

Controlling Fillet Size in Underfill Process

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Abstract

Advanced IC packaging is being driven toward smaller sizes with higher chip densities and higher I/O requirements. Automating the underfill dispensing process for robust production can be challenging as package sizes decrease, underfill materials advance, and tolerances tighten. Controlling fillet size is key to the package manufacturing process in order to control stress and improve package density. Best practices for automated underfill dispensing are discussed with regard to the fillet width and thin film residue left after the underfill material moves away from the original underfill dispense area. A 2^{6-1} fractional factorial designed screening experiment of resolution VI was conducted to quantify the relationships between the process variables and the fillet size response. Six original variables under examination were: dispense pattern, needle gage, number of passes, needle dispense gap above the substrate, needle temperature and substrate temperature. After screening and elimination of several variables, the volume of fluid dispensed was added to the variable set. A final experiment was conducted with a second type of underfill fluid to determine whether there were any differences in the model due the physical properties of the fluids. Both experiments used a basic flip chip model consisting of precision cut rectangular glass chips mounted on FR-4 substrate with a measured gap used for determining the volume under the chip. The test vehicle was designed to simulate FCOB applications, but the results can be used to guide dispensing practices for other flip chip applications.

Introduction

Figure 1 shows a cross section of the underfill package. Determining the amount of material needed to completely underfill this package is a straightforward geometry problem. Simply add the volume under the chip to the volume of the fillet, then subtract the volume of the interconnect bumps as shown in equation 1.

$$V = V_C - V_B + V_F$$

Where:

V_C : Volume under the die = Die Length x Die Width x Underfill Gap

V_B : Volume of the interconnect bumps = Area cross section of bumps x Underfill gap x Number of bumps

V_F : Volume in fillet = [(Fillet height x Fillet width x 2 x (Die length + Die Width)) + $\frac{1}{3}$ x (Fillet width)² x Fillet height] x Shape Factor

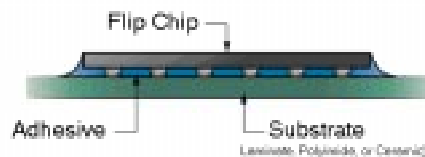


Figure 1. Cross-section of an underfill chip

In this experiment the gap under the glass chips, which substituted for the semiconductor die, was measured and held constant for each set of runs. Using the measured gap, the required fluid volume was calculated to be a nominal under-the-chip value of 32 mg. The size and shape of the fillet depends on the amount of fluid dispensed in excess of the amount required to underfill the chips and is possibly affected by the variable set. The amount of fluid dispensed is expressed as a mass (in mg) which is equivalent to the volume, given the fluid specific gravity (1.7).

Initial Screening of Variables

The initial design of experiment had six variables: ‘Pattern’, ‘Needle Gage’, ‘Number of Passes’, ‘Needle Dispense Gap’ (above the substrate), ‘Needle Temperature’ and ‘Substrate Temperature’.

<i>Variable</i>	<i>Minimum Value</i>	<i>Center Value</i>	<i>Maximum Value</i>
Pattern	Straight	--	L Shape
Needle Gage	25	22	18
Number of Passes	1	2	3
Needle Dispense Gap	.25mm	.38mm	.51mm
Needle Temperature	30° C	50° C	70° C
Substrate Temperature	70° C	90° C	110° C

Table 1: Initial Screening Variables with Values

The pattern was either L-shaped along two continuous edges of the chips, or a straight line along one edge, making the pattern a categorical variable.

