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Oxidation Protection Coatings for C/SiC Based on Yttrium Silicate

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Abstract

The factor which currently precludes the use of carbon fibre reinforced silicon carbide (C/SiC) in high temperature structural applications such as gas turbine engines is the oxidation of carbon fibres at temperatures greater than 400°C. It is, therefore, necessary to develop coatings capable of protecting C/SiC components from oxidation for extended periods at 1600°C. Conventional coatings consist of multilayers of different materials designed to seal cracks by forming glassy phases on exposure to oxygen. The objective of this work was to develop a coating which was inherently crack resistant and would, therefore, not require expensive sealing layers. Yttrium silicate has been shown to possess the required properties for use in oxidation protection coatings. These requirements can be summarised as being low Young's modulus, low thermal expansion coefficient, good erosion resistance, and low oxygen permeability. The development of protective coatings based on a SiC bonding layer combined with an outer yttrium silicate erosion resistant layer and oxygen barrier is described. Thermodynamic computer calculations and finite element analysis have been used to design the coating. C/SiC samples have been coated using a combination of chemical vapour deposition and slip casting. The behaviour against oxidation of the coating has been evaluated.

1 Introduction

The last 30 years have seen a steady development in the range of ceramic materials with potential for high temperature engineering applications. One such application is the use of ceramic matrix composites (CMCs) as structural hot section components of propulsion systems for the next generation of commercial supersonic aircraft. The inclusion of these materials in gas turbine engines would allow significantly higher operating temperatures than is possible with conventional nickel based superalloy materials. Such utilisation of CMCs offers improvements in thermal efficiency which can be translated into decreased specific fuel consumption, decreased weight and consequently lower stresses in rotating components and higher thrust to weight ratios. Raising the operating temperature would increase the thermodynamic efficiency of the engine and reduce the level of pollutant emission. These effects are achieved by moving closer to stoichiometric combustion of the fuel and reducing the amount of air which must be diverted through the turbine components for cooling purposes.

The combination of high strength and damage tolerant fracture behaviour of carbon fibre reinforced ceramics makes them candidates for this application. In non-oxidising environments, the mechanical properties of carbon fibre reinforced ceramics are retained to temperatures in excess of 2000°C.[1] The factor which currently inhibits the application of such materials in gas turbine engines is the oxidation of carbon fibres at temperatures above 400°C. To prevent oxidation requires eliminating access of oxygen to the carbon fibres. Hence there is a need for external coatings capable of preventing oxidation of carbon fibre reinforced ceramics for extended periods at temperatures in the region of 1600°C. Such coatings have been reviewed by Westwood *et al.*[2] These coatings are extremely prone to cracking, particularly when used under conditions of thermal cycling on a CMC substrate with a substantially lower thermal expansion coefficient. Thus, conventional coatings consist of multilayers of different materials

Carbon fibre reinforced silicon carbide composite manufactured by Daimler-Benz Aerospace (Dornier Research) was used as the substrate for the coating layers. Yttrium silicate, Y_2SiO_5, has been suggested as a suitable outer coating layer and promising oxidation protection results have been reported.[3] Figure 1 shows the architecture of the coating.

Previous work in this area has typically been based on a 'trial and error' approach with minimal theoretical input to the design of coatings. The use of thermodynamic modelling and finite element analysis at the design stage was intended to act as a filtering process for potential coatings, allowing experimental work to be concentrated on the most promising coatings. Oxidation studies were carried out on the coated composite samples using continuous mass measurement during isothermal exposure to air at 1600°C.

2 Thermodynamic Calculations

The software which has been used is the MTDATA package[4] supplied by the National Physical Laboratory, UK. A methodology has been developed to apply thermodynamic modelling to oxidation protection coatings.[5] The chemical compatibility between coating components and reactions of the coating with an oxidising environment have been investigated.

The chemical compatibility between Y_2SiO_5 and SiC has been assessed by performing calculations on the Y–Si–O–C system. The equilibrium phases for the composition 2Y–2Si–5O-1C (corresponding to Y_2SiO_5–SiC) have been calculated as a function of temperature (Fig. 2). The calculated amounts of Y_2SiO_5 and SiC do not change between 0 and 1750°C, indicating that the two compounds will not react with each other over that temperature range.

