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ELECTRO DEPOSITED COMPOSITES—A REVIEW ON NEW TECHNOLOGIES FOR AEROSPACE AND OTHER FIELD

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An attempt has been made to review briefly, some of the developments that have taken place in the high temperature protective coating technologies applicable for aerospace and other fields. Drawbacks of diffusion coating methods are discussed and importance of adopting the electro-deposition route to produce low cost overlay and wear resistance coatings are emphasised.

Key words: Eectrocomposites, high temperature coatings, diffusion coatings, overlay coatings, wear resistance coatings.

INTRODUCTION

Stringent requirements of durability and reliability for materials used in aircraft propulsion, marine propulsion and electric power generation under severe conditions have paved the way for development of coatings for high temperature applications. Such applications demand retention of mechanical and surface integrity for thousands of hours under conditions of very high stress at elevated temperatures, in environments which can be aggresively corrosive. In many applications turbine airstream envirionments are such that the useful life of components is limited by coating failure. This review briefly discusses some of the devlopments of protective coatings for aerospace and other fields.

TURBINE ATMOSPHERE AND DIFFUSION COATINGS

Table I compares the relaltive severity of turbine airfoil degradation [1]. It is found that hot corrosion is severe to utility and marine engines whereas exidation takes place even to a greater extent in air craft engines. Severity depends on the levels of airborne contaminants (salt) and/or the fuelborne impurities (e.g. sulphur and vanadium) encountered in such applications.

TABLE-I: Relative services of turbine air-foil degradation

	Oxidation	Hot corrosion	Inter Diffusion	Thermal Fatigue
Aircraft	S	M	S	S
Utility	M	S	M	L
Marine	M	S	L	M

L = Light, S = Severe, M = Moderate

Normally turbine air foils are made of the materials shown in Table II. [2] Initially the base material surfaces were enriched with aluminium known for its best high temperature oxidation resistance. Chromising and aluminizing were also introduced later by means of the pack cementation methods. The alloy formed on the surfaces ($NiAl_3$ or NiAl) by these techniques provide the required oxidation resistance at high temperatures (1366k). The overall oxidation do not match the requirements of ductility and thermal fatigue resistance because of the presence of the intermetallic compound formed in them [3].

Diffusion coatings based on surface enrichment with chromium were also found useful by some workers [4]. The temperature capability of these coatings are limited due to the volatility of CrO_3. Surface enriching with silicon has recently been found to be promising in respect of hot corrosion resistance [2, 5].

TABLE-II: Some turbine engine components alloys [2]

Alloy	Nominal Composition
Nimonic	Ni 20 Co 15 Cr 5 Mo 5 Al 1.2 T
IN 100	Ni 10 Cr 15 Co 4.7 Ti 5.5 Al 3 Mo 1 v
INCO 713 C	Ni 13 Cr 4.5 Mo 2.4 Ta 0.45 Ti 6 Al 2.5 Fe
Nimonic	Ni 14.5 Cr 20 Co 1.25 Ti 4.7 Al 5 Mo
MAR 302	Co 21.5 Cr 10 W 9 Ta
FSX 414	Co 29.5 Cr 10.5 Ni 7 W 0.15 Y

OVERLAY COATINGS

A recent advancement in regard to these is the production of the coatings based on MCrAlY (M = Fe, Co, Ni or combination). The oxidation and hot corrosion resistance of these coatings can be varied over wide ranges to meet the selective requirements for turbine materials [6 to 8].

Thermal barrier coatings based on ZrO_2 have also found applications as in the case of parts of combustion chambers and guide vanes of aero engines [9, 10].

Composite coatings can be produced by the following techniques: (i) Plasma spray. (ii) Sputtering (iii) Foil cladding (iv) Electron beam evaporation (v) Electrodeposition.

The electron beam evaporation and plasma techniques are currently in great use on production scale.

Diffusion and overlay coatings containing aluminium are based on the formation of alumina under oxidising conditions. Oxygen active elements such as yttrium are added to improve the oxide adherence in overlay coatings. The best coating has the following nominal composition:

Chromium : 18% (by mass); Cobalt : 23%; Aluminium : 12%; Yttrium : 0.5 %; Nickel : balance.

To improve the mechanical life of the airfoils, superalloys fabricated by special technique such as direct solidifications may be used.

The oxidation resistance determined by 1394K cyclic burner rig test is given in Table III [1] (Rank 1 corresponds to the best).

