

DOWNLOAD PDF CREEP RESISTANCE OF DISK ALLOY CH98 WITH TUNGSTEN AND NIOBIUM ADDITIONS

Chapter 1 : Superalloy | Revolv

Creep resistance of disk alloy CH98 with tungsten and niobium additions. oclc/> # Creep resistance of disk alloy CH98 with tungsten and niobium additions.

Chemical development[edit] Because these alloys are intended for high temperature applications i. Nickel Ni based superalloys have emerged as the material of choice for these applications. Each of these additions has been chosen to serve a particular purpose in optimizing the properties for high temperature application. Creep resistance is dependent, in part, on slowing the speed of dislocation motion within a crystal structure. In order to improve the oxidation resistance of these alloys, Al, Cr, B, and Y are added. The Al and Cr form oxide layers that passivate the surface and protect the superalloy from further oxidation while B and Y are used to improve the adhesion of this oxide scale to the substrate. In addition to solid solution strengthening, if grain boundaries are present, certain elements are chosen for grain boundary strengthening. B and Zr tend to segregate to the grain boundaries which reduces the grain boundary energy and results in better grain boundary cohesion and ductility. While Ni based superalloys are excellent high temperature materials and have proven very useful, Co based superalloys potentially possess superior hot corrosion, oxidation, and wear resistance as compared to Ni-based superalloys. For this reason, efforts have also been put into developing Co based superalloys over the past several years. Despite that, traditional Co based superalloys have not found widespread usage because they have a lower strength at high temperature than Ni based superalloys. However this class of alloys was reported in a PhD thesis by C. Like in the Ni-based system, there is a high degree of coherency between the two phases which is one of the main factors resulting in the superior strength at high temperatures. This provides a pathway for the development of a new class of load-bearing Co based superalloys for application in severe environments. Therefore, if the high temperature strength could be improved, the development of novel Co based superalloys could allow for an increase in jet engine operation temperature resulting in an increased efficiency. This phase composes the matrix of Ni-based superalloy. It is a solid solution fcc austenitic phase of the alloying elements. This phase constitutes the precipitate used to strengthen the alloy. Ni₃ Ti,Al are ordered systems with Ni atoms at the cube faces and either Al or Ti atoms at the cube edges. This lattice mismatch leads to high coherency strains which, together with order hardening , comprise the primary strengthening mechanisms. Carbide formation is usually considered deleterious although in Ni-based superalloys they are used to stabilize the structure of the material against deformation at high temperatures. Carbides form at the grain boundaries inhibiting grain boundary motion. Just as in Ni-based super alloys, this phase constitutes the precipitate used to strengthen the alloy. In this case, it is usually close packed with a L12 structure of Co₃Ti or fcc Co₃Ta, though both W and Al have been found to integrate into these cuboidal precipitates quite well. This stabilization is quite important as the lack of stability is one of the key factors that makes Co-based superalloys weaker than their Ni-base cousins at elevated temperatures. As is common with carbide formation, its appearance in Co-based superalloys does provide precipitation hardening, but does decrease low-temperature ductility. Like the phases found in Ni-based superalloys, Fe-based alloys feature a matrix phase of austenite iron FCC. Alloying elements that are commonly found in these stainless steel alloys include: This phase is introduced as precipitates to strengthen the alloy. Microstructure of Fe-based superalloys[edit] Two major types of austenitic stainless steels exist and are characterized by the oxide layer that forms at the surface of the steel: Chromia-forming stainless steel is the most common type of stainless steel produced. However, chromia-forming steels do not exhibit high creep resistance at high operating temperatures, especially in environments with water vapor, when compared to Ni-based superalloys. Exposure to water vapor at high operating temperatures can result in an increase in internal oxidation in chromia-forming alloys and rapid formation of volatile Cr oxy hydroxides, both of which can reduce the durability and lifetime of the alloy. Alumina is more thermodynamically stable in oxygen than chromia. More commonly, however, precipitate phases are introduced to increase strength and creep resistance. In

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alumina-forming steels, NiAl precipitates are introduced to act as Al reservoirs to maintain the protective alumina layer. In addition, Nb and Cr additions help form and stabilize alumina by increasing precipitate volume fractions of NiAl. Microstructure of superalloys[edit] In pure Ni₃Al phase atoms of aluminium are placed at the vertices of the cubic cell and form the sublattice A. Atoms of nickel are located at centers of the faces and form the sublattice B. The phase is not strictly stoichiometric. There may exist an excess of vacancies in one of the sublattices, which leads to deviations from stoichiometry. At elevated temperature, the free energy associated with the anti-phase boundary APB is considerably reduced if it lies on a particular plane, which by coincidence is not a permitted slip plane. One set of partial dislocations bounding the APB cross-slips so that the APB lies on the low-energy plane, and, since this low-energy plane is not a permitted slip plane, the dissociated dislocation is now effectively locked. Initial material selection for blade applications in Gas Turbine engines included alloys like the Nimonic series alloys in the s. Cr₂₃C₆ at the grain boundaries [22] for additional grain boundary strength. Turbine blade components were forged until vacuum induction casting technologies were introduced in the s. Modern superalloys were developed in the s. Examples of first generation superalloys include: Because the material contained no grain boundaries, carbides were unnecessary as grain boundary strengtheners and were thus eliminated. The presence of rafts can decrease creep rate in the power-law regime controlled by dislocation climb, but can also potentially increase the creep rate if the dominant mechanism is particle shearing. Younger generations of Ni-based superalloys have significantly reduced Cr content for this reason, however with the reduction in Cr comes a reduction in oxidation resistance. Advanced coating techniques are now used to offset the loss of oxidation resistance accompanying the decreased Cr contents. The effect of Ru on the promotion of TCP phases is not well-determined. Early reports determined that Ru decreased the supersaturation of Re in the matrix and thereby diminished the susceptibility to TCP phase formation. An example is Eglin steel, a budget material with compromised temperature range and chemical resistance. It does not contain rhenium or ruthenium and its nickel content is limited. To reduce fabrication costs, it was chemically designed to melt in a ladle though with improved properties in a vacuum crucible. Also, conventional welding and casting is possible before heat-treatment. The original purpose was to produce high-performance, inexpensive bomb casings, but the material has proven widely applicable to structural applications, including armor. Single-crystal superalloys[edit] Single-crystal superalloys SX or SC superalloys are formed as a single crystal using a modified version of the directional solidification technique, so there are no grain boundaries in the material. The mechanical properties of most other alloys depend on the presence of grain boundaries, but at high temperatures, they would participate in creep and must be replaced by other mechanisms. In many such alloys, islands of an ordered intermetallic phase sit in a matrix of disordered phase, all with the same crystalline lattice. This approximates the dislocation -pinning behavior of grain boundaries, without introducing any amorphous solid into the structure. Single crystal SX superalloys have wide application in the high-pressure turbine section of aero and industrial gas turbine engines due to the unique combination of properties and performance. Since introduction of single crystal casting technology, SX alloy development has focused on increased temperature capability, and major improvements in alloy performance have been associated with the introduction of new alloying elements, including rhenium Re and ruthenium Ru. The creep deformation behavior of superalloy single crystal is strongly temperature, stress, orientation and alloy dependent. For a single-crystal superalloy, there are 3 different mode of creep deformation under regimes of different temperature and stress: Rafting, Tertiary and Primary. In addition, rafting would occur quickly and suppress the accumulation of creep strain until a critical strain is reached. Oxidation involves chemical reactions of the alloying elements with oxygen to form new oxide phases, generally at the surface of the metal. If unmitigated, oxidation can degrade the alloy over time in a variety of ways, including: The primary strategy used to limit these deleterious processes is called selective oxidation. Simply, the alloy is designed such that the ratio of alloying elements promotes formation of a specific oxide phase that can then act as a barrier to further oxidation. Most commonly, aluminum and chromium are used in this role, because they form relatively thin and continuous oxide layers of alumina Al₂O₃ and chromia Cr₂O₃

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, respectively. Furthermore, they possess low oxygen diffusivities, effectively halting further oxidation beneath this layer. In the ideal case, oxidation proceeds through 2 stages. First, transient oxidation involves the conversion of various elements, especially the majority elements. Transient oxidation proceeds until the selective oxidation of the sacrificial element forms a complete barrier layer. The continuity of the thin sacrificial oxide layer can be compromised by mechanical disruption due to stress or may be disrupted as a result of the kinetics of oxidation. If the layer is not continuous, its effectiveness as a diffusion barrier to oxygen is significantly reduced. The stability of the oxide layer is also strongly influenced by the presence of other minority elements. For example, the addition of boron, silicon, and yttrium to superalloys promotes oxide layer adhesion, reducing spalling and maintaining the integrity of the protective oxide layer. More complex corrosion processes are common when operating environments include salts and sulfur compounds, or under chemical conditions that change dramatically over time. These issues and those of basic oxidation are often also addressed through thin coatings.

