Available online at www.sciencedirect.com
ScienceDirect
Surface & Coatings Technology 202 (2008) 4432–4437
SURFACE & COATINGS TECHNOLOGY
www.elsevier.com/locate/surfcoat

Advanced thermal spray technologies for applications in energy systems

R. Vaßen *, H. Kaßner, A. Stuke, F. Hauler, D. Hathiramani, D. Stöver

Forschungszentrum Jülich GmbH, IEF-1, 52425 Jülich, Germany

Available online 9 April 2008

Abstract

Atmospheric plasma spraying technologies have been used to produce coatings for different applications in energy systems as gas turbines and solid oxide fuel cells (SOFCs). Thermal barrier coatings (TBCs) are widely used in gas turbines to protect structural parts from the combustion gases. Although they are in use since several decades there is still a large amount of research focused on a further improvement going on. Especially increased temperature capability, improved microstructures or optimized optical properties of the coatings will be described in the present paper. Atmospheric plasma spraying (APS) technology has also been used to manufacture different coatings for solid oxide fuel cell systems. These coatings include NiO/YSZ coatings for anodes, YSZ coatings for electrolytes and different functional coatings as Cr-evaporation layer on interconnects. Recent results on these different kinds of coatings will be shown. Performance data of SOFCs on metallic porous substrates will also be given.

Keywords: Thermal spray; Energy systems; Solid oxide fuel cells; Thermal barrier coatings

1. Introduction

Plasma spraying technology is used in many applications for energy systems. Two different examples will be presented in this paper. In modern gas turbines thermal barrier coating (TBC) systems are applied since several decades to improve their performance. The thermally isolative layer can provide a reduction of the temperature of the metallic substrate which results in an improved component durability. Alternatively, an increase of efficiency can be achieved by allowing an increase of the turbine inlet temperatures [1,2]. TBC systems consist typically of two layers, a so-called bond coat layer, and an isolative, ceramic topcoat. The bond coat is often a metal and has two major functions. It improves the bonding between the substrate and the topcoat and it protects the substrate from corrosion and oxidation. Plasma spraying is widely used for the manufacture of both top and bond coatings. This technique offers the possibility to deposit thick layers in the mm range which is hardly possible with alternative techniques as electron beam physical vapour deposition (EB-PVD). Such thick coatings can effectively reduce metal temperature in hot sections of the gas turbine as combustion chamber liners while keeping the level of cooling air on a relatively low level [3,4]. Instead of the standard TBC material YSZ compositions with higher temperature capabilities are under investigation. The pyrochlore materials have been identified in literature to be excellent candidates [5,6]. However, due to the lower toughness of these materials they should be – as most of the new TBC materials – applied in so-called double layer system as developed at IEF-1 in Jülich [7]. In addition to new compositions also microstructural optimization can be used to enhance the performance of the coatings. Examples will be given in the paper.

Fuel cells are electrochemical devices which can directly convert chemical energy into electrical energy. As high efficiencies can be reached also for rather small unit fuel cells this technique is attractive for energy conversion systems. High temperature solid oxide fuel cells (SOFCs) [8] show a high electrical efficiency among all types of fuel cells. Correspondingly, world-wide efforts exist to introduce SOFCs in different areas of energy conversion covering combined heat and power (CHP) for residential applications [9], distributed energy production [10] or auxiliary power units (APUs) for advanced cars [11]. Although SOFCs offer attractive potentials in different areas of energy conversion, there are still obstacles which prevent a wide-spread use of SOFC based systems up to now. Besides the high degradation rates, a major obstacle are the

* Corresponding author. Tel.: +49 2461 61 61 08; fax: +49 2461 61 24 55.
E-mail address: r.vassen@fz-juelich.de (R. Vaßen).

0257-8972/$ - see front matter
doi:10.1016/j.surfcoat.2008.04.022

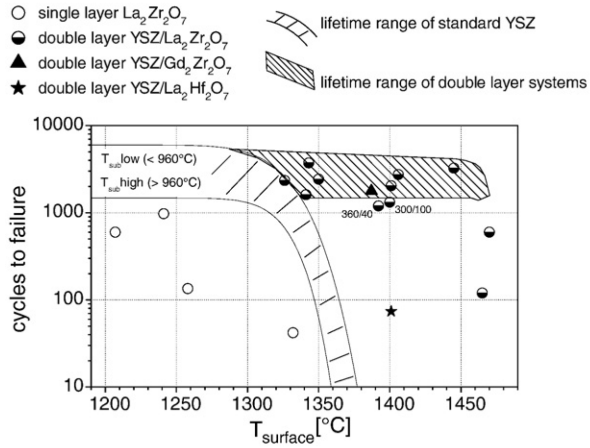

Fig. 1. Cycles to failure for different TBC systems. The numbers 360/40 and 300/100 indicate different layer thickness in micrometer of the double layers (YSZ/pyrochlore).

high production costs of the cells. One possibility to reduce production costs might be the use of atmospheric plasma spray technologies [12–14]. With the thermal spray technology cells can be produced without using time consuming sintering steps. However, it is difficult to produce on the one hand microporous electrode structure which guarantee high electrochemical performance and on the other hand dense electrolytes. The membrane manufacture by thermal spray technologies is ambitious as these coatings typically contain microcracks and pores. It will be shown in this paper that it is possible to meet the targets and to obtain cells with high performance data.

