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(19) **United States**(12) **Patent Application Publication**  
**MAKINENI et al.**(10) **Pub. No.: US 2017/0037498 A1**(43) **Pub. Date: Feb. 9, 2017**(54) **GAMMA - GAMMA PRIME  
STRENGTHENED TUNGSTEN FREE  
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CPC ..... **C22F 1/10** (2013.01); **C22C 19/07**  
(2013.01); **C22F 1/002** (2013.01)(57) **ABSTRACT**

Embodiments herein present the invention of a class of Tungsten (W) free Cobalt based ( $\gamma$ - $\gamma'$ ) superalloys with the basic chemical composition comprising in % by weight: 0.5 to 10 Aluminium (Al) and 1 to 15 Molybdenum (Mo) with at least one or both of 0.5 to 12 Niobium (Nb) and 0.5 to 12 Tantalum (Ta), with the remainder being Cobalt (Co). Some part of the cobalt can be replaced by nickel (50% or less). In Nickel added alloys, some part of either cobalt or nickel can be replaced by at least one among the transition metal selected from the group consisting of 10% or less Iridium, 10% or less Platinum, 10% or less Palladium, 15% or less Chromium and combination thereof. Again in nickel added alloys, further addition of at least one among the transition metals zirconium (5% or less), hafnium (5% or less), vanadium (5% or less), titanium (5% or less), and yttrium (5% or less), boron (2% or less), carbon (2% or less), rhenium (10% or less), ruthenium (5% or less) for further fine tune the solvus temperature, volume fraction of  $\gamma'$  and creep properties.

