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(54) NICKEL BASE SUPER ALLOY

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(57) **ABSTRACT**

A nickel base superalloy consisting of 20 to 40 wt % cobalt, 10 to 15 wt % chromium, 3 to 6 wt % molybdenum, 0 to 5 wt % tungsten, 2.5 to 4 wt % aluminium, 3.4 to 5 wt % titanium, 1.35 to 2.5 wt % tantalum, 0 to 2 wt % niobium, 0.5 to 1 wt % hafnium, 0 to 0.1 wt % zirconium, 0.01 to 0.05 wt % carbon, 0.01 to 0.05 wt % boron, 0 to 2 wt % silicon and the balance nickel plus incidental impurities. The gamma prime phase comprises $(Ni/Co)_3$ (Al/Ti/Ta).

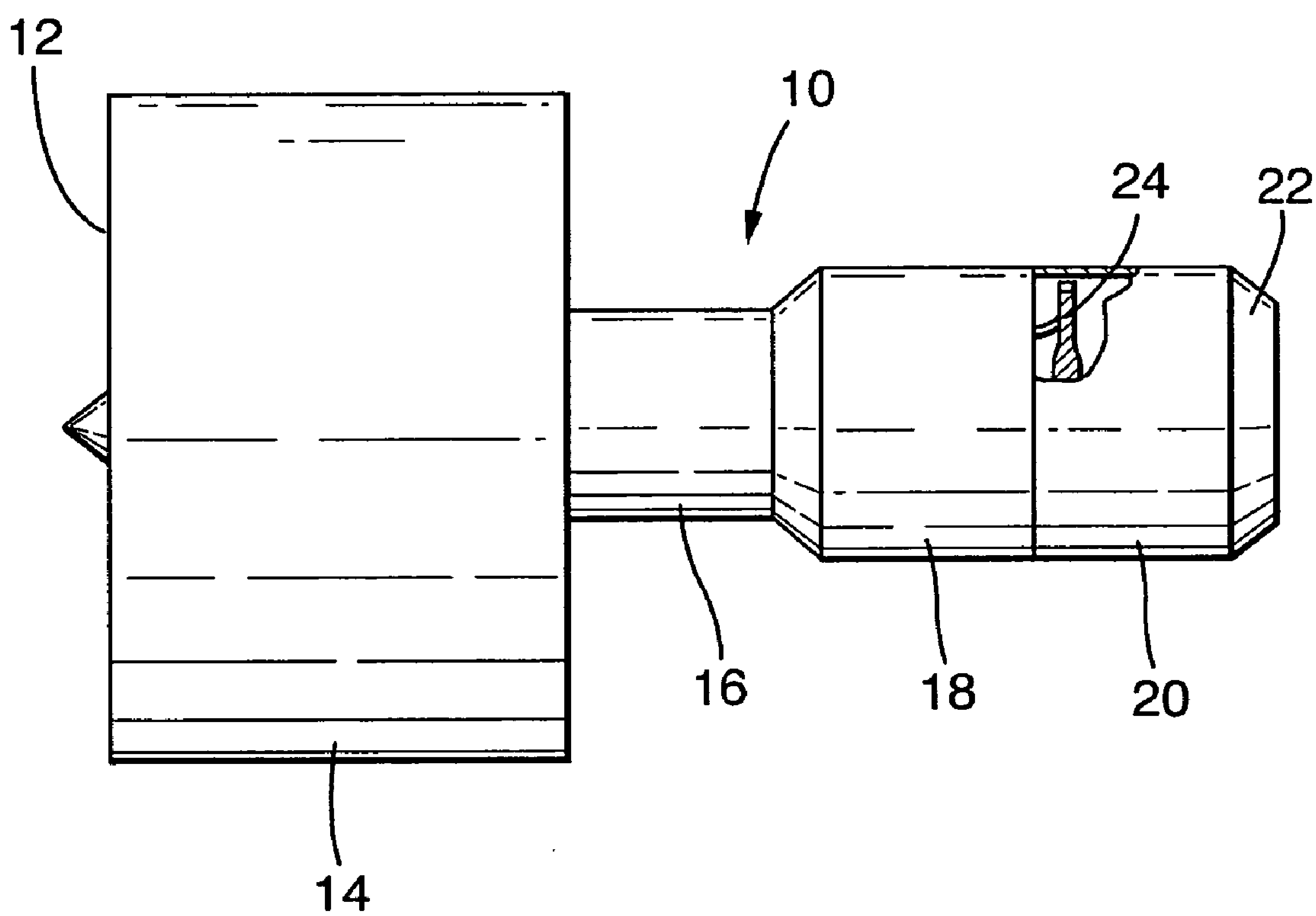


Fig.1.