For an operation of stacks additional layers are needed. These layers can also be produced by APS, an example will be given.

2. Experimental

2.1. Production of TBCs

The investigated thermal barrier coating systems have been produced by plasma spraying with an A3000 unit by Sulzer Metco (Wohlen, Switzerland). Vacuum plasma spraying (VPS) with a F4 gun (Sulzer Metco, Wohlen, Switzerland) was used to deposit a 150 µm NiCoCrAlY bondcoat (Ni 192-8 powder by Praxair Surface Technologies Inc., Indianapolis, IN) on disk shaped nickel base IN738 superalloy substrates, which were used for thermal cycling experiments. The substrates used had a diameter of 30 mm and a thickness of 3 mm. The ceramic top coats with a thickness between 300 µm and 450 µm were produced by atmospheric plasma spraying (APS) using a Triplex I gun (Sulzer Metco, Wohlen, Switzerland). The parameters have been developed during previous investigations [15]. The used powders were a 7.8 wt.% yttria stabilized zirconia powder (Metco 204 NS) supplied by Sulzer Metco GmbH, Hattersheim, Germany as well as pyrochlore materials prepared by spray drying in our institute. The investigation on new TBCs is focused on double layer systems. In the present investigation typically 200 µm for each layer was used, however also thinner pyrochlore layers were used in the $La_2Zr_2O_7$/YSZ system. The total thickness of the coatings is about 400 µm and the porosity level of the coatings is about 12%.

In addition also coatings made by the suspension plasma spraying have been prepared. The Triplex II torch by Sulzer Metco (Wohlen, Switzerland) has been used as spray gun. For the suspension preparation yttria stabilized zirconia (5YSZ) from Tosoh Corporation, Tokyo, Japan with a particle diameter of $d_{50}=300$ nm was used. The powder was dispersed in an ethanol based suspension. The mass content varied between 10 and 30 wt.%. To achieve the required particle size all powders were dispersed in ethanol and ball-milled for at least 24 h. The suspensions have been stabilized by the addition of 1.5 wt.% of a dispersant. Depending on the desired porosity level different plasma powers (400 to 525 A), plasma gas ratios (Ar:He 50:4, 30:20) and spraying distances (60 to 100 mm) were used. The porosity level was measured on free-standing coatings by mercury (Hg) porosimetry using two units of porosimeters produced by CE Instruments, Italy (Pascal 140 for the low pressure and Pascal 440 for the high pressure range). Coatings were removed from the substrates by using hydrochloric acid.

Thermal cycling experiments were performed in one of our gas burner test facilities operating with natural gas and oxygen. The substrates were cooled by compressed air from the back. The surface temperature was measured with a pyrometer

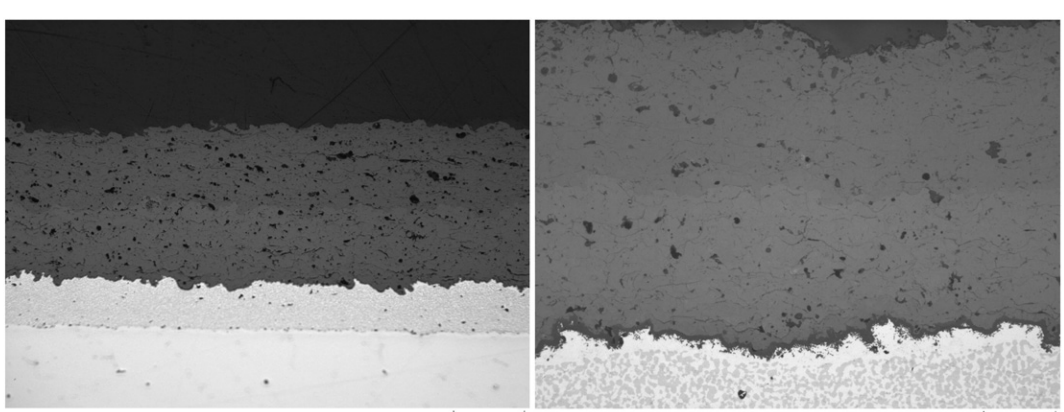

Fig. 2. Micrographs of YSZ/$La_2Hf_2O_7$ (left, 1401 °C, 74 cycles) and YSZ/$Gd_2Zr_2O_7$ (right, 1387 °C, 1782 cycles) coatings after thermal cycling.