Pull-off force measurements for tungsten dust adhered to tungsten surfaces

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Adhesion plays a pivotal role in many tokamak dust issues such as the development of efficient removal techniques, normal component dissipation upon PFC impacts, mobilization in case of loss-of-vacuum accidents and remobilization under steady state or transient plasma conditions.

Systematic investigations of in-plasma W dust remobilization[1] have revealed that, despite the fact that adhesive forces are two orders of magnitude stronger than plasma forces, adhered W grains can exhibit an intense remobilization activity (even exceeding 50%) upon plasma contact. One possible explanation of such a paradoxical behavior is that omnipresent nanoscale roughness strongly decreases the nominal adhesive force. This is an established result in the field of contact mechanics that stems from the competition between compressive forces exerted by upper asperities and the adhesive forces exerted by lower asperities[2]. Via this mechanism, nano-roughness can decrease the adhesion strength even by orders of magnitude for stiff materials with large Young's moduli[3]. Refractory metals are characterized by a large Young modulus, tungsten, in particular, has one of the largest values, 410GPa. However, there have been no measurements of the pull-off force, *i.e.* the normal force necessary to overcome adhesion and cause detachment, for micrometer W dust adhered to W substrates. In this work the pull-off force was measured by an electrical mobilization setup, based on the balance between adhesive and electrostatic forces whose magnitude is given by Lebedev's formula[4].

The experimental setup consists of two flat aluminum electrodes with an adjustable 0.5-1.0mm spacing. High voltage up to 25kV can be applied, provided breakdown is avoided. The setup includes He-Ne based optical diagnostics to monitor the mobilized dust, 2-stage and turbo-molecular vacuum pumps and high vacuum sensors. One of the electrodes was coated by a W film with a thickness of several micron (much larger than the indentation depth) produced with the aid of magnetron sputtering discharges. On this electrode, monodisperse spherical W dust (5,9,14μm) was adhered via gas-dynamic methods, in a manner that mimics sticking impacts as they occur in the tokamak environment[1]. Electrodes with varying rms roughness measures, starting from R_q=13nm, were prepared. By varying the voltage step-by-step and documenting the number of mobilized grains, a pull-off force distribution was obtained.

Comparison of the experimental results with the contact mechanics pull-off force formula [5] has confirmed that nanoscale roughness decreases the nominal adhesion strength for W-on-W by at least two orders of magnitude. Different microscopic models also accounting for the effect nano-roughness have been compared to our data[6] and the most appropriate formula describing the W-on-W adhesion strength has been determined. This formula can be employed as a reliable input to newly developed theoretical models of dust remobilization[1].

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