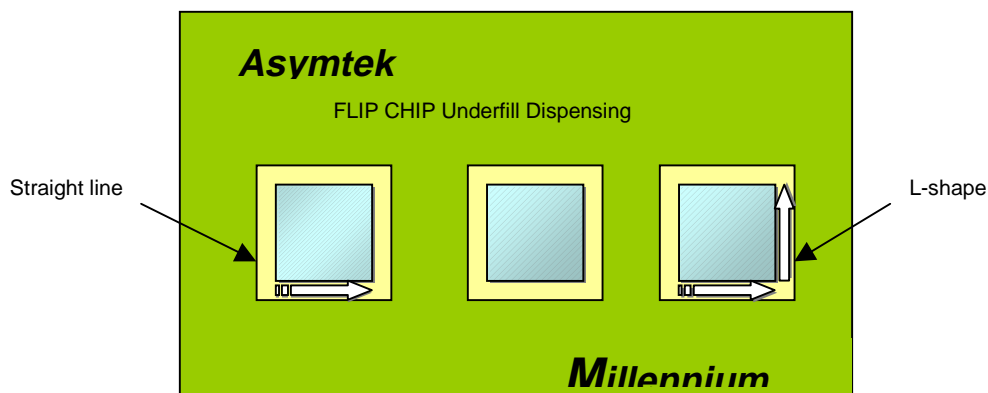


Figure2: Diagram of Board with Three Glass Chips Showing Patterns

Selected needle gages were 25, 22 and 18 gage. Gage is similar to a categorical variable but was not treated as such in this experiment. Needle dispense gaps used were 0.25 mm, 0.38 mm, 0.51 mm or 0.010”, 0.015”, 0.020”. The needle tip was heated to 30°, 50° or 71° C to ensure constant fluid temperature during the dispense and the substrate temperatures were set at 70°, 90° or 110° C. The number of passes, which is the number of times a pattern was run, was one, two or three times, in order to dispense the total amount of fluid required for the underfill. For example, if 48 mg was the total amount of material to dispense, and the number of passes was three, 16 mg was dispensed in each pass. Thirty seconds of waiting time was allowed between passes for propagation of the underfill fluid by capillary action under the chip. The screening experiment used a commercial underfill, Fluid A, with viscosity of 12,000 cps and contact angle of 10 degrees at the

substrate temperatures used in the tests. The variables were modified slightly after the screening runs to accommodate experiment design augmentation.

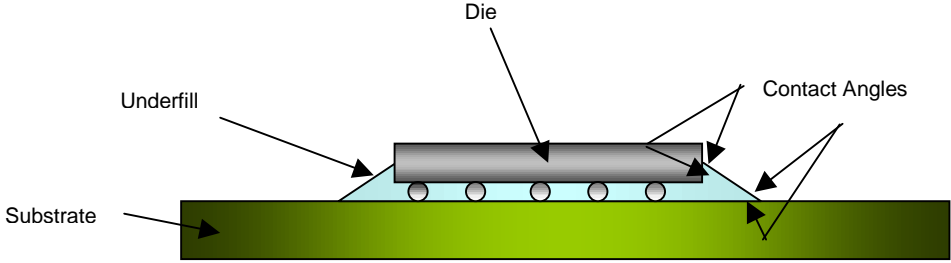


Figure 3: Contact Angle of Underfill Fluid

Analysis of the results revealed no strong correlation between fillet height and any of the factors examined. This suggests that fillet height cannot be controlled and is probably determined by the fluid’s physical property of wetting the side of the chip and remaining attached at the ‘contact angle’ of the fluid. The contact angle is affected by the temperature and the material the fluid is attached to and is assumed to be approximately equal at both angles: the angle between the substrate and fluid and the angle between the die and the fluid. Fillet width showed some affect from pattern, passes and gage, but analysis of variables indicated a need to augment the experiment to find a model with a closer fit of the data.

The strongest model obtained from the screening experiments was for the width of the residue which is a thin film left behind in the original dispense area after most of the fluid has been drawn under the chip by the capillary action. The residue width depended on pattern, the number of passes and the gage of the needle used. Figure 5 shows the residue width (in millimeters) with a 22 gage needle, 30° C needle temperature, 90° C substrate temperature, .38 mm dispense gap (0.015”), for both the L-shaped pattern and the straight pattern.

