What is an MCrAlY?

MCrAlY Powders
Thermal sprayed MCrAlY coatings are designed to provide oxidation and corrosion resistance in high temperature environments. The applications are typically on components from industrial gas turbines and aero-engines.

The group of MCrAlY coatings (M = Metal) can be iron based (FeCrAlY), nickel based (NiCrAlY) or cobalt based (CoCrAlY). Depending on the application, also combinations of base elements can be used (NiCoCrAlY, CoNiCrAlY, etc). Today, the largest field of applications can be found in the gas turbine industry. Typical applications include environmental protection for airfoils, shrouds, abrasive blade tips and as a bondcoat layer for Thermal Barrier Coating systems (TBC’s).

MCrAlY’s are widely used because of their excellent performance in engine environments. This is attributed to the selection of materials that are thermally and chemically compatible with their substrates, and which have a minimal effect on the substrate’s mechanical properties.

Performance is owed to the coating materials’ ability to generate tenacious protective scales that retard chemical interaction between the substrate and the corrosive environment. This protective scale is principally aluminium oxide. All MCrAlY coatings promote aluminium oxide formation.

However, it has been determined that besides aluminium, other elements present in the coating can oxidise. If these mixed oxides are allowed to form they are not as protective as alumina and coating degradation may be accelerated. Thus, knowledge concerning the mechanism of selective oxidation and the limits of aluminium oxide formation is necessary to the coating alloy development.

THE ROLE OF ALUMINIUM

It will become clear that the most obvious function of aluminium as a MCrAlY coating constituent is to provide a reservoir or reserve of metal to constantly replenish the oxide scale. Scale growth however is governed by the inward diffusion of oxygen along its (oxide) grain boundaries. This controlled by the alumina corundum structure. The behaviour or activity of aluminium is further proportional to the chromium content.

MCrAlY’s Explained
CHROMIUM AS AN ADDITIVE

As indicated, the oxidation rate of a MCrAlY coating is directly proportional to the formation rate of the continuous aluminium oxide scale present on its external surface. The formation of the scale is related to aluminium activity and its diffusivity into the alloy.

Chromium substantially increases the aluminium activity and enhances its diffusion rate. The addition of chromium thus effectively lowers the aluminium content required to form the oxide film (excessive aluminium may cause brittleness).

WHY YTTRIUM?

Critical to the service life of a MCrAlY coating is the adherence of the aluminium oxide film. For, as the scale is spalled away the coating's aluminium reserve is withdrawn to replenish the film. The addition of yttrium to the coating material promotes the scale adhesion. Yttrium has limited solubility in MCrAlY alloys, therefore, the excess precipitates within grain boundaries as yttria. The yttria forms pegs which protrude into the coating alloy and its surface scale. The coating alloy and the aluminium oxide film are thus mechanically keyed i.e. pinned together, hence scale adherence is improved.

OTHER ADDITIVE ELEMENTS

Silicon and hafnium additives to MCrAlY alloyed coatings are like yttrium, provided to improve oxide scale adherence. Hafnium, reported to react chemically similar to yttrium is often substituted for that element.

Combinations of silicon and chromium when added to CoCrAlY alloyed coatings, enhance the hot corrosion resistance while increasing aluminium activity – especially at lower concentrations.

Oxidation and sulphidation of a MCrAlY coating may be improved by adding tantalum. The addition of small amounts of noble metals is believed to provide properties similar to those exhibited by chromium.

Platinum, for example, has been reported to improve both oxidation and hot corrosion resistance, even at temperatures to 1100°C.

COATING ALLOYS SELECTION AND USAGE

Generally speaking, of all the MCrAlY alloyed coatings, FeCrAlY's usually exhibit the highest resistance to oxidation and corrosion. However, they readily diffuse into the base metal which rapidly depletes the FeCrAlY aluminium content to levels where the protective oxide scale cannot be regenerated, rather, it spalls or is easily eroded. Consequently, as a coating material over nickel or cobalt based alloys, FeCrAlY coatings should be limited to operating temperatures of 650 – 750°C.