Superalloy processing[edit] Processing methods used to generate various portions of a jet turbine engine. The historical developments in superalloy processing have brought about considerable increases in superalloy operating temperatures. Superalloys were originally iron based and cold wrought prior to the s. In the s investment casting of cobalt base alloys significantly raised operating temperatures. The development of vacuum melting in the s allowed for very fine control of the chemical composition of superalloys and reduction in contamination and in turn led to a revolution in processing techniques such as directional solidification of alloys and single crystal superalloys.

Casting and forging[edit] Casting and forging are traditional metallurgical processing techniques that can be used to generate both polycrystalline and monocrystalline products. Polycrystalline casts tend to have higher fracture resistance, while monocrystalline casts have higher creep resistance. Jet turbine engines employ both poly and mono crystalline components to take advantage of their individual strengths. The disks of the high-pressure turbine, which are near the central hub of the engine are polycrystalline. The turbine blades, which extend radially into the engine housing, experience a much greater centripetal force, necessitating creep resistance. As a result, turbine blades are typically monocrystalline or polycrystalline with a preferred crystal orientation.

Investment casting[edit] Investment casting is a metallurgical processing technique in which a wax form is fabricated and used as a template for a ceramic mold. Briefly, a ceramic mold is poured around the wax form, the wax form is melted out of the ceramic mold, and molten metal is poured into the void left by the wax. This leads to a metal form in the same shape as the original wax form. Investment casting leads to a polycrystalline final product, as nucleation and growth of crystal grains occurs at numerous locations throughout the solid matrix.

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Chapter 2 : Properties of Binary Rhodium Alloys | Johnson Matthey Technology Review

creep rates for coarse grain CH98 with tungsten and niobium additions over a range of temperatures and stresses of interest to disk applications. This research was originally published internally as AST in May

The criterion necessary to deliver optimal alloy performance are given in Table 3. It has been determined by the inventors that the newly developed alloy should be substantially free from additions of Mo. Currently there are no Mo free rotor disc alloys commercially produced. The present invention therefore represents a significantly innovative step. Excluding or greatly reducing Mo content enabled the creep resistance measured in terms of the creep merit index and corrosion resistance in terms of the Cr content to be maximised for a microstructurally stable alloy. Typically, Mo and W are added for creep resistance see the prior alloys listed in Table 1. These elements have a similar value for Md. However, W has a much stronger effect on creep resistance; therefore lower concentrations of W are needed to obtain adequate creep resistance. Using W in preference to Mo allows for increased levels of Cr in a high strength, creep resistant nickel based alloy that is microstructurally stable. Experimental work on alloys T1, T2 and T3, defined in Table 4, identified that additions of W had a strong influence on creep resistance, increases from 0. For this reason a minimum W content of 0. In order to achieve exceptional oxidation resistance, experimental results showed high concentrations of Cr were required. The experimental alloys T1-T6 described in Table 4 allowed for a systematic study of compositional-property relationships for oxidation resistance. In these alloys, in which only the Ti level was modified for a fixed Cr level, it was found that Nb could be substituted for Ti additions on a 1: Additions of up to 0. The alloys described herein are suitable for powder metallurgy processing. Consequently, carbon is added to the alloy compositions to pin grain boundaries for grain growth control and to inhibit grain boundary sliding during high temperature deformation during powder metallurgy processing, and particularly during heat treatment. The main grain boundary strength in the described alloys is provided by boron and zirconium through formation of oxides and borides. The preferred ranges for carbon, boron and zirconium are listed in Table 2. The alloy may also comprise small amounts of hafnium in amounts up to 0. Preferably, the composition contains less than 0. Hafnium in these quantities has been found to improve dwell crack growth resistance, thereby increasing component life of a component made of the alloy. The described alloy compositions can be produced using powder metallurgy methods. Powder metallurgy methods are particularly suitable for the production of the composition where the alloy is to be used for the formation of gas turbine rotor discs. The sintered article is then extruded to produce a fine grain size billet. Increments are then cut from these billets and forged, preferably, at low strain rates under isothermal conditions. The forging temperature and strain rates are chosen to achieve a required average grain size. Other billet and forging technology could alternatively be used to produce raw material for disc rotors. The applicability of alternative techniques, such as cast and wrought processing, i. To generate a forging having the required balance of properties, it is necessary to subject the forging to a heat treatment process. This process comprises the following process steps, conducted in the following order: The required time for a given alloy composition and initial powder size could be determined by trial and error, and determined by microscopy of samples of the resulting heat treated forging. The following examples are illustrative of several aspects of the disclosure: Example Alloy D1 Alloy D1 represents a baseline composition for the alloy described within this disclosure. The alloy consists essentially of, in weight percent, Alloy D1 has been designed with an equal weighting considered for all material properties. Alongside alloy D1, further alloys were developed. For these further alloys, a bias toward specific properties was considered. The alloys described in the following section will be described in comparison to alloy D1. Example Alloy D2 Alloy D2 has been designed with a bias toward low density and increased oxidation resistance. This oxidation resistance was improved at the expense of creep resistance with levels of Co and W being reduced to maintain microstructural stability. Lower density alloys are desirable for aerospace applications; density was reduced by decreasing the W content and increasing the

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Al content. Example Alloy D3 Alloy D3 has been designed with a bias towards creep resistance. The improvements in creep resistance have been achieved by increasing the level of W and Co in the alloy. The increase in creep resistance has been achieved at the expense of oxidation resistance and density. This alloy has improved mechanical properties at the expense of environmental resistance. Example Alloy D4 Alloy D4 has been designed for superior strength combined with increased oxidation resistance, achieved at the expense of reduced creep resistance and increased density. Increased Nb levels have been used to provide mechanical strength. Reducing the W content was necessary in order to control alloy density and stability. Example Alloy D5 Alloy D5 has been designed for low cost and reduced density; this is at the expense of oxidation resistance. The consists essentially of, in weight percent, By substituting Nb with additions of Ti it was possible to reduce the density of the alloy. The use of low Ta concentrations combined with the low Nb levels creates a low cost alloy. Example Alloy D6 Alloy D6 has been designed for superior creep resistance. High levels of Ta have been used in substitution for Ti additions. Small levels of Mo have been utilised to maximise creep resistance whilst maintaining a microstructurally stable alloy. Example Alloy D7 Alloy D7 has been designed for superior creep resistance and high specific strength. The levels of W and Mo are significantly increased in order to impart superior creep resistance. Cobalt levels have been lowered in order to maintain microstructural stability. Example Alloy D8 Alloy D8 has been designed for superior creep resistance, high specific strength and improved oxidation resistance at the expense of increased material cost. The maximum levels of Tantalum have been used to attain high specific strength as this element has the strongest effect on APB energy. Additions of iron have been included. Example Alloy D9 Alloy D9 has been designed for superior creep resistance, high specific strength and improved oxidation resistance at the expense of increased material cost. Additions of Mn have been incorporated to impart improved oxidation resistance. Cobalt levels have been lowered in order to maintain improved microstructural stability. Example Alloy D10 Alloy D10 has been designed for superior creep resistance, high specific strength and improved oxidation resistance at the expense of increased material cost. Cobalt levels have increased to improve creep properties and processing of the alloy whilst maintaining an tolerable level of microstructural stability. Whilst improvements in strength and resistance to creep strain accumulation are expected from these alloys, the major benefit is considered to be in the resistance to hot corrosion and oxidation damage and dwell crack growth, as well as dwell fatigue endurance. Figure 8 shows the yield strength for example alloys T1, T2 and T3 at various temperatures. As can be seen, example alloys T1 to T6 have a high oxidation resistance. The Cr and Ti levels have been optimised for alloys D1-D8 to ensure that these levels of oxidation resistance are achieved. Unlike the prior art, it is proposed that the disclosed alloys achieve a balance between resistance to environmental degradation and high temperature properties such as proof strength, resistance to creep strain accumulation, dwell fatigue and damage tolerance. Although the description refers to the described alloys as being particularly useful for forming rotor discs for gas turbine, the alloys could also be used to form other components. For example, the alloys could be used for hot static parts of a gas turbine engine, such as combustor and turbine casings. These applications would benefit from all of the envisaged improvements in material properties, notably the improved high temperature proof strength and resistance to creep strain accumulation. As compressor discharge temperatures and turbine entry temperatures are progressively raised to produce improvements in thermal efficiency and thus fuel consumption, the temperature of static parts in the combustor and turbine also increase during operation. Such casings could be produced using conventional cast and wrought technology, i. The latter route is preferred given the highly alloyed compositions and ability to produce compacts that are close to the component geometry, which reduces the amount of material required and the time required to machine the component. Although the alloy is described as being formed by powder metallurgy and subjected by heat treatment, other material processing methods could be used to generate articles from the alloy compositions having the required properties. Claims 16 An alloy composition consisting essentially of, in atomic percent, between 12 and An alloy composition according to claim 1 consisting essentially of, in atomic percent, between 12 and An alloy composition according to any of the preceding claims comprising,

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in atomic percent, substantially

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Chapter 3 : Superalloy - Wikipedia

Additions of the refractory elements tungsten and niobium have been shown to improve tensile and creep properties while maintaining good high temperature fatigue crack growth resistance. Further improvements in creep and crack growth resistance can be achieved with a coarse grain microstructure.

