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(54) **A heat treatment method of a ni-based superalloy for wave-type grain boundary and a ni-based superalloy produced accordingly**

(57) The present invention suggests a method of heat treatment of a Ni-based superalloy that improves resistance against creep, fatigue and stress corrosion cracking while being economical and easy, and a Ni-based superalloy produced by using the same. The method and the superalloy of the present invention include solution treatment at the high temperature region during a heat treatment process after manufacturing or final cold working fabrication. Immediately following the said solution treatment, the material is slowly cooled at 1~15°C/minute down to the intermediate temperature region for aging treatment. After the slow cooling stage, aging treatment is directly performed by holding it at the intermediate temperature region for the prescribed time. Lastly, the aging treatment is followed by air-cooling stage.

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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a heat treatment method of a Ni-based superalloy and a Ni-based superalloy produced by using the same, and more particularly, to the heat treatment method of a Ni-based superalloy improving resistance against intergranular fracture caused by creep, fatigue, stress corrosion cracking, etc., and a Ni-based superalloy with wave-type or serrated grain boundaries.

2. Description of the Related Art

[0002] Ni-based superalloy is used as a material for high temperature components such as power assembly for aero and industrial gas turbines because it is excellent in formability, weldability, corrosion resistance, high temperature mechanical properties, etc. The material is exposed to harsh environment like constant or complex strain cycle due to high temperature exposures and mechanical loads during operation, and ends in failure caused by damage from creep, fatigue, stress corrosion cracking, etc. Therefore, improving resistance of the material against main damage mechanisms such as creep, fatigue, stress corrosion cracking, etc. has been an important issue to manufacturers, component fabricators, operating companies, etc.

[0003] As illustrated in FIG.1, the existing heat treatment processes applied to manufacturing and processing of a wrought nickel based superalloy, NIMONIC 263, which is widely used for combustion lines for industrial gas turbines, transition ducts, etc. will be examined. The method generally contains water-cooling(over 50°C/second) after solution treatment(over 5 minutes at 1000~1200°C) at the high temperature region. Then, after the prescribed time, the 2^{nd} heat treatment process is applied by air-cooling after aging treatment(over 5 hours at 700~900°C) at the intermediate temperature region.

[0004] The above-stated heat treatment simply dissolves coarse carbides and γ' particles into the γ matrix at the solution treatment process after manufacturing or cold working, precipitates the carbides at grain boundaries in advance at the aging treatment process, and simultaneously distributes the γ' particles uniformly within the matrix. Accordingly, the purposes are to enhance thermal stability of the material, decrease grain boundary sensitization, and improve high temperature strength of the material. However, this kind of heat treatment method cannot improve resistance against creep, fatigue and stress corrosion cracking satisfactorily at the present time. Therefore, a heat treatment method that is more economical and simple while improving the resistance remarkably is required.

[0005] Korean Patent Publication No. 1999-024668 discloses the heat treatment method of a Ni-based superalloy for improving corrosion resistance. The above-referenced patent suggested a heat treatment method in which resistance of grain boundary fracture improves by changing the shapes of grain boundaries within the material to wavy shapes through slowing down the cooling speed to 0.1~5°C/minute in all the temperature range to room temperature or in a certain range after solution treatment at the high temperature, and again treating with an agent. However, this method is not economically efficient because the heat treatment takes too long time since it cools the material in a relatively slow speed, and the grain size becomes larger since the material is exposed to a high temperature for a long time. In addition, γ' particles become coarsened and various harmful phases can be precipitated, therefore, although resistance against stress corrosion cracking might be improved, it can deteriorate tensile properties and high temperature mechanical properties like creep, fatigue, etc. Accordingly, it is deemed that the said method can be hardly applied to actual industrial spots.

SUMMARY OF THE INVENTION

[0006] The present invention suggests a method of heat treatment of a Ni-based superalloy that improves resistance against creep, fatigue and stress corrosion cracking while being economical and easy, and a Ni-based superalloy produced by using the same.

[0007] The heat treatment method of a Ni-based superalloy of the present invention to accomplish the above-stated technical concerns includes producing or processing a Ni-based superalloy and then, performing solution treatment at the high temperature region during a heat treatment process. Immediately following the said solution treatment, the material is slowly cooled at 1~15°C/minute down to the intermediate temperature region for aging treatment. After the slow cooling stage, aging treatment is immediately performed by holding it at the intermediate temperature region for the prescribed time. Lastly, the aging treatment is followed by air-cooling stage.

