(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 2 423 342 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
12.06.2013 Bulletin 2013/24

(51) Int Cl.:
C22C 19/05 *(2006.01)* ***C22F 1/10*** *(2006.01)*

(21) Application number: **11178329.6**

(22) Date of filing: **22.08.2011**

(54) **Forged alloy for steam turbine and steam turbine rotor using the same**

Geschmiedete Legierung für Dampfturbinen und Dampfturbinenrotor damit

Alliage forgé pour turbine à vapeur et rotor de turbine à vapeur l'utilisant

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(30) Priority: **26.08.2010 JP 2010188982**

(43) Date of publication of application:
29.02.2012 Bulletin 2012/09

(73) Proprietor: **Hitachi Ltd.**
Tokyo 100-8280 (JP)

(72) Inventors:
- **Kamoshida, Hironori**
  Tokyo, 100-8220 (JP)
- **Imano, Shinya**
  Tokyo, 100-8220 (JP)
- **Sato, Jun**
  Tokyo, 100-8220 (JP)

(74) Representative: **Beetz & Partner Patentanwälte**
Steinsdorfstrasse 10
80538 München (DE)

(56) References cited:
EP-A1- 1 486 578 **EP-A1- 1 892 307**
EP-A2- 2 298 946

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

EP 2 423 342 B1

Printed by Jouve, 75001 PARIS (FR)

Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a NiFe-based forged alloy used for components of a steam turbine (for example, rotor) operating at a main steam temperature of 675°C or higher.

2. Description of the Related Art

[0002] Thermal plants operating at a steam temperature of 700°C or higher have been under development for attaining higher efficiency in coal-fired generation plants. For the existent steam turbine components (for example, rotor, bolt, blade), while 12Cr ferrite steals as iron type materials have been used so far, it is said that their limit for steam temperature in the working circumstance is 650°C. Alternatively, Ni-based materials as precipitation hardening alloys have been discussed for steam turbine components of 700°C class.

[0003] Since steam turbine components are often large, characteristics such as manufacturability for large ingot and hot forgeability are required for the alloys, and since the alloys are intended to be used in combination with ferrite steels having relatively low thermal expansion coefficients, low thermal expansion is also required.

[0004] For example, a Ni-based alloy (USC141) shown in JP-09-157779-A has a low linear expansion coefficient among Ni-based alloys and also has a good creep strength among candidate materials intended to be used for steam turbines of 700°C class.

[0005] Further, an Fe-based alloy shown in JP-2005-2929-A is a material in which manufactuability for large steel ingot and creep strength are made compatible by reducing Nb as a segregation element and increasing A1 as a y' phase forming element. Therefore, the Fe-based alloy is expected for application to large components of steam turbines, for example, rotors.

[0006] Characteristics of materials are greatly different depending on the material structure even if the material composition is identical. As the crystal grain size increases, a problem occurs that the creep strength increases but the fatigue property decreases.

[0007] EP 1892307 A1 discloses an Ni-Fe based forging superalloy which comprises 30 to 40 wt% of Fe, 14 to 16 wt% of Cr, 1.2 to 1.7 wt% of Ti, 1.1 to 1.5 wt% of A1, 1.9 to 2.7 wt % of Nb, 0.05 wt% or less of C and the remainder of Ni and inevitable impurities, which is solution-treated and aged and precipitated y phase Ni3Al have an initial mean particle size of about 50 to 100 nm.

[0008] EP 1486578 A1 discloses a rotor material for a steam turbine of which main steam temperature is 675 °C or more. The forged material containing 14 to 18 wt% of Fe, 1.0 to 2.0 wt% of A1, 1.0 to 1.8 wt% of Ti, C and N of which the sum is 0.05 or less wt%, and Nb in the range specified by the formula: $3.5-(Fe\ wt\%)/20 < (Nb\ wt\%) < 4.5-(Fe\ wt\%)/20$.

SUMMARY OF THE INVENTION

[0009] The present invention intends to provide a forged alloy for a steam turbine of good creep property and fatigue property, and a rotor for the steam turbine using the forged alloy described above and a corresponding manufacturing method of the alloy.

[0010] The above objects are accomplished by the independent claims of the present application.

