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NICKEL-BASE SUPERALLOY HAVING IMPROVED HEAT TREATMENT RANGE

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

The present invention relates to homogeneous single crystal superalloys and more particularly to an improved single crystal nickel-base superalloy article having an increased range of temperatures through which high-temperature solution heat treatments can be performed without deleterious melting of the article.

In the field of metallurgy, single crystal superalloy articles, particularly those having a nickel base, have been developed and shown to provide improved high-temperature properties especially suitable for advanced turbine airfoil applications. These advantageous properties are generally attributable to the fact that the single crystal articles, typically formed by casting and characterized by a complete absence of potentially-weak microstructural grain boundaries, provide a greater compositional flexibility than polycrystalline superalloys which commonly require addition of grain boundary strengthening elements boron, carbon, hafnium and zirconium. Nonrequirement of these additional strengthening elements has further accounted for an increase in the incipient melting temperatures of single crystal articles and allowed for a higher degree of microstructural homogenization.

Recent advances in the high-temperature strength capabilities of single crystal superalloy articles have been achieved due in large part to the high-temperature solution heat treatments typically employed after the article has been casted. These heat treatments are designed to completely dissolve the coarse matrix gamma prime (γ') phase present in the as-casted article and to reprecipitate this phase as ultra-fine particles for optimum high-temperature strength. Heat treatment above the γ' solvus temperature is necessary to completely solution the coarse matrix γ' (solid state as well as eutectic) and precipitate it as fine γ' upon subsequent cooling. However, solution heat treatment at too high a temperature, generally above the incipient melting temperature of the article, can result in a decrease in creep-rupture properties of the article. Ideally, therefore, the solution heat treatment temperature should be set above the γ' solvus temperature, but below the incipient melting temperature. In actuality, however, it has become increasingly difficult to accomplish this heat treatment in the more advanced, highly alloyed materials currently developed because the γ' solvus temperature of these materials have approached or exceeded the incipient melting temperature of the alloy so that γ' solutioning cannot be effected without deleterious melting.

SUMMARY OF THE INVENTION

Accordingly, it is a general purpose and object of the present invention to provide an improved single crystal nickel-base superalloy article having optimized high-temperature strength.

Another object of the present invention is to provide an advanced single crystal nickel-base superalloy article having an increased range of temperatures through which high-temperature solution heat treatment may be performed after casting without danger of melting the alloy structure.

Still another object of the present invention is to provide an advanced single crystal nickel-base superalloy article that is economically manufactured particularly for use in high-performance turbine components.

Briefly, these and other objects of the present invention are accomplished by a single crystal nickel-base superalloy article wherein small additions of vanadium within the range of 0.4-0.8% by weight are combined with similar levels of titanium, within the range of 0.0-1.0% by weight to lower the γ' solvus temperature and simultaneously raise the incipient melting temperature of the article. As a result, the article exhibits an expanded heat treatment range that permits complete solutioning after casting without the danger of melting.

Other objects, advantages and novel features of the present invention will become apparent from the following detailed description thereof.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention relates to a single crystal article particularly formed by casting of a specific nickel-base superalloy. Although other articles may be produced according to this invention, there is particular utility in the fabrication of airfoils (blades and vanes) for use in advanced gas turbine engines.

Conventional nickel-base superalloys typically contain chromium in levels of up to 10% by weight for use in advanced gas turbine engines.

Conventional nickel-base superalloys typically contain chromium in levels of up to 10% by weight for solid solution strengthening and oxidation resistance, aluminum and titanium in combined levels of at least 5% by weight for the formation of the strengthening γ' phase, and refractory metals such as tungsten, molybdenum, tantalum and columbium in levels of at least 5% by weight as solid solution strengtheners. Virtually all nickel-base superalloys also contain cobalt in levels of up to about 10% by weight. In accordance with the present invention, small controlled levels of vanadium, within the range of about 0.4 to 0.8% by weight, are added to a conventional nickel-base superalloy of the type described, and combined with similar levels of titanium, between about 0.0 and 1.0%, to lower the γ' solvus temperature of the conventional superalloy while, at the same time, raising its incipient melting temperature. Thus, the substantial substitution of vanadium for titanium, in small controlled amounts, is found to significantly expand the solution heat treatment range of the single crystal article after casting for safer and more effective high-temperature strengthening.

During evaluation of the present invention, several alloy compositions (Examples I-VII) were prepared and compared with a baseline alloy composition representative of an existing commercially available nickel-base superalloy. The compositions were prepared by means of conventional vacuum induction-melting and single crystal articles were cast therefrom using well-known unidirectional solidification processing. The following Table I lists the alloy compositions prepared and evaluated. All percentages appearing in Table I and elsewhere in the specification are percents by weight unless otherwise stated.