[0008] In the heat treatment method of the present invention, the above-stated slow cooling stage consists of three processes; the first process in which wave-type grain boundaries begin to form at some of flat grain boundaries made during the said solution treatment; the second process in which some of the wave-type grain boundaries formed grow with stable amplitude and frequency while more wave-type grain boundaries form at the said flat grain boundaries; and, the third process in which planar carbides begin to precipitate at the said some wave-type grain boundaries. In addition, in the aging treatment process, most of the wave-type grain boundaries formed grow into wave-type grain boundaries with stable amplitude and frequency, and the said carbides precipitated can stably grow in planar shapes with low interfacial energy on the said wave-type grain boundaries.

[0009] More preferably in the present invention, the solution treatment is processed for the prescribed time at 1000~1200°C and the aging treatment can be processed for the prescribed time at 700~900°C.

[0010] The superalloy of the present invention for accomplishing the different technical tasks has wave-type grain boundaries in which planar carbides are arrayed apart from each other at the grain boundaries. At this time, the planar carbide shares the coherent interface with one grain while sharing the incoherent interfaces with the opposite grain. The array of incoherent interfaces of planar carbide particles formed at wave-type grain boundaries is zigzag pattern.

[0011] According to the heat treatment method of a Ni-based superalloy and a Ni-based superalloy produced using the same by the present invention, it is possible to improve resistance against intergranular fracture caused by creep, fatigue, stress corrosion cracking, etc., and at the same time, to conduct a time- and cost-efficient heat treatment while maintaining basic properties of a Ni-based superalloy by leading to precipitation of low-density carbides with low interfacial energy and improving cohesive strength between the grain boundaries and the matrix through changing the shapes of grain boundaries to wave-type shapes.

[0012] The foregoing and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when considering the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013]

FIG.1 is a drawing illustrating the existing heat treatment process.

FIG.2A is a drawing illustrating the heat treatment process of the present invention, while FIG.2B is a drawing illustrating to conceptually explain changes of microstructures according to the process of FIG.2A.

FIG.3 and FIG 4 are photos showing microstructures of NIMONIC263 alloys resulted from the existing heat treatment method and the heat treatment method in the present invention, respectively.

FIG.5 and FIG.6 are photos showing the fractured surfaces after tensile test conducted at room temperature of NIMONIC263 alloys resulted from the existing heat treatment method and the heat treatment method in the present invention, respectively.

FIG.7A and FIG.7B are graphs illustrating a creep test result conducted under 760°C/295MPa and 815°C/180MPa, respectively, using NIMONIC263 alloys resulted from the existing heat treatment method and the heat treatment method in the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0014] Therefore, technical concerns the present invention intends to accomplish are to improve resistance against creep, fatigue and stress corrosion cracking, and to provide an economical and easy heat treatment method of a Ni-based superalloy. In addition, another technical concern of the invention is to provide a Ni-based superalloy produced by using the said method.

[0015] Exemplary embodiments of the present invention will now be described based upon the accompanying drawings. The following embodiments may be modified variably, and the scope of the present invention is not limited to those embodiments. The embodiments of the present invention are provided to more perfectly explain the present invention to the skilled person in the art.

[0016] Firstly, embodiments of the present invention will suggest the main damage mechanism of a Ni-based superalloy and how to overcome the damage, and further explain a heat treatment method embodying the said method. Here, main damage mechanism of a Ni-based superalloy like creep, fatigue, stress corrosion cracking, etc. is defined as grain boundary damage to meet the convenience of explanation.

[0017] In case of grain boundary damage, a main damage mechanism of a Ni-based superalloy, cracks mainly initiate and propagate along brittle grain boundaries. Accordingly, resistance against grain boundary damage can be improved by reducing energy of the grain boundaries themselves, increasing the crack propagation distance, and changing morphology and characteristics of the carbides, that is, particles precipitated at the grain boundaries. The embodiments of the present invention suggest reducing energy of the grain boundaries as mentioned above, increasing the crack propagation distance, and changing morphology and characteristics of the grain boundary carbides through the formation of wave-type or serrated grain boundaries.

[0018] The wave-type grain boundaries improve resistance against grain boundary damage for the following reasons. First of all, it improves cohesiveness with the matrix by reducing misorientation degree between two adjacent grains, and makes crack propagation distance longer by changing grain boundary configuration. In addition, the carbides precipitated at the grain boundaries become planar while having low-density and stabilized low interfacial energy. Although the planar carbides form at the same wave-type grain boundary, the preference of each carbide particle to one grain selection for sharing coherency is alternating so that the array of incoherent interfaces of carbide particles formed at the wave-type grain boundary is zigzag pattern.

