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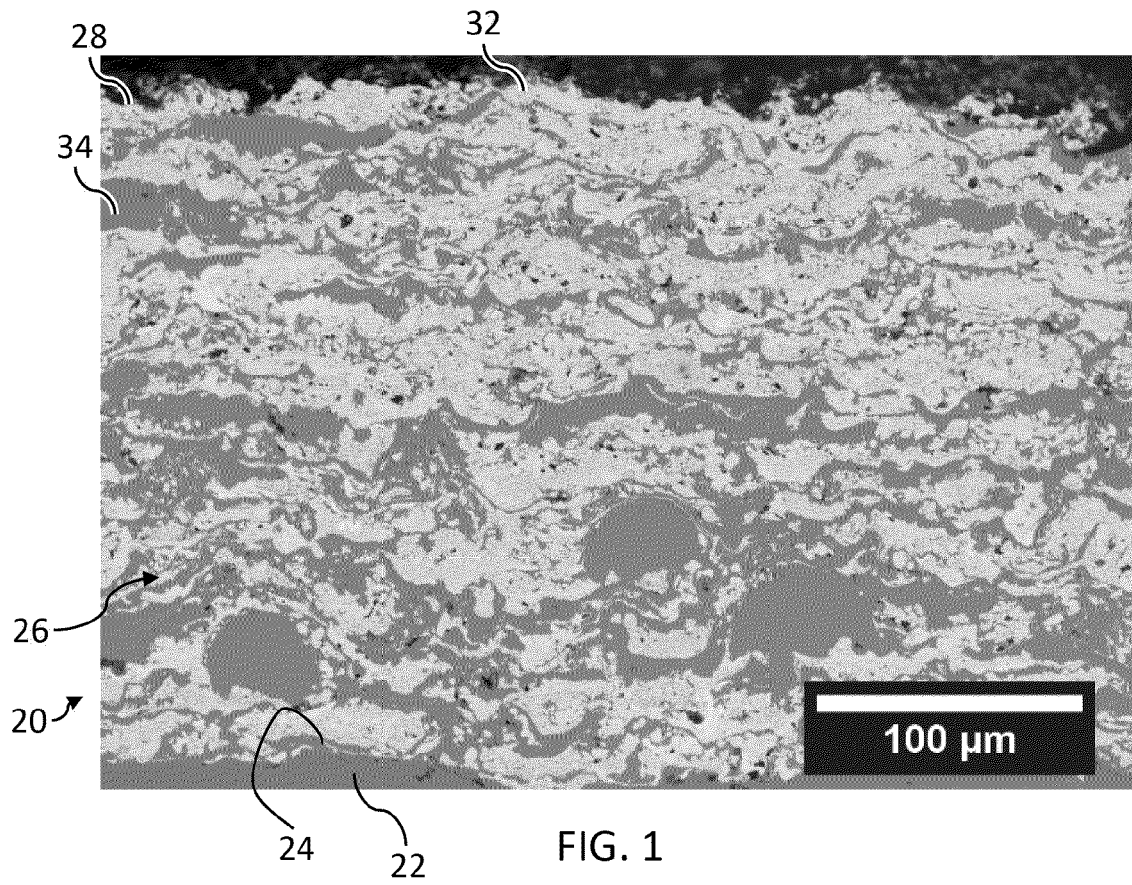
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(54) **CO-CR ALLOY CARBIDE COMPOSITE COATINGS FOR HIGH-TEMPERATURE APPLICATIONS**

(57) A method for applying a coating (26), includes: providing a mixture of powders of comprising by volume percent: 10.0 to 60.0 one or more cobalt-based alloys (34) and 5.0 to 70.0 WC-Ni (32); and spraying the mixture

on a metallic substrate (22). Each of the cobalt-based alloys (34) have by weight percent: Co as a largest constituent; 20.0-35.0 Cr; up to 3.0 C, if any; and up to 4.0 Ni, if any.

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Description

BACKGROUND

[0001] The disclosure relates to gas turbine engines. More particularly, the disclosure relates to coatings for hot section piston seal rings (PSR).

[0002] Gas turbine engines (used in propulsion and power applications and broadly inclusive of turbojets, turboprops, turbofans, turboshafts, industrial gas turbines, and the like) use piston seal rings (PSR) in a variety of locations.

[0003] Coatings produced by different thermal spray techniques are being used in a wide variety of applications. They can perform different functions such as thermal barriers, abradable, corrosion and wear resistant and, for each application, different strategies and choices of materials can be used to achieve the different properties desired for the target application. When high temperature conditions are involved, the protection against wear and corrosion in elevated temperatures becomes a main engineering challenge, because oxidation and the attack by corrosive elements combined with friction and mechanical wear can damage the materials exposed to those conditions, leading to premature failure of engineered parts.

[0004] Currently, superalloy (e.g., IN718) static seals are commonly used uncoated in turbine engine hot sections and may be subject to damage by hot corrosion. Effects of hot corrosion often are reflected in weight/mass gain. Bare superalloys may have a weight gain up to 25mg/cm² when exposed to hot corrosion conditions such as 0.5mg/cm² of Na₂SO₄ at 900°C for 24 hours. Such high weight gain means that the alloy is being attacked by sulfur, which could lead to premature failure of the seal and mating counterface component. Furthermore, these parts are also exposed to severe tribological conditions, which means they suffer premature wear during high temperature operation.

[0005] The use of commercially available self-lubricating coatings can increase the lifetime of these parts by improving tribological performance. However, these self-lubricating coatings (such as the NASA-developed PS304 and PS400) have shown poor resistance to hot corrosion conditions. PS304 is disclosed in US Patent 5866518 of DellaCorte et al., entitled "Self-Lubricating Composite Chromium Oxide", issued February 2, 1999. PS304 generally has NiCr binder with Cr₂O₃ hardener and Ag+ fluorides solid lubricant. PS400 is disclosed in US Patent 8753417 of DellaCorte et al., entitled "High Temperature Solid Lubricant Coating for High Temperature Wear Applications", issued June 17, 2014. PS400 generally has NiMoAl binder with Cr₂O₃ hardener and Ag+ fluorides solid lubricant.

[0006] A more recent proposal for a coating for such a PSR is found in US Patent Application Publication 2021/0270369A1 of Stoyanov et al., entitled "Wear Resistant Self-Lubricating Static Seal", published January 6, 2022. Another is found in US Patent Application Publication No. 2022/0325797A1 (the '797 publication), of Stoyanov et al., entitled "Low Friction, Wear Resistant Piston Seal", published October 13, 2022. The '797 publication discloses a coating with a CoCr alloy binder phase and a hard particle phase comprising Cr₂O₃. Application is via HVOF.

[0007] Composite coatings have been used on Fe alloy (e.g., carbon steel, stainless steel, Invar alloy) substrates for low and intermediate temperature ranges (e.g., room temperature up to about 500°C). In such coatings, cobalt and nickel are binder metals for WC and Cr₃C₂ (e.g., WC-Co, WC-CoCr, Cr₃C₂-NiCr, or Cr₃C₂-WC-NiCoCr).

[0008] Another seal configuration is the W-seal of which an example is found in US Patent Application Publication 2022/0065122A1 (the '122 publication) of Stoyanov et al., entitled "Seals and Methods of Making Seals", published March 3, 2022. The '122 publication discloses both PSR and self-sprung compression seals. The self-sprung compression seals have cross-sections characterized by one or more cycles of a C-shape or W-shape. With such seals, sometimes because of seal orientation a different letter may be used (e.g., the letter E may be used to designate a radially compressed seal; whereas, the letter W may be used to designate an axially-compressed seal of similar cross-section but oriented 90° opposite). The '122 publication discloses both baseline seals made of conventional alloys (e.g., nickel-based superalloys) and modified seals made of HEA.

[0009] Depending on the production process, additional heat treatments or surface processing are needed to improve the mechanical properties. For example, annealing.

SUMMARY

[0010] One aspect of the disclosure involves a method for applying a coating. The method comprises: providing a mixture of powders comprising by volume percent: 10.0 to 60.0 one or more cobalt-based alloys, and 5.0 to 70.0 WC-Ni; and spraying the mixture on a metallic substrate. Each of the cobalt-based alloys have by weight percent: Co as a largest constituent; 20.0-35.0 Cr; up to 3.0 C, if any; and up to 4.0 Ni, if any.

[0011] In a further example of any of the foregoing, additionally and/or alternatively, the mixture of powders comprises by volume percent: 12.0 to 55.0 said one or more cobalt-based alloys; and 10.0 to 65.0 said WC-Ni.

[0012] In a further example of any of the foregoing, additionally and/or alternatively, the mixture of powders further has by volume percent 5.0 to 85.0 Cr₃C₂.

[0013] In a further example of any of the foregoing, additionally and/or alternatively, the mixture of powders comprises

by volume percent: 10.0 to 30.0 said one or more cobalt-based alloys; 8.0 to 30.0 said WC-Ni; and 50.0 to 80.0 said Cr_3C_2 .

[0014] In a further example of any of the foregoing, additionally and/or alternatively, the powder of WC-Ni is an agglomerated and sintered WC-Ni.

[0015] In a further example of any of the foregoing, additionally and/or alternatively, the spraying is HVOF spraying or HVOF spraying or cold spray.

[0016] In a further example of any of the foregoing, additionally and/or alternatively, the spraying is to a thickness of 75 micrometers to 130 micrometers.

[0017] In a further example of any of the foregoing, additionally and/or alternatively, the one or more cobalt-based alloys each comprise by weight percent: Co as said largest constituent; 25.00 to 32.00 Cr; 0.9 to 2.0 C; 3.0 to 6.0 W; 1.0-4.0 Fe; up to 1.5 Mn, if any; 0.5 to 2.0 Si; up to 0.1 P, if any; up to 0.1 S, if any; up to 2.0 Mo, if any; and 1.0-4.0 Ni.

[0018] In a further example of any of the foregoing, additionally and/or alternatively, the one or more cobalt-based alloys each comprise by weight percent: Co as said largest constituent; 28.00 to 32.00 Cr; 0.9 to 2.0 C; 3.0 to 6.0 W; up to 3.0 Fe, if any; 0.5 to 2.0 Mn; 0.2 to 2.0 Si; up to 0.04 P, if any; up to 0.03 S, if any; up to 1.50 Mo, if any; and up to 3.0 Ni, if any.

[0019] In a further example of any of the foregoing, additionally and/or alternatively, the mixture of powders comprises by volume percent: 30.0 to 60.0 said one or more cobalt-based alloys; and 40.0 to 70.0 said WC-Ni.

[0020] In a further example of any of the foregoing, additionally and/or alternatively, the mixture of powders comprises by volume percent: up to 20.0 Cr_3C_2 , if any.

[0021] In a further example of any of the foregoing, additionally and/or alternatively, the mixture of powders comprises by volume percent: up to 10.0 Cr_3C_2 , if any.

[0022] In a further example of any of the foregoing, additionally and/or alternatively, the mixture of powders comprises by volume percent: 10.0 to 30.0 said one or more cobalt-based alloys. 8.0 to 30.0 said WC-Ni; and 50.0 to 80.0 Cr_3C_2 .

[0023] In a further example of any of the foregoing, additionally and/or alternatively, the substrate is a split ring seal substrate and the spraying is at least to an outer diameter surface of the substrate.

[0024] In a further example of any of the foregoing, additionally and/or alternatively, the substrate is a spring compression seal substrate and the spraying is at least to an outer an axial end surface portion of the substrate.

[0025] In a further example of any of the foregoing, additionally and/or alternatively, the substrate is a HALO seal substrate and the spraying is to an inner diameter surface of the substrate.

