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HOT WORKABLE ALLOY

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This invention relates to alloys, including ferrous alloys, containing nickel and at least one of the elements chromium, molybdenum and tungsten, from nil to 0.50% of carbon and ranges of proportions from nil to the approximate amount stated of one or more other elements as hereinafter described.

Such alloys have one or more of the following valuable properties which include corrosion resistance, resistance to attack by acids including sulphuric, nitric and hydrochloric acids, high strength at high temperatures, resistance to scaling and creep at high temperatures and other valuable properties. Those properties are important in numerous applications such as acid resistant equipment in the chemical and other industries, heat resistant baffles and shields, heat resistant parts for jet and turbo-jet aeroplanes, and heat and corrosion-resistant valves for internal combustion engines.

Chromium imparts resistance to chemical attack in the presence of specific media and resistance to oxidation.

Nickel imparts resistance to reducing media and in alloys containing iron promotes the formation of austenite of varying degrees of stability.

Carbon imparts considerable strength at room and elevated temperatures, in alloys containing iron and/or nickel as the base element.

Cobalt imparts considerable strength at room and elevated temperatures.

Copper improves resistance to sulphuric acid, brine and chloride solutions.

Molybdenum and tungsten increase the resistance to creep at elevated temperatures and increase the strength at room and elevated temperatures. Molybdenum, especially in the chromium-nickel stainless steels, increases the resistance to pitting which may occur in chloride and other salt solutions. Molybdenum in nickel alloys markedly increases the resistance to reducing acids such as hydrochloric and hydrofluoric acids.

Chromium, molybdenum and tungsten have the common effect of closing the gamma-loop in alloys containing nickel and iron as the base components. This common effect is especially important in questions relating to hot workability, and this will be apparent in the alloys to be discussed later.

Nitrogen is used to increase strength at room and elevated temperatures without impairing corrosion resistance.

Silicon increases the general oxidation resistance as well as resistance to the corrosive effects of acid, for example weak solutions of H_2SO_4 or HCl.

Manganese has an effect similar to nickel but is much less effective.

Columbium, titanium and tantalum are used where intergranular stabilization is required. They are used to combine with carbon to form

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carbides, i. e., columbium carbide, titanium carbide and tantalum carbide and thus prevent the phenomenon known as intergranular corrosion. The proportions of these elements by weight to combine with carbon and form the corresponding carbides are usually taken as follows: in the case of columbium, 10 times the carbon content, in the case of titanium, 5 times the carbon content, and in the case of tantalum, 20 times the carbon content. They may be used singly or together.

Vanadium is a carbide and nitride former but is not as potent as columbium, titanium or tantalum in fixing the carbides. Columbium, titanium, tantalum or vanadium when used in quantities greater than that required to form the carbides, have a considerable effect in increasing the resistance to creep at high temperatures.

Elements such as aluminum, zirconium, beryllium and boron are also used in varying proportions, for purposes known in the art. For instance, aluminum can be used as an adjunct with chromium in some alloys to increase resistance to scale formation at high temperatures. Beryllium and boron can be used to impart age-hardening tendencies to austenitic alloys. Zirconium can be used to fix the nitrogen in stainless steels and also serves a useful purpose in fixing the sulfur content into discrete particles for free-machining purposes.

A principal obstacle to the full utilization of the properties of such alloys has been the difficulty or practical impossibility of hot working, because unless such alloys can be readily and economically hot worked, i. e., forged, rolled, and so forth into various desired shapes such as sheets, rods, tubes and so forth, their practical utility is greatly limited.

That obstacle has existed for years and numerous efforts have been made to solve the problem.

For example, there have been available for many years various alloys containing nickel, chromium, molybdenum and copper which possess the property of satisfactorily withstanding corrosion, including resistance to the corrosive action of materials having a pronounced corroding action as, for example, sulphuric acid, weak muriatic acid and hot concentrated solutions of acetic and phosphoric acids. These alloys may be illustrated by the following composition:

Component	Percent by Weight
Carbon.....	0.20 Maximum
Manganese.....	0.50-4.00
Silicon.....	0.50-4.00
Chromium.....	15.00-23.00
Nickel.....	22.00-28.00
Molybdenum.....	1.50-5.00
Copper.....	1.00-5.00
Iron.....	(1)

(1) Substantially the balance.

The alloys of this example can be satisfactorily cast but cannot be hot worked, and when hot working is attempted on such alloys the resulting bars are so badly torn and cracked as to make them unusable. This has seriously limited the fields of usefulness of the said alloys since they have been limited to those fields in which castings would be used. By means of the present invention such alloys, and many others, are transformed and readily hot-workable products produced.

A principal object of the present invention is to impart the property of hot workability where it does not exist, at least as a practical economic matter, and to improve hot workability where it already in some degree exists and where improvement is necessary or desirable.

That is accomplished by the use of cerium or lanthanum or both within minimum and maximum proportions as herein set forth. While pure cerium or pure lanthanum may be used separately, combinations of the two metals have been found effective and such is readily obtained by the use of misch metal, the major part of which consists of cerium and lanthanum. It is to be understood in the parts of the specification which follow that the term "lanthanum" means not only lanthanum per se but also all of the rare earth components of misch metal with the exception of cerium. These rare earth metals with the exception of cerium include lanthanum as the greater percentage, neodymium and similar elements in smaller percentages.

We have discovered that the nickel content of any of the alloys of this invention determines the minimum and maximum allowable ranges of cerium and/or lanthanum which will promote hot workability. A minimum content of cerium and/or lanthanum is required to obtain hot workability where it does not exist and to improve hot workability where it already exists in some degree and where improvement is desirable. On the other hand, too much cerium and/or lanthanum produces the opposite effect, and if the critical maximum proportion thereof for an alloy having a given nickel content is exceeded, the hot workability is impaired. We have discovered, that as the nickel content increases in any of these alloys, that the allowable range of cerium and/or lanthanum which can be used to promote hot workability is narrowed, as shown by the following table:

Per Cent Nickel	Per Cent Cerium and/or Lanthanum
4.....	about 0.02 to 1.10
10.....	about 0.02 to 1.05
20.....	about 0.02 to 0.90
30.....	about 0.02 to 0.75
40.....	about 0.02 to 0.60
50.....	about 0.02 to 0.45
60.....	about 0.02 to 0.30
70.....	about 0.02 to 0.15

Within the above maximum ranges, narrower critical ranges of the cerium substance may be necessary because of the effect of relatively large amounts of elements other than nickel but said narrower ranges will always fall within said maximum ranges and the critical range in any specific instance, if narrower than that shown above, for a particular nickel content, is readily determined by the "cone test" hereinafter described.

In accordance with the invention alloys are made comprising nil to 0.50 per cent carbon, 10 to 60 per cent of at least one element of the group

consisting of chromium, molybdenum and tungsten, the amount of any individual element of said group not exceeding 30 per cent, 4 to 70 per cent of nickel, and a substance of the group consisting of cerium, lanthanum and cerium plus lanthanum in amounts correlated with and dependent on the nickel content as follows:

Per Cent Nickel	Per Cent said substance
4.....	about 0.02 to 1.10
10.....	about 0.02 to 1.05
20.....	about 0.02 to 0.90
30.....	about 0.02 to 0.75
40.....	about 0.02 to 0.60
50.....	about 0.02 to 0.45
60.....	about 0.02 to 0.30
70.....	about 0.02 to 0.15

Where only one of the elements chromium, molybdenum and tungsten is used, the minimum proportion thereof is about 10 per cent but where more than one are used, the minimum proportion of any one is 1 per cent, provided the sum of two or more thereof is about 10 per cent.