CoCrAlY coatings have excellent hot corrosion resistance. However, the oxidation resistance is below that experienced with NiCrAlY’s. It is recommended that coating usage be confined to an operating realm of 870 – 930°C, and where the environment may be laden with sodium and/or sulphur, as is the case with marine turbines.
CoCrAlY’s are adept at modifying the thermochemistry of molten Na2 SO4 by altering oxygen and sulphur activity thus reducing the rate of attack.

NiCrAlY coatings are usually selected for aircraft and land based applications. This is due to their outstanding oxidation resistance and diffusional stability. They are useful at temperatures in the 980°C range. As indicated, both NiCrAlY and CoCrAlY overlay coatings significantly increase the serviceability of superalloys. However, as also indicated, each coating type exhibits limitations.

NiCrAlY coatings, while providing excellent diffusional stability and oxidation resistance, require improvements in hot corrosion / sulphidation resistance.

Conversely, CoCrAlY coatings, while providing extremely high hot corrosion / sulphidation resistance, require improvement in those regions where NiCrAlY performs well. It has been determined that substituting a small percentage of the cobalt, in a CoCrAlY alloy coating, with nickel can attain this. Nickel dramatically increases and improves the operating capabilities of the coating in this series. Referred to as CoNiCrAlY or NiCoCrAlY they exhibit outstanding ductility while providing a satisfactory and adjustable balance of oxidation and hot corrosion resistance. Interdiffusional characteristics are also improved.

These coatings are seen as filling the voids where neither NiCrAlY’s or CoCrAlY’s were fully satisfactory.

The aforementioned coatings are particularly suited for gas turbine applications when deposited by plasma and HVOF processes.

Generally speaking, a layer used as a TBC bond is only air plasma sprayed (APS) with a coarse surface texture.

This class of coating is used on combustion cans, ducts and NGV platforms, whereas, VPS or HVOF coatings are applied in the form of both overlay and bond coat. Both HVOF and VPS coatings can be sprayed with either course or fine surface textures. These latter coatings are used for environmental protection – oxidation / hot corrosion resistance – on turbine vanes and blades, and often exhibit densities exceeding 99%.
FINISHING

A MCrAlY layer applied as a TBC bond coat, is overlayed by a zirconia top coat, in its as sprayed condition and finishing is not normally required. Those coatings that are provided to resist airfoil environmental degradation are generally finished to improve aerodynamics. This is normally accomplished by mechanical polishing. Shroud and blade tip coatings are normally ground to size. Where a MCrAlY coating is to be finished it is recommended that mechanical and/or thermal enhancement be provided prior to any stock removal. Mechanical conditioning is usually accomplished by shot peening.

Thermal treatments are typically two hours at 1080°C. This will be varied to suit the coating/substrate combination. These procedures are intended to both densify the coating and improve its bond strength. Coatings of yttria stabilised zirconia are either fully stabilised (20%) or partially stabilised (8%). These coatings are stable, hard and dense with excellent resistance to erosion and thermal shock.

The level of yttria stabilisation of the coating is expressly tailored to customer requirements. As a result of zirconia’s instability the material will change phase when subjected to high temperature. At about 1100°C zirconia undergoes a phase transformation which causes the material to grow 3%. This growth can cause a coating to crack and eventually spall. The addition of a stabilising agent, such as yttria, calcia, or magnesia resists the phase change thus increasing thermal shock resistance and mechanical properties.

However, yttria stabilised zirconias perform better at elevated temperatures and during thermal cycling, than either their calcia or magnesia counterparts. This is, in a part, due to the fact that yttria is a more effective stabilising agent than calcia or magnesia.

TBC’S

The major application for yttria stabilised zirconias, in combination with one of the highly allowed MCrAlY bond or overlay coatings, is as a TBC system in aero and industrial gas turbines. These duplex systems exhibit excellent thermal characteristics and are designed to withstand constant and cyclic exposure to the high temperatures within the hot section of the gas turbine. These coating systems have been traditionally sprayed by plasma.

However, today HVOF coatings are increasingly used to apply the MCrAlY layer in preference to plasma, when geometrical constraints allow. This is due to improved coating density and tensile bond strength, especially on gas washed areas of the turbine.

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