[0026] In a further example of any of the foregoing, additionally and/or alternatively, the substrate is a locating pin substrate and the spraying is to a base of the locating pin or a distal end section of the locating pin.

[0027] In a further example of any of the foregoing, additionally and/or alternatively, the substrate interfaces with a locating pin and the spraying is to a counterface surface for the locating pin.

[0028] In a further example of any of the foregoing, additionally and/or alternatively, the substrate is a snap fastener substrate and the spraying is to a shaft and a barb underside.

[0029] In a further example of any of the foregoing, additionally and/or alternatively, the substrate is of a component having a snap fit bead or groove and the spraying is to said bead or groove.

[0030] In a further example of any of the foregoing, additionally and/or alternatively, the substrate is of a component having a tab and the spraying is to a face of the tab.

[0031] In a further example of any of the foregoing, additionally and/or alternatively, the substrate is of a component having seal counterface and the spraying is to the seal counterface.

[0032] In a further example of any of the foregoing, additionally and/or alternatively, the substrate is a seal substrate and the coating is to a contact surface portion of the substrate.

[0033] A further aspect of the disclosure involves an article comprising: a metallic substrate; and a coating on the metallic substrate; wherein the coating comprises by volume percent: 18.0 to 50.0 an alloy having, by weight percent, Co as a largest constituent and 20.0-35.0 Cr; and 11.0 to 70.0 WC-Ni.

[0034] In a further example of any of the foregoing, additionally and/or alternatively, the coating further comprises by volume percent: up to 65% Cr_3C_2 , if any and wherein at least 95% by volume exclusive of porosity is said alloy, said WC-Ni, and said Cr_3C_2 , if any.

[0035] In a further example of any of the foregoing, additionally and/or alternatively, the coating has a thickness of 50 micrometers to 200 micrometers.

[0036] In a further example of any of the foregoing, additionally and/or alternatively, the substrate forms a split ring; and the coating is on an outer diameter surface of the substrate.

[0037] In a further example of any of the foregoing, additionally and/or alternatively, the substrate is a nickel-based superalloy or cobalt-based superalloy.

[0038] In a further example of any of the foregoing, additionally and/or alternatively: a counterface is in sliding engagement with the coating and comprising a nickel-based superalloy substrate.

[0039] In a further example of any of the foregoing, additionally and/or alternatively: the substrate is a split ring seal substrate and the spraying is at least to an outer diameter surface of the substrate; or the substrate is a spring compression

seal substrate and the spraying is at least to an outer an axial end surface portion of the substrate; the substrate is a HALO seal substrate and the spraying is to an inner diameter surface of the substrate; or the substrate is a locating pin substrate and the spraying is to a base of the locating pin or a distal end section of the locating pin; or the substrate interfaces with a locating pin and the spraying is to a counterface surface for the locating pin; or the substrate is a snap fastener substrate and the spraying is to a shaft and a barb underside; or the substrate is of a component having a snap fit bead or groove and the spraying is to said bead or groove; or the substrate is of a component having a tab and the spraying is to a face of the tab; or the substrate is of a component having a seal counterface and the spraying is to the seal counterface.

[0040] The details of one or more embodiments are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0041]

FIG. 1 is a micrograph of a substrate coated with a CoCr alloy/WC-Ni coating.

FIG. 2 is a micrograph of a substrate coated with a CoCr alloy/Cr₃C₂/WC-Ni coating.

FIG. 3 is a photograph of a CoCr alloy powder particle.

FIG. 4 is a photograph of a WC-Ni particle.

FIG. 5 is a photograph of Cr₃C₂ particles.

FIG. 6 is a plot of particle diameter for the CoCr alloy powder feedstock.

FIG. 7 is a particle size distribution plot for the WC-Ni powder feedstock.

FIG. 8 is a particle size distribution plot for the Cr₃C₂ powder feedstock.

FIG. 9 is a friction coefficient plot for CoCr alloy at room temperature.

FIG. 10 is a friction coefficient plot for CoCr alloy at 300°C.

FIG. 11 is a plot of the CoCr alloy/WC-Ni coating at room temperature.

FIG. 12 is a plot of CoCr alloy/WC-Ni coating at 300°C.

FIG. 13 is a plot of the CoCr alloy/Cr₃C₂/WC-Ni coating at room temperature.

FIG. 14 is a plot of CoCr alloy/Cr₃C₂/WC-Ni coating at 300°C.

FIG. 15 is a view of a gas turbine engine.

FIG. 15A is an enlarged view of a first seal system in the engine of FIG. 15.

FIG. 15B is an enlarged view of a second seal system in the engine of FIG. 15.

FIG. 15C is an enlarged view of a third seal system in the engine of FIG. 15.

FIG. 15D is an enlarged view combustor swirler in the engine of FIG. 15.

FIG. 16 is a longitudinal sectional/cutaway view of a locating pin joint.

FIG. 17 is a longitudinal sectional view of a snap fastener joint.

FIG. 18 is an inward radial view of a mounting tab-in-slot joint.

FIG. 19 is a longitudinal sectional view of the joint of FIG. 18.

FIG. 20 is a longitudinal sectional view of an alternate locating pin joint.

[0042] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0043] To help improve the endurance life of next generation mechanical systems in gas turbine engines, cobalt-based alloy composite coatings with the addition of WC-Ni or Cr₃C₂ and WC-Ni were produced to reach low wear rate values (WR<10⁻⁶ mm³/Nm) of the coating as well as the counterface at room temperature and elevated temperature (300°C) during reciprocating/fretting wear. Particular tests were conducted on coatings that, for the CoCr alloy feedstock used Stellite® 6 gas atomized alloy of Kennametal Inc., Latrobe Pennsylvania.

[0044] FIGs. 1 and 2 respectively show articles 20, 21 having a Stellite® 6 alloy/WC-Ni (designated SW) coating 26 and Stellite® 6 alloy/ Cr₃C₂/WC-Ni (designated SCW) coating 27 HVOF sprayed on a surface 24 of a substrate 22. The example substrate is stainless steel. The substrate may form a seal and the coating surface 28 surface may be the tribological interface of the seal (examples discussed below and discussion in the ' 122 publication). The coatings 26, 27 were deposited by the HVOF and the deposition parameters of Tables 2 and 3 below.

[0045] The FIGs. 1&2 coatings are formed by: molten and semi-molten splats (which quickly solidify) of the CoCr alloy and deformed carbides. No dendrite or spike-like structure was observed. Rather, carbides and the CoCr alloy splats were homogeneously distributed across the coating with no segregation or agglomeration of a specific phase. In the images: WC-Ni (brightest - light grey) 32; CoCr alloy (medium grey) 34; and Cr₃C₂ (dark grey) 36.

[0046] In FIG. 1, it is seen that splats of both phases, CoCr alloy and WC-Ni, are homogeneously distributed throughout the coating.

[0047] In FIG.2, it is seen that splats of the different phases, CoCr alloy, WC-Ni, and Cr_3C_2 , are homogeneously distributed throughout the coating.

[0048] The coatings tested were produced with a mixture of powders: gas-atomized Co-Cr alloy (Stellite® 6 CoCr alloy of Kennametal Inc., Latrobe PA) (FIG. 3); fused-crushed Cr_3C_2 (FIG. 5); and agglomerated and sintered WC-Ni (AM-PERIT® 547 of Höganäs AB, Höganäs, Sweden, nominal WC12N1, particle size: 45/15 μm) (FIG. 4). The powder particle size distribution is similar for the three powders, as shown in FIGs 6, 7 (WC-Ni), and 8 (Cr_3C_2). As a reference, D50 of the different powders are 34 μm (Stellite® 6 CoCr alloy), 37 μm (WC-Ni), and 37 μm (Cr_3C_2), respectively. The WC-Ni size is of the sintered agglomerate, not the particles forming the agglomerate particles (the latter being about 1 μm).

[0049] Table 1 below shows example Co-Cr alloy compositions. Table 2 shows two example tested powder blends that used Stellite® 6 CoCr alloy as the Co-Cr alloy and alternative example ranges.

Table 1

Co-Cr alloy Composition (Weight %)												
Alloy	C	Mn	Si	P	S	Cr	Ni	Co	Mo	W	Fe	Other
Cobalt Alloy 6 nom range	1-2		1-2			27-32	3-4	bal		4-6	3-4	
Cobalt Alloy 6b AMS 5894 (wrought)	0.90-1.40	0.50-2.00	0.20-2.00	0.04 max	0.03 max	28.00-32.00	3.00 max	bal	1.50 max	3.50-5.50	3.0 max	
Cobalt Alloy 6b nom. (wrought)	1.15	1.25	1.10			30		bal		4.5		
Cobalt Alloy 6k (wrought)	1.40-1.90	0.50-2.00	0.20-2.00	0.04 max	0.03 max	28.00-32.00	3.00 max	bal	1.50 max	3.50-5.50	3.0 max	
Tested alloy vendor spec.	0.9-1.4	0.5 max	0.7-1.5	0.030 max	0.030 max	27.0-30.0	3.0 max	bal	1.0 max	3.5-5.5	3.0 max	0.5 max total
Tested alloy sample assay	1.2	0.5	1.3	0.003	0.003	28.0	2.1	bal	0.2	4.8	2.1	0.06N ₂ ; 0.02O ₂
Range 1	2.0 max	2.5 max	2.5 max	0.1 max	0.1 max	27.0-32.0	4.0 max	bal	2.0 max	6.0 max	4.0 max	††
Range 2	2.0 max	2.5 max	2.5 max	0.1 max	0.1 max	27.0-32.0	4.0 max	bal	2.0 max	3.00-6.00	4.0 max	††
Range 3	0.90-2.00	0.50-2.00	0.20-2.00	0.04 max	0.03 max	28.00-32.00	3.00 max	bal	1.50 max	3.00-6.00	3.0 max	t††
Range 4	0.90-1.90	0.50-2.00	0.20-2.00	0.04 max	0.03 max	28.00-32.00	3.00 max	bal	1.50 max	3.50-5.50	3.0 max	t††
Range 5	0.90-1.90	0.50-2.00	0.20-2.00	0.04 max	0.03 max	25.00-35.00	3.00 max	bal	1.50 max	3.50-5.50	3.0 max	t††
Range 6	0.90-1.40	0.50-2.00	0.20-2.00	0.04 max	0.03 max	28.00-32.00	3.00 max	bal	1.50 max	3.50-5.50	3.0 max	t††
Range 7	0.90-1.40	0.50-2.00	0.20-200	0.04 max	0.03 max	25.00-35.00	3.00 max	bal	1.50 max	3.50-5.50	3.0 max	t††
Range 8	2.0 max	2.5 max	2.5 max	0.1 max	0.1 max	20.0-35.0	4.0 max	bal	2.0 max	6.0 max	4.0 max	t††

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(continued)

Co-Cr alloy Composition (Weight %)												
Alloy	C	Mn	Si	P	S	Cr	Ni	Co	Mo	W	Fe	Other
Range 9	0.5-2.0	2.5 max	2.5 max	0.1 max	0.1 max	25.0-35.0	4.0 max	bal	2.0 max	6.0 max	4.0 max	ttt
Range 10	0.9-2.0	1.5 max	2.0 max	0.1 max	0.1 max	25.0-35.0	4.0 max	bal	2.0 max	6.0 max	4.0 max	ttt
Range 11	0.9-2.0	1.5 max	0.5-2.0	0.1 max	0.1 max	25.0-32.0	1.0-4.0	bal	2.0 max	3.0-6.0	1.0-4.0	ttt
† ≤ 15.0 Other total; ≤ 7.0 other individually												
†† ≤ 5.0 Other total; ≤ 1.0 other individually												
††† ≤ 2.0 Other total; ≤ 0.50 other individually												

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[0050] The first four rows are taken from different industry sources. The powders were mixed according to the ratio shown in Table 2 (which ignores voids in the mixture) and were deposited by high-velocity oxygen-fuel (HVOF) spray using the spraying parameters in Table 3 to a thickness of coating 26 of 248 ± 12 micrometers and coating 27 of 230 ± 40 micrometers. The substrate was stainless steel. The coating containing the CoCr alloy and WC-Ni is identified as "SW" and the coating containing the CoCr alloy in addition to WC-Ni and Cr_3C_2 is identified as "SCW".