[0011] That is, a forged alloy for a steam turbine according to the invention comprises 15 to 45 wt% of Fe, 14 to 18 wt% of Cr, 1.0 to 1.8 wt% of Ti, 1.0 to 2.0 wt% of Al, 1.25 to 3.0 wt% of Nb, 0.05% or less of C+N and the balance of Ni, wherein the crystal grain size number after heat treatment of the forged alloy is 0 to 2, and the heat treatment includes a plurality of solution heat treatments in different temperature ranges.

[0012] The present invention can provide a forged alloy for a steam turbine of good creep property and fatigue property, and a rotor for the steam turbine using the forged alloy described above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013]

Fig. 1 is a graph showing a relation between a crystal grain size number and a creep rupture time (creeping condition; 700°C, 333 MPa); and

Fig. 2 is a graph showing a relation between a crystal grain size number and a number of cycles in low cycle fatigue rupture cycles (strain range; 0.8%, 700°C).

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0014] The present inventors have investigated the effect of the crystal grain size (crystal particle diameter) of materials on the creep strength and the fatigue property. The crystal particle diameter (crystal grain size) is made coarser by increasing the solution temperature in a γ' phase than usual.

[0015] The creep strength and the fatigue property were investigated by using NiFe forged alloys with the crystal grain size Numbers of 0 to 2. As a result, it has been found that creep rupture time is increased about six times as usual under the same creep condition. Further, no remarkable lowering has been observed for the fatigue property under identical low cycle fatigue test conditions.

[0016] The NiFe-based forged alloy according to this invention will be described.

(NiFe-based forged alloy)

[0017] Al of 1.0% by weight or more needs to be incorporated for compensating lowering of strength due to decrease in Nb and improving the structural stability. However, since excess content worsens the forgeability due to excess increase in the γ' phase, the Al content is defined as 2.0 wt% or less.

[0018] Since Ti is an element for precipitating the γ' phase and stabilizing Ni_3Ti at high temperatures, excess content is not preferred and it is defined as 1.0 to 1.8 % by weight.

[0019] C and N are defined as 0.05% by weight or less as the total for C and N in order to suppress refinement of crystal grains attributable to increase of NbC as described above.

[0020] Fe is defined as 15 to 45% by weight in order to suppress precipitation of σ phase and δ phase which are deleterious precipitation phases.

[0021] Nb is an element for stabilizing the γ' phase. Since insufficient content of Nb cannot provide effective strength whereas excessive content results in worsening of segregation property, Nb is defined as 1.25 to 3.0% by weight.

[0022] Cr may promote precipitation of the σ phase as a deleterious precipitation phase when contained in excess but it is defined as 14 to 18% by weight for obtaining oxidation resistance.

[0023] The NiFe-based super alloy of the invention comprises the ingredients described above and the balance of Ni. In addition to the ingredients described above, elements present in the starting material or intruding in the production process may sometimes be contained as impurities. Since intrusion of some impurities cannot be avoided, they are referred to as inevitable impurity.

[0024] Then, a method of manufacturing a NiFe-based forged alloy will be described.

(Method of manufacturing NiFe-based forged alloy)

[0025] First, the NiFe-based forged alloy comprising the composition described above is subjected to a 2-step solution heat treatment.

[0026] A solution heat treatment at a first step is performed at 1020°C to 1100°C for 1 to 10 hours. When it is lower than 1020°C, coarsening of crystal grains does not proceed, or long-time heat treatment is required, which is not practical. In contrast, if it exceeds 1100°C, the coarsening rate of the crystal grains increases, which makes control for the crystal particle size difficult.

[0027] The solution heat treatment at a second step is performed at 965°C to 995°C for 1 to 4 hours. The temperature range may be at such a temperature as applied generally as the solution heat treatment for Ni-based alloy of this type. The temperature is defined to the range described above, with an aim of precipitating only carbides without precipitation of the γ' phase and preventing carbides from continuously precipitating at the crystal grain boundary upon age-hardening heat treatment.

