



Comparative study of interfacial reaction between superalloy substrate and glass coating with and without alumina particles incorporation

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ARTICLE INFO

Article history:

Received 8 October 2012

Received in revised form 24 January 2013

Accepted 25 January 2013

Available online 31 January 2013

Keywords:

Glassy coating

Superalloy

Interface

High temperature oxidation

ABSTRACT

Interfacial reaction between $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-ZnO-CaO}$ based glass coating and K38G superalloy results in gaseous products of Zn and/or Na, and bubbling surface of the glassy coating. With incorporation of alumina particles, however, intact glass/alumina composite coating, which can restrict progressing of the excessive interfacial reaction, is formed on the alloy substrate. Enhanced high-temperature strength and viscosity of glass by alumina particles incorporation ensure the composite glassy coating with high stiffness and compactness which inhibits escape of Zn and/or Na gases from the interface, accounting for its suppressing effect on interfacial reaction.

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1. Introduction

Traditional protective coatings for Ni-based superalloy of gas turbine components are divided into two types: aluminide by aluminizing or overlay NiCrAlY coatings by physical vapor deposition or thermal spraying [1,2]. In general, these coatings finally fail due to the depletion of active elements such as Al and Cr by oxide formation on their surface and the interdiffusion between the coating and substrate during service. As an alternative, inert oxide coating, without this interdiffusion issue, might spall off by thermal shock, to which several parameters such as the mismatch of CTEs (coefficients of thermal expansion) between coatings and substrates and surface tension might play an important role [3,4].

Glasses or glass-ceramics with excellent compatibility to certain metal substrates show good prospect to be used as coating materials for corrosion protection [5–9]. It is well known that glasses could easily form hermetic seals to the metallic substrates and insulated them from corrosion media. The difficulties lie in the glass to alloy interface, where the glass materials must wet the alloy substrates and exhibit matched dilatometric behaviors. Satisfying of these requirements depended to a certain degree on the interfacial reaction of alloy/glass [10–15].

Recently, an $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-ZnO-CaO}$ based glass matrix composite coating demonstrated excellent protectiveness in corrosive environments at elevated temperatures from 600 to 1000 °C

for alloy substrates, such as intermetallics [16], titanium alloys [17–19] and Ni-based superalloys [20–23]. However, there still lacks enough knowledge on the bonding of glass to alloy substrate during the firing process, which is of great importance in designing glass coatings for further applications. As reported in previous studies, this glassy coating could chemically react with the K38G superalloy substrate, which resulted in bubbling within the coating and final peeling off along the interface. It was claimed that interfacial reaction accompanied with yield of gaseous products played a role for the above phenomena [20–22]. By addition of alumina particles (schmigel) to prepare glass/alumina composite coating, excessive interfacial reaction was highly suppressed and, there with, the coating exhibited higher corrosion resistance with much stable interface [22,23]. However, the relevant mechanism for the inhibiting effect of alumina particles incorporation on the interfacial reaction of glass/alloy was still unknown.

The object of this study was to physically characterize and understand the interfacial reaction between the glassy coating and K38G superalloy substrate as well as the mechanism of suppression of the interfacial reaction by alumina particles incorporation.

2. Experimental procedure

Table 1 shows the chemical composition of the glass matrix. The preparation process of the glass frit has been described in detail elsewhere [24]. After a dry ball milling in an agate container, the average size of the glass granules was reduced to less than 10 μm. The resulting glass powder was mixed with 30 wt% $\alpha\text{-Al}_2\text{O}_3$ particles (at average size of 1.0 μm) and then further ball milled with

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Table 1
Nominal composition of the glass frit (wt%).

SiO ₂	Al ₂ O ₃	ZnO	CaO	ZrO ₂	TiO ₂	B ₂ O ₃	Na ₂ O	KNO ₃
58.26	5.98	9.00	3.66	5.29	2.75	4.66	3.40	7.00

Table 2
Nominal composition of K38G alloy (wt%).

Ni	C	Cr	Al	Co	W	B	Ti	Mo	Nb	Ta	P
Balance	0.17	16.0	4.0	8.5	2.0	0.01	3.8	1.7	0.7	1.7	<0.01

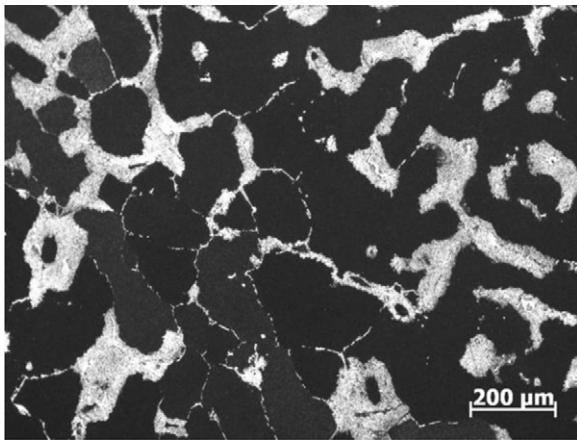


Fig. 1. Metallographic morphology of cast K38G superalloy substrate.

ethanol media for 10 h to obtain a suspension, which was then sprayed immediately onto alloy specimens. For convenience, the coatings prepared by glass with and without addition of 30 wt% alumina particles were denoted as E30A and PE, respectively.

