

CHEMICAL COMPATIBILITY OF STRUCTURAL MATERIALS IN ALKALI METALS*

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OBJECTIVE

The objectives of this task are to (a) evaluate the chemical compatibility of structural alloys such as V-5 wt.%Cr-5 wt.%Ti alloy and Type 316 stainless steel for application in liquid alkali metals such as lithium and sodium-78 wt.% potassium (NaK) at temperatures in the range that are of interest for International Thermonuclear Experimental Reactor (ITER); (b) evaluate the transfer of nonmetallic elements such as oxygen, nitrogen, carbon, and hydrogen between structural materials and liquid metals; and (c) evaluate the effects of such transfers on the mechanical and microstructural characteristics of the materials for long-term service in liquid-metal-environments.

SUMMARY

Candidate structural materials are being evaluated with regard to their compatibility, interstitial element transfer, and corrosion in liquid alkali metal systems such as lithium and NaK. Type 316 stainless steel and V-5Cr-5Ti coupon specimens with and without prealuminizing treatment have been exposed to a lithium environment of commercial purity for 3200 h at 350°C. Weight change data showed negligible corrosion of these materials at this temperature.

INTRODUCTION

Liquid metals are being considered for a coolant/tritium-breeding blanket in the ITER. These liquid metals include lithium (Li) and sodium-78wt.% potassium alloy (NaK). The structural materials considered for the first-wall application are Type 316 austenitic stainless steel and V-5 wt.%Cr-5 wt.% Ti alloy. In the fusion application, the structural material of the system must be compatible with the liquid metal and must also maintain structural integrity for long periods during exposure to moderately elevated temperatures, thermal cycling, and possible intense irradiation; it must also be amenable to low MHD losses during flow in the magnetic field.

In general, structural materials can undergo a variety of interactions upon exposure to liquid metals. The extent of interaction depends upon the conditions of temperature, temperature gradient, liquid-metal velocity and purity, alloy composition, and the materials of construction of the containment system. The peak temperature for the liquid metal in ITER is expected to be $\approx 400^\circ\text{C}$, with a maximum temperature gradient of $\approx 100^\circ\text{C}$ around the loop. Under these conditions, metallic-element mass transfer between the structural materials and the liquid metal occurs predominantly by leaching of the alloy constituents of the materials, which is dictated by the solubility of the alloy constituents in the liquid metal. Nonmetallic elements such as oxygen, carbon, nitrogen, and hydrogen are known to migrate in structural-material/alkali-metal systems as a result of chemical activity differences. The effect of transfer of these elements can affect on the microstructural changes and long-term mechanical properties of the materials. In addition, distribution of hydrogen and hydrogen isotopes between the structural material and liquid metal, as well as permeation of these elements through the structural alloy, must be known in order to control and maintain the desired inventory of tritium in the system.

Some of the key performance variables of importance in the use of liquid metals in first-wall/blankets are:

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(a) Liquid Metal Compatibility

Corrosion due to metallic element mass transfer

Nonmetallic element (O, C, and N) mass transfer

Influence of corrosion on mechanical properties

(b) Tritium Inventory and Transport

Hydrogen/tritium solubility in liquid metal

Hydrogen/tritium distribution between liquid metal and structural material

Tritium recovery methods

Effects on structural materials

EXPERIMENTAL PROCEDURE

Three static liquid-metal systems have been designed and fabricated for studies on compatibility of structural materials in liquid metals. Two of these systems have been filled with ≈ 5 L of high-purity Li, and the third system was filled with NaK. The two lithium systems are maintained at temperatures of 350 and 400°C, respectively, and the NaK system is operated at 300°C. Figure 1 is a photograph of the experimental systems. Coupon specimens of V-5 wt.%Cr-5 wt.% Ti alloy and Type 316 stainless steel were fabricated for exposure in liquid metals. In addition, specimens of both materials were aluminized by a pack-diffusion process to enrich the near-surface regions of the specimens with aluminum; these specimens were also exposed to liquid metals to evaluate the long-term stability of aluminum-enriched surface layers. Weight change measurements are used to establish the corrosion rates for the structural alloys as a function of temperature, time, and liquid-metal chemistry. After the exposures, the specimens are examined by a scanning electron microscope (SEM) equipped with an energy-dispersive X-ray (EDX) analyzer and by X-ray diffraction.

