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(54) NI-BASED SUPERALLOY

(57) The present invention relates to an Ni-based superalloy having a composition containing, in terms of % by mass, C: from 0.1 to 0.3%, Cr: from 8.0 to 12.0%, Mo: from 1.0 to 5.0%, Co: from 10.0 to 20.0%, Ta: from 0.01 to 1.50%, Ti: from 2.0 to 4.2%, Al: from 5.0 to 8.0%, V: from 0 to 1.5%, B: from 0.005 to 0.030%, and Zr: from 0.05 to 0.15%, with the balance being Ni and unavoidable impurities, and satisfying, in terms of atom%, Ti+Al being from 16.0 to 20.3% and Ti/Al being 0.3 or less.

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Description

TECHNICAL FIELD

[0001] The present invention relates to an Ni-based superalloy suitable for application as a material of high temperature parts such as a turbine wheel.

BACKGROUND ART

[0002] For example, a turbine wheel rotating with receiving an exhaust gas from an engine rotates at a high speed (e. g., the rotation number per minute being hundreds of thousands) under a high temperature (e. g., under a high temperature of about 950°C) and thus, it is required to be excellent in high-temperature strength properties.
Therefore, as a material of the turbine wheel, an Ni-based superalloy excellent in high-temperature strength properties, particularly an Ni-based cast alloy including Inconel 713C and MAR-M246 as a representative has been mainly used.

[0003] As strengthening mechanisms for high-temperature strength in the Ni-based superalloy, solid solution strengthening and γ' phase (gamma prime phase) precipitation strengthening have been used. Since the γ' phase (a phase of Ni3(Al, Ti, Nb) that is an intermetallic compound) precipitating as a strengthening phase is stable up to a high temperature, it is difficult to produce the turbine wheel by forging and thus, usually, the turbine wheel is mainly produced by casting using an Ni-based cast alloy and is used in a state as cast.

[0004] Incidentally, in a rotating body such as the turbine wheel, as the weight of the part increases, inertial weight increases and, for example, response at the rise of rotation becomes slow. Therefore, it is requested to be light in weight, that is, low in specific gravity.
In the Ni-based alloy using the solid solution strengthening and the γ' phase precipitation strengthening as strengthening mechanisms as mentioned above, the high-temperature strength is improved with an increase in the addition amount of solid solution strengthening elements. However, since specific gravity increases, it is difficult to cope with the request for a decrease in the specific gravity.
It is also considered to decrease the specific gravity while maintaining the high-temperature strength by decreasing the addition amount of the solid solution strengthening elements and, on the other hand, increasing the addition amount of constituent elements of the γ'-phase. However, there is a problem in that, in the case where the precipitation amount of the y' phase is increased, cast cracking is prone to occur during the solidification process at casting and thus productivity becomes worse.

[0005] As described above, in the alloy to be used as a material for high temperature parts such as the turbine wheel, it is required to be low in specific gravity and excellent in castability, in addition to the high-temperature strength properties. However, there has not been provided any Ni-based alloy sufficiently satisfying these requirements yet.

[0006] Incidentally, as a prior art with regard to the present invention, the following Patent Document 1 describes an invention concerning a "nickel-based alloy", and there is disclosed a nickel-based alloy having a composition consisting of, in terms of % by weight, Co: from 14 to 19%, Cr: from 10 to 15%, C: from 0.05 to 0.2%, Mo: from 0 to 3%, and Ti: from 3.1 to 4.5%, with the balance being Ni and unavoidable impurities, and satisfying a Ti/Al ratio of 0.85 or less. However, in this Patent Document 1, there is no disclosure regarding specific means for improving the castability and the component compositions in individual Examples are all different from those of the present invention.

[0007] Patent Document 1: JP-A-2015-101753

SUMMARY OF THE INVENTION

[0008] With the above circumstances as a background, the present invention has been made for the purpose of providing an Ni-based superalloy that is low in specific gravity and excellent in high-temperature strength properties and castability.