Table 2

Tested Coating Feed Powder Composition			
Coating	Powder mixture (vol%)		
	Co-Cr Alloy	Cr_3C_2	WC-Ni
SW	Bal.	-	55
SCW	Bal.	70	10
Range 1A	10.0-60.0	≤ 85.0	5.0-70.0
Range 1B	12.0-55.0	≤ 78.0	10.0-65.0
Range 1C	12.0-55.0	≤ 78.0	8.0-65.0
Range 2A	30.0-60.0	≤ 20.0	40.0-70.0
Range 2B	30.0-50.0	≤ 10.0	50.0-70.0
Range 2C	30.0-50.0	≤ 5.0	50.0-65.0
Range 3A	10.0-30.0	50.0-80.0	8.0-30.0
Range 3B	10.0-30.0	60.0-80.0	10.0-25.0
Range 4A	10.0-60.0	5.0-85.0	5.0-70.0
Range 4B	12.0-55.0	5.0-85.0	10.0-65.0

[0051] As additional variations, optionally any of these ranges may include impurity levels of other elements, compounds, and the like. In further examples these other materials may represent up to 5.0 volume percent aggregate and up to 2.0 or 1.0 volume percent individually. In yet other examples, additions include pre-formed lubricious oxides. For example, cobalt oxides and tungsten oxides may be included initially so that one does not have to wait for in-service oxidation of cobalt and tungsten. These may be included in said small aggregate amounts but possibly above the individual.

Table 3. HVOF spraying parameters

Parameter	Powder Feed Rate (g/min)	Oxygen Flow rate (LPM)	Propylene flow rate (LPM)	Air flow rate (LPM)	Spraying distance (mm)
Value	23	304	79	422	150

[0052] The spraying was by using a Diamond Jet™ 2700 gun of Oerlikon Metco, Pfaeffikon, Switzerland.

[0053] Table 4 shows: deposition efficiency (DE); volume fraction of matrix, carbide, and porosity; and Vickers hardness. Retention of Cr_3C_2 in the coating is lower than WC-Ni, decreasing the DE of SCW compared to SW. Vickers hardness was tested at room (RT) and elevated temperature (300°C). Hardness values are higher for the SCW coating at both RT and HT. Table 5 shows wear rate measured as $V/(F_N \times L)$ where V is the wear volume (mm^3), F_N is the applied load (N) and L represents the length (m).

Table 4

Hardness of as-Sprayed (pre-use and without Heat Treat) Coatings and Example Composition Ranges							
Coating	DE (%)	Percentage in Coating (vol%)				Hardness (HV0.3)	
		CoCr alloy	Cr_3C_2	WC-Ni	Porosity	RT	300°C
SW	75	37 ± 4	-	61 ± 4	3 ± 0.3	800 ± 123	693 ± 96

(continued)

Hardness of as-Sprayed (pre-use and without Heat Treat) Coatings and Example Composition Ranges							
Coating	DE (%)	Percentage in Coating (vol%)				Hardness (HV0.3)	
		CoCr alloy	Cr ₃ C ₂	WC-Ni	Porosity	RT	300°C
SCW	40	24 ± 2	58 ± 2	17 ± 1	1 ± 0.7	918 ± 114	820 ± 64
Range 1A	NA	18.0-50.0	≤ 70.0	11.0-70.0	≤ 8.0	NA	NA
Range 1B	NA	19.0-45.0	≤ 65.0	15.0-70.0	≤ 8.0	NA	NA
Range 2A	NA	25.0-50.0	≤ 20.0	35.0-70.0	≤ 8.0	NA	NA
Range 2B	NA	30.0-50.0	≤ 10.0	40.0-70.0	≤ 8.0	NA	NA
Range 3A	NA	18.0-40.0	45.0-70.0	11.0-30.0	≤ 8.0	NA	NA
Range 3B	NA	19.0-30.0	45.0-65.0	15.0-25.0	≤ 8.0	NA	NA

Table 5

Wear Rate of as-Sprayed (pre-use and without Heat Treat) Coatings			
Coating	Temperature (°C)	Average of Wear volume (×10 ⁻³ mm ³)	Average of Wear rate (×10 ⁻⁶ mm ³ /N.m)
Stellite® 6 CoCr alloy	RT	34.96 ± 2.86	69.93 ± 5.7
	300	86.64 ± 6.99	173.27 ± 14
SW	RT	0.81 ± 0.23	1.61 ± 0.45
	300	1.23 ± 0.23	2.46 ± 0.46
SCW	RT	1.16 ± 0.47	2.32 ± 0.94
	300	17.56 ± 2.97	35.13 ± 5.9

[0054] The Table 5 wear tests were conducted in a ball-on-flat configuration in reciprocating motion at room temperature and elevated temperature (300°C) on an alumina (Al₂O₃) counterface with the three identified coatings on stainless steel substrates.

[0055] FIGs. 9-14 show the average value of the coefficient of friction plotted against the number of cycles at room temperature (25°C) and 300°C for the CoCr alloy, SW, and SCW coatings on the stainless steel. At room temperature, the SW and SCW coatings showed a lower coefficient of friction than the CoCr alloy. At 300°C, the SCW coating showed a coefficient of friction behavior and values similar to the reference Stellite® 6 CoCr alloy coating, whereas the SW coating showed a higher coefficient of friction. This is because WC particles are harder, and more abrasive compared to chromium carbide (Cr₃C₂). Additionally, the thermal softening of the metallic binder (the CoCr alloy) can cause the WC particles to protrude and create more asperities on the coating surface, resulting in a higher CoF. Table 5 shows the wear rate and wear volume values at room temperature and 300°C. The SW and SCW had lower wear rates than the reference HVOF Stellite® 6 alloy. This is because the carbides offer a load bearing capacity to the coating modifying the contact area and distribution of the stresses, in addition of being more resistant to abrasion compared to the metallic matrix (Stellite® 6 alloy). The 300°C wear rate and friction coefficient of SCW are higher than those of SW. However, SCW may have advantages at yet higher temperatures (e.g., in the range of 550°C to 800°C) due to higher temperature stability of chromium carbide relative to tungsten carbide. Relative to the '797 publication, the addition of WC-Ni is believed to increase the hardness of the resultant coating to improve abrasive wear resistance. Despite testing the present parameters only on steel, the parameters are believed to transfer to nickel-based superalloy substrates and cobalt-based superalloy substrates in applications such as described above and below.

[0056] As mentioned above, the two coatings were produced to achieve low wear rate values (WR<10⁻⁶ mm³/Nm) of the coating as well as the counterface at room temperature and high temperature (300°C) during reciprocating sliding. Low wear values can translate into increasing the lifecycle of materials during operation, particularly between room temperature and 300°C or more at relatively low loads (e.g., 5N). An example seal substrate is a nickel-based superalloy such as IN 718 (e.g., equiaxed). An example counterface is a nickel-based superalloy such as IN 718 (e.g., equiaxed).

Such superalloy may be essentially uncoated (no added coating), but may form an alumina scale in service.

[0057] The composite coatings may be put into service without any post-treatment. This is distinguished from Aoh (2001) and Tan, (2018) wherein there is a post-coating heat treatment involving annealing and aging. J.N. Aoh and J.C. Chen, "On the Wear Characteristics of Cobalt-based Hard-facing Layer after Thermal Fatigue and Oxidation", Wear, October 2001, Vol 250 (1-12), pp. 611-620, Elsevier Science B.V., Amsterdam, Netherlands; J. Tan et al., "High performance Co-Cr₃C₂ composite coating by jet electrodeposition", Surface Engineering, December 2018, Vol. 34:11, pp. 861-869, Taylor & Francis Group, London, England.

[0058] HVOF allows forming high-density coatings and low decomposition of the carbides (due to melting or decarburization as in APS). The combination of the production process (HVOF) and the ratio of the metallic matrix (Stellite™ 6) to carbides showed good wear resistance (low wear rate). Additionally, high velocity air-fuel (HVOF) and cold spray are candidates. Of these three non-plasma techniques, HVOF generally has higher operating temperature and lower particle velocity than HVOF and cold spray. Cold spray generally has the lowest operating temperature and highest particle velocity. HVOF is generally intermediate in both parameters.

[0059] FIG. 15 schematically illustrates a gas turbine engine 120. The example gas turbine engine 120 is a two - spool turbofan that generally includes a fan section 122, a compressor section 124, a combustor section 126, and a turbine section 128. The fan section 122 drives air along a bypass flow path B in a bypass duct defined within a housing 115, such as a fan case or nacelle. The fan section also initially drives air along a core flow path C for compression through the compressor section and communication into the combustor section 126 then expansion through the turbine section 128. Although depicted as a two-spool turbofan gas turbine engine in the disclosed non-limiting embodiment, it should be understood that the concepts described herein are not limited to use with two-spool turbofans as the teachings may be applied to other types of turbine engines.

[0060] The example engine 120 generally includes a low speed spool 130 and a high speed spool 132 mounted for rotation about an engine central longitudinal axis A relative to an engine static structure 136 via several bearing systems 138. It should be understood that various bearing systems 138 at various locations may alternatively or additionally be provided, and the location of bearing systems 138 may be varied as appropriate to the application.

[0061] The low speed spool 130 generally includes an inner shaft 140 that interconnects, a first (or low) pressure compressor 144 and a first (or low) pressure turbine 146. The inner shaft 140 is connected to the fan 142 through a speed change mechanism, which in the example gas turbine engine 120 is illustrated as a geared architecture 148, to drive a fan 142 at a lower speed than the low speed spool 130. The high speed spool 132 includes an outer shaft 150 that interconnects a second (or high) pressure compressor 152 and a second (or high) pressure turbine 154. A combustor 156 is between the high pressure compressor 152 and the high pressure turbine 154. A mid-turbine frame 157 of the engine static structure 136 may be arranged generally between the high pressure turbine 154 and the low pressure turbine 146. The mid-turbine frame 157 further supports one or more of the bearing systems 138 in the turbine section 128. The inner shaft 140 and the outer shaft 150 are concentric and rotate via bearing systems 138 about the engine central longitudinal axis A which is collinear with their longitudinal axes.

[0062] The core airflow is compressed by the low pressure compressor 144 then the high pressure compressor 152, mixed and burned with fuel in the combustor 156, then expanded over the high pressure turbine 154 and low 146 pressure turbine. The example mid-turbine frame 157 includes airfoils 159 which are in the core airflow path C. The turbines 146, 154 rotationally drive the respective low speed spool 130 and high speed spool 132 in response to the expansion. It will be appreciated that each of the positions of the fan section 122, compressor section 124, combustor section 126, turbine section 128, and fan drive gear system 148 may be varied. For example, gear system 48 may be located aft of the low pressure compressor, or aft of the combustor section 26 or even aft of turbine section 128, and fan 142 may be positioned forward or aft of the location of gear system 48

FIG. 15A shows one example seal in the engine as a piston seal 160. The example seal 160 (and its metallic substrate) has an inner diameter (ID) surface 161, an outer diameter (OD) surface 162, and axial end surfaces 164 and 165. The seal follows a constant cross-sectional shape and forms a split ring with a shiplap or similar joint (not shown).

