Experimental study of filament break-off of dense suspensions

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ABSTRACT

Higher particle volume fractions lead to shorter break-off times in filament-stretching measurements, which correlates with higher satellite levels and poorer dot shape when jetted onto a substrate. Suspensions within a certain break-off time range show optimal jetting results. This implies that filament stretching of dense suspensions can be connected to their jetting behaviour, potentially allowing for this technique to be used to predict jetting results. The purpose of this study is to establish a deeper understanding of the break-off process of filaments of dense suspensions.

INTRODUCTION

The precise and repeatable deposition of functional fluids is increasing in importance in areas such as pharmaceuticals, digital printing, electronics production et cetera. The rheological characteristics of the functional fluids of interest in these different areas vary radically with respect to viscosity, material loading and viscoelastic properties. Within the realm of electronics production, the material connection between the printed circuit board (PCB) and the components chosen for the board is provided by a solder joint. The solder joint is created by depositing a volume of a metallic suspension, called solder paste, on the interconnection areas, or pads, on the PCB, and thereafter placing components on the solder paste. The board, with the solder paste deposits and components, is placed in a reflow oven, which melts the solder paste providing an electrical and structural connection between the PCB and the component.

As with the jet printing of dyes and other low-viscosity fluids, the jetting of dense fluid suspensions is dependent on the repeatable break-off of the fluid filament into well-formed droplets. It is well known that the break-off of dense suspensions is dependent on the volume fraction of the solid phase, particle size and morphology, fluid phase viscosity et cetera.[1–3]

Solder paste consists of an organic resin-based carrier fluid and SnAgCu-alloy spheres. The spherical particles range in size between 2 and 25 μm, see Fig. 1.

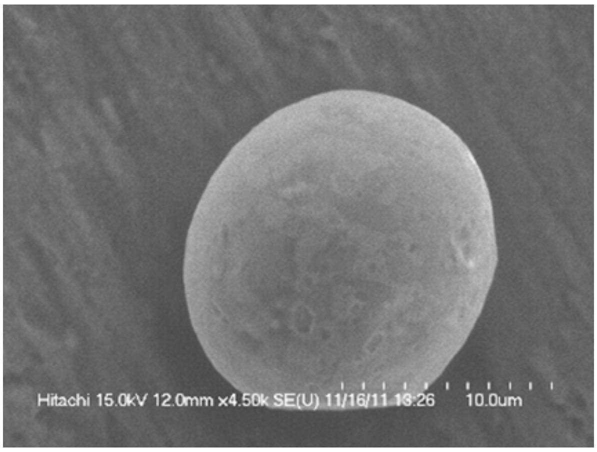

Figure 1 : A scanning electron microscopy image of an individual solder ball of a Sn-Ag-Cu alloy.

The specific size distribution of particles can be varied as well as the volume fraction of particles of the suspension. The fluid is shear-thinning, see Fig. 2. In Fig. 2, the unfilled symbols represent data from rotational rheometry, while the filled symbols represent data from experiments using capillary rheometry. The viscosity decreases by three orders of magnitude for an increase of shear rate by four orders of magnitude.

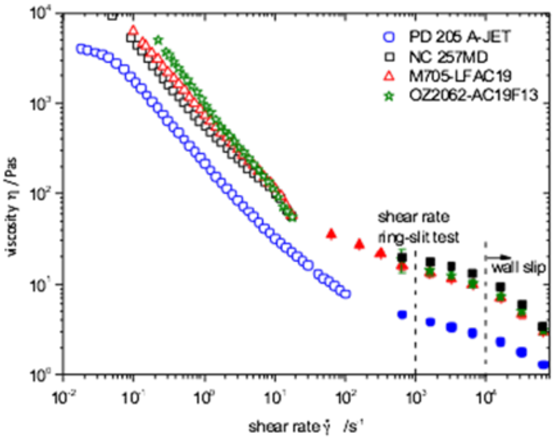

Figure 2 : Viscosity as a function of shear rate for three solder paste samples (□ , △ and ☆) together with an adhesive sample (○).

The goal of this study is to study the dynamics of filament break-off for dense suspensions with various particle size distributions and particle volume fractions. Further, the filament break-off characteristic will be correlated with quantitative measures of jetting quality.

