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The Destructive Wire Bond Pull Test Methodology for the Ultra Low Loop Application on Thinner Die Package

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Abstract

The destructive bond pull test is the most common methodology for quality control of the wire bond process on assembly manufacturing. It was introduced in the 1960's and it is described in U.S military specifications[1)]. However, compared to 40 years ago, the wire bonding process has made rapid progress. Today, some of the hottest processes that System-In-Package (SIP), Package-On-Package (PoP) and 3D package require the Ultra Low Loop (ULL, <75 μm height) process on thinner die (<100μm) [2)]. Therefore, the legacy pull test is not sufficient to apply for the ULL and thinner die applications to meet criteria. Because wire breaking values and the failure mode are significantly different by the loop height, die thickness and the position of the wire pull hook[3)].

This paper is presented in order to introduce a universal wire pull test specification and methodology for the ULL on thinner die application.

Introduction

Today, advanced wire bonding and assembly technology is driving for stacked die, PoP and SIP processes. CAAGR in 2011 will increase by 13% compared to 2006[4)]. The chart below illustrates stacked die and PoP packages.

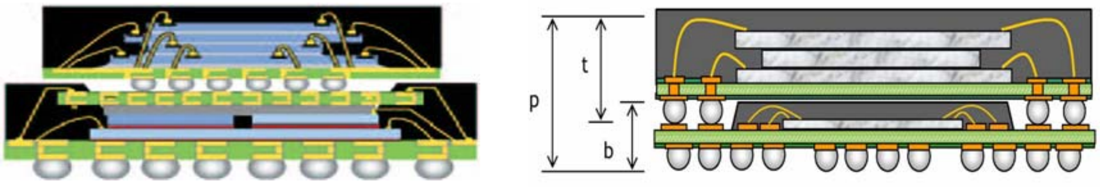

Figure 1: Multi stack and PoP package. *Source: Prismark*[5)]

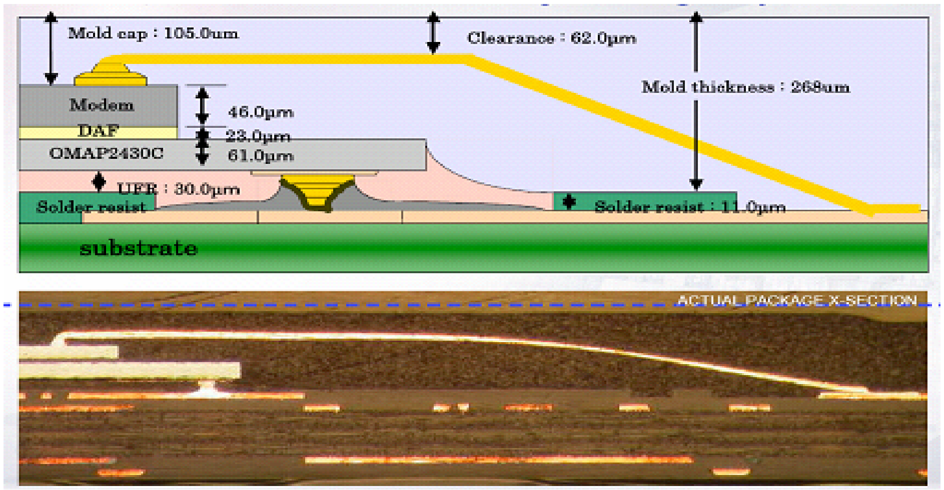

Figure 2: Stack Die Package Thickness and its Looping. *Source: Prismark*$^{6)}$

Package thickness is to 1.0mm for stack die applications. Figure 2 is a 3D package dimension and its cross-section. Wafer thinning, die attach and wire bonding are the key technology for the advanced package. Lower loop height control is the main requirement in the wire bonding process. In 2006, Kulicke & Soffa introduced the less than 60um loop height ULL technology$^{7)}$, and then it presented a lower than 50um loop height ULL on even thinner <4mils die thickness on the IConn^{PS} wire bonder in year 2008$^{8)}$. The 50um loop height advanced process is being introduced into mass production successfully with K&S wire bonder.

