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(72) Inventor: **Goller, George Albert**
Greenville, SC 29607 (US)

(74) Representative: **Szary, Anne Catherine**
London Patent Operation
General Electric International, Inc.
15 John Adam Street
London WC2N 6LU (GB)

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(71) Applicant: **General Electric Company**
Schenectady, NY 12345 (US)

(54) **Forged Austenitic Stainless Steel Alloy Components and Method Therefor**

(57) A forgeable austenitic stainless steel alloy and forging process capable of producing forged components (14) that exhibit mechanical and environmental properties and metallurgical stability suitable for use in thermally and chemically hostile environments, such as the environment of a component (10) of a gas turbine engine shroud assembly (10). The alloy contains, by weight, 18.0

to 22.0% chromium, 8.0 to 14.0% nickel, 4.0 to 7.0% manganese, 0.4 to 0.6% silicon, at least 0.2 up to 1.0% nitrogen, at least 0.05 up to 0.075% carbon; up to 0.3% molybdenum, up to 1.0% niobium, up to 0.2% cobalt, up to 4.5% aluminum, up to 0.1 % boron, up to 0.1 % vanadium, up to 1.0% tungsten, and up to 5.0% copper, with the balance iron and incidental impurities.

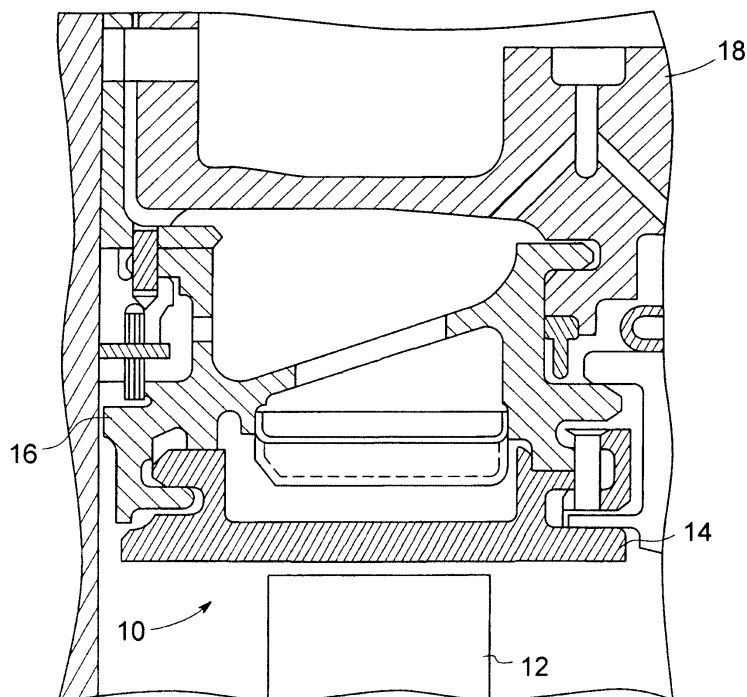


FIG.1

Description

[0001] The present invention generally relates to stainless steel alloys and their processing. More particularly, this invention relates to a forgeable austenitic stainless steel alloy and forgings formed therefrom that have desirable mechanical and environmental properties and very stable microstructures over long periods of time at operating temperatures seen by internal components of gas turbine engines.

[0002] Various alloys have been considered and used for high-temperature components of turbomachinery, with individual alloys being chosen on the basis of the particular demands of the application. Shrouds, which surround the outer blade tips within the turbine section of a turbomachine, such as a gas turbine engine, require high temperature strength and ductility, as well as good low cycle fatigue and oxidation properties. Furthermore, to maintain their performance at temperatures exceeding 700°C for extended periods of time, e.g., in excess of 50,000 operating hours, alloys suitable for shrouds must also be metallurgically stable.

