NI BASED ALLOY FOR FORGING AND COMPONENTS FOR STEAM TURBINE PLANT USING SAME

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ABSTRACT
It is an object of the present invention to provide an Ni based alloy for forging having high forging-related characteristics with a wide temperature range for high-temperature forging and high upper forging temperature limit.

An Ni based alloy for forging, containing Cr at 12 to 20%, Al at 3.5 to 5%, Co at 15 to 23%, W at 5 to 12%, C at 0.001 to 0.05%, and Nb, Ti and Ta at a total content of 0.5 to 1.0%, all percentages by mass, and a steam turbine plant component using the same.
FIG. 1

[Graph showing the amount of the γ' phase separated out at 700°C against the solvus temperature of the γ' phase (°C)]

- **CONVENTIONAL ALLOYS**
- **TESTED COMPOSITIONS**

- **KNOWN EXAMPLE 1-D**
- **KNOWN EXAMPLE 1-B**
- **KNOWN EXAMPLE 1-C**
- **KNOWN EXAMPLE 1-A**
- **SPECIMEN D OF THE PRESENT INVENTION**
- **SPECIMEN A OF THE PRESENT INVENTION**
- **SPECIMEN B OF THE PRESENT INVENTION**
- **SPECIMEN C OF THE PRESENT INVENTION**
- **IN939**
- **CON500**
- **CON750**
- **CON141**
- **CON263**
- **CON111**
- **CON738**
FIG. 2

Graph showing the relationship between stress (kg/mm²) and rupture time (hour) for specimen A of the present invention and known example 1-8 compared to CON750.
FIG. 3

![Graph showing the relationship between carbide dissolution temperature (°C) and the amount of M23C6 carbide separated out at 800°C (% by mass). The graph compares different alloys, including:
- Known Example 1-8 (with incorporated C amount varied)
- 3.5Al-1.0Ti (with incorporated C amount varied)
- 3.3Al-0.7Ti (with incorporated C amount varied)
- 3.1Al-0.5Ti-0.3Ta (with incorporated C amount varied)
- 3.8Al-0.6Ti-0.3Nb (with incorporated C amount varied)]
FIG. 4

(a) EXAMPLE OF BOILER TUBE

SPECIMEN B OF THE PRESENT INVENTION

40mm

(b) EXAMPLE OF TURBINE ROTOR

SPECIMEN C OF THE PRESENT INVENTION

4000mm

900mm

FERRITE WELD

STEAM

CON146

CAST NiCrMo

TURBINE CASING

(c) EXAMPLE OF BOLT IN A HIGH-TEMPERATURE SECTION
NI BASED ALLOY FOR FORGING AND COMPONENTS FOR STEAM TURBINE PLANT USING SAME

FIELD OF THE INVENTION

[0001] The present invention relates to high-temperature components for steam turbines and the like, and Ni based alloy for forging for the components.

BACKGROUND OF THE INVENTION

[0002] Known Document 1 (JP-A-2009-97052) discloses an alloy element balance which can greatly improve tolerable temperature of an alloy without deteriorating its hot workability, where the inventors tried to improve the tolerable temperature from 750°C, which was upper limit with the conventional alloys, to 780 to 800°C. While keeping hot workability equivalent to that of the conventional alloy and to form a surface coating film of Al, and investigated the alloy element balance which destabilized the γ’ phase at high temperature and stabilized the γ’ phase at low temperature. Increasing the γ’ phase increases alloy strength, but the γ’ phase deteriorates hot forging characteristics.

[0003] The alloy disclosed in Known Document 1 is characterized in that it is substantially free of Nb, Ti, and Ta, thereby keeping temperature at which the γ’ phase, which reinforces the alloy when separated out, can be dissolved to form a solid solution (hereinafter referred to as dissolution temperature of the γ’ phase) at a low level and decreasing the lower forging temperature limit, to successfully increase the separated phase at a tolerable temperature of 700 to 800°C. The separated components disclosed in Known Document 1 include carbides mainly of Cr, W and Mo, in addition to the γ’ phase.


BRIEF SUMMARY OF THE INVENTION

[0005] Increasing main steam temperature or combustion temperature is effective for improving power generation efficiency of steam turbine power plants, gas turbines and so on. Increasing main steam or combustion temperature increases temperature to which high-temperature components are exposed, and requires heat-resistant materials having higher tolerable temperature.

