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Performance Study of Yttria-stabilized Zirconia and Gadolinium Zirconate Coating for Nickel-base Alloy for Turbine Application

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ABSTRACT

Experimental work is carried out to deal with the development of new synthesis techniques for the functional materials such as yttria-stabilized zirconia (YSZ) and gadolinium zirconate used in the field of thermal barrier coatings (TBC). Currently, TBCs are manufactured by dry route technologies, but such methods are directional and often require costly investments and complicated operations. We have carried out significant work aimed at developing sol-gel routes, which are non-directional methods, to prepare, by suitable chemical modifications, nanocrystalline materials with a controlled morphology. The main advantage of this method is to decrease the crystallization temperature, much lower than the conventional processes, allowing the synthesis of reactive powders with nanometric particles size. In this research work, the formulation of an alkoxide sol has been optimized to obtain homogeneous YSZ films. The films microstructures have been investigated using scanning electron microscopy, and thermal property has been studied.

Key words: *Nickel alloy, Yttria-stabilized zirconia, Gadolinium zirconate, Thermal barriers coatings.*

1. INTRODUCTION

Thermal barrier coating (TBC) systems are widely used in modern gas turbine engines to lower the metal surface temperature in combustor and turbine section hardware. Engines for both aerojet propulsion and land-based industrial power generation have taken advantage of this technology to meet increasing demands for greater fuel efficiency, lower NOx emissions, and higher power and thrust [1,2]. The engine components exposed to the most extreme temperatures are the combustor and the initial rotor blades and nozzle guide vanes of the high-pressure turbine [3]. Metal temperature reductions of up to 165°C are possible when TBCs are used in conjunction with external film cooling and internal component air cooling. In film cooling, a protective blanket of cooling air is ejected onto the external surface of the turbine vane or blade, from internal passages within the airfoils, by means of holes or slots in the surface. A typical TBC consists of two key layers: An oxidation-resistant bond coat such as diffusion aluminide or overlay MCrAlY bond coating, and a ceramic top layer, typically 7-8 wt.% Y23-stabilized ZrO2(7 yttria-stabilized zirconia [YSZ]), to reduce the heat flux into the component [4,5].

The ceramic top layer is typically applied either by plasma spray or by electron-beam physical vapor deposition [6]. The significant effort is going into the development of new ceramic compositions with lower thermal conductivity. Concepts used are advanced multicomponent zirconia (ZrO_2)-based TBCs using an oxide defect clustering design and materials whose compositions have a pyrochlore structure. In addition to a low-thermal conductivity, other desired properties of a TBC are also phase stability during long-term high-temperature exposure and thermal cycling, resistance to erosion, and pollutants such as, for example, calcium magnesium aluminosilicate, which can destroy the integrity of the TBC by infiltrating the pores and react with the coating [7].

2. EXPERIMENTAL WORK

2.1. Synthesis of YSZ and Gadolinium Zirconate

Synthesis of YSZ and $Gd_2Zr_2O_7$ requires mortar and pestle. For 7 wt.% of YSZ component, ZrO_2:Y_2O_3 should be in 0.93:0.07 molar ratio, which is added to the mortar for uniform mixing. Pestle helps in crushing the components against the mortar into further nanoparticles. To ensure proper mixing, acetone/alcohol is added in a dropwise at an interval of 15 min. This process is continued for the duration of 4-5 h continuously. At the end of the process, the component is available in the form of finely divided powder which is further kept for calcination at 1000°C for 2 h. The same process is performed for the

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synthesis of gadolinium zirconate, but the calcination temperature is changed to 1500°C (Figure 1).

The microstructure morphology of coating material is investigated by a field emission scanning electron microscope (SEM), and the phase analysis is carried out by X-ray diffraction (XRD) with filtered Cu Kα radiation using laboratory facilities available at NITK Surathkal (Figure 2).

A SEM uses electrons as a probe just like an optical microscope uses light as a probe. The investigation is utilized in imaging and chemical analysis and forms the subject of scanning electron microscopy. The SEM chamber operates at high vacuum (10^{-4}-100 Pa), and the specimens are mounted on stub with two-sided carbon tape. Adjust the stage positioning using XY knobs and note specimen position and height and place the specimen gently push the stage door back. Adjust the parameters to get the best image and valid spectroscopy (Figure 3).

