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Review on material composition affecting the properties of nickel alloys

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ABSTRACT

In this study, the effects of adding Ni in different ratios to Fe-matrix material containing C-Nb-V produced by powder metallurgy on microstructure, tensile strength, hardness and corrosion behaviors were investigated.. The addition of more nickel led to decrease the strength. Analysis of Tafel curves showed that corrosion resistance of alloys increased with increasing nickel concentration. Nickel in elemental form or alloyed with other metals and materials has made significant contributions to our present-day society and promises to continue to supply materials for an even more demanding future. Nickel has always been a vital metal for a wide variety of industries for the simple reason that it is a highly versatile material that will alloy with most other metals. Nickel is a versatile element and will alloy with most metals. Nickel alloys are alloys with nickel as principal element. Complete solid solubility exists between nickel and copper. Wide solubility ranges between iron, chromium, and nickel make possible many alloy combinations. Its high versatility, combined with its outstanding heat and corrosion resistance has led to its use in a diverse range of applications; such as Aircraft gas turbines, steam turbines in power plants and its extensive use in the energy and nuclear power markets.

Keywords: Elemental compositions, Carbide, super alloys, corrosion.

INTRODUCTION

Nickel alloys are heat-resistant alloys used for jet engines and gas turbine blades. We started using the term “alloy design” after the phase computation (PHACOMP) method was developed in 1964 to predict the formation of harmful and brittle phases (e.g., σ phase) in nickel-based superalloys. This PHACOMP method has been widely used for the design and quality control of nickel-based superalloys. The parameter Nv is used for the prediction in this method. Nv is the number of vacancies or electron holes existing above the Fermi energy level in a metal d band. There are, however, several contradictions in this method. For example, it gives an ill prediction for the formation of the σ phase in some alloys. The prediction is poor for the formation of the μ phase. Furthermore, any design of Co-based and Fe-based superalloys by PHACOMP has not yet succeeded. Most of these problems are inherent in the electron vacancy concept itself, and hence could not be solved despite that enormous efforts have been made to improve the PHACOMP in some ways.

To solve these problems, new PHACOMP was developed in 1984 on the basis of the electronic structure calculations of alloys by the DV-Xα cluster method. This is a theoretical approach to the solid solubility problem of alloys, in which both solute and solvent atoms consist of transition metals. The Nv parameter is no longer used, but instead a new alloying parameter, Md, was introduced to the new PHACOMP. Here, Md is the d-orbital energy level of alloying transition metals (M) as explained in Chapter 2. Another alloying parameter, Bo, which is the bond order between alloying element (M) and mother metal (Ni) in the alloy, is also utilized for the understanding of alloy properties. A theory for alloy design using the Md and Bo parameters is presented in this chapter.

Properties

Most corrosion-resistant nickel-based alloys are solid solutions based in the element nickel (Ni). Some nickel alloys could be precipitation hardened (e.g. X-750, 625, 718). Even though Ni-based alloys in general contain a large proportion (sometimes up to 50%) of other alloying elements, nickel alloys still maintain the face centered cubic lattice structure (fcc, austenite, or gamma) from the nickel base element. As a consequence of the fcc structure, nickel-based alloys have excellent ductility, malleability and formability. Nickel alloys are also readily weldable. There are two large groups of the commercial Ni-based alloys. One group is designed to withstand high temperature and dry or gaseous corrosion while the other is dedicated mainly to lower temperature (aqueous and non-aqueous liquids) applications. Nickel-based alloys used for low temperature aqueous or condensed systems are generally known as corrosion-resistant alloys (CRA) and nickel alloys used for high

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temperature applications are known as heat-resistant alloys (HRA) or high temperature alloys (HTA). The practical industrial boundary between high and low temperature nickel alloys is in the order of 500°C (or approximately 1000°F). Most of the nickel alloys have a clear use either as CRA or HRA; however, a few alloys can be used for both applications (e.g. alloy 625 or N06625 and 718 or N07718).