[0003] Iron-nickel-chromium (Fe-Ni-Cr) austenitic stainless steel alloys have been developed that exhibit good strength, ductility, and oxidation and creep resistance at elevated operating temperatures, including those within the turbine section of a turbomachine. To promote their elevated temperature properties, austenitic stainless steel alloys are often formulated to contain carbide and nitride-forming elements such as niobium (columbium) and vanadium. Examples of such alloys include those disclosed in U.S. Patent Nos. 4,853,185 and 4,981,647 to Rothman et al. Controlled amounts of nitrogen, niobium, and carbon are typically specified in defined relationships to ensure the presence of "free" nitrogen and carbon. For example, niobium is often specified in an amount relative to the carbon content of the alloy.

[0004] Austenitic stainless steel alloys such as type 304, 347, 316, 321, etc., have stable austenitic microstructures at room temperature, but can suffer from loss of properties during extended exposures to high temperatures as a result of being prone to detrimental secondary phases formation, such as sigma phase. To avoid the problem of secondary phase formation in components of shroud assemblies, the gas turbine industry has often used stainless steel alloys with high levels of austenite stabilizers, namely nickel, to eliminate the formation of these secondary phases. Wrought stainless steel type 310 (nickel content of 19.0 - 22.0 weight percent) is a notable example of a stable austenitic stainless steel that is also forgeable, and therefore has been used to produce forged shroud components of gas turbine engines.

[0005] Due to the high cost of nickel, it would be desirable if a forgeable and metallurgically stable alloy were available that contained lower levels of nickel than that found in wrought stainless steel type 310, though without compromising the mechanical and environmental properties required for shroud components of gas turbine en-

gines.

BRIEF SUMMARY OF THE INVENTION

[0006] The present invention provides a forgeable austenitic stainless steel alloy and forging process capable of producing forged components that exhibit mechanical and environmental properties and metallurgical stability suitable for use in thermally and chemically hostile environments, such as those in gas turbine engines.

[0007] According to one aspect of the invention, a forged component is produced from a forgeable austenitic stainless steel alloy containing, by weight, 18.0 to 22.0% chromium, 8.0 to 14.0% nickel, 4.0 to 7.0% manganese, 0.4 to 0.6% silicon, at least 0.2 up to 1.0% nitrogen, at least 0.05 up to 0.075% carbon; up to 0.3% molybdenum, up to 1.0% niobium, up to 0.2% cobalt, up to 4.5% aluminum, up to 0.1% boron, up to 0.1% vanadium, up to 1.0% tungsten, up to 5.0% copper, the balance iron and incidental impurities. According to another aspect of the invention, a forged component is produced from this alloy by preparing a melt of the alloy, forming a billet of the alloy, forging the alloy to form the component, solution heat treating the forged component, and then quenching the forged component and machining the forged component to produce the component, such as a component of a turbine shroud assembly.

[0008] A significant advantage of this invention is the ability of the austenitic stainless steel alloy to be forged to produce components that have desirable mechanical properties and very stable, fully austenitic microstructures that avoid deleterious second phase formation during long exposures at high temperatures. Such mechanical and metallurgical properties are preferably comparable to and possibly better than wrought stainless steel type 310, while significantly reducing the level of nickel required in comparison to type 310 (19.0 - 22.0%). According to a preferred aspect of the invention, the forgeable austenitic stainless steel alloy can exhibit fatigue and oxidation resistance capable of withstanding the internal conditions of a gas turbine engine, such as components of a shroud assembly surrounding the turbine blades of the engine.

[0009] Strictly in terms of chemistry, the forgeable stainless steel alloy of the present invention is similar to the cast austenitic stainless steel alloy CF-8C, having a composition of, by weight, 0.08% maximum carbon, 2.00% maximum silicon, 1.50% maximum manganese, 18.0-21.0% chromium, 9.0-12.0% nickel, and 8x%C to 1.0% niobium, with the balance iron. CF-8C is nominally identified with the wrought austenitic stainless steel alloy type 347, having a composition, by weight, of 0.08% maximum carbon, 1.00% maximum silicon, 2.00% maximum manganese, 17.0-19.0% chromium, 9.0-13.0% nickel, 10x%C minimum niobium, 0.03% maximum sulfur, and 0.045% maximum phosphorus, with the balance iron. Finally, and again strictly in terms of chemistry, the forgeable stainless steel alloy of the present invention is similar

