	ⓞ	△
Crystal coarsening	□	□	□	○	ⓞ	ⓞ	□	□	○	○	ⓞ	ⓞ	○
Room temperature elongation	△	X	△	△	□	ⓞ	□	△	□	□	△ ≦0.0050 X ≧0.0050	□	□
Impact strength	△	△	△	△	○	△	○	□	○	□	△	□	ⓞ
Antioxidation	△	○	ⓞ	ⓞ	□	□	□	□	△	□	□ ≦0.0050 X ≧0.0050	△	ⓞ
Anti-lead oxide	△	△	ⓞ	ⓞ	□	□	△	□	□	□	□ ≦0.0050 X ≧0.0050	□	○
Anti-sulphur	△	○	ⓞ	ⓞ	□	□	□	□	□	□	□ ≦0.0050 X ≧0.0050	□	○

NOTE.—Mark ⓞ means that the relevant characteristic has been vastly improved. ○ means that the effect, though not conspicuous, is positive. □ means that the effect is insignificant or practically Zero. △ means that the effect is rather negative. X means that the effect is markedly negative.

TABLE 2

Chemical compositions of alloys tested.

Specimen codes	Chemical elements	C	Si	Mn	P	S	Cr	Al	Ni	Others	Remarks
a(conventional alloy)		0.06	0.57	0.46			16.51				(SUS24)
b(do.)		0.05	0.82	1.09			18.29		9.20		(SUS27)
c(do.)		0.07	0.72	1.40			22.40		12.85		(SUS41)
d(do.)		0.06	1.05	1.68			24.74		19.89		(SUS42)
e(do.)		0.07	0.67	0.95			19.90		32.45		(Incolloy800)
f(do.)		0.05	0.56	0.62			21.39		45.10	Fe	(Hastelloy X)
g(do.)		0.02	0.46	0.53			15.70		Bal	8.48 Fe	(Inconell600)
h(do.)		0.05	0.25	0.94	04959		19.80		Bal	0.63 Ti Zr	(Nimonick 75)
i(do.)		0.06	0.44	0.82	0.032	0.008	19.65	3.72	0.06	0.34 0.11	(FCH_2)
j(tentative alloy)		0.01	0.08	≦0.1	0.007	0.012	16.23	1.92	0.08	—	(Conventional alloy)
k(do.)		0.01	0.05	do.	0.006	.006	16.60	1.77	0.01	0.16 Zr	
l(do.)		0.01	0.05	do.	0.005	0.012	15.60	2.48	0.03	0.11 Ti	
m(do.)		0.01	0.06	do.	0.007	0.011	16.08	2.29	0.04	0.93	
n(tentative alloy)		0.01	1.36	do.	0.005	0.015	16.32	2.03	≦0.1	— B	
o(do.)		0.01	0.71	do.	0.005	0.011	16.24	2.55	do.	0.0014 Ti Y	
p(do.)		0.01	1.01	do.	0.006	0.009	16.23	2.28	do.	0.20 0.18	
q(do.)		0.01	0.06	≦0.1	0.007	0.012	15.47	4.60	≦0.1	—	(conventional alloy)
r(do.)		0.01	0.02	do.	0.003	0.012	16.49	4.32	do.	Ti 0.14	
s(do.)	0.01	0.03	do.	0.003	0.012	16.53	4.17	do.	1.29	V	
t(do.)		0.01	0.09	do.	0.006	0.015	20.86	1.91	do.	—	(conventional alloy)
u(do.)		0.01	0.02	do.	0.007	0.012	20.56	2.08	do.	Mo 1.00	
v(do.)		0.01	0.04	do.	0.004	0.016	20.11	1.74	do.	Nb 1.44	
w(do.)		0.01	1.30	do.	0.005	0.014	21.10	4.22	do.	—	(conventional alloy)
x(do.)		0.01	0.66	do.	0.004	0.012	20.81	4.27	do.	Be 0.12	
y(do.)		0.01	0.06	do.	0.005	0.014	21.09	4.12	do.	B 0.37	
z(do.)		0.01	0.09	do.	0.003	0.011	21.13	4.31	do.	Ti B 0.05 0.70	

TABLE 2 – Continued

Chemical compositions of alloys tested.

