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Managing the Underfill Process in Transient Thermal Environments

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Abstract:

In the world of microelectronic assembly most process developments are aimed at making smaller components to fit more functions into ever smaller portable devices. This study was designed to look at large device underfill, where the silicon die is over 15mm on a side, and the amount of underfill required is on the order of 30 to 50 mg. The manufacturing process for these large die are pushing throughput requirements to much higher levels than seen on production lines today, bringing new challenges to dispensing underfill.

When such large devices are produced at rates over 3000 uph the dispensing tools have to move a lot of material. The sheer volume of material passing through the jet may present problems in heating fluids to the desired process temperatures before dispensing. This impacts the accuracy of shot size because underfill fluids change viscosity with changes in temperature, and for a given cycle, jet the shot volume can change slightly. This in turn impacts material keep-out zones next to the die. Constant temperature of the underfill fluids results in greater repeatability of shot size, aids flow under the die, and improves fluid break off. During this study, it was also observed that the system thermal environment (inside the dispensing machine) had a large impact on the shot weight dispensed.

Introduction

Underfill materials are normally made from two part epoxies. They are mixed, degassed, packaged into syringes and frozen to -40 deg C for storage. At this temperature the underfill usually has a shelf life of 6 months or greater. There is still a small amount of curing of the two part materials at this temperature, but the reaction rate is very slow. When materials are removed from the -40 deg C storage conditions, they thaw out, and start to react more quickly. Many materials have an 8 hour pot life at room temperature, and this is often specified as a point where the materials viscosity doubles.

Figure 1 is a plot of viscosity over time during a production run using a two part underfill fluid. Essentially the fluid is curing and the viscosity is increasing. Automated dispensing equipment has Mass Flow control systems built into them, which automatically adjust the dispense weight to accommodate the changes in viscosity (ref 1). Under normally steady state conditions the fluid weight is reduced over time. To compensate for fluid changes the dispense line speed is reduced to obtain the same weight of fluid on the part, when using needle dispensing. With jet dispensing the number of cycles / dots is adjusted to add more fluid and keep the time constant.

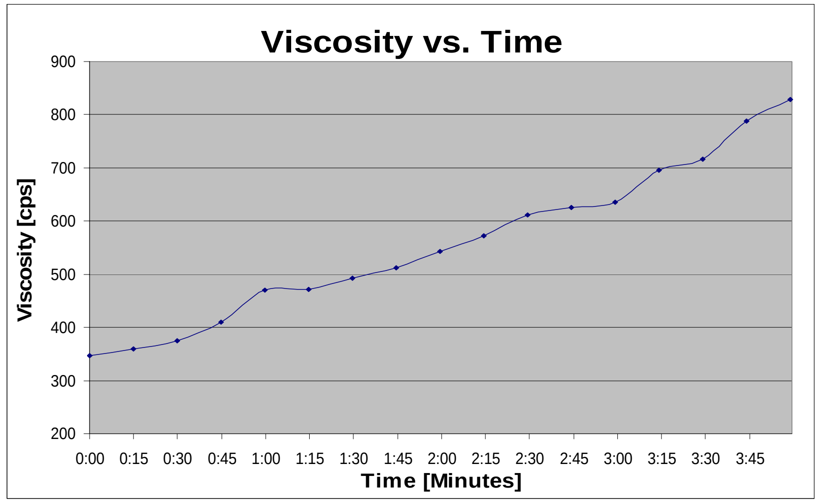


Figure 1 Viscosity vs Time

In figure 2 it can be seen that over time the flow rate of the un-calibrated fluid has decreased, hence the flow rate through a needle tip or jet has to be adjusted to compensate. Using a Mass Flow calibration procedure the dispensed weight of material is kept within the Upper and Lower control limits, as shown by the purple line.