Nickel-Based Alloys

Nickel-based alloys contain Fe and Cr, are strong at high temperatures, are resistant to corrosion, and have higher creep strength compared with austenitic and F/M steels. Large disks can be processed by means of hydrogen induced precipitation (HIP), but this process generates small grains and often leads to intermediate creep resistance. Ni-based solid solution strengthened alloys are considered for the primary circuit due to the good thermal stability, moderate creep strength, and well-established welding and metalworking techniques. Ni-based superalloys that contain Al have sufficient creep resistance for their use as helium gas turbines. Ni-based superalloys that contain gamma prime fine particles harden the material. Above 700 °C, the gamma prime precipitate coarsens and, therefore, the mechanical strength decreases.

Ni-based alloys suffer reduced tensile ductility during neutron irradiation 400–600 °C, swell at high doses, and have phase instability; therefore, they are best used in areas where radiation effects are minimal. Rapid breakdown in swelling resistance occurs from the radiation-enhanced precipitation of carbide phases, and at the same time, there is growth of attached cavities. Therefore, radiation can severely limit their use. At the grain boundary, several issues deter the use of Ni-based alloys, including radiation-enhanced precipitation of intermetallic and carbide phases, segregation of gamma prime, segregation of impurity elements, and precipitation and growth of helium bubbles. Such effects can lead to low ductility trans granular failures. Helium embrittlement is also a problem. Thus, Ni-based alloys to be used in future advanced nuclear energy systems will require microstructural design to minimize radiation-induced and radiation-enhanced carbide and intemetallics phase formation, and will require the formation of finely dispersed phases as trapping sites for small defects, impurities, and dislocations.

LITERATURE SURVEY

1. Effect of sintering temperature and heat treatment on microstructure and properties of nickel-based superalloy, Ronglu Sun, Ying Tang, Wei Niu, 2019, A nickel-based superalloy was prepared through powder metallurgy (P/M). In order to balance their microstructure and properties, heat treatments were carried on the alloys. The microstructures of the alloys were characterized by optical microscopy (OM), X-ray diffraction (XRD), scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). The solidification process in the alloys during the sintering process was calculated using Thermo-Calc software. A good quality nickel-based superalloy with a homogeneous microstructure and fine grain size can be obtained at the sintering temperature of 1140 C. The alloys mainly consist of irregular polygon CrB particles, irregular morphology Ni3B particles, hexagonal M7C3 particles, (g-Ni þ Ni3B) eutectics and bright g-Ni solid solution matrix. The calculated results show that the solidification process in the alloys during the sintering process is liquid / liquidþg-Ni / liquidþg-Ni þ M7C3 / liquidþ g-Ni þ M7C3þCrB / g-Ni þ M7C3þCrBþ(g-Ni þ Ni3B). The calculation results are helpful to understand the microstructure evolution in the nickel-based superalloy and agree well with the experimental data. The microstructure of the alloys after solution treatment is mainly composed of supersaturated g-Ni solid solution and M7C3. During the aging treatment, the supersaturated g-Ni solid solution decomposed and many small particles were uniformly precipitated in the g-Ni solid solution. As the aging temperature increased, the decomposition process of supersaturated g-Ni solid solution was accelerated and the precipitated particles became coarsen according to Ostwald ripening theory. The hardness of the alloys increased when aging treated at 300 C and 500 C due to the second phase strengthening effect, and then the hardness decreased when aging treated at 700 C due to the coarsening of precipitated particles.