EXPERIMENTAL METHODS

The suspension samples consist of a resin-based flux and tin/copper/silver spherical particles with diameters of 2–25 μm and metal loadings of 83–87 wt%. The size distribution of the particles is approximately Gaussian with a diameter deviation of $\sigma_{dp} = 0.20 \cdot d_p$.

The experimental setup consists of a Filament Break-Off (FILBO) device developed in-house. A cylindrical sample (diameter = 1 mm and height = 0.25 mm) of the suspension is extended using a cylindrical probe travelling between 100–800 mm/s in the vertical direction (Fig. 3). The filament minimum diameter is followed over time during filament extension with an imaging frequency of 8600 frames/sec. Imaging was performed with a Phantom Miro 310 (Vision Research, New Jersey, USA) high-speed camera.

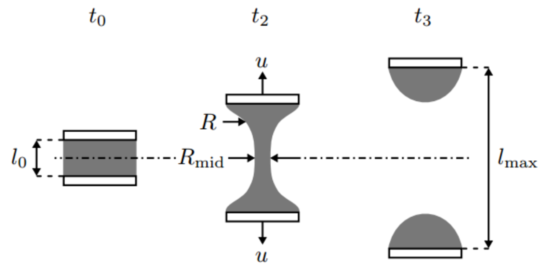

Figure 3 : Principle of extensional rheometry where a fluid element is placed between two plates at an initial distance, l_o. The plates move in opposite directions until a maximum distance l_{max} with a constant velocity u. A ligament establishes with a certain radius R and thins until break–up, where the mid–filament radius R_{mid} is observed.

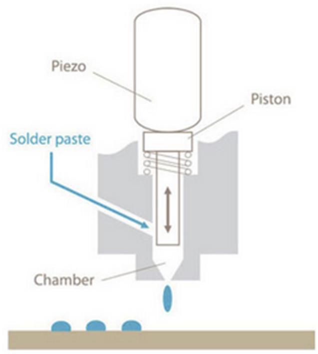

Figure 4 : Schematic of the jetting principle that is the impetus of this study.

Imaging data was also obtained for the jetting of the chosen suspensions. Jetting of the fluids was performed with a piezo-driven jet printer (Mycronic AB, Sweden), see Fig. 4. Jetting experiments were performed by syncing the ejector pulse with the camera trigger and recording images during droplet ejection and breakup into free space. Images were recorded at 116 000 frames/sec.

RESULTS AND DISCUSSION

High speed imaging of the filament breakup process showing the effect of metal loading is presented in Fig. 5. Filaments formed with higher metal loadings broke significantly earlier than those with lower metal loadings.

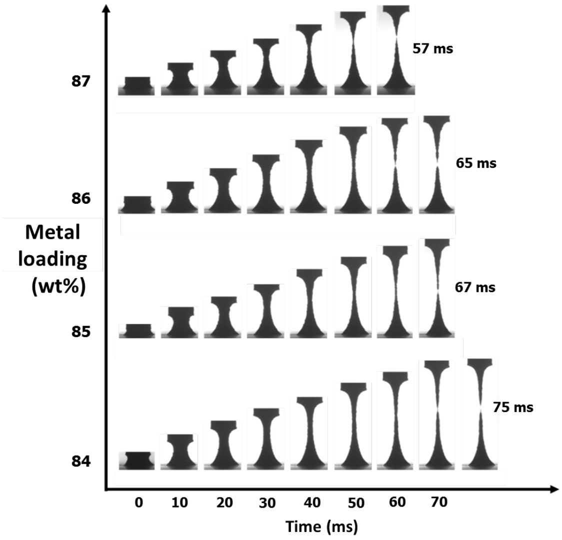

Figure 6 : Sequences of images showing the filament breakup of solder paste suspensions with 84, 85, 86 and 87 wt%.

Imaging of jetting dynamics of solder pastes also showed an accelerated thinning and pinch-off for suspensions with increasing metal loading (the **x** symbol notes the complete pinch-off of the filament head in each sequence), as seen in Fig. 6.