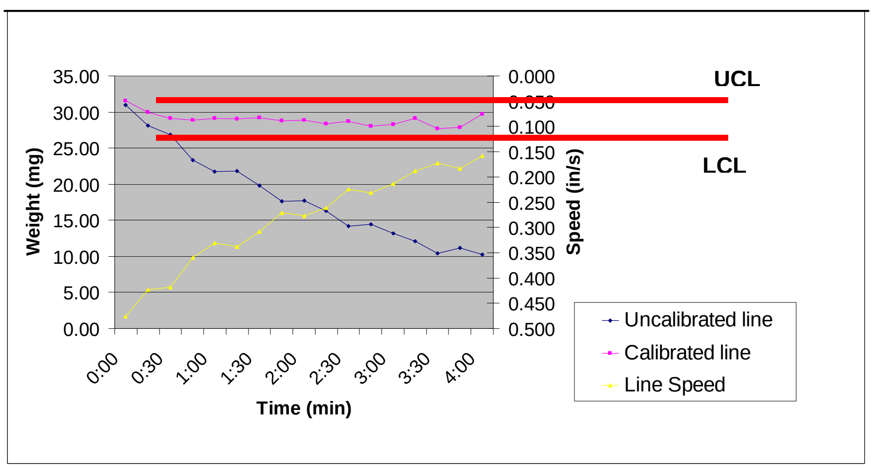
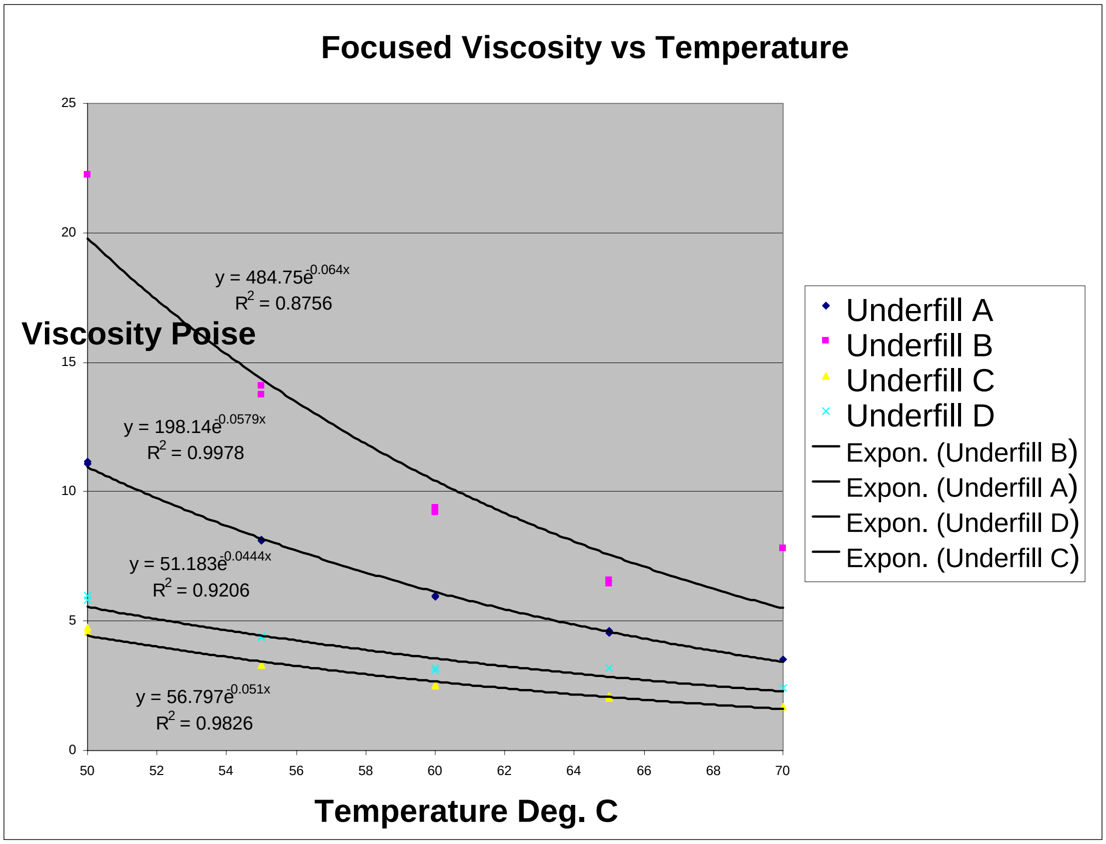


