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PROCESSING OF THE PRECIPITATION HARDENING NICKEL-BASE SUPERALLOYS

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ABSTRACT OF THE DISCLOSURE

After working and prior to aging, the precipitation hardening nickel-base superalloys are subjected to a duplex heat treatment comprising a first heat treatment at a temperature of 25°–100° F. below the secondary phase solvus and a second heat treatment in the temperature range of 0–25° F. below the secondary phase solvus.

BACKGROUND OF THE INVENTION

The present invention relates in general to the processing of the worked, precipitation hardened nickel-base superalloys.

The typical nickel-base superalloy is essentially a nickel-chromium solid solution (γ phase) hardened by the additions of elements such as aluminum and titanium to precipitate a secondary phase (γ' phase), usually represented by the formula $Ni_3(Al,Ti)$. These alloys also frequently contain cobalt to raise the solvus temperature of the γ' phase, refractory metal additions for solution strengthening, and carbon, boron and zirconium to promote ductility and fabricability.

Representative of alloys of this general nature are those identified in the industry as follows:

Description:	Nominal composition (by weight)
1N 100	10% Cr, 15% Co, 4.5% Ti, 5.5% Al, 3% Mo, 1% V, .17% C, .015% B, .06% Zr, bal. Ni.
Astroloy	15.5% Cr, 17% Co, 3.3% Ti, 4.5% Al, 5.3% Mo, .07% C., 0.3 B, bal. Ni.
Waspaloy	19.5% Cr, 13.5% Co, 3% Ti, 1.4% Al, 4% Mo, .08% C, .005% B, .08% Zr, bal. Ni.

These alloys may be fabricated by direct upset forging at or near the secondary phase solvus followed by hammer forging below the solvus temperature. After working it has been the previous practice to heat treat as close to the secondary solvus as practical followed by subsequent aging.

Unfortunately, with this processing there has typically occurred both extensive segregation of the secondary phase and non-uniform recrystallization of the polycrystalline microstructure, both of these conditions resulting in poor repeatability of mechanical properties from part to part, especially in terms of yield and creep strength, and creep-rupture ductility. This is particularly critical in sensitive aircraft engine components where the superalloys find their greatest utility and particularly in the highly-alloyed superalloys, i.e., those containing a large amount of the precipitated secondary phase. Since design criteria must be established on the basis of the weakest component in the system, the wide scatter band associated with conventionally processed superalloy components has demanded designs which do not adequately utilize the mechanical properties of which these alloys are capable.

SUMMARY OF THE INVENTION

The present invention comprises a thermal processing technique for the as-worked, precipitation hardening nickel-base superalloys, particularly the highly alloyed compositions of the γ–γ' type. It contemplates, after working but before aging, subjecting the alloy to a duplex heat treatment comprising a first heat treatment establishing uniformity of the precipitated phase throughout the alloy microstructure and nucleation of a new grain structure under conditions of restricted growth due to the presence of a secondary phase, and a second heat treatment providing uniform solutioning of the secondary phase and controlled grain growth by relying upon grain annihilation under conditions of uniform strain energy distribution within the polycrystalline aggregate. The first heat treatment is performed within the range of 25°–100° F. below the true secondary phase solvus and the solutioning heat treatment within about 25° F. of the solvus. The overall result is a uniform, reproducible microstructure from which subsequent aging heat treatments can promote maximum alloy strength.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The basic problem leading to the generation of the present invention was the non-uniformity of superalloy mechanical property response in large gas turbine engine disk forgings following normal deformation and heat treatment. The source of property scatter problem was eventually traced to extensive segregation of the secondary phase and non-uniform recrystallization of the polycrystalline structure, the problem being particularly acute in the highly alloyed compositions.

A thermal process to provide a uniformly controlled microstructural condition in the as-worked, precipitation-hardening nickel-base superalloys was developed. Basically, the process prescribes exposure of the alloy in the worked condition to a temperature 25°–100° F. below the true secondary phase solvus followed by a second exposure 0°–25° F. below that temperature.