[0006] The high-temperature forged components fall into categories of precision forged and forged ones depending on temperature to which they are exposed and their sizes. Rotor and stator blades, which are small-size components, for gas turbines operating at high temperature are generally precision-forged. Large-size components, which are difficult to fabricate them by precision forging, are generally forged. The forged components are fabricated at a temperature range of 1000 to 1200°C by hot forging. In order to secure workability in the above temperature range, the material should have low resistance to deformation at a temperature of 1000°C or more.

[0007] Ni based superalloys reinforced by the separated (precipitated) γ’ phase (Ni3Al), having a high strength at high temperature, have been widely used for forged high-temperature components. The γ’ phase is more stable at low temperature than at high temperature, and disappear as temperature increases. A high-temperature component should be hot-forged at a temperature at which the separated γ’ phase disappears (dissolution temperature), because forging efficiency is low in the presence of the separated γ’ phase. Strength of the alloy at a service temperature increases as amount of the separated γ’ phase increases, and hence it is necessary to increase the separated amount to increase alloy strength. However, the dissolution temperature increases with the amount, making hot forging difficult. This limits high-temperature strength of forged component reinforced by the separated γ’ phase.

[0008] On the assumption that a required creep temperature strength should be kept at 100 MPa for 100,000 hours, the upper tolerable temperature limit is around 750°C, with a forged component securing sufficient hot forging workability by keeping a dissolution temperature of the γ’ phase at around 1000°C or lower. As oxidation starts to notably proceed at 750°C or higher, it is essential to improve oxidation resistance of the component to increase its tolerable temperature to 750°C or higher. Incorporation of Al, which forms the stable oxide, is effective for improving oxidation stability. However, Al increases dissolution temperature of the γ’ phase to deteriorate hot forging workability. Therefore, its concentration is limited to 3% by mass or less for conventional alloys for forging; the concentration being insufficient to stably form the oxide.

[0009] One of the major carbides separating out in these alloys is of M3C type. A carbide is stable at up to 1000°C or higher to block migration of grain boundaries during a forging or dissolution forming process, and suppresses their growth. In addition to the M3C type, the MC type carbides of Ta, Ti and Nb as the major ingredients are also known to separate out in an Ni based superalloy. In order to produce a large-size forged component, the component preferably has a high upper forging temperature limit, in addition to a low dissolution temperature of the γ’ phase, as discussed in Known Document 1.

[0010] The upper forging temperature limit may be set at a temperature immediately below a partial melting point of the alloy, in which increased temperature resulting from heating caused by fabrication is included. However, the grains will become coarser when the component is forged even at a temperature at which no carbide is separated out, to deteriorate alloy characteristics related to fatigue and notch sensitivity. Therefore, the upper forging temperature limit is determined by carbide dissolution temperature.

[0011] The M23C6 type carbide is less stable than the MC type at high temperature, and has a decreased dissolution temperature in the presence of an insufficient amount of incorporated carbon to decrease the upper forging temperature limit. The MC type carbide is stable up to a high temperature immediately below the melting point with a smaller amount of carbon.

[0012] As discussed above, a carbide plays an important role of governing the upper forging temperature limit. However, it serves as a crack origin when separated out excessively to decrease fatigue strength. The alloy disclosed in Known Document 1 is substantially free of Ta, Ti and Nb to form the M23C6 type carbide. It is necessary to incorporate a large amount of carbon to increase the upper forging temperature limit, which increases the crack origins.

[0013] It is an object of the present invention to provide an Ni based alloy for forging having high forging-related characteristics with a wide temperature range for high-temperature forging and high upper forging temperature limit.

[0014] The Ni based alloy of the present invention for forging contains Cr at 12 to 20%, Al at 3.5 to 5%, Co at 15 to 23%,
W at 5 to 12%, and C at 0.001 to 0.05%, all percentages by mass. The alloy can also contain fire-retardant elements other than W and Mo at a total content of 1% by mass or less. In the alloy, at least 30% by volume of γ' phase having an average diameter of 50 to 100 nm can be separated out (precipitated).

The present invention further provides a steam turbine plant component using the above alloy, a boiler tube using the above alloy for a steam turbine plant operating with main steam having temperature of 700° C. or higher, a bolt using the above alloy used for a steam turbine plant operating at a service temperature of 750° C. or higher, and a rotor using the above alloy used for a steam turbine plant operating at an ambient temperature of 750° C. or higher.

Other objects, features and advantages of the invention will become apparent from the following description of the embodiments of the invention taken in conjunction with the accompanying drawings.