RESULTS

In the aluminizing pack-diffusion process, the substrate materials are contacted and heated for 4-12 h at temperatures of $\approx 900^\circ\text{C}$ with a pack of powders. The composition of such powders (e.g., 65 wt.% Al_2O_3 , 33 wt.% Al, 2 wt.% NH_4Cl) provides the packing with metallic Al, alumina as filler material, and NH_4Cl as activator. The Al deposited on the substrate surface diffuses into the subsurface regions of the material, where it forms intermetallic phases as aluminides of Fe or Ni in stainless steel and Al-V intermetallic in V alloy. The aluminide layers reach thicknesses of 0.015–0.20 mm, depending on the composition of the substrate materials, length of exposure in the pack, and exposure temperature. Figure 2 shows the elemental concentration profiles of Al, V, Cr, and Ti in a V-5Cr-5Ti alloy sample after an aluminizing treatment.

Figure 3 shows weight-change data for both materials with and without prealuminizing treatment after exposure at 350°C to lithium of commercial purity. The base alloys exhibited very little weight change over a 3200 h period of exposure, indicating virtually no impurity-induced corrosion of the alloys in the lithium environment. The prealuminized specimens exhibit a somewhat greater weight change, especially during the initial 200 h of exposure. This change can be attributed to loss of aluminum oxide particles embedded in the surfaces of the specimens from the aluminizing process. Thermodynamic stability calculations show that aluminum oxide is unstable in a lithium environment and that transfer of oxygen will be from the oxide to lithium. After ≈ 1500 h exposure, weight losses are negligible for the balance of the exposure period. Because corrosion rates over long periods of time are determined by the slope of the weight change vs. time curves in Fig. 2, it is evident from the data that the rates are negligible for both substrate materials with or without aluminizing treatment at 350°C.

