CORROSION RESISTANT NICKEL ALLOYS
A nickel alloy has been defined by the relevant ASTM Committee as "a material that conforms to a specification that requires, by weight percent, more nickel in the alloy than any other element with the possible exception of iron". With this definition is it any wonder that sometimes there is confusion as to which specific grades may be considered nickel alloys.

In addition to having its own inherent corrosion resistance, a feature of nickel is that it has a high capacity for alloying. This means that a wide range of other elements may be added to enhance corrosion resistance, improve strength at elevated temperatures and alter physical properties. The converse of this is that the metallurgy of nickel alloys may become quite complex and needs to be understood in order to avoid costly problems.

The role of chromium in nickel alloys is primarily the same as that in stainless steels: it enhances the formation of passive surface films in the presence of oxygen and these passive films impede the corrosion process. Iron also affects passivity as does silicon. Thus alloys containing these elements will display a corrosion resistance in oxidising media. On the other hand molybdenum and copper enhance corrosion resistance of nickel in reducing media. Nickel alloys containing both chromium and molybdenum will thus be versatile alloys for a broad spectrum of conditions although there may be some conditions in which other alloys may be the optimum. A useful way of understanding this is commonly known as the "Y" of corrosion (ref Figure).

In respect of localised corrosion resistance, nickel alloys are not prone to chloride stress corrosion cracking (as are the austenitic stainless steels) and they will display a resistance to pitting and crevice corrosion as well. For the nickel-chromium-molybdenum alloys this resistance will be a function of the amounts of the elements present.
ALLOYS FOR REDUCING APPLICATIONS

ALLOY 200 AND ALLOY 201 – These are commercially pure wrought nickel with the latter having a reduced carbon content. This results in greater microstructural stability at elevated temperatures but at the expense of strength at these temperatures. These alloys are used for caustic alkalis and a large number of organic compounds.

ALLOY 400 – a nickel copper alloy resistant to sea water and steam at elevated temperatures as well to salt and caustic solutions. Generally it is also the material of choice for applications involving HF acid. ALLOY K-500 is a high strength variant attaining the higher mechanical properties by a precipitation strengthening mechanism.

*HASTELLOY B3 – a nickel molybdenum alloy with a carefully controlled composition in respect of impurities and lower order alloying elements. The modified composition of this alloy results in thermal stability superior to that of its predecessors viz. *HASTELLOY B2.

The alloy has excellent resistance to hydrochloric acid at all concentrations and temperatures as well as to other non-oxidising media. The corrosion resistance of the alloy is sensitive to the presence of oxidizing impurities in the media even in trace quantities.

*HASTELLOY B2 – a nickel molybdenum alloy with a carefully controlled composition in respect of impurities and lower order alloying elements. The modified composition of this alloy results in thermal stability superior to that of its predecessors viz. *HASTELLOY B2.

The alloy has excellent resistance to hydrochloric acid at all concentrations and temperatures as well as to other non-oxidising media. The corrosion resistance of the alloy is sensitive to the presence of oxidizing impurities in the media even in trace quantities.

*registered name of Haynes International
Nickel alloys containing chrome, iron and silicon are favoured for “oxidizing” environments which may be typified by chromic and nitric acids, concentrated sulphuric acid and oxidizing salts solutions.

**ALLOY 600** is a nickel chrome iron alloy that is well established as a heat resisting alloy (oxidizing gasses) but also with some useful corrosion resisting properties.

However its use in wet corrosion conditions is restricted to a few special applications and it should not be considered for use in the acids quoted in the “Y” figure.

**ALLOY 690** is also a nickel alloy containing chrome and iron – 29% and 9% respectively (a higher content of chrome than **ALLOY 600**). It is thus useful at elevated temperatures but also finds application in sulphuric and nitric acid processing.

**HASTELLOY D205** is not a well known nickel alloy but with 20% chrome and a 5% silicon content is extremely resistant to oxidising acids and thus well suited to applications such as plate heat exchanges.

Although many other nickel chrome alloys exist they are mostly intended for high temperature applications and are thus not reviewed here.

There are alloys which although containing molybdenum, have chrome present in sufficient quantities to make them eminently suitable for oxidizing applications as well. 2 Such alloys are –

**HASTELLOY G30** – this 43Ni-30Cr-6Mo-15Fe-2.5W-Cu-Cb has many advantages over other metals and materials in handling fertilizer grade phosphoric acid, sulphuric and nitric acids and in fluoride environments and oxidizing acid mixtures.

**HASTELLOY G35** – with 58Ni-33.2Cr-8.1Mo-2Fe is a recent development to extend the useful service life of components in wet phosphoric acid production. The higher chromium content is of benefit in strongly oxidizing media.
ALLOYS FOR “MIXED” ENVIRONMENTS

Possibly the most widely used group of the nickel alloys are those containing, in addition to other alloying elements, both chrome and molybdenum and thus are well suited for use in environments that can be visualized as being in the middle of the 2 arms of the “Y” of corrosion i.e. their use may extend into both oxidizing and non-oxidizing applications.