to a cast austenitic stainless steel alloy disclosed in U.S. Patent No. 7,153,373 to Maziasz et al., having composition of, by weight, 0.05-0.15% maximum carbon, 0.20-3.0% silicon, 0.5-10.0% manganese, 18.0-25.0% chromium, 8.0-20.0% nickel, a niobium:carbon ratio of 8 to 11 up to a maximum of 1.5% niobium, 0.02-0.5% nitrogen, a carbon+nitrogen content of 0.1-0.5%, up to 1.0% molybdenum, up to 5.0% cobalt, up to 3.0% copper, up to 3.0% aluminum, up to 3.0% vanadium, up to 3.0% tungsten, up to 0.2% titanium, up to 0.1% sulfur, up to 0.04% phosphorus, and up to 0.01% boron, with the balance iron. A critical different between the present invention and this prior art is the requirement of the invention for forgeability and long term phase stability, which demands mechanical and physical properties including ductility and metallurgical microstructures that are unnecessary for alloys used in the cast foundry condition, such as CF-8C and Maziasz et al., as well as many wrought alloys such as type 347. As such, the composition of the present alloy must be more narrowly tailored to achieve properties specific to forgeability than is necessary for similar alloys intended for use in cast or wrought form only.

[0010] Other objects and advantages of this invention will be better appreciated from the following detailed description, in which:

Figure 1 depicts a cross-sectional view of a representative shroud assembly within a turbine section of a gas turbine engine.

DETAILED DESCRIPTION OF THE INVENTION

[0011] Figure 1 represents a fragmentary view of a longitudinal cross section through a turbine section of a gas turbine engine, and shows components of a shroud assembly 10 within the turbine section. As known, the shroud assembly 10 circumscribes the turbine rotor (not shown) of the gas turbine engine, such that a turbine blade 12 is shown in proximity to the shroud assembly 10. The blade 12 is one of multiple blades mounted on the rotor, which rotates coaxially within the stationary shroud assembly 10. The shroud assembly 10 comprises a shroud 14 and a hanger 16 by which the shroud 14 is supported. The radially inward face of the shroud 14 faces the blade tips of the turbine rotor and minimizes the gas leakage path between the shroud assembly 10 and the rotor blade tips. The shroud 14 and its hanger 16 are preferably fabricated as multiple individual sections, with shroud sections circumferentially adjoining each other to define a substantially continuous annular shape that surrounds the blade tips, and with hanger sections circumferentially adjoining each other to define a substantially continuous annular shape that surrounds and supports the shroud 14. In turn, the hanger 16 is supported using hooks and retention clips from an annular outer casing 18 of the engine. The shroud assembly 10 represented in Figure 1 is merely intended to assist with an under-

standing of the invention, and the invention is not limited to any particular configuration, shape, fastening technique, etc., depicted in Figure 1.

[0012] According to the present invention, the shroud 14, and more specifically each section of the shroud 14 is formed of a forgeable austenitic stainless steel alloy that exhibits high temperature strength and ductility, good low cycle fatigue properties, and good oxidation properties at operating temperatures sustained by the shroud 14. According to a particularly preferred aspect of the invention, the alloy also exhibits sufficient metallurgical stability to ensure that the performance of the shroud 14 is maintained at temperatures exceeding 700°C for extended periods of time, for example, in excess of 50,000 engine operating hours. Ranges for the alloy are set forth in Table I below.