[0009] First aspect of the present invention is an Ni-based superalloy having a composition containing, in terms of % by mass, C: from 0.1 to 0.3%, Cr: from 8.0 to 12.0%, Mo: from 1.0 to 5.0%, Co: from 10.0 to 20.0%, Ta: from 0.01 to 1.50%, Ti: from 2.0 to 4.2%, Al: from 5.0 to 8.0%, V: from 0 to 1.5%, B: from 0.005 to 0.030%, and Zr: from 0.05 to 0.15%, with the balance being Ni and unavoidable impurities, and satisfying, in terms of atom%, Ti+Al being from 16.0 to 20.3% and Ti/Al being 0.3 or less.

[0010] Second aspect of the present invention is the Ni-based superalloy according to the first aspect, having a specific gravity of 7.9 g/cm^3 or less.

[0011] Third aspect of the present invention is the Ni-based superalloy according to the first or second aspect, in which Ta is from 0.3 to 0.8% by mass.

[0012] In an Ni-based superalloy having a γ' phase as a strengthening phase, it is known that the precipitation amount of the γ' phase is increased with an increase of the addition amount of Al and Ti that are constituent elements of the γ'-

phase, and further the precipitation temperature of the γ' phase is also raised accompanied thereby.
The present inventors made intensive investigations to pursue possibility of lowering the precipitation temperature of the γ' phase while maintaining the total amount of Al+Ti high. As a result, they found that the precipitation temperature of the γ' phase can be lowered by decreasing a Ti/Al ratio that is a ratio of Ti to Al and in addition, in the case where the Ti/Al ratio is controlled to 0.3 or less, cast cracking can be prevented with suppressing the precipitation of the γ' phase in a temperature region where cracking due to insufficient ductility may occur during casting.

[0013] The present invention has been made based on such findings and is characterized in that the addition amount of the solid solution strengthening elements are decreased and, on the other hand, the total amount of Ti+Al that are constituent elements of the γ'-phase is controlled to 16.0% or more and the Ti/Al ratio is controlled to 0.3 or less.
In the present invention, a decrease in the specific gravity of the alloy is attained by decreasing the addition amount of the solid solution strengthening elements and, on the other hand, the high-temperature strength properties are secured by increasing the addition amount of Ti and Al that are constituent elements of the γ'-phase. When the addition amount of Ti and Al is increased, the cast cracking is prone to occur and there is a concern of inviting deterioration of the castability. However, in the present invention, by controlling the Ti/Al ratio to 0.3 or less, a rise in the precipitation temperature of the γ' phase is suppressed and the occurrence of the cast cracking during the solidification process is prevented, thereby securing the castability.

[0014] As above, the Ni-based superalloy of the present invention is low in the specific gravity and excellent in the high-temperature strength properties and the castability, and hence can be suitably used as a material for high temperature parts such as a turbine wheel.

MODE FOR CARRYING OUT THE INVENTION

[0015] The following will describe reasons for the limitation of individual components of the Ni-based superalloy in the present invention.

C: from 0.1 to 0.3%

[0016] C improves grain boundary strength through formation of carbides. For attaining sufficient high-temperature strength, it is necessary to add C in an amount of 0.1% or more. However, excessive addition of C forms coarse eutectic carbides to cause a decrease in toughness and ductility. Therefore, an upper limit is set to 0.3%.

Cr: from 8.0 to 12.0%

[0017] Cr forms a dense oxide film composed of Cr_2O_3 on a surface to improve oxidation resistance and high-temperature corrosion resistance. For exhibiting such properties, it is necessary to contain Cr in an amount of 8.0% or more.

[0018] Although the oxidation resistance and high-temperature corrosion resistance become excellent as the content of Cr increases, its excessive addition lowers phase stability and deteriorates ductility and toughness. Therefore, an upper limit is set to 12.0%. More preferable content of Cr is from 9.0 to 10.0%.

Mo: from 1.0 to 5.0%

[0019] Mo has an effect of forming a solid solution in the austenite phase to strengthen the matrix through solid solution strengthening. For the purpose, it is necessary to contain Mo in an amount of at least 1.0%. More preferably, the amount of Mo is 3.1% or more. However, its excessive addition lowers phase stability and deteriorates the ductility and the toughness. Therefore, an upper limit is 5.0%.