Within the generic scope and definition above stated one or more of numerous elements not stated therein may be included to provide the properties imparted thereby and therefore in accordance with the invention alloys are provided comprising the following components in the stated ranges of proportions:

	Per cent by weight
Carbon.....	Nil to 0.50
At least one element of the group consisting of chromium, molybdenum and tungsten.....	10 to 60
The amount of any individual element of said group not exceeding 30 percent.....	
Nickel.....	4 to 70
Copper.....	Nil to about 10
Nitrogen.....	Nil to about 0.30
Cobalt.....	Nil to about 40
Manganese.....	Nil to about 20
Silicon.....	Nil to about 4
At least one element of the group consisting of columbium, tantalum and vanadium.....	Nil to about 8
Titanium.....	Nil to about 2

A substance of the group consisting of cerium, lanthanum and cerium plus lanthanum in amounts correlated with and dependent on the nickel content as follows:

Per Cent Nickel	Per Cent said substance
4.....	about 0.02 to 1.10
10.....	about 0.02 to 1.05
20.....	about 0.02 to 0.90
30.....	about 0.02 to 0.75
40.....	about 0.02 to 0.60
50.....	about 0.02 to 0.45
60.....	about 0.02 to 0.30
70.....	about 0.02 to 0.15

Elements such as one or more of those listed below may also be included in the illustrative proportions stated:

	Per cent by weight
Beryllium.....	Nil to about 5
Boron.....	Nil to about 2
Aluminum.....	Nil to about 5
Zirconium.....	Nil to about 2

Where free-machining in the corrosion resistant steel alloys is desired, sulfur, selenium, tellurium, phosphorus or arsenic are added as well known in the steel industry. See Palmer Patents 1,835,960; 1,846,140; 2,009,713; and 1,961,777.

The invention is illustrated by composition ranges shown in Table A and further illustrated by specific compositions shown in Table B. In the tables and other examples where the propor-

tions of components other than iron do not equal 100 per cent, the balance is iron and incidental impurities. The invention applies not only to ferrous alloys (containing more than 50 per cent iron) but also to non-ferrous alloys (containing less than 50 per cent iron and no iron).

As shown in said tables, the ranges for cerium plus lanthanum are the same as the ranges for cerium per se and lanthanum per se, respectively.

TABLE A

	Groups						
	I	II	III	IV	V	VI	VII
C.....	nil-.50	nil-.50	nil-.50	nil-.50	nil-.50	nil-.50	nil-.50
Cr.....	10-30	nil	nil	1-30	1-30	nil	1-30
Mo.....	nil	10-30	nil	1-30	nil	1-30	1-30
W.....	nil	nil	10-30	nil	1-30	1-30	1-30
Cr+Mo.....	nil	nil	nil	10-60	nil	nil	nil
Cr+W.....	nil	nil	nil	nil	10-60	nil	nil
Mo+W.....	nil	nil	nil	nil	nil	10-60	nil
Cr+Mo+W.....	nil	nil	nil	nil	nil	nil	10-60
Ni.....	4-70	4-70	4-70	4-70	4-70	4-70	4-70
Cu.....	nil-10	nil-10	nil-10	nil-10	nil-10	nil-10	nil-10
N.....	nil-.30	nil-.30	nil-.30	nil-.30	nil-.30	nil-.30	nil-.30
Co.....	nil-40	nil-40	nil-40	nil-40	nil-40	nil-40	nil-40
Mn.....	nil-20	nil-20	nil-20	nil-20	nil-20	nil-20	nil-20
Si.....	nil-4	nil-4	nil-4	nil-4	nil-4	nil-4	nil-4
Co.....	nil-8	nil-8	nil-8	nil-8	nil-8	nil-8	nil-8
Ta.....	nil-8	nil-8	nil-8	nil-8	nil-8	nil-8	nil-8
Co+Ta.....	nil-8	nil-8	nil-8	nil-8	nil-8	nil-8	nil-8
Co+V.....	nil-8	nil-8	nil-8	nil-8	nil-8	nil-8	nil-8
Ta+V.....	nil-8	nil-8	nil-8	nil-8	nil-8	nil-8	nil-8
Co+Ta+V.....	nil-8	nil-8	nil-8	nil-8	nil-8	nil-8	nil-8
Ti.....	nil-2	nil-2	nil-2	nil-2	nil-2	nil-2	nil-2
Ce.....	.02-1.10	.02-1.10	.02-1.10	.02-1.10	.02-1.10	.02-1.10	.02-1.10
or La.....	.02-1.10	.02-1.10	.02-1.10	.02-1.10	.02-1.10	.02-1.10	.02-1.10
or Ce+La.....	.02-1.10	.02-1.10	.02-1.10	.02-1.10	.02-1.10	.02-1.10	.02-1.10

TABLE B
Group I

Alloys	1	2	3	4	5	6	7	8	9	10	11	12
C.....	.15	.20	.05	.048	.046	.122	.064	.074	.104	.142	.40	.07
Cr.....	25	21	21	10.19	10.12	19.27	19.82	19.88	19.65	17.57	21	20
Mo.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
W.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cr+Mo.....												
Cr+W.....												
Mo+W.....												
Cr+Mo+W.....												
Ni.....	20	12	10	20.6	20.34	67.58	24.58	24.61	24.29	4.05	12	30
Cu.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	4.13	nil	10
N.....	nil	.18	nil	nil	nil	nil	nil	nil	nil	.09	.18	nil
Co.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Mn.....	1.0	1.25	.50	10.4	20.8	1.03	.88	.92	1.01	.51	1.0	1.0
Si.....	1.0	1.0	.50	.84	.84	.72	.98	.07	1.16	.41	1.0	1.0
Co.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Ta.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
V.....	nil	nil	nil	nil	nil	nil	2.31	4.26	7.80	nil	nil	nil
Co+Ta.....												
Co+V.....												
Ta+V.....												
Co+Ta+V.....												
Ti.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Ce.....	.05	.02	.05	.02-.239	.021-.109	.014-.091	.015-.051	.021-.153	.025-.104	.12	.02	.05
La.....	.03	.02	.05	.015-.178	.015-.065	.01-.048	.012-.112	.016-.116	.019-.063	.05	.02	.05
Ce+La.....	.08	.04	.10	.035-.417	.036-.174	.024-.139	.027-.163	.037-.269	.044-.167	.17	.04	.10

Alloys	13	14	15	16	17	18	19	20	21	22	23
C.....	.12	.12	.12	.12	.07	.07	.06	.07	.07	.10	.10
Cr.....	21	18	18	18	19	19.5	20	20	20.07	20	20
Mo.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
W.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cr+Mo.....											
Cr+W.....											
Mo+W.....											
Cr+Mo+W.....											
Ni.....	12	25	20	20	23.5	23.0	28	28	28	12	12
Cu.....	nil	3.5	3.5	3.5	1.5	1.5	3.0	3.0	3.0	nil	nil
N.....	.30	.15	.15	.12	nil	nil	nil	nil	nil	nil	nil
Co.....	nil	5	20	40	nil	nil	nil	nil	nil	nil	nil
Mn.....	1.0	.75	.75	.75	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Si.....	1.0	.75	.75	.75	4.0	2.0	1.0	1.0	1.0	1.0	1.0
Co.....	nil	nil	nil	nil	nil	1.0	8.0	nil	nil	nil	nil
Ta.....	nil	nil	nil	nil	nil	nil	3.0	3.0	7.5	nil	nil
V.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Co+Ta.....											
Co+V.....											
Ta+V.....											
Co+Ta+V.....											
Ti.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	1.0	2.0
Ce.....	.02	.03	.03	.03	.08	.07	.03	.07	.04	.02	.02
La.....	.02	.02	.02	.02	.04	.04	.02	.04	.02	.02	.02
Ce+La.....	.04	.05	.05	.05	.12	.11	.05	.11	.06	.04	.04

