# Oxidation and resulting mechanical properties of Ni/8Y<sub>2</sub>O<sub>3</sub>-stabilized zirconia anode substrate for solid-oxide fuel cells

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Ni/8 mol%  $Y_2O_3$ -stabilized zirconia cermets are used in thin-film electrolyte solid-oxide fuel cells as support substrates. Rapid oxidation of the metallic Ni can cause failure of the substrate and of the whole system. The rate of Ni oxidation in air and in an inert atmosphere containing water vapor was determined as a function of temperature between 500 and 950 °C. A logarithmic rate law describes the oxidation kinetics in air, whereas a linear rate law fits the first branch of the curve of the experimental data in a humidified inert atmosphere. The substrate exhibits no significant mechanical degradation after uniform oxidation under moderate conditions. However, the observed bending of the samples after oxidation in humidified argon, due to the nonuniform oxidation, can cause damage to fuel cell.

# I. INTRODUCTION

Solid oxide fuel cells (SOFCs) are devices that convert the chemical energy of a fuel (H<sub>2</sub> or various hydrocarbons) directly to electricity without intermediate stages of thermal and mechanical energy. The conversion is achieved through an electrochemical combination of the fuel and the oxidant (O<sub>2</sub> or air). In comparison to the traditional methods of converting chemical energy to electricity (i.e., gas turbines), the main advantages of SOFCs are high efficiency and the low pollution.<sup>1,2</sup>

Because the polarization losses are lowest at the anode component, several groups have pursued a so-called "anode-supported" SOFC configuration.<sup>2–7</sup> Under typical operating conditions, in which the anode is exposed to reducing atmospheres, the mechanical properties of the anode are sufficient to support the fuel cell. However, in the case of accidental oxidation at high temperature during initiation or shut-down of fuel cell operation, mechanical failure can occur (Fig. 1). This is thought to be the result of rapid oxidation of the Ni particles and accompanying volume expansion.

This paper describes the rate of oxidation of Ni in the Ni/8 mol%  $Y_2O_3$ -stabilized zirconia (8YSZ) cermet and the influence of oxidation on the mechanical properties to determine the regime under which oxidation occurs without failure of the substrate and of the whole fuel cell system.

The oxidation mechanism and kinetics of pure nickel and nickel alloys are well known and follow a parabolic law at high temperatures and a logarithmic law at low temperatures.<sup>8–16</sup> However, porous nickel composites, such as the Ni/8YSZ cermet, are not expected to follow the mechanisms governing pure dense metallic nickel due to the fine dispersion of the nickel particles in the 8YSZ.

Furthermore, the conditions under which oxidation can occur without degrading the mechanical properties of the anode were determined.

# **II. EXPERIMENTAL**

## A. Sample preparation

The samples were fabricated by the Coat-Mix<sup>®</sup> process developed at Research Center Jülich, Germany, for manufacturing the anode substrate of the SOFC.<sup>6</sup>

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FIG. 1. False color image of a cracked specimen after oxidation at 950 °C in air.



FIG. 2. Scanning electron microscopy image of the microstructure of the anode substrate (white: Ni; gray: 8YSZ; black: pores).

According to this process described in detail elsewhere,<sup>6,7</sup> the starting ceramic material is a wellhomogenized powder mixture of 56 wt% NiO and 44 wt% 8YSZ. The green substrate plates were produced by warm pressing the powder in a metallic die at about 120 °C at a pressure between 0.8 and 1 MPa. Finally, the green plates were sintered in air at 1400 °C. The dimensions of the plates were  $100 \times 100 \times 1.5$  mm. The total porosity after sintering was 34 vol%.

A diamond saw was used for cutting the samples from the sintered substrate plates. The dimensions of the specimens used to study the influence of oxidation on the mechanical properties were  $50 \times 4 \times 1.5$  mm, and for dilatometer measurements the substrates were cut to  $25 \times 7 \times 1.5$  mm. The residuals from cutting were used as samples for the thermogravimetric experiments.

All samples, except those used as a reference for the 4-point strength test of the "as-fired" material, were subsequently reduced in an Ar (96 vol%)  $H_2$  (4 vol%) mixture by the following temperature program:

Heating to 650 °C at 3K/min,

Maintained at 650 °C for 6 h,

Heating to 900 °C at 3K/min,

Maintained at 900 °C for 10 h, and

Cooling to room temperature within 6 h.