Co: form 10.0 to 20.0%

[0020] Co has effects of strengthening the austenite phase through solid solution strengthening and also forming a solid solution in the γ' phase to strengthen the γ' phase. For the purpose, it is necessary to contain Co in an amount of at least 10.0%. More preferably, the amount of Co is 12.0% or more. However, since Co is an expensive material, it is disadvantageous in cost to add Co in a large amount. Therefore, an upper limit is 20.0%.

Ta: from 0.01 to 1.50%

[0021] Ta not only combines with C to form a carbide but also has an effect of forming a solid solution in the γ' phase to strengthen the γ' phase. For the purpose, it is necessary to contain Ta in an amount of at least 0.01%. However, since an addition of Ta in a large amount increases the specific gravity, an upper limit is set to 1.50%. More preferable content

is from 0.3 to 0.8%.

Ti: from 2.0 to 4.2%

[0022] Ti combines with Ni to form the γ' phase (Ni_3(Al, Ti) intermetallic compound) that is effective for improving strength, thereby strengthening the alloy through precipitation strengthening. For the purpose, it is necessary to contain Ti in an amount of at least 2.0%. However, an addition of Ti in a large amount increases an eutectic carbide to lower the ductility. Therefore, an upper limit is set to 4.2%. More preferable content is 3.0% or less.

Al: from 5.0 to 8.0%

[0023] Al is a component that forms the γ' phase (Ni_3Al intermetallic compound). For obtaining sufficient high-temperature strength, it is necessary to contain Al in an amount of 5.0% or more. However, an excessive increase in the addition amount of Al lowers creep strength. Therefore, an upper limit is set to 8.0%. More preferable content is from 6.8 to 7.5%.

V: from 0 to 1.5%

[0024] V forms a solid solution in the γ' phase to achieve solid solution strengthening. However, its excessive addition lowers the high-temperature strength. Therefore, 1.5% is an upper limit. In the present invention, there is a case where V is not contained.

B: from 0.005 to 0.030%

[0025] Since B strengthens a grain boundary, it is added in an amount of 0.005% or more. However, an excessive addition of B forms a boride to lower properties. Therefore, an upper limit is set to 0.030%.

Zr: from 0.05 to 0.15%

[0026] Since Zr improves the creep strength through grain boundary strengthening similarly to B, Zr is added in an amount of 0.05% or more. However, an excessive addition of Zr lowers the ductility. Therefore, an upper limit is set to 0.15%.

Ti+Al: from 16.0 to 20.3%

Ti/Al: 0.3 or less

[0027] As is explained above, the total amount of Ti+Al is an index that indicates the amount of the γ' phase and, for improving the high-temperature strength properties, it is necessary to contain Ti+Al in an amount of 16% or more in terms of atom %. However, their excessive addition lowers the ductility. Therefore, an upper limit is set to 20.3%. The Ti/Al ratio is an important factor for the precipitation temperature of the γ' phase and, in the present invention, the Ti/Al ratio is set to 0.3 or less. In the case where the total amount of Ti+Al is 16% or more and the Ti/Al ratio exceeds 0.3, the precipitation temperature of the γ' phase rises and cracking due to insufficient ductility is prone to occur during the solidification process in the casting step.

[0028] According to the present invention as described above, an Ni-based superalloy that is low in specific gravity and excellent in high-temperature strength properties and castability can be provided.

EXAMPLES

[0029] The following will explain Examples of the present invention. First, each of alloys having chemical compositions shown in Table 1 was melted in a vacuum melting furnace to cast 50 kg of an ingot. Thereafter, a specimen was prepared from the ingot by machining and, by using the specimen, specific gravity, 0.2% proof strength, elongation, and creep strength were evaluated. Moreover, by using each of the alloys having chemical compositions shown in Table 1, a turbine wheel was prepared to evaluate castability.