TABLE I

ALLOY COMPOSITION (Wt. %)

Example	Cr	Al	Ti	W	Mo	Ta	Co	Re	V	Ni
Baseline	7.6	5.1	1.01	3.7	1.88	11.8	4.9	0	0	bal.
I	7.4	5.1	0.41	3.9	1.95	12.0	4.8	0	0.40	bal.
II	7.6	5.1	0.47	4.1	1.95	10.4	4.7	0	0.81	bal.
III	7.4	5.0	0	3.9	1.89	11.9	4.7	0	0.73	bal.
IV	7.6	5.0	0	2.2	1.92	12.0	4.8	1.86	0.80	bal.
V	7.6	5.0	0	1.2	1.94	11.9	4.7	2.90	0.74	bal.
VI	7.5	5.0	0.46	2.3	1.95	12.0	4.7	1.98	0.46	bal.
VII	7.4	5.1	0.47	1.2	1.94	12.0	4.7	3.0	0.44	bal.

The baseline alloy composition is an advanced nickel-base superalloy particularly characterized by a relatively low level of about 7.5% chromium to provide it with an incipient melting temperature above its γ' solvus temperature thereby permitting solutionizing. It should also be noted that the baseline alloy composition contains only a reduced level (about 1%) of titanium to limit the formation of coarse matrix γ' in its microstructure thereby rendering the baseline composition more responsive to solution heat treatment.

Referring now to Table I, in Example I, a small amount (0.4%) of vanadium was substantially substituted for titanium in the baseline alloy composition. A somewhat higher level (0.81%) of vanadium was added in Example II in substitution for both titanium and tantalum. In Example III, the titanium content was eliminated in lieu of an addition of vanadium (0.73%) similar to that employed in Example II. It should be noted that the maximum vanadium content (0.81% in Ex. II) was carefully maintained at about 0.75% since previous research has shown that higher vanadium levels adversely affect oxidation and heat-corrosion resistance of the final superalloy article. Examples IV-VII, inclusive, reflect direct vanadium substitutions for titanium in levels similar to those of Examples I and III with additional substitutions of rhenium for tungsten in minor amounts (about 2-3%) to increase creep strength of the final superalloy article.

Several specimens of each example and the baseline alloy, all in their as-cast condition, were subjected to a heat treatment study to determine the γ' solvus and incipient melting temperatures of each alloy. It should be understood that the γ' solvus temperature is that temperature at which the γ' phase of the alloy goes into solution, while the incipient melting temperature is defined as that temperature at which localized melting, approximately 1% by volume, of the alloy occurs. Separate heat treatment trials were conducted in flowing argon at 2355°F for four hours, 2400°F for four hours, and 2415°F for four hours. These heat treatment conditions were selected based on differential thermal analyses of the alloys for their solidus and liquidus temperatures, values calculated from compositional correlations, and previously known heat treatment data for the baseline alloy. The results of the heat treatment study are listed in Table II, the temperatures listed therein having been determined metallographically using conventional analytic techniques.

TABLE II

HEAT TREATMENT RESULTS

Alloy	γ' - Solvus Temperature (°F)	Incipient Melting Temperature (°F)	Heat Treatment Range (°F)
Baseline	2385	2390	5
Example I	2375	2410	35
Example II	2355	2415	60
Example III	2355	2410	55
Example IV	2355	2415	60
Example V	2355	2415	60
Example VI	2385	2405	20
Example VII	2390	2410	20

Referring to Table II, the results clearly demonstrate an expanded heat treatment range provided by respective Examples I-VII, inclusive, in comparison with the range provided by the prior art baseline superalloy. These expanded heat treatment ranges are substantial having resulted from both a decreased γ'-solvus temperature and an increased incipient melting temperature for each example so that a desirable margin of safety is provided for complete γ' solutioning without danger of melting. It is noted that the net increases in the heat treatment ranges vary

(20-60°F) in relationship with the levels of limited vanadium substitutions in the respective Examples.

Therefore, it is now apparent that the disclosed invention provides an improved single crystal nickel-base superalloy article capable of optimized high-temperature strength. Particularly, the disclosed single crystal nickel-base superalloy article exhibits a substantially expanded range of temperatures through which high-temperature solution heat treatment may be performed after casting without risk of deleterious melting of the alloy structure. Furthermore, the described nickel-base superalloy article may be economically manufactured for particular use in high-performance turbine components.

ABSTRACT OF THE DISCLOSURE

A single crystal nickel-base superalloy article is disclosed wherein small additions of vanadium within the range of 0.4-0.8% by weight are combined with similar titanium levels, within the range of 0.0-1.0% by weight, to lower the γ' solvus temperature and simultaneously raise the incipient melting temperature of the article. As a result, the article exhibits an expanded heat treatment range that permits complete solutioning after casting without the danger of melting.

Gamma