[0063] In the illustrated example, the piston seal 160 is partially accommodated in a radially outwardly open groove 170 in an inner member and its OD surface is engaged to an inner diameter (ID) surface 171 of an outer member. The example inner member is a vane structure (e.g., circumferential vane array) of the mid turbine frame 157. The example outer member is a seal runner of the static structure 136. The example groove is formed by the interior surfaces 174, 175 of wall sections 172, 173 and a base surface 176. The example walls have OD rims and outboard axial faces opposite the respective faces 174, 175.

[0064] Principal contact between the seal and the contacting members is between the seal OD surface 162 and the runner ID surface 171. Additional contact may be between the seal axial end surfaces and the adjacent groove wall surface. Wear and damage may occur at any of these. Typically, the counterface members may be uncoated alloy at the interfaces (e.g., uncoated at the surfaces 171, 174, 175). Thus, the seal substrate surface at the seal OD and/or axial end faces (or the entire cross-sectional perimeter surface) may be coated as above.

[0065] Another example is a spring compression static seal. For example, as in the '122 publication baseline, stainless

steel or nickel- or cobalt-based superalloy or other seal substrates may be formed by deforming sheetmetal or may be cast or otherwise formed. Example seals include axial compression seals such as a bellows seal or a W-seal, or for radial compression seals, such as C-seals or E-seals. For example, seal 220 (FIG. 15B) is a bellows or similar type seal with convoluted cross-section effective to be deformed under compression to self-spring-bias engagement with the counterface members. The cross-section generally has a generally inner diameter (ID) surface 221, a generally outer diameter (OD) surface 222 generally parallel and spaced apart from the ID surface by a material thickness T_s , and end surfaces 224 and 225. In an installed axially compressed state, axial ends 226, 227 of the seal are formed by portions of one of the surfaces 221, 222 (both 221 in the example). The illustrated seal is a W-seal although other configurations are possible (e.g., more or fewer cycles of the cross-sectional wave form) as are radial seals (e.g., an E-seal).

[0066] For the example seal 220, forward counterface members engaging the axial end 226 are a radially extending end surface portions 230 of a circumferential array of blade outer air seals (BOAS) 232. BOAS ID surfaces closely surround tips of airfoils 240 of a stage of blades 242. For the example seal 220, aft counterface members engaging the axial end are a radially extending end surface portions 250 of the OD shrouds 254 of a circumferential array of vanes 252. Example vanes are in clusters with multiple airfoils 253 per cluster.

[0067] In these example embodiments, wear may notably occur at counterface surfaces 171, 174, 175, 230, and 250. Example PSR (or other seal) substrate material is nickel- or cobalt-based superalloy (e.g., wrought). Example, nickel-based superalloy legacy alloys are IN-718 (UNS N07718/W.Nr. 2.4668, Inconel® alloy 718 Huntington Alloys Corp., Huntington WV), X750 (UNS N07750/W. Nr. 2.4669, Inconel® alloy X750 Huntington Alloys Corp., Huntington WV), and Waspaloy (alloy 685, N07001). However, new alloys are continually being proposed. Each example counterface member (or other member to be coated or not described above or below) may be formed of a nickel- or cobalt-based alloy or superalloy alloy (e.g., uncoated). Example nickel-based superalloys are Inconel® 718 (IN-718; UNS N07718; AMS 5662), Inconel® 100 (IN-100; UNS N13100; AMS 5397), and Inconel® 713C (IN-713C; Alloy 713C), each of (Huntington Alloys Corp., Huntington WV) and Mar-M247. An example cobalt-based superalloy is Haynes® 188 (UNS R30188) of Haynes International, Kokomo, Indiana. Thus, the seal substrate surface at least at the axial ends 226, 227 (forming contact surfaces) (or the entire cross-sectional perimeter surface) may be coated as above. However, new alloys are continually being proposed. In the seal relaxed/extended pre-installation condition, the areas to be coated may be other than axial ends (e.g., shifted along the surface 221).

[0068] Additional seal applications include brush seal systems, namely coating the brush seal counterface (e.g., runner). Typical brush seals have radially inwardly extending bristles engaging the OD surface of the counterface. US Patent No. 6170831B1 (the '831 patent), of Bouchard, January 9, 2001, and entitled "Axial Brush Seal for Gas Turbine Engines" discloses a double-ended axial static brush seal system partially re-presented as 400 in FIG. 15C. The brush 402 has two protruding bristle sections 406, 407 (e.g., of a single cluster of bristles) engaging respective counterfaces (a case segment and a blade outer air seal segment). FIG. 15C shows the coating may be applied by the present methods to the counterface surface 408, 409 of the counterface substrate 410, 411 to engage the bristles.

[0069] Other examples involve locating pins. A typical locating pin 420 (FIG. 16) has, forming opposite axial end sections of the pin, a base section or shank 422 for press-fit or threading into a hole or socket 428 in a first component 426 and a head 424 for accommodation in a hole or socket 432 of a second component 430. A flange 434 (if present) may separate the base or shank from the head. The head will typically have a tapered portion for guidance into the receiving socket 432. With a press-fit pin, the OD surface of the press-in base or shank may be coated by the present methods. Additionally, the head and flange faces may be coated. With a threaded pin, it is more likely that only the flange and head may be coated and not the threaded shank.

[0070] FIG. 20 shows an alternate locating pin joint having a locating pin 500. FIG. 20 shows the joint and pin as having a common axis 501. Forming a first/proximal end of the pin in this example is a head or terminal flange 502. A shaft generally extends from an underside of the head to a distal end 504. A proximal portion 506 of the shaft mounts to a first component 508. An example first component is an engine case. An example mounting is via press-fit or threading into a boss of the case either directly or to an insert in the boss. In this example, the shaft exterior surface 512 along a proximal portion 510 of the shaft is so externally threaded to mate with an internal thread of the case boss or insert.

[0071] Along a distal end portion 514 of the shaft, the shaft exterior surface 512 is in sliding engagement with a second component. An example engagement is with the inner diameter surface 520 of a boss 522 of the second component acting as a socket for said pin distal end portion. In the example, the second component is an annular combustion chamber liner 526 held spaced apart from the case (e.g., radially inward). The boss may be separately formed from and welded to a main section of the liner. Example wearing movement is between the OD surface 512 and ID surface 520. Relative movement is parallel to the axis 501 and typically results from differential thermal expansion and engine vibration. Thus, one or both of these surfaces (surface 512 along the distal portion and surface 520) may be coated via the present methods.

[0072] Another snap example is a separate snap fastener 440 (FIG. 17) (e.g., holding two (or more) generally flat sections (pieces) of material 442 and 444 against each other as if a rivet). In one example, the fastener has a head 446 with an underside 448 against the outer face 443 of one terminal piece 442 of the stack of mated pieces. A shaft or

shank 450 extends from the underside to a tip/end 452. Adjacent the tip, the shaft has a barbed backlocking surface 454 (underside) facing the head and backlocked against the outer face 445 of the opposite terminal piece 444 in a sandwich of two or more pieces. Example fasteners have longitudinally split areas near the tip allowing insertion through holes in the pieces with the insertion compressing the slot 456 to allow passage of the barbs 458 and then relaxing once the barbs pass out of engagement with the members so as to back lock surfaces 454 to 445. Due to the relatively higher engagement pressures along the barb undersides 454 versus the head underside, the barb underside region and transition to shank main body 456 is a particular area for coating. With the snap fastener, the shaft/shank main body may also be coated by the present methods to limit wear of the holes in the mated components.

[0073] Among additional locations for the coating are in snap fit interfaces 460 (FIG. 15D) (e.g., either fully backlocked or detented). One example of a snap fit between two components involving a bead and groove interaction for mounting a swirler is shown in US Patent No. 10101031B2 (the '031 patent), of Williams et al., October 16, 2018, and entitled "Swirler Mount Interface for Gas Turbine Engine Combustor". The '031 patent discloses an OD (relative to swirler/injector axis 470) projection or bead 464 on a swirler 462 captured in an ID groove 468 in a bulkhead support shell 466. The coating may be applied by the present methods to one or both of the inner member (e.g., swirler) and outer member (e.g., bulkhead support shell) at the bead or groove and adjacent contacting OD and ID surface regions respectively. Often, ease of spraying may make it easiest to just apply to the OD surface of the inner member. But, with a large diameter and relatively small axial extent, it may be easy to also have normal spray access to the bulkhead ID surface to coat both pieces.

[0074] Additional examples involve tabs 481 (FIGs. 18&19) of a first component 480 in slots 483 in a second component 482. For example, in many annular mounting situations, tabs may protrude radially (inward or outward depending on the situation) and be received in associated slots. Example such tabs have first and second axial end faces 484, 485 facing or contacting slot end faces 486 and 487 and tab circumferential end faces (ends) 488, 489 contacting or facing slot circumferential end faces (ends) 490, 491. Typically, pressure or spring loading will bias one axially facing face 484 of the tab against the adjacent axially facing face 486 of the slot. Particularly that axial end face of the tab may be coated via the present methods. But also, circumferential end faces will typically provide some locating function and may also be coated. Spray access makes it easier to coat the tab faces (with a normal angle of incidence than coating slot faces (where the angle will be more off normal).

[0075] Additional seal applications include examples involve knife edge seals (not shown). A typical knife edge seal has hardened knife edges. Thus, the runner (usually an OD surface of an inner member but optionally an ID surface of an outer member) may be the counterface coated by the present methods. An example knife edge seal is shown in US Patent No. 10167729B2 (the '729 patent), of Aiello et al., January 1, 2019, and entitled "Knife Edge with Increased Crack Propagation Life".

[0076] Additional seal applications involve finger seals (e.g., of steel or other alloys discussed above). With finger seals, the contacting portions of the seals themselves and/or the counterface surface may be coated via the present methods. Example finger seals are shown in US Patent No. 10094389B2 (the '389 patent), of Chuong et al., October 9, 2018, and entitled "Flow Diverter to Redirect Secondary Flow", and US Patent No. 9845695B2 (the '695 patent), of Budnick et al., December 19, 2017, and entitled "Gas Turbine Seal Assembly and Seal Support".

[0077] Additional seal applications involve so-called HALO seals (not shown). One example is shown in US Patent No. 10221714B2 (the '714 patent), of Peters et al., March 5, 2019, and entitled "Secondary Seal Device(s) with Alignment Tab(s)". The ID surface of the HALO seal may be coated by the present methods as may be the OD surface of the inner member or shaft. Additionally, alignment or mounting tabs are typical in such seals and may be coated as noted above.

[0078] The use of "first", "second", and the like in the following claims is for differentiation within the claim only and does not necessarily indicate relative or absolute importance or temporal order. Similarly, the identification in a claim of one element as "first" (or the like) does not preclude such "first" element from identifying an element that is referred to as "second" (or the like) in another claim or in the description.

[0079] One or more embodiments have been described. Nevertheless, it will be understood that various modifications may be made. For example, when applied to an existing baseline configuration, details of such baseline may influence details of particular implementations. Accordingly, other embodiments are within the scope of the following claims.

Claims

1. A method for applying a coating (26; 27), the method comprising:

providing a mixture of powders comprising by volume percent:

10.0 to 60.0 one or more cobalt-based alloys (34), each having by weight percent:

Co as a largest constituent;
20.0-35.0 Cr;
up to 3.0 C, if any; and
up to 4.0 Ni, if any; and

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5.0 to 70.0 WC-Ni (32); and

spraying the mixture on a metallic substrate (22).

