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HIGH-TEMPERATURE ALLOY

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This invention relates to forgeable high-temperature, high-strength alloys, and more in particular to chromium-iron systems suitable for use in high-strength, high-temperature applications such as are required for turbine buckets in turbojet aircraft engines.

The best present-day, high-temperature alloys from the standpoint of mechanical properties are cobalt-base and nickel-base alloys. However, nickel and cobalt are not available in sufficient quantities for unlimited use in high-temperature applications.

Chromium is relatively more abundant than either cobalt or nickel, and sufficient quantities would be available for large-scale production of high-temperature, high-strength equipment. Various chromium-iron systems have previously been known for good high-temperature strength, but in the past these systems have been characterized by low ductility, particularly at low temperatures.

It is, therefore, an object of this invention to provide a high-temperature, high-strength alloy with a minimum of critical materials.

It is also an object of this invention to provide a high-strength, high-temperature, chromium-iron alloy with improved low-temperature ductility.

Another object of this invention is to provide a chromium-iron alloy containing at least 60% chromium, and characterized by high strength and good ductility at high temperatures.

A further object of this invention is to provide an alloy at a reduced cost for use in turbine buckets of turbojet aircraft engines.

Still another object of this invention is to provide a high-strength, high-temperature, chromium-iron alloy with increased corrosion resistance.

Further objects and advantages of this invention will become apparent from the following specifications and the appended claims.

It has generally been considered that chromium-iron alloys containing greater than 60% chromium are too brittle to be useable in high-temperature, high-strength applications. In accordance with the present invention, however, it has been found that the use of chromium in greater amounts than 60%, in combination with certain other elements, produces a chromium-iron alloy that has exceptional high-temperature strength and is sufficiently ductile to have practical usefulness. The alloy of the present invention has the following composition:

	Percent
Chromium	60–80
Molybdenum	5–11
Titanium	1.4–2
Aluminum and additional titanium	up to 1
Iron	balance

Molybdenum is added to this alloy primarily to impart high-temperature mechanical strength. The amount of molybdenum which is present in the alloy of the persent invention, however, is limited by the fact that further increases in the molybdenum content tend to cause the alloy to be unforgeable. Thus, as the molybdenum content increases, the forgeability decreases. Tungsten, vanadium, or cobalt may be substituted for all or part of the molybdenum, although cobalt is not preferred since it is not readily available.

In high-chromium alloys of this type, it is necessary to provide some means during melting for eliminating the effects of oxygen and nitrogen in the alloy. This function is here accomplished by small amounts of titanium, which acts, in part, as a nitrogen and oxygen fixer. The amount of titanium required in order to sufficiently fix the nitrogen and oxygen of the alloy is not large, and it has been found that, in the alloys of the present invention, an amount of about 1.4 to 2.0% is sufficient for this purpose. Greater amounts of titanium than 2.0% do not materially affect this function. However, increased titanium content up to about 3.0% has the effect of enhancing the surface stability of the alloy, and thus increasing its oxidation resistance at high temperatures. Thus, the titanium content of the alloy serves two functions, fixing the oxygen and nitrogen, and enhancing the surface stability. Titanium content greater than 3.0% tends to reduce the forgeability of the alloy. The latter function may also be accomplished by substituting aluminum or silicon, all or in part, for the titanium content. Thus the composition of the alloy may be as follows:

	Percent
Chromium	60–80
Molybdenum, vanadium, and tungsten	5–11
Titanium	1.4–2
Aluminum, silicon, and additional titanium	up to 1
Iron	balance

While in the past it has been indicated that small amounts of titanium in high-chromium alloys improve the stress-rupture characteristics of cast alloys, these additions have not been known to improve the cold malleability of such alloys, and high-chromium alloys in the past have been characterized by extreme brittleness at room temperatures. Because of this lack of malleability, such alloys were not useful from a practical standpoint. However, in the alloy of the present invention, the addition of titanium has been found to improve the cold malleability to such an extent that the alloy is satisfactory for use in turbine buckets of turbojet aircraft engines.

