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Investigating the microstructure and catalytic properties of Ni/YSZ cermets as anodes for SOFC applications

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ABSTRACT

Porous Ni/YSZ cermets (YSZ: yttria stabilized zirconia) have been extensively studied as anodes for solid oxide fuel cells (SOFCs) due to its low cost, high electrical conductivity, chemical stability, and thermal expansion coefficient close to that of YSZ-electrolyte. The properties of these anodes are highly dependent on the particle size and microstructure of the cermet. In the present work, Ni/YSZ cermet was prepared with 30 wt% of NiO by two different routes, co-precipitation (CP) and combustion (CB), and calcination at 600, 800 and 1000 °C. The prepared cermets were characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM) and temperature programmed reduction (TPR). The mean crystallite size of NiO is smaller for CB samples (20–33 nm), showing a higher Ni dispersion of these systems. Also, CB samples presented a more homogeneous particle size distribution, mainly at high calcination temperatures. The cermets also presented good catalytic activity and stability at 900 °C in steam reforming of methane, showing high resistance to coke deposition and to sintering of metallic particles.

1. Introduction

A solid oxide fuel cell (SOFC) is a device that converts the chemical energy of gaseous fuels, such as hydrogen and natural gas, to electricity through electrochemical processes. Due to their high efficiency, design modularity and environmentally friendly nature, SOFCs are considered one of the most promising energy converts [1–4]. Besides, one of the main advantages of SOFC, compared to other fuel cell systems, is the possibility of internal reforming of methane and other hydrocarbon fuels occurring directly on the anode, together with flexibility in fuel choice.

In order for an anode material to achieve the best performance for being applied to an SOFC, it should satisfy the following criteria: (a) high electrical conductivity; (b) stability under reducing environment; (c) thermal expansion and chemical compatibility with electrolyte and other components; (d) sufficient porosity to maintain the three-phase boundary (TPB) among electrolyte, electrode, and gas phase, which can act as an electrochemically active site for the electrode reaction [4,5].

Porous Ni/YSZ cermets (YSZ: yttria stabilized zirconia) have been extensively studied as anodes for SOFCs, as they not only meet the above-mentioned requirements but also have low cost. While Ni serves as an excellent reforming catalyst and electro-catalyst for oxidation of hydrogen as well as the electronically conducting phase, YSZ is added in order to support Ni particles, inhibit coarsening of the Ni, and provide a thermal expansion coefficient similar to that of zirconia-based electrolytes. Additionally, YSZ also offers a significant ionic contribution to the overall conductivity, effectively broadening the TPB [6,7].

The properties of Ni/YSZ anodes are highly dependent on the particle size and the microstructure of the cermet. Microstructural modifications during operation, like agglomeration and sintering of Ni particles, and carbon deposition, due to the internal reforming of hydrocarbons, are the main causes of anode performance degradation. The agglomeration of nickel particles leads to a significant reduction in TPB and an increase in the electrode polarization resistance [4,8]. The carbon formation could obstruct gas access and degrade anode performance by blocking the catalyst active sites. Usually, large quantities of steam are added to hydrocarbon fuels to avoid carbon deposition. However, the addition of excess steam leads to accelerated coarsening of Ni particles and reduction of the electrochemical potential according to the Nernst equation [6,9,10]. Thus, it is essential to optimize the morphological and structural properties of the cermets in order to improve the activity and operational stability of Ni/YSZ anodes.

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