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**OVERHAUL PROCESS FOR ALUMINIDE COATED
 GAS TURBINE ENGINE COMPONENTS**

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4 Claims

ABSTRACT OF THE DISCLOSURE

An overhaul process for coated gas turbine engine components is described wherein the components are: removed from the engine at or prior to the onset of significant coating penetration as evidenced by the loss of one or more substrate components; recoated in a pack cementation process of high aluminum activity without stripping of the old coating; and are subsequently heat treated to promote the formation of aluminides having an aluminum content less than that corresponding to Ni_2Al_3 .

BACKGROUND OF THE INVENTION

The present invention relates in general to the generation of oxidation-resistant aluminide coatings on the nickel-base superalloys, particularly in the overhaul and repair of coated gas turbine engine components.

It is the standard practice in the gas turbine engine industry to establish inspection, repair and overhaul cycles for the various engine models on a statistical basis which is related to the projected lifetimes of selected engine components. While a number of factors are involved in determining the length of such cycles and in the past the factors have involved various mechanical properties such as fatigue or creep of the substrate alloy, at the higher operating temperatures of a number of the advanced engines the components are very often coating-limited which means that in many cases it is deterioration of the coating rather than accumulated mechanical stress on the part which determines the duration of the overhaul cycle. It also means that, if the coating can be restored, the part can be salvaged and reused, possibly several times. This is of particular advantage in the case of certain advanced thin-walled hardware incorporating air cooling where the expense involved in the initial production of the component makes salvage almost mandatory, if feasible.

The present practice with salvageable parts following a coating deterioration or breakdown is to: remove all of the original coating; rework the part as necessary; and then recoat utilizing one of the standard techniques such as slurry-diffusion. These current salvage operations are not without drawback however. Most aluminide coatings are produced by or involve a diffusion mechanism whereby the coating is formed by reaction of the coating material with the substrate elements. Therefore, the formation of the usual 3 mil coating involves consumption of at least 2 mils of the substrate alloy. Thus, the removal of the old coating, even from areas where a coating failure has not occurred, necessarily results in the loss of some substrate material and a reduction in the thickness of the part. While the loss of substrate material is of some, although often lesser, concern in the case of thick walled components, the loss of 2 mils or more of thickness on the more advanced hardware, some sections being but 15-20 mils thick, is intolerable. Furthermore, there are the additional problems involving the time and expense related to the stripping operation, not to mention the difficulty of a uniform or controlled material removal. Because of these factors, there is an unacceptably high scrap rate associated with

the utilization of the current overhaul and repair techniques.

SUMMARY OF THE INVENTION

It is a primary object of the present invention to provide an improved overhaul and repair procedure for aluminide-coated superalloy components which have been exposed to a high temperature oxidizing environment.

The above and other objects and advantages of the invention are provided by processing the part involved prior to excessive coating degradation or failure, in a pack cementation aluminizing process utilizing a pack mix of high aluminum activity at the coating temperature, without stripping the prior coating therefrom.

A particularly preferred process comprises the steps of: removing the part to be processed from its oxidizing environment prior to the onset of any substantial oxidative attack on the superalloy substrate elements; superficially cleaning the oxide layer therefrom; recoating the part in a pack aluminizing process utilizing a pack mix of sufficiently high aluminum activity at the coating temperature to preferentially form the nickel aluminides having an aluminum content equal to or greater than that corresponding to Ni_2Al_3 ; and subsequently heat treating the coated components to cause further diffusion thereby converting at least a portion of the aluminides to those having an aluminum content less than that of the Ni_2Al_3 phase.

**DESCRIPTION OF THE PREFERRED
 EMBODIMENTS**

Diffused aluminum coatings for the protection of various metals from high temperature oxidation have been in use for over fifty years. Two major processes are generally used for the application of such coatings to nickel-base gas turbine hardware. The first involves covering the surface of the metal to be protected with a slurry of aluminum in a liquid vehicle, followed by drying and firing at an elevated temperature. The second process comprises the steps of embedding the article in a dry powder mix of aluminum, an inert filler such as powdered alumina, and an activator such as ammonium chloride, and heating the pack to some elevated temperature for a period of time sufficient to form a coating of the desired thickness. This latter process is typically referred to as pack aluminizing or pack cementation aluminizing. While various other elements may be added to the pack mix either as rate-controllers or to impart some additional specific property to the coating, nevertheless all such coatings consist primarily of intermetallic compounds, such as nickel aluminides derived from the aluminum in the pack and elements from the substrate and from which the basic oxidation resistance is derived.