Table 1: Chemical Composition (% by mass, provided that Ti+Al and Ti/Al are excluded)

		Ni	C	Cr	Mo	Co	Al	Ti	Zr	V	Nb	Hf	B	W	Ta	Ti+Al (atom%)	Ti/Al (atom ratio)
Alloy of Example	1	bal.	0.15	9.5	3.1	15.0	7.0	2.3	0.05	1.0	-	-	0.015	-	0.5	16.5	0.19
	2	bal.	0.15	9.5	3.1	15.0	7.0	2.3	0.05	-	-	-	0.015	-	0.5	16.6	0.19
	3	bal.	0.15	9.5	3.1	15.0	7.0	2.3	0.05	1.0	-	-	0.015	-	0.2	16.5	0.19
	4	bal.	0.15	9.5	3.1	15.0	7.0	2.3	0.05	1.0	-	-	0.015	-	1.0	16.6	0.19
	5	bal.	0.15	9.5	3.1	15.0	7.0	2.0	0.05	1.0	-	-	0.015	-	0.5	16.2	0.16
	6	bal.	0.15	9.5	3.1	15.0	7.0	3.1	0.05	1.0	-	-	0.015	-	0.5	17.4	0.25
	7	bal.	0.15	9.5	3.1	15.0	6.7	2.3	0.05	1.0	-	-	0.015	-	0.5	16.0	0.19
	8	bal.	0.15	9.5	3.1	15.0	7.8	2.3	0.05	1.0	-	-	0.015	-	0.5	18.0	0.17
	9	bal.	0.15	9.5	3.0	15.0	7.0	2.3	0.05	1.0	-	-	0.015	-	0.5	16.5	0.19
	10	bal.	0.15	9.5	5.0	15.0	7.0	2.3	0.05	1.0	-	-	0.015	-	0.5	16.7	0.19
	11	bal.	0.15	8.5	3.1	15.0	7.0	2.3	0.05	1.0	-	-	0.015	-	0.5	16.5	0.19
	12	bal.	0.15	10.5	3.1	15.0	7.0	2.3	0.05	1.0	-	-	0.015	-	0.5	16.5	0.19
	13	bal.	0.15	9.5	3.1	10.0	7.0	2.3	0.05	1.0	-	-	0.015	-	0.5	16.5	0.19
	14	bal.	0.15	9.5	3.1	20.0	7.0	2.3	0.05	1.0	-	-	0.015	-	0.5	16.5	0.19
Alloy of Comparative Example	1	bal.	0.12	12.5	4.0	-	6.0	0.7	0.10	-	1.8	-	0.012	-	-	13.0	0.07
	2	bal.	0.15	9.0	2.5	10.0	5.5	1.5	0.05	-	-	-	0.015	10.0	1.5	13.8	0.15
	3	bal.	0.15	8.3	0.7	10.0	5.5	1.0	0.05	-	-	1.5	0.015	10.0	3.0	13.4	0.10
	4	bal.	0.15	9.5	3.0	15.0	5.5	4.8	0.05	1.0	-	-	0.015	-	-	16.5	0.50
	5	bal.	0.15	9.5	3.0	15.0	4.3	3.7	0.05	1.0	-	-	0.015	-	-	13.0	0.50
	6	bal.	0.15	9.5	3.0	15.0	5.0	4.3	0.05	1.0	-	-	0.015	-	-	15.0	0.50
	7	bal.	0.15	9.5	3.0	15.0	6.0	3.5	0.05	1.0	-	-	0.015	-	-	15.9	0.33
	8	bal.	0.15	9.5	3.0	15.0	5.0	4.3	0.05	1.0	-	-	0.015	-	1.0	15.1	0.48

Specific Gravity Measurement

[0030] Measurement of specific gravity was carried out in accordance with JIS Z 8807 (2012) and evaluation was performed according to the following criteria.

A: Specific gravity is 7.9 g/cm^3 or less
B: Specific gravity is more than 7.9 g/cm^3 and 8.0 g/cm^3 or less
C: Specific gravity is more than 8.0 g/cm^3

High-Temperature Tensile Test

[0031] A specimen having a parallel part diameter of 8 mm and a gauge length of 40 mm was prepared in accordance with JIS G 0567 (2012) and a tensile test was performed at a test temperature of 1,050°C. In this test, 0.2% proof strength and elongation at 1,050°C were measured.
The 0.2% proof strength was evaluated according to the following criteria.

