A PROCESS FOR PROTECTING GAS TURBINE BLADE
COOLING PASSAGES AGAINST DEGRADATION

J.E. Restall)National Gas
B.J. Gill) Turbine Establishment
C. Hayman)Fulmer Research
N.J. Archer)Institute

ABSTRACT

A new process for the protection of turbine blades and vanes on both external and internal surfaces has been evolved. The surfaces are metallised by pressure-pulsing the coating gases from a near-conventional cementation pack. Penetration occurs into the internal cooling channels which are inaccessible to most other coating processes.

Up to 1000 small turbine blades can now be simultaneously pulse aluminised in an industrial plant.

INTRODUCTION

It is common practice to coat superalloy blades and vanes in gas turbines in order to improve their resistance to high temperature degradation by oxidation and corrosion. Coatings, predominantly containing aluminium and chromium, have been evolved for the protection of the external surfaces which are exposed directly to the hot gas stream. Most attention has been given to aluminide or chromium enriched coatings deposited by pack cementation or chemical vapour deposition methods, but, in more recent times, effort has been directed towards overlay coatings, e.g. MCrAlY, which are processed by physical methods including evaporation, ion plating and plasma spraying. These coatings are generally effective, but they are applied only to the external surfaces of blades. Oxidation and corrosion damage to the inner walls of blades narrows the cooling channels, adversely affects the heat transfer characteristics locally because of the presence of corrosion films and, in the extreme, may cause complete blockage of cooling channels and produce drastic overheating, leading possibly to melting at local hot spots. Fig 1 shows

Fig 1 Micrographs of turbine rotor blade after 7,000 h service

microsections of a turbine rotor blade withdrawn from a civil aeroengine after 7000 hours service. It can be seen that the outer surface of the blade (Fig 1(a)) has been protected by the aluminide coating, whereas the cooling channel wall has been oxidised (Fig 1(b)).

Processes such as plasma spraying or electron beam evaporation are not capable of coating internal channels. Conventional pack cementation can be adapted to coat large cooling passages with simple geometry. The reactive powder is loaded, for example as a slurry, into the cooling passages, but there are difficulties with leaving parts of the channels unprotected and with the removal of residues after treatment (1). Such a process cannot be used for advanced high temperature blades with cooling channels which are narrow and complex. Some cooling channels may be less than 0.25 mm in diameter.

We have developed a new coating process which is capable of metallising the internal and external surfaces of turbine blades simultaneously with almost equal facility (2). The process may be applied regardless of the complexity of the cooling channel configuration. So far it has been used mainly for the formation of aluminide coatings on superalloy turbine blades. The external coatings are generally about 50 μm thick while the internal coatings are rather thinner; this minimises the danger of blocking the narrower channels.

The process relies on the transport of aluminium as a volatile monohalide as in conventional pack cementation (3). However, the diffusion of the monohalide is aided by operating the process at a sub-atmospheric pressure which is varied cyclically. The effect of the pressure pulse is to improve the transport of the reactant gases in and out of the cooling passages, thereby simultaneously coating the internal and external surfaces of the blade. The process is operated in such a way that all of the reactants and by-products are gaseous so that no solid residues are formed inside the cooling channels. Another advantage of this process is that there is no direct contact between the blades and the aluminium source so that the external coatings are very uniform and free from contamination.

THE PROCESS

The pulse metallising process uses a hot-wall reaction chamber which can be operated at reduced pressure. The samples to be coated are placed in the chamber separately from the pack, which consists of an aluminium source, a halide activator and an inert diluent, as illustrated schematically in Figure 2. The pressure in the chamber is then cycled by evacuating and re-filling with argon. The pressure is cycled up to about 8 times per minute.

The choice of activator is critical for the successful operation of the process. The vapour pressures of the active species and its precursor must be sufficiently high

to permit adequate diffusion to the samples at the operating temperature, while being sufficiently low to ensure that the activator is not rapidly pumped away from the hot zone. For aluminising, aluminium trifluoride is an extremely convenient activator as its vapour pressure is about 1 Torr at 1193 K and it generates aluminium monofluoride with a vapour pressure of about 0.25 Torr. The aluminium monofluoride diffuses to the substrate where its entry into the cooling channel is assisted by the pulsing process. The volatility of the aluminium trifluoride becomes important because it must be able to diffuse away from the substrate. It is possible for the rate of arrival of aluminium monofluoride to generate more aluminium trifluoride than can diffuse away immediately.

