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SIZE DEPENDENT BEHAVIOUR OF MICRON-SIZED COMPOSITE POLYMER PARTICLES

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ABSTRACT. The mechanical properties of micron-sized composite polymer particles have been investigated by using a nanoindentation-based flat punch technique. The contact load-displacement relationship of particles has been established and the stress-strain relationship has been determined. An interesting size effect on mechanical properties of both polymer particles and metallized polymer particles has been found. The smaller the particle size is, the stiffer the particle is. Finite element analyses indicate that different mechanisms dominate the size effect of two types of particles.

1 INTRODUCTION

Ugelstad monodisperse polymer particles have been widely used in chemical industries and biotechnology [1]. Recently there is a growing interest in polymer particles with potential application in new electronic packaging technologies, such as Anisotropic Conductive Adhesives (ACA) in Flat Panel Displays [2]. The particles are conductive through deposition of nano-scale metal coating on the particle surface. The metallized particles usually consist of a micron sized polymer core for improving contact compliance, a nanoscale Ni inner layer for obtaining electrical conductivity, and a nanoscale Au outer layer for protecting inner layer from oxidation and improving the reliability of electrical performance. The use of metallized polymer particles in ACA technology possesses many advantages in terms of lead-free, reducing package size and achieving high-density interconnections. The electrical characteristics as well as the reliability of the interconnection are mainly determined by the mechanical performance of the conductive polymer particles. Therefore, the mechanical performance of particles is of crucial importance to a reliable connection. This motivates us to study the large deformation behaviours of composite polymer particles. Both experiment study and finite element analysis have been carried out to study the mechanical properties of composite polymer particles.

2 EXPERIMENT

2.1 Materials

Both polymer particles and metallized polymer particles were tested. The chemical composition of polymer particles was 98% polystyrene slightly crosslinked with 2% divinylbenzene (PS-DVB). The PS-DVB particle sizes were varied from 2.6 to 25.1µm. The core of metallized polymer particle was strongly crosslinked by 40wt% acrylic with 60wt% diacrylic (AC-DAC). The core sizes were 3.8µm and 4.8µm in diameter. The Ni and Au were deposited on the polymer core by an electroless plating process. The thickness of Ni inner layer and Au outer layer was about 50nm and 25nm, respectively.

2.2 Experiment

The mechanical test of single acrylic particles was performed by using a nanoindentation-based flat punch methodology. A diamond flat punch of 100µm in diameter was specially designed to compress single particles. During compression the real time force and displacement on particles were monitored and the contact force–displacement curves were obtained. To compare the particle behaviour, the stress–strain relationship was calculated as follows:

$$\sigma_N = \frac{P}{\pi R^2} \tag{1}$$

$$\varepsilon_N = \frac{D}{R} \tag{2}$$

where P was the applied force, D was the half displacement during compression and R was the radius of undeformed particle.

2.3 Finite element Analysis

Large deformation finite element analysis (FEA) with ABAQUS was carried out to study the mechanical behaviour of single polymer particles. The material was assumed to be linear elastic and axisymmetric elements were used to model particles. Axisymmetric analytic rigid surface was used to model the diamond flat punch. Very fine mesh was used in the contact region. The minimum element size in the model was about 0.1% of the initial sphere radius. The mesh and model used in the analysis are shown in Figure 1.

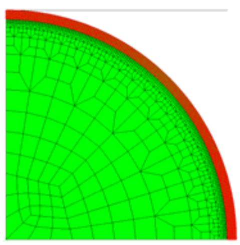

Figure 1: Finite element analysis with non-linear geometry.

3 RESULTS AND DISCUSSION

The normalized compressive stress of PS-DVB particles at 4% deformation level with different strain rates are plotted in Figure 2, in which the compressive stress is normalized to the value of the smallest particle. Particles display distinct size effect on the compressive stress. The size effect also has different trends depending on the strain rate. With the smaller strain rate, the size effect is most evident for the two smaller particles, whereas for the larger strain rate the size effect is more evenly distributed. The size effect of PS-DVB particle is mainly contributed by a "core–shell" structure where there is a higher crosslink density in the surface shell than the core due to different hydrophilicity of DVB and styrene monomers.

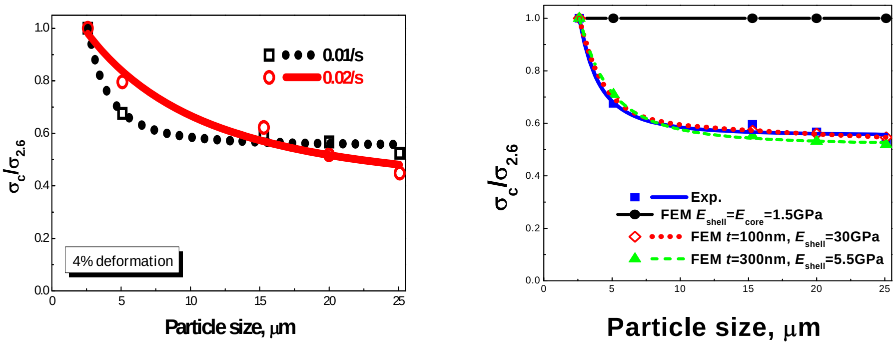

Figure 2: PS-DVB Particle size dependence of the normalized stress (a) experimental results with strain rate 0.01 and 0.02/s at deformation level 4% and (b) finite element solutions.