TABLE B—Continued
Group II

Alloys	1	2	3	4	5	6	7	8
C	.024	.030	.028	.022	.024	.046	.032	.04
Cr	nil	nil	nil	nil	nil	nil	nil	nil
Mo	20.33	19.97	20.27	16.17	19.17	19.74	16.04	10
W	nil	nil	nil	nil	nil	nil	nil	nil
Cr+Mo								
Cr+W								
Mo+W								
Cr+Mo+W								
Ni	11.0	30.83	50.14	60.87	70.69	49.96	55.05	30
Cu	nil	nil	nil	nil	nil	nil	5.08	nil
N	nil	nil	nil	nil	nil	nil	nil	nil
Co	nil	nil	nil	nil	nil	nil	nil	nil
Mn	.88	.65	.75	.56	.87	.80	.87	.75
Si	.54	.78	.79	.12	.83	.80	.26	.75
Cb	nil	nil	nil	nil	nil	nil	nil	nil
Ta	nil	nil	nil	nil	nil	nil	nil	nil
V	nil	nil	nil	nil	nil	nil	nil	nil
Cb+Ta								
Cb+V								
Ta+V								
Cb+Ta+V								
Ti	nil	nil	nil	nil	nil	nil	nil	nil
Ce	.062-.131	.025-.154	.065	.023-.238	.024-.031	.041	.016-.037	.11
La	.040-.085	.019-.119	.036	.008-.036	.009-.015	.017	.005-.006	.08
Ce+La	.102-.216	.044-.273	.101	.029-.274	.033-.046	.058	.021-.043	.19

Alloys	9	10	11	12	13	14	15	16	17	18	19	20	21
C	.05	.06	.04	.03	.04	.10	.05	.06	.07	.10	.10	.08	.08
Cr	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Mo	30	12	16	20	20	16	12	12	16	10	10	10	10
W	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cr+Mo													
Cr+W													
Mo+W													
Cr+Mo+W													
Ni	30	4	50	12	12	25	30	20	30	40	40	40	40
Cu	nil	2.0	10.0	nil	.15	.28	nil	nil	nil	nil	nil	nil	nil
N	nil	15	nil	nil	nil	35	nil	nil	nil	nil	nil	nil	nil
Co	.75	1.0	.75	.80	.75	.75	5.0	18.0	1.0	1.0	1.0	1.0	1.0
Mn	1.0	.75	.25	.50	.50	.75	1.0	1.0	3.5	1.0	1.0	1.0	1.0
Si	nil	nil	nil	nil	nil	nil	nil	nil	nil	7	nil	nil	3
Cb	nil	nil	nil	nil	nil	nil	nil	nil	nil	5	nil	nil	2
Ta	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	8	nil	3
V	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	8	nil	8.0
Cb+Ta													
Cb+V													
Ta+V													
Cb+Ta+V													
Ti	nil	nil	nil	nil	nil	1.0	nil	nil	nil	nil	nil	nil	nil
Ce	.03	.10	.04	.10	.11	.07	.15	.05	.08	.07	.07	.07	.07
La	.02	.07	.02	.06	.07	.04	.09	.04	.05	.04	.05	.04	.04
Ce+La	.05	.17	.06	.16	.18	.11	.24	.09	.13	.11	.12	.11	.11

Group III

Alloys	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
C	.03	.05	.05	.07	.07	.07	.20	.07	.07	.06	.40	.08	.07	.07	.12	.10	.07	.10
Cr	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Mo	20	20	30	10	10	20	10	15	15	15	12	12	12	12	12	12	12	12
W	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cr+Mo																		
Cr+W																		
Mo+W																		
Cr+Mo+W																		
Ni	70	50	50	20	4	50	20	30	20	30	40	40	40	40	40	40	40	40
Cu	nil	nil	nil	nil	2.5	9.0	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
N	.10	nil	nil	.30	nil	15	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Co	nil	nil	nil	nil	40	nil	10	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Mn	.75	.75	.75	.75	.75	1.0	.75	4.0	18.0	1.0	.75	.75	.75	1.0	.75	.75	.75	.75
Si	.75	1.0	1.0	.75	.75	1.0	.75	1.0	1.0	4.0	.75	.75	.75	.75	.75	.75	.75	1.5
Cb	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	1.5
Ta	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	2.0	7.0	nil	nil	nil	nil	5.0
V	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	3.0	8.0	nil	nil	8.0
Cb+Ta																		
Cb+V																		
Ta+V																		
Cb+Ta+V																		
Ti	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	1.0	nil	nil
Ce	.03	.07	.06	.04	.08	.05	.04	.14	.05	.08	.08	.07	.06	.07	.07	.07	.06	.08
La	.02	.04	.04	.03	.05	.03	.03	.09	.04	.05	.05	.04	.04	.04	.04	.03	.04	.05
Ce+La	.05	.11	.10	.07	.13	.08	.07	.23	.09	.13	.13	.11	.10	.11	.11	.10	.10	.13

TABLE B—Continued

Group IV

Alloys	1	2	3	4	5	6	7	8	9	10	11	12	13	14
C.....	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.05	.08	.07	.07
Cr.....	10	10	10	10	10	10	10	10	10	10	20	18	18	18
Mo.....	8	12	4	8	12	16	8	8	30	20	20	2.25	2	2.5
W.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cr+Mo.....	18	22	14	18	22	26	18	28	38	32	22.25	21.5	20	20.5
Cr+W.....														
Mo+W.....														
Cr+Mo+W.....														
Ni.....	10	10	30	30	30	30	20	10	20	50	28	12	14	14
Cu.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	3.25	nil	3.5	5.0
N.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Co.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Mn.....	.75	.75	.75	.75	.75	.75	.75	.75	.75	.75	.90	.75	1.5	1.5
Si.....	.75	.75	.75	.75	.75	.75	.75	.75	.75	.75	.90	.75	.40	.40
Cb.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	.70	nil	nil	nil
Ta.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
V.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cb+Ta.....														
Cb+V.....														
Ta+V.....														
Cb+Ta+V.....														
Ti.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Ce.....	.04-.10	.04-.24	.03-.25	.03-.17	.04-.26	.06-.21	.07-.15	.02-.15	.025-.12	.06-.20	.15	.02	.06	.09
La.....	.04-.06	.03-.18	.03-.23	.03-.16	.03-.17	.03-.16	.06-.11	.02-.10	.02-.07	.03-.16	.10	.02	.06	.08
Ce+La.....	.08-.16	.07-.42	.06-.48	.06-.33	.07-.43	.09-.37	.13-.26	.04-.25	.045-.19	.09-.36	.25	.04	.12	.17