After the reduction the microstructure of the samples is characterized by its high total porosity (43 vol%). The nickel particles ( $d_{50} = 1.5 \,\mu$ m) are enclosed in the 8YSZ ceramics matrix that acts as a barrier against nickel agglomeration at operating temperatures (Fig. 2).

Disc samples ( $\emptyset$  20.5 and 1.5 mm) were made either directly by pressing the Coat-Mix powder and sintering or by cutting from larger plates. These samples were used to study the influence of the materials shape in the oxidation process.

## **B.** Characterization

### 1. Thermogravimetric experiments

First a set of thermogravimetric experiments was carried out by supplying air as oxidant from the beginning of the experiment to determine the temperature range where the oxidation of the cermet occurs. The temperature was raised and maintained at 360, 460, 560, 660, and 1000 °C.

To determine the oxidation rate in air, another set of thermogravimetric investigations were carried out at 550, 600, and 650 °C. During heating the gas stream was argon (12 ml/min), and after the desired temperature was reached, it was changed to air. Possible oxidation caused by impurities of argon was checked in a separate experiment by firing a specimen to 650 °C for 3 h. The degree of oxidation was less than 3%. This fact has been taken into account in all thermogravimetric experiments.

All thermogravimetric experiments were carried out using thermogravimetry/differential thermal analysis (TG/DTA) simultaneous thermal analyzer (Netzsch STA 409C, Selb, Germany).

#### 2. Oxidation in the furnace

The specimens  $(50 \times 4 \times 1.5 \text{ mm})$  used for the investigation of the influence of oxidation on the mechanical properties were oxidized in a furnace under the following conditions:

In an air stream at temperatures of 550, 600, and 650 °C, In an argon stream saturated at 80 °C with water vapor at temperatures of 800, 900, and 950 °C, and

In an argon stream saturated at 40  $^{\circ}\mathrm{C}$  with water vapor at temperatures of 900 and 950  $^{\circ}\mathrm{C}$ 

The oxidizing gas was supplied only after the desired oxidation temperature was reached, and it was changed again to argon during cooling of the furnace.

For each oxidation condition, three to four experiments were carried out, altering the duration of the exposure of the samples to the oxidizing gas to obtain several degrees of oxidation. The degree of oxidation was afterwards calculated from the weight change of the specimens. In each experiment, two samples were oxidized. To study the detrimental influence of oxidation at high temperature on samples with different shapes, bar samples ( $50 \times 4 \times 1.5$  mm) and disc samples (Ø 20.5 and 1.2 mm) were oxidized in air at 950 °C. Again the oxidant was supplied after reaching isothermal conditions.

## 3. Bending strength

The bending strength of the specimens, either partially or completely oxidized in the furnace, was investigated at room temperature using 4-point testing with a span ratio of 20:40 mm (Instron model 1121) (Offenbach/ Main, Germany). As reference reduced specimens were used as well as "as-fired" samples (after sintering). The dimensions of all specimens were  $50 \times 4 \times 1.5$  mm.

# 4. Dilatometric behavior

The dimensional change of the cermet during oxidation was studied with a Netzsch 402E dilatometer. The dimensions of the samples used were  $25 \times 7 \times 1.5$  mm and were oxidized in an air stream at 550, 650, and 800 °C. The oxidizing stream was applied after the dilatometer furnace had reached the desired temperature.

## 5. Optical microscopy

Ceramographic cross sections were optically investigated with an Axiomat–Zeiss microscope (München, Germany) to study the evolution of cermet oxidation. For digital image (Pori, Finland) analysis a KS400–Kontron Electronics instrument was used. The observed samples were fragments of the specimens after the 4-point test experiment.

# **III. RESULTS AND DISCUSSION**

# A. Thermodynamics of Ni oxidation

Figure 3 shows the calculated partial pressure of oxygen,  $p(O_2)$ , as a function of temperature for different thermodynamic systems. For this calculation the HSC Chemistry<sup>TM</sup> 4.01 software from Outokumpu Research O<sub>v</sub> was used. The Ni/NiO straight line divides this diagram into two regions. Above the straight line, nickel oxide is in thermodynamic equilibrium whereas below this straight line, metallic nickel is thermodynamically stable. In the diagram, the partial pressure of oxygen is also shown for the three different gas streams used for the oxidation of the samples (air and argon saturated with water vapor at 80 and 40 °C). The oxygen partial pressure for the Ar/H<sub>2</sub>O gas was determined by the dissociation equilibrium of water vapor. The change in saturation temperature (40 or 80 °C) does not result in an appreciable difference in  $p(O_2)$  and is very small in comparison to the difference from the Ni/NiO equilibrium line (e.g., eight orders of magnitude at 850 °C).

