A Ni-based single crystal superalloy with good resistance to creep deformation and creep life at a high temperature is formed by adjusting the quantity of relatively inexpensive alloy elements while minimizing the quantity of expensive alloy elements. The Ni-based single crystal superalloy with good creep properties comprises Co: 11.5~13.5%, Cr: 3.0~5.0%, Mo: 0.7~2.0%, W: 8.5~10.5%, Al: 4.5~6.5%, Ti: 0.5~2.0%, Ta: 6.0~8.0%, Re: 2.0~4.0%, Ru: 0.1~2.0% in Weight %, with the rest of the superalloy comprising Ni and other inevitable impurities. In addition, the superalloy has a mixed structure of the γ matrix and γ' particles.
FIG. 1

Creep tests 950°C/350MPa

Comparative test material 1
Comparative test material 2
Comparative test material 3
Comparative test material 4
Test material 1
Test material 2

Strain

Time (hours)

0 20 40 60 80 100 120 140 160 180 200 220 240

0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
NI-BASED SINGLE CRYSTAL SUPERALLOY WITH GOOD CREEP PROPERTY

CROSS REFERENCE TO RELATED APPLICATION


FIELD OF THE INVENTION

[0002] The present invention relates to Ni-based single crystal superalloy with improved creep resistance at high temperature.

BACKGROUND

[0003] Ni-based superalloys are widely used as materials for major parts like blades and vanes of gas turbines for aircraft engines and for power generation. The application of single crystal superalloys has increased because of their excellent high-temperature mechanical properties compared with conventionally cast polycrystalline superalloys and directionally solidified superalloys.

[0004] A single crystal superalloy is strengthened by the precipitates of intermetallic γ′ (L1₂) structure, a hardening phase having ordered structure within a matrix, and its matrix being reinforced by adding alloying elements like W, Mo, Re, etc. The generation of a single crystal superalloy is classified by Re content, an alloying element; that is, the 1st generation contains no Re content, the 2nd generation contains 3% of Re, the 3rd generation contains 6% of Re, etc. Also, the 4th generation with Ru addition has recently been developed.

[0005] Although creep resistance, one of the most important properties in using a superalloy at high temperature, has improved as technology has developed, the price of superalloys has also increased due to an increase in the addition of expensive elements. For this reason, CMSX-4 (U.S. Pat. No. 4,643,782), the 2nd generation single crystal alloy containing 3% of Re developed by Cannon Muskegon, U.S., is most commonly used at the present time.

[0006] However, as environmental issues like global warming have acquired greater importance, the necessity of enhancing the efficiency of gas turbines by increasing the operating temperature has become a major concern. Therefore, the temperature capability and the creep life of blades and vanes used in the most extreme environments among gas turbine parts are becoming more important. Accordingly, development of a single crystal superalloy with better creep properties at high temperature than known superalloys is becoming more important.

[0007] Additionally, while creep rupture time of the parts used in high temperature applications is crucial as explained above, resistance to creep deformation is also a very significant factor, because deformed parts cannot be used for their original purpose or their efficiency becomes worse. Thus, production of a single crystal superalloy with good high-temperature property, long creep life, and excellent resistance to creep deformation is required by adjusting the amount of relatively inexpensive alloying elements while minimizing the amount of expensive alloying elements.

SUMMARY

[0008] Accordingly, the present invention aims to provide a Ni-based single crystal superalloy with good high-temperature properties, long creep life, and excellent resistance to creep deformation that is made by adjusting the amount of relatively cheap alloy elements while minimizing the amount of expensive alloy elements.

[0009] A Ni-based single crystal superalloy with good creep properties according to the present invention includes Co: 11.5–13.5%, Cr: 3.0–5.0%, Mo: 0.7–2.0%, W: 8.5–10.5%, Al: 4.5–6.5%, Ti: 0.5–2.0%, Ta: 6.0–8.0%, Re: 2.0–4.0%, Ru: 0.1–2.0% in Weight %, and the rest is Ni and other unavoidable impurities. The above superalloy may have a mixed structure of the γ matrix and γ′ particles.

[0010] According to the Ni-based single crystal superalloy with good creep properties of the present invention, it is possible to obtain an alloy with prolonged creep rupture life and significantly improved the time to 1% Creep Strain representing resistance to creep deformation by producing single crystal superalloy includes Co: 11.5–13.5%, Cr: 3.0–5.0%, Mo: 0.7–2.0%, W: 8.5–10.5%, Al: 4.5–6.5%, Ti: 0.5–2.0%, Ta: 6.0–8.0%, Re: 2.0–4.0%, Ru: 0.1–2.0% in Weight %, and the rest containing Ni and other unavoidable impurities.

[0011] The foregoing and other objects, features, aspects and advantages of the present invention will be more clearly understood from the following detailed description with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

[0012] FIG. 1 is a graph that shows creep life and variation of creep strain with time when creep tests are performed with Ni-based superalloy according to the present invention at the condition of 950°C/355 MPa.