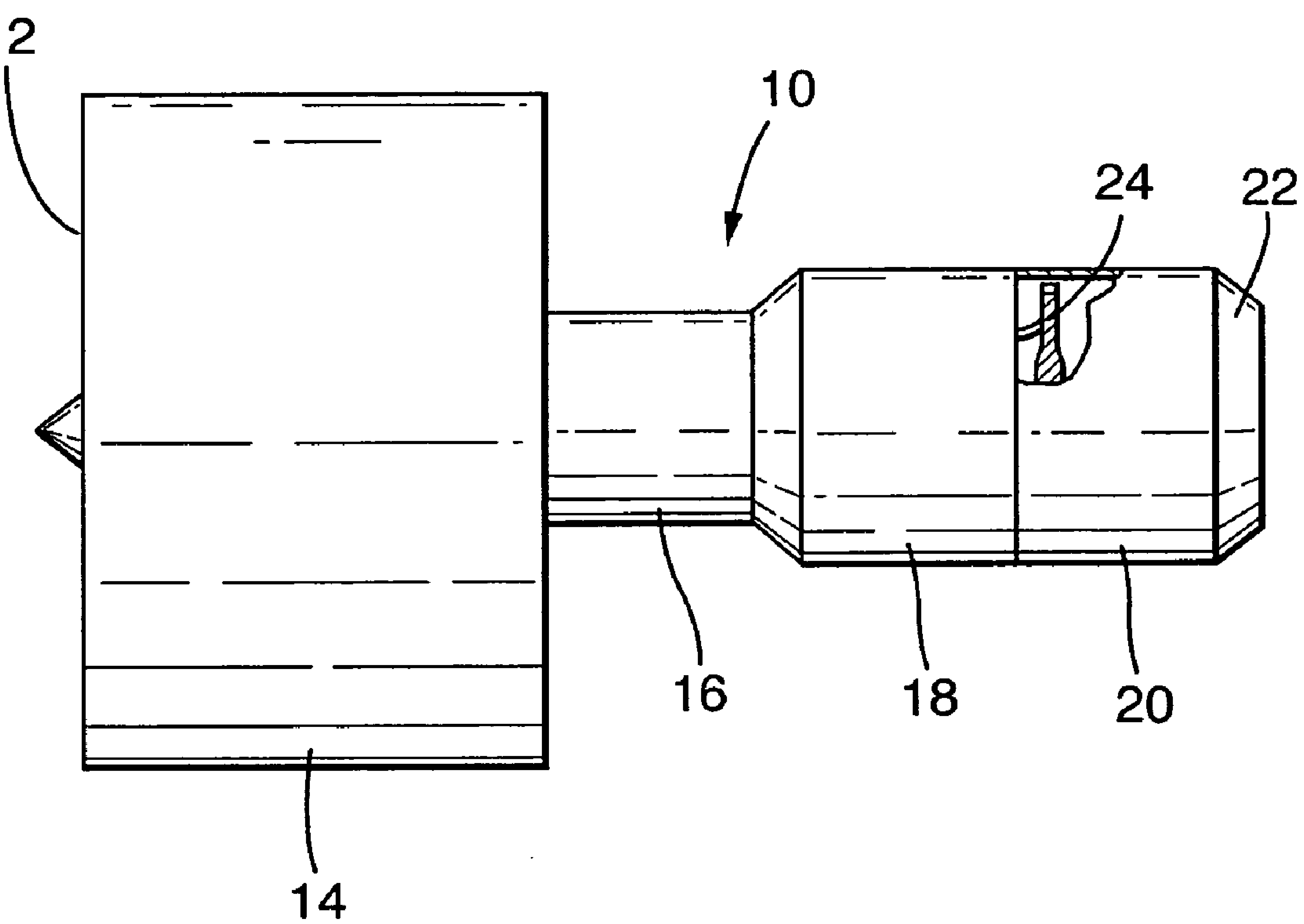