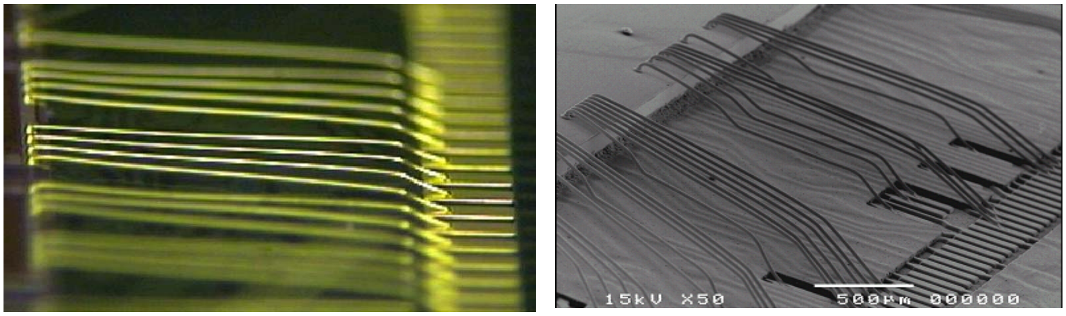

Figure 3: K&S ULL loop shape on various thinner die packages.

This paper will analyze the variables of the wire bond pull force distribution, both theoretically and experimentally, especially for ULL on thinner die processes. It will also find a possible error and problem of the required pull force criteria and Cpk specification in ULL wire bonding quality and reliability.

Equation of the Destructive Wire Bond Full Test

Conventional destructive wire bond full test methodology is well described in the 'Wire Bonding in Microelectronics Materials, process, Reliability, and Yield'$^{9)}$. This is a theoretical model used to demonstrate the geometrical configurations of the wire loop as well as the several equations that define the force distribution. The loop height, the wire length, the position of the pull hook, the height between the pad and 2nd bond surface are all factors influencing the test result.

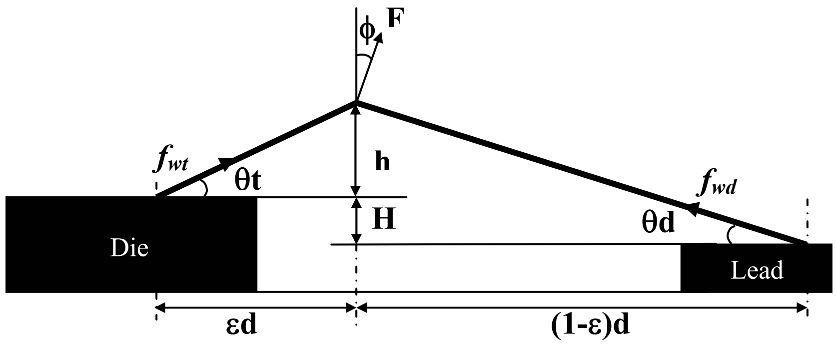

Figure 4: Geometric variables for the test

The force in each wire, (f_{wt} and f_{wd}), at break, with a specified pull force, *F*, at the hook is:

$$f_{wt} = F\left[\frac{(h^2+\varepsilon^2 d^2)^{1/2}\left((1-\varepsilon)\cos\phi + \frac{(h+H)}{d}\sin\phi\right)}{h+\varepsilon H}\right] \qquad [1]$$

$$f_{wd} = F\left[\frac{\left(1+\frac{(1-\varepsilon)^2 d^2}{(H+h)^2}\right)^{1/2}(h+H)\left(\varepsilon\cos\phi - \frac{h}{d}\sin\phi\right)}{h+\varepsilon H}\right] \qquad [2]$$

Equivalent equations using angles θ_t, θ_d, and *F* are:

$$f_{wt} = \frac{F}{\sin\theta_t + \cos\theta_t \tan\theta_d} \qquad [3]$$

$$f_{wd} = \frac{F}{\sin\theta_d + \cos\theta_d \tan\theta_t} \qquad [4]$$

Note that f_{wt} and f_{wd} are the force or tension in the wire, and in order to calculate the wire pull force, *F* must be solved in the equation. A wire will break when either f_{wt} or f_{wd} first reaches its breaking strength to each side of the wire. Typically, this is about 90% of the manufacturer-specified breaking load for Au wire (either ball or crescent bond break). A break normally occurs just above the ball in the heat–affected zone. The position of the hook (indicated as εd) and the pull angle, ϕ will significantly affect the distribution of forces at the bonds. One can choose an ε or ϕ value that will give equal forces on each bond, and it will result in more equal test of both bonds. If $\phi = 0$ and $f_{wt} = f_{wd}$:

$$f_{wt} = F\left[\frac{(h^2+\varepsilon^2 d^2)^{1/2}(1-\varepsilon)}{h+\varepsilon H}\right] \qquad [5]$$

$$f_{wd} = F\left[\varepsilon\frac{\left((h+H)^2+(1-\varepsilon)^2 d^2\right)^{1/2}}{h+\varepsilon H}\right] \qquad [6]$$

