Adhesion forces between individual nanoparticles play an important role in many different processes such as fluidization, agglomeration and coating. Currently, adhesion between particles is interpreted in terms of continuum models that are able to take into account the effects of capillary forces, surface roughness and electrostatics. This approach is generally suitable for particle sizes in the micrometer range. However, for smaller particles with characteristic sizes in the range of 10 nm, more subtle effects beyond continuum theories can influence and even dominate the adhesion behavior. We have studied adhesion forces and contact behaviour of TiO2 nanoparticles with a diameter in the range of about 10 nm. These nanoparticles were produced in a flame spray reactor using the liquid precursor consisting of 0.5 molar Ti(IV) isopropoxide in xylene. Inside a TEM, we studied stretching and de-agglomeration behaviour of TiO2 nanoparticle agglomerates using an AFM/TEM holder. These in-situ observations were correlated with the force measurements obtained from AFM force spectroscopy. To be precise, the AFM data were based on the statistical analysis of the force peaks measured in repeated approaching/retracting loops of an AFM cantilever into a film of nanoparticle agglomerates. The in-situ TEM data revealed sliding and rolling events first leading to local rearrangements in the film structure when subjected to tensile load, prior to its final rupture caused by the irreversible detaching of individual nanoparticles. The associated contact force of about 2.5 nN is in quantitative agreement with the results of Molecular Dynamics simulations of the particle-particle detachment [1]. Our results indicate that the contact forces are dominated by the structure of water layers adsorbed on the particles’ surfaces at ambient conditions. This leads to non-monotonous force-displacement curves that can be explained only in part by classic capillary effects, and highlight the importance of considering explicitly the molecular nature of the adsorbates [1].

We also studied the size dependent contact behavior of nanoparticle agglomerates by using four different size-fractionated agglomerates, with median values in the range of 78 to 161 nm. Force-distance curves of AFM as well as in-situ TEM observations show that the length of the chains and the amount of rearrangements depend on the agglomerate sizes. Larger agglomerates require more work for their aggregate rearrangement before the final breakage is induced [2].


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