Specimen codes	Chemical elements	C	Si	Mn	P	S	Cr	Al	Ni	Others	Remarks
A(Invented alloy)		0.06	0.38	0.55	0.014	0.011	17.33	2.82	0.24	Mo V Ti Zr Nb+Ta Y 1.00 0.57 0.41 0.17 0.12 0.03	
B(do.)		0.05	0.43	0.68	0.009	0.006	16.75	2.76	0.19	Mo V Ti Zr Nb+Ta Y 1.06 0.52 0.36 0.16 0.52 0.04	
C(do.)		0.07	0.36	0.63	0.013	0.008	16.98	3.13	0.23	Mo V Ti Zr Nb+Ta Y 1.00 0.58 0.39 0.18 0.12 0.37	
D(do.)		0.06	0.29	0.62	0.014	0.014	20.08	3.00	0.20	Mo V Ti Zr Nb+Ta B 0.50 0.56 0.37 0.16 0.49 0.0009	
E(do.)		0.06	0.31	0.62	0.014	0.014	20.21	2.90	0.20	Mo V Ti Zr Nb+Ta B 1.00 0.56 0.41 0.17 0.50 0.001	
F(do.)		0.06	0.29	0.66	0.014	0.018	19.99	2.72	0.26	Mo V Ti Zr Nb+Ta B 0.51 1.10 0.41 0.14 0.48 0.0009	
G(do.)		0.06	0.27	0.62	0.014	0.016	19.99	3.05	0.29	Mo V Ti Zr Nb+Ta B 1.11 1.08 0.40 0.16 0.51 0.0007	
H(do.)		0.06	0.32	0.64	0.013	0.014	19.98	3.07	0.20	Mo V Ti Zr Nb+Ta B 0.53 0.54 0.38 0.16 0.47 0.0006	Be 0.07

In the following, the features of the invented alloy will be described in examples of testing.

Table 2 is a list of chemical compositions of specimens tested. Among them, the specimen (a) –(h) are conventional commercial heat-resistant stainless alloys, while (i)–(z) are some of the tentative Fe-Cr-Al alloys obtained for development of the invented alloy; among them, (i), (j), (q), (t) and (w) are conventional Fe-Cr-Al alloys. The invented alloy is represented by the specimens (A)–(H).

In FIGS. 1–3 and Table 3, the characteristics of the invented alloy and various specimens are compared. FIG. 1 shows the etched depths of various alloys as measured after being submitted to 200 hours of oxidation in an alumina boat in an atmospheric furnace preliminarily heated to 1,200°C; these depths represent the high temperature oxidation characteristic of these alloys. It is evident from FIG. 1 that some of the commercial heat-resistant stainless alloys, for instance, the specimens (g) (h) exhibit considerably good anti-oxidation characteristic, but even compared with them, the invented alloy as well as the known Fe-Cr-Al alloys is far superior in this characteristic. It should be noted, however, that in the case of Fe-Cr-Al alloys the contents of Cr and Al affect the anti-oxidation characteristic to a certain extent, but the invented alloys (A)–(C) and the tentative alloys (K) and (P), which contain Y and are added with relatively little Cr and Al, exhibit a remarkable excellence in his characteristic — which is a striking feature when it is recalled that in the case of Fe-Cr-Al alloys, reduced contents of Cr and Al vastly improve the moldability.

FIG. 2 shows the etched depths of various alloys which represent their corrosion resistance in a hot atmosphere of P_b O, as measured after these alloys had been washed, degreased, coated with a slurry mixture of Pb O powder and waterglass solution(water: water glass=4:1) in volume ratio of 1:3; placed in an alumina boat; and then held for 25 hours in a furnace preliminarily heated to 1200°C.