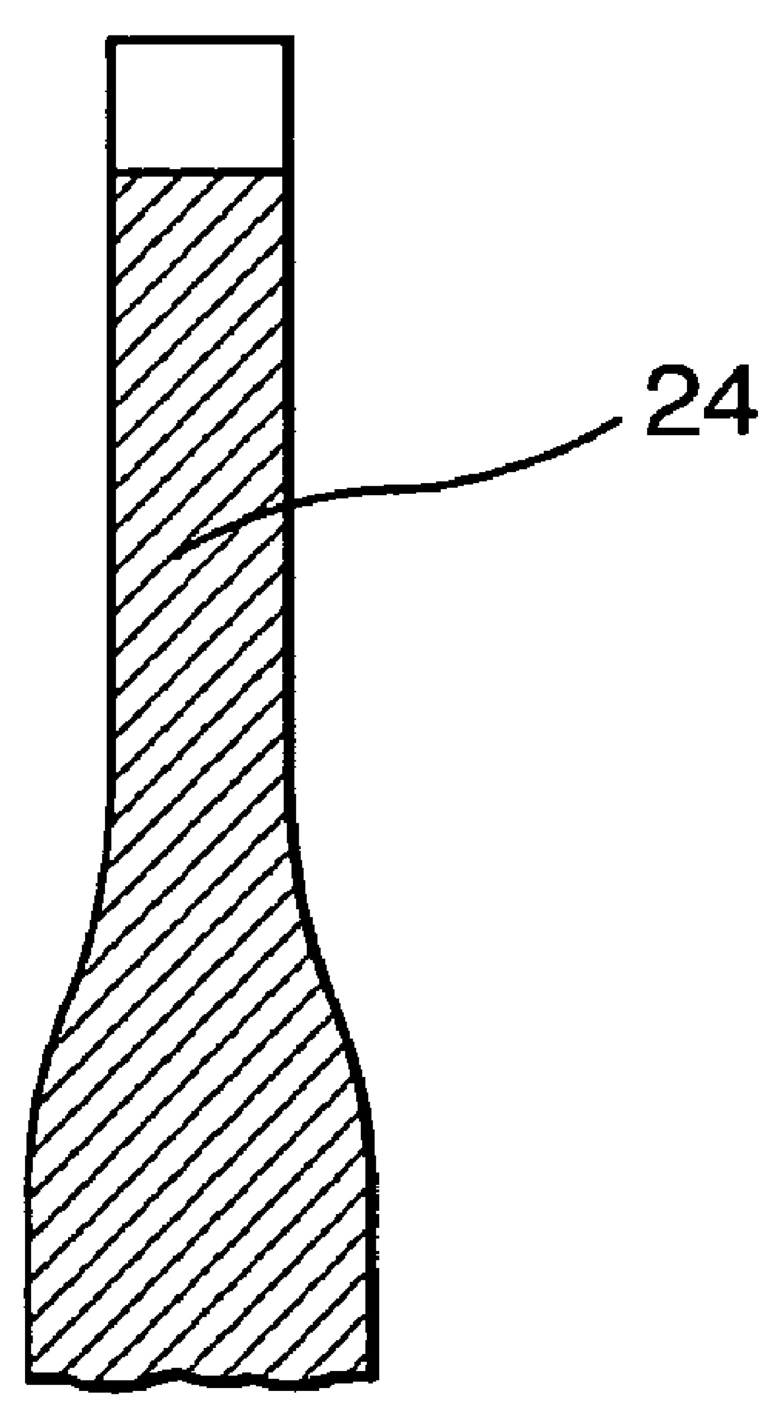


