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COOKING WITH NANOPARTICLES: A SIMPLE METHOD OF FORMING ROLL, PANCAKE, AND BREADED POLYSTYRENE MICROPARTICLES

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INTRODUCTION: We report here simple methods of forming roll and disc-shaped (pancake) microparticles that require no unusual reaction conditions, templates, or molds. In addition, we have physically embedded small "breading" particles into the surface of larger particles to form hybrid particles of various compositions. We have breaded fluorescent nanospheres into rolled magnetic polystyrene particles. We have also breaded magnetic material into fluorescent polymer pancakes. Such magnetic particles align in magnetic fields due to their magnetic anisotropy. Since a particle's shape and composition affects its magnetic, optical, chemical, and mechanical properties, our non-spherical particles may prove useful in a variety of optical, chemical and biomedical applications.

Nagy and Keller describe a physical method of forming elliptical polymer microparticles [1]. They formed a suspension of polystyrene microspheres in a polyvinyl alcohol (PVA) solution, and allowed it to dry into a thin film. The film was then stretched at a temperature above the glass transition temperature of both the polystyrene (T_g 94°C), and the PVA (T_g 85°C). The embedded microspheres were deformed into ellipses while the film was stretched. The PVA was then dissolved leaving elliptical microspheres. The amount that the film was stretched controlled the aspect ratio of the particles.

Wang et al expanded Nagy and Keller's method and formed oblate elliptical particles by compressing particles in a PVA matrix above the glass transition temperature [2]. Jaing et al invented a method of forming a polystyrene mold around microspheres, dissolved the microspheres, and stretched the mold at an elevated temperature so that it had elliptical holes. They then filled the holes with a variety of polymers and sol gels to form solid and shell shaped elliptical microparticles [3]. However, we are unaware of any room temperature deformations. In addition, we are unaware of any previous deformation of magnetic microspheres, although Gabrielson and Folkes tried unsuccessfully to deform magnetic polystyrene microspheres [4].

METHODS: Fluorescent polystyrene microspheres 3.4 µm in diameter were purchased from Bangs labs. Polystyrene microspheres containing ferromagnetic chromium dioxide 2 µm and 4.4 µm in diameter were purchased from Spherotech. Iron oxide nanoparticles were obtained from Magnox. Fluorescent decyl methacrylate and silica sol gel nanospheres were polymerized in our lab. Glass microscope slides were from Fisher Scientific.

A simple method of deforming microspheres into rolls and multirolls is illustrated in Fig. 1. Polystryrene microspheres were deposited onto a microscope slide and the slide was clamped to a laser table. A second slide was placed on top to sandwich the particles. The top slide is then moved laterally while applying pressure with the fingers. With a low concentration of particles and small lateral motions, single particle rolls are formed, while with a high concentration of particles and large lateral motions, the rolls form together into multirolls as shown in Fig. 4. The rolling procedure can be performed with microspheres that are either suspended in solution, or dry. The preferred procedure was to suspend the microspheres in ethanol and deposit them on a microscope slide to dry before rolling.

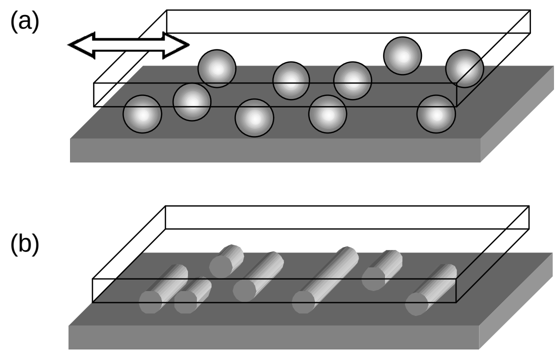

Fig. 1: Method of rolling microspheres into rolls and multirolls. Microspheres are deposited onto a microscope slide and the slide is clamped to a laser table. A second slide is placed on top to sandwich the particles. The top slide is then moved laterally while applying pressure with the fingers as shown in (a). With a low concentration of particles and small lateral motions, single particle rolls are formed, while with a high concentration of particles and large lateral motions, the rolls form together into multirolls (b).

Pancake-shaped microparticles are formed using a rolling pin (a ¼" diameter glass tube with a metal pin through it) to flatten deposited microspheres, as shown in Figure 2. This method can also be used to form coupled pancakes and flattened rolls and multirolls.

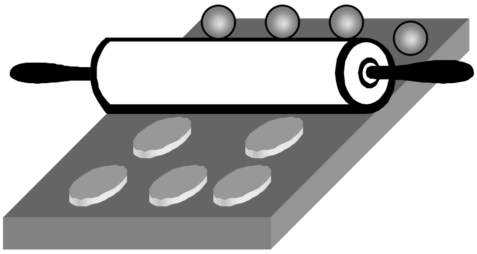

Fig. 2: Method of flattening microspheres into "micropancakes." A rolling pin, comprising a ¼" glass tube with a metal pin through it, is rolled over particles deposited on a microscope slide.

