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HIGH-TEMPERATURE ALLOYS

Ray H. English, Nathaniel B. Ornitz, and Martin N. Ornitz, Pittsburgh, Pa., assignors to Blaw-Knox Company, Pittsburgh, Pa., a corporation of New Jersey

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This invention provides a high temperature alloy having high resistance to corrosion, low creep and high load carrying ability at elevated temperatures. Over a period of many years, there has been a demand for alloys of this character. Instrumentalities such as the gas turbine, turbo super-charger and jet propulsion motors, heat treating furnace accessories, crucibles, radiant tubes, and parts for internal combustion engines contain parts which should resist the corrosive influence of hot products of combustion containing oxygen and/or other corrosive gases at elevated temperatures and, at the same time, retain their ability to carry high mechanical loads. The alloys heretofore available have only partially met these requirements, and in consequence, undesirable limitations on design have been imposed by the limitations of the available alloys.

Properties which are important in materials for this purpose are resistance to oxidation and stability of shape under load. As the temperatures increase, metals tend to burn more readily and also to have greater plastic deformation or creep over a period of time. Many metals which might be quite strong at high temperatures cannot be exposed to even mildly corrosive or oxidizing atmospheres at such temperatures without rapidly being consumed, while other compositions which are resistant to burning do not have rigidity.

Corrosion of alloys in hot gases is dependent, of course, on the atmosphere as well as the alloy. The behavior of metals maintained constantly under high temperature is characteristically a progressive burning away of the surface at a substantially constant rate, which is measured in inches penetration per year.

The behavior of specimen metals under constant stress below the elastic limit at high temperature is characterized by three stages of deformation, namely:

1. A period of internal stress distribution taking place in a relatively short time and characterized by an initial high and diminishing rate of deformation. This stage is made up of elastic and plastic flow.

2. A period of constant rate of deformation lasting over long periods of time. This phenomenon is known to metallurgists as creep, and is usually measured in terms of elongation per hour under a given tension, although it is equally characteristic of other deformations and we prefer to compare specimens in bending rather than

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in direct tension, and to express creep in terms of angular deflections per hour.

3. A final increasing rate of deformation leading to necking and failure.

The rate of deformation per unit time in stage 2 is a suitable measure of rigidity or permanence of shape of the material at the load and temperature. It is customary to select the allowable unit stress for a particular metal at a particular high temperature on the basis of the creep considered permissible at that temperature. The time to reach and pass through the different stages to creep is of importance and is influenced by the material, temperature and load or unit stress.

Our alloy has high mechanical strength, low creep and also high resistance to corrosion at very high temperatures. Our alloy is equal or superior in these respects to other known alloys at lower temperatures, its relative advantages and superiority become strikingly apparent at the higher temperatures for which it is peculiarly adaptable; e. g. at temperatures such as 2300° F. It is an alloy of nickel containing as essential alloying constituents chromium, tungsten and carbon, the balance being substantially iron along with the usual contaminants in common amounts, in certain balanced proportions which we have found required to produce these unique characteristics.

The composition of alloys satisfactory at temperatures in the vicinity of 2300° F. is much more critical than the composition producing alloys for lower temperatures. High strength is attributed to insoluble precipitated phases in the alloy, which, however, are more difficult to produce and maintain as the temperature is increased above 1800° F. Resistance to oxidation is due to the formation of a tough, adherent, protective oxide coating which is increasingly difficult to achieve as the temperature is increased, especially above 1800° F. Ingredients enhancing strength by inducing precipitation of suitable insoluble phases at 2300° F. frequently cause formation of oxides which are not effective as protective coatings, and conversely ingredients found to be effective in reducing corrosion often increase the solubility of the precipitated phases or otherwise adversely affect their strength. While alloys containing nickel, chromium, tungsten, carbon and iron are known for high temperature application, our particular composition is the first discovered to be useful for articles of the sorts previously mentioned for use at temperatures at 2300° F.; and when the ingredients are combined in the proportions here set forth, the virtues of strength and resistance to oxidation are balanced to produce articles far superior to any heretofore available.