In thermochemical equilibrium, nickel can be oxidized by the water vapor concentration in an Ar atmosphere. However, from a kinetics point of view, the difference in the concentration of the oxidant (water vapor) at the twohumidification temperatures is very important and can lead to different reaction rates.

## B. Oxidation in air

## 1. Kinetics

The thermogravimetric investigation in air revealed that oxidation starts at about 350 °C and is completed at 700 °C (Fig. 4). At 360 °C only 20% of the cermet was oxidized after 10 h of isothermal exposure; at 460 °C this value increased to 27% after the same exposure time.



FIG. 3. Oxygen partial pressure as a function of temperature for different thermodynamic systems.



FIG. 4. Thermogravimetric observations of the oxidation in air of the Ni/8YSZ cermet. Oxidation starts at about 350  $^{\circ}$ C, and it is complete at 700  $^{\circ}$ C. The heating rate was 1 K/min.

Total oxidation reached a value of 95% at 560 °C after 3 h and was completed very rapidly at 660 °C before thermal equilibrium was achieved.

The commonly encountered oxidation rate equations are classified as logarithmic, parabolic, and linear.<sup>8</sup> Since they represent only limiting and ideal cases, deviations and intermediate rate equations are also often encountered.<sup>8</sup> When these rate models were applied to the data obtained from the thermogravimetric experiments, it was determined that the oxidation of the cermet in air follows the direct logarithmic rate law, at least for the temperature range studied (Fig. 5). The direct logarithmic rate model can be described by the following equation:

$$y = k_{\log} \cdot \log(t) + A \quad , \tag{1}$$

where *y* represents the percentage of oxidized Ni metal (determined from the weight change), *t* denotes the duration of exposure to the oxidant,  $k_{log}$  represents the logarithmic rate constant, and A is a constant.  $k_{log}$  increases with increasing temperature [for 550 °C,  $k_{log} = 16.4$  mg/log(min); for 600 °C,  $k_{log} = 17.4$  mg/log(min); and for 650 °C,  $k_{log} = 244$  mg/log(min)].

Oxidation in the furnace under the same conditions shows trends similar to those of the thermogravimetric experiments.

### 2. Bending strength

The bending strength values of the sintered (100% degree of oxidation) and completely reduced substrate (0% degree of oxidation) are evaluated on about 10 specimens, as shown in Fig. 6. The Weibull parameters of these measurements and of a former investigation are listed in Table I. The bending strength of the specimens oxidized at 500, 600, and 650  $^{\circ}$ C in air is shown in Fig. 7. For comparison, the bending strength



FIG. 5. NiO mass formed as a function of  $\log (t)$  at the three-oxidation temperatures in air (direct logarithmic model). The regression lines are plotted for the three temperatures for a degree of oxidation from 30% to 80%.

values of the sintered (100% degree of oxidation) and completely reduced (0% degree of oxidation) specimens are also given in Fig. 7. The three plotted points of these boundaries correspond to the highest, average, and lowest value of 10 measurements. In general the values of the specimens oxidized in air were between the two straight lines, which connect the maximum and minimum values of the as-sintered and reduced substrates.



FIG. 6. Weibull plots of the bending strength of sintered and reduced anode substrates.

TABLE I. Weibull parameters of the bending strength values of the sintered (100% degree of oxidation) and completely reduced (0% degree of oxidation)

		No. of	of		
	Substrates	specimens	$\sigma_{\rm M}$ (MPA)	М	
This paper	NiO/YSZ	9	110.4	9.8	
	Ni/YSZ	8	77.5	14.1	
Ref. 17	NiO/YSZ	10	97.0	10.3	
	Ni/YSZ	10	53.6	13.4	



FIG. 7. Bending strength versus oxidation percentage of specimens oxidized in air at various temperatures. As a reference also plotted in black is the bending strength of the reduced cermet (oxidation degree 0%) and the bending strength of the cermet after sintering (oxidation degree 100%).

Although fracture, particularly in porous media as studied here, is highly statistical and only a limited number of experiments were carried out in this work, it can be stated that oxidation at temperatures of 650  $^{\circ}$ C and below led to an increase in bending strength.