[0028] Then, the age-hardening heat treatment is performed. The temperature for the age-hardening heat treatment may be a temperature at which the age-hardening heat treatment is applied generally for the NiFe-based forged alloys of this type. The age-hardening treatment is performed twice in which the first step is performed at 825 to 855°C within 10 hours and the second treatment is performed at a lower temperature of 710 to 740°C for 10 to 48 hours.

[0029] Then, the crystal grain size after the heat treatment will be described.

(Crystal grain size after heat treatment)

[0030] The crystal grain size (crystal particle diameter) after the heat treatment is a crystal grain size number in Japanese Industrial Standards (JIS), which is in a range of 0 to 2 and, preferably, 1 to 2. For the crystal grain number, a smaller value means a larger crystal grain size.

[0031] When the crystal grain size number is smaller than 0, that is, as the crystal particle diameter increases, the fatigue property tends to be lowered and the supersonic wave transmission is worsened. Thus flaw detectability tends

to decrease.

[0032] In contrast, when a crystal grain size number is larger than 2, that is, when the crystal particle diameter decreases, the fatigue property or the creep rupture ductility can be maintained or improved. However, the creep strength is not changed so much as in usual and no improvement is found.

[Example]

[0033] The present invention will be described specifically referring to examples.

[0034] Materials obtained by a double melt process comprising vacuum induction melting (VIM) and electroslug remelting (ESR) was subjected to hot forging to prepare specimens.

[0035] Table 1 shows the composition of a test specimen.

[Table 1]

Table 1
Composition of Test Specimen (wt%)

C	Si	Mn	P	S	Ni	Cr	Al	Ti	Nb	Fe	N	B
0.02	0.05	0.02	<0.003	0.0003	40.90	15.49	1.34	1.48	2.00	38.4	0.0032	0.0055

(Heat treatment for test specimen)

[0036] The test specimens obtained were subjected to the solution heat treatment twice under the temperature conditions shown in Table 2 and age-hardening heat treatment, and then the crystal gain size number of the test specimens was measured. The crystal grain size number was measured according to JIS G0551.

[0037] Specimens subjected to the first solution heat treatment in a temperature range of 1020 to 1100°C were referred to as invented materials A, B, and C and other specimens were referred to as comparative materials A, B, and C.

[Table 2]

Table 2

	Invented material A	Invented material B	Invented material C
First step	1020°C x 3 hr	1060°C x 3 hr	1100°C x 3 hr
Second step	980°C x 2 hr	980°C x 2 hr	980°C x 2 hr
Crystal grain size	2	1	0
	Comparative material A	Comparative material B	Comparative material C
First step	1140°C x 3 hr	1140°C x 1 hr	None
Second step	980°C x 2 hr	980°C x 2 hr	980°C x 2 hr
Crystal grain size	-1	-0.7	3

[0038] For the invented material A, the invented material B, and the invented material C, the first step solution heat treatment was performed at 1020°C for 3 hours, 1060°C for 3 hours, and 1100°C for 3 hours, respectively and then the second step solution heat treatment was performed at 980°C for 2 hours. Subsequently, the age-hardening heat treatment was performed at 840°C for 8 hours and 740° for 24 hours.

[0039] For the comparative material A and the comparative material B, the first step solution heat treatment was performed at 1140°C for 3 hours and 1140°C for one hour, respectively, and then the second step solution heat treatment was performed at 980°C for 2 hours. Subsequently, age-hardening heat treatment was performed at 840°C for 8 hours and 740°C for 24 hours.

[0040] For the comparative material C, the first step solution heat treatment was not performed and only the second step heat treatment was performed. Then, an age-hardening heat treatment was performed at 840°C for 8 hours and at 740°C for 24 hours.

[0041] As shown in Table 2, the invented materials A, B, and C subjected twice to the solution heat treatment in which the temperature for the first step was 1020 to 1100°C had crystal grain size numbers of 2, 1, and 0. The Comparative

Examples A, B, and C were had crystal grain size numbers of -1, -0.7, and 3.

[0042] By controlling the temperature range for the solution heat treatment, the crystal grain size number after the heat treatment could be 0 to 2.

[Creep test]

[0043] For the invented materials A, B, and C, and the comparative materials A, B, and C, a creep test was performed under the condition at 700°C, 333MPa.

