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Oxidation Behavior of Ferritic Stainless Steel in an Atmosphere Simulating Hydrogen Combustion

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To achieve carbon neutrality by 2050,hydrogen fuel-which emits no CO_2 during combustion-is drawing increased attention. Hydrogen engines can utilize existing internal-combustion technologies, but their exhaust differs markedly from gasoline engines. Hydrogen combustion generates roughly three times more steam (30%) and yields slightly lower flame and exhaust temperatures (673–1073 K compared with 773–1173 K for gasoline). Because ferritic stainless steels rely on protective Cr_2O_3 formation, the steam-rich environment near 873 K poses a risk of Fe_2O_3 (red scale) formation. The higher steam content and operating temperature range of hydrogen engines thus increase exposure to this critical regime. Previous studies mainly considered gasoline-engine exhaust (10% steam), while evaluations under high-steam conditions (30%) remain limited. This study therefore investigates the red-scale resistance of ferritic stainless steels under 30% steam at 400–700°C and evaluates the influence of surface polishing, given prior reports that surface strain can suppress red-scale formation.

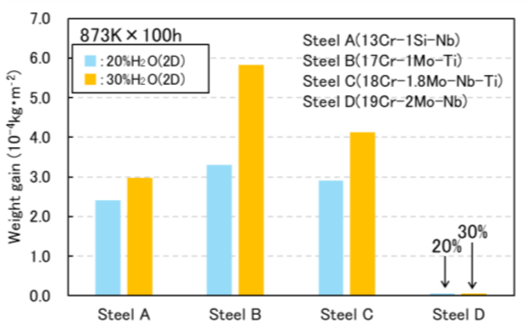

Fig1. Effect of steam content on oxidation resistance at 873 K for 100 h.

Figure 1 presents oxidation behavior at 873 K for 100 h. Steels A–C showed increased oxidation with rising steam concentration, whereas Steel D effectively suppressed red-scale formation across all conditions. These findings indicate that steam concentration accelerates oxidation but that alloy-dependent factors strongly influence sensitivity. To clarify these factors, the effects of temperature and alloy composition were examined further.Figure 2 shows the relationship between weight gain at 673–973 K and Cr + 4Si. The red-scale threshold is approximately 0.02 mg/cm², and compositions with Cr + 4Si ≧ 20 remained below this level across all temperatures. For steels that produced red scale, oxidation peaked at 873 K. At 673 K, all steels satisfied the target even under high-steam conditions, indicating that red-scale formation can be avoided at this temperature.

Figure 3 illustrates the influence of surface finishing. Steels with Cr + 4Si < 20 showed considerable red-scale formation (2.9–5.9 mg/cm²) in the 2D-finished condition, whereas polished samples limited weight gain to below 0.2 mg/cm² even with Cr + 4Si around 13. These results confirm that polishing significantly enhances steam-oxidation resistance. The improved performance is attributed to strain-introduced dislocations that promote rapid Cr and Si diffusion required for forming protective oxides.

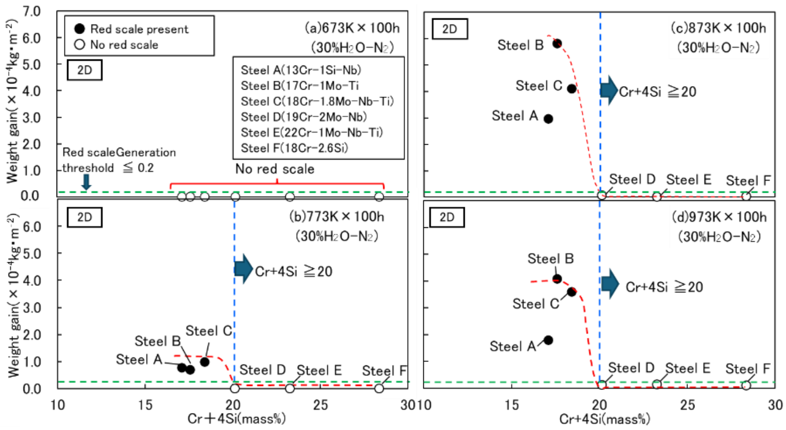

Fig.2 Relationship between Cr + 4Si and weight gain after steam oxidation test at (a)673K, (b)773K, (c)873K, and (d)973K for 100h in 30%H2O-bal.N2 atmosphere.

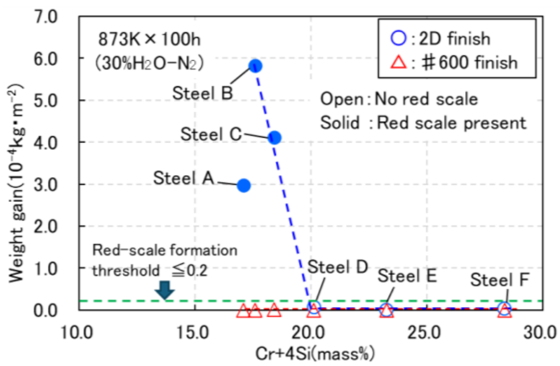

Fig.3 Effect of surface finishing weight gain after steam oxidation test at 873K for 100h in 30%H2O-bal.N2 atmosphere.