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CORROSION RESISTANT FERROUS ALLOY

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This invention relates to corrosion-resisting ferrous alloys; and it relates more particularly to ferrous alloys or alloy steels characterized by a relatively high content of nickel and chromium, together with a further content of supplementing or fortifying constituents comprising copper, molybdenum and silicon in carefully adjusted but somewhat variable percentages that are comparatively small, molybdenum being always present in substantially greater proportion than silicon. The new alloys are characterized by a high degree of resistance to corrosion and, in addition, by the fact that sound castings can be produced therefrom and that they may also be forged and rolled hot with far less loss than has been unavoidable with alloy steels of generally comparable type heretofore known.

The present application is a division of prior copending application, Serial No. 56,586, filed December 28, 1935; and it is directed to those alloys therein disclosed which contain 3 per cent or more of copper and are highly resistant to corrosion, while still retaining good casting and cold bending properties.

Corrosion-resistant austenitic alloy steels of high nickel-chromium content, fortified or reinforced with small amounts of silicon, copper and molybdenum, having been heretofore known and used for certain purposes. But the range of their practical utility has been greatly restricted because they possessed certain inherent troublesome characteristics rendering them unsuitable for certain purposes or their fabrication into required products very expensive. For example, it has been very difficult to produce from such alloys satisfactory sound castings, such as valve and pump parts, that must be tight against hydrostatic pressure, even where the copper content was much less than 3 per cent.

It has now been found that the foregoing objections and disadvantages characterizing such prior alloy steels can be largely overcome by properly adjusting and controlling the relative proportions and total amounts of the above-mentioned reinforcing or fortifying constituents, that is, silicon, copper and molybdenum, in the manner hereinafter set forth; and that when this is done, the mechanical and physical characteristics of the resultant alloy steels are greatly improved.

The novel alloys with which the present application is particularly concerned and which have especially outstanding advantages and utility in the practical art, never contain substantially less than about 23 per cent nickel and 17 per cent chromium as minima. The nickel content may run as high as 30 per cent and the chromium content as high as 22 per cent, nickel always exceeding chromium in the alloy composi-

tion. In one type of alloy within the scope of the invention which is relatively very high in copper and extremely resistant to corrosion by sulphuric acid, the proportion of nickel is between 28 and 30 per cent, and that of chromium is between 19 and 21 per cent. Iron must always be the largest single component.

Although the marked effect of copper in high nickel-chromium steels as a fortifying agent to increase corrosion-resistance has long been recognized, its employment for this purpose, even in very small proportions, has been attended heretofore with serious difficulties and objections, especially because of its adverse effect upon the hot-working properties of such alloy steels through a tendency to produce hot shortness, as well as upon their casting properties.

According to the present invention, the fortifying or reinforcing elements are so proportioned that the highly desirable effect of copper in increasing corrosion-resistance can be utilized fully while at the same time eliminating ore sufficiently reducing its tendency to produce hot shortness, and also enabling the production of sound castings. It has been found that, in order to accomplish this, it is vital to have the percentage of molybdenum always substantially greater than that of silicon, and most desirably at least two or more times as great. The percentage of silicon should not be substantially less than 0.50, and as much as 2 per cent is permissible in practice. It is generally very much better, however, to keep the silicon well below 2 per cent, and indeed not to let it greatly exceed 1 per cent. For best results, the molybdenum content of the new alloy steels should be in the neighborhood of 3 to 3.5 per cent, ranging normally in practice from 2.0 to 4.0 per cent. It is very important that the total or combined percentage of molybdenum and silicon content shall not substantially exceed 5 per cent, an upper limit of 4.5 per cent being ordinarily distinctly preferable to observe. A higher aggregate percentage of these constituents is found to have a pronounced unfavorable effect upon the hot working properties of the alloy.

Alloy steels of the present invention are also characterized essentially by low carbon content not substantially exceeding 0.12 per cent. Indeed, it is only in exceptional cases that it is advisable to permit the carbon content to exceed 0.10 per cent. Ordinarily it is found that about 0.06 to 0.08 per cent carbon is extremely satisfactory in most cases, and a range of 0.04 to 0.07 per cent may be regarded as optimum. Too high a carbon content is to be avoided because it increases vulnerability of the alloy to intercrystalline corrosion, especially upon exposure to contact with sulphuric acid.

It will be understood that the new ferrous al-

loys may contain manganese in variable percentages, e. g. 0.40 to 0.75 per cent; also minute quantities of the common impurities such as phosphorus and sulphur which, together, do not amount to more than 0.04 per cent or thereabouts in the type of iron suitable to use in manufacturing alloy steels of the type here in question.