Smaller particles could be breaded onto larger particles by applying small "breading" particles to the microscope slide before the larger microspheres are added. The breading particles are implanted into larger particle rolls or pancakes during the normal rolling or flattening procedure.

RESULTS: The rolling process works remarkably well for a process literally done by hand. It works wet or dry, with large concentrations of particles or small concentrations, with polystyrene particles, and magnetic polystyrene particles, and in the presence of breading. However, hand rolling has its limitations. The shape of particles formed by hand is hard to control; for example, rolled particles tend to be thinner and longer where direct pressure from the fingers is applied, than elsewhere. When the particles begin to deform, one feels the rolling resistance decrease, but otherwise one has to check under the microscope to see particle shape. If too much pressure is applied, the particles are crushed into pancakes, and then smeared instead of rolled. When wet rolling particles, it is important to use a sufficient volume of water: insufficient water leads to droplets that shrink with evaporation, causing particles to aggregate. This aggregation interferes in the rolling process as shown in Fig. 3. However, we have demonstrated that particles can be rolled and breaded. We are designing simple machines to apply uniform pressure and control the shape of the particles formed.

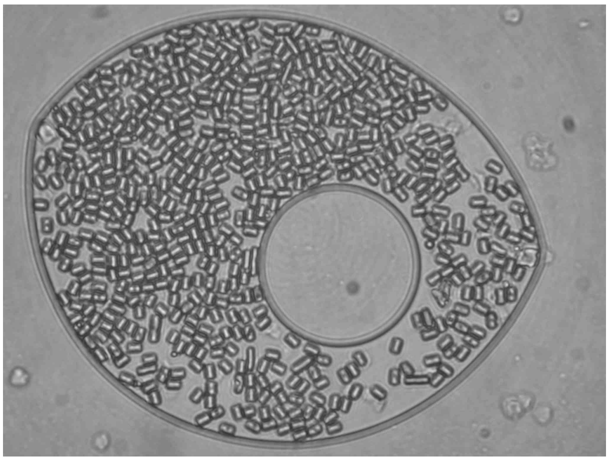

Fig. 3: Wet-rolled 3.4mm polystyrene microspheres forced together in an evaporating droplet containing a soap bubble.

Rolls and multirolls of magnetic polystyrene particles breaded with fluorescent polystyrene, sol gel, and decyl methacrylate have been formed. Fig. 4 shows a CCD image of fluorescently breaded magnetic microspheres. Due to their magnetic shape anisotropy, these rolls align with external magnetic fields when placed in solution.

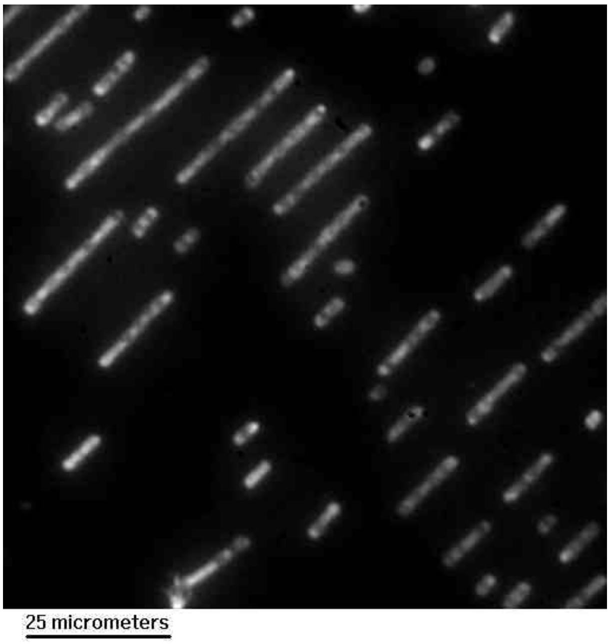

Fig. 4: Fluorescent image of breaded multirolls. They were formed from 2 mm CrO_2 containing magnetic polystyrene microspheres and breaded with ~500 nm decyl methacrylate nanospheres containing a fluorescent dye. These particles were rolled dry.

Fluorescent polystyrene pancakes have also been formed, and pancakes have been breaded with magnetic material. The magnetically breaded fluorescent pancakes align with external magnetic fields, as shown in Fig. 5. These magnetically breaded pancakes were stable in water for at least five days.

(a) (b) (c)

Fig. 5: Fluorescent 3.4 μm polystyrene microspheres were flattened onto iron oxide nanoparticles (magnetic breading). The magnetically breaded fluorescent pancakes align with external magnetic fields. a), b), and c) show fluorescent images of one particle aligned in three different magnetic field orientations.

DISCUSSION & CONCLUSIONS: We have discovered a method of forming non-spherical particles that requires no template, unusual reaction conditions, or elevated temperatures. Our early efforts have used polystyrene microspheres and polystyrene containing chromium dioxide nanoparticles. We expect the method to apply to a number of other polymer and metal micro/nanospheres. Non-spherical magnetic particles can be oriented in magnetic fields due to their shape anisotropy. We plan to elucidate the effects of temperature, solvent, stress, and rate of strain on particle formation, and to develop a machine to uniformly deform particles.

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