TABLE-III: Ranking of coarings [1]

Composition		Oxidation resistance	Ductility
NiCoCrAlY + 1.6 Si + 8.5 Ta		1	—
" "	1.6 - 2.6 Si	2	4
" "	1.6 Si + 4 Ta	3	–
" "	8 Ta	4	5
" "	0.8 Ha	5	2
" "	Base plasma	6	1
" "	Base EB	7	3

NiCoCrAlY with 1.6 to 2.6% Si proved to be best when ductility was also taken into account.

Hot corrosion caused by variety of sulphite salt compositions is generally retarded by introducing chromium in the coatings. Nickel based materials are recommended for corrosion resistance at around 973K and cobalt based materials for higher temperature applications (1173k).

As regards the thermal barrier coatings, spalling has been the most obvious failure mode thereby limiting this class of coatings for gas turbine airfoils. When using the PVD technique, tantalum metal could not be incorporated in the overlay coatings due to its low vapour pressure even though its inclusion would be beneficial for resistance to hot corrosion [1]. As already indicated, yttrium in the coating improves the oxide scale adherence. This is achieved as a result of formation of pegs at the oxide/substrate interface. Though the criteria for selecting the overlay composition is to provide the best corrosion or oxidation resistance, mechanical properties of the coatings are equally important for the overall performance of the system. A typical Co-20Cr-6Al-0.1Y overlay on IN 738 alloy produced by low pressure plasma spray ductile to brittle transition at about 923K [9]. Though spalling is considered a limiting factor for thermal barrier ceramic coatings, MCrAlY type combination have been recommended as intermediate layers for such coating [10]. Another important factor in the selection of overlay coatings is the thermal mechanical fatigue cracking (TMF), the simultaneous cycling of temperature and mechanical strain is life limiting in many engines. TMF results from different heating and cooling rate to the thin and thick section of airfoils. To improve TMF behaviour, aluminide coatings are in great use in addition to the MCrAlY overlay combination. Aluminide coatings are associated with grain boundary oxidation in the case of polycrystaline alloys. But on single crystals only aluminide coatings proved to be the best for improving TMF behaviour [8]. In thermal barrier coatings based on ZrO_2, reduction of spalling is important. Electron beam pressure vapour deposition produces a columnar structure of ZrO_2 and exhibits superior spalling resistance reproducibility [8]. Some potential failure mechanisms of these coatings are shown in Fig. 1. For better performance of these, pores in them need to be reduced and should be not only small but also homogeneously distributed in order to accommodate the thermal strain. Identifying the ceramic structure is also important, in addition to improving the stability of the bond coating interface [11]. Aluminium-silicon diffusion coatings and platinum modified aluminium coatings have the desirable degree of high temperature resistance as required for turbine applications [2, 12].

Overlay coatings by electrodeposition

Cobalt-chromium/chromium carbide alloys have been produed by diffusion treatments of composite coatings. More complex alloys can also be obtained by codeposition of a mixture of relevant powders or pre-alloyed powder. The MCrAlY combination has successfully been produced by the electrodeposition technique. A

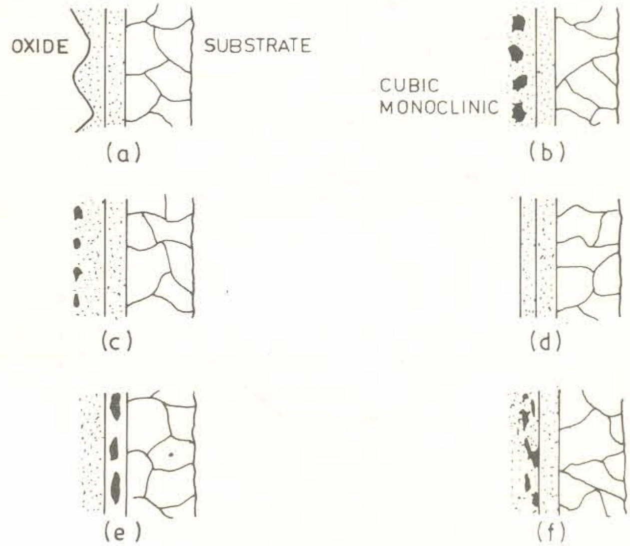


Fig. 1: Failure mechanisms of thermal barrier coatings [11]
(a) Spalling due to thermal cycling (b) Destabilization of ZrO_2 due to thermal cycling (c) Erosion microspalling due to particulate - Hot gas impingement (d) Reaction with fuel imparities (e) Oxidation of bond coat - Hot corrosion (f) Infiltrate by gaseous impurities and condensation of H1 σ phases.