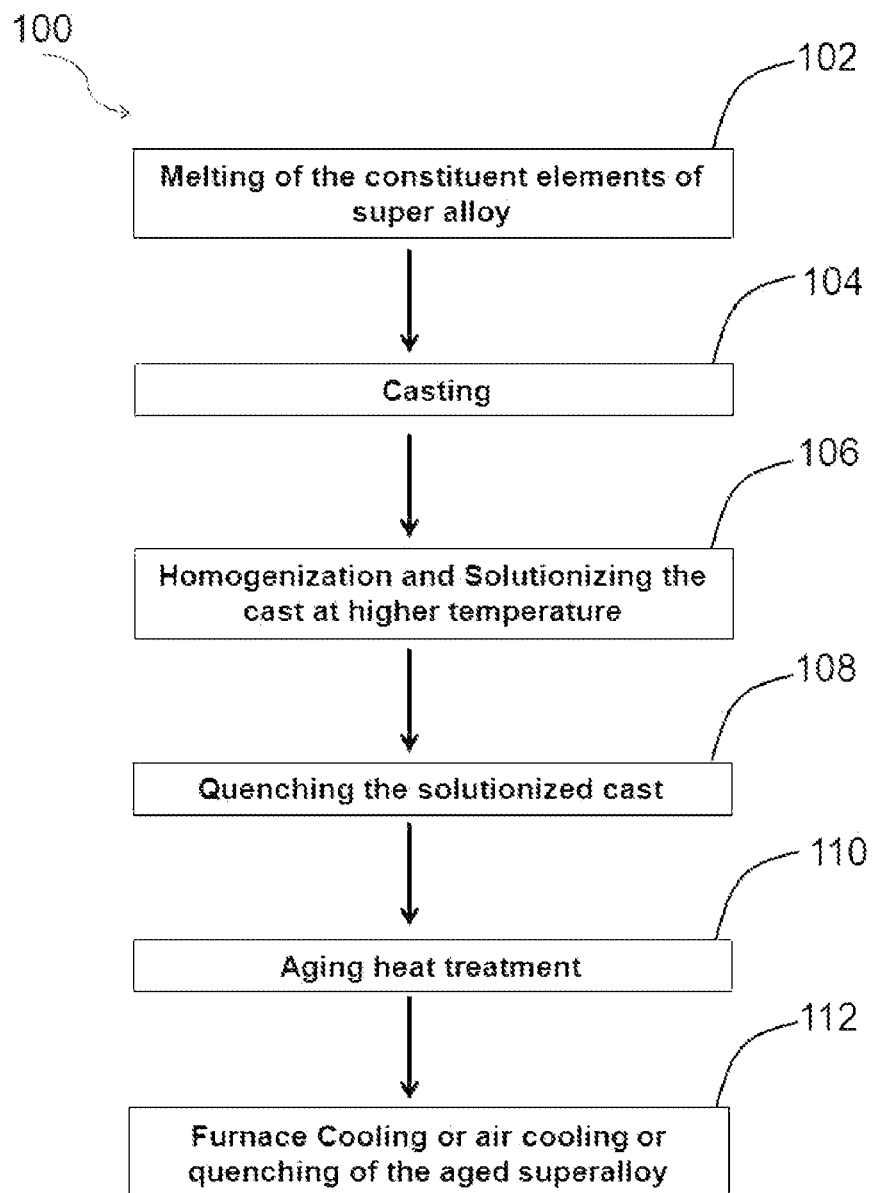


Figure 1

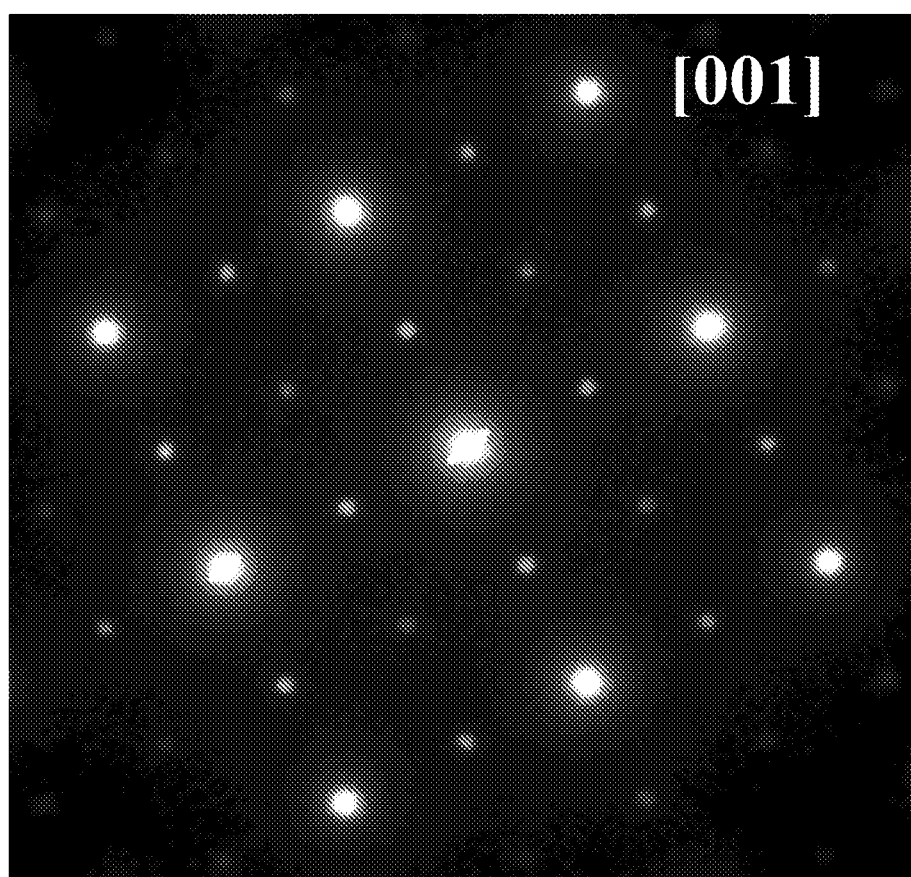


Figure 2

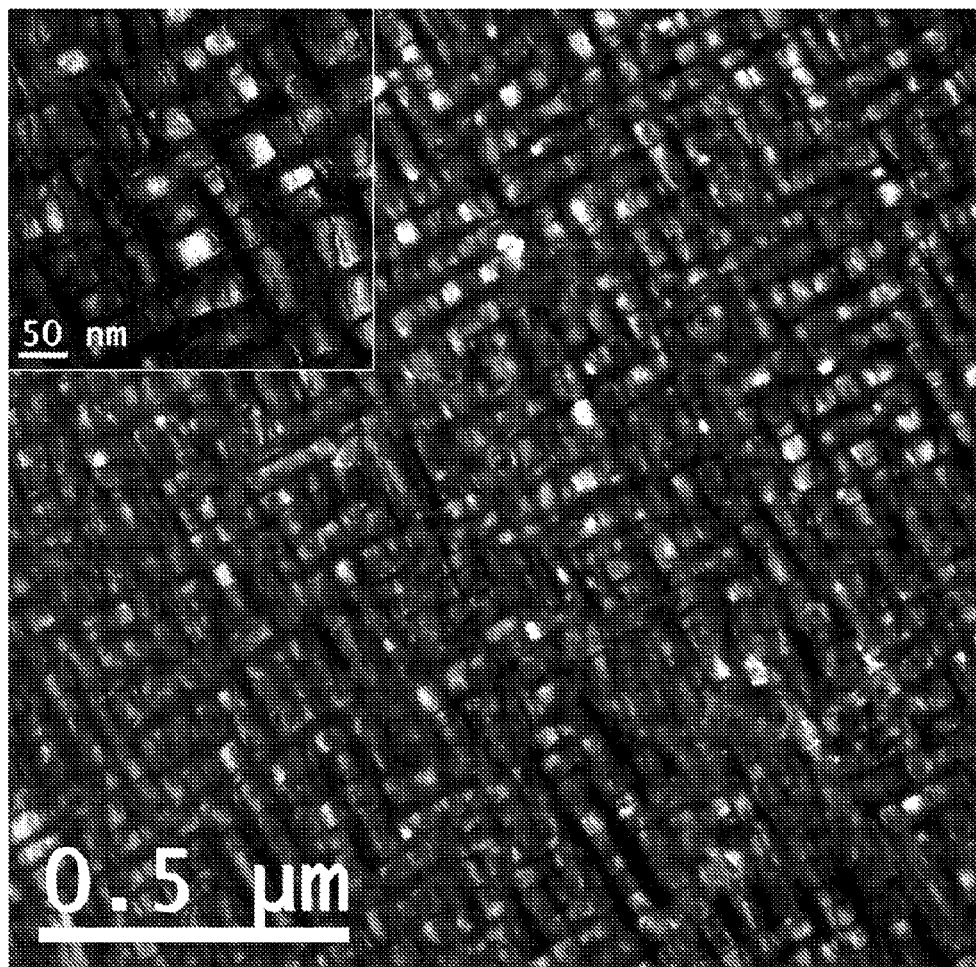


Figure 3

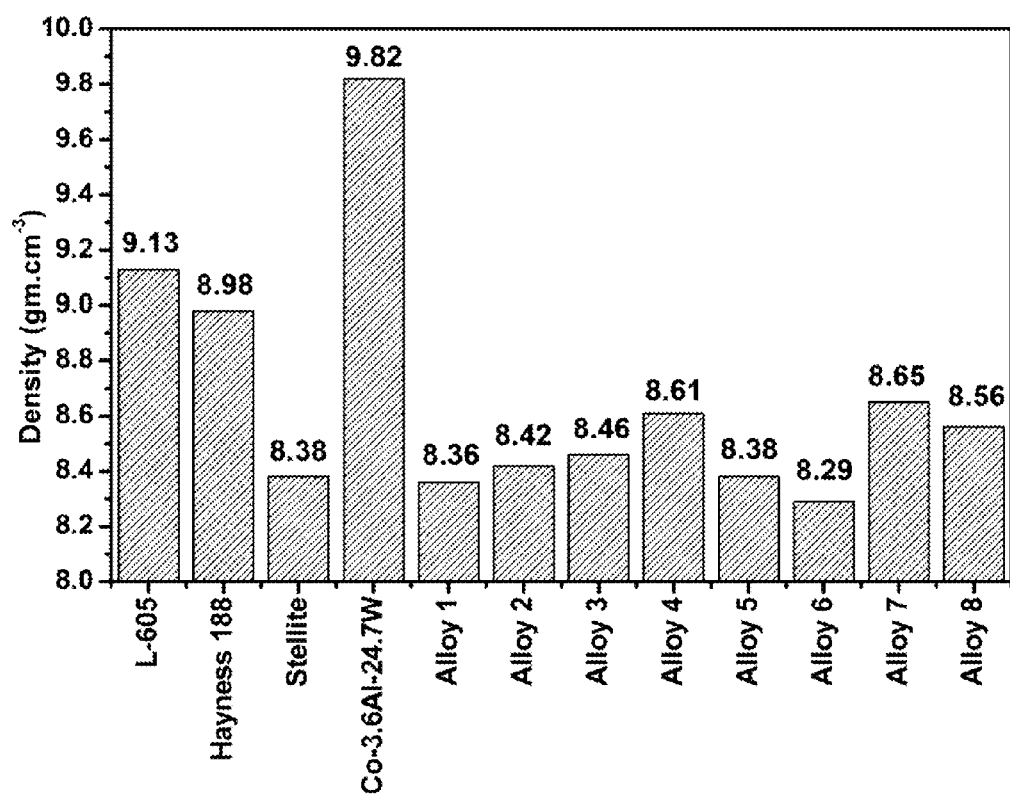


Figure 4

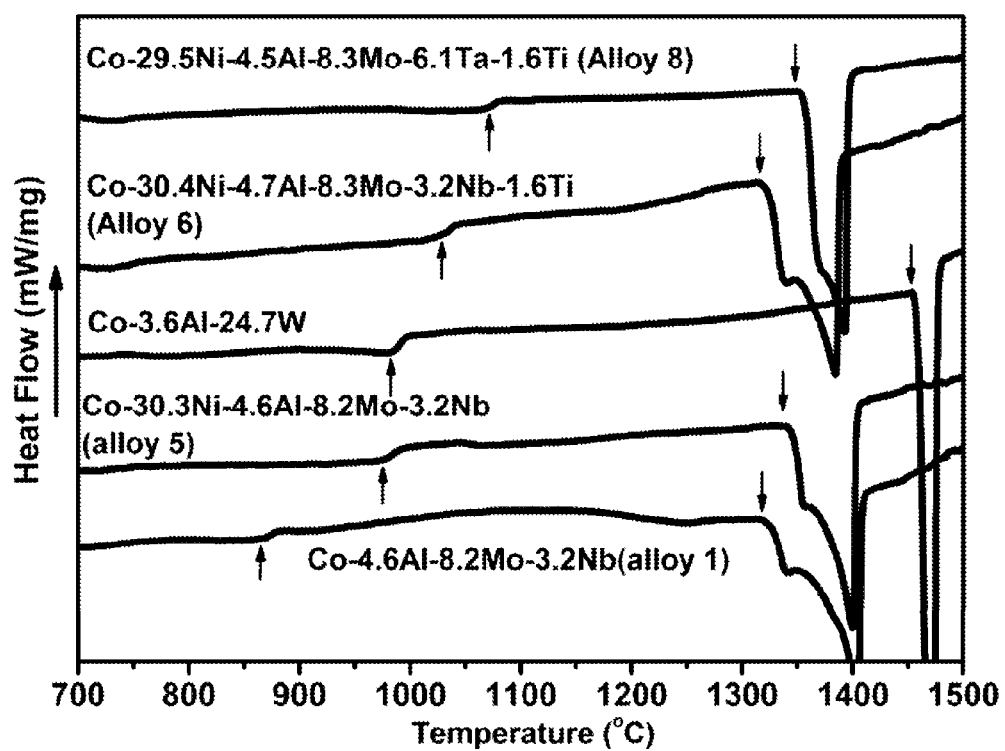


Figure 5

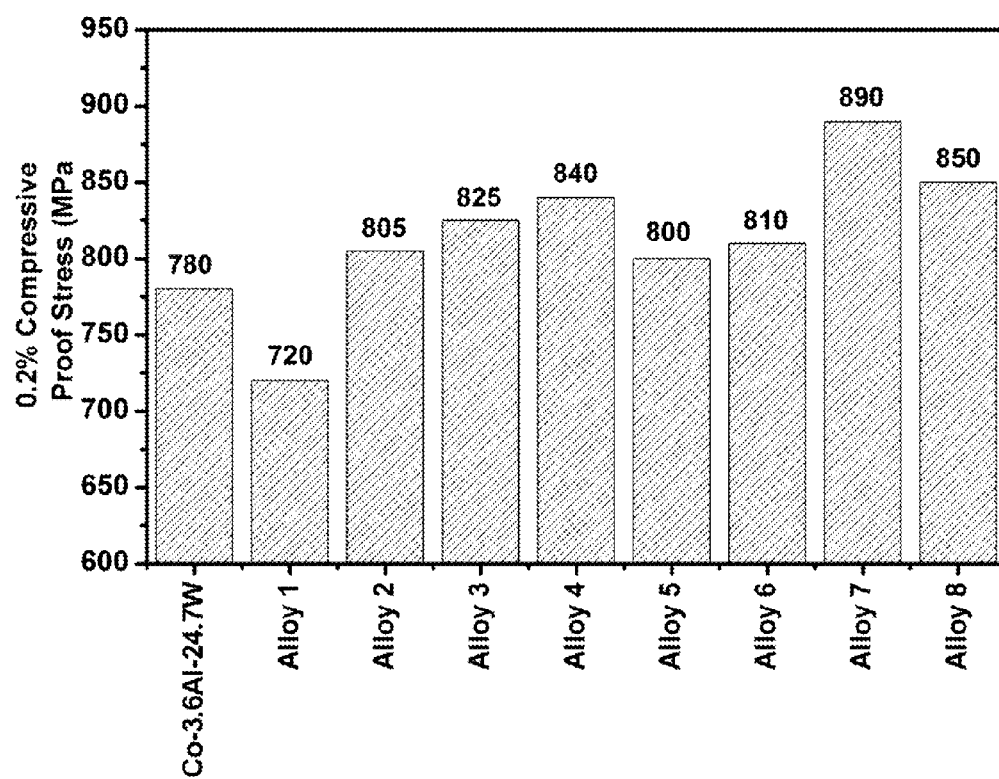


Figure 6

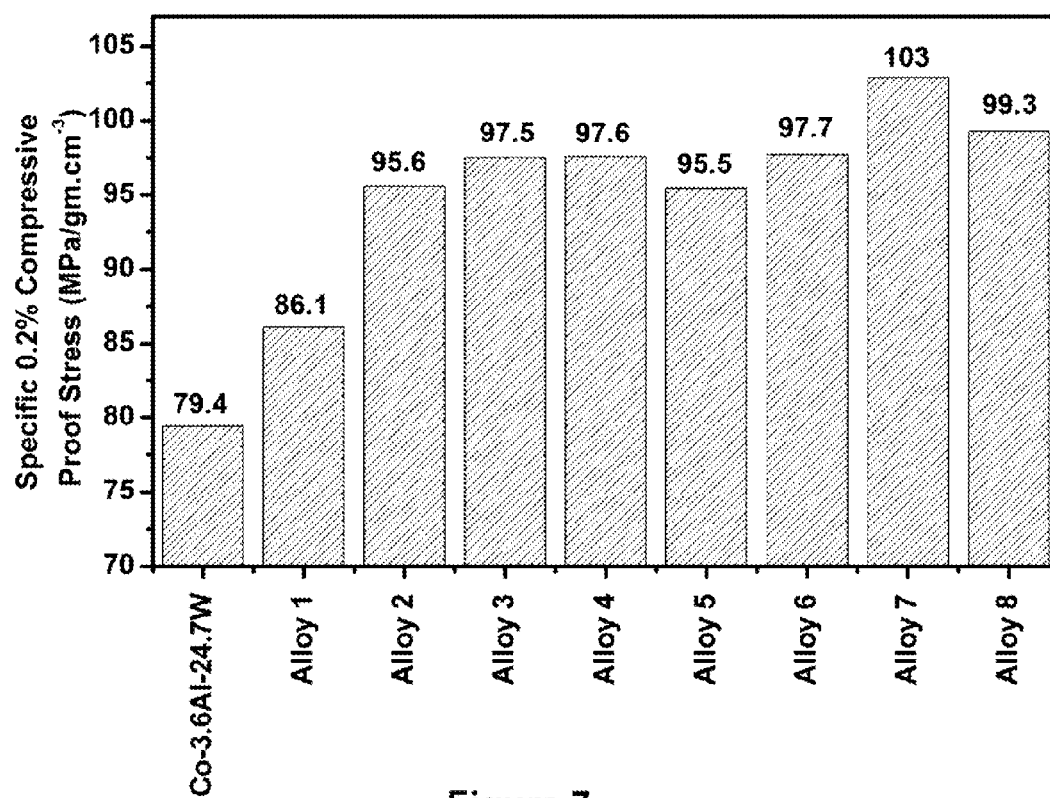


Figure 7

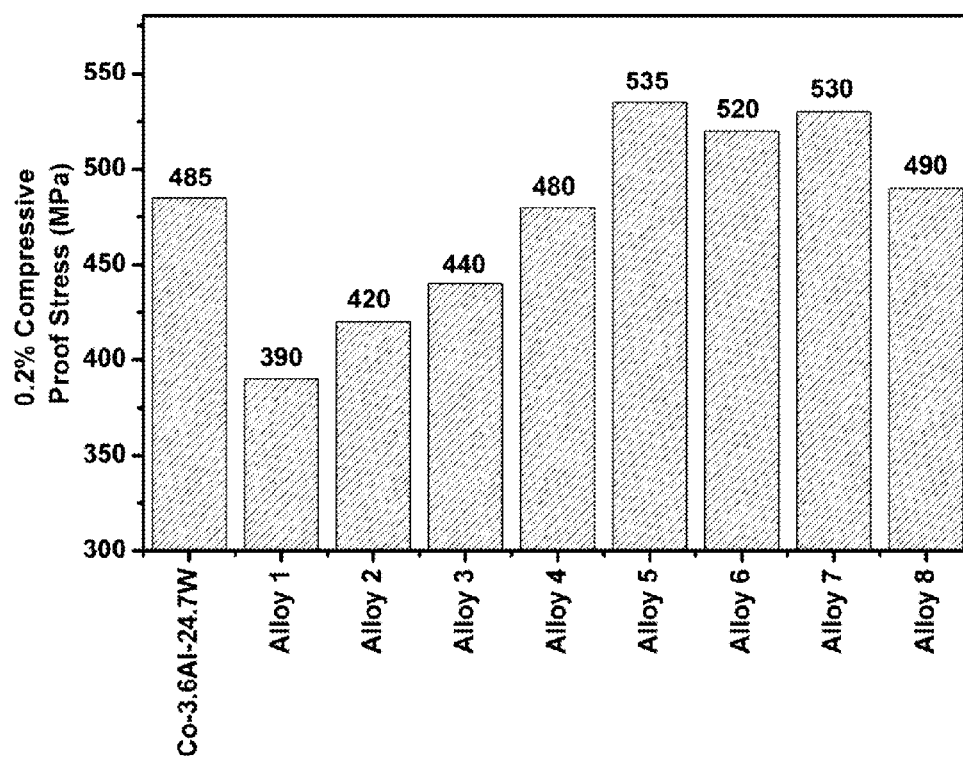


Figure 8

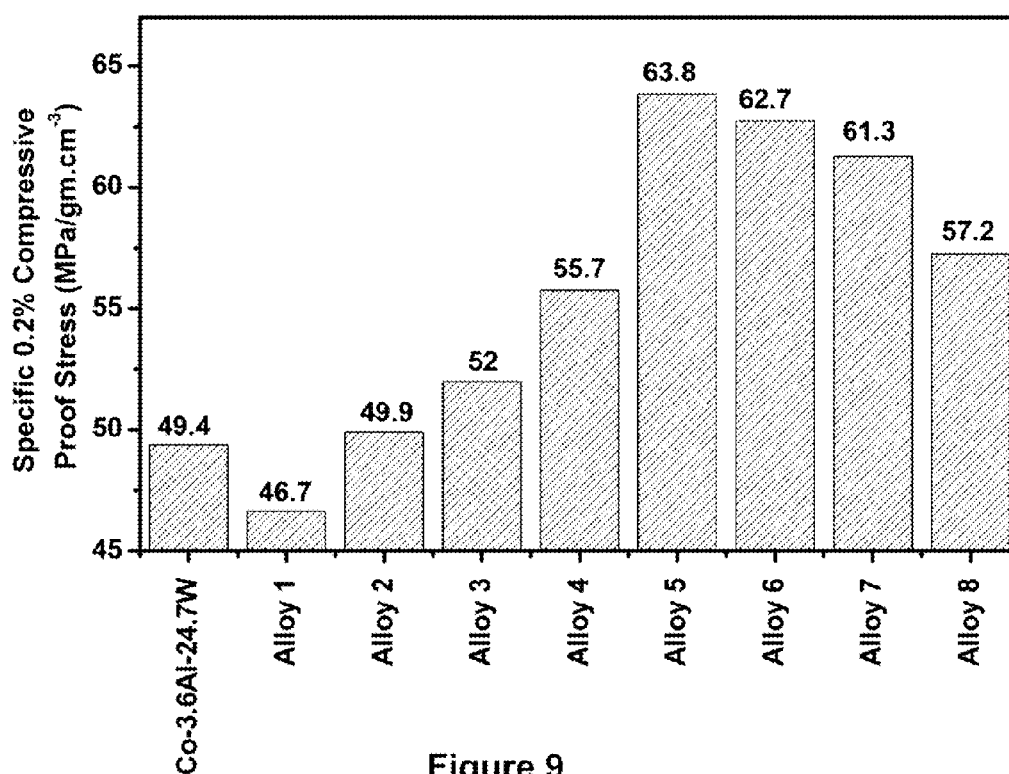


Figure 9

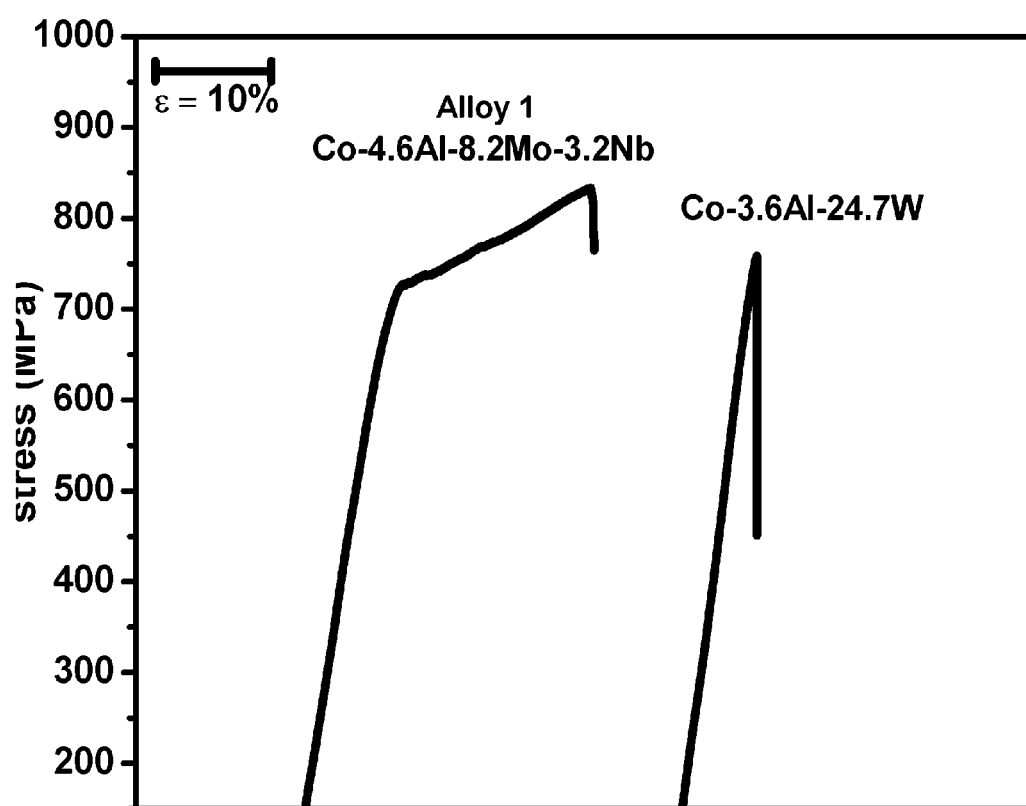


Figure 10

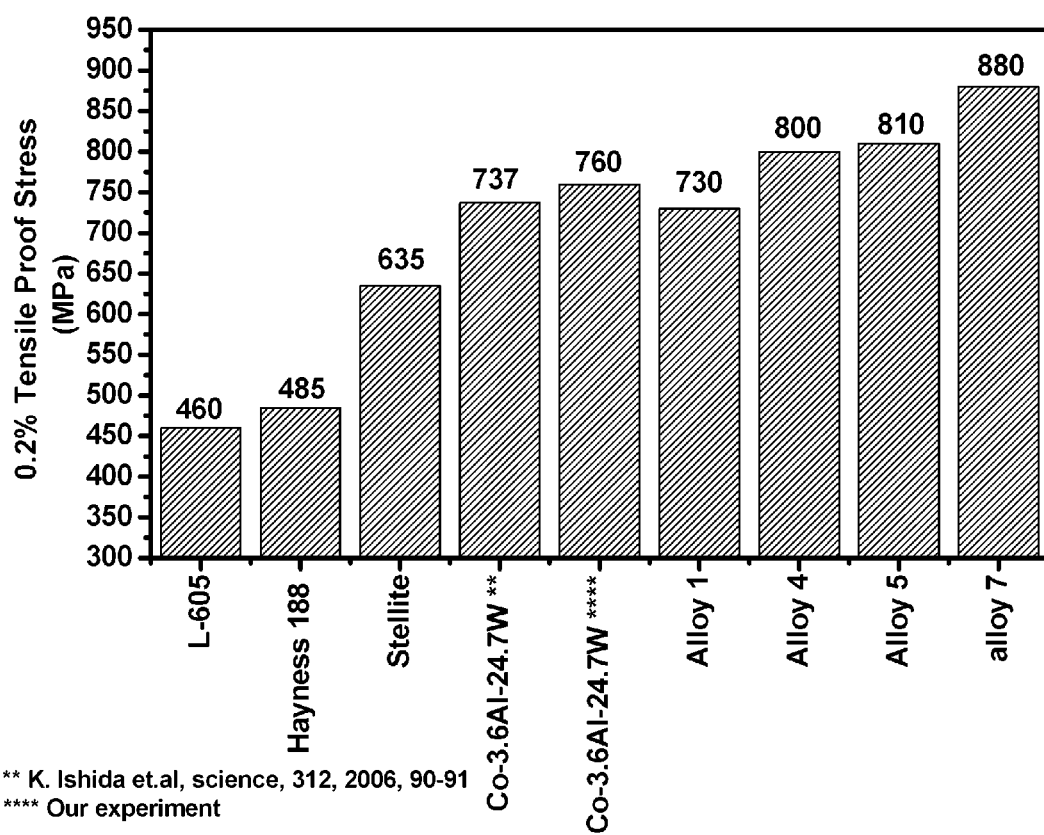


Figure 11

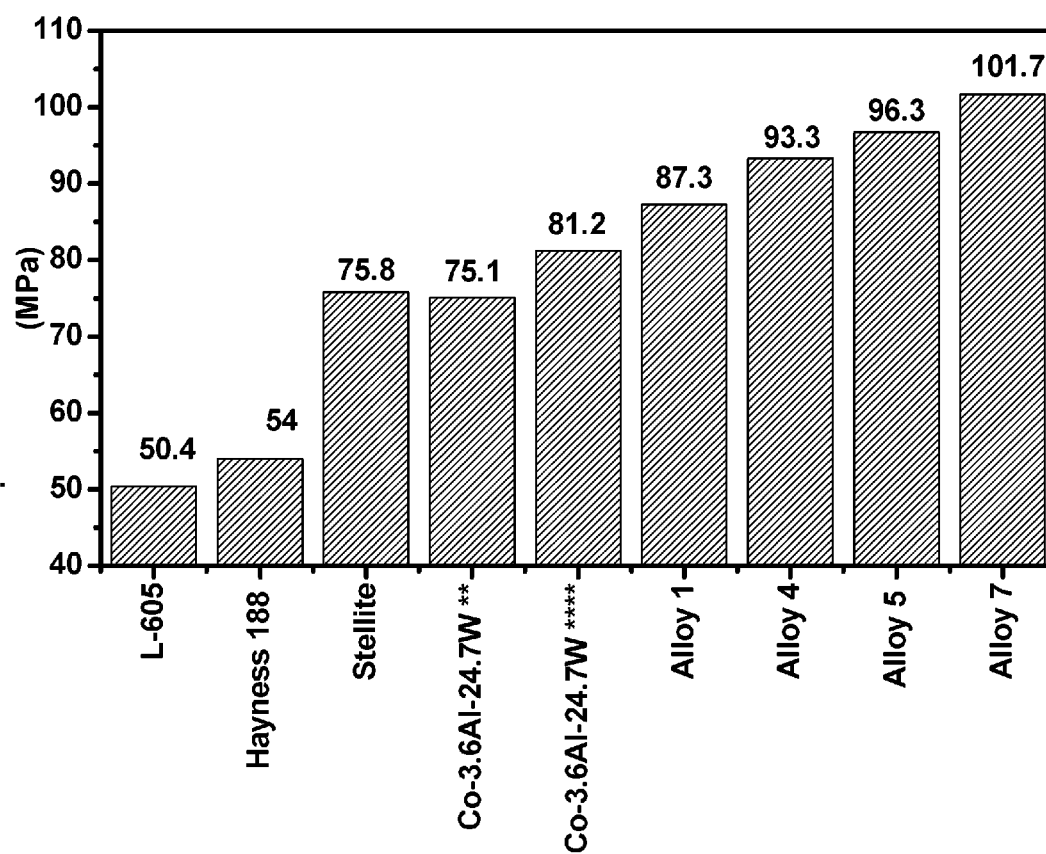


Figure 12

# **GAMMA - GAMMA PRIME STRENGTHENED TUNGSTEN FREE COBALT-BASED SUPERALLOY**

## **TECHNICAL FIELD**

**[0001]** The present disclosure generally relates to the field of materials science, and more specifically to a cobalt-base superalloy with a  $\gamma/\gamma'$  microstructure. Embodiments herein particularly relate to a composition of high temperature resistant, tungsten free cobalt based superalloy.

## **BACKGROUND**

**[0002]** The background description includes information that may be useful in understanding the embodiments herein. It is not an admission that any of the information provided herein is prior art or relevant to the presently claimed embodiments, or that any publication specifically or implicitly referenced is prior art.

**[0003]** For a vast majority of materials, the yield strength decreases with increasing temperature. As is obvious, a decrease in yield strength at high temperature becomes a limiting factor for use of such materials for high temperature applications. However, certain alloys such as superalloys (nickel, iron and cobalt based) exhibit superior mechanical properties even at high temperatures. These are a class of high performance alloys that exhibit excellent mechanical strength and resistance to creep at high temperatures: good surface stability; and corrosion and oxidation resistance. Their development has been driven primarily by aerospace and power industries on account of their requirements of materials for manufacture of blades of gas or marine turbines and hot sections of jet engines that operate at high temperatures.

**[0004]** Superalloys are based on Group VIII elements of periodic table and usually consist of various combinations of Iron (Fe), Nickel (Ni), Cobalt (Co), and Chromium (Cr), as well as lesser amounts of Tungsten (W), Molybdenum (Mo), Tantalum (Ta), Niobium (Nb), Titanium (Ti), and Aluminum (Al). Three major classes of superalloys based on their base alloying element include nickel (Ni), cobalt (Co), or nickel-iron. Some of the well-known superalloys developed include Hastelloy, Inconel (e.g. IN100, IN600, IN713), Waspaloy, Rene alloys (e.g. Rene 41, Rene 80, Rene 95, Rene N5), Haynes alloys, Incoloy, MP98T, disk alloys such as TMS alloys and cast equiaxed, directionally solidified and single crystal alloys such as CMSX (e.g. CMSX-4).

**[0005]** In a class of nickel based superalloys the strength is achieved as a result of precipitation during which strengthening, intermetallic constituent  $\text{Ni}_3(\text{Al}, \text{Ti})$  is formed. This intermetallic phase is a primary strengthening phase in these superalloys and is known as gamma prime (hereafter referred as  $\gamma'$ ), which is present in a continuous matrix called as gamma (hereafter referred as  $\gamma$ ). Typically,  $\gamma$  is a face-centered-cubic (FCC) structure that usually contains a high percentage of solid-solution elements such as Co, Cr, Mo, and W. These  $\gamma'$  precipitates, cuboidal in shape, have  $\text{L1}_2$  structure which is coherent with the  $\gamma$ -Ni matrix with a lattice mismatch less than 0.5% at the interface making the interfacial energy very low and hence increasing microstructural stability for long time exposure at high temperature.