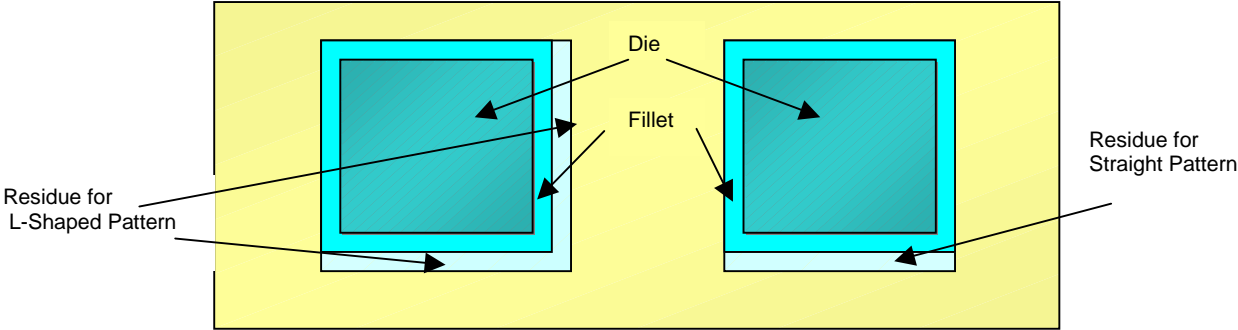
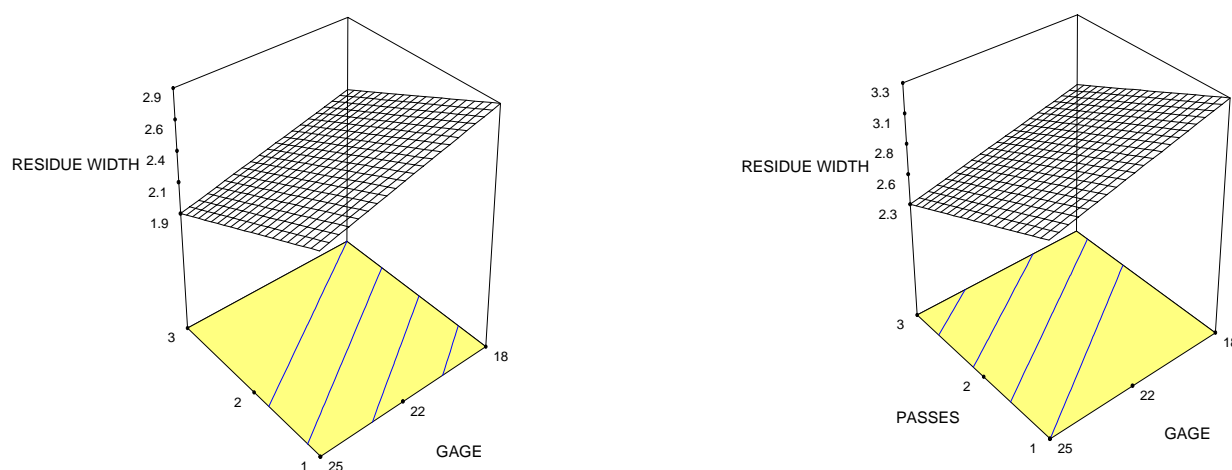


Figure 4: Top View of Residue for L-Shape and Straight Pattern

The graph for the straight pattern is similarly shaped but with slightly larger residue widths. The smallest residue width was achieved using the smallest needle with the most number of passes and the L-shaped pattern. Passes and pattern determine the amount of fluid dispensed per unit length, referred to as ‘line weight’. The amount of fluid needed to achieve a certain underfill and fillet shape is a constant quantity. Dividing the amount dispensed into smaller ‘packets’ by

increasing the number of passes and the length over which it is deposited gives a lower line weight and allows for the fluid to be drawn under the chip and away from the dispense area before it can spread as in the case of a heavier line. A smaller needle gage allows the center point of the needle, and thus the dispense area, to be placed closer to the edge of the chip resulting in quicker capillary draw action and quicker underfill.

A higher number of passes has a negative impact on throughput since there is a necessity for waiting between passes to let the fluid wavefront propagate under the chip. Smaller needle sizes also result in a tradeoff since higher pressures will develop in the dispensing chamber for the same flow rate. Higher pressures can be avoided to a small extent with slower dispense rates, which will have a negative impact on throughput. A 23 gage needle is the smallest recommended for most applications. There is no inherent disadvantage to the L-shaped pattern since the amount of fluid dispensed is constant and spreads out over a longer line length. The dispense tip will simply move faster. The one possible drawback to the L-shape is that the fluid will be deposited on two sides of the chip. Since the residue width is greater than the fillet width the distances between the chips will have to account for this on more than one side. The straight line residue width will be larger than the L-shaped. Whether to use the L-shaped pattern of the straight line is an application dependent decision.