In nearly the same way as in the results of anti-oxidation test, all Fe-Cr-Al alloys including the known ones and the invented one are superior in corrosion resistance in a hot atmosphere of Pb O to any of the conventional commercial heat-resistant stainless alloys.

Similarly, FIG. 3 shows the etched depths of the specimens which represent their corrosion resistance in a hot atmosphere of sulphur, as measured after the specimens were coated with a slurry mixture of powder sulphur and waterglass solution (water: waterglass = 1:1) in volume ratio of 1:3; placed in an alumina boat; and held for 6 hours in a furnace preliminarily heated to 1,200°C.

These results, just as those of oxidation tests and hot Pb O corrosion tests, point to the superiority in corrosion resistance in a hot atmosphere of sulphur of Fe-Cr-Al alloys including the known ones and the invented one to any of the conventional commercial stainless alloys or heat-resistant alloys; and these Fe-Cr-Al alloys are found free from any intercrystalline corrosion in FIG. 4 which is recognized in a sulphur-etched austenitic alloy or nickel base alloy.

Table 3 summarizes the characteristics of the conventional Fe-Cr-Al alloys and the invented Fe-Cr-Al alloy, such as strength at room temperature and at high temperature; elongation at room temperature; impact strength; and crystal coarsening. As seen from this Table, the invented alloys (A)–(H) are remarkably better in high temperature strength characteristic than any Fe-Cr-Al alloy in the prior art; particularly the alloy (H) is about two times superior to any one of the conventional (j), (q), (t), (w) and (i).

This is probably due to the great effects of B, Be, Mo, Ta, Nb and V, as testified by the performances of the tentative alloys (o), (r), (s), (u), (v), (x), (y) and (z); to be more specific they are mainly the effect of solid solution by invasion in the case of B, that of solid solution by substitution in the case of the other elements; and partly that of precipitation of carbides.

Concerning the room temperature elongation characteristic, the contents of Cr, Al and particularly that of Al are supposed to made great contributions; in this characteristic, the invented alloys are generally superior to the known (i), (j), (q), (t) and (w). This is, as suggested by the performances of the tentative alloys (r), (n), (o), (s), presumably due to the addition of Ta being small and those of B, Si and V being well controlled.

The impact strength mentioned in the Table is expressed by the energy absorption needed to break a

specimen of a special shape indicated in FIG. 5, using a 5 kg-m small size Charpy impact tester, as divided by the original cross-sectional area of the specimen.

The contributions of Cr, and Al — particularly the latter — to this impact strength are supposedly immense; the invented alloys are in general superior in this strength to any of the known (i), (j), (g), (t) and (w) which contain the same amounts of Cr and Al as the invented alloys. As suggested by the performances of tentative alloys, this seems to be due to additions of Y and Mo and restrictions of Si, B and V contents. It is noteworthy, as suggested by the performances of the tentative alloy (k) and the invented ones (A) (B) and (C), that the alloys added with Y are markedly improved in impact strength.

The crystal coarsening characteristic in Table 3 is expressed in terms of temperatures at which the ferrite crystal size becomes less than 1 when each alloy specimen has been held for 25 hours in the range of 800°–1,200°C at intervals of 50°C and then observed for coarsening of crystals as the results of heating. An increase in the contents of Cr and Al is apt to be accompanied by a slight rise in the coarsening temperature, but in the case of the invented alloys the coarsening temperature is definitely high even with the contents of Cr and Al remaining unchanged; this is supposed, as testified by the performance of tentative alloys, to come from the fact that the invented alloys contain Y, B, Ta, Mo and Be, i.e., the elements which are effective for raising the level of the coarsening temperature.