**[0006]** Since Co has a higher melting point metal than nickel, superalloys are also developed with Co as the matrix.

Nickel based alloys exist in FCC form throughout the temperature range of application, while Co transforms to hexagonal close pack (HCP) structure at room temperature. Cobalt based superalloys, such as Vitallium (Co—Cr—Mo) and Co—Ti alloys are biocompatible, and hence are used for orthopaedic implants because of their extremely high corrosive wear resistance. Alloys such as Co—Cr—W—C (Stellite, Hayness) are used where both high temperature strength and corrosion resistance is required such as valves for IC engines. In these alloys the strengthening comes from the solid solution and metal carbides. Carbon, added at levels of 0.05-0.2%, combines with reactive and refractory elements such as titanium, tantalum, and hafnium to form carbides (e.g., TiC, TaC, or HfC). During heat treatment, these begin to decompose and form lower carbides such as  $\text{M}_{23}\text{C}_6$  and  $\text{M}_6\text{C}$ , which tend to form on grain boundaries. **[0007]** Recently, several patents (US0080185078, US20100061883, US20120312434, and CN103045910) reported  $\gamma$ - $\gamma'$  microstructure in W containing cobalt based alloys similar to that of nickel based super alloys. These patent discloses in the composition range (0.1%-10% Al, 3%-45% W, and Co as a remainder) stable cuboidal  $\text{L1}_2$  ( $\gamma'$ ) precipitates of  $\text{Co}_3(\text{Al}, \text{W})$  in  $\gamma$ -Co FCC matrix. These precipitates are stable at high temperature and have lattice misfit of around 0.53%. Subsequently, several alloying additions such as Nickel (Ni), Titanium (Ti), Tantalum (Ta), Niobium (Nb), Zirconium Zr, Vanadium (V) or Hafnium (Hf) were added to replace some part of Aluminum (Al) or Tungsten (W) or Cobalt (Co) in order to increase