By maintaining the ratio of molybdenum to silicon such that the molybdenum always substantially predominates, with their combined percentages not substantially exceeding 5 per cent, and by observing the other precautions herein set forth, it becomes possible to employ, for example, from 3 to 5 per cent of copper in an alloy steel containing, say, 17 to 22 per cent chromium and from 23 to 30 per cent nickel, which is of particularly great industrial value not only because of its high degree of corrosion-resistance to sulphuric acid over a wide range of practical conditions, but also because sound, tight castings can be made from it. Furthermore, it possesses good cold bending properties notwithstanding the high copper content.

Not only do the new alloy steels show extremely high corrosion-resistance toward sulphuric acid especially but their mechanical properties are also excellent. Whereas standard bend test specimens of prior alloy steels of generally comparable type fail at less than 90° when bent cold, similar test specimens of the new alloy steels show no cracking or other failure when bent 90°. This is evidently due to the superior microstructure of the new alloy steels which is found upon examination to be homogeneous in character, there being little or no precipitation of ferrite on the crystallographic planes of intracrystalline faces. Also there is practically no formation of insoluble carbides at the grain boundaries; and accordingly these new alloy steels are especially free from attack through intergranular corrosion. Thin sections of castings produced from the new alloys are much less or not at all subject to the severe coring or "double wall effect", commonly characterizing castings from comparable prior alloy steels, which coring is not only conducive to porosity (leaky castings) but lowers corrosion-resistance as well as the elastic limit of the metal.

In the alloy steels of the present invention, which always contain at least 3 per cent copper in order to confer upon them the desired high resistance to sulphuric acid corrosion, it is necessary that the nickel content be not less than about 23 per cent, in order to retain the other valuable properties characteristic of the alloys, the other constituents being kept within the ranges hereinbefore set forth. For convenience, the composition of said alloys may be stated in tabular form as follows:

	Per cent
Nickel.....	23.00 to 30.00
Chromium.....	17.00 to 22.00
Silicon.....	0.50 to 2.00
Copper.....	3.00 to 5.00
Molybdenum.....	2.00 to 4.00
Carbon up to.....	0.12

the remainder to make 100 per cent being chiefly iron, which must always be the principal constituent, while the sum of molybdenum and silicon

should never substantially exceed 5 per cent and most desirably does not exceed 4.5 per cent.

Where especially high sulphuric acid corrosion-resistance is demanded, requiring an alloy with particularly high copper content, the essential components of such an alloy steel embodying the present invention are proportioned substantially in accordance with the following table of percentage ranges:

	Per cent
Nickel.....	28.00 to 30.00
Chromium.....	19.00 to 21.00
Molybdenum.....	2.70 to 3.20
Silicon.....	0.75 to 1.10
Copper.....	4.50 to 5.00
Carbon up to.....	0.07
Remainder to make 100 per cent, chiefly iron.	

In these high copper alloys the resistance to corrosion by sulphuric acid increases with increase of copper, while the good casting properties and bending properties as cast are retained, a standard test specimen as cast withstanding a cold bend of at least 90° without failure.

The new alloy steels may be manufactured by ordinary methods well known to those skilled in the art of making high nickel-chromium alloy steels, no special expedients or precautions being required. So also, the production of castings from these steels, and the heat treatment thereof, may be carried out in the usual way. It is accordingly unnecessary to describe these methods here.

What is claimed is:

1. An alloy comprising the following elements in proportions falling within range of percentages substantially as follows:

	Per cent
Nickel.....	23.00 to 30.00
Chromium.....	17.00 to 22.00
Silicon.....	0.50 to 2.00
Copper.....	3.00 to 5.00
Molybdenum.....	2.00 to 4.00
Carbon up to.....	0.12

the remainder to make 100 per cent being practically all iron, which must always be the principal constituent, and molybdenum always predominating over silicon, while the sum of the two never substantially exceeds 5 per cent; said alloy being resistant to corrosion, having good casting properties and good cold bending properties as cast, a standard test specimen as cast withstanding a cold bend of at least 90° without failure.

2. An alloy comprising the following elements in proportions falling within ranges of percentages substantially as follows:

	Per cent
Nickel.....	28.00 to 30.00
Chromium.....	19.00 to 21.00
Molybdenum.....	2.70 to 3.20
Silicon.....	0.75 to 1.10
Copper.....	4.50 to 5.00
Carbon up to.....	0.07

the remainder to make 100 per cent being practically all iron; said alloy being resistant to corrosion, and having good casting properties and good cold bending properties as cast, a standard test specimen as cast withstanding a cold bend of at least 90° without failure.

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