DETAILED DESCRIPTION

[0013] A Ni-based single crystal superalloy with good creep properties will be explained in the following embodiment. The creep property here means resistance to creep deformation as well as creep rupture life that is essential to use of a superalloy at high temperature. The Ni-based superalloy has the following major features.

[0014] A Ni-based single crystal superalloy with good creep property in the present invention obtains high temperature strength by both precipitation hardening and solid solution hardening. A hardening phase, γ′ (L1₂) structure having an ordered structure forms by adding Al and Ti in the γ-phase matrix, and the matrix is reinforced by adding solid solution hardening elements like W, Mo, Re, Ru, etc. Like this, the Ni-based single crystal superalloy is characterized by more improved creep properties than commonly used alloy by adjusting the amount of alloying elements.

[0015] In order to get the Ni-based single crystal superalloy with good creep property in the present invention, master ingots are cast using a vacuum induction melting process. Then, single crystal specimens are produced from each master ingot respectively by the Bridgman method. Next, micro-
structure consisting of two phases of $\gamma$ and $\gamma'$ can be obtained by applying heat treatment to the specimens.

Composition of the Alloy

[0016] The Ni-based superalloy of the present invention has the following composition for each element. The reason for limiting amounts of each element will be explained here. The below weight % is gained by converting the amount added to weigh while defining the entire Ni-based alloy as 100. For simplicity, explanation of Ni and other inevitable impurities will be omitted.

(1) Cobalt (Co): 11.5–43.5%

[0017] Cobalt influences solution treatment temperatures by changing a $\gamma'$ solidus, a major hardening phase of Ni-base superalloy, and $\gamma$ solidus, a matrix, in addition to solid solution hardening. It also improves high temperature corrosion resistance. Creep property becomes worse if the Co content is less than 11.5%, while it is difficult to decide heat treatment conditions because the temperature range of solution treatment becomes narrow if the Co content is more than 13.5%.

(2) Chrome (Cr): 3.5–5.0%

[0018] Chrome improves corrosion resistance of the superalloy; however, the amount of Chrome is limited because it may produce carbides or TCP (Topologically Close Pack) phases which are detrimental to creep behavior. Corrosion resistance becomes poor if Cr content is less than 3.5%, while more than 5.0% Cr content may lower the creep property and create TCP phases that negatively influence mechanical properties in the event of long exposure at high temperature.

(3) Molybdenum (Mo): 0.7–2.0%

[0019] Molybdenum improves properties of the superalloy at high temperature as a solid solution hardening element. However, a large amount may increase density and create TCP phases. It is hard to expect a solid solution hardening effect under 0.7%, while more than 2.0% increases the density.

(4) Tungsten (W): 8.5–10.5%

[0020] Tungsten is an element that enhances creep strength by solid solution hardening. However, a large amount may increase density, and lower toughness, corrosion resistance and phase stability. In addition, a possibility of casting defects like freelack increases at a time of single crystal and directional solidification. Accordingly, more than 8.5% Tungsten is added for improving high temperature strength while Tungsten content is limited to 10.5% in order to inhibit undesirable effects.

(5) Aluminum (Al): 4.5–6.5%

[0021] Aluminum is an essential element to improve high temperature creep property because it is a constitutive element of $\gamma'$, a major hardening phase of the Ni-based superalloy. In addition, it improves oxidation resistance. However, creep strength lowers under 4.5%, while mechanical properties worsen due to precipitate of excessive $\gamma'$ phases in case of adding more than 6.5%.

(6) Titanium (Ti): 0.5–2.0%

[0022] Titanium, like Aluminum, improves creep strength as a constitutive element of $\gamma'$ phase and enhances corrosion resistance. Therefore, more than 0.5% should be added. However, the amount should be limited to 2.0% because excessive addition may reduce oxidation resistance.

(7) Tantalum (Ta): 6.0–8.0%

[0023] Tantalum improves creep strength by hardening $\gamma'$ phases. In addition, partitioning of tantalum to interdendritic region increases the density of interdendritic liquid, resulting in inhibition of freelack, one of casting defects. Therefore, more than 6.0% content is required. However, if more than 8.0% is added, harmful $\delta$ phases can be precipitated.

(8) Rhenium (Re): 2.0–4.0%

[0024] Rhenium, a solid solution hardening element, greatly contributes to improvement of creep property because its diffusivity is very low. In other words, Rhenium considerably improves resistance to creep deformation as well as creep life of the superalloy. Yet, a large quantity lowers phase stability, increases density and raises the price; therefore, the present invention limits the amount of Rhenium to 2.0–4.0%.

(9) Ruthenium (Ru): 0.1–2.0%

[0025] Ruthenium improves high temperature properties by inhibiting creation of TCP phases through broadening the solid solution range of $\gamma'$ phase and contributing to homogenization of segregation. Accordingly, in the present invention Ruthenium is added to enhance resistance to creep deformation as well as creep life of the superalloy. However, the amount is limited to 0.1–2.0% because the cost of the superalloy becomes expensive and the density increases if a large quantity of Ruthenium is contained.