10 2. The method of claim 1 wherein the mixture of powders comprises by volume percent:

12.0 to 55.0 said one or more cobalt-based alloys (34); and
10.0 to 65.0 said WC-Ni (32).

15 3. The method of claim 1 or 2 wherein:
the mixture of powders further has by volume percent 5.0 to 85.0 Cr₃C₂ (36).

4. The method of claim 3 wherein the mixture of powders comprises by volume percent:

20 10.0 to 30.0 said one or more cobalt-based alloys (34);
8.0 to 30.0 said WC-Ni (32); and
50.0 to 80.0 said Cr₃C₂ (36).

25 5. The method of any preceding claim wherein:
the powder of WC-Ni (32) is an agglomerated and sintered WC-Ni (32).

6. The method of any preceding claim wherein:
the spraying is HVOF spraying or HVAF spraying or cold spray.

30 7. The method of any preceding claim wherein:
the spraying is to a thickness of 75 micrometers to 130 micrometers.

8. The method of any preceding claim the one or more cobalt-based alloys (34) each comprise by weight percent:

35 Co as said largest constituent;
25.00 to 32.00 Cr;
0.9 to 2.0 C;
3.0 to 6.0 W;
1.0-4.0 Fe;
40 up to 1.5 Mn, if any;
0.5 to 2.0 Si;
up to 0.1 P, if any;
up to 0.1 S, if any;
up to 2.0 Mo, if any; and
45 1.0-4.0 Ni; or

the one or more cobalt-based alloys (34) each comprise by weight percent:

50 Co as said largest constituent;
28.00 to 32.00 Cr;
0.9 to 2.0 C;
3.0 to 6.0 W;
up to 3.0 Fe, if any;
0.5 to 2.0 Mn;
55 0.2 to 2.0 Si;
up to 0.04 P, if any;
up to 0.03 S, if any;
up to 1.50 Mo, if any; and

up to 3.0 Ni, if any.

9. The method of claim 1 wherein the mixture of powders comprises by volume percent:

30.0 to 60.0 said one or more cobalt-based alloys (34); and
40.0 to 70.0 said WC-Ni (32),
optionally, either:

wherein the mixture of powders comprises by volume percent up to 20.0 Cr₃C₂ (36), if any; or
wherein the mixture of powders comprises by volume percent up to 10.0 Cr₃C₂ (36), if any.

10. The method of claim 1 the mixture of powders comprises by volume percent:

10.0 to 30.0 said one or more cobalt-based alloys (34).
8.0 to 30.0 said WC-Ni (32); and
50.0 to 80.0 Cr₃C₂ (36).

11. The method of any preceding claim wherein:

the substrate (22) is a seal substrate (160; 220) and the spraying is at least to a contact surface portion (162; 226, 227) of the substrate (22).

12. An article comprising:

a metallic substrate (22); and
a coating (26; 27) on the metallic substrate (22);
wherein the coating (26; 27) comprises by volume percent:

18.0 to 50.0 an alloy (34) having, by weight percent, Co as a largest constituent and 20.0-35.0 Cr; and
11.0 to 70.0 WC-Ni (32).

13. The article of claim 12 wherein the coating (26; 27) further comprises by volume percent:

up to 65% Cr₃C₂ (36), if any and wherein at last 95% by volume exclusive of porosity is said alloy (34), said WC-Ni (32), and said Cr₃C₂ (36), if any.

14. The article of claim 12 or 13 further comprising:

a counterface (171; 174; 175; 230; 250) in sliding engagement with the coating (26; 27) and comprising a nickel-based superalloy substrate; and/or
wherein the coating (26; 27) has a thickness of 50 micrometers to 200 micrometers;
and/or
wherein the substrate (22; 160) forms a split ring and the coating (26; 27) is on an outer diameter surface (162) of the substrate (22; 160); and/or
wherein the substrate (22) is a nickel-based superalloy or cobalt-based superalloy.

15. The article or method of any preceding claim, wherein:

the substrate (22; 160) is a split ring seal substrate (22; 160) and the spraying is at least to an outer diameter surface (162) of the substrate (22; 160); or
the substrate (22; 220) is a spring compression seal substrate (22; 220) and the spraying is at least to an outer an axial end surface portion (226; 250) of the substrate (22; 220);
the substrate (22) is a HALO seal substrate and the spraying is to an inner diameter surface of the substrate (22); or
the substrate (22; 420) is a locating pin substrate (22; 420; 500) and the spraying is to a base (422; 502) of the locating pin (22; 420; 500) or a distal end section (424; 514) of the locating pin (22; 420; 500); or
the substrate (22) interfaces with a locating pin (420; 500) and the spraying is to a counterface surface (432; 520) for the locating pin (420; 500); or
the substrate (22; 440) is a snap fastener substrate (22; 440) and the spraying is to a shaft (450) and a barb underside (454); or

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the substrate (22) is of a component (462; 466) having a snap fit bead (464) or groove (468) and the spraying is to said bead (464) or groove (468); or
the substrate (22) is of a component (480) having a tab (481) and the spraying is to a face (484; 485) of the tab (481); or

5 the substrate (22) is of a component (136; 172; 173; 232; 254; 410; 411) having a seal counterface (171; 174; 175; 230; 250; 408; 409) and the spraying is to the seal counterface (171; 174; 175; 230; 250; 408; 409).

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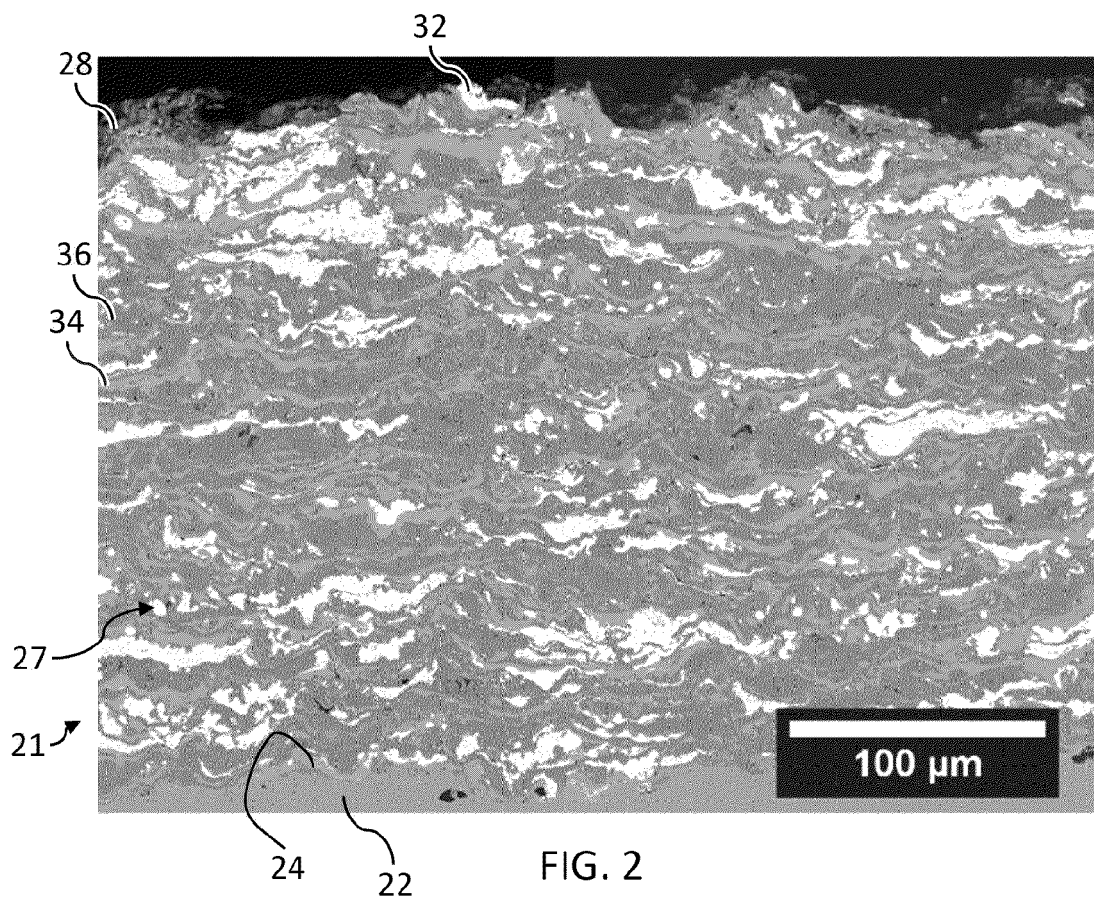
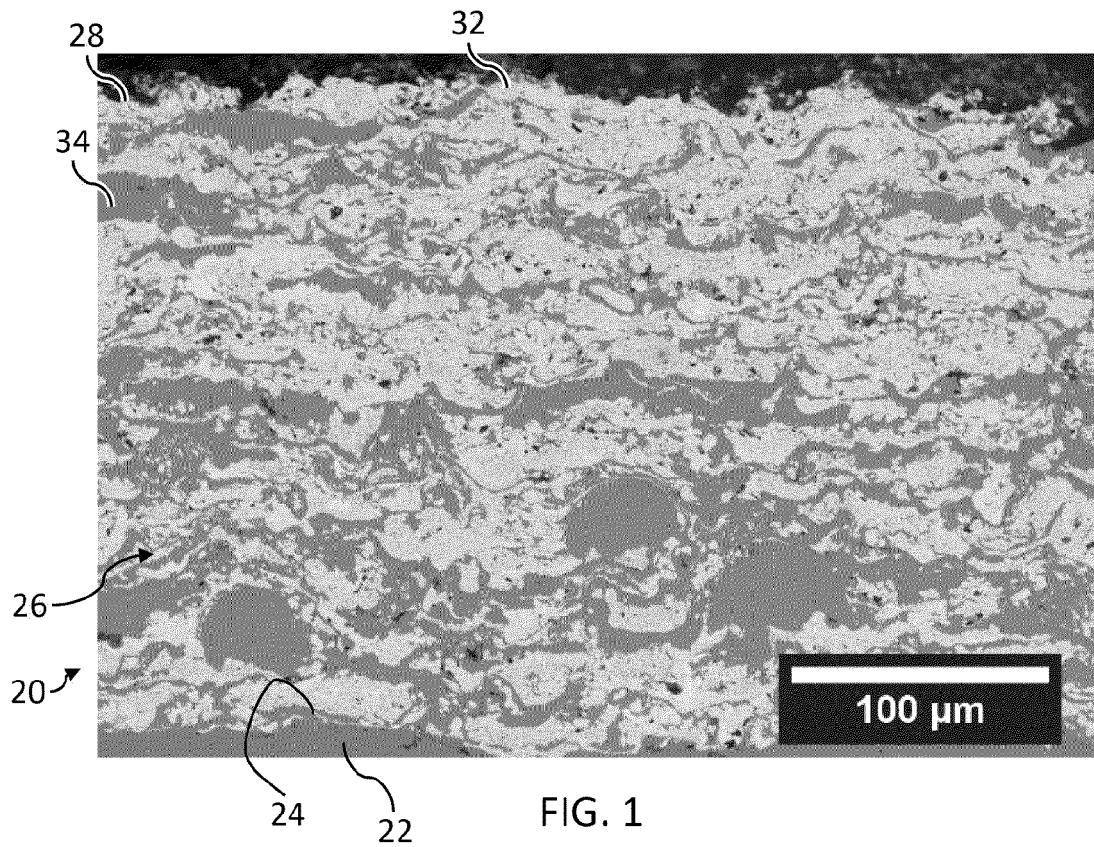
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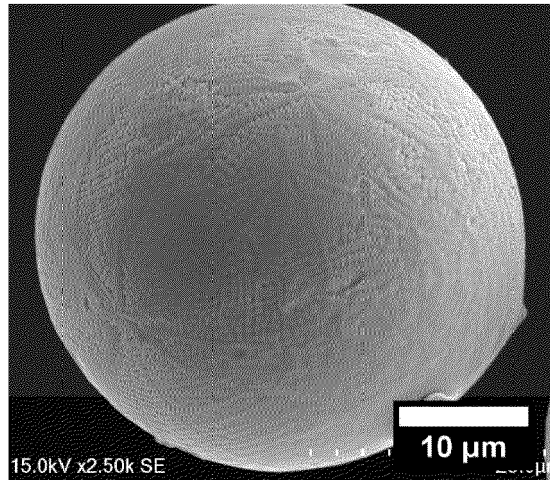