Figure 1: (a-c) Coating powder developed at laboratory.

Figure 2: JOEL scanning electron microscope

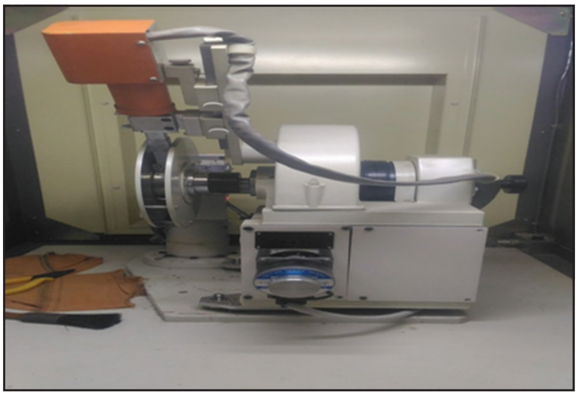

Figure 3: JEOL X-ray diffractometer.

XRD is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. The analyzed material is finely ground and homogenized, and average bulk composition is determined. XRD consists of three basic elements such as an X-ray tube, a sample holder, and an X-ray detector. X-rays are generated in a cathode-ray tube by heating a filament to produce electrons, accelerating the electrons toward a target by applying a voltage, and bombarding the target material with electrons. When electrons have sufficient energy to dislodge inner shell electrons of the target material, characteristic X-ray spectra are produced.

2.2. Coating Process

Before the coating process begins, the substrate has to be cleaned and obtain dust free. Hence, the substrate was grounded with SiC paper up to 100 µm. They were then cleaned with a series of acetone, methanol, and distill water in an ultrasonic set. To remove moisture and other adsorbents and improve coating adhesion, the substrate was preheated at 95°C for 5 min (Figure 4).

The necessary coating paste was made by addition of polyvinyl alcohol to the coating powder YSZ in a mortar to the mixture and appropriate amount of absolute alcohol is added. Using the paint brush, the coating paste produced is applied on to the surface of substrate material and left undisturbed for an hour to get dry. To complete the coating process, the coated substrate is kept in a furnace at 1000°C, and the samples were held at this temperature for 5 h. After the temperature of samples was let cool to room temperature and later, testing and analysis on specimens are carried out.

3. RESULT AND DISCUSSION

XRD pattern is taken for ZrO_2 for phase analysis with filtered Cu Ka radiation. The obtained XRD pattern is compared with a standard pattern of similar ZrO_2 and by referring the characteristic peaks, and hence, we concluded that ZrO_2 exhibits tetragonal phase further it can be verified through Bragg's law satisfying the formula $n\lambda = 2d(\sin\theta)$.

Figure 4: Ultrasonic setup to clean the substrate.

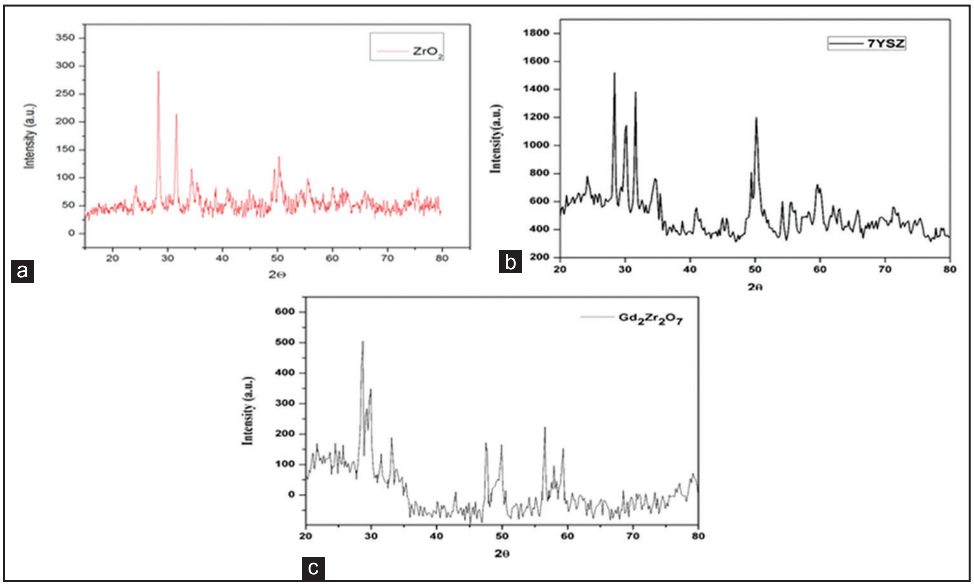

Figure 5: (a) X-ray diffraction (XRD) pattern for zirconia, (b) XRD pattern for 7 yttria-stabilized zirconia, (c) XRD image of gadolinium zirconate.