Alloys	15	16	17	18	19	20	21	22	23	24	25	26	27	28
C.....	.07	.07	.07	.07	.18	.12	.07	.06	.50	.50	.05	.05	.05	.07
Cr.....	20	20	22	22	23	23	20	20	20	20	10	10	10	10
Mo.....	3.5	2.5	2.5	2.5	4.6	2.2	1.0	2.75	4.0	4	16	20	20	20
W.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cr+Mo.....	23.5	22.5	24.5	24.5	27.6	25.2	21	22.75	24	24	26	30	30	30
Cr+W.....														
Mo+W.....														
Cr+Mo+W.....														
Ni.....	29	30	28	28	34	21	22	22	50	20	70	10	30	70
Cu.....	5	10	3.5	3.5	1.2	3.6	1.0	1.75	nil	nil	nil	nil	nil	nil
N.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Co.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Mn.....	1.5	.75	1.0	1.0	5.0	3	3	nil	.75	.75	.50	.50	.50	.7
Si.....	1.0	1.0	1.0	1.0	.87	1.5	3.0	3.0	.75	.50	.50	.50	.50	.75
Cb.....	nil	nil	nil	nil	nil	nil	0.7	nil	nil	nil	nil	nil	nil	nil
Ta.....	nil	nil	nil	1.5	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
V.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cb+Ta.....				nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cb+V.....														
Ta+V.....														
Cb+Ta+V.....														
Ti.....	nil	nil	.40	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Ce.....	.14	.12	.12	.12	.10-.20	.10-.20	.10-.20	.07-.18	.03-.30	.03-.20	.06-.10	.02-.07	.03-.17	.05-.10
La.....	.12	.10	.11	.11	.04-.12	.04-.12	.04-.12	.05-.17	.02-.25	.026-.07	.03-.06	.02-.04	.02-.14	.03-.06
Ce+La.....	.26	.22	.23	.23	.14-.32	.14-.32	.14-.32	.12-.35	.05-.55	.056-.27	.09-.16	.04-.11	.05-.31	.08-.16

Alloys	29	30	31	32	33	34	35	36	37	38	39	40	41	42
C.....	.07	.07	.07	.176	.066	.06	.058	.07	.028	.038	.032	.078	.068	.052
Cr.....	20	10	20	23.53	19.26	19.3	19.8	19.0	3.55	5.05	5.26	10.20	10.26	10.24
Mo.....	8	16	4	4.60	2.73	2.53	2.01	2.75	15.70	19.07	23.30	3.91	15.10	4.03
W.....	28	26	24	28.13	21.99	21.83	21.81	21.75	19.25	24.12	28.56	14.11	25.36	14.27
Cr+Mo.....														
Cr+W.....														
Mo+W.....														
Cr+Mo+W.....														
Ni.....	40	40	30	34.20	23.14	22.89	27.91	23.5	61.23	69.88	68.23	10.32	10.24	20.11
Cu.....	.50	nil	nil	1.22	1.78	1.45	2.46	1.75	nil	nil	nil	nil	nil	nil
N.....	nil	.10-.12	.10-.15	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Co.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Mn.....	.75	.75	.75	5.05	.65	.74	.96	.55	.87	1.04	1.08	.87	.92	.80
Si.....	.75	.75	.75	.87	3.06	3.02	.69	2.0	.29	.96	.93	.84	.79	.83
Cb.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Ta.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
V.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cb+Ta.....														
Cb+V.....														
Ta+V.....														
Cb+Ta+V.....														
Ti.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Ce.....	.07-.15	.06	.02-.2	.10-.20	.05-.15	.175	.14	.3-.6	.024	.038	.064-.074	.022-.072	.025-.135	.048-.175
La.....	.04-.10	.04	.02-.15	.04-.12	.04-.12	.10	.08	nil	.007	.020	.035-.043	.014-.051	.021-.147	.041-.136
Ce+La.....	.11-.25	.10	.04-.35	.14-.32	.09-.27	.275	.22		.031	.058	.099-.117	.036-.123	.046-.282	.089-.311

TABLE B—Continued

Group IV—Continued

Alloys	43	44	45	46	47	48	49	50	51	52	53	54	55	56
C.....	.054	.054	.050	.046	.040	.034	.042	.036	.030	.040	.066	.062	.132	.218
Cr.....	10.24	10.26	10.39	10.33	10.65	10.09	10.16	10.03	10.11	9.97	19.48	20.46	21.07	29.90
Mo.....	11.90	15.67	18.64	24.08	25.03	8.19	16.00	18.87	23.43	3.98	12.07	15.81	4.04	4.18
W.....	22.14	25.93	29.03	34.41	35.68	18.28	26.16	28.90	33.53	13.95	31.65	36.27	25.11	34.08
Cr+Mo.....														
Cr+W.....														
Mo+W.....														
Cr+Mo+W.....														
Ni.....	20.34	20.28	20.54	20.24	30.79	50.10	50.66	60.43	60.37	64.31	10.07	9.61	21.08	22.03
Cu.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
N.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	.059	19.20
Co.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Mn.....	.86	.86	.84	1.15	.81	.87	.86	.89	.91	.98	.99	.98	1.32	1.30
Si.....	.86	.88	.99	.60	.81	.89	.91	.95	.95	.88	.95	.85	.93	.82
Sb.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cb.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Ta.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
V.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cb+Ta.....														
Cb+V.....														
Ta+V.....														
Cb+Ta+V.....														
Ti.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Ce.....	.054-.155	.062-.133	.036	.069	.092	.031-.144	.028-.087	.085	.055-.108	.037-.065	.012-.120	.012-.120	.031-.143	.088
La.....	.026-.083	.037-.068	.026	.044	.055	.014-.076	.012-.051	.051	.030-.068	.015-.030	.010-.100	.010-.100	.023-.102	.037
Ce+La.....	.080-.238	.099-.201	.062	.113	.147	.045-.220	.040-.138	.136	.085-.176	.052-.095	.022-.220	.022-.220	.054-.245	.095

Alloys	57	58	59	60	61	62	63	64	65	66
C.....	.138	.132	.042	.044	.040	.040	.048	.47	.07	.062
Cr.....	21.04	20.88	19.88	20.70	19.94	19.97	19.97	19.26	19.74	19.77
Mo.....	7.87	12.03	2.89	7.63	4.12	7.95	11.50	4.28	4.17	7.79
W.....	28.91	33.01	22.77	28.33	24.06	27.92	31.47	23.54	23.91	27.86
Cr+Mo.....										
Cr+W.....										
Mo+W.....										
Cr+Mo+W.....										
Ni.....	21.10	20.80	20.40	19.41	30.07	30.24	30.58	21.38	49.95	49.62
Cu.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
N.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Co.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Mn.....	1.38	1.29	1.09	.97	.97	.97	.99	1.08	.94	.93
Si.....	.96	.96	1.04	.94	.96	.95	.92	.96	.96	1.00
Sb.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cb.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Ta.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
V.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cb+Ta.....										
Cb+V.....										
Ta+V.....										
Cb+Ta+V.....										
Ti.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Ce.....	.029-.127	.021-.121	.036-.124	.023-.074	.020-.155	.021-.180	.093-.137	.03-.15	.038-.195	.052-.171
La.....	.021-.079	.016-.072	.026-.070	.018-.046	.014-.125	.015-.180	.058-.092	.02-.07	.021-.270	.043-.151
Ce+La.....	.050-.206	.037-.193	.062-.194	.041-.120	.034-.280	.036-.360	.151-.229	.05-.22	.059-.465	.095-.322