ADVANTAGES OF THE INVENTION

The present invention can provide an iron based alloy for forging having high forging-related characteristics with a wide temperature range for high-temperature forging and high upper forging temperature limit.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows the relation between amount of the γ' phase separated out (precipitated) at 700° C. and solvus (dissolution) temperature of the γ' phase. Fig. 2 shows the creep test results, comparing the alloy of the present invention with the conventional alloys. Fig. 3 shows the relation between carbide dissolution temperature and amount of separated carbide. Fig. 4 shows the forged components of the alloys of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is described below in detail.

The present invention increases dissolution temperature of carbide from that disclosed in Known Document 1 (JP-A-2009-97052) by reducing amount of carbon incorporated to decrease amount of the separated carbide and crack origins, and thus increases the upper forging temperature limit, which is beneficial in production of larger-size forged components.

It is effective to select the chemical composition of the alloy from the following range for each of the alloy elements.

Cr is an important element to secure corrosion resistance, and should be incorporated at 15% by mass or more. It separates the γ phase known as an embrittling phase when incorporated excessively, and should be incorporated at 23% by mass or less.

Nb, Ti and Ta work to increase alloy strength by stabilizing the γ' phase up to high temperature, and are the essential elements for the conventional alloy for forging. As disclosed in Known Document 1 (JP-A-2009-97052), amount of the γ' phase separated out at 700 to 800° C. can be increased by decreasing the total content of Nb, Ti and Ta to decrease dissolution temperature of the γ phase. Known Document 1 keeps the total content at 0.5% by mass or less. It is possible to increase the upper forging temperature limit by adequately incorporating small amounts of Nb, Ti and Ta elements to separate out the MC type carbide phase stable at up to high temperature, decrease amount of C incorporated and decrease crack origins. The MC type carbide will not be separated out to an extent necessary to pin the grain boundaries when Nb, Ti and Ta elements are incorporated at a total content of 0.05% by mass or less. At a total content above 1.0% by mass, on the other hand, the MC type carbide has a dissolution temperature exceeding the partial melting point of the alloy system, and no longer works to improve the upper forging temperature limit. Keeping the total content at a low level is effective for increasing alloy strength at a service temperature while decreasing the lower forging temperature limit. It is therefore effective to keep the total content at above 0.5% by mass to 1.0% by mass or lower.

Al works to stabilize the γ' phase, increase alloy strength and improve oxidation resistance. It is incorporated preferably at 3.5% by mass or more for oxidation resistance and 5.0% by mass or more for strength. However, dissolution temperature of the γ' phase increases when it is incorporated at more than 4% by mass, making hot forging difficult. Therefore, the upper limit of Al content should be 4% by mass.

Co works to decrease dissolution temperature of the γ' phase, thus decreasing the lower forging temperature limit in the presence of a larger amount of Al. Viewed from this, Co is incorporated at 15% by mass or more. At a content above 23% by mass, on the other hand, it accelerates separation of undesirable phases. Therefore, it should be incorporated at 15 to 23% by mass.

W works to effectively reinforce the alloy matrix when incorporated at 5% by mass or more. On the other hand, W dissolved in the mother phase is reinforced to inhibit its deformation to deteriorate hot forging workability, when incorporated at more than 15% by mass. Its content is preferably 15% by mass or less. Moreover, it separates the undesirable phase when incorporated at more than 12% by mass. Therefore, W content is in a range from 5 to 12% by mass.

Fire-retardant elements other than W and Mo can be incorporated at a total content of 1% by mass or less. They are concentrated in the liquid or solid phase during the solidification process to accelerate segregation. Therefore, they are undesirable additive elements.

C separates out in the grain boundaries in the form of carbide, to reinforce the grain boundaries. Moreover, the carbide works to suppress growth of the grains during the forging or dissolution process. It is preferably incorporated at 0.01% by mass or more. As discussed above, it suppresses growth of the grains during the high-temperature forging or dissolution process when incorporated at 0.05% by mass or less in the presence of adequate small amounts of Nb, Ta and Ti. The coarse MC type carbide separates out excessively, when C is incorporated at above 0.05% by mass, to become fatigue crack origins. The C content therefore is preferably 0.01 to 0.05% by mass.

EXAMPLES

The preferred embodiments of the present invention are described by referring to Examples and Comparative Example.
Example 1

[0033] Table 1 shows the chemical compositions of the alloy specimens.

