

SURFACE STRENGTHENING OF OVERLAY COATINGS

This invention relates to the field of coatings for superalloy substrates. The coating and the coated articles described in the present application are
5 useful in high temperature environments including gas turbine engines at extremes of temperature and stress. Through the use of the present invention substantial increases in useful coating life are possible.

Superalloys are widely used particularly in gas
10 turbine engines. The demands placed on superalloys in modern gas turbine engines require that they be given a protective coating in order to adequately resist the environment to which they are exposed for a useful period of time. Overlay coatings consist of a metallic
15 layer which is applied to the substrate. One used family of overlay coatings is that referred to as MCrAlY coatings where M is a metal selected from the group consisting of nickel and cobalt and mixtures thereof. Patents describing coatings of this type include U.S.
20 Patent Nos. 3 542 530, 3 676 085, 3 754 903 and 3 928 026.

By their nature, overlay coatings are optimized to resist environmental attack, namely oxidation and hot corrosion. The compositions which lend themselves to providing the requisite oxidation and corrosion
25 resistance are generally not particularly strong and it has not generally been recognized that strength is an important coating requirement since it has generally been thought that the substrate material provides the strength while the coating material provides the environmental
30 protection. However, it has been observed in certain situations that where turbine engines are operated at extremes of temperature and stress strains that the prior art coating material appears to flow and to form a surface pattern referred to as rumpling consisting of
35 alternating peaks and valleys. This phenomenon can occur early in the service and it is a serious problem since it reduces the effectiveness of the articles and can reduce engine efficiency. Rumpling is detrimental in several respects. First, the valleys in the coating represent

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areas of reduced thickness where environmental attack can rapidly affect the substrate. Secondly, the peaks in the coating interfere with the gas flow and can
5 result in local increases in metal temperature which can increase the rate of attack. Thirdly, the surface area of the coating is increased which can lead to more rapid depletion of protective elements. And finally, the roughened surface can lead to fatigue
10 crack initiation.

Attempts have been made to address this problem through the development of stronger coatings but these attempts have not been successful since all attempts to produce stronger coatings have compromised the
15 environmental resistance of the coating.

In a related area, increasing development efforts have been aimed at the production of so-called thermal barrier coatings. These are coatings usually of a ceramic material which provide a thermal insulating
20 effect thereby reducing the temperature of the underlying substrate and/or coating. Such coatings can also benefit the oxidation resistance of the substrate and/or coating even though most thermal barrier coatings are permeable to corrosive gases.
25 The corrosion and oxidation benefit from thermal barrier coatings arises from the fact that the thermal barrier coating can reduce the metal temperature by as much as 111°C (200°F) thereby substantially reducing the rate of attack. Prior art patents dealing with
30 thermal barrier coatings include U.S. Patent Nos. 3 091 548, 4 055 705, 4 095 003, 4 248 940, 4 269 903, 4 321 310, 4 328 285 and 4 335 190. Some of these patents describe the application of thin ceramic coatings to overlay coatings and may for example include
35 ceramic thicknesses on the order of from 25.4 to 1270 µm (1 to 50 mils). However, from consideration of the specification and examples in these patents it is clear that these are broad ranges and not reflective of the preferred ranges which would be

used by one seeking the true thermal barrier (insulative) effect.

In prior art thermal barrier coatings, the ceramic thickness is usually greater than the MCrAlY or bond coat thickness. In the present invention the ceramic thickness will usually be less than the MCrAlY or bond coat thickness.

To the knowledge of the inventors it has not heretofore been appreciated that a thin ceramic coating on an overlay coating can strengthen the surface of the overlay coating and prevent its deformation and flow under extremes of temperature and stress without producing any significant thermal barrier benefit.

The present invention comprises a surface strengthened coating system which can protect metal articles from environmental attack particularly under conditions of high temperature and high stress. The coating system includes an initial overlay layer of an MCrAlY coating on the substrate having a thickness of from about 76.2 μm to about 254 μm , (about 3 to about 10 mils) and a thin ceramic layer on the overlay layer having a thickness of from about 7.62 to about 101.6 μm (0.3 to about 4 mils), preferably from 12.7 μm to 76.2 μm (0.5 to 3.0 mils), and most preferably from 12.7 to 50.8 μm (0.5 to 2.0 mils).

The ceramic outer coating strengthens the surface of the overlay coating preventing rumpling in service even after extended periods of time.

Other features and advantages will be apparent from the specification and claims and from the accompanying drawing which illustrates an embodiment of the invention.

The Figure is a graph showing the surface roughness of a coating produced according to the present invention and a coating produced according to the prior art as a function of time at temperature.

The invention coating consists of a metallic layer of an MCrAlY composition having a continuous adherent thin

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ceramic layer on its outer surface. The broad composition for the MCrAlY is 10-30% Cr, 5-15% Al, 0.01 to 1% Y (or Hf, La, Ce, Sc, and mixtures thereof) with M, the balance being selected from the group consisting of Co, Ni and mixtures thereof. Minor amounts of other elements such as silicon may also be used without departing from the scope of the invention. Such alloys are known in the prior art for use alone as protective coatings and are described in various U.S. patents including 3 542 530, 3 676 085, 3 754 903 and 3 928 026.