The steel is particularly suited for high temperature applications including, but not limited to, current collecting interconnects in solid oxide fuel cells, furnace hardware, equipment for the chemical process, petrochemical, electrical power generation, and pollution control industries, and equipment for handling molten copper and other molten metals. More particularly, the present invention is directed to a ferritic stainless steel alloy having microstructural stability and mechanical properties making it particularly suited for high temperature applications. Such applications include, but are not limited to, current collecting interconnects in solid oxide fuel cells, furnace hardware, equipment for the chemical process, petrochemical, electrical power generation, and pollution control industries, and equipment for handling molten copper and other molten metals. The basic principle behind the operation of fuel cells is the generation of electricity by the combustion of fuel. The fuel is separated from an oxidizer by a permeable barrier known as an electrolyte. Hydrogen atoms on the fuel side of the electrolyte are ionized. The resulting protons pass through the electrolyte, while the liberated electrons travel through an external circuit. On the air side of the electrolyte, opposite the fuel side, two protons combine with an oxygen atom and two electrons to create a water molecule, liberating heat and completing the electric circuit. Energy is extracted from the process by using the electrons in the external circuit to do work. A type of fuel cell currently attracting much interest is the solid oxide fuel cell SOFC. Internal reformation recycles thermal energy and eliminates the need for expensive platinum group metal catalysts. Hydrogen and carbon monoxide are both used as fuel in the SOFC. Hydrogen combines with oxygen in a modification of the generic fuel cell reaction detailed previously. The electrolyte is an oxide ceramic, which is permeable to oxygen ions O^{2-} , rather than to protons. Thus, the SOFC runs in a reverse direction relative to certain other fuel cell types. In addition to combusting hydrogen, carbon monoxide is oxidized to carbon dioxide at the anode, releasing heat. This is an advantage because carbon monoxide is present in unrefined fuels and can poison low temperature fuel cells, reduce operating efficiency. Several variants on the basic SOFC design exist. The electrolyte is typically a form of zirconia that has been stabilized by the addition of oxides to inhibit lattice changes and provide high ionic conductivity when heated to high temperatures. Such oxide-stabilized materials are generally known, and are referred to herein, as "stabilized zirconia". The anode and cathode plates are typically ceramic materials. Permeable nickel-zirconia cermets have also been used for the anode. Interconnects are needed to collect the electrons generated by a fuel cell. Interconnects also function as a physical separator for the oxidizing and reducing gas streams. Accordingly, the material used to form fuel cell interconnects should be electrically conductive, oxidation resistant, and mechanically stable, and should have thermal expansion properties substantially matching those of the ceramic components of the cell, which may be physically disposed adjacent to the interconnects. Although ceramics typically are stable when subjected to high temperatures for prolonged periods, ceramics also are brittle and relatively expensive, and are poor conductors of electricity relative to metals. Certain metallic interconnects have been fabricated from a chromium-based alloy developed for that purpose. The alloy provides adequate oxidation resistance and a good thermal expansion match with stabilized zirconia. Fabricating SOFC interconnects from stainless steels may provide advantages over ceramics because the steels would have greater electrical conductivity and may be in a form less brittle than ceramics. However, problems associated with the use of stainless steels in SOFC interconnect applications include oxidation, thermal expansion, and creep problems. Oxidation can reduce the capacity of a stainless steel to conduct current, thereby reducing cell output over time. Standard austenitic stainless steels do not provide a good thermal expansion match with conventional SOFC electrolyte ceramics. Ferritic stainless steels that may provide a good thermal expansion

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match with the ceramic electrolytes typically exhibit low creep resistance. The present invention also provides a method for making a ferritic stainless steel alloy wherein the method includes forming a steel comprising greater than 25 weight percent chromium, 0. In a subsequent step, the steel is solution annealed and then cooled from the annealing temperature. If desired, the solution annealed stainless steel is precipitation heat treated to harden the steel. The present invention also provides for the fabrication of articles of manufacture from the stainless steel of the present invention. The articles may be fabricated using conventional techniques. The stainless steel of the present invention exhibits improved high temperature mechanical properties, including improved high temperature creep resistance, relative to other ferritic stainless steels. The steel also may be suitable for use in high stress, high temperature applications including, for example, oxygen sensor devices, certain chemical process, petrochemical, electrical power generation, and pollution control equipment, high temperature furnace hardware, and molten metal handling equipment. The reader will appreciate the foregoing details and advantages of the present invention, as well as others, upon consideration of the following detailed description of embodiments of the invention. Initial work in this area, however, revealed drawbacks in the various existing stainless steels considered. For example, austenitic nickel-base materials were found to exhibit a poor coefficient of thermal expansion ratio. Alumina-forming ferritic alloys were found deficient because they are not electrically conductive after they oxidize. Through experimentation, the present inventor identified such a ferritic stainless steel, including greater than 25 weight percent chromium, 0. Preferably, the carbon content of the alloy is limited to 0. When the SOFC is subsequently cooled, if the CTE of the metal is less than that of the stabilized zirconia electrolyte, the metal will be placed in compression while the ceramic is placed in tension. It is well known that brittle materials preferably are loaded in compression and may fail unexpectedly when loaded in tension. Thus, it is preferable that the metal have a CTE as least as great as the oxide-stabilized ceramic. The inventor has further discovered that to optimize the properties of the ferritic stainless steel of the invention for SOFC interconnect applications, the steel preferably is solution annealed and then cooled from the annealing temperature during processing. The inventor has found that annealing the alloy at excessive temperatures for example, in excess of. Rapid cooling from the annealing temperature, such as is produced by water quenching, was not found to be required, but is not deleterious. Very slow cooling, such as by furnace cooling, also has not been found to be necessary. Air cooling or cooling by alternate means at an equivalent rate is generally preferred. To modify certain mechanical properties of the alloy for use in applications where increased hardness is required, the solution annealed stainless steel may be precipitation heat treated by conventional means Chromium contributes to the oxidation resistance of the stainless steel and to its formation of a Cr_2O_3 scale that is electrically conductive at high temperatures. It also is largely responsible for reducing thermal expansion of the steel so that it generally matches that of zirconia. It is believed that steels including less than about 25 weight percent chromium would not exhibit these desired properties. As chromium content is increased above about 35 weight percent, however, the steel becomes more difficult to hot work and, therefore, more expensive to produce. Moreover, a steel including such a high chromium content would be more likely to form an undesirable intermetallic sigma FeCr phase. Accordingly, the chromium content preferably is no greater than about 35 weight percent, more preferably is no greater than about 30 weight percent, and even more preferably is no greater than about 25 weight percent. Molybdenum reduces thermal expansion. It also provides solid solution strengthening and in conjunction with niobium forms the strengthening Laves phase $\text{Fe}_2\text{Nb,Mo}$ precipitate. Molybdenum, however, substantially increases the tendency of the stainless steel to precipitate the undesirable sigma phase, as well as the equally undesirable chi Fe,Cr,Mo phase. Molybdenum also impairs the oxidation resistance of the steel and can, under certain circumstances, promote a catastrophic form of oxidation. For these reasons, the molybdenum content of the stainless steel preferably is carefully controlled. A molybdenum content of about 0. In particular, experimental alloys produced by the inventor including 0. The role of carbon in ferritic stainless steels is well known. Carbon contents less than about 0. To optimize properties, carbon contents less than 0. The niobium content of the stainless steel of the present invention, however, will mitigate many of the effects of the carbon.