TABLE I

	Broad	Preferred	Nominal
Cr	18.0 to 22.0	19.0 to 21.0	20
Ni	8.0 to 14.0	8.0 to 10.0	9
Mn	4.0 to 7.0	4.0 to 6.0	4.5
Si	0.4 to 0.6	0.4 to 0.6	0.5
N	0.2 to 1.0	0.2 to 0.6	0.25
C	0.05 to 0.075	0.05 to 0.075	0.07
Nb	1.0 Max	0.5 to 1.0	0.7
Mo	0.3 Max	0.3 Max	0.2 Max
Co	0.2 Max	0.2 Max	0.2 Max
Al	4.5 Max	4.5 Max	4.5 Max
B	0.1 Max	0.1 Max	0.03
W	1.0 Max	0.5 Max	0.5 Max
Cu	5.0 Max	5.0 Max	5.0 Max
V	0.1 Max	0.1 Max	Impurity
S	0.03 Max	Impurity	Impurity
P	0.045 Max	Impurity	Impurity
Fe	Balance	Balance	Balance

[0013] The above compositional ranges differ significantly from other forgeable alloys currently used for shrouds of the type represented in Figure 1, such as the type 310 stainless steel having a composition of, by weight, 0.25% maximum carbon, 1.50% maximum silicon, 2.00% maximum manganese, 24.0 to 26.0% chromium, 19.0 to 22.0% nickel, 0.03 % maximum sulfur, 0.045% maximum phosphorus, the balance iron. However, consistent with the type 310 alloy, the alloy of this invention must be sufficiently ductile and tough to permit the shroud 14 to be fabricated from the alloy by a suitable forging operation. As such, the alloy must have properties

unnneeded and unspecified for cast austenitic stainless steel alloys such as CF-8C.

[0014] For the alloy of this invention, the broadest chromium and nickel levels were patterned after the type 347 austenitic stainless steel (17.0-19.0 and 9.0-13.0 weight percent, respectively), though with higher and lower ranges, respectively, to achieve the desired stable microstructure for the forging alloy.

[0015] The specified minimum and maximum amounts for carbon are intended to control the formation of stable niobium carbides and prevent the formation of M₂₃C₆ carbides, resulting in increased microstructural stability when exposed to high temperatures for long durations.

[0016] The specified minimum and maximum amounts for silicon are intended to improve the castability of the alloy, enabling the casting of a billet from which a near-net-shape component can be forged.

[0017] The ranges for manganese and nitrogen are tied together, as these elements cooperate to stabilize the austenitic phase in the alloy. Manganese increases the solubility of nitrogen in austenite, which is beneficial for promoting the austenite stabilizing effect without decreasing the ductility or toughness of the alloy, especially at preferred nitrogen levels of up to 0.6 weight percent, more preferably up to 0.4 weight percent. Manganese also stabilizes austenite, thereby preventing the formation of delta (δ) ferrite (bcc crystal form of iron) in the microstructure, increases the solubility of carbon, thereby desirably reducing grain boundary carbide formation in the alloy. Though not wishing to be limited by any particular theories, manganese levels below 4% may result in a not fully austenitic structure, while manganese levels above 7% may adversely affect forgeability. In the amounts disclosed, it is believed that manganese and nitrogen are able to effectively stabilize the austenitic phase to the extent that deleterious secondary phases are avoided that otherwise form in other low-nickel forgeable austenitic stainless steels, such as type 347. Because the cost of manganese and nitrogen are considerably less than nickel, the material cost of the alloy is less than type 310.

[0018] The permissible levels of molybdenum, niobium, cobalt, aluminum, boron, vanadium, tungsten, copper, sulfur, and phosphorus are intended to allow for tailoring the strength and oxidation resistance, and therefore preferred levels of these constituents will depend on the type of forging being produced, for example, the particular operating conditions of the shroud 14. The levels of aluminum and tungsten are particularly important for tailoring strength and oxidation resistance. For example, relatively high aluminum levels, for example, in excess of 3 weight percent, can be used to promote oxidation resistance. Finally, niobium is preferably present in the alloy in an amount to yield a niobium:carbon ratio of at least 10:1 by weight to ensure the presence of niobium carbides.

[0019] Iron preferably constitutes the balance of the alloy. Aside from iron, the alloy is preferably limited to

incidental impurities, such as phosphorus and sulfur, preferably at the lowest amounts possible. The total impurity content of the alloys is preferably less than 0.075 weight percent.