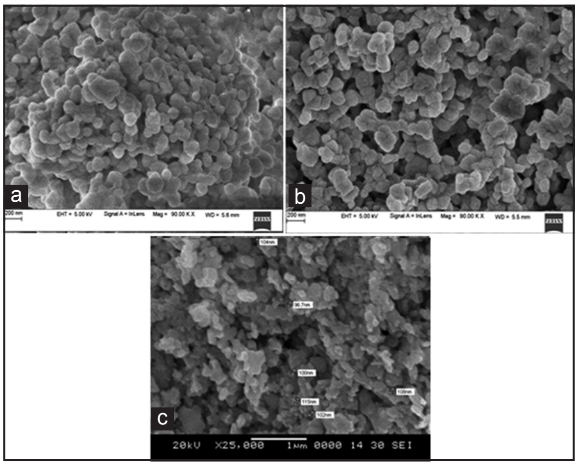

Figure 6: (a) Scanning electron microscope (SEM) image of 7 yttria-stabilized zirconia (YSZ), (b) SEM image of 8YSZ, (c) SEM image of Gd_2Zr_2O7.

Figure 5 obtained by XRD calcined at 1000°C shows for 7YSZ and 8YSZ phase transformation from cubic to tetragonal. The characteristic peaks obtained are correlated with the reported XRD pattern that shows similar representation confirming the above said. The XRD pattern of $Gd_2Zr_2O_7$ shows a pyrochlore, and the additional peaks incorporated are the indications of impurities present in specimens.

3.1. Microstructure Analysis by SEM

The morphology of three feedstock shown through SEM images, and it is that 7YSZ and 8YSZ prepared by solid state reaction depict well-grown spherical grains with dense microstructure with varying size of 80-100 nm, whereas $Gd_2Zr_2O_7$ prepared by co-precipitation technique represents the small nanograins of approximately 96-115 nm with dense microstructure (Figure 6).

3.2. Thermal Conductivity

Thermal conductivity measured for different specimens was recorded in tabular column and graph is plotted for the same (Figure 7).

The graph obtained from the data recorded, performed through measuring the surface temperature of the coated specimen at corresponding temperature of the furnace shows that 7YSZ has lower thermal conductivity compare to 8YSZ and gadolinium zirconate. While uncoated specimen found to have higher thermal conductivity value than coated specimens.

4. CONCLUSIONS

During the experimental work, we developed a new synthesis technique for functional material such as YSZ and gadolinium zirconate used in the field of TBCs. We have carried out significant work aimed at developing sol-gel routes, which are non-directional methods to prepare by suitable chemical modifications, nanocrystalline material with controlled morphology. The films microstructure investigated using scanning electron microscopy, the images of particles seem to be dense with small nanograin size ranging from 90 to 100 nm. The XRD data collected are referred with reported data available through literatures indicate that characteristic peaks in a XRD pattern of 7YSZ and 8YSZ exhibit tetragonal phase while $Gd_2Zr_2O_7$ exist as pyrochlore and other interrupted peaks show the presence of impurities among the samples. The conductivity of 7YSZ is lower compared with 8YSZ, $Gd_2Zr_2O_7$, and substrate uncoated. This might be due

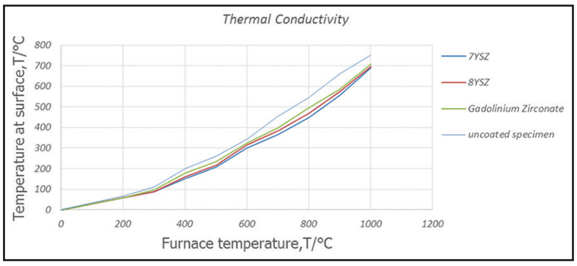

Figure 7: Thermal conductivity comparison of various specimens.

to a lower density for a pallet prepared for 7YSZ compared to other pallets.

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***Bibliographical Sketch**

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