

chromia-rich sublayer and a $(\text{Mn}, \text{Cr})_3\text{O}_4$ spinel-rich top layer during oxidation at 800°C in air at different times (Yang *et al.*, 2004; Brylewski *et al.*, 2001). During the early stages of oxidation, both chromia and spinel phases have nucleated and grown with preferred crystallographic orientations on the alloy surface. With time, the separate spinel crystallites tend to coalesce, and its microstructure becomes more homogenized. Further oxidation leads to the growth of a chromia-rich scale beneath the spinel-rich layer, resulting in two compositionally distinct oxide layers (Huang *et al.*, 2000).

The oxide scales formed on various commercial ferritic steels oxidized at 800°C in air for 100-1000 h consist of an external MnCr_2O_4 spinel layer and a sub-layer of Cr_2O_3 (Schutze, 1997). The oxide surface morphology for the alloys containing titanium and lanthanum is very similar, with the delineation of the alloy grain boundaries due to the formation of internal titanium oxides (Kofstad, 1988). When these alloys are oxidized in air, a slight increase in the oxidation rate was observed for those with Ti and La additions, due mainly to the formation of pronounced internal titanium oxides at the alloy grain boundaries, forming a buckled oxide scales, but no detachment from the alloy surface was observed. The alloys without those additions form a relatively smooth oxide with no internal-oxide formation, which provides better oxidation resistance (Schutze, 1997).

A ferritic stainless steel AISI 430 was investigated after exposure at 800°C for 300 h in air and in a dual atmosphere (Yang *et al.*, 2003). Microstructure and EDX analyses indicated that the scale grown during heating was comprised of a manganese-rich $(\text{Mn}, \text{Cr}, \text{Fe})_3\text{O}_4$ top layer and a Cr_2O_3 rich sublayer. Occasionally, a thin silica film was observed between the chromium and manganese-rich scale and the alloy substrate. The oxidation behaviour (scale growth and composition) on the air/fuel-side was found to be different from the behaviour observed when the steels exposed to air only. SEM observation of scale surfaces confirmed that both scales had similar composition and microstructure, with MnO crystals on a spinel-rich substrate, and a silica layer lying beneath the spinel-rich layer. From the point of view of contact resistance, the formation of SiO_2 or Cr_2O_3 layers may be considered as a disadvantage (Yang *et al.*, 2003)

Ferritic stainless steels ITM 14, ZMG232, 446 and

Crofer22APU were studied after oxidation tests at 800°C in air for 5000 h (Venskutonis *et al.*, 2005). Mass gain vs. time derived from oxidation showed compatible behaviour where mass changes were $<2.25 \text{ mg/cm}^2$. ZMG232 was found to be more subjected to oxidation and higher weight gains ($\sim 2 \text{ mg/cm}^2$). For comparison, weight changes of others steels were within the limits of $0.5\text{-}1.5 \text{ mg/cm}^2$.

2. Experimental

Several ferritic stainless steels (types 430, ITM14 (Plansee), ZMG232 (Hitachi), Crofer 22APU (Thyssen Krupp)) were studied in this work. Steel plates were cut in squares $\sim 15 \times 15 \times 2\text{-}3 \text{ mm}$ and further used as supplied but grinded with SiC paper 800 grit. The chemical compositions of steels are shown in Table 1. The chromium equivalents were calculated using conventional rules for stainless steels.

The first experiments for high-temperature oxidation were carried out at 800°C for 168-170 h (1 week) in static air. The next series were done at 900 and 1000°C for 24 h in static air. All specimens were weighed before and after furnace tests. The oxidized surfaces were studied by SEM for general morphology, specific features and composition (cross-section analysis was not in the objectives of this particular study).

3. Results

The thickness and structure of the oxide layers depend on the steel composition and temperature. A significant difference in oxidation resistance at temperatures above 800°C was observed on the various steels (Fig. 1).

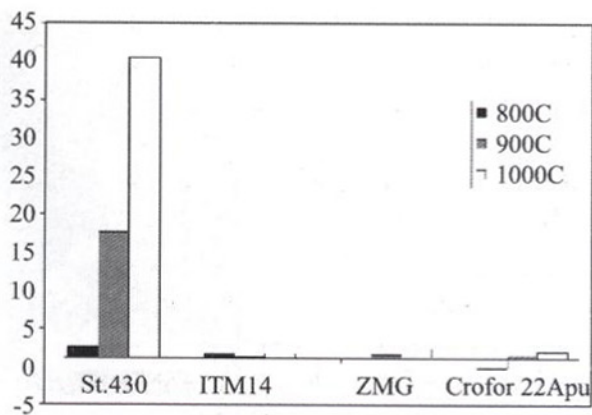


Fig. 1. Weight changes after high-temperature oxidation in air (170 h at 800°C , others 24 h).