In general, the thickness, composition and structure of a pack cementation coating are determined by the following controllable variables: (a) pack mix composition; (b) processing temperatures; (c) time at temperature; and (d), any subsequent heat treatment of the coated component. Historically, the pack cementation processes have been performed in large retorts necessitating the use of long times at temperature to obtain thermal equilibrium. To prevent large differences in coating thicknesses as a result of different thermal histories in such large containers, a pack mix of low time-sensitivity is generally employed, such a mix being characterized by a low aluminum activity.

It has now been discovered that, if the aluminum activity of the pack mix is such that the equilibrium coating phase is $NiAl$ or other phases lower in aluminum content, then the coating will form only by outward diffusion of nickel from the substrate and the phases will form on top of the substrate alloy. Virtually no aluminum motion is

involved in the formation of such a coating. While this is an unusual diffusion phenomenon, it has nevertheless been experimentally established. On the other hand, if the aluminum activity of the pack mix is such that the equilibrium coating phase is Ni_2Al_3 or phases higher in aluminum content, then the coating will form only by an inward diffusion of aluminum and virtually no nickel motion is involved in the formation of such a coating. Again, this is an unusual and unexpected diffusion phenomenon, but nevertheless experimentally established.

For mechanical property reasons, the coating comprising the Ni_2Al_3 phase generated in a pack of high aluminum activity cannot be practically employed in many cases because of its brittleness. Therefore, the coated alloy is normally subsequently heat treated to cause further diffusion to occur which promotes the formation of the more ductile $NiAl$ phase. Because the driving force of high aluminum activity is no longer present, nickel diffusion from the substrate now occurs in combination with diffusion of the aluminum from the Ni_2Al_3 phase to form a layer of $NiAl$ beneath the original Ni_2Al_3 coating.

The aluminide coatings derive their protectivity from the intermetallic compounds of aluminum which in turn are protected by a thin layer of aluminum oxide formed by high temperature oxidation of the coating. Gradually, however, the oxide is lost by a process of erosive spalling, but a reoxidation occurs and the protective function is reestablished. Accordingly, the substrate remains protected as long as sufficient aluminum is retained in the coating to provide for the preferential oxidation to aluminum oxide, and a coating failure or rapid degradation occurs when one or more of the substrate metals commences to oxidize. The protective function of the coating is, hence, a direct function of its aluminum content.

A major factor contributing to the success of the present invention involves recognition of the fact that aluminide coatings may be formed on the superalloys by an inward diffusion of aluminum provided the aluminum activity of the pack mix is sufficiently high to form equilibrium aluminide phases of high aluminum content as previously described. For such a pack aluminizing process there is a parabolic relationship between coating thickness and time. Thus, a part with no coating in an eroded zone and a retained coating of 3 mils in a cooler zone will, during such a recoating process, form a new coating of Ni_2Al_3 , or phases of higher aluminum content, of the required thickness in all zones but in so doing will absorb considerably less aluminum in the undegraded zones than in the degraded or eroded zone. This occurs because in the undegraded zones the aluminum content, before recoating amounts to about 30%, corresponding to the β ($NiAl$) phase, whereas in the degraded zone the aluminum content may be as low as 5%. That is to say, that in being transformed to the Ni_2Al_3 phase, which contains 40% aluminum, the undegraded zones absorb the equivalent of about 10% aluminum while the degraded zone absorbs as much as the equivalent of 35% aluminum. Upon subsequent heat treatment to form the desired ductile β ($NiAl$) phase, as previously described, the coating on the previously undegraded zones exhibits minimal new growth because these zones have absorbed relatively small amounts of aluminum during the recoating process, whereas a completely new coating has formed on the previously degraded zone because this zone has absorbed a relatively large amount of aluminum. The net result is that new coating of the required thickness has been formed on the previously eroded area of the part with insignificant increase in coating thickness in the cooler, undegraded zones thereby eliminating the necessity of performing the expensive and otherwise undesirable stripping operation of the current processes wherein the old coating is totally removed.