[0020] Because the alloy is intended for forged components such as the shroud 14 of Figure 1, the alloy undergoes processing that includes preparing a melt of the alloy according to appropriate and known melting and deoxidation practices. An ingot/billet is then cast from the melt, followed by forging the ingot/billet to form a near-net-shape forged component, again according to known practices. After forging, the component preferably undergoes a solution heat treatment, such as at a temperature of about 1070 to about 1200°C for a duration of about one hour per inch of forging thickness (four hours minimum), followed by a quench that is sufficiently rapid so that the resulting microstructure has a fully austenitic grain structure with well distributed carbides (including niobium carbides), does not contain M₂₃C₆ carbides or other deleterious phases, does not contain delta ferrite, and is free of segregation. The mechanical properties of the heat treated and quenched forging are equal to or better than conventional 300 series stainless steels, and are capable of remaining so for extended periods of turbine operating time at temperatures exceeding 700°C. Following quenching, the forging is machined to produce the final dimensions required of the component.

[0021] While the invention has been described in terms of particular embodiments, it is apparent that other forms could be adopted by one skilled in the art. Therefore, the scope of the invention is to be limited only by the following claims.

35 Claims

1. A forged component (14) formed of an austenitic stainless steel alloy comprising, by weight:

40 18.0 to 22.0% chromium;
8.0 to 14.0% nickel;
4.0 to 7.0% manganese;
0.4 to 0.6% silicon;
at least 0.2 up to 1.0% nitrogen;
45 at least 0.05 up to 0.075% carbon;
up to 0.3% molybdenum;
up to 1.0% niobium;
up to 0.2% cobalt;
up to 4.5% aluminum;
50 up to 0.1 % boron;
up to 0.1 % vanadium;
up to 1.0% tungsten; and
up to 5.0% copper;
55 the balance being iron and incidental impurities.

2. The forged component (14) according to claim 1, **characterized in that** nitrogen is present in the alloy in a range of 0.2 to 0.6 weight percent.