The hook position to have an equal force of 1st and 2nd bond, $f_{wt} = f_{wd}$ is:

$$\varepsilon = \frac{1}{2+\dfrac{H}{h}} \qquad [7]$$

A plot of the calculated pull force (F) at wire rupture for higher loop height wire bonded on thicker die thickness is given for a typical two-level semiconductor device-bond configuration in Figure 5, pulled straight up $\phi = 0$ at the center of the loop.

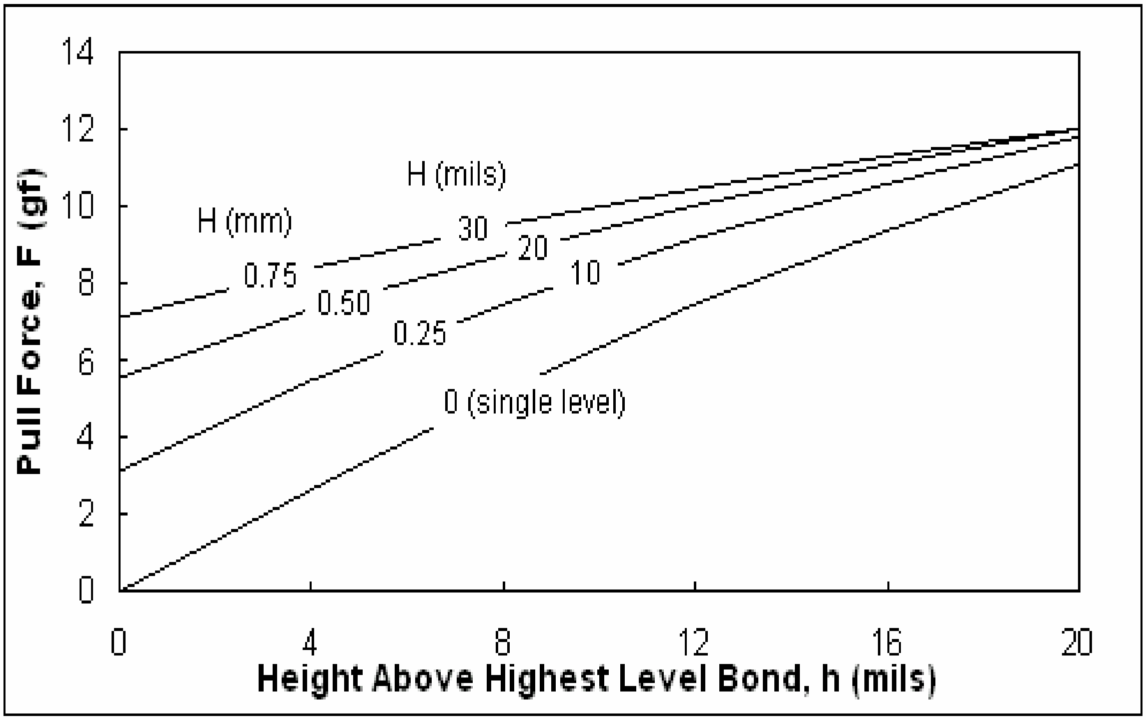

Figure 5: Pull force manner of higher loop height on thicker die thickness. Bond pull force for legacy packages calculated with Eqs. [5] and [6] for various loop heights and package pad heights, pulled in the center of the loop. Where ϕ=0, d=60mils, and fwd = 10gf.

Theoretical Model of the Wire Pull Force for ULL on Thinner Die

Based on the above equations, the wire pull force is predicated to dramatically decrease on ULL less than 4mils loop height on thinner than 4mils die thickness. This is the most common device configuration for the stacked die, PoP and many of the 3D packages. It represents the calculated pull force as a function of hook position for various loop height (h), die thickness (H), and wire length (d) with 0.8mil (20.3µm) diameter Au wire (breaking load: 7.9gm) bonding. The effects of each function are described below.