TABLE 3

Comparison of various properties among different Fe-Cr-Al alloys (known, tentative and invented)

Specimen codes	High temperature tensile strength Kg/mm²	Room temperature elongation %	Impact Strength Kg.m/col	Crystal coarsening temperature (°C)
(i)known	4.7	8	3.1	1150
(j)tentative	4.3	32	5.7	1050
(k) do.	4.1	36	14.5	1150
(l) do.	4.9	32	5.7	1100
(m) do.	4.9	36	8.1	1050
(n) do.	4.2	20	4.6	1000
(o) do.	5.7	10	3.5	1200 up
(p) do.	4.4	30	4.6	1100
(q) do.	4.7	10	4.6	1100
(r) do.	5.8	44	3.5	1200
(s) do.	5.9	22	3.5	1100
(t) do.	4.8	26	7.0	1100
(u) do.	5.4	32	10.2	1200 up
(v) do.	5.8	28	11.6	1100
(w) do.	5.0	6	2.7	1100
(x) do.	5.9	4	2.4	1200 up
(y) do.	5.8	4	2.7	1200 up
(z) do.	5.7	4	2.7	1200 up
(A)invented	5.9	42	6.8	1200 up
(B) do.	7.6	37	8.8	1200 up
(C) do.	6.4	39	13.3	1200 up
(D) do.	7.4	28	4.8	1200 up
(E) do.	8.3	27	4.3	1200 up
(F) do.	7.3	35	4.2	1200 up
(G) do.	8.7	25	4.1	1200 up
(H) do.	9.2	18	3.7	1200 up

Next, the functional effect of each element contained in the invented alloy and the limitation of its content are to be discussed in detail.

The ferrite structure of the invented alloy, as compared with the austenitic alloy, makes the coefficient of thermal expansion of the invented alloy so low that in service as a thermal reactor, the invented alloy receives less thermal strain due to heating and cooling and accordingly suffers less thermal fatigue.

Carbon as a solid solution constitutes a part of the alloy and strengthens it. As combined with elements such as Mo, V, Nb, it forms carbides, which contribute to the strengthening of the alloy, but its content should be limited to less than 0.15 percent, because too much carbon is likely to cause intercrystalline and intracrystalline precipitations of carbides (or nitrides) heated in the process, after permeating the carbon into the texture in the form of a solid solution; and thus, corrosion resistance is reduced through lack of Cr in the vicinity of the precipitates and with this, the moldability too becomes poor.

Si is effective for improving anti-oxidation, anti-sulphur and anti-PbO characteristics, but Si not as effective as Cr or Al. Meanwhile Si is likely to cause heavy deterioration in the moldability at room temperature and impact strength if used in large quantities. Thus, it is advisable to limit its content to less than 2 percent.

Cr as a solid solution in the texture is indispensable for giving heat resistance and anti-oxidation characteristics to the alloy and securing its ferrite structure.

Thus, its content should be more than 12 percent, but should not exceed 28 percent, because its excess deteriorates the moldability or weldability and is likely to cause 475°C brittleness and σ-phase precipitation.

The favorable effect of Al on anti-oxidation, anti-sulphur and anti-PbO characteristics is prominent and its effect on high temperature strength, though insignificant, is also recognized. Its effects, however, are not so great when its content is to little. Thus, 0.3 percent is the lower content limit on the contrary if 6 percent is exceeded, the moldability and weldability are adversely affected to a great degree.

Mo, partly as a solid solution in the texture and partly as a carbide, is found useful for strengthening the alloy and preventing the coarsening of its crystals.

Too much Mo, however, results in deterioration of

the anti-oxidation characteristic and corrosion resistance at high temperatures. The appropriate content of Mo would be 0.2–3.0 percent. W exhibits a similar effect as Mo, so a partial or whole content of Mo may be substituted by W.

V, similarly to Mo, serves to strengthen the alloy partly through its effect as a solid solution in the texture and partly through its effect as a carbide. Too much V, however, will result in reduction of its elongation at room temperature, its impact strength and its corrosion resistance at high temperatures such as its anti-oxidation characteristic. Thus, the recommendable content of V should be 0.1–2.0 percent.