A: 0.2% Proof strength is 200 MPa or more
B: 0.2% Proof strength is 150 MPa or more and less than 200 MPa
C: 0.2% Proof strength is less than 150 MPa

Also, the elongation was evaluated according to the following criteria.

A: Elongation is 15% or more
B: Elongation is 10% or more and less than 15%
C: Elongation is less than 10%

Creep Rupture Test

[0032] A specimen in accordance with JIS Z 2271 (2010) was prepared, a load stress of 180 MPa was imparted thereto at a test temperature of 1,000°C to measure a life until rupture, and evaluation was performed according to the following criteria. The specimen has a diameter of 6.4 mm at a parallel part.

A: Rupture life is 25 h or more
B: Rupture life is 15 h or more and less than 25 h
C: Rupture life is less than 15 h

Castability Evaluation

[0033] By using each of the alloys having chemical compositions shown in Table 1, turbine wheels having the same shape and the same size were cast under reduced pressure under the same conditions. For 100 pieces of the turbine wheels prepared by using the alloy having the same alloy composition, the occurrence of cracking at edges was visually confirmed and evaluation was performed according to the following criteria.

A: No occurrence of cracking was observed
B: Incidence of turbine wheels on which cracking is observed is less than 30%
C: Incidence of turbine wheels on which cracking is observed is 30% or more These results are shown in Table 2.

Table 2

		Specific gravity	1,050°C 0.2% Proof strength	1,050°C Elongation	1,000°C×180 MPa Creep strength	Castability
Alloy of Example	1	A	A	A	A	A
	2	A	A	A	A	A
	3	A	A	A	B	A
	4	A	A	B	A	A
	5	A	A	A	A	A
	6	A	A	B	A	A
	7	A	B	A	A	A
	8	A	A	B	A	A
	9	A	B	A	A	A
	10	A	A	A	A	A
	11	A	A	A	A	A
	12	A	A	A	A	A
	13	A	B	A	A	A
	14	A	A	A	A	A
Alloy of Comparative Example	1	B	C	A	C	A
	2	C	A	A	A	A
	3	C	A	A	A	A
	4	A	A	C	B	C
	5	A	C	A	C	B
	6	A	B	B	C	B
	7	A	B	B	C	B
	8	A	B	B	B	B

[0034] In Comparative Example 1, Co and Ta that are solid solution strengthening elements were not added, as compared to the composition of the present invention. Moreover, the amount of Ti that is a constituent element of the γ' phase was lower than the lower limit of the present invention, while Nb that is not added in the present invention was added. In Comparative Example 1, sufficient high-temperature strength properties were not obtained and the 0.2% proof strength and the creep strength were evaluated as "C". Furthermore, the specific gravity was evaluated as "B", which is inferior to Examples to be mentioned later.

[0035] In Comparative Example 2, the amount of Ti and the total amount of Ti+Al were lower than the lower limits of the present invention, while a heavy element W that is not added in the present invention was added. Therefore, in Comparative Example 2, the 0.2% proof strength and the creep strength were good as evaluated as "A" but the specific gravity was evaluated as "C".

[0036] In Comparative Example 3, the amount of Ti and the total amount of Ti+Al were lower than the lower limits of the present invention, while heavy elements Hf and W that are not added in the present invention were added. Moreover, the amount of Ta was also higher than the upper limit 1.5% of the present invention. Therefore, in Comparative Example 3, the 0.2% proof strength, elongation and creep strength were good as evaluated as "A" but the specific gravity was evaluated as "C".

[0037] In Comparative Example 4, the total amount of Ti+Al fell within the defined range of the present invention, while the Ti/Al ratio was higher than the upper limit 0.3 of the present invention. Therefore, in Comparative Example 4, the precipitation temperature of the γ' phase was higher than that in the other examples, so that occurrence of solidification cracking (cast cracking) was observed in the castability evaluation and the evaluation was "C". Moreover, since the precipitation temperature of the γ' phase was high, the ductility at a high temperature was low and hot elongation was also evaluated as "C".