Effect of loop height and die thickness

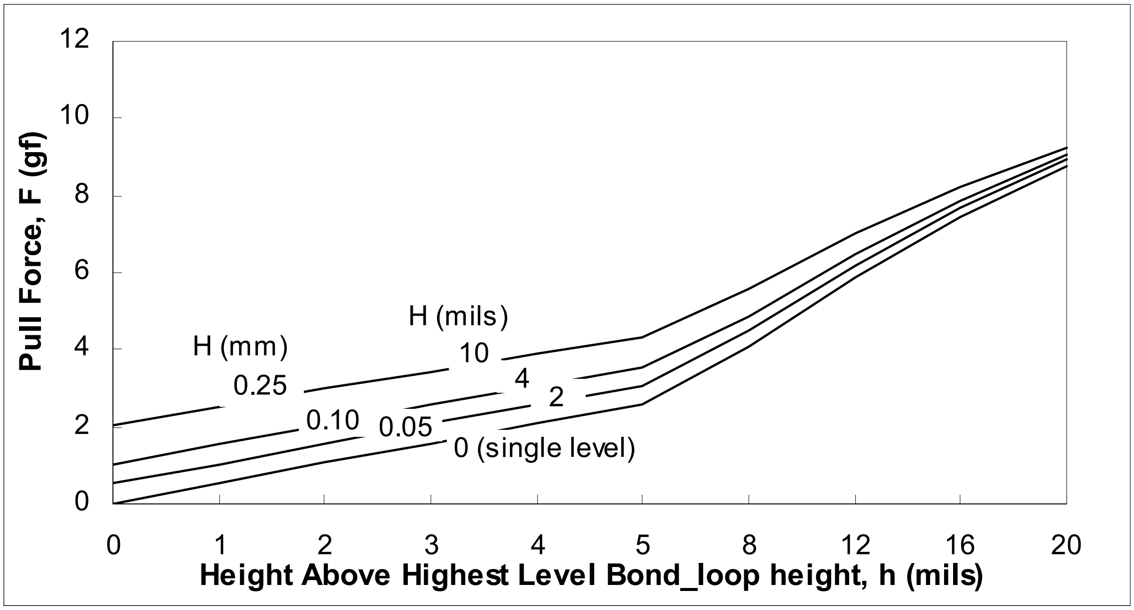

Figure 6: Pull force manner of ULL loop height on thinner die thickness. As seen in Equ 5, the bond pull force is significantly decreased on lower loop height, and thinner die thickness. Where hook position, ε = 0.5 (center of wire length, 30mils from 1st bond), and wire length, d = 60mils.

Effect of loop height with various hook positions

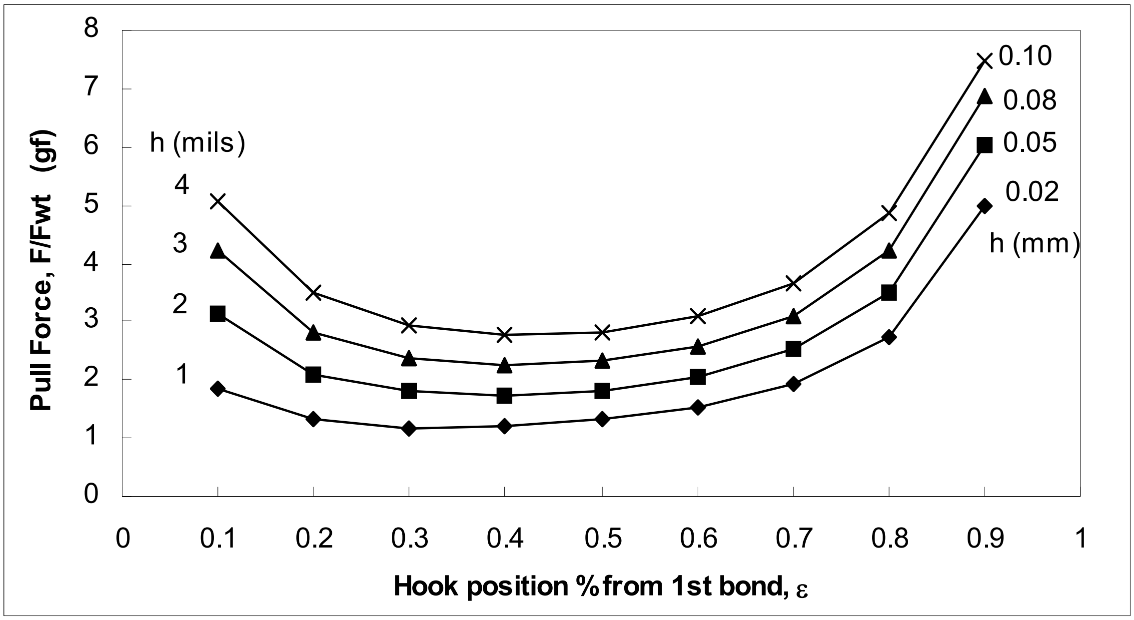

Figure 7: Calculated from Equ. [3]. Bond pull force is significantly decreased on lower loop height. Where die thickness, H = 3mils (0.08mm), and wire length, d = 60mils. First bond is located at ε = 0 and second bond is at ε = 1.

