NANOINDENTATION-BASED FLAT PUNCH CHARACTERIZATION OF SINGLE MONODISPERSE ACRYLIC PARTICLES

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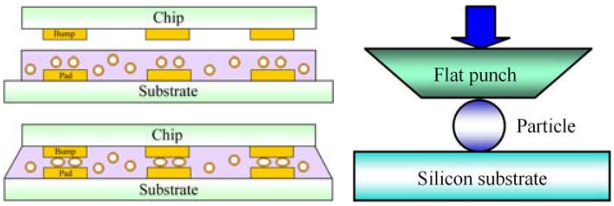
Introduction

The Ugelstad method is a well known and versatile technology for the manufacturing of mono-sized polymer particles. The technology has been proven highly successful within biotechnology [1]. Recently this technology has been exploited for the use in electronics and micro-systems, where there are numerous potential applications [2]. Until now, the focus has been on metal-coated polymer particles for use in Anisotropic Conductive Adhesive (ACA), shown in Fig. 1 (a), but also in Ball Grid Arrays (BGA) and Chip Scale Packaging (CSP). In these applications the electrical characteristics as well as the reliability of the interconnection are mainly determined by the mechanical properties of the polymer particles. Therefore the detailed knowledge of mechanical properties of the polymer particles, especially the single polymer particle, would be beneficial for the design of ACA assemblies. Due to the inherent complexity of the spherical geometry, characterization of the nanostructured polymer particles is different from traditional material characterization and possesses great challenges.



(a) (b)

Fig. 1 Schematic plot of (a) ACA connection with metal-coated polymer particles and (b) nanoindentation-based flat punch test on a single polymer particle.

The present work focuses on mechanical properties of acrylic particles where recovery rate, *K*-value, breaking force and breaking displacement have been measured as mechanical properties on individual particle. A nanoindentation-based flat punch technique developed by the authors has been employed, shown in Fig. 1 (b) [3]. The development showed that choice of substrate material as well as sample preparation is very important to obtain repeatable measurement results. The effect of loading rate during indentation has been investigated.

Experimental

Materials

The commercially available acrylic copolymer (AC) particle (ConcoreTM, Conpart AS, NO) synthesized by an activated swelling method has been tested. The particle is strongly crosslinked by 60 wt% diacrylic with 40 wt% acrylic. The particle size is 3.0µm in diameter and the coefficient of variance (C.V.) of the particle size distribution is less than 2% in which C.V. is defined as the ratio of the standard deviation to the mean diameter.

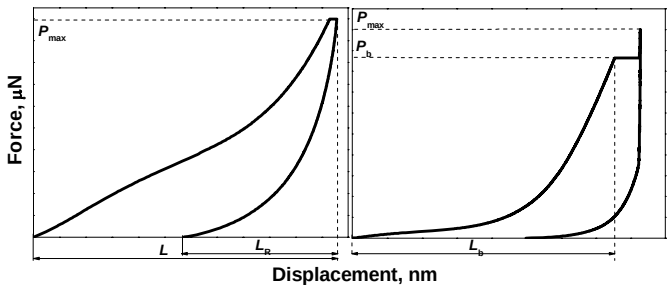
Method

The indentation test of single acrylic particles has been performed with a nanoindentation system (Triboindenter®, Hysitron Incorporated, Minneapolis, USA). A diamond flat punch of 100µm in diameter was specially designed to compress the single particles. Using the attached optical microscope, a single particle with more than 75µm distance to the closest neighbour was selected and then compressed between the diamond flat punch and the silicon substrate.

For the recovery rate measurement, the three loading rates 10, 100 and 1000µN/s have been placed on the particles with the peak load 1000µN. For the *K*-value, breaking force and displacement measurement, the loading conditions with four loading rates 20, 200, 2000 and 10000µN/s and the peak load 10000µN have been applied. Recovery rate and *K*-value are expressed as follows, in which *R* is particle radius and *P* and *D* are the load and displacement value at the points of 20% and 40% of the rupture deformation of the particle.

Recovery rate: $R_R = (L_R / L) \times 100$

K-value: $K = (3/\sqrt{2}) P D^{-3/2} R^{-1/2}$



(a) (b)

Fig. 2 Plots of load versus compression displacement for measuring (a) recovery rate and (b) *K*-value, breaking force and breaking displacement.