the solvus temperature and high temperature strength. However, these alloys have high density, low creep strength, and ductility. Tungsten (W) addition is crucial and essential in this class of alloys to stabilize the  $\gamma'$  phase although it reduces specific strength due to its high density.

**[0008]** It is well known that thermal efficiency of gas turbines used in jet engines or power plant facilities can be most effectively increased by elevating temperature of combustion gases. However, limiting factor for achieving this objective is availability of materials capable of withstanding higher temperatures without losing strength. Achieving higher strength at elevated temperatures with higher density does not provide a solution as turbine blades with higher mass shall inherently generate higher stresses. Therefore, there is a need to provide materials having higher specific strength at elevated temperatures than those already available.

**[0009]** With these considerations in mind, there is a need in the art for new Co-based superalloy compositions that exhibit a desirable combination of properties noted above, such as environmental resistance, high-temperature strength, and ductility.

**[0010]** Prior inventions considered tungsten (W) as an essential element to stabilize  $\gamma'$  in Co base alloys. Since, tungsten (W) is not desirable because of high density, very high melting point making homogenization difficult, therefore current invention demonstrates tungsten (W) free Co base superalloys.

## **OBJECTS OF THE INVENTION**

**[0011]** It is an object of the present disclosure to provide  $\gamma$ - $\gamma'$  cobalt based superalloys that are free of tungsten (W).

**[0012]** It is an object of the present disclosure to provide low density tungsten (W) free  $\gamma$ - $\gamma'$  cobalt based superalloys having a microstructure that is stable at high temperature.