Effect of die thickness with various hook position

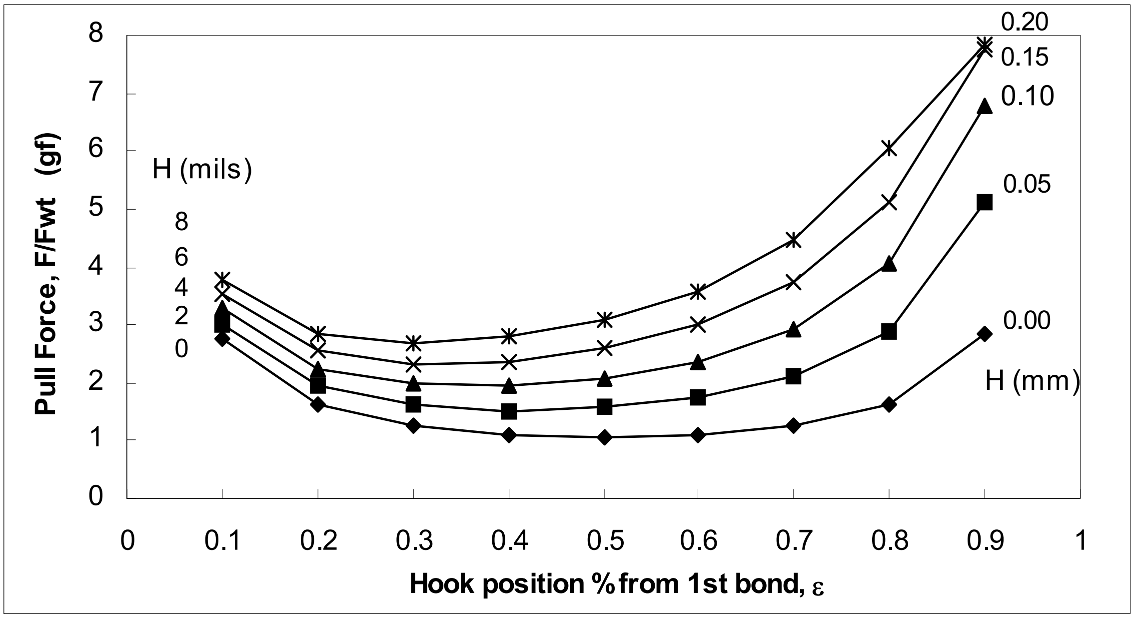

Figure 8: Calculated from Equ. [3]. Bond pull force is significantly decreased on thinner die thickness. Where loop height, h = 3mils (0.08mm), wire length, d = 60mils. First bond is located at ε = 0 and second bond is at ε = 1.