Alloys	67	68	69	70	71	72	73	74	75	76	77
C.....	.076	.080	.074	.056	.068	.064	.068	.056	.056	.048	.058
Cr.....	19.84	19.66	19.34	26.67	29.14	29.19	29.14	29.23	10.12	10.19	20.09
Mo.....	15.60	19.94	11.87	.98	4.15	7.71	7.58	4.32	16.01	15.47	4.09
W.....	35.44	39.60	31.21	27.65	33.29	36.90	36.72	33.55	26.13	25.66	24.18
Cr+Mo.....											
Cr+W.....											
Mo+W.....											
Cr+Mo+W.....											
Ni.....	49.31	48.23	65.24	4.77	10.49	10.15	30.49	45.09	59.13	67.97	69.76
Cu.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
N.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Co.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Mn.....	.98	1.05	.99	.42	1.02	1.10	1.00	.99	1.09	1.17	1.01
Si.....	1.08	1.02	1.02	.43	1.08	1.03	1.03	1.12	.95	1.04	1.16
Sb.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cb.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Ta.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
V.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cb+Ta.....											
Cb+V.....											
Ta+V.....											
Cb+Ta+V.....											
Ti.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Ce.....	.015-.060	.040-.052	.030	.015-.029	.025-.055	.013-.078	.052-.098	.050-.154	.033-.054	.062-.073	.038-.061
La.....	.005-.022	.020-.027	.014	.011-.020	.018-.035	.010-.049	.034-.061	.026-.102	.016-.029	.033-.041	.017-.029
Ce+La.....	.020-.088	.060-.079	.044	.026-.049	.043-.090	.023-.127	.086-.159	.076-.256	.049-.083	.095-.114	.055-.090

TABLE B—Continued
Group IV—Continued

Alloys	78	79	80	81	82	83	84	85	86	87	88	89	90	91
C.....	.070	.054	.052	.072	.174	.048	.054	.056	.048	.044	.050	.044	.056	.068
Cr.....	29.96	9.60	5.00	19.22	20.15	19.64	10.24	10.02	10.09	10.02	10.17	24.81	19.68	29.79
Mo.....	3.84	19.10	22.80	11.37	4.26	2.46	8.23	7.92	3.76	3.90	7.97	3.48	3.09	2.52
W.....	33.80	28.70	27.80	30.59	24.41	22.10	18.43	17.94	13.85	13.92	18.14	28.29	22.77	23.31
Cr+Mo.....														
Cr+W.....														
Mo+W.....														
Cr+Mo+W.....														
Ni.....	58.42	67.97	69.15	65.69	21.39	27.39	5.04	5.03	24.73	20.02	9.80	20.68	28.06	28.65
Cu.....	nil	nil	nil	nil	nil	3.20	nil	nil	nil	nil	nil	2.75	3.30	3.6
N.....	nil	nil	nil	nil	.068	nil	nil	nil	nil	nil	nil	nil	nil	nil
Co.....	nil	nil	nil	nil	nil	28.38	3.39	5.34	10.40	19.97	19.97	nil	nil	nil
Mn.....	.96	.96	.96	.96	1.37	2.54	.83	.72	.79	.75	.82	.79	1.01	1.03
Si.....	1.07	1.00	.93	1.01	1.01	.93	.93	.78	.71	.73	.78	.68	.93	.93
Cb.....	nil	nil	nil	nil	nil	.96	nil	nil	nil	nil	nil	nil	1.95	3.51
Ta.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
V.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cb+Ta.....														
Cb+V.....														
Ta+V.....														
Cb+Ta+V.....														
Ti.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Ce.....	.021-.088	.070-.089	.080-.158	.161	.123	.01-.181	.031-.069	.031-.069	.028-.166	.028-.145	.022-.114	.034-.120	.014-.157	.019-.043
La.....	.004-.046	.033-.053	.040-.068	.100	.074	.01-.180	.022-.045	.022-.045	.020-.144	.020-.108	.016-.068	.023-.071	.011-.128	.014-.029
Ce+La.....	.025-.134	.103-.152	.120-.256	.261	.197	.02-.361	.053-.114	.053-.114	.048-.310	.048-.253	.038-.182	.057-.191	.025-.285	.033-.072

Alloys	92	93	94	95	96	97	98	99	100	101	102	103
C.....	.048	.064	.044	.044	.040	.12	.07	.10	.10	.10	.10	.10
Cr.....	20.25	20.24	20.24	20.24	19.60	16.	18.	25.	25.	25.	25.	25.
Mo.....	8.46	2.39	2.51	2.57	2.68	4.	4.	2.5	2.5	2.5	2.5	2.5
W.....	28.71	22.63	22.75	22.81	22.18	20.	22.	27.5	27.5	27.5	27.5	27.5
Cr+Mo.....												
Cr+W.....												
Mo+W.....												
Cr+Mo+W.....												
Ni.....	40.74	28.12	28.64	28.12	27.07	25.	12.	20	20	20	20	20
Cu.....	.68	3.50	3.53	3.41	3.28	nil	nil	nil	nil	nil	nil	nil
N.....	nil	nil	nil	nil	nil	.30	.15	nil	nil	nil	nil	nil
Co.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Mn.....	.95	1.17	1.02	1.04	.87	.75	18.0	.75	.75	.75	.75	.75
Si.....	.99	1.33	1.16	1.07	.34	.75	1.0	1.0	1.0	1.0	1.0	1.0
Cb.....		7.87	nil	nil	.83	nil	nil	3.0	1.0	.80	1.0	.83
Ta.....	nil	nil	nil	nil	nil	nil	nil	3.0	7.0	nil	nil	6.50
V.....	nil	nil	nil	nil	nil	nil	nil	3.30	8.0	2.0	7.5	6.50
Cb+Ta.....												
Cb+V.....												
Ta+V.....												
Cb+Ta+V.....												
Ti.....	nil	nil	.97	2.18	nil	nil	nil	nil	nil	nil	nil	7.83
Ce.....	.033-.139	.025	.031	.020	.030	.040	.040	.05	.05	.04	.04	.05
La.....	.022-.094	.015	.022	.015	.020	.030	.030	.03	.03	.02	.02	.03
Ce+La.....	.055-.233	.040	.053	.035	.050	.060	.070	.08	.08	.06	.06	.06

Group V

Alloys	1	2	3	4	5	6	7	8	9	10	11	12
C.....	.10	.07	.07	.05	.04	.07	.20	.20	.10	.07	.07	.07
Cr.....	10	25	5	10	10	18	21	21	25	18	18	15
Mo.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
W.....	28	10	5	12	6	5	3.5	3.5	5	8	5	10
Cr+Mo.....												
Cr+W.....	38	35	10	22	16	23	24.5	24.5	30	26	23	25
Mo+W.....												
Cr+Mo+W.....												
Ni.....	20	30	70	5	25	14	12	12	20	12	14	25
Cu.....	.15	nil	nil	nil	nil	9.0	nil	nil	nil	nil	nil	nil
N.....	nil	nil	nil	nil	nil	nil	.15	.28	nil	.15	nil	nil
Co.....	nil	nil	nil	40	5.0	nil	nil	nil	nil	nil	nil	nil
Mn.....	1.0	1.0	1.0	.80	1.0	1.0	.75	.75	1.0	20.0	1.0	1.0
Si.....	1.0	1.0	1.0	.75	1.0	1.0	.75	.75	4.0	1.0	1.0	1.0
Cb.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	1.0	8.0
Ta.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	.50	nil
V.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	1.50	nil
Cb+Ta.....												
Cb+V.....												
Ta+V.....												
Cb+Ta+V.....												
Ti.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	1.0
Ce.....	.04	.03	.05	.03	.06	.05	.04	.05	.03	.04	.04	.04
La.....	.03	.02	.03	.02	.05	.03	.03	.03	.02	.03	.02	.02
Ce+La.....	.07	.05	.08	.05	.11	.08	.07	.08	.05	.07	.06	.06