Considering for the moment only the essential constituents the preferred analysis of the alloy for most purposes is:

	Per cent
Ni	52
W	5
Cr	27
C	0.50

Balance substantially iron

The composition of the alloy may extend over a fairly wide range and still retain its desirable and unique characteristics. However, it is desirable to limit the composition of the alloy within the following range of concentrations of alloying constituents:

	Per cent
Ni	40– 60
W	4.0– 6.5
Cr	22– 34
C	0.35–0.75

Balance substantially iron

For those desiring to hold their product to more restricted limits the alloy having the following limits would be satisfactory:

	Per cent
Ni	45– 55
W	5– 6
Cr	25– 31
C	0.45–0.60

Balance substantially iron

The balance of the alloy, apart from its essential constituents nickel, tungsten, chromium and carbon, is substantially iron along with the usual contaminants in common amounts.

Historically, the search for suitable high temperature alloys has supported the present trend to employ cobalt in substantial amounts. This is a very costly ingredient and its wide use is founded not on suggestion that cobalt is a mere permissible substitute for nickel, but on the now prevalent belief that unless cobalt is used in substantial amounts, a satisfactory alloy having high strength and rigidity cannot be produced. Our alloy is superior to alloys which are characteristically of cobalt base. While some cobalt may be used in the alloy, the properties are not enhanced thereby and an advantage of our invention resides in the economy of not requiring this relatively expensive ingredient. Cobalt, in fact, has the effect of materially reducing the corrosion resistance of the alloy at temperatures above 2000° F. when used in amounts heretofore regarded as adequate to justify its addition to alloys successfully used at temperatures below 2000° F. Our alloy is preferably substantially free from cobalt.

Molybdenum and tungsten have been heretofore considered equally valuable in promoting resistance to corrosion over the same range of concentration. We have found, however, that molybdenum in place of tungsten in our alloy causes pitting, and furthermore, does not produce the remarkable rigidity achieved by tungsten.

In tests at 2300° F. our alloy has been found to have great resistance to corrosion and excellent mechanical strength. In air, the surface does not corrode at a rate exceeding .07 inch penetration per year, and the creep, under a tensile stress of 143 lbs. per square inch, is less than .00013 per cent elongation per hour. These values are expressed in conventional units, being reduced by calculations and extrapolation from tests further described below. Because of the ease and accuracy with which bending tests can be made, we prefer to compare the creep of high temperature alloys in terms of rate of bending in radians per hour of a horizontal bar of given section modulus loaded to a given extreme fibre stress at a fixed support for one end of the bar. Expressed in these terms, the rate of bending of bars of our alloy having a section modulus of .0123 in.^{3} (for one half inch diameter specimens) loaded to an extreme fibre stress of 143 pounds per square inch is substantially below .00010 radian per hour.

Those who require articles of rigidity even better than the above may achieve it with our alloy. For example, we have found it readily possible to cast bars of our alloys having a per cent elongation per hour when loaded to 143 lbs./sq. in. tensile stress at 2300° F. not exceeding the extremely low value of .00005%, or correspondingly for beam specimens of .0123 in.^{3} section modulus, a rate of bending not exceeding .00004 radian per hour when loaded to an extreme fibre stress of 143 pounds per square inch at the support. This combination of characteristics is unique with our alloy and answers a long felt need.

By way of illustration, the results of creep and corrosion tests on alloys within the limits of our alloy composition are given with their chemical compositions:

TABLE I

Behavior of half-inch diameter alloy specimens under constant stress at 2300° F.

	Test results at 2300° F.		
	Percent Elongation per hour under 143 lbs./in.^{2} tension	Rate of Bending When Stressed to 143 lb./in.^{2}, Radians per hr.	Maximum Oxidation rate in air-inches penetration per year
Alloy A	.000035	.0000268	0.06
Alloy B	.000035	.000027	0.08
Alloy C	.000035	.000027	0.06

TABLE II

Composition of alloy specimens in Table I

Alloy	Ni	CO	Cr	W	Mo	Fe	C	Mn	Si	Cb	Al
A	52.70		27.60	5.20		11.80	.49	.91	1.13		
B	50.00		29.00	5.11		12.93	.52	.98	1.46		
C	41.00		33.00	5.50		16.27	.60	.98	1.65		

A brief description of the manner of making the above tests will be necessary for a complete understanding of their true worth. A test bar of each alloy is cast and machined to one-half inch plus or minus 0.001 inch diameter, and of suitable length for testing as a cantilever beam.

