

Interaction forces between talc and hydrophobic particles probed by AFM

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Abstract

The interaction between cleaved talc surfaces and hydrophobic probe particles, silanized silica and thiolized gold, has been investigated employing the atomic force microscopy (AFM) colloidal probe technique. These model systems have hydrophobicities similar to some of the talc-pitch combinations present during pulp and paper manufacture. The talc surfaces used in this study, in the [001] plane, show a micro-roughness with sharp peaks of up to 3 nm in height. The force profiles obtained demonstrate the predominance of a long-range attractive force. However, the range and magnitude of the attractive force show large variability. The variability of the attractive force, and the frequent observations of clear steps in the force curve demonstrate that it is caused by gas/vapor cavities bridging the surfaces once the surfaces are brought sufficiently close together. The results suggest that the same mechanism is of importance in applications where talc is used as a collector for pitch.

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1. Introduction

Talc is described by the chemical formula $Mg_3Si_4O_{10}(OH)_2$. It consists of a magnesium hydroxide layer ($MgO \cdot H_2O$) sandwiched between two silicate layers (SiO_2), forming a three-layer structure (Fig. 1). Adjacent layers are connected by weak van der Waals forces, giving pure talc a platy structure. The low energy silicate layers on talc planes, [001] crystal domains, have hydrophobic properties, while the edges displaying the hydroxyl groups are more hydrophilic. The talc particles break preferentially between the crystal layers that are held together by van der Waals forces, exposing more planes than edges and thus talc particles are, statistically, relatively hydrophobic. In various studies, the water contact angle has been found to be 66–90° (e.g. [1,2]). The large spread in reported contact angles can be due to several factors: a larger than expected number of edges displayed at the surface; some accessibility to the hydroxyl groups in the second

layer of the crystal structure; or impurities adsorbed from the air [2]. Talc has a density of 2.75 g/cm³, a brightness of 86–90% and a refractive index of 1.57. It is the softest of all minerals; Mohs relative hardness scale starts with talc at 1 and ends with diamond at 10. However, due to impurities, the apparent hardness of talc minerals is normally closer to 2.

One important industrial use of talc is in pulp and paper manufacture. A major part of all printing papers contain some kind of mineral filler. The original reason for mixing minerals into the paper pulp was economic; the fibre material is more expensive than the finely pulverised minerals [3]. However, it was soon noticed that the mineral fillers also improved the paper properties in several respects. Printing properties are improved by increasing the paper surface smoothness, opacity and brightness. Due to its good lightness, softness, particle shape, inert properties and low price, talc is considered as suitable filler for many applications, and it has been used as paper filler for about a century. In the 1960s talc's range of use in the paper industry was broadened by its introduction into pitch control applications. Furthermore, in 1982, its use as a coating pigment was reported, mainly for lightweight coated (LWC) gravure paper [4].

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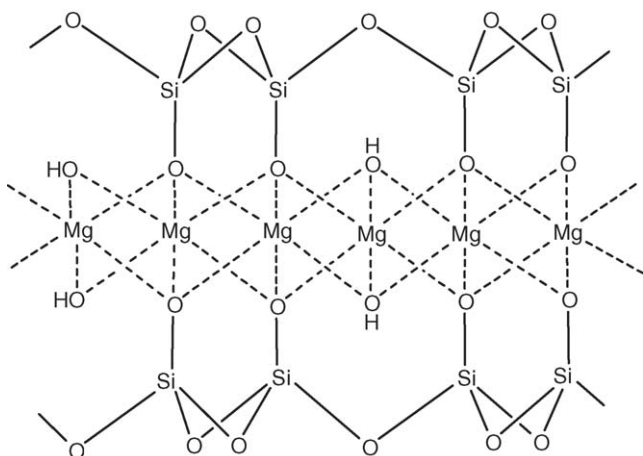


Fig. 1. Talc structure.