The results are shown in Fig. 1.

[0044] Fig. 1 is a graph showing a relationship between the crystal grain number and the creep rupture time. The creep conditions are 700°C and 733 MPa. In the material of this invention, the rupture time is 200 hours when the grain size is controlled by defining the crystal grain size number to 3 or less. As shown in Fig. 1, the rupture time tends to be longer as the crystal grain size number is smaller.

[Low cycle fatigue test]

[0045] Then, Fig. 2 shows results of a low cycle fatigue test for test specimens. Fig. 2 is a graph showing a relation between the crystal grain size number and the number of cycles in low cycle fatigue rupture.

[0046] The strain range is 0.8% at 700°C. The number of cycles stays substantially flat when the crystal grain number is 1 or greater, and tends to lower somewhat when the crystal grain number is 0, and the number of rupture cycles is greatly lowered when the number is less than 0.

[0047] Accordingly, as shown in Fig. 1 and Fig. 2, the crystal grain size number is 2 or less for the creep strength and 0 or more and, more preferably, 1 or more for the fatigue property.

[0048] By using the NiFe-based forged alloy for which the crystal grain size number is controlled to 0 to 2, preferably, 1 to 2 by the heat treatment, the fatigue property can be improved without decrease in creep strength.

[0049] Since the material of the invention has the characteristics described above, it is suitable for components of the steam turbines (for example, a rotor) in the steam turbine power generation plants that provide a main steam temperature of 675°C or higher.

[0050] A steam turbine generally comprises a high pressure turbine (or medium pressure turbine) and a low pressure turbine. For example, iron type materials are used even in a steam turbine at a steam temperature of 700°C class, since the steam temperature is 600°C or lower in a low pressure turbine whose temperature is lowered. By contrast, since a high pressure turbine or a medium pressure turbine for use in some steam turbines is subjected to a steam temperature of 700°C or higher, Ni-based or NiFe-based alloy is used for rotors, blades, casing bolts of the turbines.

Claims

1. A forged alloy for a steam turbine, comprising 15 to 45 wt% of Fe, 14 to 18 wt% of Cr, 1.0 to 1.8 wt% of Ti, 1.0 to 2.0 wt% of Al, 1.25 to 3.0 wt% of Nb, 0.05% or less of C+N and the balance of Ni, wherein the final crystal grain size number in accordance with Japanese Industrial Standards (JIS) is 0 to 2

2. A rotor for a steam turbine comprising the forged alloy for the steam turbine according to claim 1.

3. A method of manufacturing a forged alloy for a steam turbine, the forged alloy comprising 15 to 45 wt% of Fe, 14 to 18 wt% of Cr, 1.0 to 1.8 wt% of Ti, 1.0 to 2.0 wt% of Al, 1.25 to 3.0 wt% of Nb, 0.05% or less of C+N and the balance of Ni, the manufacturing method comprising the steps of:

   performing a first solution heat treatment of said forged alloy at 1020°C to 1100°C for 1 to 10 hours, and performing a second solution heat treatment of said forged alloy at 965°C to 995°C for 1 to 4 hours, wherein an age-hardening heat treatment includes two steps one of which is performed at 825°C to 855°C within 10 hours and the other one of which is performed at a lower temperature of 710°C to 740°C for 10 to 48 hours.
   wherein the forged alloy is manufactured such that the final crystal grain size number in accordance with Japanese Industrial Standards (JIS) after the heat treatments is 0 to 2.

Patentansprüche

1. Geschmiedete Legierung für eine Dampfturbine,
die enthält:

   15 bis 45 Gew.-% Fe, 14 bis 18 Gew.-% Cr, 1,0 bis 1,8 Gew.-% Ti, 1,0 bis 2,0 Gew.-% Al, 1,25 bis 3,0 Gew.-% Nb, 0,05 oder weniger C+N und als Rest Ni, wobei die endgültige Kristall-Korngrößenzahl gemäß den Japanischen Industrienormen (JIS) 0 bis 2 beträgt.