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For this reason, carbon contents up to about 0. One having ordinary skill in the art may readily determine the content of carbide forming elements that must be present in a given alloy of the present invention to stabilize a given carbon content. If welded articles are to be formed from a steel of the present invention, it may be preferable to respect the preferred 0. Small additions of niobium have been found to improve creep or "sag" resistance in ferritic stainless steels. These niobium additions, under the right circumstances, produce a fine dispersion of Laves phase $\text{Fe}_2\text{Ta,Nb,Mo}$ precipitates. The suitable content of niobium in the stainless steel of the invention was determined through experimentation, as described below. It is believed that titanium may be substituted for a portion of the niobium in the alloy. In addition, tantalum is similar to niobium in its influence on the properties of the alloy, but is heavier and substantially more costly than niobium. It is believed that tantalum may be substituted for niobium and titanium in whole or in part on the basis that 2 weight percent tantalum is equivalent to 1 weight percent niobium and titanium. Thus, it is believed that the improved properties of the stainless steel of the invention observed by the inventor may be achieved by including in the steel at least one of niobium, titanium, and tantalum, wherein the sum of the weight percentages of niobium, titanium, and tantalum satisfies the following equation: One benefit of adding titanium to the stainless steel of the present invention is that it will remove nitrogen from solution as TiN . This will better prevent the formation of NbN and CrNbN precipitates, thus preserving the niobium a more costly alloying addition than titanium for the formation of desirable Laves Fe_2Nb phase strengthening precipitates. It is also believed that the addition of titanium may similarly remove carbon from solution and thereby better prevent formation of NbC and NbCN . It also has been observed that titanium in amounts above about 0. To better ensure a significant improvement in high temperature properties while limiting costs associated with the alloying additions, the sum of the weight percentages of niobium, titanium, and tantalum in the steel of the present invention is more narrowly controlled to satisfy the following equation: In addition, to the foregoing elements, the ferritic stainless steel of the present invention may include additions of one or more rare earth elements. These optional rare earth additions include, but are not limited to, up to about 0. Additions of rare earth elements as alloy additions have been shown to be highly beneficial for increasing the oxidation resistance of iron-base alloys. Such effect has been demonstrated for yttrium, lanthanum, and cerium. The other rare earth elements tend progressively to be more costly and less effective, but can be used for that purpose. It is not necessary to add only a single rare earth metal REM when adding such elements to the stainless steel of the present invention. As is known in the art, mischmetal is a naturally derived mixture of metallic rare earth elements containing about 50 weight percent cerium, with the remainder principally lanthanum and neodymium. Various mechanisms have been proposed for the effect of rare earth elements on the oxidation resistance of metal alloys. Acceptance of this mechanism is supported by the finding that reducing sulfur in REM-free alloys to ultra-low levels less than 1 ppm has much the same effect as adding REM to alloys with typical sulfur contents ppm. Other theories that have been proposed include increased scale plasticity, promotion of protective oxide formation, and mechanical keying of the scale to the metal by formation of rare earth oxide pegs. Regardless of the actual mechanism, it is the increased corrosion resistance offered by REM addition that is significant to the present invention. It is important not to add too great an amount of REM, because these elements have limited solubility in iron-based alloys, and the excess solute forms undesirable intermetallic phase, deep eutectics, or both, with very significant impairment of hot workability. High levels of REM also may lead to "overdoping", which is characterized by the formation of islands of REM oxides and increased oxidation rates.

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Chapter 4 : Copper-Nickel Alloys: Properties, Processing, Applications

Additions of the refractory elements tungsten and niobium have been shown to improve tensile and creep properties while maintaining good high temperature fatigue crack growth resistance.

Cronstedt succeeded in isolating nickel. However, Cu-Ni alloys were in existence much earlier, mostly prepared by processing ores. Today, Cu-Ni alloys have gained a variety of interesting applications because of their specific characteristics [1]. Copper and nickel are adjacent to one another in the periodic system of elements, with atomic numbers 29 and 28 and atomic weights 63.5 and 58.7 respectively. The two elements are closely related and are completely miscible in both the liquid and solid state. Cu-Ni alloys crystallise over the whole concentration range in a face-centred cubic lattice. The lattice spacing of the face-centred cubic solid solution varies almost linearly with atomic concentration between the values for copper and nickel. When other elements are present, nickel has the largest individual content after copper, compared with each other element. As with other copper alloys, it is necessary to distinguish between wrought alloys, which are processed to semi-finished products, and cast alloys, from which castings are produced by various casting processes. The age-hardenable copper-nickel-silicon alloys with 1. The most ancient Cu-Ni coin that has been saved for posterity comes from the period around 600 BC. It was found in Bactria and consists of an alloy similar to the modern cupronickel. These and many other old coins are outstanding examples for the high corrosion resistance of Cu-Ni alloys. It was only in the 19th century that nickel pyrites, $NiAs_2$, for the veins of ore worked in seams also incorporated copper and iron sulphides as well as arsenides. Around 1850, it was recognised that additions of iron significantly improve the resistance of Cu-Ni alloys to erosion corrosion in flowing seawater and other aggressive waters. Alloys of the two metals form a continuous series of solid solutions having a face-centred cubic lattice, i.e. The equilibrium diagram is therefore very simple. The melting points of the two components broaden to a melting range in the alloys. A two-phase area in which liquid and a crystals co-exist is formed between liquidus and solidus. Below a dotted straight line at the bottom right, behaviour is ferromagnetic, above it is paramagnetic. While tensile strength, 0. Tensile strength and elongation are shown in Fig. Manganese is added to the melt for deoxidation. It ties up sulphur, which is detrimental to hot working, as harmless manganese sulphide, improves casting characteristics, increases strength, and especially the softening temperature Fig. It promotes the formation of an adherent, uniform protective coating in water and thus improves corrosion resistance, primarily in fast-flowing seawater see 2. The solubility of iron in the Cu-Ni solid solution decreases as temperature is lowered Fig. Mechanical properties are improved somewhat by iron. Cold workability is slightly worsened. Tin as an addition element raises tensile strength, tarnish resistance and wear resistance of Cu-Ni alloys. Cu-Ni alloys containing c. In the Cu-Ni system, the solubility of silicon increases with nickel content. Up to the solubility limit, increasing silicon contents raise strength and reduce ductility. Niobium increases tensile strength and proof strength, while elongation drops. The favourable effect of niobium on the weldability of cast alloys is crucial see 3. Lead is kept below 0. Even lead contents of more than 0. However, cast alloys with high lead contents, e. Zinc-free alloys are required as materials for fittings in electron tubes to avoid zinc vaporisation. Titanium promotes the formation of pore-free welds because it can tie up oxygen, hydrogen and nitrogen, due to its high affinity for these gases. Therefore titanium is an essential constituent of welding consumables. Phosphorus has a strongly embrittling effect in Cu-Ni alloys and decreases weldability hot shortness and crack formation. Therefore phosphorus content is kept as low as possible, but at most 0. Furthermore, chromium, aluminium and beryllium are interesting as alloying elements. These additions make Cu-Ni alloys age-hardenable. Chromium increases strength and has a surprisingly favourable effect on resistance to erosion corrosion in fast-flowing seawater and to erosion by solids. Aluminium increases strength, seawater and scaling resistance. Beryllium has the strongest effect on mechanical properties after age-hardening. The solubility of carbon in nickel max. Carbon is not detrimental in Cu-Ni alloys. Cobalt can often occur as an uncontrolled constituent in Cu-Ni alloys depending on the cobalt content of the nickel used. Antimony, arsenic, sulphur, tellurium and

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bismuth are embrittling in small quantities, alone or in combinations, and should not be present in practice in Cu-Ni alloys.

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Chapter 5 : LOW DUCTILITY ALLOY - DONCASTERS PARALLOY

Creep resistance of disk alloy CH98 with tungsten and niobium additions [microform] Creep properties. Creep strength. Nickel alloys. Tungsten. Niobium. Refractories.

A multi-stage shift reactor includes a vessel having an inner chamber configured to contain a first shift catalyst, the first shift catalyst configured to receive anode exhaust gas from a fuel cell and to output a first shifted gas, and an outer chamber annularly disposed about the inner chamber and configured to contain a second shift catalyst, the second shift catalyst configured to receive the first shifted gas and output a second shifted gas. The shift reactor further includes a water injection port downstream from the inner chamber and packing between the water injection port and the outer chamber, the packing configured to prevent liquid water from passing therethrough. Grant Date of Patent: October 23, Assignee: Ni-based superalloy with excellent unsusceptibility to segregation Patent number: A subject for the invention is to diminish the occurrence of streak-type segregation in producing a material comprising a Ni-based superalloy. The invention relates to a Ni-based superalloy having excellent unsusceptibility to segregation, characterized by comprising: January 2, Assignee: A nickel-chromium-aluminum-iron alloy includes in wt. May 23, Assignee: Heike Hattendorf Nickel-chromium alloy having good processability, creep resistance and corrosion resistance Patent number: The invention relates to a nickel-chromium alloy comprising in wt. May 16, Assignee: Heike Hattendorf Weldable oxidation resistant nickel-iron-chromium aluminum alloy Patent number: A weldable, high temperature oxidation resistant alloy with low solidification crack sensitivity and good resistance to strain age cracking. January 24, Assignee: Nickel-chromium-iron-aluminum alloy having good processability Patent number: October 25, Assignee: Heike Hattendorf, Jutta Kloewer Exhaust valve spindle for an exhaust valve in an internal combustion engine Patent number: An exhaust valve spindle for an exhaust valve in an internal combustion engine has a shaft and a valve disc at the lower end of the shaft, which valve disc at its upper surface has a seat area. The seat area is of a seat material comprising at least from October 11, Assignee: Uffe Bihlet Ni-based casting alloy and steam turbine casting part using the same Patent number: To provide, in producing a large product through casting, a Ni-based alloy with a composition that minimizes variations in strength at different locations even when the solidification rate becomes slow and the amount of micro segregation increases. Mitsubishi Hitachi Power Systems, Ltd. November 3, Assignee: A nickel-base alloy having the following composition in weight percent unless otherwise stated: July 7, Assignee: April 2, Inventor: February 19, Applicant: Heike Hattendorf Alloy composition for the manufacture of protective coatings, its use, process for its application and super-alloy articles coated with the same composition Patent number: Alloy composition for the manufacture of protective coatings, comprising cobalt, nickel, chromium, aluminium, yttrium and iridium in amounts so as to obtain the phases? Preferably, such super-alloy article is a turbine component. December 30, Assignee: An electrode material contains, on a mass percent basis, Al: The remainder are Ni and inevitable impurities. Because of the inclusion of specific amounts of Al, Si, Cr, and Y and the Si content higher than the Al content, the electrode material has an oxidation inhibiting effect. The inclusion of the specific amount of Ti can reduce the occurrence of expansion and cracking of the oxide film. Because of the inclusion of the specific amount of Y, the oxide film can maintain the microstructure even at high temperatures and have high resistance to high-temperature oxidation. December 18, Inventors: This alloy has an improved oxidation resistance and good creep properties at high temperatures. December 9, Assignee: A Ni based alloy material consists of by mass percent, C? October 14, Assignee: Disclosed herein are nickel beryllium alloys having improved corrosion and hardness characteristics relative to known nickel beryllium alloys. The alloys have a chemical composition with about 1. The alloys display improved hardness and corrosion resistance properties. September 18, Applicant: Coatings as may be used in a gas turbine are provided. August 21, Applicant: A Ni-based heat resistant alloy as pipe, plate, rod, forgings and the like consists of C? In the formula, d denotes an average grain size? The alloy has improved ductility after