One end of the specimen is secured rigidly in a support, the bar extending horizontally therefrom, inside an enclosure through which hot products of combustion of natural gas are passed. Each bar is loaded so that the extreme fibre stress adjacent the support is precisely equal 143 lbs. per square inch in tests at 2300° F., this being a reasonable stress value at this temperature.

The temperature within the enclosure is maintained accurately at 2300° F. as specified, within plus or minus 2°, for a sufficient time to conclude the test, which is normally run for several weeks. The deflection of the bar is measured at 48 hour intervals and reduced by calculation to angular deflection in radians. The angular deformation per hour is a direct index of the creep of the material under the specified load and temperature. The total deflection where such rates are given is very small, being less than two degrees, and the angular deformation and unit linear deformations are closely related.

Careful comparison of results of tests made in this manner with results of direct tension tests shows that there is a direct correlation in the results. Our method of beam testing has proven to give more precise and consistent results, easily duplicated, and not subject to the variations commonly found in conventional creep tests. However, the superiority of our alloy is of great magnitude, and readily apparent from any method of testing or standard of units, in comparison with other alloys heretofore suggested.

A few words may be helpful in explanation of the corrosion results. A specimen is maintained in an atmosphere of air heated to 2300° F. for many hours, as for 500 or 1000 hours, after which it is descaled and the loss in weight determined. From this the penetration during the test period is found, and the corrosion reduced to a yearly basis by calculation. The test in air is very severe, the gases encountered ordinarily in practice being less corrosive.

While we have described and disclosed the preferred embodiment of our invention, it is to be understood that the invention is not so limited but may be otherwise embodied and practiced within the scope of the following claims.

We claim:

1. A nickel-base alloy having new creep and corrosion-resistance properties at very high temperatures in which in air the surface does not corrode at a rate exceeding about .07 inch penetration per year and the creep is less than about .00013 per cent elongation per hour under a tensile stress of 143 pounds per square inch, consisting essentially of nickel in the range from 40% to 60%, tungsten in the range from 4% to 6.5%, chromium in the range from 22% to 34%, carbon in the range from 0.35% to 0.75%, and the balance substantially iron.

2. A nickel-base alloy having new creep and corrosion-resistance properties at very high temperatures in which in air the surface does not corrode at a rate exceeding about .07 inch penetration per year and the creep is less than about .00013 per cent elongation per hour under a tensile stress of 143 pounds per square inch, consisting essentially of nickel in the range from 45% to 55%, tungsten in the range from 5% to 6%, chromium in the range from 25% to 31%, carbon in the range from 0.45% to 0.60%, and the balance substantially iron.

3. A nickel-base alloy having new creep and corrosion-resistance properties at very high temperatures in which in air the surface does not corrode at a rate exceeding about .07 inch penetration per year and the creep is less than about .00013 per cent elongation per hour under a tensile stress of 143 pounds per square inch, consisting essentially of about 52% nickel, 5% tungsten, 27% chromium, 0.5% carbon, and the balance substantially iron.

4. A nickel-base alloy having new creep and corrosion-resistance properties at very high temperatures in which in air the surface does not corrode at a rate exceeding about .07 inch penetration per year and the creep is less than about .00013 per cent elongation per hour under a tensile stress of 143 pounds per square inch, consisting essentially of nickel in the range from 40% to 60%, tungsten in the range from 4% to 6.5%, chromium in the range from 22% to 34%, carbon in the range from 0.35% to 0.75%, and the balance substantially iron, said alloy being free from molybdenum.

5. A nickel-base alloy having new creep and corrosion-resistance properties at very high temperatures in which in air the surface does not corrode at a rate exceeding about .07 inch penetration per year and the creep is less than about .00013 per cent elongation per hour under a tensile stress of 143 pounds per square inch, consisting essentially of nickel in the range from 45% to 55%, tungsten in the range from 5% to 6%, chromium in the range from 25% to 31%, carbon in the range from 0.45% to 0.60%, and the balance substantially iron, said alloy being free from cobalt and molybdenum.

RAY H. ENGLISH.
NATHANIEL B. ORNITZ.
MARTIN N. ORNITZ.

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