The microstructure of the substrates indicated the formation of a continuous ceramic yttria-stabilized zirconia (YSZ) matrix. The strength of the substrates is governed by this ceramic matrix and is lower than the value of the dense sintered YSZ because of their porosity. The Ni phase does not contribute significantly to the mechanical properties.

The reduced samples had a significantly lower bending strength that could most probably be attributed to their higher porosity (43 versus 34 vol% for the reduced and sintered samples).<sup>18,19</sup> When the cermet was oxidized at temperatures below 650 °C, the bending strength increased due to the reduction of porosity resulting from the volume change during oxidation of metallic Ni to NiO.

Dilatometric measurements in air indicate that, when the oxidation starts the length of the sample increases rapidly. At 550 and 650 °C the ratio  $\Delta l/L_0$ , (where  $\Delta L$ represents the length increase of the specimen and  $L_0$  to the initial length) increases due to the oxidation reaching a value of 0.27% (Fig. 8). At 800 °C the length change increases reaching a maximum of 0.54% followed by a very slow decrease (Fig. 8), revealing that the sample is cracked, as observed after the end of the experiment. A relatively low oxidation rate probably allows stress relaxation. On the contrary, oxidizing the cermet at high temperatures (i.e., 950 °C) and consequently at high rates, the rapid volume increase of the nickel particles causes tension in the surrounding 8YSZ matrix. Tension leads to the formation of cracks and failure in the mechanically prestressed areas of the bar specimens (i.e., near the edges where the specimens have been cut). Contrary to that, the pressed-disk samples did not have such flaws and therefore do not fail under the same oxidation conditions. Disk samples produced by cutting in a diamond saw also cracked after the oxidation at 950 °C.

#### C. Oxidation in argon saturated with H<sub>2</sub>O

### 1. Oxidation kinetics

The degree of oxidation is plotted in Fig. 9 as a function of time. Each plotted point is the average value of two specimens. For  $Ar/H_2O_{(T=80^{\circ}C)}$  the degree of oxidation increases during the first 100 min at the same rate



FIG. 8. Linear thermal expansion of the cermet versus time during oxidation in air.



FIG. 9. Degree of oxidation as a function of time for different oxidation temperatures in argon saturated with water vapor at 80 and 40  $^{\circ}$ C.



FIG. 10. Bent samples after oxidation in argon saturated with water vapor at 80 °C. The first sample was oxidized at 900 °C for the 5 h (oxidation degree 85%), and the second sample was oxidized at 950 °C for 4 hs (oxidation degree 90%).

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for all three investigated temperatures. This indicates that the reaction rate is initially independent of temperature, but after prolonged periods different reaction rates arise.

In this case the direct logarithmic rate model can describe the kinetics of the small number of the experimental data.

Nearly all the specimens were slightly bent after oxidation. In Fig. 10 the two most deformed specimens are pictured. The deformation occurred due to a nonuniform oxidation of the samples, which is revealed by the optical microscopy of the cross sections, as discussed in Sec. III. D of this paper.

The rate of oxidation in  $Ar/H_2O_{(T=40^{\circ}C)}$  is independent of temperature up to a degree of oxidation of 50% (Fig. 9), similar to the oxidation in  $Ar/H_2O_{(T=80^{\circ}C)}$ . Under these conditions the linear rate model showed the best fitting.

There is big difference in the oxidation rate of the two humidization conditions of the inert gas. After 180 min oxidation at 950 °C the degree of oxidation reached the value of about 76% for  $Ar/H_2O_{(T=80^\circ C)}$  compared to only 16% for  $Ar/H_2O_{(T=40^\circ C)}$ .

#### 2. Bending strength

As in the case of low-temperature oxidation in air (at 550–650 °C) the substrate retained its mechanical properties when oxidized in Ar/H<sub>2</sub>O<sub>(T = 80°C)</sub> [Fig. 11(a)]. The bending strength is already near the values of the sintered specimens after the first oxidation steps (<50%). This phenomenon can be understood from the observations of optical microscopy as discussed in detail in Sec. III. D. The bending of the specimens did not cause a significant problem, since, apart from the two extreme examples of bending shown in Fig. 10, it was barely noticeable.

The bending strength as function of the degree of oxidation for the specimens oxidized in  $Ar/H_2O_{(T=40^{\circ}C)}$  is shown in Fig. 11(b).