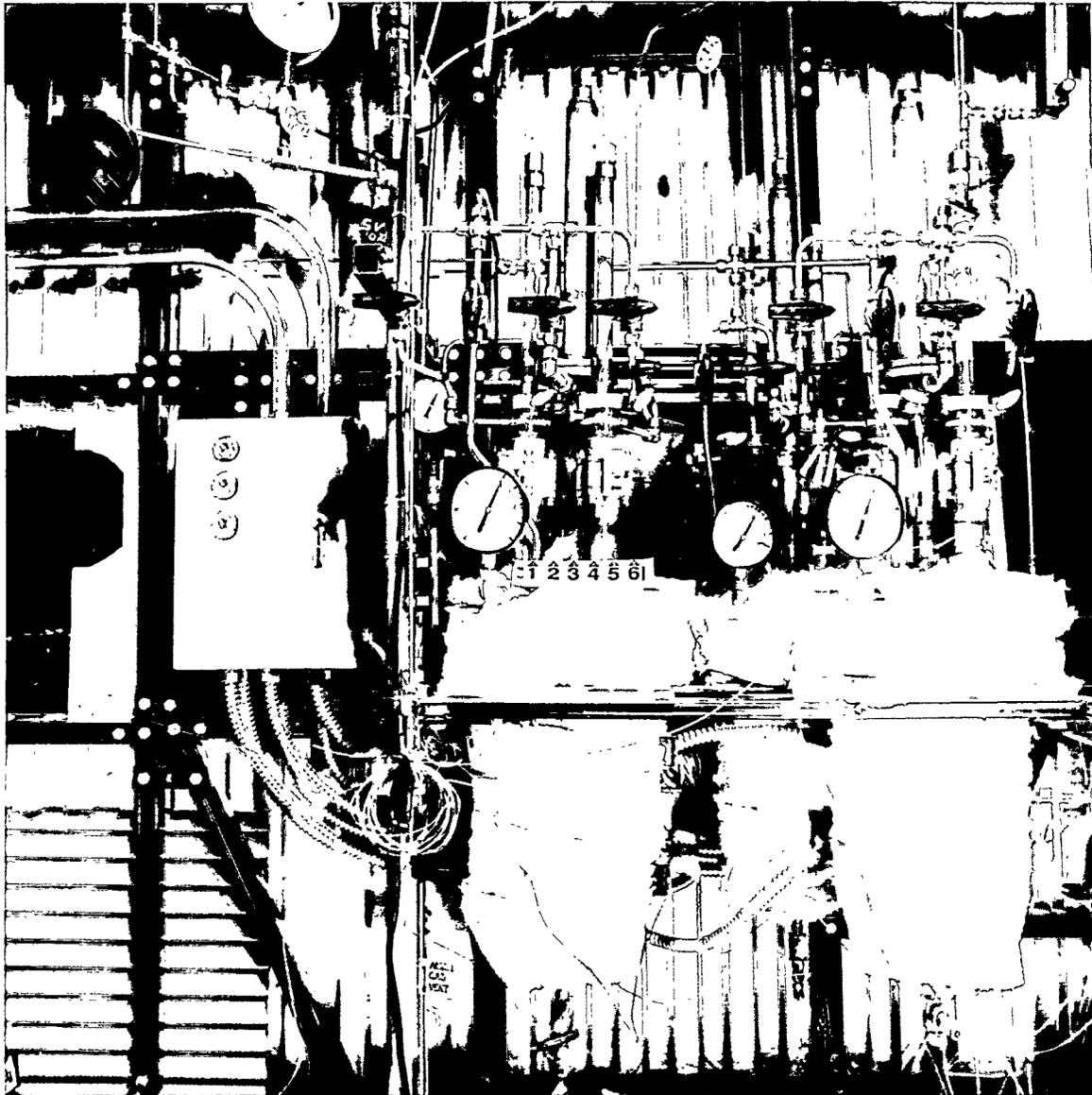


Figure 1. Photograph of alkali metal systems used in the present study.

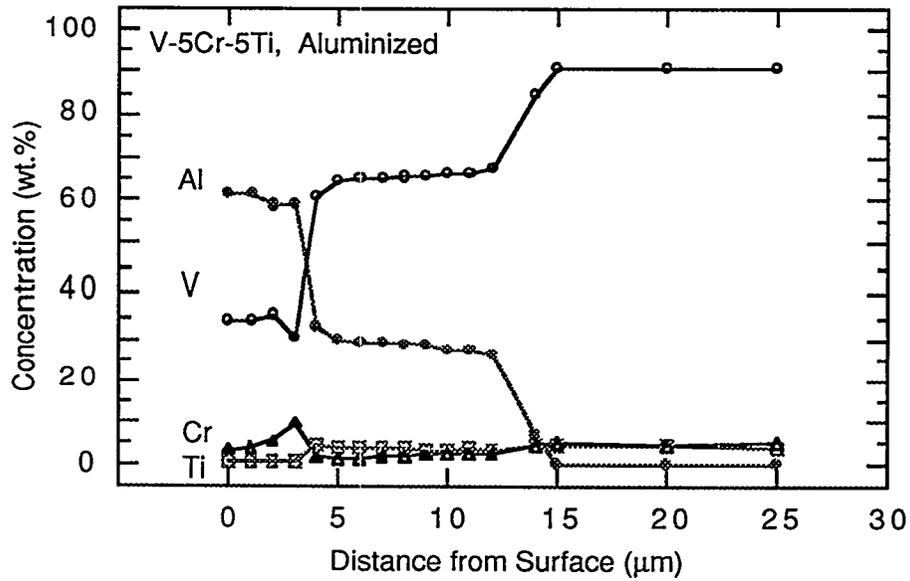


Figure 2. Depth profiles for Al, V, Cr, and Ti for aluminized specimen of V-5Cr-5Ti alloy

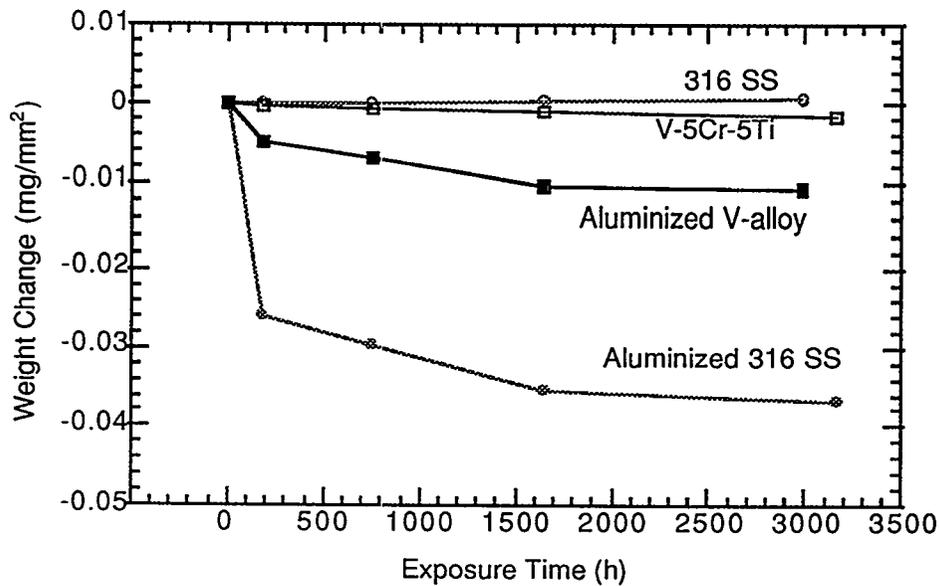


Figure 3. Weight change data for bare and aluminized Type 316 stainless steel, and bare and aluminized V-5Cr-5Ti alloy, after exposure to lithium at 350°C.