Results and discussion

The standard load-controlled mode has been selected for the test which means the applied load on the particles is following a predefined load function. For every test, at least three individual particles have been tested in order to check stability of particle properties and the repeatability of the results. As shown in Fig. 3, the recovery rate of the particle decreases with the increasing loading rate. As the loading rate is 10μN/s, the recovery rate after unloading is 51.9%; while it is only 44.7% when loading rate is up to 1000μN/s. The relationship of *K*-value to the loading rate is displayed in Fig. 4. Both *K*-values at 20% and 40% rupture deformation of particles increase with faster compression in which K_{20} is more pronounced than K_{40}. Fig. 5 shows the effect of loading rate on particle rupture. The results show the breaking force at loading rate 10000μN/s is 960MPa which is higher than at other loading rates. At two smaller loading rates the breaking force is very similar, around 850MPa. The breaking displacement does not show the same trend as breaking force. The smallest breaking displacement occurs at a loading rate of 200μN/s, whereas the breaking displacements for the slowest and fastest compression values are almost identical.

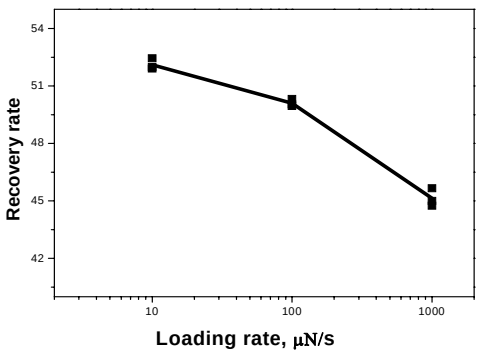


Fig. 3 Plots of particle recovery rate versus loading rate.

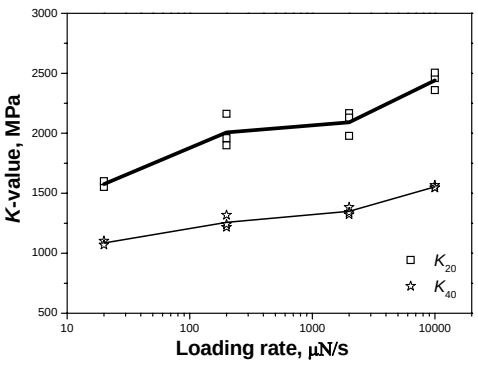


Fig. 4 Plots of *K*-value at 20% and 40% rupture deformation versus loading rate.

During deformation, the particle behaviour is complex and it is a combination of geometrical nonlinearity (large deformation) and material nonlinearity (plasticity, viscosity, hardening/softening and fracture) [4]. Due to the presence of viscosity, the particle behaviour has significant strain rate dependence. At higher loading rates, the compression modulus is increased probably due to the reduced time available for the stresses redistributing in terms of molecular segments rearrangement/reorientation within the particle. The strain at break seems to be independent of the loading rate, whereas the load at break is increasing with strain rate, in accordance with the increased compression modulus.

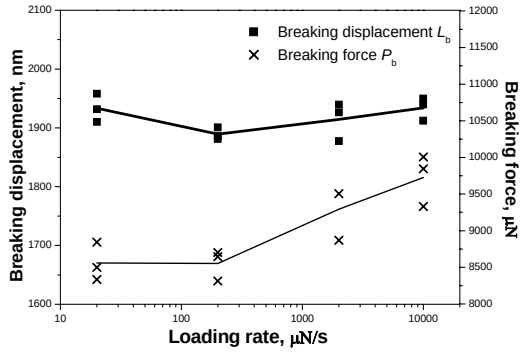


Fig. 5 Plots of particle breaking displacement and force versus loading rate.

Conclusions

A nanoindentation-based flat punch method has been demonstrated to measuring mechanical properties of single acrylic particles with a narrow size distribution. The effect of loading rate on the deformation behaviour has been investigated and the results show that the loading rate strongly affects the particle deformation process. Both the recovery rate and the *K*-value are very sensitive to variation in loading rate. It is believed that the effect can be explained by a viscoelastic/plastic material model.

References

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