[0026] The present inventions will be explained in more detail through the following embodiments.

[0027] Table 1 shows the chemical composition of a single crystal superalloy according to the present invention and an alloy compared with the superalloy.

[0028] According to Table 1, Test Material 1 presents the composition of a Ni-based alloy with 1.0 weight % of Ru added, while Test Material 2 shows a case with 0.5 weight % of Ru. In contrast, all the Comparative Test Materials do not contain Ru, while Comparative Test Material 1 does not contain Re as well. In addition, although Comparative Test Material 2 contains Re, more Cr content is contained, while Comparative Test Material 3 has less Co content contained. Comparative Test Material 4 is CMSX-4 that is being most commonly used at the present time.

[0029] The above Test Materials and Comparative Test Materials were produced as follows. First, master ingots were cast using a vacuum induction melting process. Then, single crystal specimens of 15 mm diameter and 180 mm length were produced by the Bridgman method with drawal rate of 4.0 mm/min. Next, a microstructure consisting of two phases of $\gamma$ and $\gamma'$ was obtained by applying heat to the specimens.
<table>
<thead>
<tr>
<th>Alloy</th>
<th>Co</th>
<th>Cr</th>
<th>Mo</th>
<th>W</th>
<th>Al</th>
<th>Ti</th>
<th>Ta</th>
<th>Re</th>
<th>Ru</th>
<th>Hf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test</td>
<td>11.44</td>
<td>4.07</td>
<td>1.03</td>
<td>8.48</td>
<td>5.47</td>
<td>1.02</td>
<td>6.95</td>
<td>3.02</td>
<td>1.02</td>
<td>0</td>
</tr>
<tr>
<td>Test</td>
<td>11.51</td>
<td>4.11</td>
<td>1.02</td>
<td>8.51</td>
<td>5.46</td>
<td>1.03</td>
<td>7.01</td>
<td>2.97</td>
<td>0.51</td>
<td>0</td>
</tr>
<tr>
<td>Test</td>
<td>11.02</td>
<td>4.03</td>
<td>0.48</td>
<td>8.07</td>
<td>5.51</td>
<td>1.01</td>
<td>6.81</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Test</td>
<td>10.99</td>
<td>8.02</td>
<td>0.52</td>
<td>8.12</td>
<td>5.50</td>
<td>1.02</td>
<td>7.02</td>
<td>2.99</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Materials 3</td>
<td>5.02</td>
<td>4.10</td>
<td>0.52</td>
<td>7.99</td>
<td>5.48</td>
<td>0.98</td>
<td>7.02</td>
<td>3.01</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Materials 4</td>
<td>9.80</td>
<td>6.40</td>
<td>0.61</td>
<td>6.40</td>
<td>5.65</td>
<td>1.01</td>
<td>6.50</td>
<td>2.90</td>
<td>0</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Table 1 shows creep life and time to 1% creep strain when creep tests are conducted by applying stress of 355 MPa at 950° C. with the above alloys. FIG. 1 is a graph that shows variation of creep strain with time when creep tests are performed at the condition of 950° C./355 MPa.

Table 2 shows creep life and time to 1% creep strain when creep tests are conducted by applying stress of 355 MPa at 950° C. with the above alloys. FIG. 1 is a graph that shows variation of creep strain with time when creep tests are performed at the condition of 950° C./355 MPa.

Table 2

As is seen from Table 2 and FIG. 1, the creep properties of a Ni-based alloy is greatly dependent on Re content. That is, it is found that Comparative Test Material 1 with no Re shows significantly shorter Creep Rupture Time and Time to 1% Creep Strain than other Test Materials or Comparative Test Materials. In addition, comparing Test Materials 1–2 containing Re and Ru with Comparative Test Materials 2–4 with Re without Ru, it is found that Ru plays a principal role in improving creep property of the Ni-based alloy. Of course, selecting contents of other alloying elements is necessary in order to improve the creep properties by Ru stated above.

In the concrete, Creep Rupture Time of Test Materials 1–2 containing Ru was 192.3–211.7 hours, while Time to 1% Creep Strain was 87.0–112.0 hours. On the other hand, Comparative Test Materials 2–4 without Ru presented was 71.0–123.1 hours of Creep Rupture Time and 29.0–57.0 hours of Time to 1% Creep Strain. In comparison between Comparative Test Material 4 with relatively good creep properties and Test Material 1 of the present invention, it was found that Test Material 1 of the present invention showed almost double the Creep Rupture Time and Time to 1% Creep Strain compared with Comparative Test Material 4.

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.

1. A Ni-based single crystal superalloy comprising: Co: 11.5–13.5%, Cr: 3.0–5.0%, Mo: 0.7–2.0%, W: 8.5–10.5%, Al: 4.5–6.5%, Ti: 1.02–2.0%, Ta: 6.0–8.0%, Re: 2.0–4.0%, Ru: 0.1–2.0% in weight %, and Ni.

2. The Ni-based single crystal superalloy of claim 1, wherein the superalloy has a mixed structure of γ matrix and γ′ particles.

3-11. (canceled)