Any amount of work above approximately ten percent deformation will cause recrystallization. The present process effects recrystallization at a low temperature where the presence of a secondary phase will inhibit grain growth followed by a treatment at about the solvus temperature with control of grain growth by annihilation of one recrystallized grain by another rather than, as in conventional processing, by annihilation of a deformed grain by a recrystallized grain, the latter being the faster and more coarsening operative.

The initial heat treatment causes partial dissolution of the secondary phase in alloy segregated areas followed by elemental diffusion to regions of alloy depletion and subsequent reprecipitation to an equilibrium concentration. The net transfer established uniformity of the precipitated phase through the worked structure. Additionally, this initial exposure promotes partial or complete recrystallization and annealing, depending upon the specific energy input during working, under conditions of restricted grain growth.

The second heat treatment produces uniform solutioning of the secondary phase and enables the completion of recrystallization and annealing while still maintaining a condition of inhibited grain growth. The overall result is a uniform structure from which subsequent aging heat treatments can promote maximum alloy strength.

The time required for the initial heat treatment is essentially one which, based on metal diffusion rates, is equivalent to the time required for equilibration at the true solvus temperature. The time required for the second

heat treatment is that for which equilibrium between the primary and secondary phases can be achieved.

After the normal working is completed, the true solvus of the component is determined experimentally. At this temperature for the nickel-base superalloys of the γ–γ' type it has been determined that a ten hour exposure will equilibrate the entire system, other than that of grain boundary area reduction which is a reduction of crystal surface energy. With knowledge of the true solvus and the ten hour baseline as the time for certain equilibration, the time requirements to achieve the same conditions at lower temperatures may be found from the following equation:

$$\log t_2 = \frac{(K+1)(T_1) - KT_2}{T_2}$$

where

T_1=true solvus
T_2=lower temperature being considered
K=constant

The constant K for the nickel-base superalloy compositions precipitating the γ' phase remains essentially constant at a value approximating 24 for all of these alloys.

Once the time-temperature relationships are established, the practical aspects of heat treatment become controlling insofar as temperature conditions are concerned. In the initial heat treatment at temperatures more than 100° F. below the solvus, heat treatment times become extremely long, thus establishing a practical lower temperature limit. As the temperature is raised approaching the solvus, the problems associated with conventional processing are approached. Thus, an initial heat treatment 25°–100° F. below the true secondary phase solvus is established. Within this range closer control may be desired with specific temperature selection based primarily upon the fundamental problem to be solved or the condition to be achieved during the cycle. If more uniform recrystallization is demanded, a lower temperature is used. If alloy segregation is the main concern, a higher temperature is employed.

In practice once the processing parameters have been established, otherwise standard heat treatment techniques

are employed and the part is usually air cooled (although this is of no importance because of the metallurgical phenomena involved).

The solution heat treatment is accomplished at about the true solvus temperature, usually specifying heat treatment 0–25° F. below the solvus to compensate primarily for thermal variations within commercial furnaces.

ROOM TEMPERATURE TENSILE PROPERTIES

0.2% yield (K s.i.)		Ultimate (K s.i.)		Elongation (percent)		Reduction of area (percent)	
Standard processing	Duplex processing	Standard	Duplex	Standard	Duplex	Standard	Duplex
151.9	144.0	216.0	202.8	18.5	19.0	20.4	26.0
146.6	144.0	208.0	201.2	16.5	21.0	19.2	27.0
152.0	144.0	215.2	200.0	16.0	20.0	17.4	23.0
149.0	140.0	214.0	195.6	16.5	20.0	19.6	27.0
152.0	146.6	217.0	206.0	17.5	21.0	18.1	29.0
152.8	141.0	209.5	196.8	12.0	21.0	13.0	27.0
155.2	144.0	218.0	198.0	13.0	20.0	13.8	22.0
160.8	149.8	222.0	210.4	13.0	21.0	12.3	28.0
159.8	150.9	217.5	212.1	11.0	21.0	11.5	29.0
111.0	144.0	181.7	202.0	5.0	20.0	6.3	27.0
130.8	145.8	214.0	204.0	12.0	19.0	14.2	24.0
160.7	144.0	220.0	197.8	12.5	20.0	18.1	25.9
165.8	138.0	225.5	195.6	10.0	20.0	11.9	22.3
	142.0		201.2		20.0		22.3
	138.2		200.6		21.0		24.5
[1] 140.0		[1] 190.0		[1] 12.0		[1] 13.0	
1,400 F. TENSILE PROPERTIES							
141.3	130.4	158.6	156.8	25.0	33.0	39.4	44.0
138.4	132.4	178.0	152.4	21.5	32.0	28.6	42.0
119.3	131.2	159.0	154.2	24.0	33.0	42.4	44.0
128.0	128.4	160.4	152.4	26.5	31.0	38.2	51.3
132.2		160.4		29.5		43.6	
135.0		160.3		25.5		42.0	
141.7		167.5		30.0		45.3	
114.2		163.5		15.0		19.9	
132.5		162.1		23.0		30.6	
129.8		158.7		22.0		37.6	
[1] 125.0		[1] 150.0		[1] 12.0		[1] 13.0	