Effect of wire length with various hook position

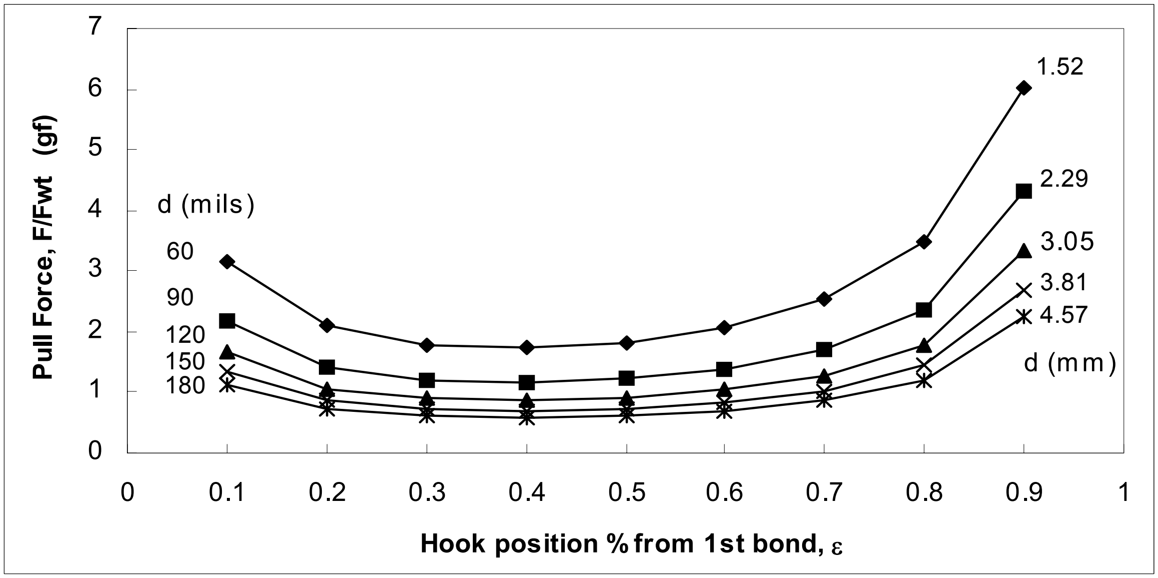

Figure 9: Calculated from Equ. [3]. Bond pull force is significantly decreased on longer wire length. Where loop height, h = 3mils (0.08mm), die thickness, H = 3mils. First bond is located at ε = 0 and second bond is at ε = 1.

Experimental data of the Wire Pull Force for ULL on Thinner Die

As illustrated above on the calculated wire pull force distribution for ULL on thinner die, an actual wire pull force of the new package type like PoP, SIP, and 3D packages would be much lower than most common wire bonding devices. Experimental data will be used to understand difference in the wire pull force as well as process capability (Cpk) for ULL wire bonding on thinner die. There is progress for 3mils and 4mils thinner die thickness and 2mils loop height on K&S IConn^{PS} wire bonder with 0.8mil (20.3μm) Heraeus Formax™ Au wire. On the experiment, it used 2.4gf lower spec limit (LSL) 10) to calculate Cpk, and its target is greater than 1.67 Cpk. The elongation of the wire, the hook diameter, the hook angle impact11), and pull tester HW setting are not considered in analysis of the experiment data. The additional wire payout to form the last kink loop shape that will affect θ_t, θ_d during pull test is also ignored on the pull force calculation. Therefore the experimental pull force will be a little different compared to the theoretical calculation force.

Before starting the experiment, loop as well as all wire bonding parameters was carefully optimized to remove any abnormal noise. The ball neck and loop shape followed the normal K&S compressed ULL process, and a complete pre-inspection was conducted to ensure there was no ball neck damage and stitch heel crack during wire bonding with SEM. Refer the Figure 10.

Wire pull was executed with the Dage pull tester series 4000-WP100 cartridge. A test load of 3g, speed of 635μm/sec, and hook diameter of 2mils were used.

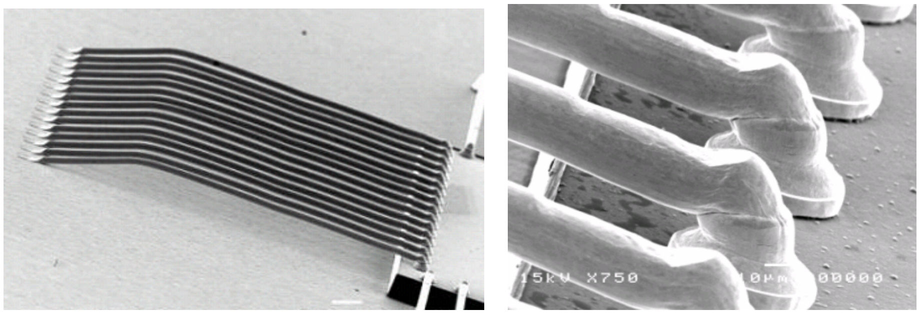

Figure 10: Basic loop shape and compressed ball neck formation for 2mils loop height on 3mils die.

Wire Pull Force of ULL process on thinner die thickness

Figures 11 and 12 are the wire pull force and Cpk for 2mils loop height ULL with various wire lengths and hook positions on 3mils and 4mils die thickness applications. As confirmed by the calculated wire pull force model, the pull strength is increased with higher die thickness (H), the closer the hook positions to 1st bond, and the shorter the wire length. Thus, the force of the ULL will be much lower compared with conventional die thickness (>5mils) and loop height (>4mils) device. Therefore, in order to meet greater than average 3g, the general requirement to achieve confident SPC, the hook position has to move to close to 1st bond.