3. The forged component (14) according to claim 1 or claim 2, **characterized in that** nitrogen is present in the alloy in a range of 0.2 to 0.4 weight percent.
4. The forged component (14) according to any preceding claim, **characterized in that** niobium is present in the alloy in a range of 0.5 to 1.0 weight percent. 5
5. The forged component (14) according to any preceding claim, **characterized in that** niobium is present in the alloy in an amount to yield a niobium: carbon ratio of at least 10:1 by weight percent. 10
6. The forged component (14) according to any preceding claim, **characterized in that** the austenitic stainless steel alloy consists of 19.0 to 21.0% chromium, 8.0 to 10.0% nickel, 4.0 to 6.0% manganese, 0.4 to 0.6% silicon, at least 0.2 up to 0.6% nitrogen, at least 0.05 up to 0.075% carbon, up to 0.3% molybdenum, 0.5 to 1.0% niobium, up to 0.2% cobalt, up to 4.5% aluminum, up to 0.1% boron, up to 0.1% vanadium, up to 1.0% tungsten, up to 5.0% copper, the balance iron and incidental impurities. 15
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7. The forged component (14) according to any preceding claim, **characterized in that** the component (14) is a component (14) of a gas turbine engine shroud assembly (10). 30
8. The forged component (14) according to any preceding claim, **characterized in that** the component (14) has a microstructure that is fully austenitic, contains stable carbides including niobium carbides, and does not contain delta ferrite or segregation. 35
9. A process of producing the forged component (14) according to any one of claims 1 to 8, the process comprising: 40
 - preparing a melt of the alloy;
 - forming an ingot/billet of the alloy;
 - forging the ingot/billet to form the forged component (14);
 - solution heat treating the forged component (14); and then 45
 - quenching the forged component (14).
10. The process according to claim 9, **characterized in that** the solution heat treating step is performed at a temperature of about 1070 to about 1200°C, and the quenching step is sufficiently rapid to form a fully austenitic microstructure that contains stable carbides including niobium carbides and does not contain delta ferrite or segregation. 50
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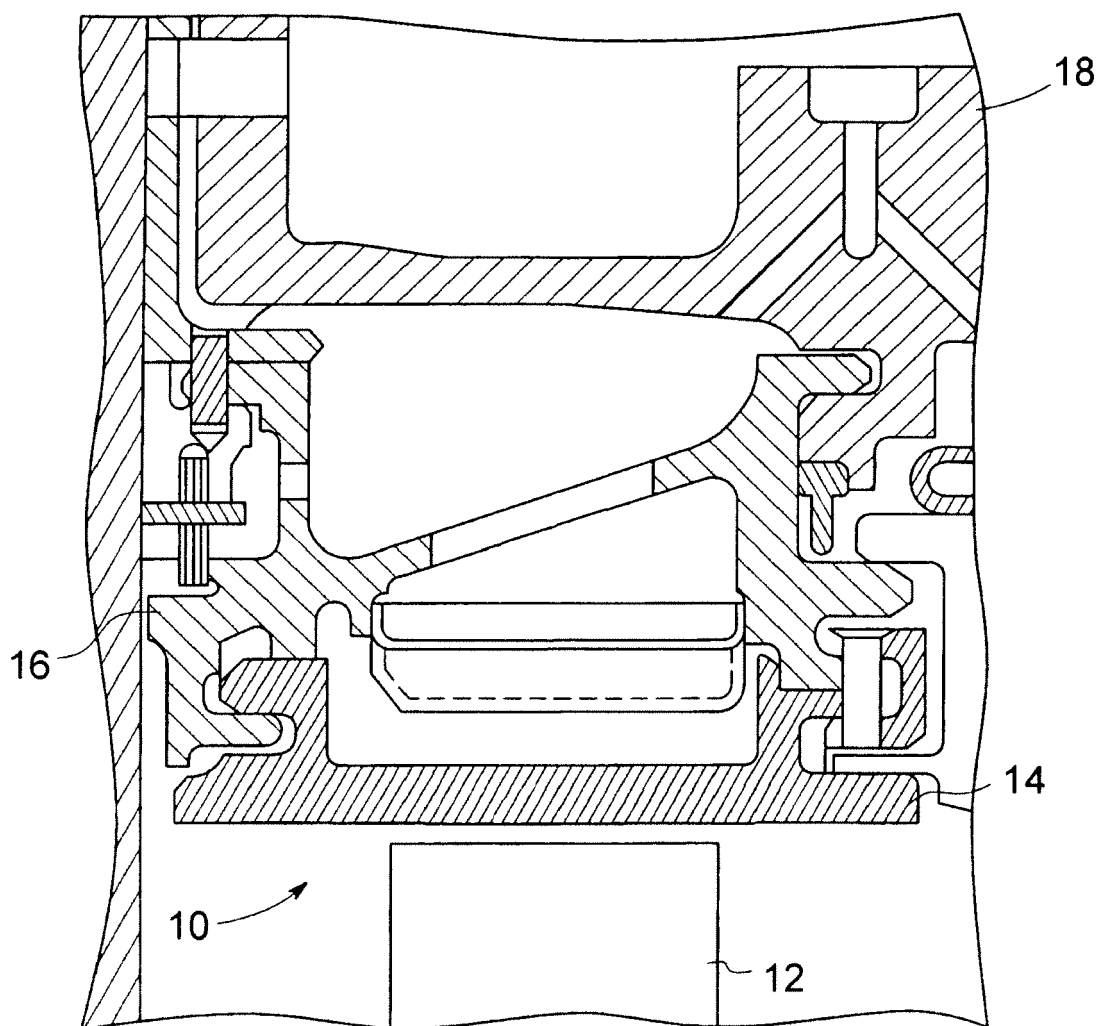


FIG.1



EUROPEAN SEARCH REPORT

Application Number
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EUROPEAN SEARCH REPORT

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