**[0013]** It is an object of present disclosure to state that no other phase except  $\gamma$ - $\gamma'$  phases are present in the invented class of alloys.

**[0014]** It is an object of the present disclosure to declare a new class of superalloys with high temperature strength.

**[0015]** Yet another object of the present disclosure is to provide a  $\gamma$ - $\gamma'$  cobalt based superalloys having better specific strength, compressive as well as tensile, good ductility in combination with good creep strength and corrosion resistance at elevated temperatures.

**[0016]** Yet another object of the present disclosure is to provide exemplary heat treatment process for tungsten free  $\gamma$ - $\gamma'$  cobalt based superalloys for achieving claimed mechanical properties.

### SUMMARY

**[0017]** In view of the foregoing, embodiments herein present the invention of a class of Tungsten (W) free Cobalt based ( $\gamma$ - $\gamma'$ ) superalloys with the basic chemical composition comprising in % by weight: 0.5 to 10 Aluminium (Al) and 1 to 15 Molybdenum (Mo) with at least one or both of 0.5 to 12 Niobium (Nb) and 0.5 to 12 Tantalum (Ta), with the remainder being Cobalt (Co). Some part of the cobalt can be replaced by nickel (50% or less). Nickel added alloys can be added further with at least one among the transition metals zirconium (5% or less), hafnium (5% or less), vanadium (5% or less), titanium (5% or less), and yttrium (5% or less), boron (2% or less), carbon (2% or less), rhenium (10% or less), ruthenium (5% or less) for further fine tune the solvus temperature, volume fraction of  $\gamma'$  and creep properties.

**[0018]** In an embodiment, the present disclosure provides a number of exemplary combinations of all or some of the above alloying elements to obtain superalloys exhibiting different capabilities. Achievable superalloys are not limited to these exemplary ones and it is possible for one conversant in the art to work out many other combinations to achieve claimed properties in accordance with the present disclosure.

**[0019]** These and other aspects of the embodiments herein will be better appreciated and understood when considered in conjunction with the following description and the accompanying drawings. It should be understood, however, that the following descriptions, while indicating preferred embodiments and numerous specific details thereof, are given by way of illustration and not of limitation. Many changes and modifications may be made within the scope of the embodiments herein without departing from the spirit thereof, and the embodiments herein include all such modifications.

### BRIEF DESCRIPTION OF THE DRAWINGS

**[0020]** The embodiments herein will be better understood from the following detailed description with reference to the drawings, in which:

**[0021]** FIG. 1 illustrates an exemplary method for heat treatment of disclosed superalloys in accordance with an embodiment of the present invention.

**[0022]** FIG. 2 illustrates an exemplary Transmission Electron Microscopy (TEM) diffraction pattern in [001] zone axis showing  $L1_2$  super-lattice reflections along with matrix reflections for Co-4.6Al-8.2Mo-3.2Nb alloy (alloy 1) after final aging heat treatment.

**[0023]** FIG. 3 illustrates an exemplary Transmission Electron Microscopy (TEM) darkfield image taken from 010 super lattice  $L1_2$  spot in [001] zone axis for Co-4.6Al-8.2Mo-3.2Nb alloy (alloy 1) after final aging heat treatment.

**[0024]** FIG. 4 illustrates an exemplary comparison of densities of present invented alloys with other available cobalt based superalloys.

**[0025]** FIG. 5 illustrates an exemplary comparison of DSC curves of present invented alloys (Alloy 1, Alloy 5, Alloy 6, and Alloy 8) with Co-3.6Al-24W alloy.

**[0026]** FIG. 6 illustrates exemplary comparison of 0.2% compressive proof stress of present invented alloys with known Co-3.6Al-24.7W alloy at room temperature.

**[0027]** FIG. 7 illustrates exemplary comparison of specific 0.2% compressive proof stress of present invented alloys with known Co-3.6Al-24.7W alloy at room temperature.

**[0028]** FIG. 8 illustrates exemplary comparison of 0.2% compressive proof stress of present invented alloys with known Co-3.6Al-24.7W alloy at 870° C. temperature.

**[0029]** FIG. 9 illustrates exemplary comparison of specific 0.2% compressive proof stress of present invented alloys with known Co-3.6Al-24.7W alloy at 870° C. temperature.

**[0030]** FIG. 10 illustrates exemplary comparison of tensile test curves of Alloy 1 as an example and Co-3.6Al-24.7W alloy.

**[0031]** FIG. 11 illustrates exemplary comparison of 0.2% tensile proof stress of Alloy 1, Alloy 4, Alloy 5 and Alloy 7 with known Co-3.6Al-24.7W and other commercially available cobalt superalloys.

**[0032]** FIG. 12 illustrates exemplary comparison of specific 0.2% tensile proof stress of Alloy 1, Alloy 4, Alloy 5 and Alloy 7 with known Co-3.6Al-24.7W and other commercially available cobalt superalloys.

### DETAILED DESCRIPTION

**[0033]** The following discussion provides many example embodiments. Although each embodiment represents a single combination of inventive elements, the embodiments herein are considered to include all possible combinations of the disclosed elements. Thus, if one embodiment comprises elements A, B, and C, and a second embodiment comprises elements B and D, then the inventive subject matter is also considered to include other remaining combinations of A, B, C, or D, even if not explicitly described.

**[0034]** If the specification states a component or feature “may”, “can”, “could”, or “might” be included or have a characteristic, that particular component or feature is not required to be included or have the characteristic.

**[0035]** Embodiments described herein generally relate to the field of materials science, and to a cobalt-base superalloy with a  $\gamma/\gamma'$  microstructure. The described embodiments herein, more particularly relate to compositions of high temperature resistant tungsten free cobalt based superalloys. Embodiments herein describe Tungsten (W) free Cobalt based superalloy with base chemical compositions comprising in % by weight: 0.5 to 10 Aluminium (Al), 1 to 15 Molybdenum (Mo), and one or both of 0.5 to 12 Niobium (Nb) and 0.5 to 12 Tantalum (Ta), with the remainder being Cobalt (Co). Cobalt can be replaced by nickel (50% or less) in the base alloy mentioned above. Further, transition metals such as chromium, platinum, palladium, iridium, titanium, vanadium, zirconium, hafnium, platinum, palladium, chromium, yttrium, iron, iridium, ruthenium, rhenium, carbon

and boron, at least one among these can be a part of the Nickel added composition with respective purposes.

**[0036]** Table 1 shows eight different exemplary compositions of Co based superalloys in accordance with exemplary embodiments of the present invention. It should be appreciated that the below compositions are purely exemplary in nature and any other suitable composition within the above mentioned range is completely within the scope of the present disclosure. Each superalloy composition is designated with a number and referred as alloy 1, alloy 2, alloy 3, alloy 4, alloy 5, alloy 6, alloy 7 and alloy 8.

TABLE 1

Composition of alloys weight % (atomic %)							
Alloy No.	Co	Ni	Al	Mo	Nb	Ta	Ti
1	84 (83)	—	4.6 (10)	8.2 (5)	3.2 (2)	—	—
2	83.3 (83)	—	4.6 (10)	8.2 (5)	2.4 (1.5)	1.5 (0.5)	—
3	82.6 (83)	—	4.6 (10)	8.1 (5)	1.6 (1)	3.1 (1)	—
4	81.5 (83)	—	4.5 (10)	8 (5)	—	6 (2)	—
5	53.7 (53)	30.3 (30)	4.6 (10)	8.2 (5)	3.2 (2)	—	—
6	51.8 (51)	30.4 (30)	4.7 (10)	8.3 (5)	3.2 (2)	—	1.6 (2)
7	52.1 (53)	29.4 (30)	4.5 (10)	8 (5)	—	6 (2)	—
8	50 (51)	29.5 (30)	4.5 (10)	8.3 (5)	—	6.1 (2)	1.6 (2)

**[0037]** FIG. 1 shows an exemplary process flow chart (100) for producing above mentioned exemplary tungsten (W) free cobalt based superalloys. According to one embodiment, the process (100) can include heat treatment required to be performed on superalloys to achieve desired physical properties of materials. At step 102, constituent elements required to make above mentioned compositions (table 1), can be melted, for example but not limited to, in an electric arc furnace. In an implementation, 30 grams of these constituent elements were melted in a laboratory scale electric arc furnace having a water-cooled copper hearth. During this step, constituents were melted a number of times to ensure homogeneity. In an embodiment of laboratory scale process, this was done 12 to 15 times to ensure homogeneity. However, such melting is not limited to any specific number of steps any change in the process or steps involved there in are within the scope of the present invention.