L-shaped pattern

Straight Pattern

30°C needle and 90°C substrate temperature. 22 gage needle. 0.38mm dispense gap

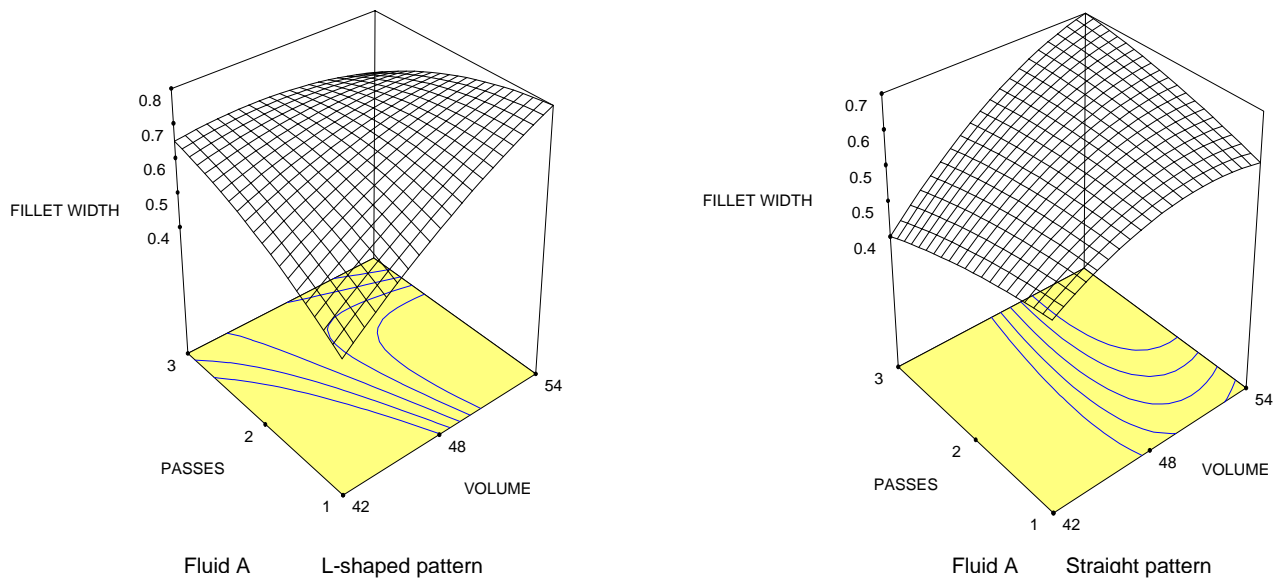
Figure 5 – Residue Width (mm) as a Function of Needle Gauge and Passes

The temperatures used during the screening appeared to have minimal effect on the fillet or residue width. The effect of needle temperature on residue width is very minor, with higher needle temperature giving slightly larger widths probably due to the fluid being able to flow out farther before the capillary draw can remove it from the dispense area, due to lowered viscosity. Substrate temperature had no measurable effect on any of the responses.

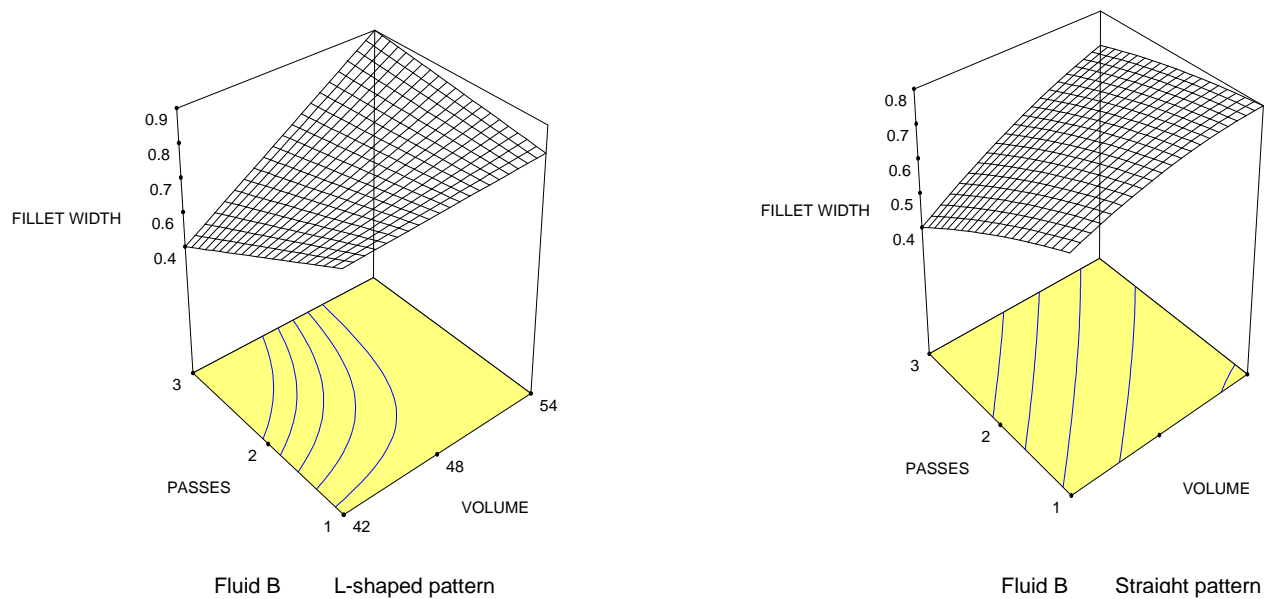
Design Augmentation

The experiment was augmented to obtain better fit for a curve on the fillet width response. Needle temperature and substrate temperature were dropped from the original set of variables creating a 2⁴

