Advanced Processing Approaches for Producing Magnesia stabilized zirconia TBCs of high Quality Performance for multi-functional applications deposited by A.P.S technique on Ni-base alloys for blades and vanes of Aircraft engine parts and Machine tools.

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1-Abstract

Material performance in many industrial applications is strongly affected by the behavior of the surfaces. For example, corrosion response reactivity with environments, wear characteristics, and thermal properties are all critically dependent on surface character. Utilization of coatings to upgrade component performances is often a cost effective alternative to substitution of superior bulk materials. The advantage of coating technology, in general is that it marries two dissimilar materials to improve the performance of the whole. The coatings comprised of zirconia top coat and nickel-aluminum bond coat.

Ni - 5wt % Al (bond coat) and ZrO2 - 20wt % Mg O. (top coat) have been deposited on the super alloy Ni Cr 20 Ti Al. by using by A.P.S technique.

The main focus of this work is to study the surface microstructure, mechanical characteristic, and thermo-physical properties as well as their properties with those obtained using reference techniques. Thermal expansion studies were used to study the high temperature stability of the different coatings structures. As low thermal conductivity is one of the most important features of TBC, thermal diffusivity and specific heat measurements were carried out. Also the mechanical measurements (e.g. micro-hardness and tensile bond strength)

Key words: porosity, tensile bond strength, bond coat, top coat, corrosion resistance, micro-hardness, Thermal barrier coating, air plasma spray, plasma spray parameters, ceramic coating, thermal expansion coefficient, thermal conductivity, zirconia stabilized with magnesia and turbine-Engine.

2- Introduction

Aim and Scope of the Present Work

Plasma spraying is often assumed to be a mature technology in which all the important phenomena have been observed and described adequately.

TBCs are applied to metallic super alloys to not only limit heat transfer through the coating but to also protect engine components from oxidation and hot corrosion by reducing thermal conductivity and thermal expansion coefficient.

This project was designed to obtain a better understanding of the surface microstructure, phase structures mechanical characteristic, and thermo-physical properties of ceramic coatings and help the designers to increase the life of the turbine engine.

Review

Aerospace gas turbine engines are now designed such that the heat resistant super alloys operate at temperature very close to their melting, so current strategies for performance improvement are centered on thermal barrier coatings.

TBCs are often applied to metallic super alloys to extend the temperature regime in which a component can operate (1 - 6). A common failure mechanism of TBCs on thermal cycling is delamination of the ceramic just above the bond coat ceramic interface due to high local stresses and that thermal expansion mismatch between the substrate and ceramic layer is a significant contributor to these stresses (7 - 12).

Determination of the optimum parameters, powder structure, phase composition and thermal properties as function of the undergone laser treatments permits to select the suitable treatments improving the insulation function and also to study the influence of TBCs composition, thermal aging and chemical treatment on coating performance using A.P.S technique. The microstructural characterization plays a key role in understanding the structure-property relationship in a lot of materials, as well as in making some predictions about the service behavior of the related components and systems.To this aim, scanning

electron microscopy (SEM) can be a powerful tool to analyze both the morphological and microstructural features of powder-based and bulk materials, as well as the effects promoted by processing and aging on the final microstructure. This advanced technique of analysis can be successfully employed to study the unique microstructure of coatings produced by thermal spraying, starting from powder-based materials with different size (micro or nanostructured) and morphology. Thermal spraying processes of metallic, ceramic and composite raw materials are recognized as particularly suitable to fabricate protective coatings for multi-functional applications, such as thermal barrier coatings for blades and vanes of gas turbines, anti-oxidant coatings, anti-wear coatings for components and tools used in oil, paper and textile industries [13,14].The thermal effects associated to the spraying process play a significant role on the final microstructure of the deposited coatings and the microstructural analysis is expected to provide a great contribution in order to detect the typical characteristics and their dependence on processing parameters, as well as their evolution during thermal exposure or at typical service conditions, depending on the operative environment and usually promoting some degradation effects associated to oxidation, corrosion, erosion and wear phenomena. These environmental effects can typically produce phase changes, sintering, degradation and damaging by delamination and spallation, reducing the performance and the durability of the whole coating system [15-17]. The limited resolution of micro-tomography does not allow to resolve the finest features, such as the small micro cracks and Nano pores embedded within the microstructure, that contribute to the total porosity of the coatings and then affect their thermal and mechanical properties [18,- - 21]. The advanced Processing Approaches for Producing Magnesia stabilized zirconia TBCs of high Quality Performance for multi-functional applications deposited by A.P.S technique is commonly used in many industrial sectors including aeronautics and industrial gas turbines [22].