[0019] As stated above, characteristics of the carbides are modified so as to be favorable for resistance against grain boundary damage by forming the wave-type grain boundaries. That is, the density of incoherent interface between the carbides and the matrix providing a preferential site for cavitation or crack formation becomes lower and stabilized so that the resistance against cavity or crack formation could be improved. Moreover, the zigzag array of incoherent interface of carbide makes it more difficult for cavities or cracks to interlink to form an intergranular path for crack propagation; therefore, a lower rate of crack propagation along the grain boundaries.

[0020] Hence, the embodiments of the present invention suggest how to lead planar carbide particles by forming wave-type grain boundaries.

[0021] Although there are various models regarding the formation of serrated or wave-type grain boundaries, recently, the present inventors have found that grain boundary serration occurs spontaneously in the absence of carbides as a result of the total free energy minimization of a material. That is, at the high temperature region, straight-line flat grain boundaries develop in order to reduce the surface area term as small as possible because the influence of surface energy is bigger than misorientation between two adjacent grains. The grain boundaries tend to serrate to have several wavy segments in order to lower their interfacial free energy at the intermediate temperature region where the misorientation term becomes more important than surface area term.

[0022] Considering this occurrence model of wave-type grain boundaries, the following prerequisites are essential in order to form wave-type grain boundaries in a Ni-based superalloy of the present invention.

[0023] Firstly, carbide precipitation at the grain boundaries should be retarded as much as possible because of the following reasons; the carbide particles may inhibit the boundary movement as pinning points, and it might be difficult to modify the carbide characters like density and shape if the carbides form prior to the grain boundary serration. Thus, the supersaturation of carbon atoms should be suppressed. Secondly, sufficient temperature and time should be provided for the grain boundaries to move largely; A thermal equilibrium state should be continuously maintained during cooling from a higher solution to a lower aging treatment temperature, since grain boundary serration is known to occur spontaneously.

[0024] In order to satisfy the above-mentioned prerequisites, the embodiments of the present invention suggest holding a Ni-based superalloy for the prescribed time at the high temperature region in which the carbides are dissolved; slowly cooling down to under the intermediate temperature region in which misorientation between two adjacent grains is important; and then, immediately conducting aging treatment at the same temperature. In addition, the said method maintained basic characteristics required by Ni-based superalloy while creating wave-type grain boundaries. Accordingly, the present invention suggests a new heat treatment method that is simpler than the existing heat treatment methods and corresponds with the purpose of the present invention.

[0025] The present invention suggests the optimum heat treatment conditions that lead wave-type grain boundaries while maintaining the grain size and the volume fraction of γ' particles through heat treatment tests with various conditions. Detailed conditions include holding at the high temperature region for the prescribed time for solution treatment; slowly cooling down to the intermediate temperature region for aging treatment; immediately conducting the aging treatment at the intermediate temperature region; and then successively air-cooling. At this time, the slow cooling down to the intermediate temperature region is performed at 1~15°C/minute.

[0026] The heat treatment process of the present invention can be compared with prior methods as follows. The prior inventions applied a two-step heat treatment method in which solution treatment is processed at the high temperature region(1000~1200°C), water cooling is conducted(over 50°C/second), and aging treatment is again performed at the intermediate temperature region(700~900°C). However, the current invention is a one-step heat treatment method in which slow cooling is conducted down to the intermediate temperature region immediately after solution treatment, and then heat treatment is completed after holding it untouched at the intermediate temperature region.

[0027] FIG.2A is a drawing illustrating the heat treatment process of the present invention, while FIG.2B is a drawing illustrating to conceptually explain changes of microstructures according to the process of 2A. Here, the heat treatment temperature and the heat treatment duration are examples of representative conditions for heat treatment, but don't limit the range of the present invention. For this, a Ni-based superalloy hot-rolled NIMONIC 263 was used.

[0028] Referring to FIGs 2A and 2B, the heat treatment method of the present invention is divided into a solution treatment process(Step a), a slow cooling process(Steps b-c), an aging treatment process(Step d) and an air-cooling process. That is, first of all, for the solution treatment, solution treatment duration, e.g. for over five minutes, is maintained at 1000~1200°C of high temperature region. Then, the material is cooled slowly with a speed of 1~15°C/minute to the intermediate temperature region or the aging treatment temperature of 700~900°C. Later, the aging treatment temperature of 700~900°C is maintained for over five hours, then, the heat treatment is completed after air-cooling.

