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The Use of Cordierite Based Materials as Radiant Burners

E. García, P. Miranzo and M. I. Osendi

Instituto de Cerámica y Vidrio, CSIC, Campus de Cantoblanco 28049, MADRID, Spain.

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Abstract. Industrially developed perforated cordierite ceramic tiles were aged under accelerated conditions in a radiant combustion mode. Changes in the original phases, microstructure and mechanical properties were evidenced in the aged plates. The extent of the degraded zone was localised at the uppermost layer of the burner. These effects are attributed to the corrosion of the cordierite-based material by gaseous species generated in the combustion.

Introduction

The hazardous species generated by the combustion of gas (CO_x, NO_x) can be partially reduced by using gas infrared radiant burners [1]. Both metals and ceramics are used for radiant burner applications in many shapes and configurations, such as perforated plates, foams or fibermats [2]. Here, we will focus on perforated ceramic plates, which typically have several thousands of closely packed channels through which gas flows. Initially, porous cordierite seems to be a suitable material for this application due to its low thermal conductivity [3] and low thermal expansion coefficient [4] that enhance its thermal shock response [5].

In a radiant combustion mode, the flame temperature together with the concentration of transitory chemical species, like OH and H, have been proposed as the responsible agents for degradation of different ceramic plates [6,7]. In fact, it was assumed that the degradation kinetics of a ceramic burner was governed by the local concentration of monatomic hydrogen [7]. Even though these concentrations are very low, they are very important owing to the fact that volatile hydroxides or suboxides can form by reaction of the ceramic with the monatomic hydrogen [6,7].

Consequently, cordierite perforated plates were tested in the radiant mode as being the most aggressive working condition. The plates aged in that way were analysed to correlate the total combustion time to possible variations in the plate properties with the aim of finding a convenient parameter for monitoring the burner degradation. The degradation of these perforated ceramic tiles was experimentally proved and treated according to the above corrosion model.

Experimental

The perforated ceramic tiles, developed by Morgan Matroc (Barcelona, Spain), had rectangular shape (13 cm x 16 cm x 1.5 cm) with thousands of cylindrical evenly arranged through thickness holes of 1mm of diameter.

The apparent density (ρ) of the plates, measured by the water immersion technique, was approximately 0.60 g/cm^3 and the porosity was around 70 vol.%. Plates had a chemical composition close to the stoichiometric cordierite ($2MgO.2Al_2O_3.5SiO_2$) The X-ray diffraction (XRD) patterns recorded from powdered samples showed the presence of indialite, which is the hexagonal form of cordierite, as the main phase together with traces of mullite.

The plates were aged in Standardised Combustion Chambers (SCC) developed by Ikerlan S. A. (Vitoria, Spain) using natural gas as fuel. These combustion chambers consisted basically in a combustor and a control system, which allowed an automatic control of the combustion parameters. The combustor reproduced the usual operating conditions existing in commercial boilers used for space heating.

Ageing tests carried out in these combustion chambers were on/off cycles whose duration varied from 75 to 3600s. The maximum ageing time tested was 3000 h of radiant mode working.

For the microstructure observations, the top (combustion) surface and the cross-section specimens of both aged and original plates were gold coated before prior to scanning electron microscope (SEM) examinations (or investigations). Standardless microanalyses were done by energy dispersive X-ray spectroscopy (EDS) in selected zones along the gas channels using a window analysis of 50 x 50 μm^2.
XRD patterns were taken at a fixed incident angle of 0.5º to reduce the penetration depth of the X-ray beam, which made it possible to analyse only the surface layer (≈ 1 μm). Specimens were sectioned from aged plates and mounted in the XRD holder with the scanned surface as the combustion one. Once the pattern was recorded, the surface was removed by gently grinding and the thickness reduction measured with a micrometer with an accuracy of ±0.001 mm. This process was stepwise repeated until the initial composition of the plate was reached.

Results and Discussion
In Fig. 1, some examples of the microstructures observed in the original and aged plates near the combustion face are compared. It is noticeable that a glassy phase usually surrounds grains in the unburned plate (Fig. 1a) which is lacking in the aged plates where the microstructures are more precisely revealed (Fig. 1b).

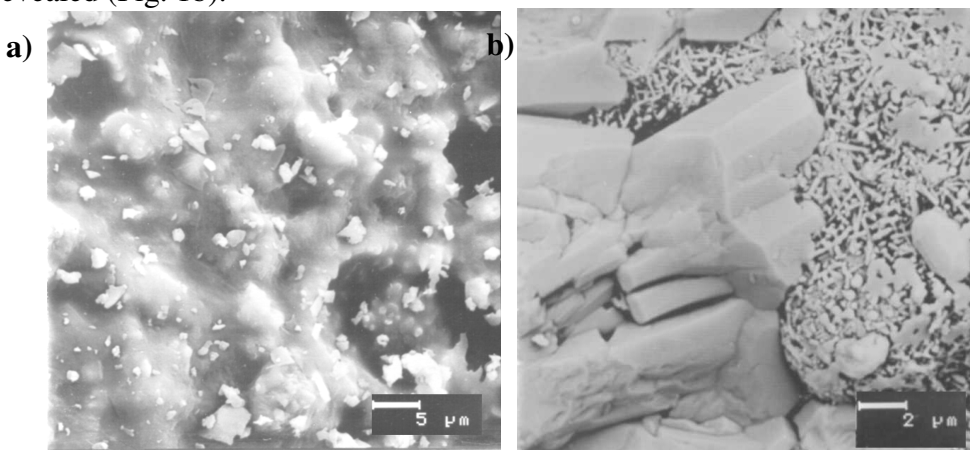

Figure 1.- Representative SEM micrographs of a gas channel zone near the combustion surface from (a) an original plate, (b) plate aged for 1200 h