3-Methods

3.1. Process Description.

PLASMA - TECHNIK AG M - 1000 apparatus for plasma and auxiliary equipment for the spraying of aerospace components. It comprise : powder source (PT - 800), control console (M - 1000), plasma torch (F4), feed unit (TWIN - 10), water cooler system (T -powder 500) and holding device for the work piece in addition to dust separator (MK - 9) and wet separator (NA - 100). Figure (1)., gives a schematic diagram of the apparatus. Samples cut out of Nickel base super alloy Ni-Cr 20 Ti Al of DIN designation number is corresponding to 2.4631) of 1.4 mm thickness have been subjected to investigations. First, Ni - 5wt % Al (AMDRY, 956) alloy (bond coat) of 0.4 mm to 0.6 mm thickness and then, Zro2 - 20wt % Mg O (AMDRY 333) (top coat) of 0.5 mm to 0.8 mm thickness have been deposited by air plasma spraying method upon their surface.

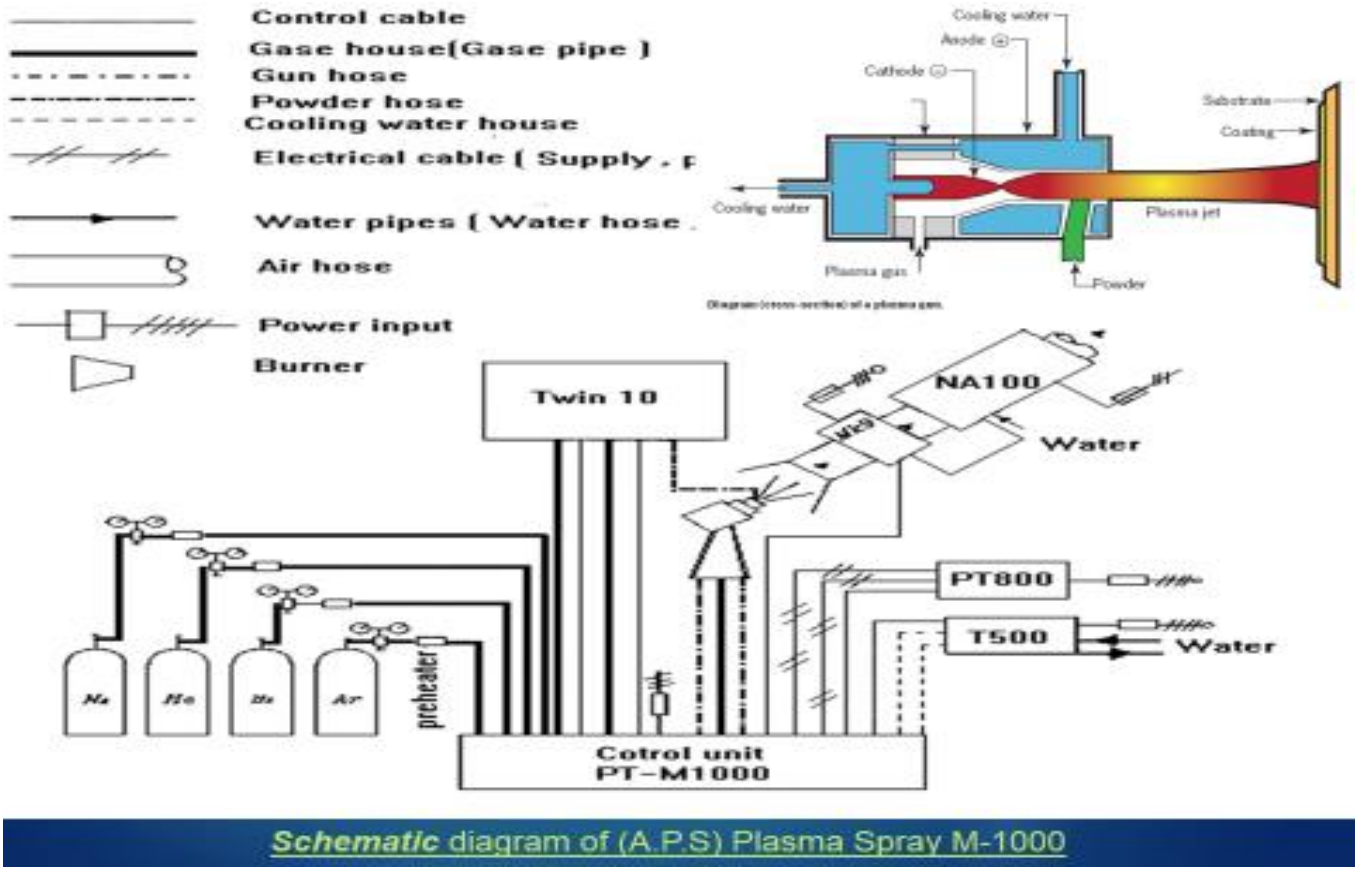


Figure (1) Systematic diagram of A.P.S (PLASMA - TECHNIK AG M - 1000 apparatus)

3-2 Spraying Material Investigation:

The most important powder parameters are grain size described, in ASTM standard B. 214- 86 using mesh designation number also, in DIN standard DIN 32529 using number to describe the grain size), internal porosity (correlated with apparent density and flow ability (described, in ASTM standard B. 329- 76 and B 213- 83. receptivity). E.D.X (Electron Diffraction X- ray) was used in chemical analysis. XRD (X- Ray Diffraction) was used in phase identification and quantitative phase analysis studies.

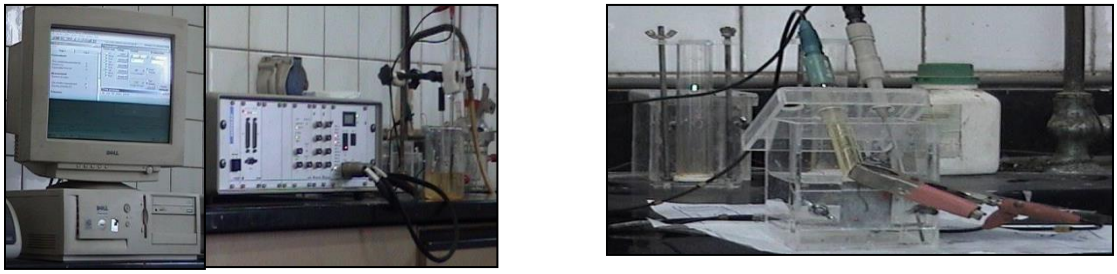
3-3 Surface Investigation:

The Vickers Hardness (HV3) was determined using ASTM E- 384 - 73 standard. The Tensile bond strength measurement using ASTM 633 - 96 or DIN 50160 standard. Porosity were tested with (MIP). EDX and XRD were used in chemical and phas identification. The corrosion behavior of specimens was determined using AUTOLAP PGSTAT 30 show in figure (2). Thermal conductivity, λ, was calculated from thermal diffusivity, α, with laser flash apparatus (Theta Industries Inc., Part Washington, NY, USA), specific heat, cp. With DSC 404 C, and density of the free standing coating specimen.

$$\Lambda = \alpha * Cp * \rho$$

TEC were carried out by dilatometer (Adamel Lhomargy SAS, model DI - 24, France).

TCR test was studied in a thermal cycling facility illustrated in figure (3) and table (1).