2. Rotor für eine Dampfturbine, der die geschmiedete Legierung für die Dampfturbine nach Anspruch 1 aufweist.

3. Verfahren zur Herstellung einer geschmiedeten Legierung für eine Dampfturbine, wobei die geschmiedete Legierung 15 bis 45 Gew.-% Fe, 14 bis 18 Gew.-% Cr, 1,0 bis 1,8 Gew.-% Ti, 1,0 bis 2,0 Gew.-% Al, 1,25 bis 3,0 Gew.-% Nb, 0,05 oder weniger C+N und als Rest Ni enthält,
wobei das Herstellungsverfahren folgende Schritte umfasst:

   Durchführen eines ersten Lösungsglühens der geschmiedeten Legierung bei 1020 °C bis 1100 °C während 1 bis 10 Stunden
   und
   Durchführen eines zweiten Lösungsglühens der geschmiedeten Legierung bei 965 °C bis 995 °C während 1 bis 4 Stunden,
   wobei eine Glühbehandlung zur Härtezunahme durch Alterung zwei Schritte umfasst, von denen einer bei 825 °C bis 855 °C bis zu 10 Stunden und der andere bei einer niedrigeren Temperatur von 710 °C bis 740 °C während 10 bis 48 Stunden durchgeführt wird,
   wobei die geschmiedete Legierung so hergestellt wird, dass die endgültige Kristall-Korngrößenzahl gemäß den Japanischen Industrienormen (JIS) nach den Glühbehandlungen 0 bis 2 beträgt.

Revendications

1. Alliage forgé pour une turbine à vapeur, comprenant 15 à 45% en poids de Fe, 14 à 18% en poids de Cr, 1,0 à 1,8% en poids de Ti, 1,0 à 2,0% en poids d'Al, 1,25 à 3,0% en poids de Nb, 0,05% ou moins de C+N et le reste de Ni, dans lequel le numéro de taille finale de grains cristallins conformément aux Normes Industrielles Japonaises (JIS) est 0 à 2.

2. Rotor pour une turbine à vapeur comprenant l'alliage forgé pour la turbine à vapeur selon la revendication 1.

3. Procédé de fabrication d'un alliage forgé pour une turbine à vapeur, l'alliage forgé comprenant 15 à 45% en poids de Fe, 14 à 18% en poids de Cr, 1,0 à 1,8% en poids de Ti, 1,0 à 2,0% en poids d'Al, 1,25 à 3,0% en poids de Nb, 0,05% ou moins de C+N et le reste de Ni, le procédé de fabrication comprenant les étapes de :

   exécution d'un premier traitement thermique en solution dudit alliage forgé à 1 020°C à 1 100°C pendant 1 à 10 heures, et
   exécution d'un deuxième traitement thermique en solution dudit alliage forgé à 965°C à 995°C pendant 1 à 4 heures,
   dans lequel un traitement thermique de durcissement par vieillissement inclut deux étapes, dont l'une est exécutée à 825°C à 855°C pendant 10 heures et dont l'autre est exécutée à une température plus basse de 710°C à 740°C pendant 10 à 48 heures,
   dans lequel l'alliage forgé est fabriqué de telle manière que le numéro de taille finale de grains cristallins conformément aux Normes Industrielles Japonaises (JIS) après les traitements thermiques est 0 à 2.