[0029] The solution treatment process is processed during the solution duration that dissolves coarse carbides and γ' particles sufficiently resulting in enough solution treatment of the superalloy in the present invention, but does not cause grain growth. At this time, grain boundaries of the material after the solution treatment or Step a are flat(20).

[0030] Wave-type grain boundaries begin to form during the slow cooling process with a speed of 1~15°C/minute to the intermediate temperature region. The grain boundaries begin to have wave-type partially at Step b called the early stage of slow cooling process. At this time, the amplitude and frequency of the wave-type grain boundaries(22) at the early stage of a slow cooling process have not developed completely(this will be referred to as incomplete wave-type grain boundaries for convenience).

[0031] On the other hand, in Step c, the incomplete wave-type grain boundaries(22) are forming continuously and some of them grow into complete wave-type grain boundaries(24) with stable wave-type, which is called the late stage of a slow cooling process. Namely, incomplete wave-type grain boundaries(22), complete wave-type grain boundaries (24) and some flat grain boundaries(20) with no wave-type coexist at the late stage of slow cooling process. At this time, planar carbides(30) begin to precipitate at the incomplete wave-type grain boundaries(22) and the complete wave-type grain boundaries(24) and precipitation hardened phase γ' begins to form at the matrix. The planar carbide(30) shares the coherent interface with one grain constituting the wave-type grain boundary(22 and 24) while sharing the incoherent interface with opposite grain.

[0032] The slow cooling process is immediately followed by the aging treatment process, and after a prescribed time passes, most of wave-type grain boundaries grow to complete wave-type grain boundaries(24) as stated in Step d and the precipitated carbides(30) grow to form planar carbides(32). At this time, the carbides(32) grow creating an incoherent interface to the direction of the opposite grain of the coherent interface, while sharing the coherency with one grain. At this time, the array of incoherent interfaces of the planar carbides is zigzag pattern because of crystallographic variants of the wave-type grain boundary itself.

[0033] The aging treatment process is processed during the aging treatment duration in which sufficient aging treatment takes place securing no microstructural changes under exposure to the same aging treatment temperature region (700~900°C), by uniformly distributing γ' particles of the said superalloy within the matrix and stabilizing the carbides at the grain boundaries, coinciding with the purpose of the present invention. At this time, the planar carbides(32) grow stably at the complete wave-type grain boundaries(24).

[0034] The planar carbides(32) with completed aging treatment process are arrayed away from each other by the wave-type boundaries(24). Although the said planar carbides(32) form at the same serrated grain boundary, the preference of each carbide(32) to one grain selection for sharing coherency is alternating so that the array of incoherent interfaces of the carbide particles(32) formed at wave-type grain boundaries is zigzag pattern.

[0035] In brief, the interfacial energy of the grain boundary itself can be lowered significantly because of transformation from the flat grain boundaries(20) to the complete wave-type grain boundaries(24). In addition, the density of the carbides (32) precipitated on the wave-type grain boundaries with low interfacial energy becomes lower while incoherent interfacial energy of the carbides(32) significantly becomes lower because they grow to stable planar carbides. Further, the array of incoherent interfaces of the planar carbides can be a zigzag pattern because of crystallographic variants of the wave-type grain boundary itself.

[0036] In the present invention, the reason why the slow cooling is limited to 1~15°C/minute at process to the aging treatment temperature immediately after the solution treatment is due to concern about that basic mechanical characteristics can be deteriorated since the grains and precipitation hardened γ' phase coarsen as the exposure time becomes longer in case that the cooling speed is under 1 °C/minute. In addition, if the cooling speed exceeds 15°C/minute, it is impossible to obtain wave-type grain boundaries because carbides are precipitated first since there is no enough time for the grain boundaries to transform into wave-type grain boundaries.

[0037] On the other hand, in case that the material is slowly cooled at 1~15°C/minute in the entire temperature region from the solution treatment temperature to room temperature after the solution treatment, the material cannot be used as it is and requires separate aging treatment causing extra time and cost because γ' precipitation and thermal stability are not sufficient. If the material is slowly cooled at 1~15°C/minute of the different temperature region from the aging treatment temperature of the present invention after the solution treatment, not only wave-type grain boundaries do not form, but also aging treatment should be conducted again.

[0038] In addition, microstructure would be shown as Step c if the material is water-quenched quickly after the slow cooling process suggested in the present invention. That is, incomplete wave-type grain boundaries(22), complete wave-type grain boundaries(24) and flat grain boundaries(20) coexist at this stage. The carbon atoms are at the state of supersaturation due to the water-quenching, so if aging treatment is conducted, granular shapes of carbides with high density are precipitated at the incomplete wave-type grain boundaries(22), the complete wave-type grain boundaries (24) and even the flat grain boundaries(20). These cases have higher interfacial energy than the present invention.