AUTOLAP PGSTAT 30 **CORROSION CELL**

Figure (2): Photograph of AUTOLAP PGSTAT 30 and corrosion cell

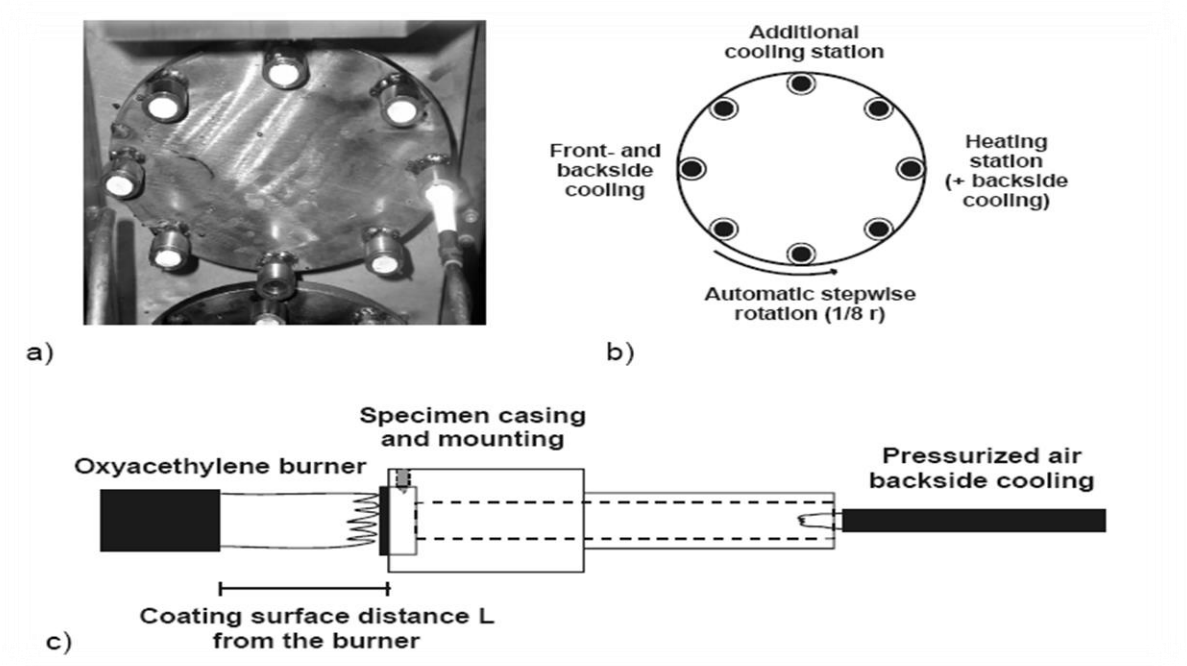


Fig (3). Illustration of the thermal cycling device, a) photo of the super specimen holder during test, b) position of heating and cooling stations and C) side view of the specimen mounting.

Table (1). Thermal cycling test parameter:

Parameter	Test
Coating burner distance (mm)	50
Coating maximum temperature C^0	1200
Coating minimum temperature C^0	250 ± 50
Heating time (sec)	20
Total cycle number	500

4- Result and Discussion

4-1 The Plasma Spray Parameter and Coating Performance

The deviation of plasma spray parameters from the optimum condition lead to the fine microstructure coating became lower in quality i.e. increase of porosity, voids (pull - out effect), un-melted phase, and delamination.

Plasma voltage versus H_2 - content % , Metallographic / Image analysis of sprayed Ni-Al bond coat are show in tables (6, 7) and ZrO2–MgO top coat with different spray parameters are show in Figures (9, 10) and (11, 12) receptivity. The effect of hydrogen may be roughly explained: the hydrogen ionization potential is lower than Argon only by about 2 E.V, and the high thermal conductivity of hydrogen at temperature higher than 400k results in a severe constriction of the arc column reducing the enhanced conductive thermal loses. These phenomena load to an increase of the electric field strength, and thus, of the arc voltage. The hydrogen flow rate has no effect on the particle velocity. The reason is that the acceleration of particle is linked to the flow momentum, which means that it depends strongly on the mass flow rate of the plasma gas. Because Argon ions are much heavier than hydrogen ions. The mass flow rate "of Argon was much higher than that of hydrogen. Correspondingly, Argon was mainly responsible for accelerating the powder particles. The higher particle velocity resulted in a worse melting behavior of the powder due to the shorter dwell time, leading to a lower coating thickness, namely a lower deposition efficiency of the powder. The arc current play a very important role with the increase of the pumping effect lead to increase in the particle velocity as well as in the particle surface temperature. The decrease in the plasma power led to a decrease in the deposition efficiency.