The additions of titanium to the alloy of the present invention have also been found to improve the forgeability of the alloy. An alloy containing 70 parts of chromium, 30 parts of iron, 3 parts of molybdenum, 3 parts of vanadium, 3 parts of tungsten, and 0.1 part of carbon was found to be forgeable when it contained about 1.75 percent titanium, but cracked on forging when it contained only about 0.85 percent titanium. Similarly, alloys containing 70 parts chromium, 30 parts iron, 4 parts molybdenum, 4 parts vanadium, 4 parts zirconium, and 0.1 part carbon, and alloys containing 70 parts chromium, 30 parts iron, 4 parts molybdenum, 4 parts vanadium, 4 parts tungsten, and 0.1 part carbon were found to be forgeable when they contained about 1.75 percent titanium, but cracked on forging when they contained only 0.85 percent titanium. The latter two alloys are mentioned here only from the standpoint of showing the effect of titanium in improving forgeability, and they do not possess sufficient strength to be useable.

Special melting techniques are necessary with this alloy in order to reduce the oxygen and nitrogen content of the ingots. Satisfactory results can be obtained when the alloy is melted under a lime-alumina or a lime-alumina-magnesia slag. An argon blanket may be used over the slag, although such a blanket is not necessary. This slag-melting process holds to a minimum the amounts

of nitrogen and oxygen entering the melt from the air. The slag removes oxygen from the melt as chromium oxides which react with metallic aluminum added to the slag. The products of this reaction are aluminum oxides, which remain in the slag, and chromium metal which returns to the melt. The aluminum metal may be added to the slag in any convenient form, such as granules or chips.

The alloys may be heated for forging by heating them slowly to 1600° F., holding them at 1600° F. for one to to two hours, and then heating them to a forging temperature of from 2250° to 2400° F. After forging, various heat treatments have been found to have an unexpected effect upon their high-temperature strength, as will be seen. These treatments consist in soaking the alloy after forging for about two hours in an inert atmosphere at a temperature of from 2200° F. to 2400° F., and then air cooling. This may be followed by aging for about 16 hours at about 1400° F., although this latter step is not necessary.

Examples of compositions of various high chromium-iron alloys used in tests leading to the present invention are given in Table I, wherein the amounts of the constituents are given in parts by weight and percentages. This table indicates the intended compositions of the alloys tested. Due to the melting techniques used, the actual compositions contained somewhat less titanium than indicated. In heats A–8974 to A–9368, the titanium recovery was from 60% to 65%. In the remaining heats, the titanium recovery was about 85% to 90%. The aluminum recovery varies from 85% to 90%.

Table I also gives the results of stress-rupture test at 1500° F. of these alloys. Heat treatment (if any) consisted of two hours soaking at the specified temperature, and aging (if any) consisted of 16 hours of treatment at the specified temperature. The heat treatment was done subsequent to forging, and those alloys which were not heat treated were tested in the "as forged" condition.

From these results, it is seen that alloys within the range of the present invention exhibit high strength at high temperatures, and that several of the alloys, e. g., intended compositions 70 Cr, 30 Fe, 4 Ti, 9 Mo, and 70 Cr, 30 Fe, 2 Ti, 9 Mo, ½ Al exhibit exceptionally good characteristics. The heat treatment used has in some cases produced a remarkable effect on the alloys. These alloys have good high-temperature ductility, and the low-temperature ductility is considerably improved over previous high chromium-iron alloys containing over 60% chromium. Amounts of zirconium up to 3% may be added to this alloy without materially changing its characteristics.

As is seen in the composition of the alloy system of the present invention, a high-temperature, high-strength alloy is produced without the use of critical materials. The high-temperature ductility is good, and the low-temperature ductility is satisfactory for use of the alloy in turbine buckets of turbojet aircraft engines. The additives of this alloy have also greatly increased the high-temperature corrosion resistance of chromium-iron systems containing over 60% chromium.

Although the alloy system of this invention has been described as being specifically adaptable to use in turbine buckets of turbojet aircraft engines, this application of the alloy system is merely illustrative and is not intended to be a limitation of the invention. The system may be used in any application which requires the use of the resultant characteristics of the material without departing from the scope of the appended claims.