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long-term use at high temperatures, and cracking due to welding can be avoided. July 22, Assignee: An alloy composition includes a blend of a first alloy and a second, different alloy. The blend has a combined composition including about July 8, Assignee: A nickel-based super alloy includes, by weight, about 1. May 15, Applicant: Nickel based alloys capable of forming bulk metallic glass are provided. The alloys include Ni-Cr-Si-B compositions, with additions of P and Mo, and are capable of forming a metallic glass rod having a diameter of at least 1 mm. March 20, Applicant: This alloy has an improved oxidation resistance, good creep properties at high temperatures and. February 20, Applicant: Known protective coatings having a high Cr content, as well as silicon, have brittle phases that become additionally brittle under the influence of carbon during use. A protective coating is provided. December 19, Inventors: December 5, Applicant: Known protective layers with a high Cr content and additionally silicon form brittle phases which additionally embrittle during use under the influence of carbon. November 14, Inventors: November 7, Applicant: Known protective layers with a high Cr content and in addition silicon form brittle phases which additionally embrittle during use under the influence of carbon. October 31, Inventors: The alloy provides exceptional coal ash corrosion resistance in low partial pressures of oxygen. The alloy also increases in hardness and in thermal conductivity at service temperature over time. The increased hardness improves erosion resistance of the tubes while the increased thermal conductivity improves the thermal efficiency of the boiler and its power generation capabilities. October 29, Assignee: An alloy designed for use in gas turbine engines which has high strength and a low coefficient of thermal expansion is disclosed. The alloy must further satisfy the following compositional relationship: October 1, Assignee: A metallic coating or alloy is provided. The metallic coating includes iron, cobalt, chromium, and aluminum. Tantalum may also be included. A component including the metallic coating or alloy is also provided. August 29, Applicant:

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Chapter 6 : EPA1 - A nickel based alloy composition - Google Patents

Both alloys exhibit excellent creep resistance. The composition of these alloys includes molybdenum and rhenium (80/20 nickel-chromium alloy with additions of.

Save Nickel superalloy jet engine RB turbine blade A superalloy, or high-performance alloy, is an alloy that exhibits several key characteristics: The crystal structure is typically face-centered cubic austenitic. Superalloy development has relied heavily on both chemical and process innovations. Superalloys develop high temperature strength through solid solution strengthening. Oxidation or corrosion resistance is provided by elements such as aluminium and chromium. The primary application for such alloys is in turbine engines, both aerospace and marine. Chemical development Because these alloys are intended for high temperature applications i. Nickel Ni based superalloys have emerged as the material of choice for these applications. Each of these additions has been chosen to serve a particular purpose in optimizing the properties for high temperature application. Creep resistance is dependent, in part, on slowing the speed of dislocation motion within a crystal structure. In order to improve the oxidation resistance of these alloys, Al, Cr, B, and Y are added. The Al and Cr form oxide layers that passivate the surface and protect the superalloy from further oxidation while B and Y are used to improve the adhesion of this oxide scale to the substrate. In addition to solid solution strengthening, if grain boundaries are present, certain elements are chosen for grain boundary strengthening. B and Zr tend to segregate to the grain boundaries which reduces the grain boundary energy and results in better grain boundary cohesion and ductility. While Ni based superalloys are excellent high temperature materials and have proven very useful, Co based superalloys potentially possess superior hot corrosion, oxidation, and wear resistance as compared to Ni-based superalloys. For this reason, efforts have also been put into developing Co based superalloys over the past several years. Despite that, traditional Co based superalloys have not found widespread usage because they have a lower strength at high temperature than Ni based superalloys. However this class of alloys was reported in a PhD thesis by C. Like in the Ni-based system, there is a high degree of coherency between the two phases which is one of the main factors resulting in the superior strength at high temperatures. This provides a pathway for the development of a new class of load-bearing Co based superalloys for application in severe environments. Therefore, if the high temperature strength could be improved, the development of novel Co based superalloys could allow for an increase in jet engine operation temperature resulting in an increased efficiency. This phase composes the matrix of Ni-based superalloy. It is a solid solution fcc austenitic phase of the alloying elements. This phase constitutes the precipitate used to strengthen the alloy. Ni Ti,Al are ordered systems with Ni atoms at the cube faces and either Al or Ti atoms at the cube edges. This lattice mismatch leads to high coherency strains which, together with order hardening, comprise the primary strengthening mechanisms. Carbide formation is usually considered deleterious although in Ni-based superalloys they are used to stabilize the structure of the material against deformation at high temperatures. Carbides form at the grain boundaries inhibiting grain boundary motion. Just as in Ni-based super alloys, this phase constitutes the precipitate used to strengthen the alloy. In this case, it is usually close packed with a L1 structure of CoTi or fcc CoTa, though both W and Al have been found to integrate into these cuboidal precipitates quite well. This stabilization is quite important as the lack of stability is one of the key factors that makes Co-based superalloys weaker than their Ni-base cousins at elevated temperatures. As is common with carbide formation, its appearance in Co-based superalloys does provide precipitation hardening, but does decrease low-temperature ductility. Like the phases found in Ni-based superalloys, Fe-based alloys feature a matrix phase of austenite iron FCC. Alloying elements that are commonly found in these stainless steel alloys include: This phase is introduced as precipitates to strengthen the alloy. Microstructure of Fe-based superalloys Two major types of austenitic stainless steels exist and are characterized by the oxide layer that forms at the surface of the steel: Chromia-forming stainless steel is the most common type of stainless steel produced. However, chromia-forming steels do not exhibit high creep