When jetted onto a substrate, pastes with higher metal loading also result in higher satellite levels and a higher number of dots with very bad shape (Fig. 7).

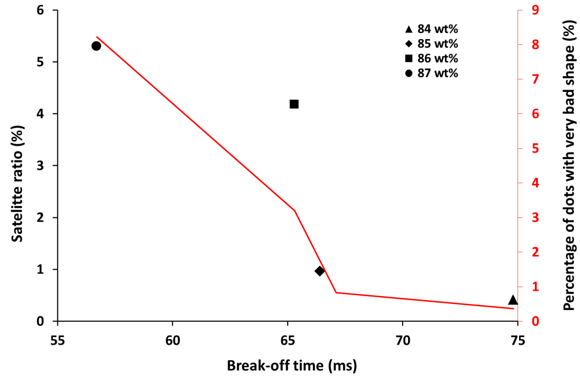

Figure 7 : Satellite ratio and percentage of dots with very bad shape when jetted onto substrate plotted against break-off time from FILBO measurement for solder pastes with 84 (▲), 85 (♦), 86 (■) and 87 (●) wt%.

CONCLUSIONS

The FILBO device provides an effective setup for performing extensional filament breakup experiments on dense and viscous

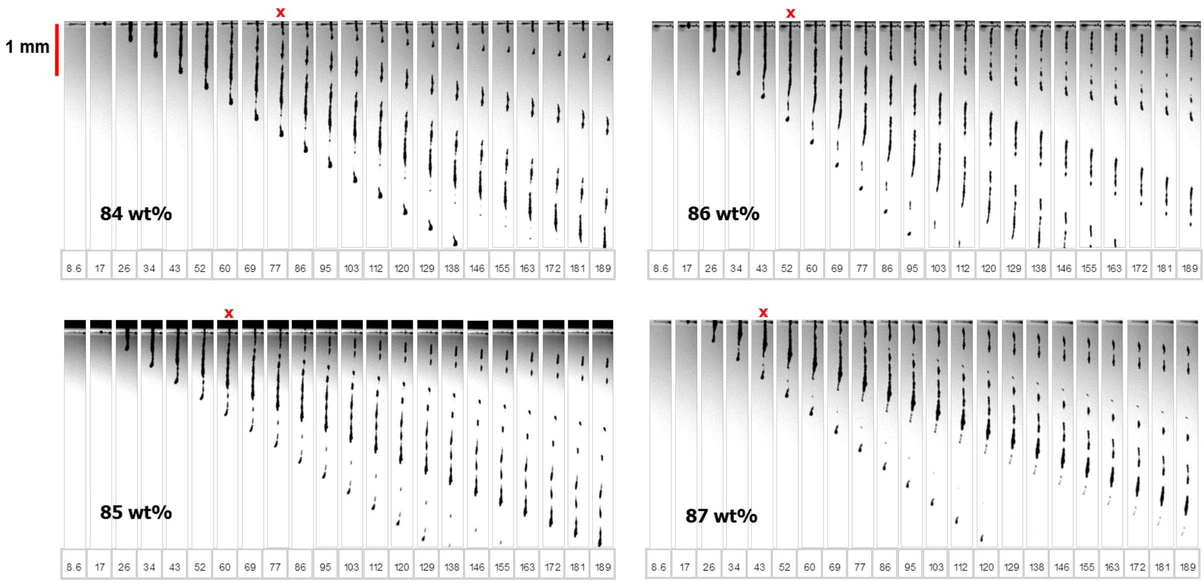

Figure 5 : Sequences of images showing the jetting of solder paste with 84–87 wt% using the same input ejection energy. Numbers below each image indicates time after droplet ejection in μs. The scale bar corresponds to 1 mm. The x symbol indicates complete pinch-off at the filament head.

fluids.

Higher metal loadings in solder paste suspensions result in accelerated thinning and pinch-off of the filament both under extensional filament stretching and jetting. This could explain the higher satellite level and poorer dot shape when these pastes are jetted onto substrates.

Extensional filament stretching can therefore be used as a technique to characterize dense suspensions and relate these properties to high-speed jetting applications.

ACKNOWLEDGMENTS

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