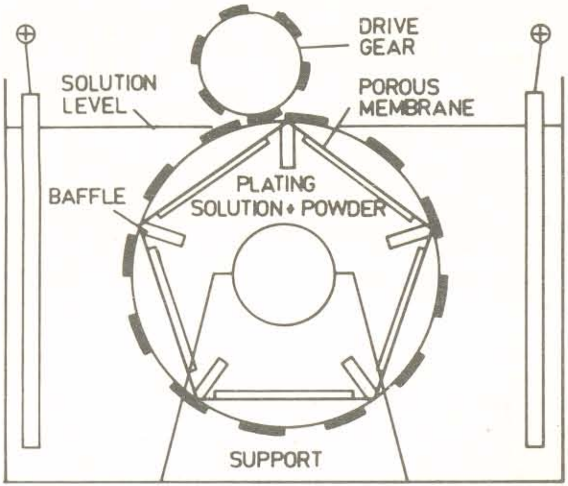
rotating barrel enables production of semibright coatings based on cobalt or nickel and prealloyed powder (66% Cr - 33% Al - 1% Y). Thus coatings containing 20% Cr, 10% Al and 0.3% Y can be produced. The experimental set up is shown in Fig. 2. Deposits containing 40% (v/v) of pre-alloyed powder after suitable heat treatment have thus been produced on overlay alloy coatings of acceptable composition [13]. Electrodeposited coatings are also found to be superior to plasma and PVD coatings.

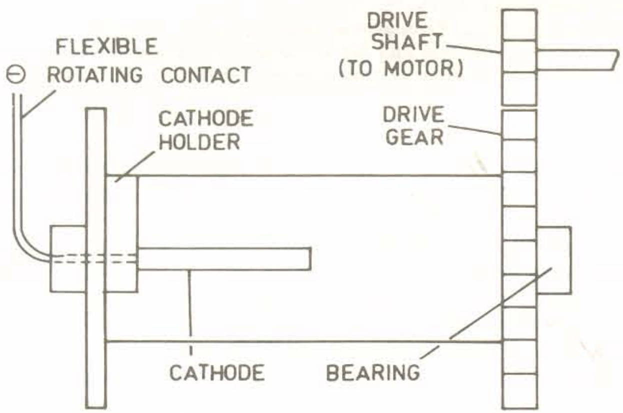
COATINGS FOR WEAR RESISTANCE

Cobalt-chromium carbide coatings provide very good wear resistance upto 573k due to the formation of a glaze like material which prevents metal to metal contact. The oxidation resistance can be improved by heat treating the composite to produce a homogeneous alloy [14]. Using a plate pumper technique, high quality coatings for aerospace industry [15] have been produced. The composite coatings based on nickel, cobalt and chromium with tungsten carbide, titanium carbide and zirconium diboride particulates find wide application in aero components [12, 16]. Cobalt based composites with desirably high wear resistance have been produced employing liquid or plate pump agitation technique. The electrolytic deposition of a four component alloy system can be achieved in two stages by deposition of a composite layer of Ni-Co-Zr and application of an undercoat or overlayer of chromium. The four components are then alloyed by diffusion at about 1273k under vacuum [17]. Nickel coatings deposited on alloy steel specimen from an electrolyte containing 30 Ti, 20Si, 20 SiO_2 20 Al and 20 ($g.l^{-1}$) when tested in 3% NaCl solution showed significant rise in the corrosion resistance after vacuum annealing of the coatings [18]. United Technology Corporation, USA, has recently filed a patent on electrodeposition of multi-nickel layers on turbine engine blade tips with abrasive particles followed by heat treatment for improved bond and fatigue strength [19].

CONCLUSION

The above review clearly shows the potentiality of overlay





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Barrell experimental setup for electrodepositing compositics [13]

coatings of MCrAlY and various other types for high temperature applications and that these can be produced at minimum possible costs by employing the electrodeposition technique. Various other techniques such as sputtering, plasma and electron beam evaporation require the use of more highly expensive requirements. In view of the fact that certain electrodeposition techniques are promising, commercial scale processes of electrodeposition of composites for applications requiring resistance to wear and high temperature are in the development stage.

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