Fig.2.



NICKEL BASE SUPER ALLOY

[0001] The present invention relates to a nickel base superalloy.

[0002] It is proposed to add cobalt and titanium to Udimet 720Li as disclosed in "Microstructure and Yield Strength of Udimet 720Li Alloyed with Co-16.9 wt % Ti" C Cui, Y Gu, H Harada and A Sato, Metallurgical and Materials Transactions A, Volume 36A, November 2005, pp2921-2927 and "New Ni—Co-Base Disk Superalloys with Higher Strength and Creep Resistance" Y Gu, H Harada, C Cui, D Ping, A Sato and J Fujioka, Scripta Materialia, Volume 55, Issue 9, November 2006, pp815-818.

[0003] The addition of cobalt and titanium to Udimet 720Li increases the temperature and flow stress capability. It is known that cobalt modifies the solubility of the gamma prime phase in the gamma phase, raises the solidus temperature, lowers the gamma prime solvus temperature and lowers the stacking fault energy. The addition of titanium increases the volume fraction of gamma prime phase by forming Co_3Ti with the same crystal structure as Ni_3Al.

[0004] The addition of higher levels of cobalt and titanium to Udimet 720Li make the superalloy more prone to macro segregation during the casting process, suggesting a powder metallurgy process is more suitable for manufacturing large articles and limiting segregation to the nano-scale. The addition of large amounts of titanium to a nickel base superalloy, when coupled with high levels of cobalt, make it liable to the formation of Topologically Close Packed (TCP) phases, in particular the eta phase, a phenomonen excarbated due to cast and wrought processing. The TCP phases are detrimental to mechanical properties of the superalloy article. The TCP phases form during the initial processing, ageing heat treatment and/or during long-term exposure to heat in service. The papers mentioned above only consider the production of the superalloy using cast and wrought processing.

[0005] Nickel base superalloys containing high levels of refractory elements such as molybdenum, niobium, tantalum, tungsten etc, are difficult to process by conventional cast and wrought processing routes. This is due to the macro-segregation that occurs between atomic species, including aluminium and titanium, leading to variable microstructures and mechanical properties. Udimet 720Li is produced by the cast and wrought processing route, although it may be produced in a powder metallurgy form. Processing by the powder metallurgy route, although considered more expensive, allows for a greater degree of alloying additions to be made and eliminates macro-segregation, limiting segregation to the micro/nano-scale.

[0006] Accordingly the present invention seeks to provide a novel nickel base superalloy.

[0007] Accordingly the present invention provides a nickel base superalloy consisting of 23 to 40 wt % cobalt, 10 to 15 wt % chromium, 3 to 6 wt % molybdenum, 0 to 5 wt % tungsten, 2.5 to 4 wt % aluminium, 3.4 to 5 wt % titanium, 1.35 to 2.5 wt % tantalum, 0 to 2 wt % niobium, 0.5 to 1 wt % hafnium, 0 to 0.1 wt % zirconium, 0.01 to 0.05 wt % carbon, 0.01 to 0.05 wt % boron, 0 to 2 wt % silicon and the balance nickel plus incidental impurities.

[0008] Preferably the present invention provides a nickel base superalloy consisting of 23.5 to 30 wt % cobalt, 10 to 15 wt % chromium, 3 to 6 wt % molybdenum, 0 to 5 wt % tungsten, 2.5 to 4 wt % aluminium, 3.4 to 5 wt % titanium, 1.35 to 2.5 wt % tantalum, 0 to 2 wt % niobium, 0.5 to 1 wt % hafnium, 0 to 0.1 wt % zirconium, 0.01 to 0.05 wt % carbon, 0.01 to 0.05 wt % boron, 0 to 1 wt % silicon and the balance nickel plus incidental impurities.

[0009] Preferably the present invention provides a nickel base superalloy consisting of 23.5 to 28 wt % cobalt, 10 to 15 wt % chromium, 3 to 6 wt % molybdenum, 0 to 5 wt % tungsten, 2.5 to 4 wt % aluminium, 3.4 to 5 wt % titanium, 1.35 to 2.5 wt % tantalum, 0.5 to 1 wt % hafnium, 0 to 0.1 wt % zirconium, 0.01 to 0.05 wt % carbon, 0.01 to 0.05 wt % boron, 0 to 0.2 wt % silicon and the balance nickel plus incidental impurities.

[0010] Preferably the present invention provides a nickel base superalloy consisting of 24 to 27 wt % cobalt, 14.5 wt % chromium, 5 wt % molybdenum, 3 wt % aluminium, 4.5 wt % titanium, 2 wt % tantalum, 0.55 wt % hafnium, 0.06 wt % zirconium, 0.027 to 0.03 wt % carbon, 0.015 to 0.02 wt % boron, 0 to 0.2 wt % silicon and the balance nickel plus incidental impurities.

[0011] The present invention provides a nickel base superalloy consisting of 46.34 wt % nickel, 24 wt % cobalt, 14.5 wt % chromium, 5 wt % molybdenum, 3 wt % aluminium, 4.5 wt % titanium, 2 wt % tantalum, 0.55 wt % hafnium, 0.06 wt % zirconium, 0.03 wt % carbon, 0.02 wt % boron.