Fig 2 Flow Rate vs Line Speed

While this relationship between time and viscosity is fairly predictable as production rates increase and underfill fluid keep out zones are reduced, variations in fluid volume from other factors can cause changes in the final product that are not acceptable. To understand the problems being experienced, an extensive study was undertaken to determine the factors acting upon a DispenseJet.

Variable Analysis

Heat can quickly change the viscosity of an underfill fluid. Figure 3 shows the measured relationship of viscosity verses fluid temperature for four common underfill materials. It is interesting to note that even the underfill "C" halves in viscosity over the focused temperature range of 50 to 70 deg C. Therefore any changes in underfill fluid temperatures can be critical to the process.



For this study a six factor, two level screening, Design of Experiment (DOE) was conducted with the variables being min and max fluid pressure, needle stroke, on / off times, and a heat exchanger on or not used at 60 deg C. The addition of the heat exchanger allows the fluid to arrive at the dispense nozzle at a predetermined temperature. Figure 4 shows the jet used for these tests. The heat exchanger is placed in the fluid feed line close to the nozzle. Fluid arrives at the temperature controlled nozzle at a predetermined temperature.

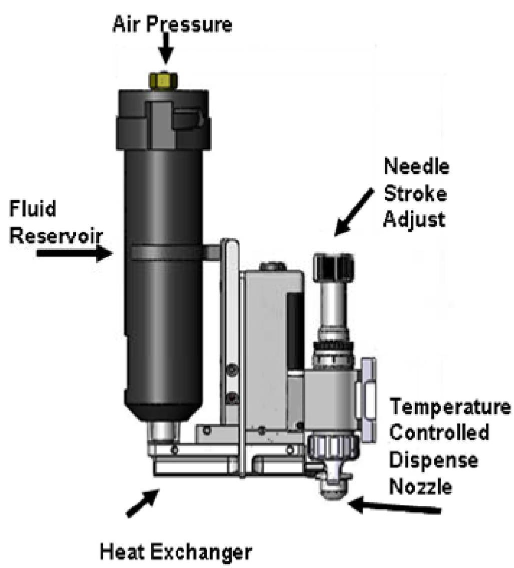


Fig 4 Dispense Jet with Heat Exchanger

Typically in jet dispensing systems, some type of temperature control is built into the dispense nozzle. In this case, active heating and cooling is available at the dispense nozzle, to control the fluid temperature within plus or minus one degree centigrade. At very high fluid flow rates the concern is that the fluid does not reach the desired temperature before being dispensed. Hence the reason for a Heat Exchanger built into the fluid path immediately before the jet nozzle.

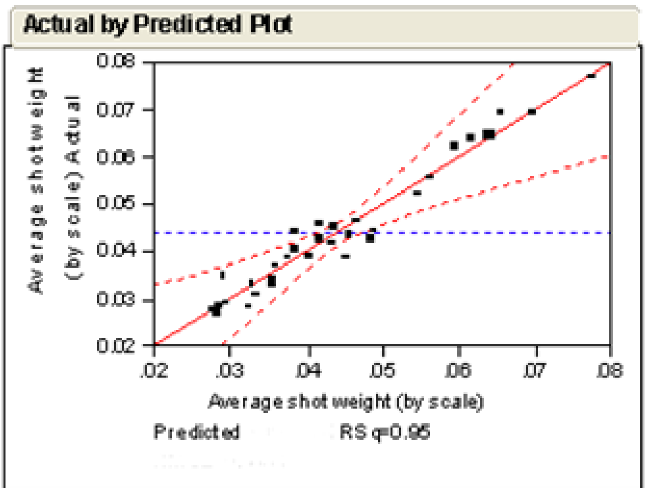


Figure 5 Actual vs Predicted Shot Weight

A model was developed to look at the impact of the jets variable factors verses shot weight. Figure 5 shows the result of the model verses dispense or shot weight. The model shows that there is a greater than 90% confidence level that the model can accurately predict shot weight based on known factors of the DispenseJet's features.