While a number of gas turbine engine components can be satisfactorily recoated as herein described even in those instances where there has been substantial corro-

sive attack on the substrate metal, maximum usefulness of the present process occurs if the overhaul period selected allows recoating of the components prior to a substantial loss of substrate components by oxidation-erosion. This substrate loss occurs when the aluminum content of the coating fall below that level at which the oxidation mechanism is preferentially toward the formation of aluminum oxide as evidenced, in the nickel-base systems, by the occurrence of macroscopic amounts of the blue-green, nickel-rich oxide.

The particular pack aluminizing process preferred in the present overhaul and repair process is one selected to provide for the incorporation of the desirable substrate alloying elements in the coating while minimizing the formation of deleterious phases. In the process, the article to be coated is embedded in a pack mix containing 5-20 weight percent aluminum, 0.5-3 percent ammonium chloride, balance alumina. The pack is then heated to a relatively low temperature 1200-1600° F. in an inert atmosphere and coating growth is allowed to proceed for 1-4 hours. In the recoating process a minimum coating thickness of 0.003 inch is effected. Subsequently, the recoated article is subjected to a ductilizing heat treatment in the temperature range of 1900°-2200° F. usually matched to the strengthening heat treatments specified for the superalloy substrate.

The exact pack composition and coating parameters employed in a given case are, of course, dependent upon the particular component being processed and the particular end result desired. In each case, however, the pack of the present invention will be characterized by a high aluminum activity, and will tend to yield coatings high in aluminum content for a given time at temperature. Those skilled in the art will readily recognize the variety of alternative techniques and compositions adapted to provide the requisite high aluminum activity.

As used herein, the term "nickel-base superalloys" will be understood to have reference to those multiphase alloys of the γ - γ' type which are characterized by high strengths at temperatures of 1500° F. and higher. Several representative alloys of this type are listed in the following table.

TABLE I

Nominal composition (percent by wt.)	
Designation:	
Udimet 700.....	15% Cr, 18.5% Co, 3.3% Ti, 4.3% Al, 5% Mo, .07% C, .03% B, balance Ni.
MAR-M200.....	9% Cr, 10% Co, 2% Ti, 5% Al, 12.5% W, 1% Co, .15% C, .015% B, .05% Zr, balance Ni.
IN-100.....	10% Cr, 15% Co, 4.5% Ti, 5.5% Al, 3% Mo, .17% C, .75% V, .015% B, .075% Zr, balance Ni.
B-1900.....	8% Cr, 10% Co, 1% Ti, 6% Al, 6% Mo, 4.3% Ta, .11% C, .15% B, .07% Zr, balance Ni.

In one test an erosion bar formed of the B-1900 alloy was coated by slurry techniques to a thickness of about 3 mils and run in an oxidation-erosion environment at 2100° F. for 100 hours. The bar was removed from test at the first sign of coating penetration and substrate oxidation as evidenced by the appearance of the blue-green, nickel-rich oxide. The specimen was sectioned through the eroded zone and one half was examined metallographically as a control specimen while the other half was recoated in a pack of high aluminum activity for 1½ hours at 1400° F., followed by a heat treatment of 4 hours at 2000° F. This specimen was then examined metallographically to determine coating uniformity, thickness and structure.

Examination of the control specimen revealed pitting through the coating at the eroded zone which resulted in the formation of the blue-green oxide. The uneroded portion of the coating in the hot zone of bar contained no β ($NiAl$) aluminide and a thin layer of carbides was observed to be in the process of resolution in the γ (nickel solid solution)- γ' (Ni_3Al) phases of the coating

layer. The recoating process uniformly covered the defect area and the remaining γ - γ' phase layer with but a slight depression in the coating surface at the eroded zone, but otherwise little difference was noted in the coating structure or thickness after recoating. The cooler zones of specimen before recoating showed some effects of aluminum depletion with the presence of the γ' phase of the aluminide at the grain boundaries of the β (NiAl) aluminide. The recoated structure after diffusion heat treatment was all β aluminide with a slightly different carbide morphology than in the original specimen; but no unusual or detrimental phases were present. As indicated by the absence of a hyper-stoichiometric aluminum rich β phase layer, the recoated structure was not excessive high in aluminum content.