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resistance at high operating temperatures, especially in environments with water vapor, when compared to Ni-based superalloys. Exposure to water vapor at high operating temperatures can result in an increase in internal oxidation in chromia-forming alloys and rapid formation of volatile Cr oxy hydroxides, both of which can reduce the durability and lifetime of the alloy. Alumina is more thermodynamically stable in oxygen than chromia. More commonly, however, precipitate phases are introduced to increase strength and creep resistance. In alumina-forming steels, NiAl precipitates are introduced to act as Al reservoirs to maintain the protective alumina layer. In addition, Nb and Cr additions help form and stabilize alumina by increasing precipitate volume fractions of NiAl. Microstructure of superalloys In pure NiAl phase atoms of aluminium are placed at the vertices of the cubic cell and form the sublattice A. Atoms of nickel are located at centers of the faces and form the sublattice B. The phase is not strictly stoichiometric. There may exist an excess of vacancies in one of the sublattices, which leads to deviations from stoichiometry. At elevated temperature, the free energy associated with the anti-phase boundary APB is considerably reduced if it lies on a particular plane, which by coincidence is not a permitted slip plane. One set of partial dislocations bounding the APB cross-slips so that the APB lies on the low-energy plane, and, since this low-energy plane is not a permitted slip plane, the dissociated dislocation is now effectively locked. Initial material selection for blade applications in Gas Turbine engines included alloys like the Nimonic series alloys in the s. CrC at the grain boundaries [22] for additional grain boundary strength. Turbine blade components were forged until vacuum induction casting technologies were introduced in the s. Modern superalloys were developed in the s. Examples of first generation superalloys include: Because the material contained no grain boundaries, carbides were unnecessary as grain boundary strengtheners and were thus eliminated. The presence of rafts can decrease creep rate in the power-law regime controlled by dislocation climb, but can also potentially increase the creep rate if the dominant mechanism is particle shearing. Younger generations of Ni-based superalloys have significantly reduced Cr content for this reason, however with the reduction in Cr comes a reduction in oxidation resistance. Advanced coating techniques are now used to offset the loss of oxidation resistance accompanying the decreased Cr contents. The effect of Ru on the promotion of TCP phases is not well-determined. Early reports determined that Ru decreased the supersaturation of Re in the matrix and thereby diminished the susceptibility to TCP phase formation. An example is Eglin steel, a budget material with compromised temperature range and chemical resistance. It does not contain rhenium or ruthenium and its nickel content is limited. To reduce fabrication costs, it was chemically designed to melt in a ladle though with improved properties in a vacuum crucible. Also, conventional welding and casting is possible before heat-treatment. The original purpose was to produce high-performance, inexpensive bomb casings, but the material has proven widely applicable to structural applications, including armor. Single-crystal superalloys Single-crystal superalloys SX or SC superalloys are formed as a single crystal using a modified version of the directional solidification technique, so there are no grain boundaries in the material. The mechanical properties of most other alloys depend on the presence of grain boundaries, but at high temperatures, they would participate in creep and must be replaced by other mechanisms. In many such alloys, islands of an ordered intermetallic phase sit in a matrix of disordered phase, all with the same crystalline lattice. This approximates the dislocation -pinning behavior of grain boundaries, without introducing any amorphous solid into the structure. Single crystal SX superalloys have wide application in the high-pressure turbine section of aero and industrial gas turbine engines due to the unique combination of properties and performance. Since introduction of single crystal casting technology, SX alloy development has focused on increased temperature capability, and major improvements in alloy performance have been associated with the introduction of new alloying elements, including rhenium Re and ruthenium Ru. The creep deformation behavior of superalloy single crystal is strongly temperature, stress, orientation and alloy dependent. For a single-crystal superalloy, there are 3 different mode of creep deformation under regimes of different temperature and stress: Rafting, Tertiary and Primary. In addition, rafting would occur quickly and suppress the accumulation of creep strain until a critical strain is reached. Oxidation involves chemical reactions of the alloying elements with oxygen to form new oxide phases,

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generally at the surface of the metal. If unmitigated, oxidation can degrade the alloy over time in a variety of ways, including: The primary strategy used to limit these deleterious processes is called selective oxidation. Simply, the alloy is designed such that the ratio of alloying elements promotes formation of a specific oxide phase that can then act as a barrier to further oxidation. Most commonly, aluminum and chromium are used in this role, because they form relatively thin and continuous oxide layers of alumina Al_2O_3 and chromia Cr_2O_3 , respectively. Furthermore, they possess low oxygen diffusivities, effectively halting further oxidation beneath this layer. In the ideal case, oxidation proceeds through 2 stages. First, transient oxidation involves the conversion of various elements, especially the majority elements. Transient oxidation proceeds until the selective oxidation of the sacrificial element forms a complete barrier layer. The continuity of the thin sacrificial oxide layer can be compromised by mechanical disruption due to stress or may be disrupted as a result of the kinetics of oxidation. If the layer is not continuous, its effectiveness as a diffusion barrier to oxygen is significantly reduced. The stability of the oxide layer is also strongly influenced by the presence of other minority elements. For example, the addition of boron, silicon, and yttrium to superalloys promotes oxide layer adhesion, reducing spalling and maintaining the integrity of the protective oxide layer. More complex corrosion processes are common when operating environments include salts and sulfur compounds, or under chemical conditions that change dramatically over time. These issues and those of basic oxidation are often also addressed through thin coatings. Superalloy processing Processing methods used to generate various portions of a jet turbine engine. The historical developments in superalloy processing have brought about considerable increases in superalloy operating temperatures. Superalloys were originally iron based and cold wrought prior to the 1950s. In the 1960s investment casting of cobalt base alloys significantly raised operating temperatures. The development of vacuum melting in the 1970s allowed for very fine control of the chemical composition of superalloys and reduction in contamination and in turn led to a revolution in processing techniques such as directional solidification of alloys and single crystal superalloys. Casting and forging Casting and forging are traditional metallurgical processing techniques that can be used to generate both polycrystalline and monocrystalline products. Polycrystalline casts tend to have higher fracture resistance, while monocrystalline casts have higher creep resistance. Jet turbine engines employ both poly and mono crystalline components to take advantage of their individual strengths. The disks of the high-pressure turbine, which are near the central hub of the engine are polycrystalline.

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Chapter 7 : NICKEL-BASE SUPERALLOY - ROLLS-ROYCE PLC

The creep resistance of these rhodium alloys was less than that of ZGS 10 per cent rhodium-platinum; the elongation to fracture for the rhodium alloys was a minimum of per cent at $\hat{A}^{\circ}\text{C}$, and per cent at $\hat{A}^{\circ}\text{C}$, compared with per cent for ZGS 10 per cent rhodium-platinum at both these test temperatures.

Tantalum and Niobium The contribution of niobium and tantalum to gamma prime is advantageous as these elements show slower rates of diffusion in nickel compared to aluminium and titanium, which is significant during quenching of forgings and high temperature operation in terms of reducing the rate of coarsening of secondary and tertiary gamma prime respectively, and in terms of resistance to oxidation damage since aluminium and titanium readily migrate from gamma prime to form oxidation products. Sufficient quantities of tantalum and niobium are added to develop stable primary MC carbides where M can represent Ti, Ta or Nb. Equation 4 shows that MC carbides can decompose at lower temperatures to M₂₃C₆ carbides. These M₂₃C₆ carbides form as films or elongated particles on grain boundaries and can reduce creep stress rupture life if extensive films decorate grain boundaries. The formation of M₂₃C₆ carbides may remove chromium from the gamma phase adjacent to the grain boundary, and therefore reduces the resistance to oxidation in this region. If thermal and fatigue loading conditions do not give rise to fatigue cracks, then chromium from near-surface M₂₃C₆ carbides can diffuse along grain boundaries towards the surface, leaving voids. These voids are a form of internal oxidation damage, which can reduce the resistance of the alloy to fatigue crack nucleation. Unlike titanium and niobium see later discussion, tantalum may not be detrimental to oxidation resistance and has been shown to improve time dependent crack growth resistance. The negative impact of adding higher levels of tantalum is increasing density and cost. Currently, tantalum is the second most expensive element in the proposed compositions after hafnium and can be subject to fluctuations in price as it is used heavily in micro-electronics. The effect of niobium on dwell crack growth behaviour of nickel disc alloys can vary significantly. A small fraction of the available niobium partitions to the gamma phase and may segregate to grain boundaries in material ahead of a growing crack as a result of chromium depletion from the gamma phase as chromia forms from exposure to oxygen. Oxygen diffusion along grain boundaries is accelerated as a result of stress, particularly in material ahead of a crack tip during dwell fatigue cycles. The formation of Nb₂O₅ may be particularly detrimental as it produces a large volume change, as indicated by the Pilling-Bedworth Ratio of 2. The effect of niobium up to about 1. As powder metallurgy may be used to produce the above mentioned compositions, niobium levels of up to 1. Cobalt Cobalt has beneficial effects in lowering the solvus temperature and improves material properties. However, high levels of cobalt may produce non-optimised resistance to hot corrosion and may increase the cost of the alloy. Cobalt is beneficial in lowering stacking fault energy of the gamma phase and in promoting annealing twins. This first aspect of lowering stacking fault energy is advantageous, particularly for solid solution strengthening, since the ability of dislocations to climb over gamma prime particles is made more difficult if the length of the stacking fault between partial dislocations increases as a result of a lower stacking fault energy. This produces an improvement in creep resistance of the alloy. Since PSBs are the dominant damage mechanism for fatigue crack nucleation at these temperatures, increasing the number of annealing twins may improve fatigue performance. It is beneficial therefore to minimise the gamma prime solvus temperature and maximise the temperature difference between this and the solidus temperature of the alloy. Increasing cobalt content reduces gamma prime solvus temperature, particularly if aluminium and titanium levels are also carefully selected. A further, less established benefit of cobalt is its ability to influence the size and shape of secondary or quenching gamma prime precipitates, particularly those in intergranular locations. For a given cooling rate from super-solvus solution heat treatment, increasing cobalt content reduces the size of secondary gamma prime precipitates. Increasing cobalt content may also retard the deviation from a spherical morphology at slower cooling rates. High levels of cobalt in excess of 16 wt. However, it may also reduce the solidus

