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Loss of Y from NiCrAlY powder during air plasma spraying

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ABSTRACT

This study involves changes in microstructures and chemical compositions of NiCrAlY particles that occurred during an air plasma spraying of the powder. In this work the spraying particles were rapidly cooled and collected at a spraying distance just before the coating deposition in order to study the mid-flight transformation. Microscopy analysis of the particle cross-sections reveals that different structural and chemical transformations took place presumably depending on the flight path in relation to the plasma plume. *Particle A* group has a tendency to show some increase in Al and Y contents, possibly due to an evaporation of γ-(Ni solid solution) and β-(NiAl). Accompanying β grain growth can sometimes be observed. *Particle B* group often forms a large amount of Al–Y rich oxide due to an increase in oxygen activity during flight. This results in a significant reduction of Y in the particle. The coating produced using the same set of spraying parameter shows a heterogeneous structure with respect to the distribution of Y.

1. Introduction

Yttrium has been added to NiCrAl alloy as a reactive element to produce a starting material for a bondcoat used extensively as part of a thermal barrier coating (TBC) for land-based gas turbine Ni alloy components [1,2]. Various techniques can be employed for TBC deposition including plasma spraying, physical vapour deposition and chemical vapour deposition [3–7]. In plasma spraying processes, the coating materials in powder form are deposited in a molten or semi-molten condition on a substrate to form a spray deposit. During a coating deposition, the spraying material is subjected to a temperature higher than 1000 °C for a short time. The function of the bondcoat is to protect the component from oxidation. The oxidation resistance is achieved mainly by a formation of a continuous protective Al_2O_3 scale during service [8,9]. The scale helps to reduce the extent of corrosion of the underlying substrate thus allowing the engine to operate at a higher efficiency. After the deposition of the bondcoat, ZrO_2 topcoat stabilised with other oxides such as Y_2O_3 and CeO_2 can also be deposited to create TBC [10,11].

The exact role of Y in NiCrAlY has received attention in recent years. Previous research works have shown that Y can increase the adhesion of the thermally-grown oxide scale formed during TBC service at high temperature via sulphur gettering or oxide pegging mechanisms, thus enhancing the service life of the coating [12,13].

Scarcity of rare earth metals including Y has sent their prices soaring since before 2011. Their global demands continue nevertheless, encouraging more exploration and development of new mines. More mining of rare earth metals unavoidably leads to more environmental degradation and human health hazards [14]. It is vital then that the usage of the metals is justified and this requires a good understanding of their functions.

This work investigates the loss of Al and Y from NiCrAlY during its in-flight oxidation. This was achieved by rapidly cooling the spraying powder mid-flight. The powder was then characterised in order to obtain a better insight into its oxidation behaviour. The result was compared with that of a coating produced using the same spraying parameter. The findings will form a basis to the understanding of the mechanism of Y in prolonging the life of NiCrAlY coating at high temperature.

2. Experimental procedure

An air plasma spraying experiment is carried out with an aim to collect the spraying bondcoat powder mid-flight at a deposition distance. The equipment setup is shown in Fig. 1. The bondcoat powder used in this work is Amdry 962 from Sulzer Metco with a particle size of 53–106 μm. The chemical composition is Ni–(21–23)Cr–(9–11)Al–(0.8–1.2)Y in weight percent. The topcoat powder is Amperit 827.7 from H.C. Stark with a particle size of 45–90 μm. The chemical composition is ZrO_2–$7Y_2O_3$ (wt.%).

The bondcoat powder was sprayed using a 3MBII plasma spray gun (Sulzer Metco) and a set of parameter as shown in Table 1. A metal screen with a 5 mm opening was placed at a distance of 125 mm in front of the spray gun in order to allow a small amount of spraying powder through. As the spraying powder passed through the opening, an Argon jet of 0.1 MPa pressure was used as a medium to rapidly cool the powder. An earlier experiment was also carried out using

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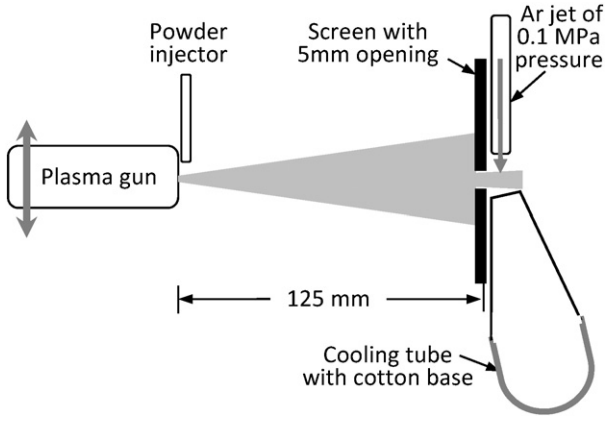

Fig. 1. Experiment setup.

water as a cooling medium. Even though the water cooling process was simpler but the collected particles were found to be enveloped in thick crusts of oxide. This is believed to be because the collecting distance was specified at 125 mm which was close to the plasma jet thus some of the water may be dissociated while in contact with the particle, resulting in a rapid oxidation of the powder particle. Further experiment was therefore carried out using Ar as the cooling medium.