These Ni-Cr-Mo alloys, often referred to as the “C-Family” of alloys, is the most versatile range of nickel alloys and they are used extensively in the chemical processing industry as well as in pollution control and minerals beneficiation. A convenient way of reviewing these alloys is by their chronology of development and several of the alloys produced by HAYNES INTERNATIONAL are listed.

**HASTELLOY C** – this Ni-16Cr-16Mo-6Fe-4W alloy had its origins in the 1930’s and although was a significant step forward in its time it was susceptible to intergranular corrosion in the heat affected zones of welds in certain environments. This meant that for many applications post fabrication heat treatment was required.

**HASTELLOY C276** – the Ni-16Cr-16Mo-6Fe-4W basic composition was modified in the 1960’s by controlling the carbon and silicon contents to very low levels for improved thermal stability. The result was an alloy which to this day is extensively used in industry because of its corrosion resistance and widespread availability. However, market place competition in the search for an alloy to cover the widest range of oxidizing and non-oxidizing conditions and the need to have even better alloys for specific applications resulted in other modified alloys.
**HASTELLOY C4** – a Ni-16Cr-16Mo-2Fe alloy. This was introduced in the 1970’s to cater for applications in which the thermal stability of C276 was still inadequate. The removal of tungsten and tighter control of iron reduced the susceptibility to form intermetallic compounds.

**HASTELLOY C22** – in the 1980’s a Ni-21Cr-13Mo-3Fe-3W alloy was introduced to cater for strongly oxidizing conditions – a consequence of the higher chrome and lower molybdenum in the alloy. It has been used extensively in Flue Gas Desulphurisation systems.

**HASTELLOY C2000** – a Ni-23Cr-16Mo-1.6Cu-2Fe alloy was a product of the 1990’s with the added benefit of superior resistance to sulphuric acid. It is the result of a quest for excellent general corrosion resistance over a range – oxidizing and non-oxidizing – of conditions - an alloy with high thermal stability - excellent localized corrosion resistance. There are several Ni – Cr – Mo alloys which don’t form part of the “C – Family” listed above. Many of these have an increased amount of iron in their make-up and thus including some of them in a review on nickel alloys may be questioned but they are included here for the sake of completeness.

**ALLOY 625** – is a 62Ni-21.5Cr-9Mo-(Cb+Ti) alloy that has been used for chemical, pollution control and offshore applications and in organic and mineral acids. It has good mechanical properties at high temperatures and is useful for a wide range of aerospace and high temperature applications. Variants of this grade have been introduced to optimize resistance to mechanical and thermal fatigue at 650 deg c.

**ALLOY 825** – this 42Ni-21.5Cr-3Mo-2Fe-2Cu-Ti is a well established alloy for sulphuric acid as well as a variety of mixed acid media.

**ALLOY 20** – this 35Ni-20Cr-2.5Mo-37Fe-3.5Cu-Nb is another well established alloy for sulphuric acid as well as a variety of mixed acid media.

**ALLOY 28** – a 31Ni-28Cr-3.5Mo-37Fe is yet another well established alloy for acid applications and is used extensively in phosphoric acid (fertilizer grade) applications.

*Registered name of Haynes International*
There exist several alloys which are derived from a “base” which has been modified in some way to obtain enhanced properties. These grades are manufactured and marketed for certain specific applications. Examples of these grades are:

- **ALLOY 31** from **ALLOY 28** by increasing molybdenum for improved corrosion resistance
- **ALLOY 825HMo** from **ALLOY 825** by increasing molybdenum for improved corrosion resistance
- **ALLOY 625LF or SQ** from **ALLOY 625** by controlled composition for improved elevated temperature fatigue strength
- **HASTELLOY C 22 HS** from **HASTELLOY C 22** by controlled composition for higher strength by heat treatment

* A RECENT DEVELOPMENT.
A recent development has been commercialization of a Ni – Mo – Cr alloy (as opposed to the “C-family” Ni – Cr – Mo alloys) which offers enhanced corrosion resistance to many key chemicals even in the presence of oxygen.

*HASTELLOY® HYBRID B1® is a Ni-22Mo-15Cr alloy which offers advantages over competitor materials (e.g., Ni-Mo and Ni-Cr-Mo alloys and Zr) in sulphuric and hydrochloric acids.

And so the quest for alloys to meet the demands of the chemical, petrochemical and minerals processing industries continues and notwithstanding the market conditions which impact on the availability and pricing of nickel itself, its alloys are not out of the limelight.
THE SOURCES CONSULTED IN THE PREPARATION OF THIS REVIEW ARE:

1. NICKEL, VOL. 18, NO. 3 JUNE 2003
2. Trade Literature, Haynes International
3. Trade Literature, Special Metals Corporation.
4. Trade Literature, Sandvik Special Metals
5. Trade Literature, ThyssenKrupp VDM.

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