Table (6): The effect of the plasma gas on the coating performance of Ni - Al bond coat, at plasma current = 450 A, injector angle = 90º, substrate temperature = 140 º C, and injection distance = 130 mm

Specimen No	Plasma gas flow rate (L/min)		H_2-content (%)	Plasma voltage (V)	Hardness (HV_3)	Tensile bond strength (M. Pa)	Porosity (%)	Thickness (µ. m)
	Ar.	H_2						
S_0	47	9.5	20.2	68	190	35	2	250
S_1	47	8.6	18.2	60	150	30	6	160

Table (7): The effect of the plasma gas on the coating performance of Zr. O_2 -Mg O top coat at plasma current = 630 A, injection angle = 90°, substrate temperature = 150°C, and spraying distance = 90 mm.

Specimen No.	Plasma gas flow rate (L/min)		H_2-Content (%)	plasma voltage (V)	Hardness (HV_3)	Tensile bond strength (M. Pa)	Corrosion rate (m. p. y)	Porosity (%)	Thickness (µ. m)
	Ar	H_2							
$'S_0$	47	13	27.6	72	200	22	0.0683	9.8	230
$'S_1$	47	0	0	27	115	12	0.99135	18.9	155

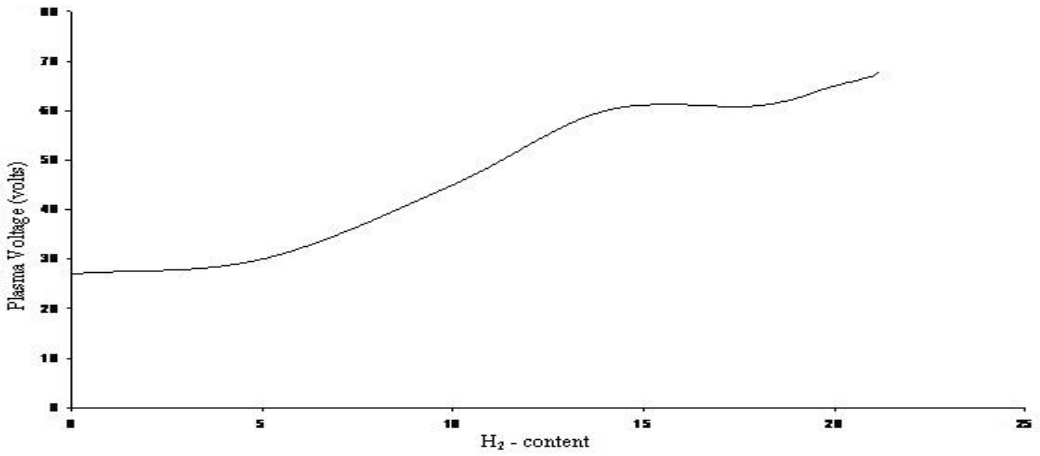
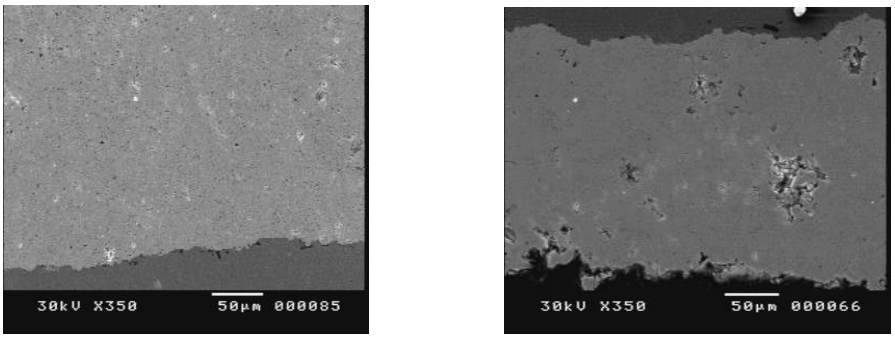


Figure (9): Effect of the percentage of H_2 - content on plasma voltage (plasma voltage versus H_2 - content %): Total flow rate = 56.5 L / min, I = 450 for Ni - Al bond coat.