K38G alloy was used as the substrate material, of which the nominal composition was given in Table 2. Its metallographic morphology is shown in Fig. 1. The cast K38G alloy consist mainly of the matrix γ phase (nickel solid solution, 52.6 wt%), γ' phase (Ni₃(Al, Ti), 46.1 wt%), and carbides (1.3 wt%). The carbides include MC distributed uniformly throughout and M₂₃C₆ located predominantly in the grain boundaries [25]. Its grain size was larger than 100 μm . The specimens with dimension of 15 \times 10 \times 3 mm³ were successively ground, polished with 2.5 μm diamond paste to a mirror surface and cleaned with acetone in an ultrasonic cleaner. Thereafter, they were sprayed at room temperature with the glass suspension, dried at 250 °C for 15 min and finally fired at 1000 °C for 30 min.

Characterization of the coatings was carried out, firstly using a camera (Canon, EOS 600D, Japan) for macroscopic morphology observation, and then scanning electron microscopy (SEM, Inspect F 50, FEI Co., Hillsboro, Oregon) coupled with an energy dispersive spectrometer (EDS, X-Max, Oxford instruments Co., Oxford, UK) for microstructure characterization. The highest resolution of SEM is 1.0 nm. The chamber pressure is lower than 7 \times 10⁻³ Pa, and gun pressure is about 4 \times 10⁻⁸ Pa. The working high voltage is chosen 25 KV. Electron probe microanalysis (EPMA-1610, Shimadzu, Kyoto, Japan) technique was employed to reveal the distribution of elements at the alloy/glass interfaces.

3. Results

Fig. 2 shows the SEM surface morphology of the glass coatings (PE and E30A) as fired on the K38G superalloy substrates. Interfacial reaction induced bubbles at different sizes featured the surface of pure glass coating. At bubbling sites, the alloy substrate was already

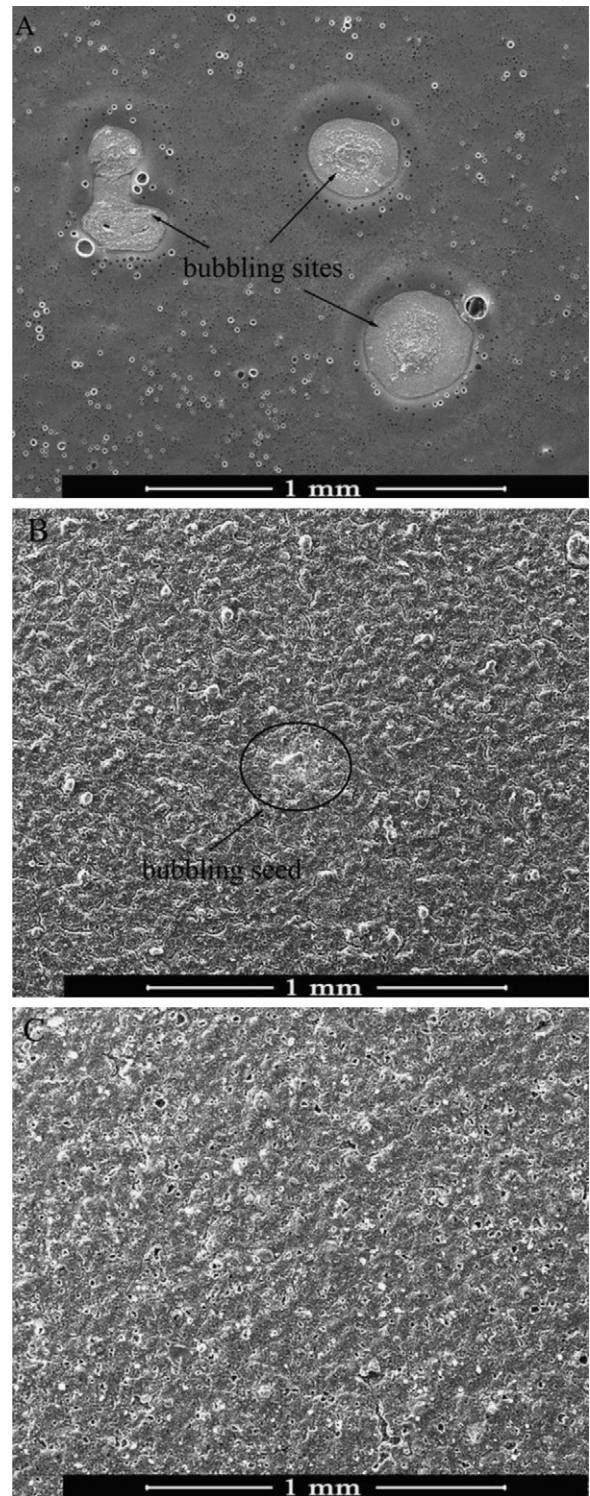


Fig. 2. Surface morphologies of coated K38G alloys with (A) PE coating of 15 μm thick; (B) E30A coating of 8 μm thick and (C) E30A coating of 15 μm thick.

exposed to the atmosphere. With incorporation of alumina particles into the glass coating, interfacial reaction of coating/substrate was highly suppressed. For the thin E30A coating of 8 μm thick, scattered faint bubbling seeds could still be detected, however, the coating was intact and spread well on the alloy substrate. With increasing thickness up to 15 μm , no bubbles were then found on the surface. Sintering micro-pores could be seen exactly at the top surface of E30A coating, which might originate from the increasing

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