The bending strength initially increased with the degree of oxidation and then decreased again after long oxidation times. Almost all specimens were bent after oxidation in  $Ar/H_2O_{(T=40^{\circ}C)}$ . The deformation was more pronounced than for the specimens oxidized in  $Ar/H_2O_{(T=80^{\circ}C)}$  and caused minor cracks, which led to poor bending strength values.

### **D.** Microstructure investigations

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Optical observations on cross-sections of specimens oxidized in air revealed a homogeneous oxidation over the entire thickness of the specimens even after 30 min at 550 °C (degree of oxidation about 50%), shown schematically in Fig. 12.



FIG. 11. Bending Strength versus oxidation percentage of specimens oxidized at various temperatures: (a) in argon saturated at 80  $^{\circ}$ C and (b) argon saturated at 40  $^{\circ}$ C. As a reference, also plotted in black is the bending strength of the reduced cermet (oxidation degree 0%) and the bending strength of the cermet after sintering (oxidation degree 100%).



Less oxidized

FIG. 12. Schematic diagram of oxidation pattern in the different oxidation atmospheres

#### III. DISCUSSION

The homogenous oxidation of the specimens in air leads to the conclusion that the migration of oxygen into the interior of the porous cermet is faster than the reaction rate and produces a uniform oxygen concentration over the entire specimen from the start of the oxidation. The ratedetermining step of the reaction is then the nickel diffusion through the growing nickel oxide layer.

In dense metallic nickel with a small specific surface, oxidation typically follows parabolic growth.<sup>8</sup> In the case of the porous cermet, the nickel particles are nearly spherical,  $1-2 \mu m$  in size, corresponding to a large specific surface area. Oxidation proceeds rapidly at the beginning on the surface of the particles and then slows down due to the formation of the NiO layer and the gradual decrease in the size of the Ni mass. Therefore, the oxidation of nickel in the present work deviates from the parabolic rate law and can be better described by the logarithmic model.

The migration of oxygen and of water vapor into the interior of the specimens is similarly rapid in the case of oxidation in air or in saturated Ar stream. However, homogeneous oxidation is observed only in specimens oxidized by more than 50% (Fig. 12). In specimens oxidized by less than 50%, a gradient in the degree of oxidation from the surface to the interior of the samples is observed (Figs. 12 and 13). The gradient becomes more pronounced as the oxidation percentage decreases.

Oxidation in  $Ar/H_2O_{(T=40^\circ C)}$  proceeds in a way similar to that in  $Ar/H_2O_{(T=80^\circ C)}$  (Fig. 12). However, the gradient from the outside inwards is much more pronounced. It seems that the oxidation degree at the center of the specimen is close to zero.



FIG. 13. Cross section (at 100× magnification) of a specimen oxidized at 900 °C for 60 min in argon saturated with water vapor at 80°C reaching a degree of oxidation of 39%. Oxidation is not uniform. The cernet is less oxidized in the center and more oxidized near the surface. The same phenomenon, more pronounced, is also observed in oxidation in argon saturated with water vapor at 40 °C.

The conditions in the porous structure of the cermet, which determine oxidation, differ greatly between the two atmospheres used (i.e., air and argon saturated with water vapor). As already discussed, during the oxidation in air, the partial pressure of the oxygen in the cermet is uniform, right from the start, and therefore cermet is oxidized homogeneously. The rate-determining step in this case is the nickel diffusion through the growing oxide layer.

The situation is different when the oxidant is water vapor. In this case the reaction mechanism might be described as follows:

$$2H_2O \leftrightarrows 2H_2 + O_2$$
 , (i)

$$2Ni + O_2 \Leftrightarrow 2NiO$$
 , (ii)

$$Ni_{Ni} \xrightarrow{Diffusion through NiO layer} Ni_{NiO} , \qquad (iii)$$

$$H_2|_{cermet} \xrightarrow{\text{Diffusion through pores}} H_2|_{gas stream}$$
 . (iv)

Step (ii) occurs too quickly to become the rate-determining step.