Having thus described the invention and given several specific embodiments thereof, it is believed apparent that the same may be widely varied without essential departure therefrom, and all such modifications and departures are contemplated as may fall within the scope of the following claims.

What is claimed is:

1. A forgeable high-temperature, high-strength alloy consisting of 60% to 80% chromium, 5% to 11% molybdenum, 1.4% to 3% titanium, and the balance essentially iron.

2. A forgeable high-chromium alloy comprising 60% to 80% chromium, 5% to 11% molybdenum, 1.4% to 2.0% of titanium as a nitrogen- and oxygen-fixing metal, up to 1.0% of surface-stabilizing metals of the group consisting of aluminum, silicon and additional titanium, balance substantially iron, and characterized by high strength, high corrosion resistance, and good ductility at high temperatures.

3. An alloy comprising substantially 62% chromium, 8% molybdenum, 2.2% titanium, balance essentially iron, and characterized by high strength, high corrosion resistance, and good ductility at high temperatures.

4. An alloy comprising substantially 62.8% chromium, 8.08% molybdenum, 1.7% titanium, and 0.45% aluminum, balance essentially iron, and characterized by high strength, high corrosion resistance, and good ductility at high temperatures.

5. A forgeable high-temperature, high-strength alloy consisting of from 60 to 80 percent chromium, 5 to 11 percent molybdenum, 1.4 to 2 percent titanium, up to 1 percent aluminum, and the balance essentially iron.

Table I

Heat Number	Intended Composition Parts by Weight										Intended Composition Parts by Per Cent										Stress, 1,000 p. s. i.	Hours to Rupture
	Cr	Fe	Ti	Mo	V	W	Zr	Al	Cb	C	Cr	Fe	Ti	Mo	Al	V	W	Zr	Cb	C		
A–8974	70	30	0.5								69.7	29.8	0.5								23	1.3
A–9095	70	30	1	9							63.6	27.3	0.9	8.2							23	8.1
A–9098	70	30	2	6							64.8	27.8	1.85	5.55							23	84.1
A–9099	70	30	2	9							63	27.1	1.8	8.1							23	55.1
A–9167	70	30	2	3	3	3				0.1	63	27	1.8	2.7		2.7	2.7			0.09	23	18.1
A–9167 [1]	70	30	2	3	3	3				0.1	63	27	1.8	2.7		2.7	2.7			0.09	23	55.6
A–9282	70	30	2	3		3	3				63	27.1	1.8	2.7			2.7	2.7			23	48.3
A–9319	70	30	4	9							61.9	26.6	3.54	7.96							23	85.8
A–9319 [1]	70	30	4	9							61.9	26.6	3.54	7.96							23	449.7
A–9319 [1]	70	30	4	9							61.9	26.6	3.54	7.96							28	160.9
A–9362 [1]	70	30	2	12							61.4	26.3	1.75	10.5							28	28.7
A–9363 [1]	70	30	3	9							62.5	26.8	2.68	8.03							28	80.2
A–9368 [1]	70	30	2	9					1		62.5	26.8	1.79	8.03					0.89		28	40.9
A–9506 [2]	70	30	2	9				¼			62.9	27.0	1.79	8.09	0.22						28	9.2
A–9506 [3]	70	30	2	9				¼			62.9	27.0	1.79	8.09	0.22						28	9.3
A–9506 [1]	70	30	2	9				¼			62.9	27.0	1.79	8.09	0.22						28	8.2
A–9506 [4]	70	30	2	9				¼			62.9	27.0	1.79	8.09	0.22						28	14.4
A–9523 [4]	70	30	2	9				½			62.8	26.9	1.79	8.08	0.45						28	357+

[1] Heat treatment, 2 hours at 2,400 degrees F.
[2] Heat treatment, 2 hours at 2,200 degrees F.
[3] Heat treatment, 2 hours at 2,200 degrees F. and 16 hours at 1,400 degrees F.
[4] Heat treatment, 2 hours at 2,400 degrees F. and 16 hours at 1,400 degrees F.

6. A forgeable high-temperature, high-strength alloy consisting of from 60 to 80 percent chromium, 5 to 11 percent molybdenum, 1.4 to 2 percent titanium, up to 1 percent silicon, and the balance essentially iron.

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