Certain evidence of changes in the average composition across the aged plates is confirmed by the EDS window analysis done along a gas channel, from the combustion face down to the cooler face. This result totally agrees with above microstructural observations that showed the loss of the original glassy phase. Furthermore, this change in chemical composition at the upper surface was accompanied by a change in the original phases as is demonstrated in Fig. 2, where a selection of XRD patterns recorded from the specimen aged for 2540 h at increased depths from the combustion face are displayed. At the combustion surface, the peaks of indialite together with some peaks characteristic of spinel ($MgO.\ Al_2O_3$) and forsterite ($2MgO.\ SiO_2$) can be observed. The spinel and forsterite peaks gradually reduce their intensity in the patterns of the plate inner regions. The original pattern of the cordierite plates is recovered after removing about 150 μm in depth from the top surface layer of the 2540 h aged plate.
The combustion environment (high temperatures and presence of radicals) is directly related to the plate degradation.

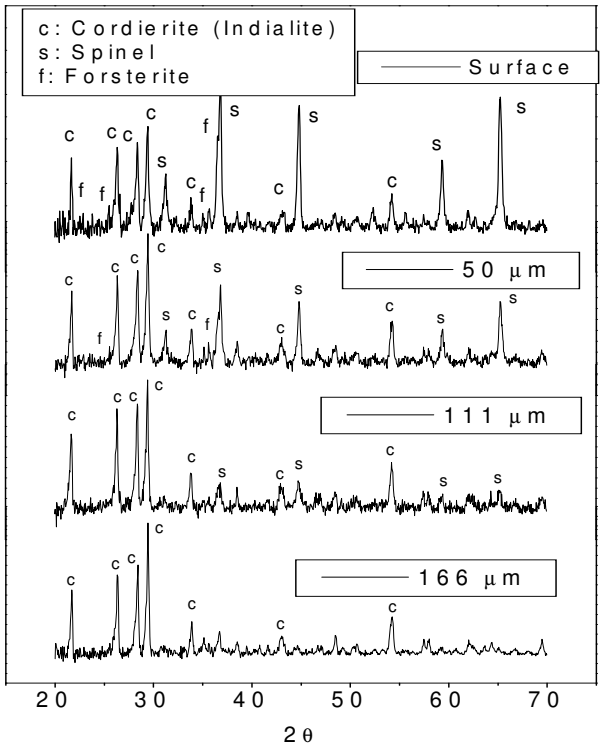

Figure 2. Grazing angle XRD spectra of a plate aged for 2520 h recorded at different depths from the combustion surface.

Among the oxide ceramics, silica and silica-containing materials show a poor stability in reducing atmospheres [6]. Particularly, cordierite can be reduced by monatomic hydrogen according to the expression:

$$\underset{\text{cordierite}}{2MgO \cdot 2Al_2O_3 \cdot 5SiO_2} + 10H(g) = \underset{\text{spinel}}{2(MgO \cdot Al_2O_3)} + 5SiO(g) + 5H_2O(g) \,.$$

The decomposition of cordierite to form spinel is favourable for temperatures of 900ºC or above, which is within the typical range of surface temperatures of the burner rig working in radiant mode [8].

The extension of this corrosion zone is limited to the free surface region because the rapid temperature drop occurring within the burner plate [8] and the decrease in the concentration of the free radicals underneath the combustion surface [9,10]. Additional experimental confirmation of this localised degradation is offered in Fig. 3. This figure collects values for the elastic modulus of several aged plates as a function of the thickness of the layer removed from the combustion surface by gently polishing. Measurements were done on bars (13 x 20 x 60 in mm) machined from the aged plates and subjected to stepwise polishing repeated until steady values were reached. A decrease in the elastic modulus proportional to the total ageing time is clearly observed. Considering these tests and the XRD results, we can say that the extension of the corrosion zone is in the range of 100-1500 μm for ageing times around 3000h. In fact, the original crystalline phases were recovered after a ≈100 μm layer was removed, while the original flaw population and, therefore, the original elastic modulus, was only regained when a layer of approx. 1mm is removed. Therefore, the decrease in the elastic modulus observed in aged plates is due to the localised corrosion phenomena described.

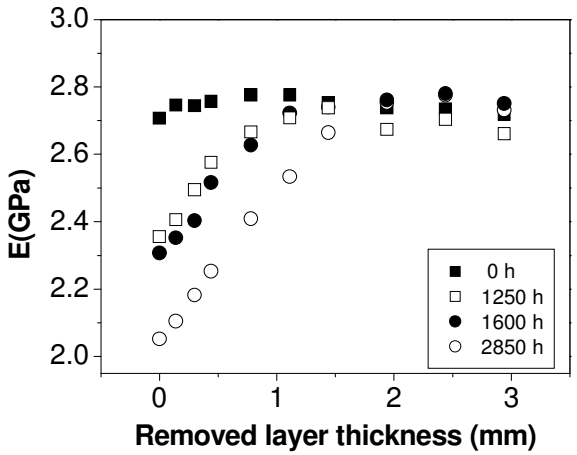

Figure 3. Elastic modulus of prismatic bars machined from different aged plates as a function of the of the removed surface layer thickness (combustion surface).

Conclusions

Cordierite based plates aged in a combustion radiant mode show a localised degradation at the combustion face caused by both the removal of the existing glassy phase and simultaneous decomposition of cordierite by monatomic hydrogen. The reduction reaction of cordierite during the combustion to form spinel is thermodynamically favourable in complete consonance with the experimental data. This reaction is limited to a small zone close to the radiant surface, where the burner temperatures are higher enough and a low but meaningful concentration of radicals existed.

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