This invention also contemplates the possible use of various interlayers between the superalloy substrate and the MCrAlY layer and in particular it is known from U.S. Patent No. 4 005 989 that the provision of an aluminide layer (produced by pack aluminizing) between the substrate and an MCrAlY layer can provide improved coating durability. Other materials such as platinum have also been proposed for interlayer use. Of course, such interlayers will only be used where necessary and only where they do not adversely affect the bond between the substrate and the MCrAlY coating.

The MCrAlY layer may be applied by vapor deposition, plasma spraying or sputtering. Vapor deposition has the advantage of producing a smooth surface although recent advances in plasma spraying can also provide a usefully smooth surface. Sputtering will also produce a smooth surface. It is known to use a variety of post coating treatments in order to improve the properties of the MCrAlY coating including peening and heat treatment.

As an optional, though preferred next step, the MCrAlY layer can be oxidized to produce an alumina surface layer. Such oxidation can be performed in air at a temperature of between about 260° and 1093°C (500° and 2000°F). We have used hydrogen atmosphere at a temperature of about 1080°C (about 1975°F) for about four hours. The use of a commercially pure hydrogen atmosphere appears to produce a desirable oxide coating

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by virtue of the inherent oxygen impurities in the atmosphere.

Following the application of the MCrAlY coating and the optional oxidation step, the thin ceramic surface layer can be applied. We have employed partially stabilized zirconia as the surface ceramic coating material. The selection of zirconia has been based in part upon the relatively low thermal conductivity of zirconia. We believe, however, that other ceramic materials will produce an equivalent result. The ceramic layer must be adherent to the MCrAlY coating and adherence is believed to require in part some solid solubility between alumina which is the native oxide forming on the MCrAlY layer and the surface ceramic material. The zirconia employed to date has been partially stabilized with either yttria or magnesia in order to eliminate the detrimental phase transformation which would otherwise occur in the use temperature range. Other ceramics which may be employed include alumina, ceria, mullite, zircon, silica, silicon nitride, hafnia and certain zirconates, borides and nitrides.

It must be emphasized that the function of the ceramic layer is one of strength rather than thermal insulation. The thickness of the ceramic layer is so slight that the thermal advantage resulting from the layer is negligible, less than 28°C (50°F). The strengthening effect has been observed to persist even after spallation of the ceramic (resulting from application process defects) has left only thin residue of the ceramic on the MCrAlY coating.

The ceramic coating can be applied by a variety of techniques including plasma spraying, sputtering and vapor deposition. Plasma spraying is a preferred technique mainly from an economic standpoint. Sputtering and vapor deposition can under some situations both produce structures containing defects or cracks extending from the substrate to the surface of

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the coating. It is a surprising observation that even coatings with such numerous defects are effective in strengthening the surface of the overlay coating. It is theorized that the relative percentage of the surface area exposed to the cracks is slight and that each island of ceramic material is firmly bonded to the overlay coating and is effective in eliminating the surface flow and rumpling which would otherwise occur.

10 The present invention will be better understood through consideration of the following illustrative example. Samples of a nickel base superalloy were given a 127 μm (5 mil) coating of a NiCoCrAlY material having a nominal composition of 20% Co, 18% Cr, 12% Al, 0.4% Y and
15 balance Ni. This material was applied by vapor deposition in accordance with the teachings of U.S. Patent No. 3 928 026. The coated articles were vapor blasted and were then heat treated at 1080°C (1975°F) for 4 hours consistent with commercial practice; during this heat
20 treatment an alumina layer formed on the surface. One of the bars was then given a 25.4 μm (1 mil) coating of yttria stabilized zirconia (7% yttria) using a plasma spray technique. Material was provided in the form of 0.037 mm (-400 mesh) powder and was sprayed
25 from a high energy plasma gun in a plasma spraying apparatus operated at a pressure between 98.7 kPa and 13.3 kPa (one atmosphere and 100 mm of Hg); the feed input to the gun was 40 volts, 900 amps, 5.66 m³ (200 cubic feet) of argon gas and 40 grams/minute of the ceramic
30 powder. The part being coated was maintained at a temperature of less than 316°C (600°F). After coating, the surface roughness of the samples was measured and was found to be for the case of the MCrAlY material about 1.27 μm (50 microinches) (arithmetic average)
35 and in the case of the ceramic coated material about 1.90 μm (75 microinches) (arithmetic average). These samples were then tested in a burner rig which produced an open flame which heated the material to a temperature of about 1163°C (2125°F) using the following temperature cycle

1163°C (2125°F)/2 minutes + 1010°C (1850°F)/10 minutes + force air cool for 2 minutes. Since the bars were not internally air cooled, the thermal effect of the ceramic coating was negligible. The Figure shows the comparative roughness of the two samples as a function of exposure time. It can be seen that the sample coated with only the MCrAlY material went from a surface roughness of 1.27 μm (50 microinches) to a surface roughness of about 15.87 μm (625 microinches) in 1400 hours, an increase of about 12X. In contrast the ceramic coated sample went from a starting surface finish of 1.90 μm (75 microinches) to a final finish of 5.08 μm (200 microinches) in the same period of time, an increase of less than 3X.