**[0038]** At step 104, molten material can be cast/molded in a mold, such as a copper mold, into desired shapes. Casting is a process of manufacturing, wherein liquid metal or pliable raw material is given a required shape using a rigid frame called a mold. In a laboratory scale embodiment, this can, for example, be done using water cooled copper mold, wherein the cast shape can be say a cylindrical rod.

**[0039]** At step 106, cast alloy can be subjected to solution heat treatment (solutionized). Solution heat treatment (SHT) can be typically done on age or precipitation hardenable alloys, which gain strength due to presence of fine second phases formed during precipitation hardening. SHT can be carried out before final ageing or precipitation heat treatment to re-introduce solute into a matrix so that it can be utilized to form a fine dispersion of phases on subsequent processing. The solutionising temperature can be between 1100 to 1400° C. for time between 1 to 20 hours. In an embodiment, cylindrical rods were solutionised at 1300° C. temperature for 15 hrs in a vacuum furnace.

**[0040]** At step 108, SHT can be followed by water quenching, wherein quenching involves rapid cooling of an alloy to obtain supersaturated solid solution (SS) at room temperature. It prevents low-temperature processes, such as phase transformations, from occurring by providing only a narrow window of time in which reaction is both thermodynamically favorable and kinetically accessible. Important parameters of quenching process include solutionising temperature from which alloy is quenched, and medium of quenching. In an embodiment, solutionising temperature depends on the alloy being processed and the medium

determines the rate of cooling, which also depends on the alloy. In an embodiment, quenching of disclosed superalloys can be carried out from 1300° C., with water being used as the cooling medium.

**[0041]** At 110, solutionised and quenched alloys can be subjected to process of aging, otherwise known as precipitate hardening. Upon rapid cooling from high temperatures for example after quenching, alloys retain solute in the matrix at low temperatures. Aging of these alloys at intermediate temperatures decomposes supersaturated solid solution. Aging or precipitation hardening relies on this change in solid solubility with temperature to produce secondary phase—gamma prime ( $\gamma'$ ) in the subject matter and hardens the material. Alloys must be kept at intermediate temperature for hours to allow precipitation or aging to take place. The intermediate aging temperature can be between 500° C. to 1100° C. for the present invented alloys. In an implementation herein, all alloys (with reference to table 1) were vacuum sealed in quartz tube and aged at 800° C. upto to the time when peak hardness was achieved. The time varies according to the alloy composition and is shown in table 2.

**[0042]** At step 112, aged alloys can be cooled through furnace cooling, air cooling or quenching in water from the temperature at which aging was done. In the present embodiment all alloys were furnace cooled. For Ni added alloys (alloy 5, alloy 6, alloy 7 and alloy 8), cooling can be done by both air cooling or quenching in water. Air cooling and quenching in water was not done for alloy 1, alloy 2, alloy 3 and alloy 4 to avoid the transformation of FCC matrix ( $\alpha$ -Co) to HCP ( $\epsilon$ -Co).

**[0043]** In the exemplary embodiments described in succeeding paragraphs, the densities of the alloys were measured in accordance with ASTM standard B311-08 at room temperature. Transmission Electron Microscopy (TEM) FEI F30 is used for microstructural studies and Differential Scanning calorimetry (DSC) NETZSCH STA 449 F3 Jupiter is used for determination of melting and solvus temperature

of the alloys. Peak age time for all the alloys was determined by measuring Vickers hardness (Hv) using 0.5 Kg load. Compressive and tensile tests for peak aged samples were done on DARTEC tensile testing machine at a strain rate of  $10^{-3}$  at both room temperature and at 870° C. However, it would be appreciated that any such technique/mechanism is purely for experimental purpose and does not limit the scope of the invention in any manner whatsoever, and hence any change in construction/structure can be used for preparation/evaluation/testing of the superalloy composition of the present invention.

**[0044]** FIG. 2 shows an exemplary TEM diffraction pattern for Alloy 1 after final aging heat treatment, along [001] zone axis showing  $L1_2$   $\gamma'$  super lattice reflections along with  $\gamma$  matrix reflections, in accordance with an embodiment of the present invention.

**[0045]** FIG. 3 shows an exemplary TEM darkfield micrograph of alloy 1 taken from 010 super lattice  $L1_2$  spot which corresponds to  $\gamma'$ , in [001] zone axis in accordance with an embodiment of the present invention. It is clear from dark-field micrograph that microstructure contains  $L1_2$  ordered cuboidal  $\gamma'$  precipitates throughout the  $\gamma$  matrix. Their size ranges from 25 to 50 nm.

**[0046]** FIG. 4 shows an exemplary comparison of densities of the present invented alloys (table 1) with other commercially available cobalt superalloys and tungsten (W) containing cobalt superalloy (Co-3.6Al-24.7W) in accordance with the embodiment herein. Clearly the present invented alloys have much lower densities compared to Co-3.6Al-24.7W and other cobalt superalloys (L-605, Hayness 188, Stellite). Density of the alloys described in embodiments herein i.e. alloy 1, alloy 2, alloy 3, alloy 4, alloy 5, alloy 6, alloy 7 and alloy 8 are 8.36, 8.42, 8.46, 8.61, 8.38, 8.29, 8.65 and 8.56 gm/cm<sup>3</sup> respectively which are much lower than 9.82 gm/cm<sup>3</sup> of Co-3.6Al-24.7W alloy. It is clear from the illustration that alloys described in the embodiments herein, have lower density and are comparable to existing nickel based superalloys.

**[0047]** FIG. 5 shows exemplary comparison DSC heating curves of alloy 1, alloy 5, alloy 6 and alloy 8 with Co-3.6Al-24.7W alloy in accordance with the embodiment herein. As illustrated in the heating curve, the melting points for alloy 1 and alloy 5 are found to be 1315° C. and 1355° C. respectively, which are in the range of incipient melting points of nickel based superalloys. The solvus temperatures for Alloy 1 and Alloy 5 are 866° C. and 976° C. which are lower compared to Co-3.6Al-24.7W alloy (986° C.). But, the Alloy 6 and Alloy 8 have values of 1026° C. and 1068° C. which higher than the Co-3.6Al-24.7W alloy and commercially used nickel based superalloy (waspalloy).

**[0048]** Table 2 below shows exemplary peak hardness values for all the alloys (with reference to table 1) and

Co-3.7Al-24.7W alloy (heat treatment schedule was given according to the reference [1]) in accordance with an embodiment of the present invention. Alloy 1 attains peak hardness after aging of 2 hours, alloy 2, alloy 3, alloy 4, alloy 6 and alloy 8 get peak hardness after aging of 10 hours while for Alloy 5 and Alloy 7, peak hardness is attained in 5 hours.

TABLE 2

Peak hardness and aging time		
Alloy No.	Peak Hardness (Hv)	Aging Time (hours)
Co-3.6Al-24.7W	390	24
Alloy 1	392	2
Alloy 2	395	10
Alloy 3	395	10
Alloy 4	405	10
Alloy 5	410	5
Alloy 6	395	10
Alloy 7	445	5
Alloy 8	410	10

**[0049]** FIG. 6 shows exemplary results of compression tests performed at room temperature on all the alloys after subjecting them to heat treatment as disclosed above and compared with Co-3.6Al-24.7W alloy (heat treated according to the reference [1]). As illustrated, compressive strength values for all present disclosed alloys are above the Co-3.6Al-24.7W alloy except alloy 1. Alloy 7 showed 0.2% compressive proof stress value of about 890 MPa which is higher than 780 MPa of Co-3.6Al-24.7W alloy.

**[0050]** FIG. 7 shows specific 0.2% compressive proof stress for all the alloys and it is clear that all present invented alloys have much higher values compared to Co-3.6Al-24.7W alloy. Among these, Alloy 7 has a higher value of 103 MPa/gm·cm<sup>-3</sup> compared to 79.4 MPa/gm·cm<sup>-3</sup> for Co-3.6Al-24.7W alloy.