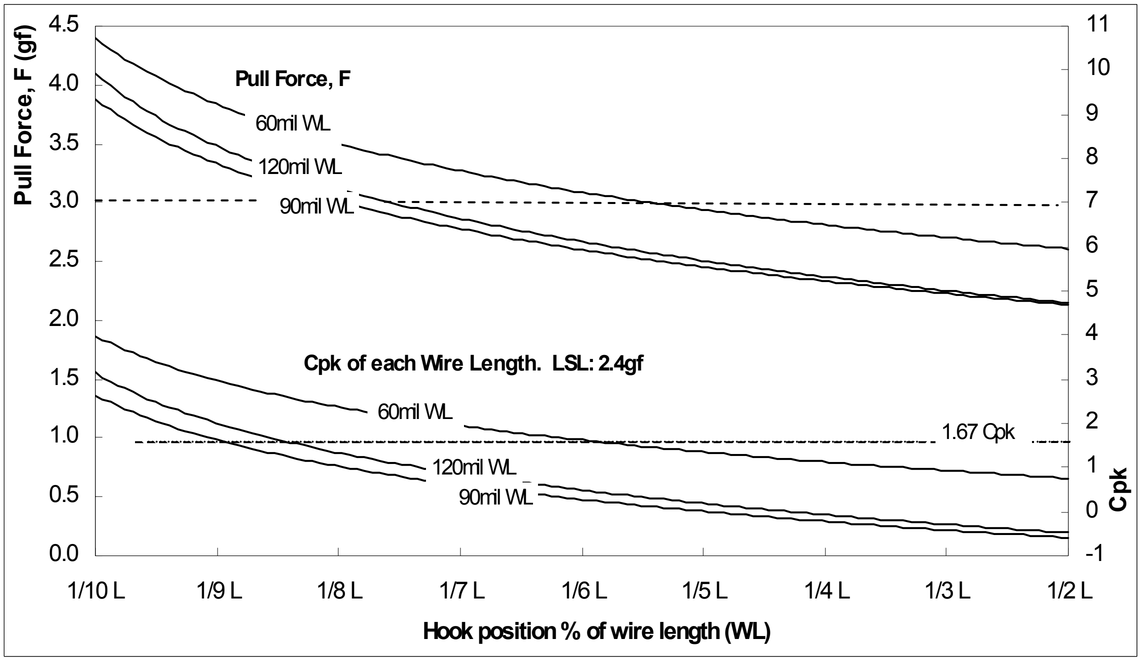

Figure 11: 3mils (0.08mm) die thickness application. Logarithmic trend of the measured pull force and calculated Cpk as a various hook position for different wire length. All of the wire is broken above the ball neck. 0.8mil (20.3µm) Au wire, loop height, h = 2mils (0.05mm). The coefficient of determination, R^2, is >0.8 indicating an acceptable model to describe the variations in, y, pull force.