2. Development of Ni-based Superalloy Metal Matrix Composites, Featuring High Creep Resistance, Author-Georges Lemos,Year-2020, The increasing demand for competitive, whilst also environment-friendly airplane travel, compels the design of highly efficient engines in the aeronautical field. A potential for improvement of traditional polycrystalline Ni-based superalloys, aiming higher creep resistance, was investigated. The approach adopted the concept of metal matrix composites (MMCs) to incorporate a rigid discontinuous phase, in the form of particles, to a γ'-strengthened Ni-based super alloy. In order to make the concept feasible, different microstructures resulting from diverse manufacturing techniques were investigated. By using distinct mixing and sintering methods, powders of Inconel X-750 and TiC were combined to form composites containing 15 vol.% of reinforcing particles. Powders were prepared with low and high energy milling processes, and formed by uniaxial pressure sintering and spark plasma sintering methods. Non-reinforced variants and composites had microstructures thoroughly examined at their initial state and after long isothermal aging treatments. Selected variants were further submitted to tensile and compression creep tests at temperatures between 700 and 800 °C, in the stress range of 200 to 500 MPa.

3. Microstructure and Hardness of Spark Plasma Sintered Inconel 625-NbC Composites for High-Temperature Applications, Author-Jan Huebner, Paweł Rutkowski, Year-2021, The study focuses on obtaining Inconel 625-NbC composites for high-temperature applications, e.g., jet engines, waste-to-energy combusting systems or gas engine turbines, and characterizing them in terms of their microstructure and hardness improvement. Synthesis was performed utilizing Spark Plasma Sintering (SPS) at 1150 ◦C under

the load of 45 MPa in medium vacuum (under 10−3 MPa) for a total time of 60 min. Four sets of samples with different Inconel 625 to NbC weight ratios were prepared (5, 10, 20, and 30 wt.%), followed by a reference sample containing no ceramic reinforcement. Obtained materials were hot-rolled at 1150 ◦C with a 10% reduction step and later cut and polished to perform characterization utilizing scanning electron microscopy (SEM) equipped with energy dispersive spectroscopy (EDS) module and microhardness testing device equipped with Vickers indenter. Hardness was improved proportionally to NbC addition achieving an increase of up to 20% of reference values. Additional heat treatment was conducted on the hot-rolled samples at 1200 ◦C in an argon atmosphere to further observe the interaction between reinforcement and alloy. Their microstructure revealed the coarsening of precipitates within the metal matrix and partial reinforcement dissolution, which proved to be crucial to obtaining the highest quality composites with homogenous hardness improvement.

METHODOLOGY

Existing System

Several families of commercial corrosion resistant high nickel alloys are used to handle aggressive industrial environments such as high temperature acids. Nickel alloys are resistant to cracking in hot chloride aqueous solutions. Environments that may cause stress corrosion cracking in nickel alloys include hot caustic solutions, high temperature water and hot and wet hydrofluoric acid. This chapter addresses the cracking behavior of nickel alloys in industries such as chemical process, nuclear power generation and in oil and gas exploration and production.

Proposed System

Nickel-based alloys have been and continue to be indispensable materials for fabricating PWR components, especially dissimilar metal weld joints. Coriou cracking has been detected in many kinds of components and parts in Japanese PWR plants. However, after developing TT Alloy 690 and the new heat treatment for alloy X-750, the Coriou cracking (primary water SCC) problem seems to have been solved practically. Nevertheless, many components and parts made of Alloy 600 and other similar susceptible materials remain in service in operating PWRs.

Consequently, more reliable prediction of the life span of components susceptible to primary water SCC based on scientific theoretical studies is required for the management of aging plants. In addition, appropriate quality assurance for the fabrication of TT Alloy 690 components also is needed to establish reliable plant life management.

Metals And Alloys

Nickel alloys These are generally extremely resistant to caustics up to high temperature, and to neutral water and sea water. They resist some acids. Alloys such as Inconel have good resistance up to 1170°C which increases with chromium content. Nickel alloys have high resistance to stress corrosion cracking. Different alloys have resistance to different acids. Nickel alloys are used for tanks, heat exchangers, furnace parts, and chemical plant.

Magnesium and magnesium alloys These have better resistance than steel in the atmosphere, but are inferior to aluminium. They corrode in salty air. They are fairly resistant to caustics, many solvents and fuels, but not to acids.