[1] Property sought.

NOTE.—Underlined values failed specification.

STRESS RUPTURE PROPERTIES

Specimen type	Test temp. (° F.)	Stress (K s.i.)	Life (hrs.)		Elongation (percent)	
			Standard	Duplex	Standard	Duplex
Smooth	1,400	85.0	21.8	77.4	17.1	19.8
			27.1	74.4	19.1	24.7
			16.3	77.9	29.7	28.8
			19.4	140.6	20.9	19.1
			27.9	70.3	9.9	25.3
			32.4	52.9	6.0	21.9
				99.8		33.0
	[1] 1,400	[1] 85.0	[1] 30.0		[1] 10.0	

0.1% CREEP PROPERTIES

		Time to 1.0% (hrs.)	
		Standard	Duplex
1,300	74.0	144.7	168.5
		173.4	242.0
		84.7	141.0
		126.4	223.0
		81.9	174.0
		120.8	
		130.1	
[1] 1,300	[1] 74.0	[1] 150.0	

[1] Specification property.

NOTE.—Underlined values failed specification.

The preferred duplex processing for a number of alloys is as follows.

Alloy description: Heat treatment
1N 100 (extruded) ____ 2125° F. for 100 hours, air cool, plus 2200° F. for 4 hours.

Alloy description:	Heat treatment
Astroloy (forged)	2025° F. for 50 hours, air cool, plus 2065° F. for 4 hours.
Waspaloy (forged)	1825° F. for 50 hours, air cool, plus 2150° F. for 4 hours.

Temperature control ±10° F.

Comparative test data for Astroloy showing mechanical property uniformity and reduction of scatter is summarized below.

Although the invention has been described in detail and with reference to several preferred embodiments for the purposes of illustration, the invention in its broader aspects is not limited to the exact details described, for obvious modications will occur to those skilled in the art.

What is claimed is:

1. The method of processing the precipitation hardening nickel-base superalloys of the γ,γ'-type containing as essential elements about, by weight, 5–30 percent chromium, up to 0.2 percent carbon, and at least 4 percent of at least one element selected from the group consisting of aluminum and titanium, which comprises, after working but prior to aging:

heat treating the as-worked superalloy at a temperature about 25°–100° F. below the true γ' solvus temperature to provide a uniform distribution of the γ' phase;

and subsequently heat treating the superalloy at about the true γ' phase solvus temperature to effect uniform solutioning and essentially complete recrystallization with inhibited grain growth.

2. The method according to claim 1 wherein:

the latter heat treatment is conducted within 25° F. of but below the true γ' phase solvus temperature.

3. The method of processing the precipitation hardening nickel-base superalloys of the γ,γ'-type containing as essential elements about, by weight, 5–30 percent chromium, up to 0.2 percent carbon, and at least 4 percent of at least one element selected from the group consisting of aluminum and titanium, which comprises, after working:

heat treating the as-worked superalloy at a temperature 25–100° F. below the true γ' phase solvus temperature for a minimum of about 10 hours;

subsequently heat treating the alloy within about 25° F. of but not substantially exceeding the true γ' phase solvus temperature for a minimum of about 4 hours;

and then aging the superalloy to promote alloy strength.

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