[0038] In Comparative Example 5, the amount of Al and the total amount of Ti+Al were lower than the lower limits of the present invention. Therefore, sufficient high-temperature strength properties were not obtained, and the 0.2% proof strength and the creep strength were evaluated as "C". Moreover, the total amount of Ti+Al itself was small in Comparative

Example 5 but the Ti/Al ratio was higher than the upper limit 0.3 of the present invention as in Comparative Example 4, so that the occurrence of cast cracking was observed and the castability was evaluated as "B".

[0039] In Comparative Examples 6 and 7, the total amount of Ti+Al was large as compared to that in Comparative Example 5 but the amount was still lower than the lower limit 16% of the present invention. In addition, Ta was not added. Therefore, the creep strength was evaluated as "C".

[0040] Comparative Example 8 is different from aforementioned Comparative Examples 6 and 7 and Ta was added so as to fall within the component range defined in the present invention but the total amount of Ti+Al was still lower than the lower limit 16% of the present invention. Therefore, the creep strength was improved as compared to that in Comparative Examples 6 and 7 but was evaluated as "B". In Comparative Example 8, in addition to the creep strength, the 0.2% proof strength, elongation and castability were also evaluated as "B". Thus, properties as a whole were poor as compared to those of Examples to be mentioned later.

[0041] On the other hand, in Examples 1 to 14 in which individual elements satisfied the component ranges of the present invention, the specific gravity was evaluated as "A" in all the cases and thus was good. Moreover, the 0.2% proof strength, elongation and creep strength were evaluated as all "A" or, for only one item, "B", which are considered as good. Furthermore, in all Examples, there was no problem in castability, which was evaluated as "A". Thus, the alloys of Examples were low in specific gravity (7.9 g/cm^3 or less in all the alloys), had high high-temperature strength properties in a high temperature region in the vicinity of 1,000°C, and also had castability. Particularly, in Examples 1, 2, 5, 10, and 14 in which individual elements satisfied more preferable ranges, all the evaluation items are evaluated as "A" and alloys excellent in balance were obtained.

[0042] Although the present invention has been described in detail and by reference to the specific embodiments, it is apparent to one skilled in the art that various modifications or changes can be made without departing from the spirit and scope of the present invention.

[0043] The present application is based on Japanese Patent Application No. 2017-033971 filed on February 24, 2017, which contents are incorporated herein by reference.

Claims

1. An Ni-based superalloy having a composition,
consisting of: in terms of % by mass,

C: from 0.1 to 0.3%,
Cr: from 8.0 to 12.0%,
Mo: from 1.0 to 5.0%,
Co: from 10.0 to 20.0%,
Ta: from 0.01 to 1.50%,
Ti: from 2.0 to 4.2%,
Al: from 5.0 to 8.0%,
V: from 0 to 1.5%,
B: from 0.005 to 0.030%, and
Zr: from 0.05 to 0.15%,

with the balance being Ni and unavoidable impurities, and satisfying, in terms of atom%,

Ti+Al being from 16.0 to 20.3% and
Ti/Al being 0.3 or less.

2. The Ni-based superalloy according to claim 1, having a specific gravity of 7.9 g/cm^3 or less.

3. The Ni-based superalloy according to claim 1 or 2, wherein the content of Ta is from 0.3 to 0.8% by mass.

4. Use of the Ni-based superalloy according to one of claims 1 to 3, for manufacturing a turbine wheel.

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EUROPEAN SEARCH REPORT

Application Number
EP 18 15 7015

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A,D	JP 2015 101753 A (IHI CORP) 4 June 2015 (2015-06-04) * abstract; table 1 *	1-4	INV. C22C19/05
A	EP 1 795 621 A1 (HITACHI LTD [JP]) 13 June 2007 (2007-06-13) * claims 1,18 *	1-4	
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A	EP 2 796 578 A1 (GEN ELECTRIC [US]) 29 October 2014 (2014-10-29) * claim 1 *	1-4	
			TECHNICAL FIELDS SEARCHED (IPC) C22C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	27 April 2018	Rolle, Susett

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 18 15 7015

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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