[0012] The present invention provides a nickel base superalloy consisting of 43.35 wt % nickel, 27 wt % cobalt, 14.5 wt % chromium, 5 wt % molybdenum, 3 wt % aluminium, 4.5 wt % titanium, 2 wt % tantalum, 0.55 wt % hafnium, 0.06 wt % zirconium, 0.027 wt % carbon, 0.015 wt % boron.

[0013] The present invention also provides a nickel base superalloy consisting of 24 to 27 wt % cobalt, 10 to 15 wt % chromium, 3 to 6 wt % molybdenum, 0 to 5 wt % tungsten, 2.5 to 4 wt % aluminium, 3.4 to 5 wt % titanium, 1.35 to 2.5 wt % tantalum, 0.5 to 1 wt % hafnium, 0 to 0.1 wt % zirconium, 0.01 to 0.05 wt % carbon, 0.01 to 0.05 wt % boron, 0 to 0.2 wt % silicon and the balance nickel plus incidental impurities.

[0014] Preferably the precipitated gamma prime phase comprises a $(Ni/Co)_3$ (Al/Ti/Ta).

[0015] Alternatively the precipitated gamma prime phase comprises a $(Ni/Co)_3$ (Al/Ti/Ta/Nb).

[0016] Preferably the precipitated gamma prime phases comprises Co_3Ta and/or Co_3Ti.

[0017] The present invention will be more fully described by way of example with reference to the accompanying drawings in which:—

[0018] FIG. **1** shows a turbofan gas turbine engine having a turbine disc comprising a nickel base superalloy according to the present invention.

[0019] FIG. **2** shows an enlarged view of turbine disc comprising a nickel base superalloy according to the present invention.

[0020] A turbofan gas turbine engine **10**, as shown in FIG. **1**, comprises in axial flow series an inlet **12**, a fan section **14**, a compressor section **16**, a combustion section **18**, a turbine section **20** and an exhaust **22**. The turbofan gas turbine engine **10** is quite conventional and will not be discussed further.

[0021] The turbine section **20** comprises one or more turbine discs **24**, shown more clearly in FIG. **2**, comprising a nickel base superalloy according to the present invention. The present invention seeks to provide a nickel base superalloy which is a high strength alloy capable of use for applications at 750° C. and above and which is stable.

[0022] The nickel base superalloy consists of 23 to 40 wt % cobalt, 10 to 15 wt % chromium, 3 to 6 wt % molybdenum, 0 to 5 wt % tungsten, 2.5 to 4 wt % aluminium, 3.4 to 5 wt % titanium, 1.35 to 2.5 wt % tantalum, 0 to 2 wt % niobium, 0.5 to 1 wt % hafnium, 0 to 0.1 wt % zirconium, 0.01 to 0.05 wt % carbon, 0.01 to 0.05 wt % boron, 0 to 2 wt % silicon and the balance nickel plus incidental impurities.

[0023] Preferably the nickel base superalloy consists of 23.5 to 30 wt % cobalt, 10 to 15 wt % chromium, 3 to 6 wt % molybdenum, 0 to 5 wt % tungsten, 2.5 to 4 wt % aluminium, 3.4 to 5 wt % titanium, 1.35 to 2.5 wt % tantalum, 0 to 2 wt % niobium, 0.5 to 1 wt % hafnium, 0 to 0.1 wt % zirconium, 0.01 to 0.05 wt % carbon, 0.01 to 0.05 wt % boron, 0 to 1 wt % silicon and the balance nickel plus incidental impurities.

[0024] More preferably the nickel base superalloy consists of 23.5 to 28 wt % cobalt, 10 to 15 wt % chromium, 3 to 6 wt % molybdenum, 0 to 5 wt % tungsten, 2.5 to 4 wt % aluminium, 3.4 to 5 wt % titanium, 1.35 to 2.5 wt % tantalum, 0.5 to 1 wt % hafnium, 0 to 0.1 wt % zirconium, 0.01 to 0.05 wt % carbon, 0.01 to 0.05 wt % boron, 0 to 0.2 wt % silicon and the balance nickel plus incidental impurities.