Figure 6 shows the results from the model in a Pareto chart of the features of a jet that can be varied to change the shot weight and the set points used for the test. The chart shows the variables listed in order of magnitude of the affect. It can be seen that the largest effect on shot weight is the temperature of the fluid, followed by fluid pressure, and on time, with the presence of a heat exchanger in the top four shot weight influencing factors.

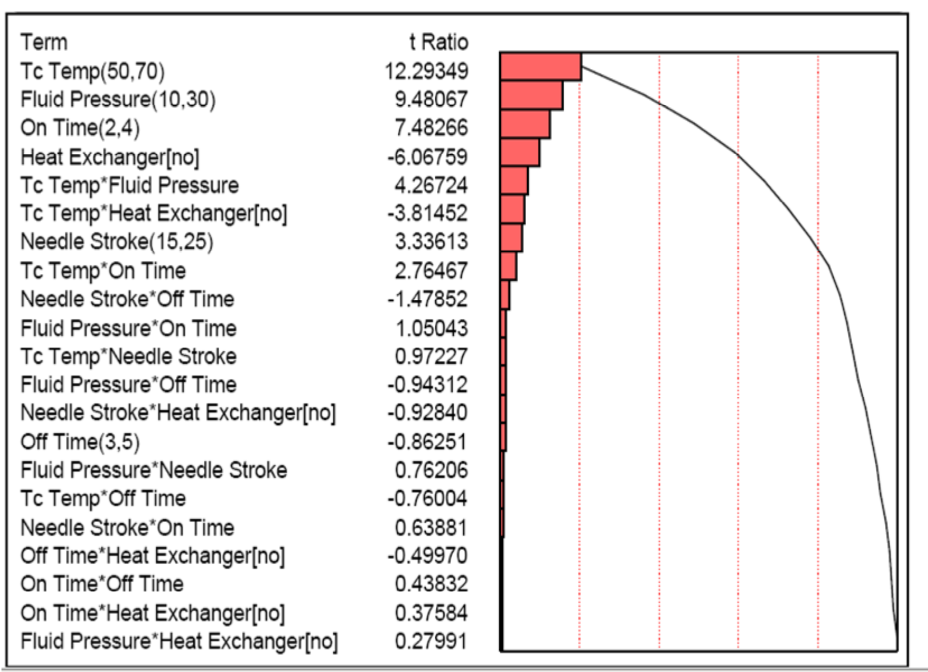


Figure 6 Pareto of Jet Variable Properties

Experimental Data

A series of dispense test were run using identical conditions with a focus on shot weight of fluid and the heat exchanger.

The Dispensing system internal temperature was measured at approximately 43 deg C after a heat soak period of one hour. A 6oz fluid cartridge was allowed to come to room temperature over two hours prior to loading into the system. The test was designed to run over, eight hours, with a target shot weight of 40 mg, with an upper specification limit of 44mg, and a lower specification limit of 36mg. The heat exchanger and the nozzle temperature were set at 60 degrees centigrade when powered.

Weight sampling was set for every 30 minutes using 10 glass slides, with the first sampling set for time zero. Each test slide would receive 44 dots of underfill, and this was dispensed in 2.5 seconds with a wait time between slides of 42 seconds. When not dispensing on test slides, the jet would dispense on an FR4 substrate, using a simulated underfill pattern motion. Prior to starting the test the jet was purged for 30 seconds. Before dispensing on the test slides a short 30 second purge was run. Prior to each slide a 0.5 second purge was run to ensure nozzle cleanliness.