The compression stress–strain curves of uncoated and metalized AC-DAC particles are shown in Figure 3. The metallized particle sizes are 3.875 and 4.875μm, respectively, while uncoated counterparts are 3.8 and 4.8μm. At the beginning of loading, the metallized particle is significantly stiffer than the uncoated one. The occurrences of a large "pop-in" on the loading segment suggest that a significant change has happened to the metallized particles. With further deformation, one or more additional smaller "pop-ins" occurs, and finally the loading curves of the metallized and uncoated particles overlap each other. At this stage it is evident that the metal coating has no effect on the particle behaviour any more.

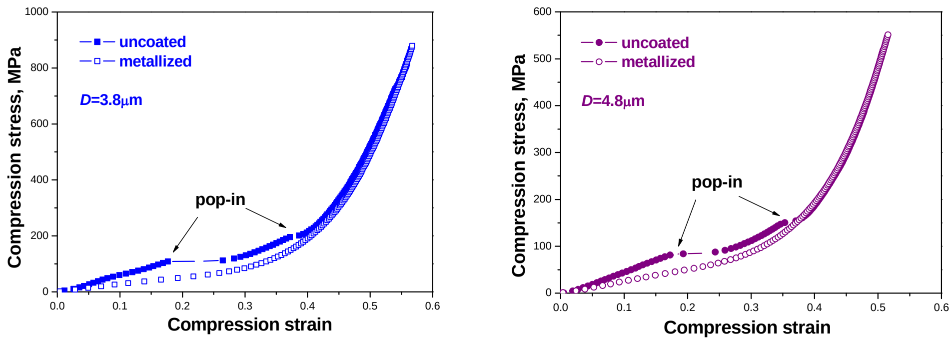

Figure 3: The compression stress–strain curves of uncoated and coated AC-DAC particles: (a) 3.8μm particles and (b) 4.8μm particles.

The stress–strain relationship of two metallized particles is compared in Figure 4 (a). The pop-in on both particles occurs at around 18% deformation. A particle size effect can be clearly observed, which shows that the 3.8μm particle is harder than the larger 4.8μm particle. This is consistent with the PS-DVB particles. Unlike the mechanism of size effect on PS-DVB particles, the presence of the metal coating significantly influences the particle behaviour. Since the metallized particles have different core size but same coating thickness, the volume fraction of the metal coating in two metallized particles are different. This results in the particle size effect. The finite element solutions of metallized AC-DAC particles and uncoated AC-DAC particles are shown in Figure 4 (b). Metallized particles are much stronger than uncoated ones, in agreement with experimental results. Two uncoated particles behave identical while metallized particles display a particle size effect that the smaller particle is harder. This demonstrates that the metal coating plays a dominate role on the particle size effect.

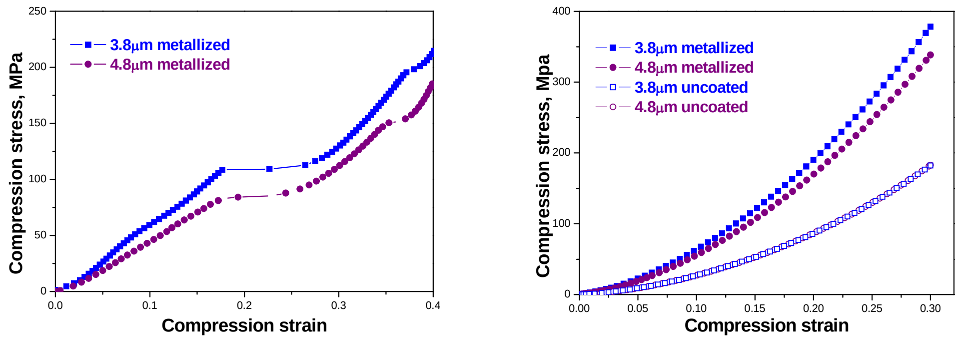

Figure 4 : AC-DAC Particle size dependence of the normalized stress (a) experimental and (b) Finite element solutions.

4 CONCLUSIONS

The mechanical behaviour of PS-DVB polymer particles and metallized AC-DAC particles was studied by using the nanoindentation–based flat punch method. A size effect of both particles was discovered. For the PS-DVB polymer particles, a core-shell structure is possibly a main contributor; while the presence of nanoscale metal coating is the leading factor for the metallized AC-DAC particles. The findings have important implications in the design of the metallized polymer particles for electrical packaging applications.

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