FIG. 1

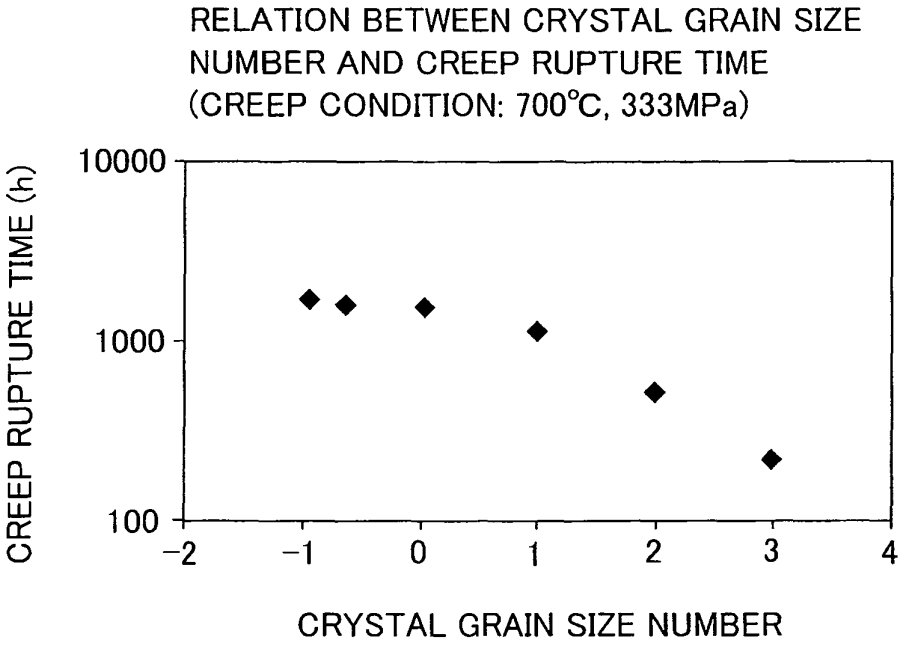
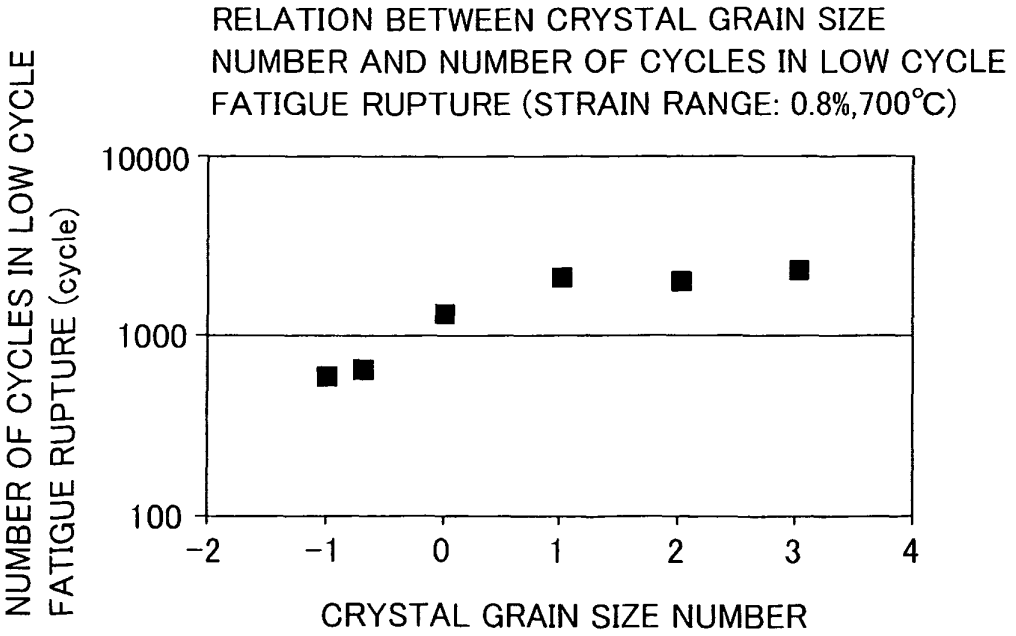

RELATION BETWEEN CRYSTAL GRAIN SIZE NUMBER AND CREEP RUPTURE TIME (CREEP CONDITION: 700°C, 333MPa)
CREEP RUPTURE TIME (h)
10000
1000
100
−2
−1
0
1
2
3
4
CRYSTAL GRAIN SIZE NUMBER

FIG. 2


RELATION BETWEEN CRYSTAL GRAIN SIZE NUMBER AND NUMBER OF CYCLES IN LOW CYCLE FATIGUE RUPTURE (STRAIN RANGE: 0.8%,700°C)
NUMBER OF CYCLES IN LOW CYCLE FATIGUE RUPTURE (cycle)
10000
1000
100
−2
−1
0
1
2
3
4
CRYSTAL GRAIN SIZE NUMBER

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 9157779 A **[0004]**
- JP 2005002929 A **[0005]**
- EP 1892307 A1 **[0007]**
- EP 1486578 A1 **[0008]**