[0025] More preferably the nickel base superalloy consists of 24 to 27 wt % cobalt, 14.5 wt % chromium, 5 wt % molybdenum, 3 wt % aluminium, 4.5 wt % titanium, 2 wt % tantalum, 0.55 wt % hafnium, 0.06 wt % zirconium, 0.027 to 0.03 wt % carbon, 0.015 to 0.02 wt % boron, 0 to 0.2 wt % silicon and the balance nickel plus incidental impurities.

[0026] One preferred nickel base superalloy consists of 46.34 wt % nickel, 24 wt % cobalt, 14.5 wt % chromium, 5 wt % molybdenum, 3 wt % aluminium, 4.5 wt % titanium, 2 wt % tantalum, 0.55 wt % hafnium, 0.06 wt % zirconium, 0.03 wt % carbon, 0.02 wt % boron.

[0027] Another preferred nickel base superalloy consists of 43.35 wt % nickel, 27 wt % cobalt, 14.5 wt % chromium, 5 wt % molybdenum, 3 wt % aluminium, 4.5 wt % titanium, 2 wt % tantalum, 0.55 wt % hafnium, 0.06 wt % zirconium, 0.027 wt % carbon, 0.015 wt % boron.

[0028] The present invention also provides a nickel base superalloy consisting of 24 to 27 wt % cobalt, 10 to 15 wt % chromium, 3 to 6 wt % molybdenum, 0 to 5 wt % tungsten, 2.5 to 4 wt % aluminium, 3.4 to 5 wt % titanium, 1.35 to 2.5 wt % tantalum, 0.5 to 1 wt % hafnium, 0 to 0.1 wt % zirconium, 0.01 to 0.05 wt % carbon, 0.01 to 0.05 wt % boron, 0 to 0.2 wt % silicon and the balance nickel plus incidental impurities.

[0029] The starting chemistry for a nickel base superalloy according to the present invention is RR1000 nickel base superalloy. The RR1000 nickel base superalloy is a gamma/gamma prime strengthened superalloy, which has a gamma prime composition of Ni_3 (Al/Ti/Ta/Hf) and an increased volume fraction of gamma prime over Udimet 720Li. The addition of cobalt and titanium to the RR1000 nickel base superalloy increases the gamma prime volume fraction further and changes the gamma prime chemistry to $(Ni/Co)_3$ (Al/Ti/Ta). In addition there is precipitation of a Co_3Ta phase and/or Co_3Ti phase. Alternatively cobalt and titanium may be added to other advanced nickel base superalloys, e.g. Rene95, ME3, Alloy10 or LSHR, to provide similar nickel base superalloys. In the case with nickel base superalloys containing niobium the gamma prime chemistry changes to $(Ni/Co)_3$ (Al/Ti/Ta/Nb).

[0030] The nickel base superalloys of the present invention are only capable of processing by the powder metallurgy route due to the high content of refractory elements. This allows for a wider range of elemental additions to be incorporated into the final nickel base superalloy composition.

TABLE 1

wt %	Alloy 720Li	RR1000	Rene95	Rene 88DT	ME3	Alloy 10	LSHR
Ni	bal	bal	bal	bal	bal	bal	bal
Co	15	18.5	8.12	13.1	20.6	17.93	20.8
Cr	16	15	12.94	15.8	13	10.46	12.7
Mo	3	5	3.45	4	3.8	2.52	2.74
W	1.25	0	3.43	3.9	2.1	4.74	4.37
Al	2.5	3	3.42	2	3.4	3.53	3.48
Ti	5	3.6	2.44	3.7	3.7	3.79	3.47
Ta	0	2	0	0	2.4	1.61	1.65
Nb	0	0	3.37	0.7	0	0.97	0
Hf	0	0.5	0	0	0	0	0
Zr	0	0.06	0.05	0.045	0.05	0.07	0.049
C	0.015	0.027	0.07	0.05	0.04	0.027	0.024
B	0.015	0.015	0.012	0.016	0.03	0.028	0.028
Gamma primeformers (Ti + Ta + Al + Nb)	7.5	8.6	9.23	6.4	9.5	9.9	8.6
TCP formers (Mo + Cr + W)	20.25	20	19.82	23.7	18.9	17.72	19.81

[0031] Table 1 shows the compositions of Udimet 720Li and some advanced powder metallurgy nickel base superalloys and shows how the advanced powder metallurgy nickel base superalloys have sought to optimise gamma prime volume fraction. It is clear that the level of the gamma prime forming elements, in terms of at %, is increased as well as the level of tantalum and niobium to change the chemistry of the gamma prime phase precipitated to $(Ni/Co)_3$ (Al/Ti/Ta/Nb).