The screen served multiple functions. It helped to shield the spray plume from interference from Ar jet which could cause an abnormal turbulence. Also Ar jet can cool the small amount of spraying powder more effectively and propel it into a cooling tube where the powder can be collected. It was originally intended that the screen will also act as a sampling window, allowing the powder collection from different sections across the plume. When the powder was collected after spraying however, it was found that the distinction in average powder appearances across the cross section of the plume was not obvious. This is because there is an arc fluctuation in a plasma spraying process making it difficult to predict the flight path of the particles. However, individual powder particles exhibited differences in appearance and composition.

The bondcoat powder specimens were indicated as "as-received" for the starting powder and "Ar-cooled" for the sprayed powder, cooled and collected at 125 mm spraying distance. Accuraspray-g3 (Tecnar, Sulzer Metco) plume diagnostic equipment was used to determine the temperature of the powder at 125 mm spraying distance. The powder temperature was measured through thermal emission from the semi-molten particles. This technique may produce inaccurate results due to its reliance on a database on the emissivity of materials. The result should be treated only as a guideline. Coating specimens were also produced with both bondcoat and topcoat deposition using the parameters in Table 1.

The specimens were cross-sectioned. Scanning electron microscope and quantitative energy-dispersive X-ray spectroscopy (EDS) (JEOL6301) were used to characterise the specimens.

Table 1
Parameters for plasma spraying.

	Bondcoat NiCrAlY	Topcoat ZrO_2-Y_2O_3
Hydrogen pressure	0.34 MPa	0.34 MPa
Hydrogen flow rate (SCFm)	1.2×10^{-4} m^3 s^{-1}	1.2×10^{-4} m^3 s^{-1}
Nitrogen pressure	0.69 MPa	0.69 MPa
Nitrogen flow rate (SCFm)	7.9×10^{-4} m^3 s^{-1}	7.9×10^{-4} m^3 s^{-1}
Current	500 A	500 A
Potential difference	70–80 V	65–70 V
Powder feed rate	0.78 g s^{-1}	0.71 g s^{-1}
Spraying distance	125 mm	125 mm
Hopper pressure	0.55 MPa	0.9 MPa

3. Results and discussion

3.1. As-received powder

The cross-sectional structure of the as-received powder is shown in Fig. 2. The particle surface is free of continuous oxide layer. The back scattered electron image shows that the alloy contains 2 major phases, γ (Ni solid solution) and β (NiAl). This is in accordance with the isothermal section of a Ni–Cr–Al ternary phase diagram as proposed by Gleeson et al. (1993) [15]. There is also Y segregation in γ phase, seen as light-coloured patches in the particle, see Fig. 3. The as-received powder shows structural consistency from one particle to another. Examples of the chemical composition of the individual particles using EDS are shown in Table 2. It should be noted that Y content is slightly higher than the powder specification.

3.2. Ar cooled powder

As the powder was passed through a high temperature H_2/N_2 plasma plume, each particle was subjected to different environments according to its flight path in relation to the plume. For example, if *Particle A* travels through the centre of the plume, it will be subjected to the highest temperature of that plasma plume in a reducing atmosphere until it leaves the centre or travels further from the nozzle where the temperature begins to drop and oxygen partial pressure increases [16]. Whereas *Particle B* travels along the edge of the plasma plume, it will be subjected to a lower temperature throughout the flight in a more oxidising atmosphere. Even though the plasma gas does not contain oxygen, there are turbulences at the edge of the plasma plume resulting in air entrainment. The presence of oxygen together with the high temperature of the plasma results in a highly oxidising environment [17]. Plume analysis reading indicates that the average temperature of the powder surface at the centre of the plume and at a spraying distance of 125 mm is 3078 ± 23 °C and the average powder velocity is 424 ± 4 m/s. At this high temperature it can be expected that *Particle A* and *B* will exhibit a different microstructure. The comparison between *Particle A* and *B* is an extreme example where the two particles take very different paths. It is more likely however that a particle take a non-linear path, for example, it may starts off at the centre of the plume where the temperature is high and very quickly moves to the fringe of the plume where oxygen is abundance.

In this experiment, the powder was sprayed and collected at a spraying distance of 125 mm which is a distance generally used for this set of spraying parameter. In order to "freeze" the structure at the distance of 125 mm, an argon jet of 0.1 MPa pressure was used to intersect the powder in mid-flight and propel it into a cooling tube. A temperature sensor indicated that on average the ambient temperature

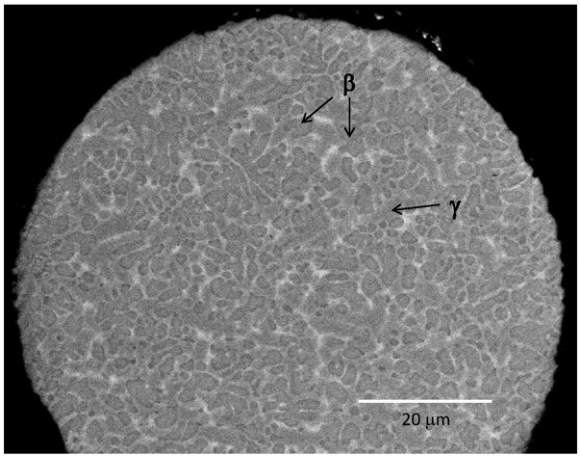

Fig. 2. Back scattered micrograph of an as-received powder particle.