TABLE B—Continued
Group V—Continued

Alloys	13	14	15	16	17	18	19	20	21	22
C.....	.07	.07	.07	.38	.07	.074	.090	.112	.138	.148
Cr.....	18	15	25	21	10.07	10.09	10.09	10.16	9.85	9.85
Mo.....	5	10	10	3.5	3.68	7.88	15.77	15.78	19.34	22.51
W.....										
Cr+Mo.....	23	25	35	21.5	14.05	17.97	25.86	25.94	29.19	32.36
Cr+W.....										
Mo+W.....										
Cr+Mo+W.....	14	25	20	12	20.21	20.47	20.52	20.28	20.09	20.45
Ni.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Cu.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
N.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Co.....	1.0	1.0	1.0	1.0	.73	.64	.62	.84	.76	.82
Mn.....	1.0	1.0	1.0	1.0	.61	.55	.49	.89	.89	.80
Si.....	.75	.30	.50	nil	nil	nil	nil	nil	nil	nil
Cb.....	1.0	7.5	.30	nil	nil	nil	nil	nil	nil	nil
Ta.....	2.0	nil	7.0	nil	nil	nil	nil	nil	nil	nil
V.....		7.8								
Cb+Ta.....										
Cb+V.....										
Ta+V.....										
Cb+Ta+V.....	3.75	nil	nil	nil	nil	nil	nil	nil	nil	nil
Ti.....	.05	.05	.04	.04	.028-.152	.024-.143	.028-.150	.019-.103	.046-.106	.042
Ce.....	.03	.03	.02	.02	.020-.118	.017-.100	.020-.135	.013-.061	.030-.063	.028
La.....	.08	.08	.06	.06	.048-.270	.041-.243	.048-.285	.032-.164	.076-.169	.070
Ce+La.....										

Group VI

Alloys	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
C.....	.05	.04	.05	.06	.06	.04	.04	.04	.07	.06	.05	.40	.10	.10	.10
Cr.....	10	15	5	10	5	25	6	6	5	5	6	5	5	5	5
Mo.....	15	10	25	15	23	5	15	15	12	10	12	10	12	12	12
W.....															
Cr+Mo.....	25	25	30	25	28	30	21	21	17	15	18	15	17	17	17
Cr+W.....															
Mo+W.....															
Cr+Mo+W.....	10	30	50	60	70	50	55	50	5	25	20	40	40	40	40
Ni.....	nil	nil	nil	nil	nil	nil	5	10	nil	nil	nil	nil	nil	nil	nil
Cu.....	nil	nil	.25	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
N.....	nil	nil	nil	nil	nil	nil	nil	nil	40	5	nil	nil	nil	nil	nil
Co.....	10.0	1.0	1.0	.75	.75	.75	.75	.75	.75	.75	18.0	1.0	1.0	1.0	1.0
Mn.....	1.0	1.0	1.0	.75	.75	.75	2.5	.75	.75	.75	.75	1.0	1.0	1.0	1.0
Si.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	7.0	5.0	nil	1.0
Cb.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	1.0	5.0	nil	1.0
Ta.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	.75	8.0	
V.....												8.0			
Cb+Ta.....															
Cb+V.....															
Ta+V.....													6.25		
Cb+Ta+V.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	1.0
Ti.....	.08	.09	.06	.10	.03	.04	.03	.04	.03	.06	.05	.07	.06	.07	.09
Ce.....	.06	.07	.04	.07	.02	.02	.03	.03	.02	.04	.03	.04	.04	.03	.06
La.....	.14	.16	.10	.17	.05	.06	.05	.07	.05	.10	.08	.11	.10	.10	.15
Ce+La.....															

Group VII

Alloys	1	2	3	4	5	6	7	8	9	10	11	12	13	14
C.....	.07	.07	.07	.15	.07	.05	.05	.05	.07	.07	.12	.40	.30	.12
Cr.....	10	10	10	20	20	15	20	20	10	15	25	20	20	20
Mo.....	4	4	4	5	20	5	3.5	3.5	4	3	1.5	3.5	3.5	3.5
W.....	12	12	12	15	3	25	3	3	8	4	1.5	3.5	3.5	3.5
Cr+Mo.....														
Cr+W.....														
Mo+W.....														
Cr+Mo+W.....	26	26	26	40	43	45	26.5	26.5	22	22	28	27	27	27
Ni.....	10	30	65	50	50	50	5	5	5	30	20	20	20	30
Cu.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	1.5
N.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	.15	.25	nil	nil	nil
Co.....	nil	nil	nil	nil	nil	nil	nil	nil	40	nil	nil	20	20	nil
Mn.....	1.0	1.0	1.0	.75	.75	1.0	.75	.75	1.0	18	1.0	1.0	1.0	1.0
Si.....	1.0	1.0	1.0	.75	.75	1.0	.75	.75	1.0	1.0	1.0	1.0	1.0	4.0
Cb.....	nil	nil	nil	nil	nil	nil	1.0	.75	nil	nil	nil	4.0	nil	nil
Ta.....	nil	nil	nil	nil	nil	nil	.25	nil	nil	nil	nil	3.0	nil	nil
V.....	nil	nil	nil	nil	nil	nil	nil	nil	nil	1.0	1.0	5.0	5.0	nil
Cb+Ta.....							1.25							
Cb+V.....												5.0		
Ta+V.....													8.0	
Cb+Ta+V.....														
Ti.....	nil	nil	nil	nil	nil	nil	nil	.75	nil	nil	nil	.60	nil	nil
Ce.....	.12	.09	.05	.05	.04	.05	.08	.10	.04	.05	.04	.03	.04	.10
La.....	.10	.06	.03	.03	.03	.03	.06	.06	.03	.03	.02	.02	.02	.07
Ce+La.....	.22	.15	.08	.08	.07	.08	.14	.16	.07	.08	.06	.05	.06	.17

Further specific examples are shown as follows:

Example 47

An alloy was selected having the following analysis:

Component	Percent by Weight
Carbon.....	0.176
Manganese.....	5.05
Silicon.....	0.87
Phosphorus.....	0.004
Sulfur.....	0.005
Chromium.....	23.53
Nickel.....	34.20
Copper.....	1.22
Molybdenum.....	4.60

To this analysis was added 4 pounds, 8 pounds, 10 pounds, 12 pounds and 25 pounds per ton of "misch metal." The addition was made to the molten metal just before tapping and casting. The hot workability was rated by means of a "cone test" which is a conical-shaped cast section having a base 2½ inches in diameter by ¾ of an inch thick. A truncated cone section extends 2½ inches above the base, having a taper of approximately ¼ of an inch per inch. The flat-top section of the cone is ¾ of an inch in diameter while the base of the cone proper is approximately 1⅞ of an inch in diameter. The cones are hot forged at a hammer by striking the hot cone with three hammer blows to form a pancake. This is an extremely severe test to judge the hot-workability of steels, and if the metal is not completely ductile at the forging and rolling temperatures the pancake will show tears in the reduced cone section and also in the heavy base section.

Pancakes which are rated as poor have extremely deep and sharp tears on the outside face, those rated as "fair" will show some tears, but the majority of the outside surface will be smooth and free of hot tears, while those rated as "good" will be entirely smooth on the outside surface similar to that obtained with SAE 1020 steel.

The correlation of the cone test with actual ingot behavior in these austenitic alloys during hot-working is that those ingots made from metal which are rated poor on the cone test will check and tear apart during the first break-down operations. Ingots made from metal rated as "fair" on the cone test can be broken down with some difficulty. Ingots made from metal rated as "good" on the cone test can be broken down at the hammer without difficulty, and will need only slight surface preparation to prepare the resulting billets.

In the above example, the metal was rated as "poor" when no cerium or misch metal was used in the melting. Similarly, a 4 pound addition per ton of misch metal to this analysis caused little or no improvement in hot-working.

Additions of 8 pounds and 12 pounds of misch metal per ton yielded metal which was rated as "fair" and could be hot-worked commercially.

Additions of 20 pounds and 50 pounds of misch metal per ton to the analysis caused the metal to be rated as "poor," and in fact was worse than the analysis without any additions of misch metal.

