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Friction, wear and mechanical behavior of nano-objects on the nanoscale

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ABSTRACT

Nano-objects are used in various applications where they come into sliding contact with each other and the surfaces where they are used. This can lead to nano-object deformation. Some examples of these applications include drug delivery for cancer treatment, oil detection, contaminant removal, catalysis, and tribology on the macro- to nanoscale. Fundamental understandings of friction and wear of nano-objects, mechanical properties, and deformation mechanisms have been gained through studies. These examined friction mechanisms in nano-object(s) contact sliding on dry and submerged-in-liquid surfaces, sliding on a single nano-object, and mechanical behavior. Nano-object friction studies used an atomic force microscope. Single nano-object contact studies (lateral-push) provide understanding of friction mechanisms, showing friction is influenced by real area of contact, roughness, and work of adhesion. Friction is lower in liquid environments versus dry environments. Contact studies of multiple nano-objects investigate whether several nano-objects reduce friction and wear between sliding surfaces as a result of lower contact area. Further studies on single nano-object friction reveal dependence on topography, scale, and material. Mechanical behavior studies investigate deformation during indentation and compression. Indentation studies investigate scale effects on hardness and Young's modulus. Compression studies investigate reverse plasticity and deformation resistance. This comprehensive study review assists understanding of fundamental interfacial interactions and deformation mechanisms. Studies reported use gold nano-objects, molybdenum disulfide and tungsten disulfide multi-walled nanotubes, and carbon nanohorns, which are of general interest.

Contents

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1. Introduction

1.1. Background

Nano-objects can be described as a single material or composite having at least one dimension that is between 1 and 100 nm [1]. They come in a variety of discrete geometries which include spheres, tubes, rods, wires, and pillars. Compared to their bulk material counterparts, many nano-objects exhibit enhanced mechanical, electrical, magnetic, chemical, friction and wear reducing properties. This makes them attractive for use in many applications on the macro- to nanoscale.

Nano-objects are used in various applications where they come into sliding contact with each other and the surfaces where they are used which can lead to nano-object deformation. Some examples of these applications include drug delivery for cancer treatment, oil detection, contaminant removal, catalysis, and tribology on the macro- to nanoscale. Nano-objects made of various materials including gold (Au), graphene, iron oxide, polymer and silica have been studied in targeted drug delivery for cancer treatment [2–8]. Cancer cells differ from healthy cells due to their reduced intercellular adhesiveness and unregulated growth which allows them to spread throughout the body [9,10]. Fig. 1a shows a nano-object coated with a therapeutic drug and functionalized with a ligand that selectively attaches to protein receptors that are specific to the cancer cell. As the nano-object diffuses into the diseased cell, the drug is released which kills the cancer cell. It is necessary to overcome several challenges before of nano-objects can be successfully employed in targeted drug delivery. Barriers such as the reticulo-endothelial system (RES), which detects and sequesters blood-borne particles along with biological surfaces can prevent nano-objects from reaching their intended target [7]. Smaller nano-objects may diffuse through surfaces and avoid detection by the RES. Nano-objects also come into contact with biological surfaces during diffusion into diseased cells where friction of the nano-objects against the cell wall can reduce the diffusion rate. Reducing agglomeration and friction of nano-objects moving through a liquid and in contact with surfaces is important for efficient transport to diseased sites.

For oil detection applications, as in the example shown in Fig. 1b, oxidized carbon black nanoparticles with a polyvinyl alcohol shell are coated with an oil detecting agent. This agent is released on contact with hydrocarbons in oil and its absence on recovery and analysis of the nano-objects is an indication of the presence of oil [11]. Agglomeration of nano-objects can prevent flow through porous media, which results in losses and prevents eventual recovery of the nano-objects [12]. Friction on surfaces and during flow in liquids can also hinder recovery. Low friction of the nano-objects over surfaces and within liquids is of interest.

In contaminant removal, magnetic shell cross-linked knedel-like nanoparticles (MSCKs) are of interest. These are composites of polymer layers on iron oxide nanoparticles. In Fig. 1c the MSCKs are added to the polluted water (left), where they selectively absorb the oil (center) and are finally removed by introduction of a neodymium magnet [13]. Reducing agglomeration and fluid friction is important for efficient manipulation of the nano-objects through liquids to contaminated sites.

In applications involving catalysis for hydrogen evolution recovery (HER), nanowires have been used to aid in the catalytic activity as shown in Fig. 1d. The nanowires consist of an inner molybdenum trioxide (MoO_3) core and outer molybdenum disulfide (MoS_2) shell. The core is used for transporting electrons to edge sites of the outer MoS_2 shell, which is catalytically active. This is preferred over bulk MoS_2 which has a limited number of edge sites for the same volume of material compared to the nanowires. At these sites the transfer of electrons necessary for