<Experiment Examples>

[0039] FIG.3 is a photo showing microstructures of NIMONIC263 alloys resulted from the existing heat treatment method. The below one is an enlarged photo of near a grain boundary. Solution treatment was performed for about 30 minutes at the temperature of 1150°C, and the material was water-quenched to room temperature (over 50°C/second), and then, aging treatment was conducted again for about 8 hours at the temperature of 800°C, and then the material is air-cooled. As illustrated in the photo, with respect to the microstructures of the existing alloy, it was found that small granular carbides are precipitated with high density at straight-line flat grain boundaries. It was identified that the size of grains is 60~70 μm.

[0040] FIG.4 is a photo showing microstructures of NIMONIC263 alloys resulted from the heat treatment method in the present invention. The below one is an enlarged photo of near a grain boundary. Solution treatment was performed for about 30 minutes at the temperature of 1150°C, and immediately the material was slowly cooled down to the aging treatment temperature of 800°C at the speed of 10°C/minute, and then the material is air-cooled after holding for 8 hours at 800°C.

[0041] According to FIG.4, it was found that, in the microstructures of the embodiments of the present invention, wave-type grain boundaries are well developed and planar carbides with low interfacial energy are precipitated at the grain boundaries with low density. At this time, the size of grains is 70~80 μm which is similar to microstructures obtained from ordinary heat treatment.

[0042] Characteristics of alloys obtained from the existing heat treatment method as illustrated FIG.3 and alloys obtained from the heat treatment method in the present invention as illustrated FIG.4 are to be examined in the following.

[0043] [Table 1] is results of tensile test of each alloy conducted at room temperature.

[Table 1]

Sample	Grain Size (μm)	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)
Alloy from the existing heat treatment	62	640	1083	23.3
Alloy from the present invention	75	622	1079	38.1

[0044] As we know from the above table, an alloy from the present invention presented similar yield strength and tensile strength to an alloy from the existing heat treatment. However, it was found that elongation indicating ductility significantly increased from 23.3% of the existing alloy to 38.1%.

[0045] FIG.5 and FIG.6 are photos showing the fractured surfaces after tensile test conducted at room temperature of NIMONIC263 alloys obtained from the existing heat treatment method and the heat treatment method in the present invention, respectively. At this time, heat treatment is as explained above. As illustrated, it was found that the grain boundary facets of the existing alloy were separated easily and fractured without particular plastic deformation.

[0046] However, as illustrated in FIG.6 of the present invention, considerable deformation such as dimples and shearing on the wave-type grain boundary facets were found although the fracture mode remains essentially intergranular. Hence, it was found that the alloy of the present invention is fractured through sufficient plastic deformation up to just before fracture. In another words, the alloy of the present invention has relatively stronger cohesive strength between the grain boundaries and the matrix than the existing alloy. This result may be considered as one of elements increasing ductility as stated in [Table 1].

[0047] In the concrete, in the present invention, the carbides(32) with completed aging treatment are planar carbides that exist away from one another on the stable wave-type grain boundaries(24). The planar carbides(32) form by turns in a zigzag pattern (FIG.4a and FIG.4b) towards two adjacent grains, not the array of incoherent interfaces placed in one direction by growing toward the only grain out of the two grains constituting wave-type grain boundaries(24). Therefore, characteristics of the carbides(32) can be changed so as to be favorable to resistance against grain boundary damage because the wave-type grain boundaries(24) form as stated above. That is, the density of incoherent interfaces between the carbides(32) and the matrix providing preferential site for cavitation or crack formation becomes lower and energy becomes more stable, causing the lower rate of grain boundary cracking. Even though grain boundary cracking is initiated, sufficient plastic deformation is made up to just before fracture because crack propagation along the grain boundary through interlinking is delayed due to the incoherent interfaces in a zigzag pattern.

[0048] FIG.7A and FIG.7B are graphs illustrating creep test results conducted under 760°C/295MPa and 815°C/180MPa, respectively, using NIMONIC263 alloys obtained from the existing heat treatment method and the heat treatment method in the present invention.