Ta, when added to Fe-Cr-Al alloys, behaves uniquely; thereby a small amount of Ta can improve the high temperature strength, the crystal-coarsening characteristic and the room temperature elongation; but its excessive addition will heavily reduce the impact strength of the alloy. Thus, the right addition of Ta should be 0.05–3.0 percent. The effect of Nb is nearly the same as that of Ta. Besides, it would be so difficult to make separate use of Nb and Ta that a part of Ta addition might be substituted by Nb.

B as a very small addition, can make a remarkable improvement on the high temperature strength, but too much addition of B will result in heavy deterioration. The room temperature elongation, anti-oxidation, anti-sulphur and anti-Pb O characteristics. The appropriate addition of B should be 0.0001–0.0050 percent.

Y as a very small addition can improve the bonding of a protective film at high temperature heating and vastly enhance the high temperature anti-oxidation and anti-Pb O characteristics. Whereas in Fe-Cr-Al alloys when they contain relatively low amounts of Cr and Al (Cr $\leqq$ 15%, Al $\leqq$ 3%) they develop local and accelerated corrosion due to imperfectness of the protective film of α-Al_2O_3 which should bring about a high corrosion resistance at high temperatures, in the case of the invented alloy with a Y-content, this film can be compact and can adhere well to the base metal, thereby compensating for the imperfectness of the film and exhibiting an excellent characteristic of high temperature corrosion resistance. Y is an expensive metal; its addition exceeding 1.5 percent will not be so effective as might be expected and thus, 0.01–1.5 percent will be the limits of its addition. Meanwhile, rare earth elements other than Y, i.e., Ce, La, Ca are practically as effective as Y and accordingly, a partial or whole addition of Y may be substituted by rare earth elements such as Ce, La, Ca.

Ti is an element which is added to the conventional Fe-Cr-Al alloys, too; it is found effective through formation of TiC for fixation of solid-solution carbon or prevention of crystal coarsening. Since too much Ti is likely to deteriorate the anti-oxidation characteristic and impact strength of the alloy, it has been limited to 0.05–1.0 percent.

Zr, just like Ti, is an element added to the conventional Fe-Cr-Al alloys, too. For the purpose of preventing the crystal coarsening its addition should be more than 0.01 percent, but it is an expensive metal; moreover, its excessive addition is likely to result in poor elongation at room temperature and lower impact strength. Thus, its appropriate addition should be from 0.01–1.0 percent.

Be is also known as an element which as a very small addition can vastly enhance the high temperature strength and can serve to prevent the coarsening of crystals. Accordingly, it constitutes one of the essential elements for the invented alloy, but it is extremely costly; besides, too much Be will deteriorate the room temperature elongation and the impact strength. Thus, the optimum addition of it should be 0.01–2.0 percent.

What is claimed is:

1. A heat-resistant, anti-corrosive alloy for high temperature service, said alloy consisting essentially of:
- less than 0.07 percent by weight carbon,
- less than 0.5 percent by weight silicon,
- 15 to 21 percent by weight chromium;
- 2.5 to 4.0 percent by weight aluminum,
- 0.5 to 1.2 percent by weight molybdenum,
- 0.5 to 1.1 percent by weight vanadium,
- less than 0.45 percent by weight titanium,
- less than 0.18 percent by weight zirconium,
- 0.1 to 0.5 percent by weight of an element selected from the group consisting of niobium and tantalum,
- at least one element selected from the group consisting of:
  - yttrium in an amount less than 1.5 percent by weight,
  - beryllium in an amount less than 2.0 percent by weight,
  - and boron in an amount less than 0.0050% by weight;
- and the balance of iron and inevitable impurities.

2. The alloy of claim **1**, wherein yttrium is present in an amount in the range of 0.03–0.4 percent by weight.

3. The alloy of claim **1**, wherein beryllium is present in an amount in the range of 0.0006–0.001 percent by weight.

4. The alloy of claim **1**, wherein at least one element selected from the group consisting of boron and beryllium is present in an amount less than 0.008 percent by weight.

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