Study on the Interfacial Reaction Mechanism Between Superalloy Melt and Alkaline Earth-Rare Earth Composite Oxide System

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Abstract: Superalloys are the most important materials for aeroengine hot section. The improvement of its trace element control level has always been a hot topic in the field. The precise control of sulfur (S) and rare earth (RE) elements, which are the most harmful and beneficial trace elements affecting the properties of superalloys, has been increasingly valued by the academic and engineering fields. The Alkaline earth-Rare earth ceramic system has the application prospects of both desulfurization and increasing rare earth elements. In this paper, the phase and element distribution of interfacial reaction products between MgO-Y_2O_3, CaO-Y_2O_3, MgO-CaO-Y_2O_3 ceramics and typical high activity superalloys were systematically studied by innovative experimental methods combined with XRD and SEM-EDS characterization methods. Furthermore, the reaction mechanism equations of different refractories and superalloy melts were summarized. The CaO-Y_2O_3 and MgO-CaO-Y_2O_3 systems have been confirmed to have the ability of desulfurization and rare earth addition by reacting with active elements such as Al in the melt. The interface reaction mechanism is revealed.

Keywords: Alkaline earth-Rare earth composite oxide; superalloy; interface reaction; ultra-low sulfur; rare earth addition

1 Introduction

Nickel based superalloys are the most important materials for the aeroengine hot section, and their usage in advanced turbine engines has exceeded 50% [1,2]. With the background of its temperature bearing capacity approaching the theoretical upper limit, improving the purity of the melt and accurately controlling the content of trace beneficial elements are important means to maximize the alloy performance[3,4].

Sulfur(S) has a significant impact on the elevated temperature service performance of casting superalloys and is recognized as one of the harmful elements. Smialek[5,6] reported that S content in superalloy is less than 1ppm, and its oxidation resistance is greatly improved. Rare earth (RE) elements (La, Ce, Y, etc.) are recognized by researchers as the most significant beneficial trace elements affecting superalloys[7]. The addition of a small amount of REs can significantly improve the properties of superalloys[7-8]. Alkaline earth-Rare earth oxide refractory materials can be used as a promising refractory system for superalloys melt in desulfurization and rare earth element control.

In this study, typical Alkaline earth-Rare earth oxide systems (MgO-Y_2O_3, CaO-Y_2O_3, MgO-CaO-Y_2O_3) are taken as the research object. The interface reaction behavior between highly active K417G superalloy melt and ceramics has been systematically studied. By analyzing the morphology, phase, and elemental composition of the reaction layer before and after the reaction, the interfacial reaction mechanism is revealed.

2 Experimental procedure

The immersion method was used to observe the interface reaction between ceramics and superalloys melt. The mixed Rare earth-Alkaline earth oxide was pressed into a rod shape (8 *10*100mm). According to specific heating gradients and insulation stages, the final product was kept at 1600 ℃ for 1 hour and cooled in the furnace to produce a dense ceramic rod. The ceramic samples were inserted into the alloy melt and held for 5 minutes before being directly taken out and cooled to room temperature for further characterization.

3 Result and discussion

The morphology and element distribution after the reaction at 1500 ℃ are shown in Figure 1. There are two continuous dense reaction layers with coexisting Ca and S, as well as coexisting Ca, Al, Y, and O (Figure 1 (a)). Further microscopic elemental analysis indicates the presence of a small amount of elongated channels of $CaAlYO_4$ composite oxide phase in the region dominated by solid CaS in the outer reaction layer. At the same time, there is a clear trend of internal infiltration in the oxide layer dominated by $CaAlYO_4$, which exists between unreacted CaO and Y_2O_3 particles (Figure 1 (b)).

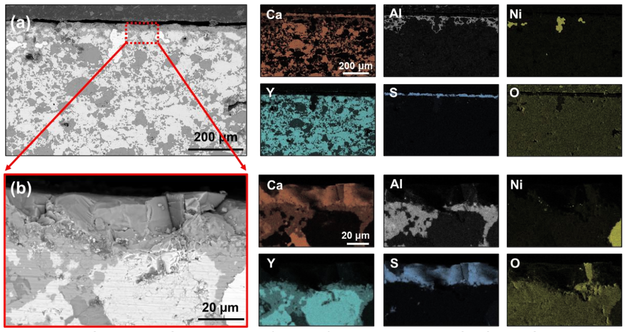

Figure 1 SEM-EDS results of interface between CaO-Y2O3 ceramic and superalloys after 1500 ℃ reaction

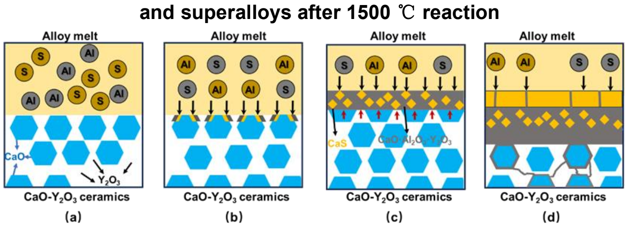

Figure 2 Interfacial reaction mechanism between CaO-Y_2O_3 and superalloy melt

The interfacial reaction can be divided into four stages. The first stage is the contact between the high temperature alloy melt (containing Al and S elements) and the uniformly distributed dense CaO-Y_2O_3 ceramics. The second stage is the initial stage of the reaction. The reaction occurs in the area where the melt contacts with CaO and Y_2O_3 particles, and the reaction products are solid CaS and CaO-Al_2O_3-Y_2O_3 ternary oxides. The third stage is the development stage of the reaction. Subsequently, the two products generated in the second stage form a continuous reaction layer. With the progress of the reaction, the solid CaS accumulates and occupies most of the physical space in the external desulfurization reaction layer containing S. At the same time, in order to ensure the continuous reaction, the $CaAlYO_4$ composite oxide medium layer presents a network channel to ensure the transmission of Al and S in the melt and CaO and Y_2O_3 phases in the ceramics (Fig.2).

4 Conclusion

In this study, the interfacial reaction behavior between highly active K417G superalloy melt and CaO-Y_2O_3 ceramics was studied.

(1) By in situ reaction with superalloy melt, MgO-Y_2O_3 system has the ability of rare earth addition, CaO-Y_2O_3 and CaO-MgO-Y_2O_3 systems have the ability of both desulfurization and rare earth addition.

(2) The interface reaction occurs between CaO-Y_2O_3 ceramics and Al, S elements in the superalloy melt. The reaction equation is CaO-Al_2O_3+[Al]+[S] → CaS+ $xCaO\cdot yAl_2O_3\cdot zY_2O_3$ + [Y];

(3) $CaO\cdot Al_2O_3\cdot Y_2O_3$ multi-oxides play a decisive role as the interface reaction of the medium layer. The internal CaO, Y_2O_3 and Al, S in the melt maintain the continuity of the interfacial reaction through its transport channel.

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