The exposure of the coating to oxygen has been simulated by calculating the equilibrium species at 1600°C as a function of increasing oxygen concentration for the composition 2Y–2Si–$(5+x)$O–1C

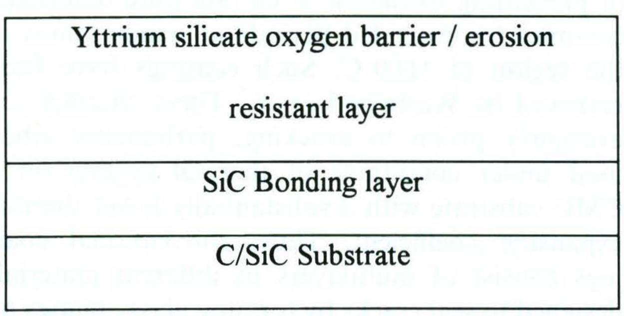

Fig. 1. Yttrium silicate based coating architecture.

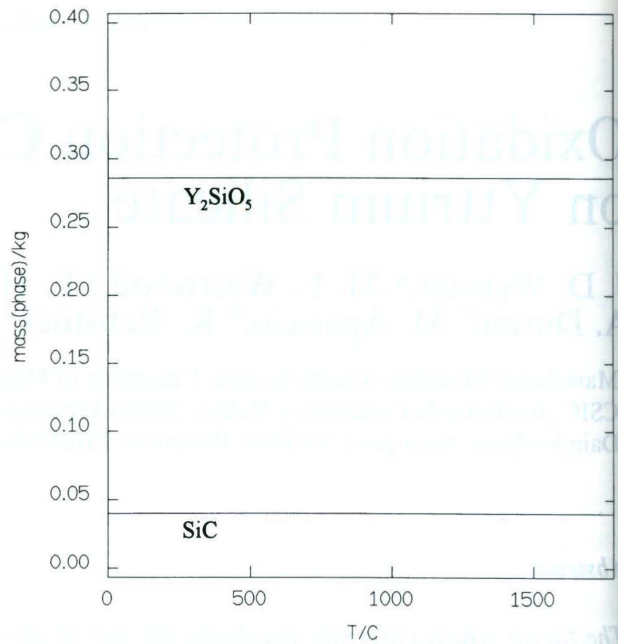

Fig. 2. Calculated equilibrium phases up to 1700°C for the composition 2Y-2Si-50-1C.

($Y_2SiO_5 + SiC + xO_2$). The results of these calculations are shown in Fig. 3. The reactions involved in the oxidation of a $Y_2SiO_5 + SiC$ coating are thought to be:

$$Y_2SiO_{5(s)} + SIC_{(s)} + \frac{3}{2}O_{2(g)} \rightarrow Y_2SI_2O_{7(s)} + CO_{(g)} \quad (1)$$

$$Y_2SiO_{5(s)} + SiC_{(s)} + 2O_{2(g)} \rightarrow Y_2Si_2O_{7(s)} + CO_{2(g)} \quad (2)$$

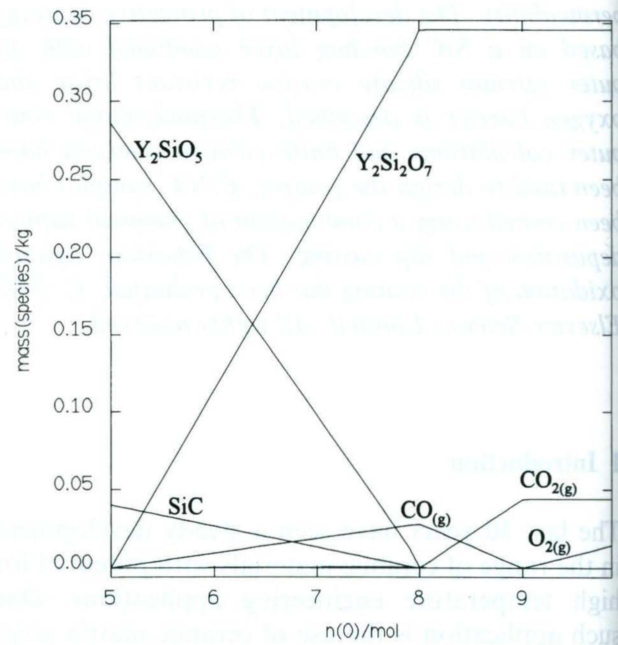

Fig. 3. Calculated equilibrium species at 1600°C as a function of oxygen concentration for the composition 2Y-2Si-(5+x)O-1C.

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