FIG. 3
Stellite™ 6
(Prior Art)

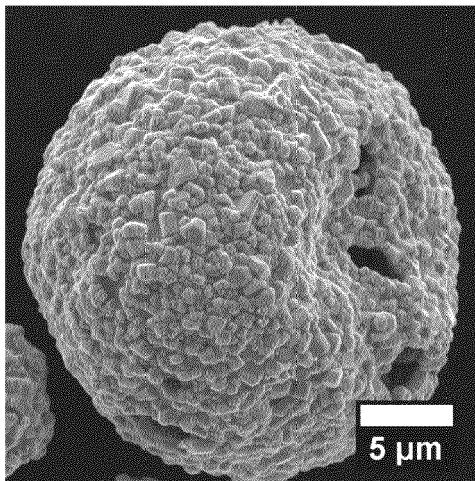


FIG. 4
WC12Ni
(Prior Art)

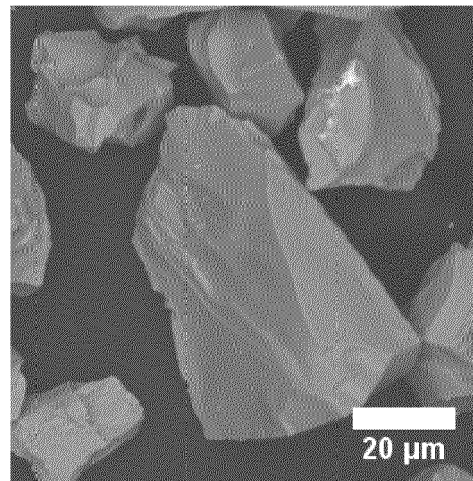


FIG. 5
Cr₃C₂
(Prior Art)

FIG. 6

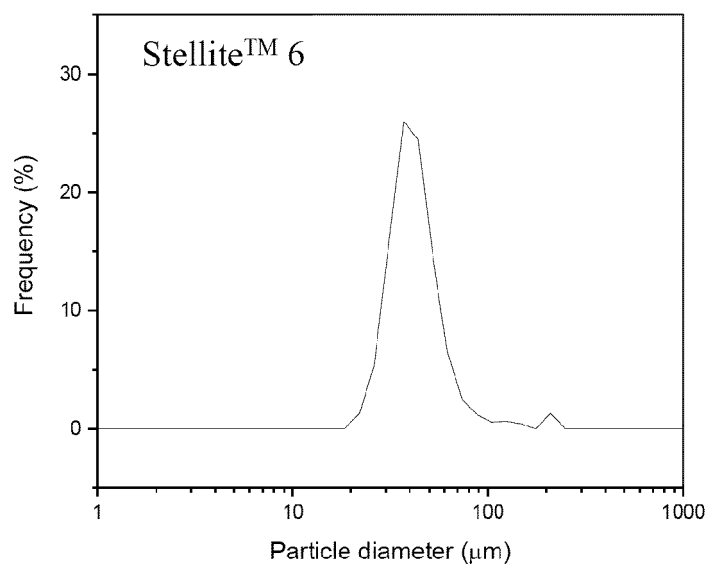


FIG. 7

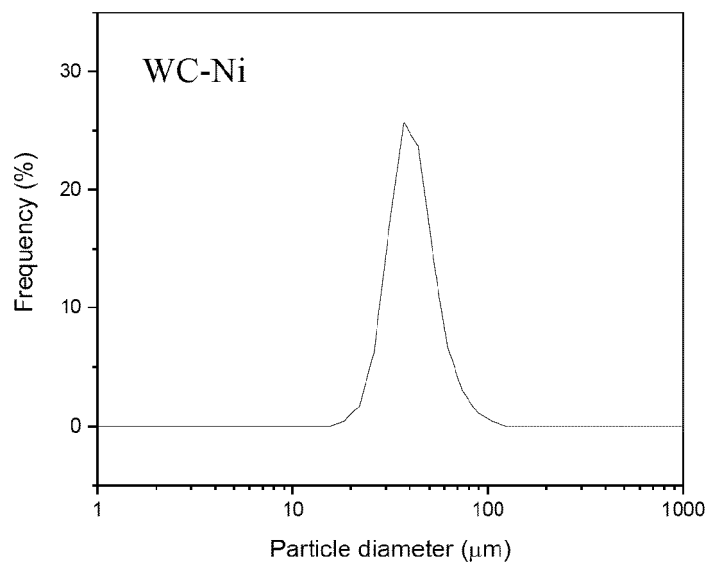
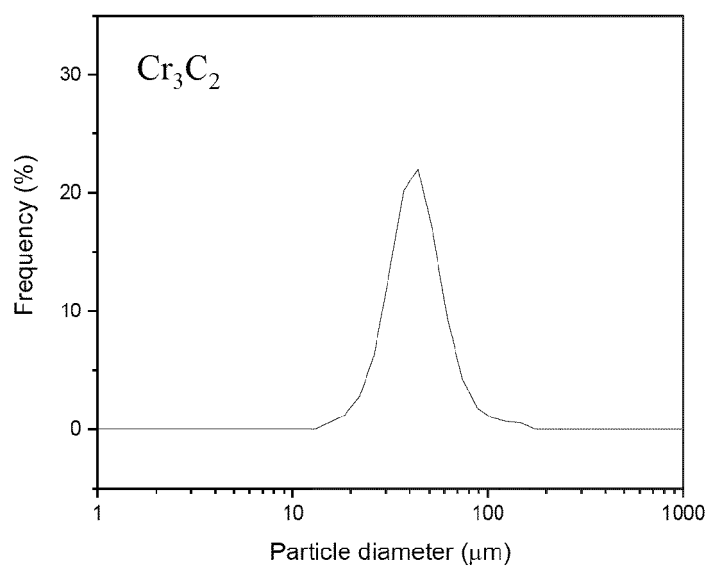