**[0051]** FIG. 8 shows exemplary results of compression tests performed at elevated temperature (at 870° C.) on all the alloys after subjecting them to heat treatment as disclosed above and compared with Co-3.6Al-24.7W alloy. As illustrated, Alloy 5 (535 MPa), Alloy 6 (520 MPa) and Alloy 7 (530 MPa) showed higher 0.2% compressive proof stress values than Co-3.6Al-24.7W (485 MPa) alloy and Alloy 4 (480 MPa) and Alloy 8 (490 MPa) show similar values as Co-3.6Al-24.7W alloy.

**[0052]** FIG. 9 shows specific 0.2% compressive stress values at 870° C. for all the alloys. It is clear that present disclosed alloys (except alloy 1 and alloy 2) have much higher values (highest among these, Alloy 5 with 63.8 MPa/gm·cm<sup>-3</sup>) than the Co-3.6Al-24.7W having 49.4 MPa/gm·cm<sup>-3</sup>. Table 3 shows comparison of density, peak hardness (Hv) and compression test results among all the present disclosure alloys and Co-3.6Al-24.7W alloy.

TABLE 3

Comparison of density, hardness and compression test results							
Alloy		Density	Peak Hardness	0.2% compressive		Sp. 0.2% compressive PS	
designation	Alloys			PS (MPa)		(MPa/gm · cm <sup>-3</sup> )	
		(gm · cm <sup>-3</sup> )	(Hv)	RT	at 870° C.	RT	at 870° C.
Co—3.6Al—24.7W	Co—3.6Al—24.7W	9.82	390	780	485	79.4	49.4
Alloy 1	Co—4.6Al—8.2Mo—3.2Nb	8.36	392	720	390	86.1	46.7

TABLE 3-continued

Comparison of density, hardness and compression test results							
Alloy designation	Alloys	Density (gm · cm <sup>-3</sup> )	Peak Hardness (Hv)	0.2% compressive PS (MPa)		Sp. 0.2% compressive PS (MPa/gm · cm <sup>-3</sup> )	
				RT	at 870° C.	RT	at 870° C.
Alloy 2	Co—4.6Al—8.2Mo—2.4Nb—1.5Ta	8.42	395	805	420	95.6	49.9
Alloy 3	Co—4.6Al—8.1Mo—1.6Nb—3.1Ta	8.46	395	825	440	97.5	52.0
Alloy 4	Co—4.5Al—8Mo—6Ta	8.61	405	840	480	97.6	55.7
Alloy 5	Co—30.3Ni—4.6Al—8.2Mo—3.2Nb	8.38	410	800	535	95.5	63.8
Alloy 6	Co—30.4Ni—4.7Al—8.3Mo—3.2Nb—1.6Ti	8.29	395	810	520	97.7	62.7
Alloy 7	Co—29.4Ni—4.5Al—8Mo—6Ta	8.65	445	890	530	102.9	61.3
Alloy 8	Co—29.5Ni—4.5Al—8.3Mo—6.1Ta—1.6Ti	8.56	410	850	490	99.3	57.2

[0053] FIG. 10 shows exemplary tensile test curve as an example for peak aged alloy 1 and for Co-3.6Al-24.7W alloy at room temperature. Comparison of 0.2% tensile proof stress for alloy 1, alloy 4, alloy 5 and alloy 7 with Co-3.6Al-24.7W and other cobalt based superalloys (L605, Hayness 188, Stellite) were shown in FIG. 12. We see that for Co-3.6Al-24.7W (made by us under identical condition) shows 0.2% tensile proof stress of about 760 MPa but fracture immediately (from the curve) without any elongation. But, alloy 1, alloy 4, alloy 5 and alloy 7 shows ultimate tensile strength of about 835 MPa with 19% elongation, 925 MPa with 16% elongation, 950 MPa with 16% elongation and 1000 MPa with 16% elongation respectively (table 4). Alloy 1, alloy 4, alloy 5 and alloy 7 have much higher values than L-605 (460 MPa), Hayness 188 (485 MPa), Stellite (635 MPa) and comparable to Co-3.6Al-24.7W alloy. FIG. 12 shows comparison of specific 0.2% tensile proof stress for all above mentioned alloys and it is clear that Alloy 1, alloy 4, Alloy 5 and alloy 7 have much higher values than other cobalt based superalloys. Table 4 shows comparison of all tensile results among these superalloys.

TABLE 4

Yield Strength and Specific Yield Strength at room temperature and 900° C.				
Alloy	Tensile Properties			
	0.2% PS (MPa)	UTS (MPa)	% El	Specific 0.2% PS (MPa/gm · cm <sup>-3</sup> )
L-605	460	1005	59	50.4
Hayness 188	485	960	70	54
Stellite	635	1010	11	75.8
Co-3.6Al-24.7W **	737	1090	20	75.1
Co-3.6Al-24.7W ****	760	—	—	81.2
Alloy 1	730	835	19	88.6
Alloy 4	800	925	16	93.3
Alloy 5	810	950	16	96.7
Alloy 7	880	1000	16	101.7

\*\* K. Ishida et.al, science, 312, 2006, 90-91

\*\*\*\* Our experiment

1. A Tungsten (W) free Cobalt based ( $\gamma$ - $\gamma'$ ) superalloy composition with high strength and ductility comprising, in weight percentage,

- i) 0.5 to 10% Aluminium (Al);
- ii) 1 to 15% Molybdenum (Mo);

iii) one or both of 0.5 to 12 Niobium (Nb) and/or 0.5 to 12 Tantalum (Ta);

iv) remainder Cobalt (Co) and unavoidable impurities.

2. The Cobalt based ( $\gamma$ - $\gamma'$ ) superalloy by composition of claim 1, wherein a part of the weight percentage of Cobalt is replaced by 50% or less Nickel.

3. The Cobalt based ( $\gamma$ - $\gamma'$ ) superalloy composition of claim 2, wherein a part of the weight percentage of Cobalt is replaced by at least one transition metal selected from the group consisting of 10% or less Iridium, 10% or less Platinum, 10% or less Palladium, 15% or less Chromium and combinations thereof.

4. The Cobalt based ( $\gamma$ - $\gamma'$ ) superalloy composition of claim 2, wherein a part of the weight percentage of Nickel is replaced by at least one transition metal selected from the group consisting of 50% or less Iridium, 10% or less Platinum, 10% or less Palladium, 15% or less Chromium and combinations thereof.

5. The Cobalt based ( $\gamma$ - $\gamma'$ ) superalloy composition of claim 2, further comprising at least one transition metal selected from the group consisting of 5% or less Titanium, 5% or less Vanadium, 5% or less Hafnium, 5% or less Zirconium, 5% or less Yttrium, 2% or less Boron, 2% or less Carbon, 10% or less Rhenium, 5% or less Ruthenium and combinations thereof.

6. The Cobalt based ( $\gamma$ - $\gamma'$ ) superalloy composition of claim 1, wherein no other phase except  $\gamma$ - $\gamma'$  is present.

7. A process of producing Tungsten (W) free  $\gamma$ - $\gamma'$  cobalt based superalloy with high strength and ductility comprising the steps of:

- a. Melting constituents of the composition of any of the claims from 1 to 5 to form a molten material;
- b. Casting the molten material into a desirable mold to form a cast alloy;
- c. Optionally the cast alloy can be mechanically worked like forging, rolling or related processes to produce wrought product,
- d. Homogenizing and solutionizing the alloy at a higher temperature to form a solutionized alloy;
- e. Cooling of the solutionized alloy;
- f. Aging of the solutionized alloy at a temperature ranging from 500° C. to 1100° C. to form an aged alloy; and
- g. Cooling of the aged alloy to form the  $\gamma$ - $\gamma'$  cobalt based superalloy with high strength and ductility.

8. The process of claim 7, wherein the cooling of the solutionized or the aged alloy is done by furnace cooling or air cooling or water quenching.

9. The process of claim 7, wherein the alloy is solutionized at the temperature ranging from 1100° C. to 1400° C. for time between 1 to 20 hours.

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