The analytical cerium and lanthanum contents corresponding to additions of misch metal of 8 to 12 pounds per ton are cerium=.10 to .20 percent and lanthanum=.04 to .12 percent. The

differences between these values and the added amounts are due to losses.

It is also to be noted that the presence of 5 percent manganese in the above alloy was not effective in promoting the hot-workability of the alloy. This is in accord with prior art experience in the alloys under discussion, that is, the presence of manganese in the range 1 percent to 4 percent is no criterion of hot-workability, and has not resulted in commercially forged and rolled products in the above range of compositions.

Example 48

The hot-workability of an analysis of the following composition:

Component	Per cent by Weight
Carbon.....	0.066
Manganese.....	0.65
Silicon.....	3.06
Phosphorus.....	0.012
Sulfur.....	0.013
Chromium.....	19.26
Nickel.....	23.14
Molybdenum.....	2.73
Copper.....	1.78

was studied by means of the "cone test" and forging experiments.

An addition of 4 pounds of misch metal per ton of metal caused some improvement in the hot-workability, so that the cones were rated as "fair."

Additions of 8 pounds and 12 pounds per ton of misch metal caused a definite improvement and the metal was rated as "good" on the hot forging "cone test."

An addition of 20 pounds of misch metal per ton caused the metal to be again rated as poor on the hot forging test.

The preferred analytical cerium and lanthanum contents corresponding to additions of 8 to 12 pounds of misch metal per ton are, cerium=.05 to 0.15 per cent, lanthanum=.04 to 0.12 percent.

Example 49

To further illustrate the marked advantages in hot-working obtained in accordance with this invention by adding cerium and/or lanthanum to the above analysis in the restricted range set forth above, a 1000 pound high-frequency Ajax charge was melted. The charge consisted of approximately 70 percent solid scrap of the approximate analysis: carbon 0.10 percent maximum, manganese 1.00%, silicon 1.00%, chromium 20.00%, nickel 22.00%, copper 1.25%, molybdenum 2.00%, together with ingot iron, plate nickel, copper, molybdenum and ferro-chromium to complete the analysis. The melt was deoxidized at tap with 4 pounds of CaSi and 6 pounds of misch metal were added before tap.

This heat, designated as O-13569 was cast into 7 inch ingots and hammer cogged successfully to 3½ inch square billets. The prepared billet yield was about 70 percent of the ingot weight. The analysis of O-13569 is as follows: carbon 0.060 percent, manganese 0.74%, silicon 3.02%, phosphorus 0.013%, sulfur 0.007%, chromium 19.30%, nickel 22.89%, copper 1.45%, molybdenum 2.53%, cerium 0.175%, lanthanum 0.10%.

Ajax production lots of similar analysis melted with similar scrap mixes but without misch metal were scrapped at the hammer due to deep corner and surface tears.

Example 50

A 1000 pound Ajax production heat with a variation of the above austenitic analysis was melted containing the equivalent of 12 pounds of misch metal per ton. The charge again consisted of 70 percent solid scrap as shown above with the necessary ferro alloys to complete the analysis. The melt was deoxidized with 4 pounds of CaSi and 6 pounds of misch metal.

The 7 inch ingots from this heat were of the following analysis, carbon 0.058%, manganese 0.96%, silicon 0.69%, phosphorus 0.012%, sulfur 0.006%, chromium 19.80%, nickel 27.91%, copper 2.46%, molybdenum 2.01%, cerium 0.14%, lanthanum 0.08%. The ingot to prepared billet yield of the ingot weight was about 85%.

Previous attempts at hammer cogging austenitic alloys of this similar type without the addition of cerium and/or lanthanum resulted in scrapped ingots.

Component	Percent by Weight
Carbon.....	10.07
Manganese.....	0.55
Silicon.....	2.00
Phosphorus.....	0.020
Sulfur.....	0.010
Chromium.....	19.00
Nickel.....	23.50
Molybdenum.....	2.75
Copper.....	1.75

¹ Maximum, 23.16.

To the above analysis was added the equivalent of 6 pounds and 12 pounds, respectively, of cerium per ton in the form of pure cerium (91.9% cerium).

The hot-workability was rated by means of the "cone" tests. The addition of 6 pounds of cerium per ton produced cones which were rated as "fair" while the addition of 12 pounds of cerium per ton produced cones which were rated as "good." The cerium additions in these heats is equivalent to 0.30 percent and 0.60 percent added cerium, respectively.

The marked advantages in hot-workability of alloys in the range of analyses of this invention can also be demonstrated by impact tests made from ingots or forged bars. Hot charpy tests in the temperature range of 1900° F. to 2200° F. show an improvement in impact tests of about 400 percent to 500 percent improvement can be obtained by the use of cerium and/or lanthanum in the ranges set forth in the appended claims.

We have found it desirable to incorporate the cerium and/or lanthanum into the molten steel by an addition of misch metal just before tap in the case of Ajax high-frequency melting. In the case of electric arc melting we prefer to add the cerium and/or lanthanum in the form of misch metal in the ladle after the heat is tapped from the furnace. The cerium must be quickly plunged below the surface of the bath to incorporate the desired quantities of the cerium and/or lanthanum into the molten metal and to avoid undue loss.

This application is a continuation-in-part of our co-pending application, Serial No. 100,546, filed June 1, 1949, which is a continuation-in-part of our application, Serial No. 718,254, filed December 24, 1946, now abandoned.

What is claimed is:

1. An alloy capable of being hot worked, said alloy comprising nil to 0.50 per cent carbon, 10

to 60 per cent of at least one element of the group consisting of chromium, molybdenum and tungsten, the amount of any individual element of said group not exceeding 30 per cent, 4 to 70 per cent of nickel, and a substance of the group consisting of cerium, lanthanum and cerium plus lanthanum in amounts correlated with and dependent on the nickel content as follows:

Percent nickel	Percent said substance
4.....	about 0.02 to 1.10
10.....	about 0.02 to 1.05
20.....	about 0.02 to 0.90
30.....	about 0.02 to 0.75
40.....	about 0.02 to 0.60
50.....	about 0.02 to 0.45
60.....	about 0.02 to 0.30
70.....	about 0.02 to 0.15

2. An alloy capable of being hot worked and comprising the following components in the stated proportions:

	Per cent by weight
Carbon.....	Nil to 0.50
At least one element of the group consisting of chromium, molybdenum and tungsten....	10 to 60
The amount of any individual element of said group not exceeding 30 per cent	
Nickel.....	4 to 70
Copper.....	Nil to about 10
Nitrogen.....	Nil to about 0.30
Cobalt.....	Nil to about 40
Manganese.....	Nil to about 20
Silicon.....	Nil to about 4
At least one element of the group consisting of columbium, tantalum and vanadium.....	Nil to about 8
Titanium.....	Nil to about 2

A substance of the group consisting of cerium, lanthanum and cerium plus lanthanum in amounts correlated with and dependent on the nickel content as follows:

Per cent nickel	Per cent said substance
4.....	about 0.02 to 1.10
10.....	about 0.02 to 1.05
20.....	about 0.02 to 0.90
30.....	about 0.02 to 0.75
40.....	about 0.02 to 0.60
50.....	about 0.02 to 0.45
60.....	about 0.02 to 0.30
70.....	about 0.02 to 0.15

3. An alloy capable of being hot worked and comprising the following components in the stated proportions:

	Per cent by weight
Carbon.....	Nil to 0.50
Chromium.....	10 to 30
Nickel.....	4 to 70
Copper.....	Nil to 10
Nitrogen.....	Nil to 0.30
Cobalt.....	Nil to 40
Manganese.....	Nil to 20
Silicon.....	Nil to 4
At least one element of the group consisting of columbium, tantalum and vanadium.....	Nil to 8