Figure 7 shows one of the test plots for a system with a jet that has a heat exchanger present (Blue), and one with the exchanger removed (Purple line). It can be seen that at the start of both tests, the volume of fluid increases slightly.

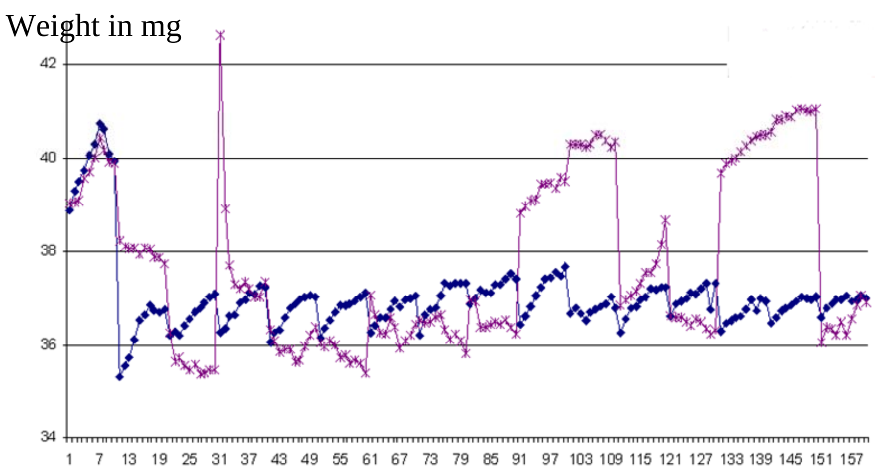


Figure 7 Heat Exchanger Test

This was due to the fluid sitting in the jet being heated, after the first few shots cooler fluid enters the jet and in both test results drop towards the lower specification limit, where it is now in a controlled dispensing regime. The small raise and fall (saw tooth) nature of booth traces are a result of the system's impingement (forced air) heaters controlling the temperature of the substrates to 130 deg C. These are approximately 25mm below the jet nozzle with a substrate of FR4 or a glass slide between the Jet and nozzle.

When the jet was run without the heat exchanger (see the purple line), on three occasions the flow rate through the jet increased over several hours approaching the upper control limit of 40 mg and then dropped back to the lower control limit of 36 mg. These types of changes were not seen when the heat exchanger was present. Unfortunately the instrumentation at this time cannot explain these anomalies. Which suggests that a factor in the experiment was not accounted for or we have an interaction of more than one variable. It has been observed that simply opening the door on the dispensing system can have a similar effect to what is seen here, although usually of a shorter duration. Although the changes in shot weight in figure 7 are taking place over several hours what is interesting is that the heat exchanger appears to even out these transient changes and provide a consistent thermal environment, and therefore a consistent shot weight of underfill fluid. The original model for this work focused on the jet. However from this testing it was realized that the whole system needs to be modeled to fully understand all interactions affecting the dispensing process.

Summary

At the beginning of this testing, it was believed that large volumes of underfill fluids flowing at high rates in production may not be heated to desired operating process set points, prior to being dispensed. This would change the weight of underfill fluid being dispensed. The model predicted that fluid temperature has a large impact on shot weight. Unfortunately, the model was only based on the Jet dispensing head and did not include the total system. During these tests it was also found small shot weights could be affected by the ambient temperature changes.

This is an ongoing development program. I is clear from the laboratory test data and results from field testing that a consistent fluid temperature is critical to controlling the underfill dispensing process. By adding a temperature controlled heat exchanger to the fluid input line, and tightly coupling this with the jet nozzle temperature controller, it was demonstrated that a precise controlled dispense was obtained even when multiple variables were changing in the system environment.

Reference: 1) Use of Closed-Loop Process Controls in Dispensing - J. Klocke (Circuits Assembly Magazine, January 2006)