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temperature, and may produce local incipient melting at temperatures approaching the solidus temperature. Equally, the amount of silicon added is limited as it promotes the formation of TCP phases, notably σ . The preference is to add silicon at levels of 0. Manganese Manganese, at levels of 0. The beneficial effects of manganese can be attributed to its ability to scavenge sulphur and form high melting point sulphides. This reduces the available sulphur in the alloy that can form low melting point Ni_3S_2 , which produce high temperature grain boundary embrittlement of Ni-Cr alloys. Impurities such as sulphur and phosphorus should be minimised to promote good grain boundary strength and mechanical integrity of oxide scales. As mentioned above, the alloys in tables 10, 18, 28 may have levels of sulphur and phosphorus of less than 5 and 20 ppm respectively. In some examples, the alloys in tables 10, 18, 28 may have a level of sulphur that is less than 20 ppm, and a level of phosphorus of less than 60 ppm. Zirconium and Boron Additions of zirconium in the region of 0. For both cast and forged polycrystalline superalloys for gas turbine applications, zirconium provides improved high temperature tensile ductility and strength, creep life and rupture strength. Zirconium has an affinity for oxygen and sulphur and scavenges these elements, thereby limiting the potential of oxygen and sulphur to reduce grain boundary cohesion. However, boron can be detrimental if added in sufficient quantities as it reduces the melting temperature of Ni such that grain boundary films can form, particularly if high solution heat treatment temperatures are required. In the above described alloys, boron is specified to an upper limit of 0. Iron Iron is intentionally added to the above described alloys at a level of about 1 at. Such levels of iron can be tolerated, in terms of alloy stability, and may reduce material costs. Carbon The level of carbon in the above described alloys is between 0. A value of about 0. However, this level of carbon is not as effective as 0. The higher concentration of carbon may produce a smaller average grain size and a narrow grain size distribution, with lower values for isolated grains that determine the upper end of the grain size distribution. Hafnium The level of hafnium in the above described alloys is between 0. The addition of hafnium is beneficial as it scavenges S, like Zr and Mn, and therefore improves grain boundary ductility and strength. The table 38 includes a plurality of columns 40 for the following properties: Roth et al, , Met. The table 38 also includes a row 42 for the alloy A, a row 44 for the alloy B, a row 46 for the alloy C, a row 48 for the alloy RR Alloy A has Alloy B has Alloy C has Alloy RR has The graph 50 includes a vertical axis 52 for median metal loss in micrometres, and a horizontal axis 54 for the type of alloy. The alloy RR has two bars 56 and 58 for two hundred hours and five hundred hours respectively. The first bar 56 has a height of approximately 3. Alloy C has two bars 60, 62 for two hundred hours and five hundred hours respectively. The first bar 60 has a height of approximately 3. The graph 64 includes a vertical axis 66 for median metal loss in micrometres, and a horizontal axis 68 for the type of alloy. The alloy RR has three bars 70, 72, 74 for one hundred hours, two hundred hours and five hundred hours respectively. The first bar 70 has a height of approximately 21 micrometres, the second bar 72 has a height of approximately 53 micrometres, and the third bar 74 has a height of approximately micrometres. Alloy C has three bars 76, 78, 80 for one hundred hours, two hundred hours and five hundred hours respectively. The first bar 76 has a height of approximately 15 micrometres, the second bar 78 has a height of approximately 38 micrometres, and the third bar 80 has a height of approximately 72 micrometres. The graphs 50, 64 in FIGS. A specified dose of salt is applied every 50 hours. The results of two levels of salt concentration are shown. The first concentration level, of 1. Corrosion damage is characterised by metal losses, i. The metal loss data shown in the graphs 50, 64 below are the median values from measurements taken from 24 positions around the circumference of the samples. Data for alloy C is compared with data for powder nickel disc alloy RR It should be appreciated from the graphs that alloy C shows lower metal loss data than alloy RR, which indicates that alloy C shows improved resistance to hot corrosion. Average values of oxidation damage were obtained from 50 measurements, taken from 10 images, such as those in FIGS. The CG RR has a scale of 5. Alloy C has a scale of 2. The resistance to oxidation damage may be characterised by measuring the depth of oxide scale predominantly chromia, Cr_2O_3 , and rutile, TiO_2 and internal oxide alumina, Al_2O_3 . Prior to exposure, the surfaces of these coarse grain RR and alloy C samples were polished. The images show that the depth of oxidation damage in alloy C

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is smaller than that for RR, indicating improved oxidation resistance for alloy C. This is quantified in the table 86 from average values of oxidation damage that have been determined from 50 measurements, from 10 images, such as those in FIGS. Rates of time dependent crack growth, i. Dwell fatigue cycles have a period of sustained load at the maximum load value. Fatigue cycles are excursions between minimum and maximum loads. The duration of the dwell period at maximum load is selected so as to produce a fully intergranular crack growth mechanism, i. The inventor expects Alloy A and B to show much improved resistance to time dependent crack growth. For creep resistance, the above described alloys that is, for alloys falling within the ranges in table 10 illustrated in FIG. The gas turbine engine has a principal and rotational axis and comprises, in axial flow series, an air intake , a propulsive fan , an intermediate pressure compressor , a high-pressure compressor , combustion equipment , a high-pressure turbine , an intermediate pressure turbine , a low-pressure turbine and an exhaust nozzle A nacelle generally surrounds the engine and defines both the intake and the exhaust nozzle The gas turbine engine comprises one or more of the superalloys described in the preceding paragraphs. The gas turbine engine operates so that air entering the intake is accelerated by the fan to produce two air flows: The intermediate pressure compressor compresses the air flow directed into it before delivering that air to the high pressure compressor where further compression takes place. The compressed air exhausted from the high-pressure compressor is directed into the combustion equipment where it is mixed with fuel and the mixture combusted. The resultant hot combustion products then expand through, and thereby drive the high, intermediate and low-pressure turbines , , before being exhausted through the nozzle to provide additional propulsive thrust. The high , intermediate and low pressure turbines drive respectively the high pressure compressor , intermediate pressure compressor and fan , each by suitable interconnecting shaft. Other gas turbine engines to which the present disclosure may be applied may have alternative configurations. By way of example, such engines may have an alternative number of interconnecting shafts e. The component comprises one or more of the superalloys described in the preceding paragraphs such as an alloy falling within the ranges in table 10 illustrated in FIG.

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Chapter 8 : Inconel - WikiVisually

the oxidation resistance of these alloys. At the which had the longest creep life were zirconium-niobium-rhodium, molybdenum- niobium-rhodium and tungsten-tantalum-.

Nickel – Nickel is a chemical element with symbol Ni and atomic number 28. It is a silvery-white lustrous metal with a golden tinge. Nickel belongs to the transition metals and is hard and ductile. Meteoric nickel is found in combination with iron, a reflection of the origin of elements as major end products of supernova nucleosynthesis. An iron–nickel mixture is thought to compose Earth's inner core, use of nickel has been traced as far back as BCE. Nickel was first isolated and classified as an element in 1791 by Axel Fredrik Cronstedt. Nickel's other important ore minerals include garnierite, and pentlandite, major production sites include the Sudbury region in Canada, New Caledonia in the Pacific, and Norilsk in Russia. Nickel is slowly oxidized by air at room temperature and is considered corrosion-resistant, historically, it has been used for plating iron and brass, coating chemistry equipment, and manufacturing certain alloys that retain a high silvery polish, such as German silver. Nickel-plated objects sometimes provoke nickel allergy, Nickel has been widely used in coins, though its rising price has led to some replacement with cheaper metals in recent years. Nickel is one of four elements that are ferromagnetic around room temperature, alnico permanent magnets based partly on nickel are of intermediate strength between iron-based permanent magnets and rare-earth magnets. As a compound, nickel has a number of chemical manufacturing uses. Nickel is a nutrient for some microorganisms and plants that have enzymes with nickel as an active site. Nickel is a metal with a slight golden tinge that takes a high polish. It is one of four elements that are magnetic at or near room temperature. Chromium – Chromium is a chemical element with symbol Cr and atomic number 24. It is the first element in Group 6 and it is a steely-grey, lustrous, hard and brittle metal which takes a high polish, resists tarnishing, and has a high melting point. A major development was the discovery that steel could be highly resistant to corrosion and discoloration by adding metallic chromium to form stainless steel. While chromium metal and Cr ions are not considered toxic, hexavalent chromium is toxic and carcinogenic, abandoned chromium production sites often require environmental cleanup. Chromium is remarkable for its properties, it is the only elemental solid which shows antiferromagnetic ordering at room temperature. This layer is a structure only a few molecules thick. It is very dense, and prevents the diffusion of oxygen into the underlying metal and this is different from the oxide that forms on iron and carbon steel, through which elemental oxygen continues to migrate, reaching the underlying material to cause incessant rusting. Passivation can be enhanced by short contact with oxidizing acids like nitric acid, passivated chromium is stable against acids. Passivation can be removed with a reducing agent that destroys the protective oxide layer on the metal. Chromium metal treated in this way readily dissolves in weak acids, Chromium, unlike such metals as iron and nickel, does not suffer from hydrogen embrittlement. However, it suffers from nitrogen embrittlement, reacting with nitrogen from air. Chromium is the 22nd most abundant element in Earth's crust with a concentration of 100 ppm. Chromium compounds are found in the environment from the erosion of chromium-containing rocks, Chromium is mined as chromite ore. About two-fifths of the ores and concentrates in the world are produced in South Africa, while Kazakhstan, India, Russia. Untapped chromite deposits are plentiful, but geographically concentrated in Kazakhstan, although rare, deposits of native chromium exist.