<table>
<thead>
<tr>
<th>Material names</th>
<th>C</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Co</th>
<th>Al</th>
<th>Ti</th>
<th>W</th>
<th>Nb</th>
<th>Ta</th>
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<td>0.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>18.7</td>
<td>1.9</td>
<td>3.8</td>
<td>2.1</td>
<td>1.0</td>
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<td></td>
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<td>1.6</td>
<td>2.8</td>
<td>7.1</td>
<td>0.9</td>
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<td>7.1</td>
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<td>17</td>
<td>0</td>
<td>21</td>
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<tr>
<td>3.1Al—0.5Ti—0.3Ta</td>
<td>0.04</td>
<td></td>
<td>16.5</td>
<td>0</td>
<td>20</td>
<td>3.1</td>
<td>0.5</td>
<td>8</td>
<td>0</td>
<td>0.3</td>
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</tr>
<tr>
<td>3.8Al—0.6Ti—0.3Nb</td>
<td>0.03</td>
<td></td>
<td>18</td>
<td>0</td>
<td>19</td>
<td>3.8</td>
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</tbody>
</table>

[0034] The alloy specimens were prepared by dissolution with the aid of high-frequency waves. FIG. 1 shows the relation between amount of the y' phase (area ratio) separated out at 700°C and dissolution temperature of the y' phase. 

[0035] Dissolution temperature of the y' phase can be determined by differential thermal analysis. The analysis separates out the y' phase by solid solution forming and aging, and then heats the specimen to determine the dissolution temperature based on the temperature at which the heat of reaction by the dissolution is detected. Amount of the y' phase separated out at 700°C can be determined by aging the specimen at 700°C for a long time and observing the specimen by a scanning electron microscope to analyze the SEM images. The adequate aging time is around 48 hours.

[0036] As shown in FIG. 1, each of the conventional alloy specimens has an amount of the y' phase separated out at 700°C increasing as dissolution temperature of the y' phase increases, to increase alloy strength by reinforcing effect of the phase. The y' phase notably deteriorates hot workability and hot working temperature should be higher than dissolution temperature of the y' phase. An alloy having a higher strength is more difficult to work at high temperature, and an alloy having a y' phase dissolution temperature higher than 1050°C is practically difficult to forge. Such an alloy is not forged but cast. Casting is difficult to apply to large-size components, because the components will have casting-caused defects, and forging is more suitable for production of large-size components. Known Document 1 demonstrates that at least 35% by volume of the y' phase can be separated out in the alloy at 700°C, even when a y' phase dissolution temperature is around 1000°C. The alloy therefore has the potential of greatly improving high-temperature strength from that of the conventional alloy. The alloy of the present invention is intermediate between the conventional alloy and that disclosed in Known Document 1. It has a y' phase dissolution temperature higher by about 50°C when it has a similar volumetric fraction of the separated y' phase.

[0037] Next, the alloy of the present invention was tested for its high-temperature strength with specimen A. It was compared with CON750 and alloy disclosed in Known Document 1. Specimen A has an amount of the y' phase separated out at 700°C similar to that of the alloy disclosed in Known Document 1, but an about 50°C higher y' phase dissolution temperature. CON750 has a highest strength as a conventional alloy for large-size forged components, and has been used for turbine discs in aircraft engines. For the tests, 20 kg of each of the specimens was dissolved with the aid of high-frequency waves and hot-forged at 1050 to 1200°C into a round bar, 40 mm in diameter. Then, the round bar having a diameter of 40 mm was hot-swaged to a diameter of 15 mm. Each of the specimens was treated to form the solid solution at a dissolution temperature of the y' phase or higher and then aged at a dissolution temperature of the y' phase or lower to separate out the y' phase, 50 to 100 mm in diameter. The treated specimen having a parallel portion 6 mm in diameter and 30 mm long was prepared for the creep test from the treated round bar having a diameter of 15 mm. The creep test was carried out at 825°C.

[0038] FIG. 2 shows the creep test results. The alloy of the present invention has a strength on a level with that of the alloy disclosed in Known Document 1, and creep rupture lifetime at least 3 times higher than that of CON750.