THE EQUIPMENT

The industrial plant (Fig 3) consists of a double-skinned

FIG.3: LAYOUT OF PILOT PLANT FOR ALUMINISING WITH GAS PULSING

vacuum furnace which has an inner nickel alloy retort approximately 22 in. diameter $\times$ 9 ft long. A system was adopted in which the pack was placed in circular trays carried on a central support rod with the blades positioned on wires above the pack. The retort is loaded, evacuated and then transferred to the hot furnace. As soon as the retort is coupled up to the pumping system, the automatic pressure pulsing sequence is started. On completion, the retort is back-filled with argon and cooled. The equipment has successfully coated up to one thousand small engine blades at a time.

PROCESS PARAMETERS

The factors which have the greatest influence on the pulse aluminising process are:- 1. process temperature, 2. pack composition, and 3. geometric disposition of blades. Other factors having less effect are the total pressure, pulse rate and run time.

Process Temperature

The effect of temperature on the process has been studied over the temperature range 1098 to 1253 K. The coating rate at 1098 K was very low and increased rapidly with temperature above 1143 K. This corresponds to the increasing vapour pressure of aluminium fluoride. Temperature also influenced the

Fig. 4

effectiveness of the pulsing action. Very little coating was deposited on internal surfaces at 1098 K, but the ratio between the external and internal coating thicknesses decreased rapidly at 1198-1223 K to a value between 1 and 3 depending on other factors (Fig 4). It is advantageous to heat the retort as rapidly as possible to the operating temperature.

Pack Composition

The total amount of halide present is critical for several reasons, because it is transferred away from the hot zone during the process and condenses on the cold parts of the equipment. The depletion of halide in the hot zone terminates the process. However, a large concentration is undesirable, because if the aluminising process proceeds too rapidly, the local concentration of aluminium trifluoride around the blade can exceed its vapour pressure, causing a deposit of aluminium trifluoride crystals on the blades. Also, if fluoride is still present in the pack at the end of the treatment, it is possible for aluminium trifluoride crystals to condense on the blades because of differential cooling between the blades and the pack.

Geometric Disposition of Blades

By adjusting the placing of the blades with respect to the pack it is possible to achieve an optimum distribution of coating thickness (Fig 5). As the blades were moved further away from the pack, the overall coating became thinner and more uniform, and the external:internal ratio approached unity.

Fig. 5. Thickness variation (μm) of aluminide coating around aerofoil.

Other factors

The throwing power of the process increased as the total pressure was decreased, but also the coating rate decreased because this aided the loss of activator from the hot zone. A high pulse rate reduced the external:internal ratio, but also aided the loss of activator.

Properties of Coatings

Fig 6 shows the aluminide coating on external and internal surfaces produced by the pulse aluminising process at 1173 K. The section shows the coating obtained at the mid-point of a cooling channel 60 mm long with a diameter of 1 mm. The coatings obtained by pulse aluminising tend to resemble high activity deposits on external surfaces and low activity deposits on internal surfaces (4). The compositions were typical of those found in conventional aluminising processes, containing >28 wt% aluminium.

Fig 6 Micrographs of pulse-aluminised blade section

Further Developments

On an experimental scale, the pressure pulse process has been adapted for coatings more advanced than plain aluminides. The method is particularly suitable for the generation of multilayer coatings, whereby the final stage in the coating operation may include pulse aluminising or chromising to seal cracks or other defects in the surfaces of overlay coatings deposited by plasma spray (5).

Turbine rotor blades plasma sprayed with MCrAlY compositions and subsequently pulse aluminised or chromised (followed by creep-recovery treatments) have been subjected to cyclic oxidation tests for durations up to 2000 hours at 1423 K. Testpieces coated by the same techniques have also been subjected to high velocity sulphidation-corrosion tests in burner rigs. In all instances the plasma spray coatings failed before those which had been pulse aluminised or chromised. Laboratory oxidation tests showed that pulse-aluminising satisfactorily protected the inner surfaces.

CONCLUSIONS

The pulse metallising process has been demonstrated as an effective method of aluminising turbine blades on both external and internal surfaces. The ratio between the coating thicknesses on the external and internal surfaces can be in the range 1.5 to 3. No internal geometry has yet been encountered which cannot be coated by the process.

The very high throwing power of the process is now being examined as a method for the sealing of porous overlay coatings.

Copyright © Controller HMSO, London, 1980

REFERENCES

1. B.J. Gill, J.E. Restall, N.J. Archer, S.M. Edwards and C. Hayman, Proc. 3rd Conf. on Gas Turbine Materials in Marine Environment, Bath, 1976.
2. J.E. Restall and C. Hayman, British Patent 1,549,845, August 1979 and U.S. Patent No. 4,156,042, May 1979.
3. Sperry Rand Corporation, British Patent 1,007,222. Dec. 1961.
4. G.W. Coward and D.H. Boone, Oxidation of Metals, 3 (1971) 475.
5. J.E. Restall, Corrosion resistant coatings for metal articles. British Patent Application 7,926,456.