[0032] Table 2 shows the compositions of alloys according to the present invention and the prior art alloy RR1000.

TABLE 2

wt %	Alloy RR1000	Invention A	Invention B	Broad Range	Preferred Range
Ni	52.3	46.34	43.35	Balance	Balance
Co	18.5	24	27	23 to 40	24 to 27
Cr	15	14.5	14.5	10 to 15	10 to 15
Mo	5	5	5	3 to 6	3 to 6
W	0	0	0	0 to 5	0 to 5

TABLE 2-continued

	Alloy	Invention		Broad	Preferred
wt %	RR1000	A	B	Range	Range
Al	3	3	3	2.5 to 4	2.5 to 4
Ti	3.6	4.5	4.5	3.4 to 5	3.4 to 5
Ta	2	2	2	1.35 to 2.5	1.35 to 2.5
Nb	0	0	0	0 to 2	0
Hf	0.5	0.55	0.55	0.5 to 1	0.5 to 1
Zr	0.06	0.06	0.06	0 to 0.1	0 to 0.1
C	0.027	0.03	0.027	0.01 to 0.05	0.01 to 0.05
B	0.015	0.02	0.015	0.01 to 0.05	0.01 to 0.05
Si	0	0	0	0 to 2	0 to 0.2

[0033] There is a requirement to reduce the levels of TCP phase forming elements, in particular chromium, in order to reduce the propensity for TCP phase formation during long term exposure at high temperatures. There is a requirement to increase the levels of gamma prime forming elements to greater than 12 at %, but increases of gamma prime forming elements above 13 at % are likely to increase the propensity for processing problems, such as forgeability, quench cracking etc. The addition of large amounts of titanium to a nickel base superalloy make it liable to the formation of TCP phases, in particular the eta phase, which is detrimental to the mechanical properties of the nickel base superalloy.

[0034] The advantages of the present invention is that the nickel base superalloy has an increase in the volume fraction of the gamma prime phase, the precipitation of gamma prime phase with a Co_3 (Ta/Nb) chemistry, powder metallurgy processing route eliminates macro-segregation and allows more alloying additions. The nickel base superalloy has lower density than conventional nickel base superalloys due to the increased level of cobalt. The level of gamma prime forming elements is not too high. There is a reduced tendency for formation of TCP phases by control of chromium, titanium and the aluminium to titanium ratio.

[0035] The level of cobalt is determined using the fact that it is known to generate a minimum stacking fault energy promoting planar deformation when there is at least 15 wt % cobalt. Cobalt is also considered to reduce fatigue crack growth rates as less damage accumulation occurs in planar slip, due to the ease of slip reversal. Addition of more than 20 wt % cobalt increases the volume fraction of gamma prime precipitates and substitutes for nickel. Higher levels of cobalt reduce the gamma prime solvus temperature.

[0036] The level of chromium is controlled to balance a requirement for reduced fatigue crack propagation rates, e.g. higher levels of chromium, and greater propensity for TCP phase formation, e.g. lower levels of chromium.

[0037] Molybdenum and tungsten are both beneficial for creep properties. The beneficial effects on tensile strength and ductility at high temperatures through solid solution strengthening are balanced against the propensity to form TCP phases.

[0038] Tantalum is controlled at a level to reduce crack growth and stabilise the MC carbide. Tantalum controls the volume fraction of gamma prime phase with aluminium and titanium.

[0039] Titanium is controlled with levels of tantalum to provide volume fraction of gamma prime phase. Additional titanium lowers the gamma prime solvus temperature. The maximum amount of titanium is controlled to prevent excessive formation of TCP phases.

[0040] Aluminium is controlled with the levels of tantalum and titanium to optimise strength.

[0041] Other elemental additions are niobium, boron, carbon, zirconium, hafnium, rhenium, yttrium and silicon.

[0042] It is preferred that there is no niobium in the nickel base superalloy and/or that there is no tungsten in the nickel base superalloy.

[0043] A feature of the nickel base superalloys according to the present invention is their ability to be processed at temperatures either below or above the gamma prime solvus temperature. Thus, they are capable of being produced in a fine grain size, typically 5 to 10 micrometers, or coarse grain size, typically greater than 30 micrometers.