3. Corrosion – Corrosion is a natural process, which converts a refined metal to a more chemically-stable form, such as its oxide, hydroxide, or sulfide. Corrosion engineering is the dedicated to controlling and stopping corrosion. In the most common use of the word, this means electrochemical oxidation of metal in reaction with an oxidant such as oxygen or sulfur, rusting, the formation of iron oxides, is a well-known example of electrochemical corrosion. This type of damage typically produces oxide or salt of the original metal, corrosion can also occur in materials other than metals, such as ceramics or polymers, although in this context, the term degradation is more common. Corrosion degrades the useful properties of materials and structures including strength, appearance and permeability to liquids, many

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structural alloys corrode merely from exposure to moisture in air, but the process can be strongly affected by exposure to certain substances. Corrosion can be concentrated locally to form a pit or crack, because corrosion is a diffusion-controlled process, it occurs on exposed surfaces. As a result, methods to reduce the activity of the surface, such as passivation and chromate conversion. However, some corrosion mechanisms are less visible and less predictable, in a galvanic couple, the more active metal corrodes at an accelerated rate and the more noble metal corrodes at a slower rate. When immersed separately, each metal corrodes at its own rate, what type of metal to use is readily determined by following the galvanic series. For example, zinc is used as a sacrificial anode for steel structures. Galvanic corrosion is of major interest to the industry and also anywhere water contacts pipes or metal structures. Factors such as size of anode, types of metal. The surface area ratio of the anode and cathode directly affects the corrosion rates of the materials, galvanic corrosion is often prevented by the use of sacrificial anodes. In any given environment, one metal will be more noble or more active than others. Two metals in electrical contact share the same electrons, so that the tug-of-war at each surface is analogous to competition for free electrons between the two materials. Using the electrolyte as a host for the flow of ions in the same direction, the resulting mass flow or electric current can be measured to establish a hierarchy of materials in the medium of interest. This hierarchy is called a series and is useful in predicting and understanding corrosion 4.

Hereford is a cathedral city, civil parish and county town of Herefordshire, England. It lies on the River Wye, approximately 16 miles east of the border with Wales, 24 miles southwest of Worcester, with a population of 58, it is the largest settlement in the county. The name Hereford is said to come from the Anglo-Saxon here, an army or formation of soldiers, and the ford, if this is the origin it suggests that Hereford was a place where a body of armed men forded or crossed the Wye. The Welsh name for Hereford is Henffordd, meaning old road, much of the county of Herefordshire was Welsh-speaking, as reflected in the Welsh names of many places in the county. An early town charter from granted by Richard I of England describes it as Hereford in Wales, Hereford has been recognised as a city since time immemorial, with the status being reconfirmed as recently as October It is now known chiefly as a centre for a wider agricultural and rural area. Products from Hereford include, cider, beer, leather goods, nickel alloys, poultry, chemicals, hostilities between the Anglo-Saxons and the Welsh came to a head with the Battle of Hereford in , in which the Britons freed themselves from the influence of the English. Hereford had the only mint west of the Severn in the reign of Athelstan, and it was to Hereford, then a border town, the present Hereford Cathedral dates from the early 12th century, as does the first bridge across the Wye. The city gave its name to two suburbs of Paris, France, Maisons-Alfort and Alfortville, due to a manor built there by Peter of Aigueblanche, Bishop of Hereford, in the middle of the 13th century. Hereford, a base for successive holders of the title Earl of Hereford, was once the site of a castle, Hereford Castle, which rivalled that of Windsor in size and scale. A plaque now marks the spot of the execution, Vaughan was later himself executed, under a flag of truce, by Owens son Jasper. During the civil war the city changed several times. On 31 July a Scottish army of 14, under Alexander Leslie, 1st Earl of Leven besieged the city but met resistance from its garrison 5. He is credited with inventing the turbojet engine. A patent was submitted by Maxime Guillaume in for an invention, however. Whittles jet engines were developed some years earlier than those of Germanys Hans von Ohain who was the designer of the first operational turbojet engine, from an early age, Whittle demonstrated an aptitude for engineering and an interest in flying. He was taught the theory of aircraft engines and gained experience in the engineering workshops. His academic and practical abilities as an Aircraft Apprentice earned him a place on the training course at Cranwell. He excelled in his studies and became an accomplished pilot, while writing his thesis there he formulated the fundamental concepts that led to the creation of the turbojet engine, taking out a patent on his design in His performance on an engineering course earned him a place on a further course at Peterhouse. Without Air Ministry support, he and two retired RAF servicemen formed Power Jets Ltd to build his engine with assistance from the firm of British Thomson-Houston, despite limited funding, a prototype was created, which first ran in In when Power Jets was nationalised he again suffered a nervous breakdown, in , Whittle retired from the RAF and received a

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knighthood. He joined BOAC as a technical advisor before working as an engineering specialist with Shell, after emigrating to the U. In August , Whittle died of cancer at his home in Columbia. Whittle developed a rebellious and adventurous streak, together with an early interest in aviation, at the age of 15, determined to be a pilot, Whittle applied to join the RAF. In January , having passed the RAF entrance examination with a high mark and he lasted only two days, just five feet tall and with a small chest measurement, he failed the medical. Whittle hated the strict discipline imposed on apprentices and, convinced there was no hope of becoming a pilot he at one time seriously considered deserting. However, throughout his days as an aircraft apprentice, he maintained his interest in model aircraft and joined the Model Aircraft Society 6. SpaceX â€™” Space Exploration Technologies Corporation, better known as SpaceX, is an American aerospace manufacturer and space transport services company headquartered in Hawthorne, California. It was founded in by entrepreneur Elon Musk with the goal of reducing space transportation costs, SpaceX has since developed the Falcon launch vehicle family and the Dragon spacecraft family, which both currently deliver payloads into Earth orbit. As of March , SpaceX has since flown ten missions to the International Space Station under a cargo resupply contract, SpaceX announced in they were beginning a privately funded reusable launch system technology development program. In December , a first stage was flown back to a landing pad near the launch site and this was the first such achievement by a rocket for orbital spaceflight. In April , with the launch of CRS-8, SpaceX successfully vertically landed a first stage on an ocean drone-ship landing platform, in May , in another first, SpaceX again landed a first stage, but during a significantly more energetic geostationary transfer orbit mission. In March , SpaceX became the first to successfully re-launch and this is the main purpose this System was designed for. In February , Elon Musk announced that the company had contracted by two private individuals to send them in a Dragon spacecraft on a free return trajectory around the Moon. Provisionally launching in , this may become the first instance of lunar tourism. Musk tried to buy cheap rockets from Russia, but returned empty-handed after failing to find rockets for an affordable price, on the flight home, Musk realized that he could start a company that could build the affordable rockets he needed. According to early Tesla and SpaceX investor Steve Jurvetson, Musk calculated that the raw materials for building a rocket actually were only 3 percent of the price of a rocket at the time. SpaceX started with the smallest useful orbital rocket, instead of building a complex and riskier launch vehicle. In early , Musk was seeking staff for his new space company, Musk approached renowned rocket engineer Tom Mueller and Mueller agreed to work for Musk, and thus SpaceX was born. SpaceX was first headquartered in a warehouse in El Segundo, California, the company has grown rapidly since it was founded in , growing from employees in to nearly 5, in late and February As of December , SpaceX had a total of 50 future launches under contract, Musk has stated that one of his goals is to improve the cost and reliability of access to space, ultimately by a factor of ten. Musk stated in a interview that he hopes to send humans to Mars surface within 10â€™”20 years, in , Musks calculations convinced him that the colonization of Mars was possible. After completing its primary burn, the first stage of the rocket detached from the second stage as usual 7. He has a brother, Kimbal, and a younger sister. His paternal grandmother was British, and he also has Pennsylvania Dutch ancestry, after his parents divorced in , Musk lived mostly with his father in the suburbs of Pretoria. During his childhood he had an interest in reading and often did so for hours at a time, at age 10, he developed an interest in computing with the Commodore VIC He taught himself computer programming at the age of 12, sold the code for a BASIC-based video game he created called Blaster, to a magazine called PC and Office Technology, a web version of the game is available online. Musk was severely bullied throughout his childhood, and was hospitalized when a group of boys threw him down a flight of stairs. Musk was initially educated at schools, attending the English-speaking Waterkloof House Preparatory School. Musk later graduated from Pretoria Boys High School and moved to Canada in June , just before his 18th birthday, therefore, with the law change, he is considered to have always been a Canadian citizen by birth. At the age of 19, Musk was accepted into Queens University in Kingston, Ontario, Musk extended his studies for one year to finish the second bachelors degree. While at the University of Pennsylvania, Musk and fellow Penn student Adeo Ressi rented a bedroom

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fraternity house, in , he became a U.