Titanium and titanium alloys These have excellent resistance to e.g. seawater and aqueous chloride solutions over a wide temperature range. Most alloys resist nitric acid. When alloyed with noble metals such as palladium they will resist reducing acids. These materials are high in the galvanic series and so should not be used with other metals.

Zinc An oxide film gives reasonable resistance to water and normal atmosphere.

Aluminium An oxide coating gives good resistance to water and atmosphere, but stress corrosion cracking occurs.

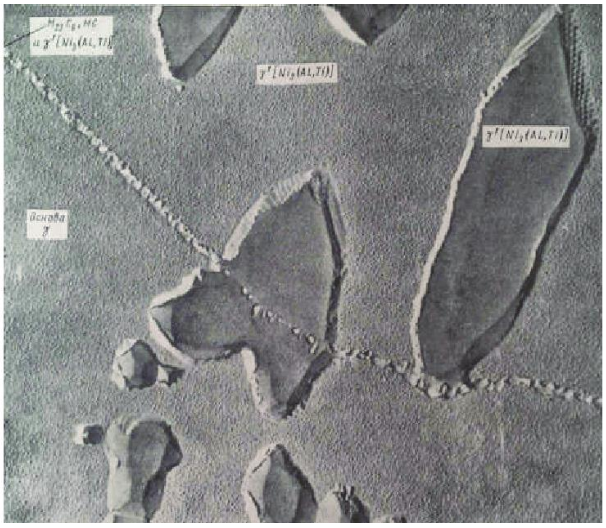


Fig 1: Chromium-Nickel alloy

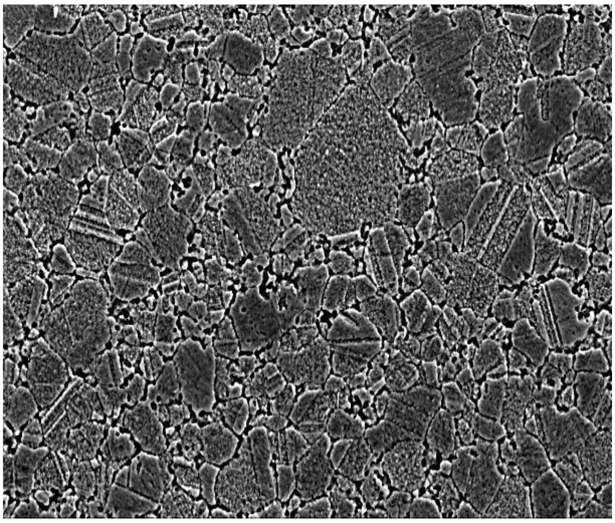


Fig 2: Microscopic Structure

Classification of Nickel Alloys

The nickel alloys can be classified in the following groups on the basis of their chemical compositions:

Nickel

- Pure nickel (99.56%)
- Commercially pure nickel (wrought) 99.6–99.7%.

Nickel and copper

- Low nickel alloys (2–13% Ni)
- Cupronickel (10–30% Ni)
- Non-magnetic alloys (~60% Ni)
- High nickel alloys (over 50% Ni)

Nickel and iron

- Wrought alloys steels (0.5–9% Ni)
- Cast alloy steels (0.5–0.9% Ni)
- Alloy cast iron (1–6, 14–36% Ni)