[0049] From FIG.7A and FIG.7B, it was verified that the heat treatment of the present invention leads to excellent creep properties regardless of test conditions. More concretely, creep rupture life increased from about 129 hours to about 178 hours, and creep strain also increased from about 6% to about 11% in the test under 760°C/295MPa. In addition, creep rupture life increased from about 181 hours to about 252 hours, and creep strain increased from about 17% to about 20% in the test under 815°C/180MPa.

[0050] As the present invention may be embodied in several forms without departing from the characteristics thereof, it should also be understood that the above-described embodiments are not limited by any of the details of the foregoing description, therefore, various variations are possible by a person of ordinary skill in the pertinent art within the range of technical features of the present invention.

Claims

1. A heat treatment method of a Ni-based superalloy for wave-type grain boundary in heat treatment stage after producing or processing a Ni-based superalloy, comprising:

    a solution treatment process at the high temperature region;
    a slow cooling process at 1~15°C/minute down to the intermediate temperature region for direct aging treatment after the said solution treatment;
    an aging treatment process by holding it for the prescribed time at the said intermediate temperature region for the aging treatment immediately after the said slow cooling process; and
    an air-cooling process after the said aging treatment.

2. The heat treatment method of the Ni-based superalloy according to claim 1, wherein the slow cooling process comprises,
    a stage in which incomplete wave-type grain boundaries form at some of flat grain boundaries formed during the said solution treatment process; and
    a stage in which the incomplete wave-type grain boundaries grow into stable wave-type grain boundaries, incomplete wave-type grain boundaries form at the flat grain boundaries, and planar carbides begin to precipitate at the wave-type grain boundaries.

3. The heat treatment method of the Ni-based superalloy according to claim 2, wherein aging treatment process is **characterized by** that;
    most of the incomplete wave-type grain boundaries transform into stable wave-type grain boundaries; and
    the precipitated carbides form incoherent interfaces by growing into planar shapes towards the opposite grain while being coherent with one grain constituting the wave-type grain boundary.

4. The heat treatment method of a Ni-based superalloy for wave-type grain boundary according to claim 1, wherein the solution treatment is processed at 1000~1200°C during the solution treatment time, and the aging treatment is processed at 700~900°C during the aging treatment time.

5. A Ni-based superalloy for wave-type grain boundary wherein wave-type grain boundaries are included and the planar carbides are placed at the grain boundaries away from one another.

6. The Ni-based superalloy according to claim 5, wherein the carbides create a coherent interface with one grain with the above grain boundary, and make an incoherent interface by growing toward the opposite grain.

7. The Ni-based superalloy for wave-type grain boundary according to claim 5, wherein the array of incoherent interfaces of the planar carbides formed at the wave-type grain boundaries is zigzag pattern.

FIG. 1

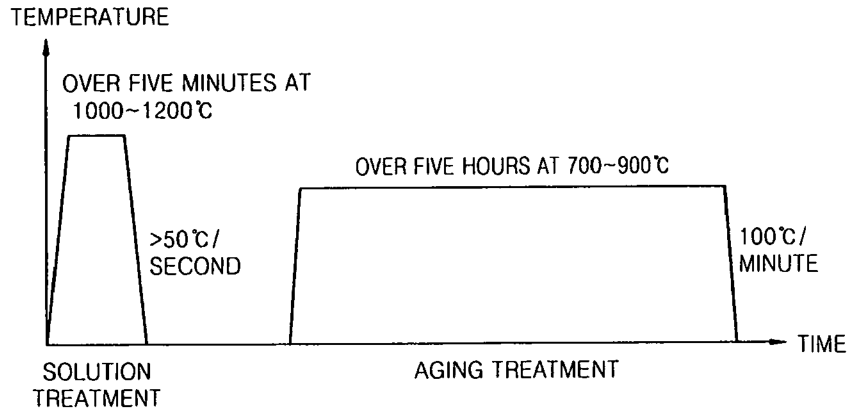

TEMPERATURE
OVER FIVE MINUTES AT 1000~1200℃
>50℃/ SECOND
OVER FIVE HOURS AT 700~900℃
100℃/ MINUTE
TIME
SOLUTION TREATMENT
AGING TREATMENT