[0039] FIG. 3 shows the relation between carbide dissolution temperature and amount of carbide separated out at 800°C, where amount of carbon incorporated in some alloys listed in Table 1 was varied. With Known Example 1-B alloy, increasing incorporated carbon amount increases dissolution temperature of the carbide, thus increasing the upper forging temperature limit. However, amount of the carbide separated out at a service temperature increases to increase the crack origins. On the other hand, the alloy of the present invention, incorporated with Ti, Ta and Nb at an adequate total content,
allows the stable MC carbide to separate out at up to higher temperature in spite of a smaller amount of carbide separated out at a service temperature. The alloy of the present invention has a 50 to 100° C. higher carbide dissolution temperature than that disclosed in Known Document 1. As discussed above, the alloy of the present invention has a higher forging temperature limit by about 50° C. than that disclosed in Known Document 1 having a similar strength. However, the carbide in the alloy is stable at up to higher temperature to increase the upper forging temperature limit by 50 to 100° C. Therefore, the alloy has a forgeable temperature range either equaling or surpassing that disclosed in Known Document 1. An alloy is forged more easily as temperature increases, because of decreased resistance to deformation, and it is therefore apparent that the alloy of the present invention is more forgeable than that disclosed in Known Document 1. The alloy of the present invention forgeable at higher temperature is particularly useful for forging large-size components of Ni based superalloy, which needs a very large force, because of decreased deformation resistance. Thus, the alloy of the present invention is more easily forged than that disclosed in Known Document 1, because it is forged at a higher temperature, at which deformation resistance is decreased.

Example 2

Some examples of forged components of the alloys of the present invention are described.

FIG. 4 (a) illustrates the alloy of the present invention applied to a boiler tube for a steam turbine plant. The main steam temperature at a steam turbine is 600 to 625° C. at the highest, and research/development efforts have been made to increase the temperature to 700° C. and thereby to further improve turbine efficiency. The highest boiler temperature will be 750° C., when main steam temperature is 700° C. Tolerable temperature of the conventional forged alloy is limited to 750° C., and it is difficult to increase main steam temperature to 700° C. or higher. The alloy of the present invention has a tolerable temperature of 780 to 800° C. or higher, and can possibly increase main steam temperature to 750° C. or higher, when used for a boiler tube. Main steam passes over a turbine, works to have temperature decreased to around 300° C. and is returned back to the boiler to be reheated. Reheating temperature is generally higher than main steam temperature. However, main steam greatly loses its temperature, and the alloy of the present invention, when used for a boiler tube, can increase reheating temperature to 800° C. or higher in the boiler, and temperature of the reheated steam to be passed to the turbine to 750° C. or higher.

FIG. 4 (b) illustrates the alloy of the present invention applied to a turbine rotor. Weight of a component of superalloy is limited to around 10 tons from the limitations set by a forging apparatus. Therefore, a rotor heavier than 10 tons has a welded structure, where the steam inlet side, which is exposed to the highest temperature, is made of a superalloy and the lower temperature sections are made of ferrite. The alloy of the present invention is used for the section exposed to the highest temperature. A reheating turbine with a rotor of the conventional forged alloy, which has a tolerable temperature limited to 750° C., should be cooled with low-temperature, high-pressure main steam, when steam entering the turbine has a temperature of 750° C. or higher. The turbine with the cooling system should have a more complex structure and lose thermal efficiency. The turbine with a rotor of the alloy of the present invention, having a tolerable temperature of 750° C. or higher, needs no cooling system.

FIG. 4 (c) illustrates the alloy of the present invention applied to a bolt for a turbine casing. A turbine casing is a pressure vessel, and should withstand high temperature and pressure, where the upper and lower portions are generally fabricated separately and integrated with each other by bolts. Increased temperature can be coped with by increasing casing thickness, which, however, involves problems of increased loosening of the bolts resulting from creep deformation when the bolts are made of the conventional forged alloy. The bolt of the alloy of the present invention can withstand higher temperature to suppress loosening.

It should be further understood by those skilled in the art that although the foregoing description has been made on embodiments of the invention, the invention is not limited thereto and various changes and modifications may be made without departing from the spirit of the invention and the scope of the appended claims.

1. An Ni based alloy for forging, containing Cr at 12 to 20%, Al at 3.5 to 5%, Co at 15 to 23%, W at 5 to 12%, C at 0.001 to 0.05%, and Nb, Ti and Ta at a total content of 0.5 to 1.0%, all percentages by mass.

2. The Ni based alloy for forging according to claim 1, wherein fire-retardant elements other than W and Mo are incorporated at a total content of 1% by mass or less.

3. The Ni based alloy for forging according to claim 1, wherein at least 30% by volume of γ phase having an average diameter of 50 to 100 nm is separated out.

4. A steam turbine plant component using the Ni based alloy for forging according to claim 1.

5. A boiler tube using the Ni based alloy for forging according to claim 1 for a steam turbine plant operating with main steam having temperature of 700° C. or higher.

6. A bolt using the Ni based alloy for forging according to claim 1, used for a steam turbine plant operating at a service temperature of 750° C. or higher.

7. A rotor using the Ni based alloy for forging according to claim 1, used for a steam turbine plant operating at an ambient temperature of 750° C. or higher.

* * * * *