At the beginning, oxidation step (iii) occurs too quickly because the nickel oxide layer is not thick enough. The formation of H<sub>2</sub> in step (i) reduces the partial pressure of oxygen and the reaction described in step (ii) decelerates. The oxidation stops if the partial pressure of the produced hydrogen reaches a high enough value (at 950 °C,  $2.75 \times 10^{-3}$  for 80 °C and  $4.31 \times 10^{-4}$  for 40 °C), and consequently the oxygen partial pressure is reduced to the calculated equilibrium for reaction (ii). The oxidation of nickel can only proceed by removing the hydrogen produced outside of the pores of specimen to the gas stream [step (iv)], where the partial pressure of hydrogen is equal to the decomposition pressure of water vapor, about  $10^{-6}$  atm. The gas transport rate (H<sub>2</sub> diffusion) is nearly constant through the porous cermet  $[\Delta p(H_2) \approx 10^{-3} \text{ atm}]$ , and therefore a hydrogen concentration gradient is formed in the cermet, resulting in nonuniform oxidation. The oxidation rate depends on the diffusion rate of hydrogen. Since the diffusion coefficient of hydrogen is not strongly influenced by a temperature change of 100 °C (i.e., 850–950 °C), the oxidation of the cermet is independent of the temperature, as observed for  $Ar/H_2O_{(T=80^\circC)}$  and  $Ar/H_2O_{(T=40^\circC)}$  up to 50% oxidation.

As the oxidation of Ni proceeds to the inner part and finally all the Ni particles have formed an oxide layer, oxidation becomes slower, and finally step (iii) imposes the rate-determining mechanism. The concentration gradient of hydrogen gradually diminishes, and oxidation becomes uniform. Since the self-diffusion coefficient of nickel in the nickel oxide layer is strongly dependent on temperature, the oxidation rate becomes temperature dependent, as observed in  $Ar/H_2O_{(T=80^{\circ}C)}$ . These can be concluded from the small number of experiments available.

The nonuniform oxidation of samples oxidized in  $Ar/H_2O_{(T=80^{\circ}C)}$  explains the observed relative high bending strength at low degrees of oxidation. The samples were well oxidized near the surfaces that withstood the stress under the 4-point test, and the mechanical behavior was close to that of the sintered specimens.

The dilatation under oxidation of the cermet explains the bending of the samples observed by nonuniform oxidation of those that were oxidized in the furnace in  $Ar/H_2O$ . The surface of the specimens in contact with the bottom of the furnace was less oxidized than the surface directly exposed to the gas stream (Fig. 12). Therefore, the dilatation was less for the bottom of the specimen than for the surface exposed to the gas, and the specimen was bent.

# **IV. CONCLUSIONS**

The same laws governing the oxidation of pure nickel do not necessary rule the oxidation of Ni in an anodic substrate cermet for SOFCs. In this study, the oxidation of the Ni/8YSZ cermet follows the direct logarithmic rate law in air, due to the large specific surface area of the nickel particles. The oxidation takes place homogeneously throughout the cross-section of the sample. When the cermet is oxidized in a stream of argon atmosphere saturated with water vapor, the rate-determining step at the beginning is the diffusion of hydrogen, produced through the oxidation, from the inner pores of the cermet to the gas stream. At the beginning of the oxidation with water vapor, the microstructure is not homogeneous and more oxidized near the surface area of the sample. The self-diffusion of nickel through the growing nickel oxide layer becomes the rate-determining step later, when the NiO layer grows. Therefore, at the start, the linear rate model describes the experimental data.

The influence of the oxidation in air on the mechanical properties of the cermet depends on the temperature, which triggers different reaction rates. At operating temperatures (800 °C) the oxidation is so rapid that the cermet cracks at already existing flaws in the microstructure. At 550–650 °C, the oxidation proceeds without damaging the cermet. In this temperature range, the bending strength increases with the degree of oxidation reaching the values of the sintered cermet at high oxidation degrees.

The influence of the oxidation by water vapor on the mechanical properties of the cermet is characterized by a rapid increase in bending strength of the cermet due to selective oxidation near the surface area of the sample, where the tension by the 4-point bending test is stronger.

The observed nonuniform oxidation with water vapor causes bending of the specimens. This effect is more pronounced in the case of oxidation with argon saturated with water vapor at 40 °C. Any thoughts on oxidizing the

anode substrate of the SOFCbefore shutting down with pure water vapor should be abandoned, since the bending would cause hazardous damage to the fuel cell.

Apart from the scientific interest on the oxidation of a porous composite such as the Ni/8YSZ cermet, the study of the oxidation and its influence on the mechanical properties of the cermet ought to answer whether a deliberate oxidation of the cermet can occur without damaging the cell. Oxidizing the substrate at 550–650 °C in air is safe regarding the oxidation rate and its influence to the mechanical properties of the cermet.

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