FIG. 2A

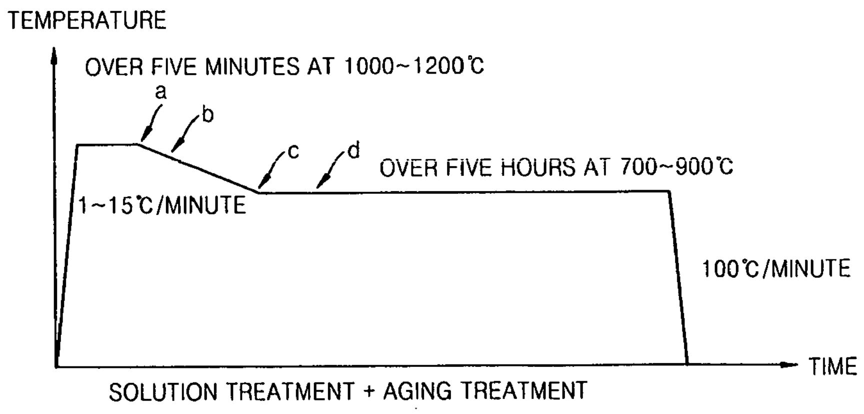

TEMPERATURE
OVER FIVE MINUTES AT 1000~1200℃
a
b
c
d
OVER FIVE HOURS AT 700~900℃
1~15℃/MINUTE
100℃/MINUTE
TIME
SOLUTION TREATMENT + AGING TREATMENT