factorial design. Upon analysis of this model and while entering data from the screening experiment, it was found that a second order equation was still needed for the best fit. A 2^3 design was created by dropping the categorical pattern variable and running the experiment twice, once for each pattern. The 2^3 design was then augmented to a central composite design (CCD) in order to get a higher order model. This set of experiments was performed twice, once for each of two different types of underfill fluid. The first fluid, Fluid A, has a viscosity of 12,000 cps and a contact angle of 10 degrees and Fluid B has a viscosity of 10,000 and contact angle of 15 degrees for the same conditions. Typical response surfaces are shown in Figure 6.



All runs with 22 gage needle, 0.38mm dispense gap, 30°C needle and 90°C substrate heat



All runs with 22 gage needle, 0.38mm dispense gap, 30°C needle and 90°C substrate heat

Figure 6: Fillet Width (mm) as a Function of Fluid Volume and Number of Passes

The amount of fluid dispensed is expressed in mg but can be considered a volume since the specific gravity of the fluids used is known (1.7). If the amount dispensed is 48 mg and it is divided by 1.7 mg/• L, 28.2 • L is dispensed. Mass is easier to use since the dispensing machines used have built in scales for determining flow rate. Fluid volume was inserted as a variable since it is known to have an affect on the size of the fillet and can be controlled in the dispensing process.

The response surfaces in Figure 6 show the dominance of volume in determining the fillet width. As the volume gets smaller the rate at which the fillet size decreases gets larger. This confirms the concept of critical volume of fluid for a given application. The fillet is the reservoir for the underfill volume. The fillet width is zero if the exact amount required for the underfill is dispensed. If the chip gap is slightly above the upper specification limit or the amount of fluid dispensed is slightly below the lower specification limit, air bubbles or voids will occur under the chip. In either case the resulting product is defective. The converse of these two cases will result in a fillet of some width, possibly not a defect unless it touches areas not intended. As the volume of fluid approaches the critical amount the curve approaches infinite slope. This suggests it is the best dispensing practice to allow for a slightly larger fillet width than is needed by calculation.

Analysis of the data shows that the number of passes has minimal impact on the fillet width. In three of the four cases shown in Figure 6, as the volume decreases, an increase in the number of passes gives a slightly smaller fillet width. As the volume increases only two of the four cases tend in this direction, the other two showing a slight decrease in fillet width for fewer passes. It is determined that for the overall average the number of passes has no significant effect. The gage of the needle used showed no significant effect either.

There is a difference in fillet width for the type of fluid used. Fluid A has a slightly lower fillet width average of 0.598 mm for all runs. Fluid B has an average fillet width of 0.671 mm. The experiment showed no correlation for this fillet width difference for any of the factors measured. It is probable that the quantitative difference is related to the physical properties of the fluid used.

Conclusions

Control of the fillet width for underfill applications is dependent on the choice of fluid and accurate control of the dispensed volume. The operator can select the pattern, number of passes, needle gage, dispense gap and control temperatures. However, these factors do not change the physics of the fluid. Conversely, the operator has significant control of the thin film residue deposit. The best dispensing results for the thin film residue come with a higher number of passes, use of a pattern with more length (L-shaped in this experiment) for dispensing the fluid, use of a smaller gage needle and a needle temperature close to room temperature. These factors are listed in order of their affect on the result. Unfortunately, the first two factors have a potential impact on throughput.

Using a dispense needle of 18 to 23 gage is recommended, with the larger needles allowing more comfortable operating parameters for the equipment and better control of the dispensing process and the smaller needle allowing dispensing in smaller gaps. Needle dispense gap can vary up to about half the thickness of the chip, with a dispense gap of 0.5 mm (0.020") recommended as a starting point. Substrate temperature should be 90° C. Needle temperature should be controlled to 30° C if operating in a variable room temperature environment. The L-shaped pattern is preferred, except in cases where a slight increase in throughput is more important than the advantages of smaller residue and better process control. Use of the maximum number of passes results in better process control, while a minimum number of passes should be used when throughput is most important.