FIG. 8



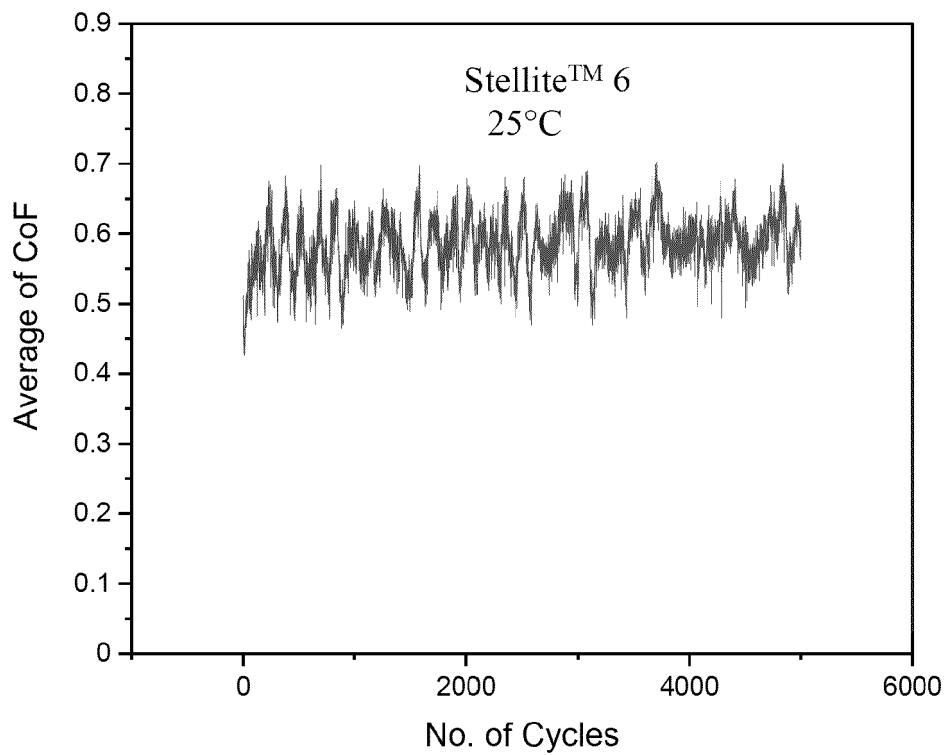


FIG. 9

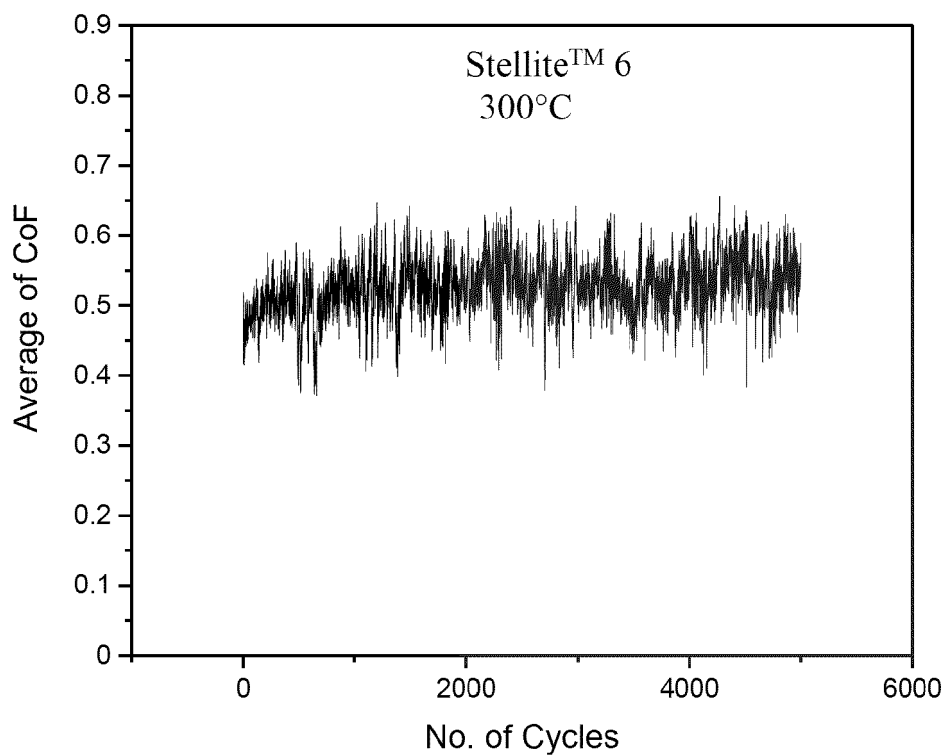


FIG. 10

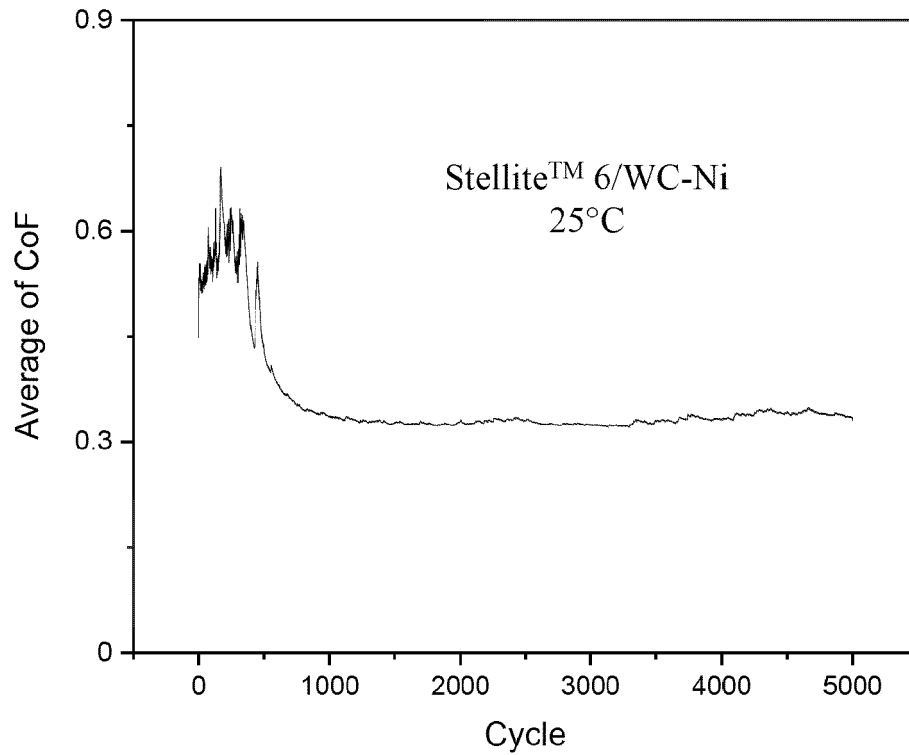


FIG. 11

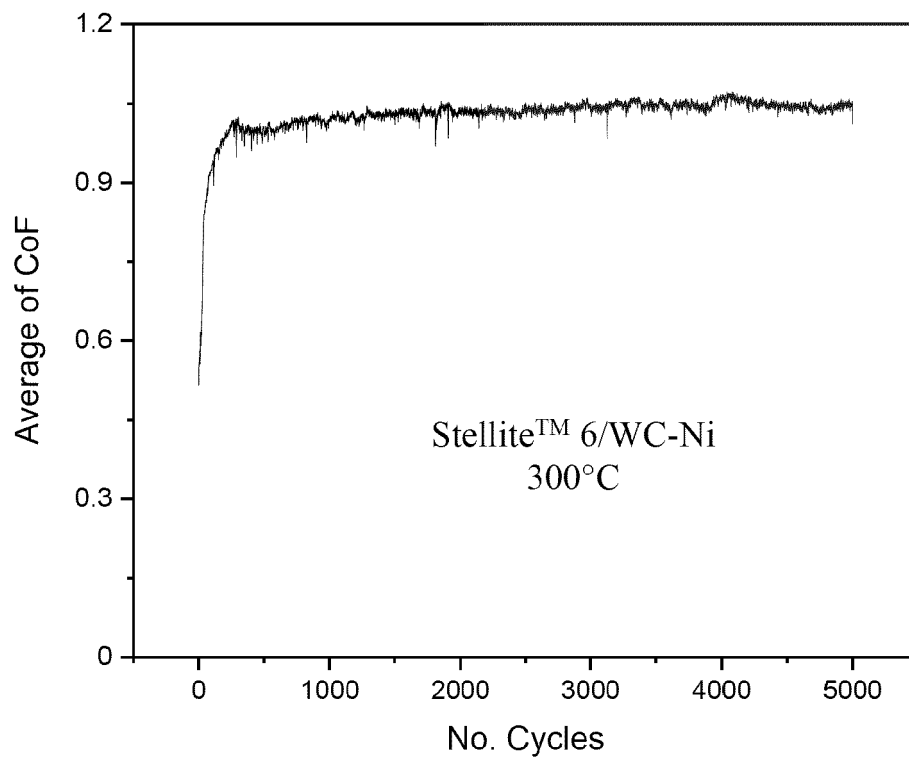


FIG. 12

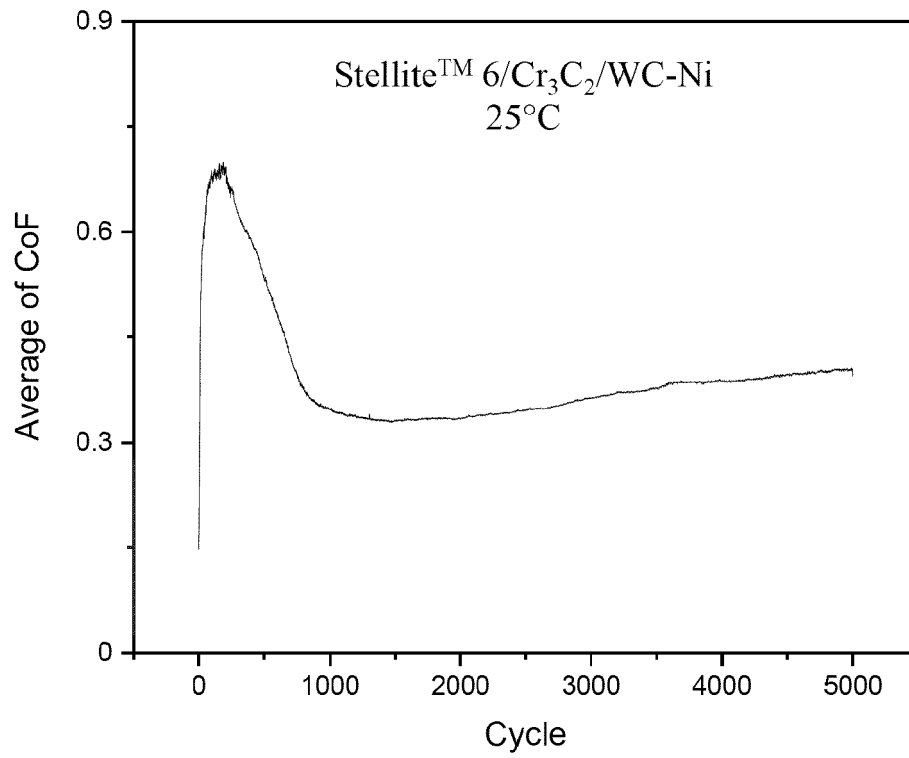


FIG. 13

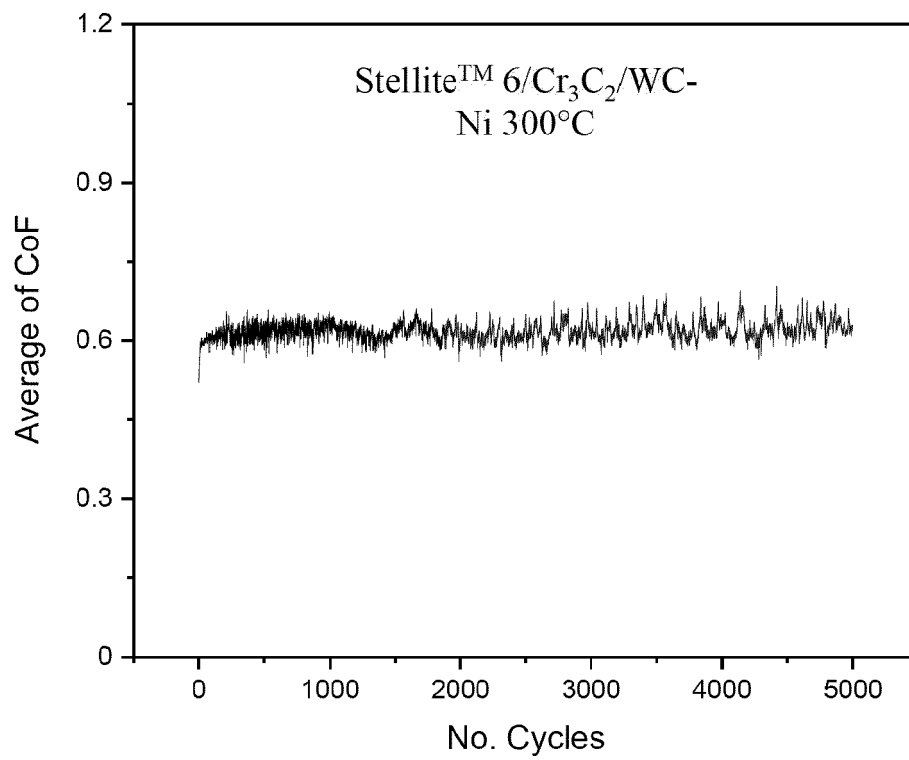


FIG. 14

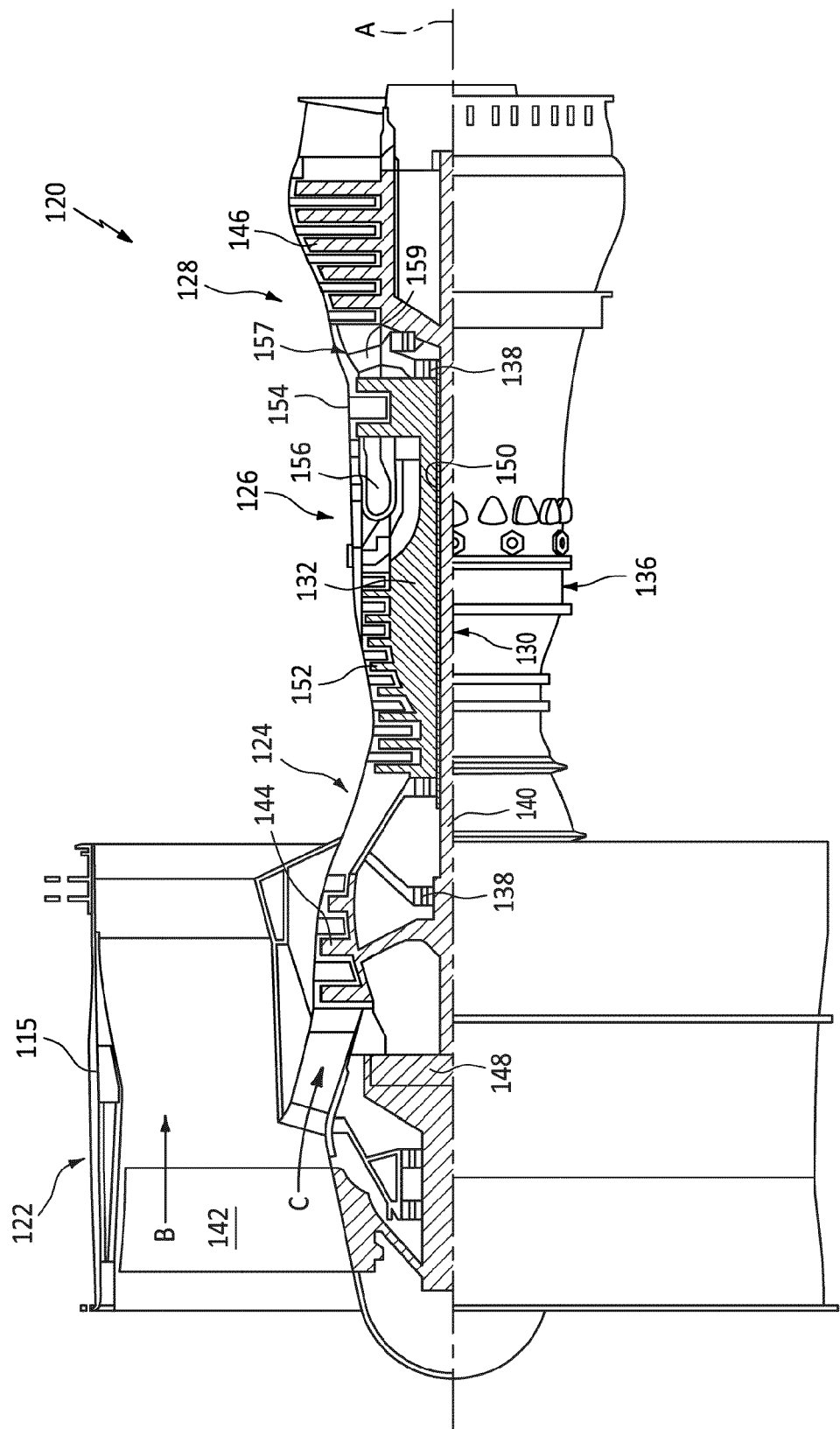


FIG. 15

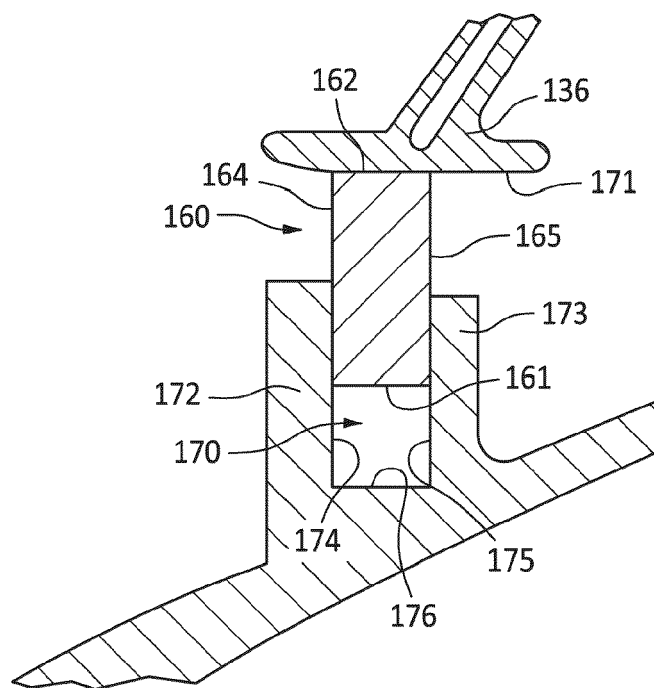


FIG. 15A

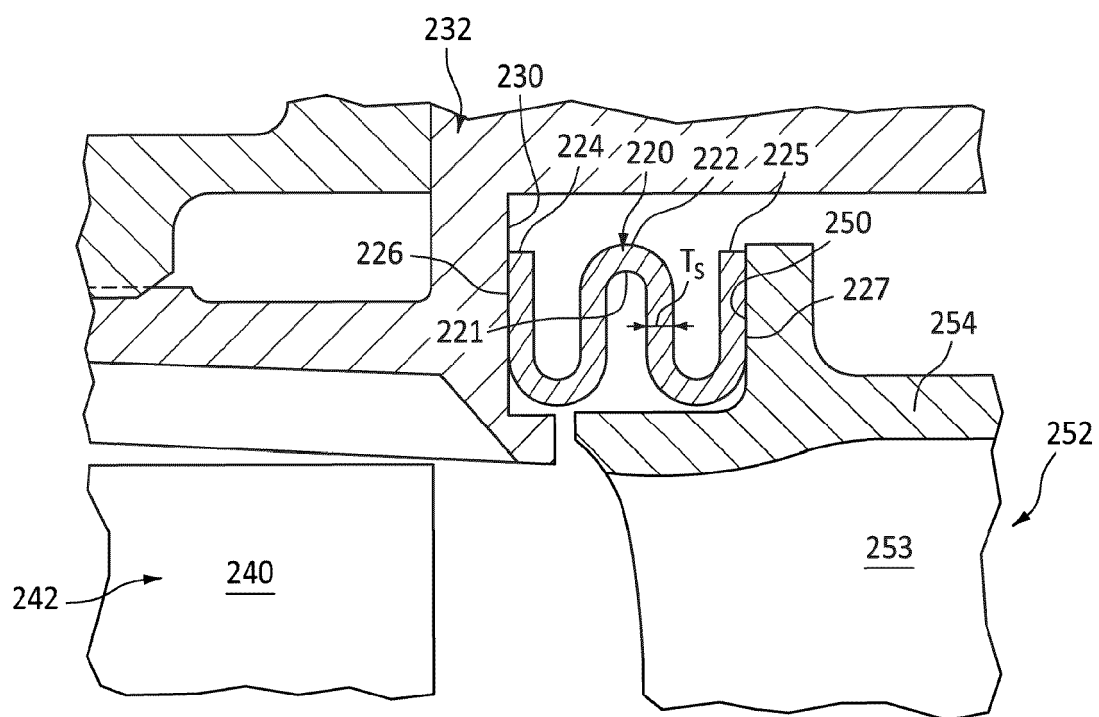


FIG. 15B

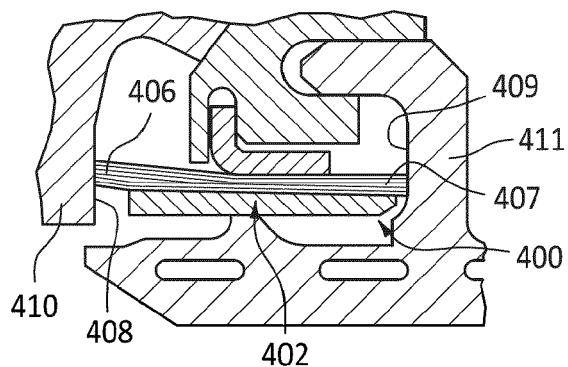


FIG. 15C