We claim:

1. A nickel base superalloy consisting of 23 to 40 wt % cobalt, 10 to 15 wt % chromium, 3 to 6 wt % molybdenum, 0 to 5 wt % tungsten, 2.5 to 4 wt % aluminium, 3.4 to 5 wt % titanium, 1.35 to 2.5 wt % tantalum, 0 to 2 wt % niobium, 0.5 to 1 wt % hafnium, 0 to 0.1 wt % zirconium, 0.01 to 0.05 wt % carbon, 0.01 to 0.05 wt % boron, 0 to 2 wt % silicon and the balance nickel plus incidental impurities.

2. A nickel base superalloy as claimed in claim **1** consisting of 23.5 to 30 wt % cobalt, 10 to 15 wt % chromium, 3 to 6 wt % molybdenum, 0 to 5 wt % tungsten, 2.5 to 4 wt % aluminium, 3.4 to 5 wt % titanium, 1.35 to 2.5 wt % tantalum, 0 to 2 wt % niobium, 0.5 to 1 wt % hafnium, 0 to 0.1 wt % zirconium, 0.01 to 0.05 wt % carbon, 0.01 to 0.05 wt % boron, 0 to 1 wt % silicon and the balance nickel plus incidental impurities.

3. A nickel base superalloy as claimed in claim **1** consisting of 23.5 to 28 wt % cobalt, 10 to 15 wt % chromium, 3 to 6 wt % molybdenum, 0 to 5 wt % tungsten, 2.5 to 4 wt % aluminium, 3.4 to 5 wt % titanium, 1.35 to 2.5 wt % tantalum, 0.5 to 1 wt % hafnium, 0 to 0.1 wt % zirconium, 0.01 to 0.05 wt % carbon, 0.01 to 0.05 wt % boron, 0 to 0.2 wt % silicon and the balance nickel plus incidental impurities.

4. A nickel base superalloy as claimed in claim **3** consisting of 24 to 27 wt % cobalt, 14.5 wt % chromium, 5 wt % molybdenum, 3 wt % aluminium, 4.5 wt % titanium, 2 wt % tantalum, 0.55 wt % hafnium, 0.06 wt % zirconium, 0.027 to 0.03 wt % carbon, 0.015 to 0.02 wt % boron, 0 to 0.2 wt % silicon and the balance nickel plus incidental impurities.

5. A nickel base superalloy as claimed in claim **4** consisting of 46.34 wt % nickel, 24 wt % cobalt, 14.5 wt % chromium, 5 wt % molybdenum, 3 wt % aluminium, 4.5 wt % titanium, 2 wt % tantalum, 0.55 wt % hafnium, 0.06 wt % zirconium, 0.03 wt % carbon, 0.02 wt % boron.

6. A nickel base superalloy as claimed in claim **4** consisting of 43.35 wt % nickel, 27 wt % cobalt, 14.5 wt % chromium, 5 wt % molybdenum, 3 wt % aluminium, 4.5 wt % titanium, 2 wt % tantalum, 0.55 wt % hafnium, 0.06 wt % zirconium, 0.027 wt % carbon, 0.015 wt % boron.

7. A nickel base superalloy as claimed in claim **1** consisting of 24 to 27 wt % cobalt, 10 to 15 wt % chromium, 3 to 6 wt % molybdenum, 0 to 5 wt % tungsten, 2.5 to 4 wt % aluminium, 2.4 to 5 wt % titanium, 1.35 to 2.5 wt % tantalum, 0.5 to 1 wt % hafnium, 0 to 0.1 wt % zirconium, 0.01 to 0.05 wt % carbon, 0.01 to 0.05 wt % boron, 0 to 0.2 wt % silicon and the balance nickel plus incidental impurities.

8. A nickel base superalloy as claimed in claim **1** wherein the precipitated gamma prime phase comprises a $(Ni/Co)_3$ (Al/Ti/Ta).

9. A nickel base superalloy as claimed in claim **1** wherein the precipitated gamma prime phase comprises a $(Ni/Co)_3(Al/Ti/Ta/Nb)$.

10. A nickel base superalloy as claimed in claim **1** wherein the precipitated gamma prime phases comprises Co_3Ta and/or Co_3Ti.

11. A gas turbine engine component comprising a nickel base superalloy as claimed in claim **1**.

12. A gas turbine engine component as claimed in claim **11** wherein the component is a turbine disc or a compressor disc.

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