Iron-nickel and chromium alloys

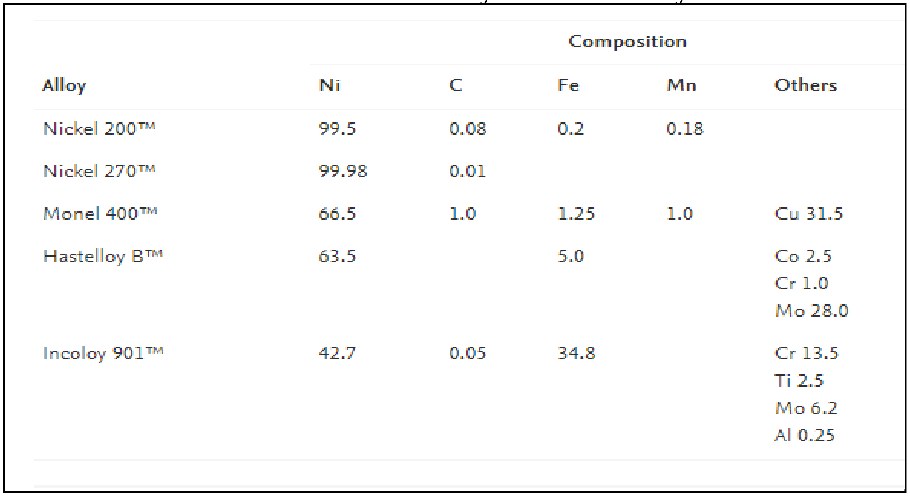
- Stainless steels (2–25% Ni)
- Maraging steels (18% Ni)

Nickel-chromium-molybdenum and iron-nickel base precipitation hardened alloys.

Hydrogen Containment Materials

Nickel alloys cover a wide range of chemical compositions, microstructures, and mechanical properties. In general, they have higher corrosion resistance than the stainless steels.

Table 1: Commonly used nickel alloys



	Composition				
Alloy	Ni	C	Fe	Mn	Others
Nickel 200™	99.5	0.08	0.2	0.18	
Nickel 270™	99.98	0.01			
Monel 400™	66.5	1.0	1.25	1.0	Cu 31.5
Hastelloy B™	63.5		5.0		Co 2.5 Cr 1.0 Mo 28.0
Incoloy 901™	42.7	0.05	34.8		Cr 13.5 Ti 2.5 Mo 6.2 Al 0.25

Compound steels with nickel as the principal element, such as Inconel 625 and Hastelloy C276, are considered nickel alloys. Nickel alloys in general are expensive, corrosion-resistant alloys that are used for different valve components.

Nominal pipe size (NPS) piping or valves in inch as an imperial unit. NPS 2 means that the size of the piping is 2″.

Non-destructive testing (NDT) refers to a group of tests for materials and components performed to detect possible defects without causing damage to the material.

NDT is typically performed on weld joints, and could include different types of tests, such as visual inspection, magnetic particle tests, liquid penetration tests, radiography, and ultrasonic tests. Ultrasonic test and radiography NDT are categorized as volumetric NDT.

Nickel alloy is formed by combining nickel with other metals, commonly titanium, copper, aluminum, iron, and chromium. Approximately 3,000 nickel-based alloys are in use, forming products for numerous industries. Roughly 90% of all new nickel sold every year is used to create alloys. The most popular one is stainless steel, which accounts for approximately two-thirds of new nickel alloys produced.

The enhancements this material provides includes:

- Improved versatility
- Higher toughness
- Increased corrosion resistance
- Oxidation resistance
- Improved strength at higher and lower temperatures
- Magnetic properties
- Electronic properties

Many nickel-based alloys offer superior performances at temperatures above 1000°C, making them well suited for extremely harsh environments. These offer excellent oxidation resistance at high temperatures while maintaining quality weldability, workability, and ductility.

Nickel alloy has a life span between 25 and 35 years on average and can last much longer depending on the application. With its extended service life, this material is more cost effective than other metals. Nickel alloy is recyclable and is among the most recycled materials around the world. Approximately half of the nickel in stainless steel products comes from recycled nickel materials.

CONCLUSION

Nickel in elemental form or alloyed with other metals and materials has made significant contributions to our present-day society and promises to continue to supply materials for a demanding future. This article provides a historical overview and physical metallurgy of nickel and nickel alloys. It lists and describes the compositions, mechanical and physical properties, and applications of commercial nickel and its alloys. The article briefly explains the forms of corrosion resulting from the exposure of nickel alloys to aqueous environments. It provides valuable information on the commercial forms of nickel alloys, namely, nickel-copper alloys, nickel-chromium and nickel-chromium-iron series, iron-nickel-chromium.

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