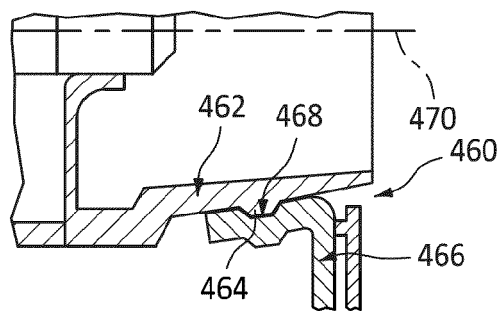


FIG. 15D

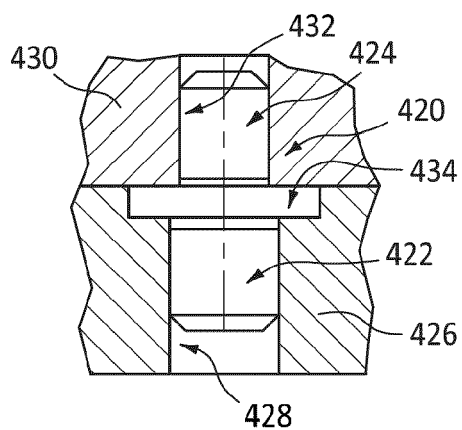


FIG. 16

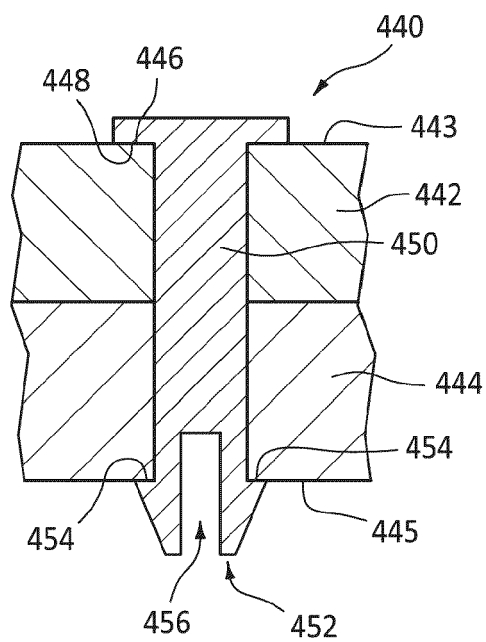


FIG. 17

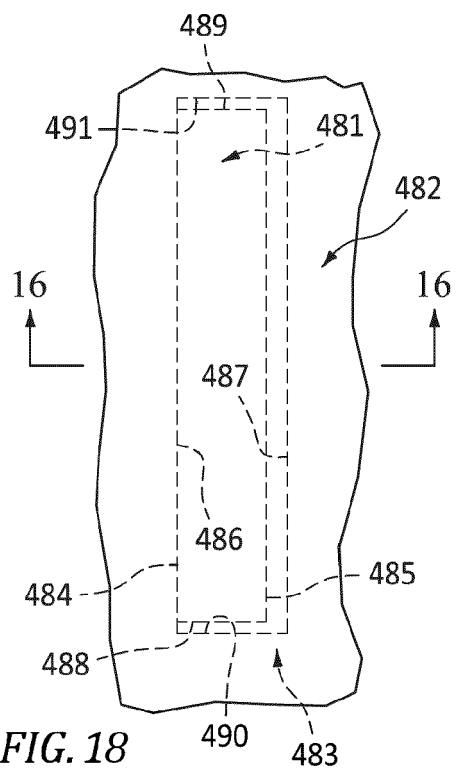


FIG. 18

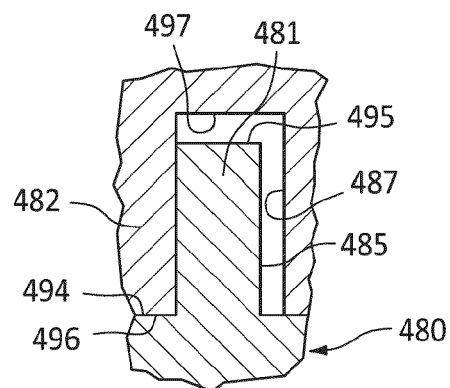


FIG. 19

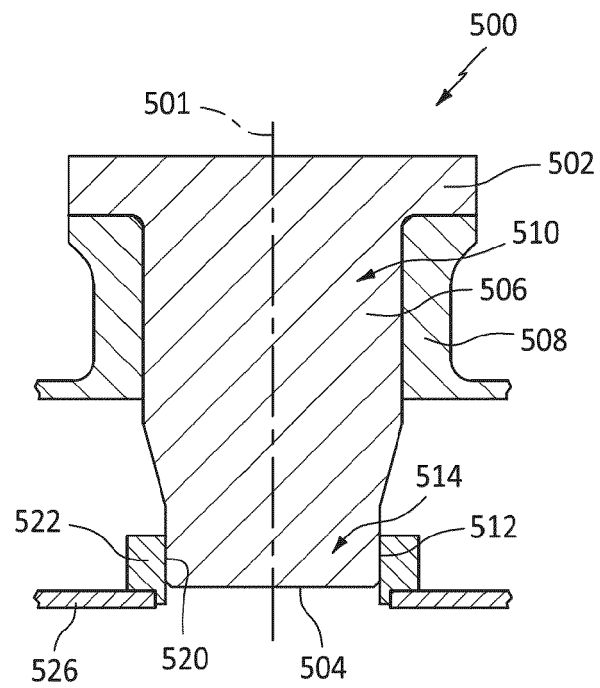


FIG. 20



EUROPEAN SEARCH REPORT

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Place of search The Hague		Date of completion of the search 6 September 2024	Examiner Chalaftris, Georgios
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