The above-mentioned use as a collector for detrimental lipophilic compounds, collectively termed “pitch and stickies”, has opened up an interesting application for talc. The term “pitch” describes colloidal wood resin components present in pulp, and which may agglomerate and deposit in and on the paper machine. Chemically, pitch covers a wide range of substances such as fats and fatty acids, steryl esters and sterols, and terpenoids, including terpenes. Compounds from adhesives contained in recycled paper, such as polyisoprenes and waxes [5], as also residues of defoamers, are called stickies, while particles containing residual latex, arising from recycled coated paper or broke, are termed “white pitch”. The pitch adsorbing properties of talc have been investigated by a number of authors [6–11]. When pitch is adsorbed onto talc, subsequent agglomeration of the pitch particles is prevented, thus keeping the water and pulp system of the paper machine cleaner. The softness and good retention of talc gives economical advantages by increasing the lifetime of the wire used in forming the paper. Talc is believed to act in pitch control mainly as a detackifier [8], but the detailed mechanisms involved in pitch adsorption are not clear.

Little discussion is found in the literature about what forces contribute to the attraction of talc to pitch. Beyond the omnipresent Lifshitz–van der Waals forces, donor–acceptor- and Coulombic interactions, some authors, dealing recently with other pigments, reflect about hydrophobic interactions [12] without going into details.

The interaction between hydrophobic surfaces across water has been a controversial issue since the first studies of Israelachvili and Pashley that suggested the presence of a long-range hydrophobic interaction between such macroscopic surfaces [13]. Subsequent studies confirmed the presence of a long-range attractive force, significantly larger than the van der Waals force, for a range of hydrophobic surfaces. However, the measurements showed a large degree of discrepancy in the absolute range and magnitude of this force [14,15]. It was early realised that cavitation occurred when two hydrophobic surfaces were brought in contact [16], but it took several years before it was suggested that cavitation or bridging bubbles could explain the long-range nature of the attractive force observed on bringing

the surfaces together [17–19]. This mechanism seems to explain many, but not all, of the results reported in the literature [20], and the topic is still frequently discussed [21,22]. Some studies show that the interactions between two model hydrophobic surfaces that have been exposed to air give rise to a stronger adhesion force and a longer range of attraction [23], which is explained as being due to the fact that dissolved air promotes cavitation and bubble formation. The complexity of the subject is emphasized by the observation that surface roughness and heterogeneity sometimes have a more significant influence on the ultimate range of the long-range attractive force than the actual hydrophobicity [24].

Chi et al. investigated the interaction between talc and a hydrophobic toner particle using atomic force microscopy (AFM), and evaluated the interaction data using the DLVO theory [25]. The long-range interaction was found to be due to a repulsive double layer force. However, an attractive force pulled the surfaces together from a separation slightly larger than would have been expected considering the van der Waals force alone, which was taken as an indication of the presence of a hydrophobic interaction.

In the present study, the interaction forces between cleaved talc surfaces and silanized silica probes, or thiolized gold probes, are investigated with AFM. In terms of hydrophobicity, this system mimics the most hydrophobic components present during pulp and paper manufacture. The presence of long-range attractive interactions will be demonstrated and the origin of this interaction will be discussed. In future studies, colloidal pitch particles will be used as probes for the AFM measurement.

2. Experimental

2.1. Materials

The first challenge of investigating interactions using one talc surface was to find suitable samples that were clean and easily cleaved, and thus allowed preparation of smooth and planar layers without debris. Fig. 2 displays a collection of talc samples from different parts of the world.

Even though all these talc samples, except sample 6, are very pure according to X-ray diffraction analysis, they are different in structure, colour and hardness. Samples 1–6 show rock-like structures and cannot easily be delaminated, while samples 7 and 8 have a more layered structure. Since force measurements employing atomic force microscopy require smooth substrates, samples 1–6 were cut to form 1 cm × 1 cm × 0.2 cm pieces with a diamond saw and polished with a silica-containing polishing agent. Shiny surfaces were obtained, but they exhibited a too high micro-roughness for accurate force measurements. Samples 7 and 8 were found to have a more lamellar structure than the other talc samples and could be cleaved by gently pulling away sheets with tweezers (Fig. 3). Since sample 8 was present in a greater amount than sample 7, it was used for the extensive series of force measurements.

Colloidal silica with a radius, R , of 2.5 μm (Bangs Laboratories Inc., USA) and gold particles with a radius, R , of 4–12 μm (preparation described in Section 2.2) were used as probes for

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