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PLASMA-WALL INTERACTIONS

R.A. Gross, B. Jensen, J.K. Tien, N. Panayotou
Plasma Physics Laboratory, Columbia University
New York, N.Y. 10027 U.S.A.

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R.A. Gross, B. Jensen, J.K. Tien, N. Panayotou
Plasma Physics Laboratory, Columbia University
New York, N.Y. 10027 U.S.A.

ABSTRACT

Experimental and theoretical studies have been carried out to provide information on important phenomena occurring when a hot, dense plasma containing a transverse magnetic field is brought into sudden contact with a cold metal wall. Computational simulation has been used to study the physics of the fusion plasma boundary layer which forms at the plasma-wall interface. Thermal, magnetic, and neutral gas boundary layers rapidly develop. The rate of energy transfer to the metal wall is computed and compared with experimental data. The agreement is rather good. Candidate fusion-reactor first wall materials have been exposed repeatedly to a warm ($T_i \sim 600$ eV) deuterium plasma containing a transverse 1.0 W/m^2 magnetic field. Polished samples were subjected to $6 \times 10^{21} \text{ eV cm}^{-2}$, the energy flux expected at the first wall in about one year operation of a tokamak fusion power reactor. Stainless steels show significant erosion at grain boundaries, formation of deuterium blisters on the surface, evidence of surface melting to a depth of $25 \mu\text{m}$, and rapid resolidification. Some cracking is observed, which extends for about a grain size length along grain boundaries into the bulk material. Decrease in tensile ductility is also measured, indicative of possible hydrogen embrittlement.

It is an important and realistic fact that in every plasma experiment and in all potential fusion power reactor concepts, plasma comes into contact with material walls. Imploding liners, some laser or e-beam heated solenoid fusion concepts, and proposed wall-confined fusion systems all involve planned wall-plasma contact. Magnetic fusion confinement concepts avoid this contact (except for diffusive leakage and limiters) until the end of the cycle pulse, at which time the plasma may strongly interact with walls. Consequently, it is of considerable interest and importance that the nature of such plasma-wall interactions be understood and the magnitude of plasma induced wall material damage be assessed.

We are studying a well defined initial value problem characteristic of this class of plasma-wall interaction. We have developed a computer code which simulates the physics occurring when a hot, dense plasma containing a uniform transverse magnetic field is brought into sudden contact with a cold metal wall. Physical effects in our computer program include thermal conduction, plasma convection, atomic recombination and ionization, neutral atom diffusion and radiation. The earliest results of our plasma boundary layer simulation studies were presented in a publication by M.S. Chu [1].

little blistering, generally at the grain boundaries. Also, the surface consists of many droplets or blisters over about 50% of its area. An enlarged view of these is shown in figure 3. To confirm that these are indeed gas filled blisters and not resolidified solid drops, the surface was lightly scratched with an abrasive. The results is seen in figure 4, clearly showing that these are blisters.

Evidence of cracking was observed. The cracked grain boundaries are usually associated with areas where melting has taken place which is about 10-20% of the surface. In figure 5 we show an electron micrograph of intergranular cracking in a region where surface melting had taken place. An electron micrograph of a transverse plane at the crack, figure 6, shows that it had penetrated into the bulk material about $30\text{ }\mu\text{m}$, or about the characteristic grain length. Also seen in figure 6 is evidence of surface melting and rapid resolidification, to a depth of $20\text{-}30\text{ }\mu\text{m}$.

Finally, we mention that physical tests of exposed samples have shown a definite decrease in tensile ductility of PE-16, indicative of possible hydrogen embrittlement. PE-16 suffered a decrease in ductility of 20% after exposure to $6 \times 10^{21}\text{ eV/cm}^2$. Similar tests with 304 stainless steel, a lower nickel, very hydrogen sensitive alloy, show even greater decrease in ductility; namely a change of almost 50% after one thousand shots.

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FIGURE CAPTIONS

- Figure 1. An optical photomicrograph of the polished surface of PE-16 prior to being exposed to plasma.
- Figure 2. An electron microscope micrograph of PE-16 after being exposed to deuterium 600 eV ion bombardment for a total exposure of 6×10^{21} eV/cm².
- Figure 3. An enlarged view of the surface showing droplets formed on PE-16.
- Figure 4. After scratching, the droplets are clearly seen as deuterium blisters.
- Figure 5. Intergranular cracking in PE-16 in a region where surface melting had occurred.
- Figure 6. A transverse view of the crack penetration into the bulk material, PE-16, and evidence of surface melting and subsequent rapid re-solidification.

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Figure 5: Intergranular cracking in PE-16 in a region where surface melting had occurred.

Figure 6: A transverse view of the crack penetration into the bulk material, PE-16, and evidence of surface melting and subsequent rapid resolidification.