In another evaluation two turbine blades were prepared and engine tested. The blades had a nominal composition of 9% Cr, 10% Co, 12% W, 1% Nb, 2% Ti, 5% Al, 0.015% B, 2% Hf, balance nickel and had an MCrAlY layer 127 μm (5 mils) in thickness, of a nominal composition of 18% Cr, 23% Co, 12.5 % Al, 0.3% Y, balance nickel, applied in accordance with the teachings of U.S. Patent No. 3 928 026. One of the blades then received 50.8 μm (2 mil) thick coating of zirconia stabilized with 7% yttrium using a previously described plasma spray coating process. These two blades were tested in a JT9D-7Q gas turbine engine having a thrust capability of about 21792 kg (48,000 pounds). The test consisted of a series of cycles simulating severe commercial service. The cycles were performed at a rate of about 1000 cycles in about 150 hours and the maximum gas temperature was about 1538°C (2800°F). Periodic inspections were made and it was found that the blade having only the overlay coating had failed in about 2,000 cycles. After 2,000 cycles the substrate surface was partially exposed and had started to oxidize. After 2,000 cycles the blade having the invention coating had not failed. The ceramic coating was intact and there was no visual indication of attack of the

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overlying MCrAlY coating.

Thus it can be seen that the provision of a thin ceramic layer having a trivial thermal insulating effect can reduce the relative degree of rumpling by at least 4X.

In a third evaluation of the invention two sample bars were prepared following the same procedure described with regard to the initial illustrative example. One had a ceramic coating thickness of 76.2 μm (3 mils) while the other had a ceramic coating thickness of 101.6 μm (4 mils). Testing was performed following the procedure described with respect to the first example. This testing sequence is representative of the conditions to be found in a modern high performance commercial gas turbine engine, e.g., a first turbine blade application. The 76.2 μm (3mil) coated sample withstood 1100 hours of testing with no spalling of the ceramic material and testing was discontinued at this time. The 101.6 μm (4 mil) coated sample displayed a significant spallation in 250 hours of testing. Thus, in a severe gas turbine engine environment 101.6 μm (4 mils) appears to be the upper limit for coating thickness if spallation is to be avoided.

It should be understood that the invention is not limited to the particular embodiments shown and described herein, but that various changes and modifications may be made without departing from the scope of this novel concept as defined by the following claims.



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CLAIMS

1. A coated article characterized in comprising
 - a. a superalloy substrate
 - 5 b. an MCrAlY overlay coating on at least a portion of the substrate and having a thickness in the range from 76.2 to 254 um (approximately 3-10 mils)
 - c. a thin durable adherent ceramic coating on at least a portion of the overlay coating said ceramic coating being effective in reducing coating rumpling without providing a significant thermal barrier effect and having a thickness in the range of from 7.62 to 101.6 um (approximately 0.3-4 mils)
- 10 2. A coated article according to claim 1 characterized in that the MCrAlY overlay coating has a composition consisting essentially of 10-30% Cr, 5-15% Al, 0.01-1% of a material selected from the group consisting of Y, La, Ce, Sc and mixtures thereof, balance selected from the group consisting of Ni, Co and mixtures thereof.
- 15 3. A coated article according to claim 1 characterized in that the ceramic coating has a thickness of from about 12.7 - 76.2 um (0.5 - 3.0 mils).
- 20 4. A coated article according to claim 1 characterized in that the ceramic coating has a thickness of from about 12.7 - 50.8 um (0.5 - 2.0 mils).
- 25 5. A coated article according to claim 1 characterized in that the thermal benefit resulting from the ceramic layer is less than about 28°C (50°F).
- 30 6. A coated article according to claim 1 characterized in that the ceramic is essentially stabilized zirconia.
7. A method for reducing rumpling in an overlay coating having a thickness in the range from 76.2 to 254 um of MCrAlY to a superalloy substrate characterized in that it comprises applying a thin durable adherent ceramic coating having a thickness in the range of from 7.62 to 101.6 um to the overlay coating.
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8. A method according to claim 7, characterised in that the ceramic coating has a thickness of from about 12.7 - 76.2 m (0.5-3.0 mils).
- 5 9. A method according to claim 7, characterised in that the ceramic coating has a thickness of from about 12.7 - 50.8 m (0.5-2.0 mils).
- 10 10. A method according to claim 7, characterised in that the thermal advantage from the ceramic coating is less than about 28°C (50°F).
- 15 11. A method according to claim 7, characterised in that the ceramic is essentially stabilised zirconia.
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