S_0 **S_1**

Fig. (10): Back scattered SEM image for cross section view of Nickel - Aluminum bond coat sprayed with the optimum conditions (S_0) and Nickel - Aluminum bon coating sprayed decreasing of the H_2-gas flow rate (S_1) , H_2 - Content 18.2% show the effect of the % H_2 - Content on the plasma voltage(60V) and the porosity percentage (6%).

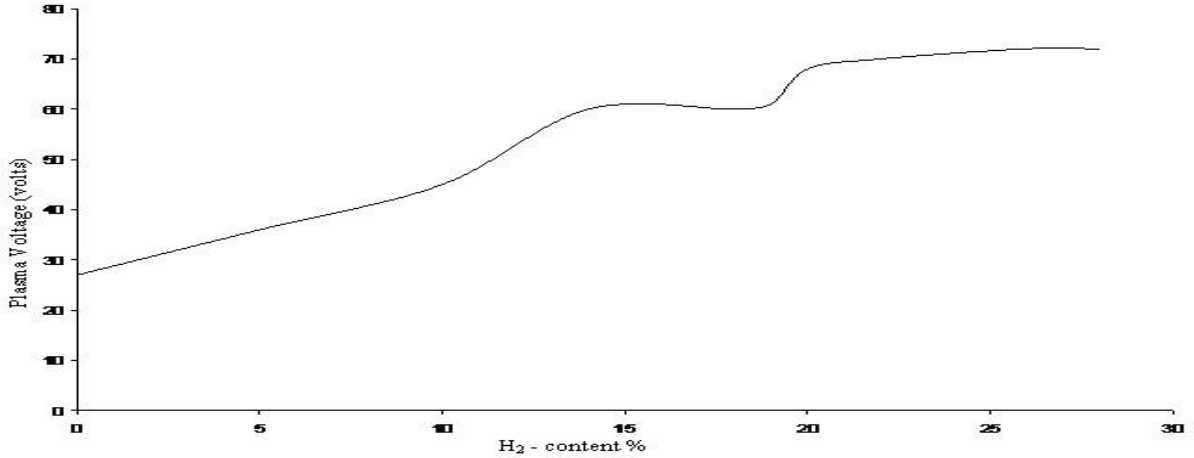
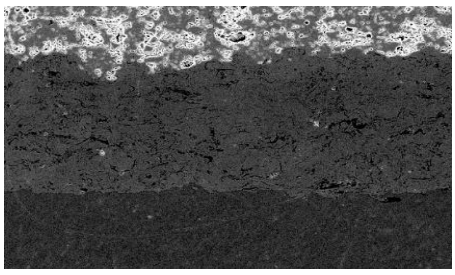
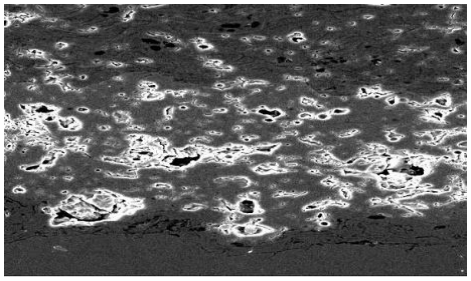


Figure (11): Effect of H_2-content % on plasma voltage, (plasma voltage versus H_2-content): Total flow rate = 60 L/min, I = 630A for zirconia (top coat) coating.