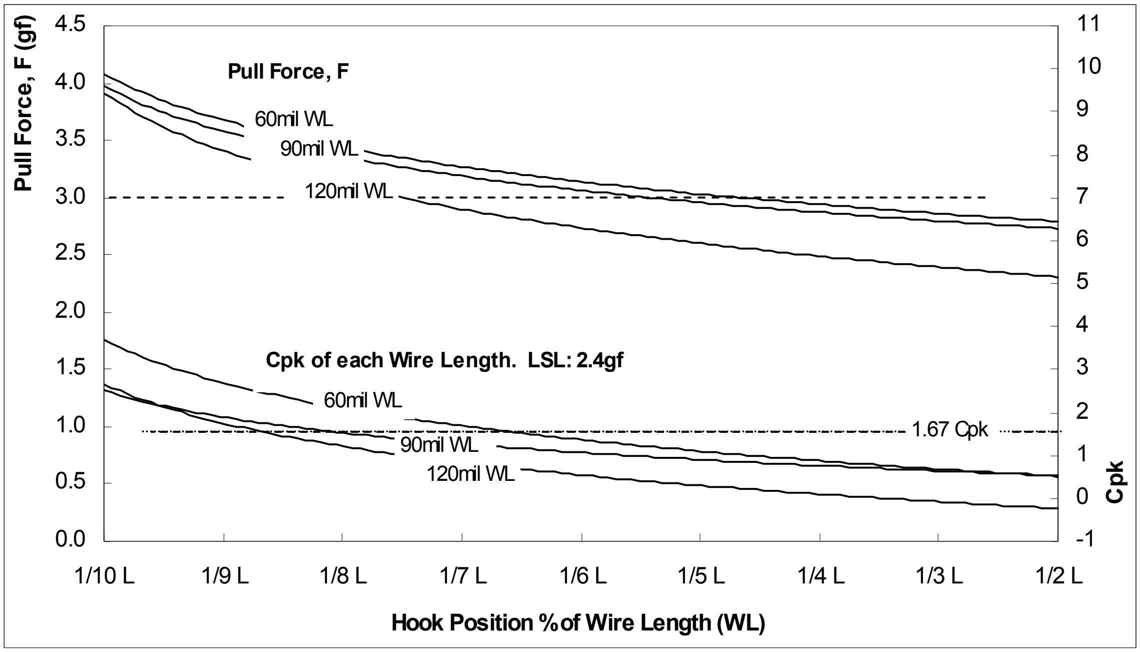

Figure 12: 4mils (0.10mm) die thickness application. Logarithmic trend of the measured pull force and calculated Cpk as a various hook position for different wire length. All of the wire is broken above the ball neck. 0.8mil (20.3µm) Au wire, loop height, h = 2mils (0.05mm). The coefficient of determination, R^2, is >0.8 indicating an acceptable model to describe the variations in, y, pull force.

Cpk is dramatically increased as the hook position is moved closer to the 1st bond location. For the 120mils wire length on the above thinner die, the hook must be located closer than 1/8 L of wire length in order to meet the 1.67Cpk specification. For thinner die and/or lower loop height, and/or longer wire length configurations, the hook needs to move even closer to the 1st bond location. The universal wire pull test method for the SPC and quality specification like Cpk calculations is based on ⅓ L or ¼ L as given in Equ [7]. Based on the experiment data, this method will fail the Cpk spec as shown in Tables 1 and 2.

TABLE 1. Wire pull force data at ⅓ L of wire length hook position ($\varepsilon = 0.33$).

Die Thickness	**3mils**			**4mils**		
Wire Length	Pull statistical	Min - Max	Cpk	Pull statistical	Min - Max	Cpk
60mils	2.56 +/- 0.11	2.41 – 2.76	0.494	2.79 +/- 0.22	2.23 – 3.27	0.597
90mils	2.15 +/- 0.10	1.88 – 2.31	-0.887	2.71 +/- 0.16	2.40 – 3.06	0.670
120mils	2.18 +/- 0.13	1.98 – 2.39	-0.544	2.62 +/- 0.17	2.25 – 3.02	0.436

Table 1: Wire pull force data at ⅓ L of wire length hook position ($\varepsilon = 0.33$) as the common production requirement. Both average force and Cpk failed to meet the specification.

TABLE 2. Wire pull force data at ¼ L of wire length hook position ($\varepsilon = 0.25$).

Die Thickness	**4mils**		
Wire Length	**Pull statistical**	**Min - Max**	**Cpk**
60mils	2.93 +/- 0.26	2.51 – 3.41	0.673
90mils	2.88 +/- 0.21	2.54 – 3.24	0.733
120mils	2.52 +/- 0.17	2.15 – 2.92	0.244

Table 2: Wire pull force data at ¼ L of wire length hook position ($\varepsilon = 0.25$) as the given calculation in Equ. [7]. Both average force and Cpk failed to meet the specification.

These results indicate that the low pull force reading and its Cpk calculation of ULL on thinner die do not come from the ball neck crack during wire bonding. This matter, as a result of the package's geometrical configuration, cannot be avoided in ULL on thinner die case as is defined by the theoretical and experimental analysis. In order to meet the Cpk requirement, the measurement method should be reviewed by either the wire pull specification (LSL) or the hook position.

Conclusions

The rapidly growing demand for multi stacked die, PoP and 3D packages has prompted the development of new equipment, material and processes in order to meet these needs. Ultra Low Loop (ULL) on thinner die is the wire bonding technology needed to realize a thin and light package size for advanced packaging. An accurate concept of this wire bonding process along with the appropriate quality control needs to be considered. As demonstrated in the above discussion, the current industry pull test methodology is not able to meet the Cpk and process quality requirements. The problem is inherent in the thinner die configuration instead of the ULL wire bonding issue. A new wire pull test methodology and ULL process specification needs to be developed in order to continue to keep up with the market demands.

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