FIG. 2B

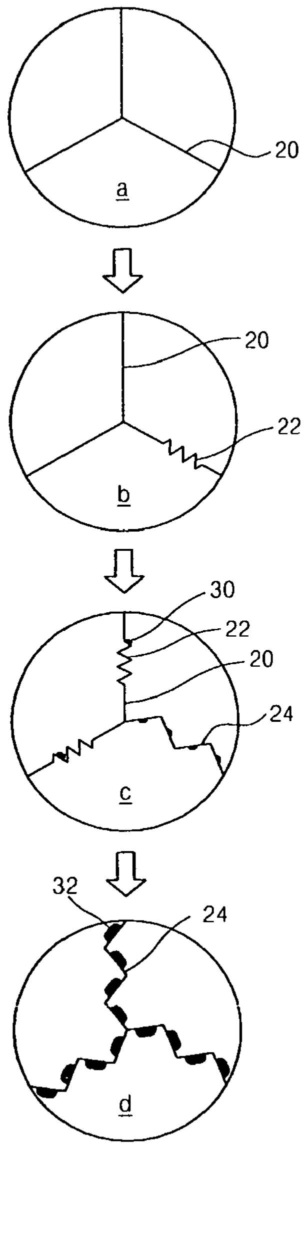


FIG. 3

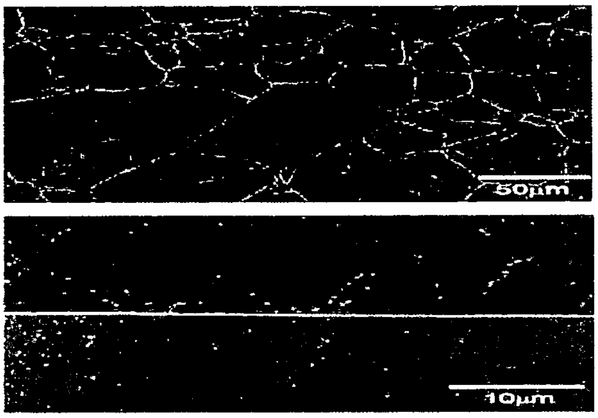


FIG. 4

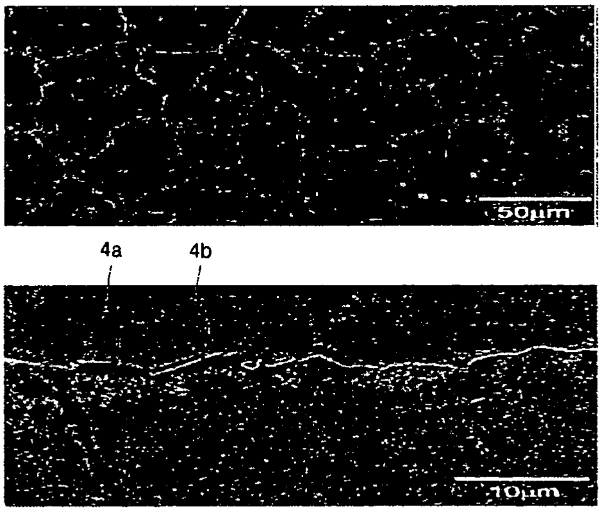


FIG. 5

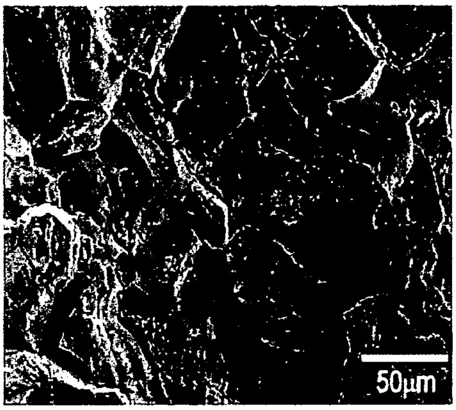


FIG. 6

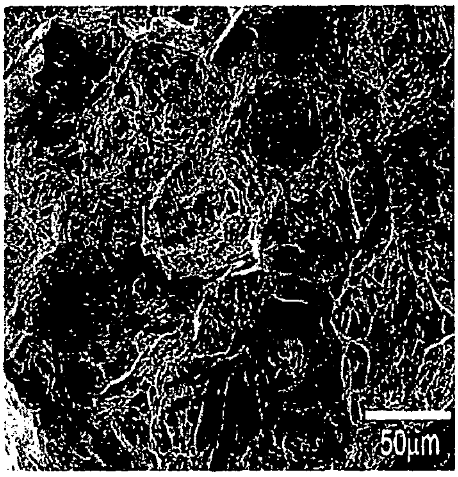


FIG. 7A

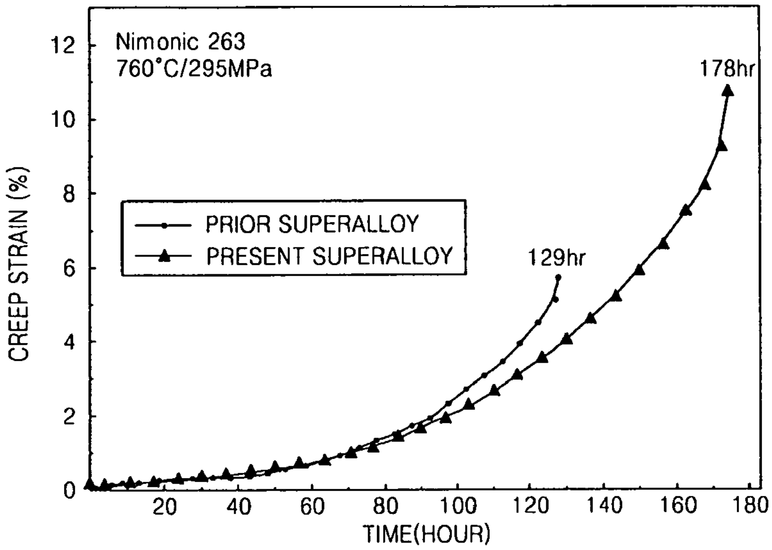
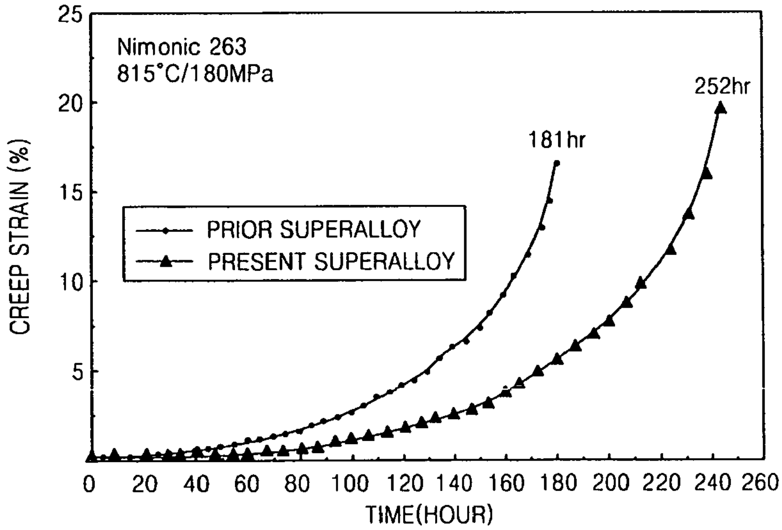

Nimonic 263
760°C/295MPa
178hr
129hr
PRIOR SUPERALLOY
PRESENT SUPERALLOY
CREEP STRAIN (%)
TIME(HOUR)
0
2
4
6
8
10
12
20
40
60
80
100
120
140
160
180

FIG. 7B


Nimonic 263
815°C/180MPa
252hr
181hr
PRIOR SUPERALLOY
PRESENT SUPERALLOY
CREEP STRAIN (%)
TIME(HOUR)
5
10
15
20
25
0
20
40
60
80
100
120
140
160
180
200
220
240
260

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EUROPEAN SEARCH REPORT

Application Number
EP 09 00 7693

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