X-150
(Sub) + (Ni - Al) + (ZrO_2-MgO)
(/So)

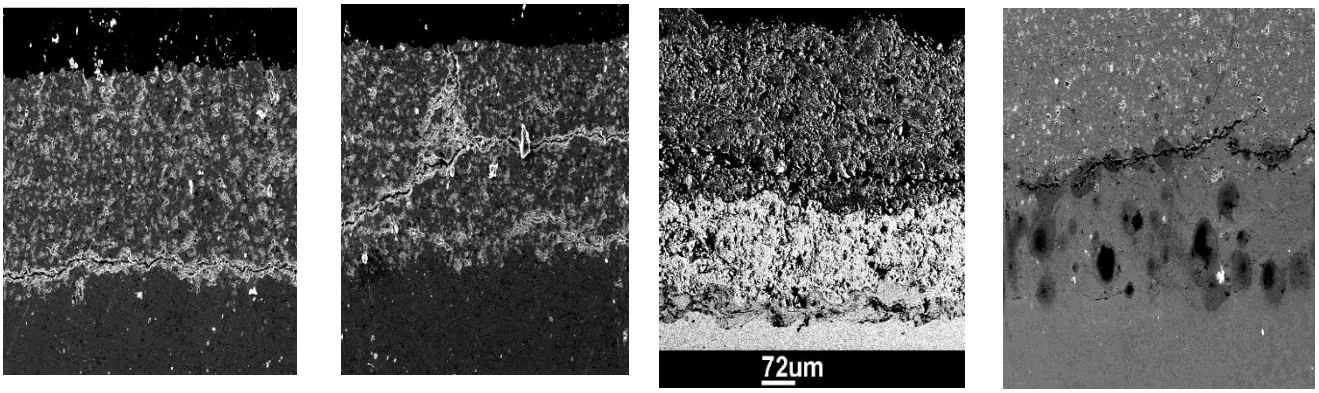


X - 150
(ZrO_2 - MgO) + (Ni-Al)
Pure Ar (no H_2), plasma voltages 27.6 V
(/S1)

Figure (12): Back scattered SEM image for cross-section view of zirconia (top coat) coatings on Nickel-Aluminum (bond coat) sprayed with the optimum conditions (/S_o), without H_2-gas flow rate (/S1)

4-3 Thermal expansion of thermal cycling and calculated thermal conductivity corresponding to the measured porosity:

The production of TBCs with fabrication of tow layers have suitable thermal expansion coefficient values for each layer lead to reduce the generation of residual stress, the coating failure by thermal cycles depends on the applied stress. The production of TBCs with fabrication of two layers have suitable thermal expansion coefficient values for each layer lead to reduce the generation of residual stress, the coating failure by thermal cycles depends on the applied stress. Pure Zirconia (not stabilized Zirconia) coating was damage after 280 cycles showed visible delamination and cracking. While the Reference coating peeled of near the bond coat after 950 cycles (double layer coatings). The close thermal expansion match between Ni-base super alloy and Ni-5wt% bond coat and also the close thermal expansion match between bond coat and 20wt% magnesia partially stabilized zirconia top coat lead to significantly longer thermal barrier substrate in cyclic temperature tests. This increased to 1200ºC. SEM after different cycles and the Calculation of the thermal conductivity λ (T) corresponding to the measured porosity results are presented in figure (14 and table (11) respectively.



X-75
Reference coating
after 400 cycles
(A

X-75
Reference coating
after 500 cycles
(B)

X-75
Reference coating after 950 cycles
(K)

X-75
Non stabilized ZaO_2
after 280 cycles
(C)

Figure (14): Optical microstructure (SEM) of undamaged coatings and damage coatings after 280, 400, 500 and 950 cycles.

Table (11): Calculated thermal conductivity, λ (T) results for reference material was used in λ (T) corresponding to the measured porosity.

Coating layer type deposited on Ni substrate using APS technique	Porosity (δ) %	Density (ρ) Kg/m^3	Specific heat (C p) J/Kg/K	Thermal diffusivity $\alpha * 10^{-7}$ m^2/S	Thermal conductivity $\lambda = \rho C_p \alpha$ W/m K	Temperature C°
Ni - base -super allay	0.1	8900	444	190	75	300
Din (2.4631)			580	130	66	700
			635	150	84.7	1000
			647	160	92.1	1300
Ni - 5wt % Al bond coat	2	7500	450	40	9	300
			530	41.5	10.2	700
			560	43	13	1000
			585	34	15	1300
ZrO_2 - 20 wt% MgO	9.8	4280	614	2.85	0.75	300
			640	7.5	2	700
			657	7.8	2.2	1000
			660	8.85	2.5	1300

4-4 Corrosion resistance and corresponding Vickers Hardness investigations.