A second B-1900 alloy erosion bar was coated in a process similar to that used with the first specimen and was run in an oxidation-erosion test at 2100° F. Although the specimen failed at about 50 hours by pitting through the coating to the substrate, the test was run to 100 hours. As a result, some excessive substrate damage in hot zone on the trailing surface was noted because of the excessive time in test. However, the specimen was lightly cleaned with a vapor blast and recoated by a pack aluminizing process of high aluminum activity. This recoated specimen was then retested for an additional 60 hours at 2100° F. until coating failure again occurred.

The specimen was again cleaned and recoated, this time to produce a coating of 3½ mils thickness. A third oxidation erosion cycle at 2100° F. was run and coating failure did not occur for an additional 80 hours.

After these tests the following observations were made with respect to the specimen: (1) the specimen surface was still smooth and free from any indication of defects; (2) a slight depression of 3-5 mils on the surface of the hot zone was present, the result, however, of testing of the specimen beyond the limit of the coating protection in the initial oxidation-erosion test which resulted in some substrate attack; (3) the lifetime of the nickel-base substrate was successfully extended to 3 or more times its normal useful level; (4) no excessive buildup of the coating occurred in the previously undegraded areas and no masking was required; (5) the problems associated with the stripping of the coating were eliminated.

It is evident that aluminide-coated alloy systems can be recoated several times by the disclosed pack cementation process without the necessity of prior coating stripping. The principal considerations are the removal of the specimen from its oxidizing environment prior to coating breakthrough and significant substrate attack, and the use of a pack aluminizing process utilizing a pack mix of high aluminum activity.

In view of the continuing upward trend in engine operating conditions, the increased use of thin-walled components is anticipated with the consequent increased component cost resultant from the added complexity. Furthermore, the trend toward higher temperatures clearly forecasts that a number of engine components will continue to be coating-limited. Thus, the salvage of these expensive components will continue to be mandatory and the overhaul and repair procedure described herein should find wide utility in such salvage operations.

While the present invention has been described in connection with certain examples and preferred process compositions and parameters, these will be understood to be illustrative only and numerous modifications will be

evident to those skilled in the art from the detailed description. The invention in its broader aspects is not limited to the specific details shown and described but departures may be made from such details without departing from the principles of the invention and without sacrificing its chief advantages.

What is claimed is:

1. An overhaul and repair procedure for aluminide-coated gas turbine engine components formed from the nickel-base superalloys which comprises:

removing the oxidized components from the engine prior to the onset of substantial oxidative attack on the superalloy substrate;

superficially cleaning the surface of the coated components to remove the accumulated oxide layer therefrom;

recoating the components in a pack aluminizing process utilizing a pack mix having an aluminum activity at the coating temperature sufficient to preferentially form equilibrium aluminides having an aluminum content not less than that corresponding to Ni_2Al_3 ; and diffusion heat treating the recoated components to convert the aluminides formed in the aluminizing process to aluminides having an aluminum content substantially corresponding to NiAl.

2. An overhaul and repair procedure for aluminide coated gas turbine engine components formed from the nickel-base superalloys which comprises:

removing the oxidized components from the engine prior to the first appearance of macroscopic amounts of blue-green nickel-rich oxide;

superficially cleaning the surface of the coated components to remove the accumulated oxide layer therefrom;

recoating the components in a pack aluminizing process utilizing a pack mix having an aluminum activity at the coating temperature sufficiently high to promote formation of the coating by an inward diffusion of aluminum toward the superalloy substrate;

and, after removal from the pack, diffusion heat treating the recoated components to preferentially form aluminides having an aluminum content substantially corresponding to NiAl.

3. The procedure according to claim 2 wherein the final diffusion heat treatment is conducted in the temperature range of 1900°-2200° F.

4. The procedure according to claim 3 wherein in the recoating process a minimum coating thickness of 0.003 inch is effected.

References Cited

UNITED STATES PATENTS

3,079,276	2/1963	Puyear et al.	117-107.2 (P)
3,129,069	4/1964	Hanink et al.	29-197 X
3,141,744	7/1964	Couch et al.	29-197 X
3,257,230	6/1966	Wachtell et al.	117-107.2 (P)
3,345,197	10/1967	Martini et al.	117-107.2 (P)X
3,436,249	4/1969	Lambert et al.	117-107.2 (P)
3,450,512	6/1969	Maxwell	29-197 X

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