Per cent by weight

Titanium ----- Nil to 2

A substance of the group consisting of cerium, lanthanum and cerium plus lanthanum in amounts correlated with and dependent on the nickel content as follows:

Per cent nickel	Per cent said substance
4.....	about 0.02 to 1.10
10.....	about 0.02 to 1.05
20.....	about 0.02 to 0.90
30.....	about 0.02 to 0.75
40.....	about 0.02 to 0.60
50.....	about 0.02 to 0.45
60.....	about 0.02 to 0.30
70.....	about 0.02 to 0.15

4. An alloy capable of being hot worked and comprising the following components in the stated proportions:

	Per cent by weight
Carbon	Nil to 0.50
Molybdenum	10 to 30
Nickel	4 to 70
Copper	Nil to 10
Nitrogen	Nil to 40
Cobalt	Nil to 40
Manganese	Nil to 20
Silicon	Nil to 4
At least one element of the group consisting of columbium, tantalum and vanadium	Nil to 8
Titanium	Nil to 2

A substance of the group consisting of cerium, lanthanum and cerium plus lanthanum in amounts correlated with and dependent on the nickel content as follows:

Per cent nickel	Per cent said substance
4.....	about 0.02 to 1.10
10.....	about 0.02 to 1.05
20.....	about 0.02 to 0.90
30.....	about 0.02 to 0.75
40.....	about 0.02 to 0.60
50.....	about 0.02 to 0.45
60.....	about 0.02 to 0.30
70.....	about 0.02 to 0.15

5. An alloy capable of being hot worked and comprising the following components in the stated proportions:

	Per cent by weight
Carbon	Nil to 0.50
Tungsten	10 to 30
Nickel	4 to 70
Copper	Nil to 10
Nitrogen	Nil to 40
Cobalt	Nil to 40
Manganese	Nil to 20
Silicon	Nil to 4
At least one element of the group consisting of columbium, tantalum and vanadium	Nil to 8
Titanium	Nil to 2

A substance of the group consisting of cerium, lanthanum and cerium plus lanthanum in amounts correlated with and dependent on the nickel content as follows:

Per cent nickel	Per cent said substance
4.....	about 0.02 to 1.10
10.....	about 0.02 to 1.05
20.....	about 0.02 to 0.90
30.....	about 0.02 to 0.75
40.....	about 0.02 to 0.60
50.....	about 0.02 to 0.45
60.....	about 0.02 to 0.30
70.....	about 0.02 to 0.15

10 6. An alloy capable of being hot worked and consisting essentially of the following composition:

	Per cent by weight
Carbon	Nil to 0.50
At least one element of the group consisting of chromium, molybdenum and tungsten	10 to 60
The amount of any individual element of said group not exceeding 30 per cent	
Nickel	4 to 70

A substance of the group consisting of cerium, lanthanum and cerium plus lanthanum in amounts correlated with and dependent on the nickel content as follows:

Per cent nickel	Per cent said substance
4.....	about 0.02 to 1.10
10.....	about 0.02 to 1.05
20.....	about 0.02 to 0.90
30.....	about 0.02 to 0.75
40.....	about 0.02 to 0.60
50.....	about 0.02 to 0.45
60.....	about 0.02 to 0.30
70.....	about 0.02 to 0.15

the balance being iron except incidental impurities.

7. An alloy capable of being hot worked and consisting essentially of the following composition:

	Per cent by weight
Carbon	Nil to 0.50
At least one element of the group consisting of chromium, molybdenum and tungsten	10 to 60
The amount of any individual element of said group not exceeding 30 per cent	
Nickel	4 to 70
Copper	Nil to about 10
Nitrogen	Nil to about 0.30
Cobalt	Nil to about 40
Manganese	Nil to about 20
Silicon	Nil to about 4
At least one element of the group consisting of columbium, tantalum and vanadium	Nil to about 8
Titanium	Nil to about 2

A substance of the group consisting of cerium, lanthanum and cerium plus lanthanum in amounts correlated with and dependent on the nickel content as follows:

Per cent nickel	Per cent said substance
4.....	about 0.02 to 1.10
10.....	about 0.02 to 1.05
20.....	about 0.02 to 0.90
30.....	about 0.02 to 0.75
40.....	about 0.02 to 0.60
50.....	about 0.02 to 0.45
60.....	about 0.02 to 0.30
70.....	about 0.02 to 0.15

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the balance being iron except incidental impurities.

8. An austenitic alloy according to claim 7 in which the content of nickel is not less than about 10%.

9. An austenitic corrosion resistant ferrous alloy capable of being hot worked and having an analysis as follows:

Component	Per cent
Carbon.....	up to 0.5.
Chromium.....	10 to 30.
Nickel.....	10 to 35.
Molybdenum.....	1.5 to 5.
Manganese.....	0.5 to 5.
Silicon.....	0.5 to 4.
Copper.....	1.0 to 4.
Columbium.....	nil to 10 times the carbon.
Tantalum.....	nil to 20 times the carbon.
Titanium.....	nil to 5 times the carbon.

said alloy containing cerium plus lanthanum in amounts from 0.80 to 0.04, the balance being iron except incidental impurities.

10. An austenitic corrosion resistant ferrous alloy capable of being hot worked and having an analysis as follows:

Component	Per Cent by Weight
Carbon.....	0.20 maximum.
Manganese.....	0.50 to 5.00.
Silicon.....	0.50 to 4.00.
Chromium.....	15.00 to 24.00.
Nickel.....	22.00 to 35.00.
Molybdenum.....	1.50 to 5.00.
Copper.....	1.00 to 4.00.

said alloy containing cerium plus lanthanum in amounts from 0.80 to 0.04 per cent, the balance being iron except incidental impurities.

11. An austenitic corrosion resistant ferrous alloy capable of being hot worked and having an analysis as follows:

Component	Per cent by Weight
Carbon.....	0.20 maximum.
Silicon.....	0.50 to 4.00.
Chromium.....	15.00 to 24.00.
Nickel.....	22.00 to 35.00.
Molybdenum.....	1.50 to 5.00.
Copper.....	1.00 to 4.00.

said alloy containing cerium plus lanthanum in amounts from 0.80 to 0.04 per cent, the balance being iron except incidental impurities.

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12. An austenitic corrosion resistant ferrous alloy capable of being hot worked and having an analysis as follows:

Component	Per cent by Weight
Carbon.....	0.20 maximum.
Manganese.....	0.50 to 5.00.
Silicon.....	0.50 to 4.00.
Chromium.....	15.00 to 24.00.
Nickel.....	22.00 to 35.00.
Molybdenum.....	1.50 to 5.00.
Copper.....	1.00 to 4.00.

said alloy also containing 0.10 to 0.20 per cent of cerium and 0.04 to 0.12 per cent of lanthanum and the balance being iron except incidental impurities.

13. An austenitic corrosion resistant ferrous alloy capable of being hot worked and having an analysis as follows:

Component	Per cent by Weight
Carbon.....	0.20 maximum.
Manganese.....	0.50 to 5.00.
Silicon.....	0.50 to 4.00.
Chromium.....	15.00 to 24.00.
Nickel.....	22.00 to 35.00.
Molybdenum.....	1.50 to 5.00.
Copper.....	1.00 to 4.00.

said alloy also containing 0.05 to 0.15 per cent cerium and 0.04 to 0.12 per cent lanthanum and the balance being iron except incidental impurities.

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DONALD G. SCHOFFSTALL.

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