The electromagnetic parameters derived from linear polarization on experiment and the corresponding Vickers hardness for blank, reference, and modified specimens with the same spray conditions are present in table (12).

Table (12): The electromechanically parameters. Corrosion potential E_{corr} corrosion current I_{corr} polarization resistance R_P, and corrosion rate C_R derived from linear polarization experiments and the corresponding hardness (HV_3) for blank specimen, reference and modified coatings with the same spray conditions.

Specimen Type	E_{corr} (v)	R_p Ohm. $Cm^2 * 10^3$	I_{corr} μ A/Cm^2	Corrosion rate (m.p.y)	Efficiency %	Hardness HV_3
Ni-base super alloy substrate	-0.297	8.416	3.2906	0.97832	—	180
ZrO_2 - MgO reference coating	-0.237	185.8	0.22988	0.06834	93.01	200

5- Conclusion

Plasma spraying has great advantage over the known galvanizing process in cases where it can be used to coat electrically non- conductive surface with metal.

In this study, A.P.S of T.B.Cs was investigated using several systems to conclude the influence of plasma spray parameters on the coating performance, from the obtained data, discussion and interpretation of the results, it could be concluded that:

1. **The effect of hydrogen lead to an increase of the electric field strength, and thus, of the arc voltage.**

2. **The hydrogen flow rate has no effect on the particle velocity.**

3. **The arc current play a very important role with the increase of the pumping effect led to an increase in the particle velocity as well as in the particle surface temperature. The decrease in the plasma power led to a decrease in the deposition efficiency.**

4. **The strengths are correlated with material used to spray, its size and method of preparation, processing technique, the selection of parameter substrate thermo physical properties e.g. thermal conductivity .Ideally the substrate/ coating temperature during deposition should be high enough to promote good cohesion coating, but not so high that coating adhesion is seriously impaired.**

5. **The deviation of the spray parameters from the optimum condition lead to high corrosion rates with lower efficiencies.**

6. **The corrosion resistance properties of Ni-base super alloy substrate are enhanced significantly by thermal spray treatment.**

7. **A number of new coating methods have evolved and older methods have been refined. New analytical tools are introduced. The development and evaluation of coatings are expensive and there is now a need, more than ever, to conserve resources, optimize test programmes and for a greater coordination dissemination of information.**

8. **The close thermal expansion match between substrate and bond coat and also the close thermal expansion match between bond coat and top coat lead to significantly longer thermal barrier substrate in cyclic temperature tests. This increased to 1200ºC.**

9. **Whilst the work is still at an interim stage, it has the potential of providing much improved barrier/corrosion resistant coatings for use on gas turbine parts.**

10. **Reducing heat losses increases efficiency but raises temperatures. Thus thermal barrier coatings are needed on valves, piston crowns and cylinder heads. To improve efficiency the engine can be operated uncooled, Viz, the adiabatic engine, requiring TBCs such as zirconia. Stabilized magnesia on a Ni-Al bond coating, graded and up to 0.8mm thick have performed well on piston crowns of marine diesels using normal fuel. Low quality fuel contains vanadium (V) which reacts with Y_2O_3 or CaO stabilizers in the ZrO_2 and causes disintegration. MgO. stabilizer is more resistant.**

11. **Good thermal stress resistance was achieved by ZrO_2 – MgO coatings on super – alloys. An inner Ni-Al layer improved fracture properties.**

6- Future Work

TBCs, need further development work, both in production technology and characterization Erosion - corrosion resistant, TBCs are needed to prevent overheating of metal part in engines and heat exchangers, for which both coating formulation and deposition methods are needed.

Thicker Zirconia coatings and more strain - tolerant coatings are needed for combustion Zones of aero gas turbine engines.

Repair of joining techniques for coating materials are always in need of further research. Some turbine blades in service have been re - coated several times, showing the importance of this aspect.

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