TESTING AND EVALUATING FLEXURAL STRENGTH OF STACKED SILICON DIE CONFIGURATIONS.

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INTRODUCTION

Advancing trends in microelectronics has led to shrinking package sizes with smaller footprint which means reduced die size and thickness of microelectronic circuits. Reduced die size demands more functional performance per unit area of silicon die and thinner die have allowed lowered package height. Inevitably, the reliability issues due to deformation from high stresses induced in the die during assembly processes, reliability and functional tests began to surface. Due to brittle nature of silicon, even low stress levels can result in detrimental failure such as cracking and fracture in thinned, backgrounded die. Thus, investigating these stress induced die failure modes has been critical to package development activities. This issue becomes more severe in case of stacked die (3D) laminate packages since these comprise of thinned, backgrounded dice stacked on top of each other by means of thin layers (typically ~10μm-30μm) of die attach adhesives. Understanding the deformation under stress and stress transfer in stacked structure becomes critical to realize overall package reliability and robustness [1]-[3].

OBJECTIVE

Structural integrity and mechanical robustness of the die stack is critical for its uncompromised functionality.

The mechanical strength of the stacked structure is dominantly a function of layers of die attach between multiple substrates and whether the package is a molded one or cavity package. The purpose of this study is twofold:

- To develop a good experimental setup repeatability and reproducibility for a simple 3- point flexural test.
- To evaluate flexural strength and corresponding flexural extension at predefined failure modes (initial fracture in die) which were used to compare these die configuration and comment on packages mechanical robustness.

MATERIAL & METHOD

Stacked die configurations evaluated as a part of designed experiments are comprised of identical die structures stacked on thin laminates with varying intermediate die attach materials – **A, B & C.**

STACKED DIE CONFIGURATION UNDER TESTING AND EVALUATION

Stack 1	Stack 2	Stack 3
Die 2	Die 2	Die 2
Die Attach A	Die Attach B	Die Attach C
Die 1	Die 1	Die 1
Die Attach A	Die Attach B	Die Attach C
Laminate	Laminate	Laminate

A simple 3-point flexural test setup was developed to suitably subject specimens to load from the laminate side to avoid any premature failure in the die.

- Lower support anvils allow variable span control;
- An upper anvil with radius ≈ 0.4mm allows line contact along the sample width;
- Universal tensile machine – **Instron.**

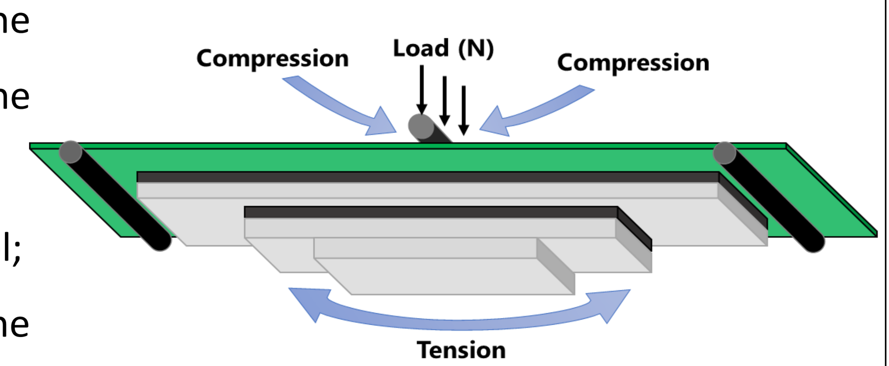


Fig.1 –Forces acting on specimen in 3-point flexural test

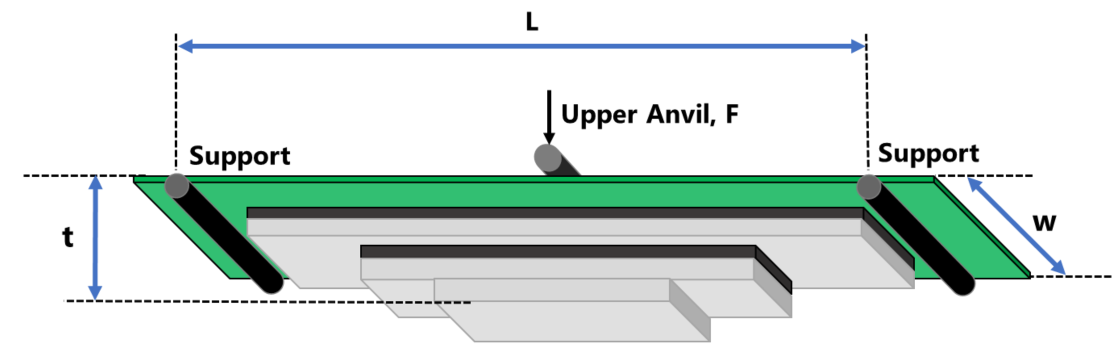


Fig.2 – Critical parameters for stress calculation in 3-point flexural test

Stress at given load under 3-point loading is fiven by, $\boldsymbol{\delta = stress\,(MPa) = \frac{3FL}{2wt^2}}$ **.......(1)**

Where, F = load (N) or breaking load (N) at yield point for calculating flexural strength;

L = Support length (mm);

w = width of specimen (mm);

t = thickness of specimen (mm).

Experiments conducted to validate the reliability of experimental methodology:

Two-sample t-Test: To realize the effect of extension rate (μm/min) on the loading force (N) exerted on the specimens

Repeatability & Reproducibility Tests: Destructive approach using nested method to investigate the source of variability that affect the measurements made using designed experimental setup.

Two- Sample t-Test Results: Extension rates investigated - **200 μm/min** & **500 μm/min.**

Method

μ_1: mean of Ext. Rate 500μm/min
μ_2: mean of Ext. Rate 200μm/min
Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Ext. Rate 500μm/min	15	4.206	0.413	0.11
Ext. Rate 200μm/min	15	4.014	0.418	0.11

Estimation for Difference

Difference	95% CI for Difference
0.192	(-0.119, 0.504)

Test

Null hypothesis $H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis $H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
1.27	27	0.217

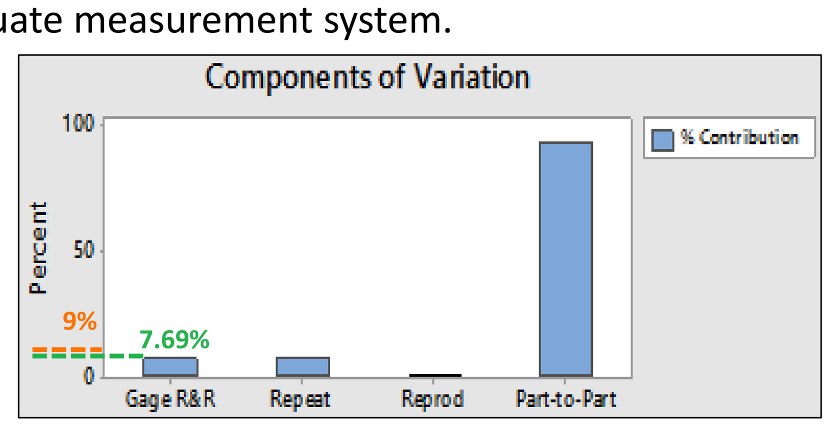
Fig. 3 – Two sample t-Test output

- P-value of 0.217 **>** significance level α =0.05
- The difference between the means is not statistically significant.
- Failed to reject null hypothesis - $H_0: \mu_1 - \mu_2 = 0$. Thus, a level of 500 μm/min was chosen to increase the experiment execution speed.

Repeatability & Reproducibility Results: Results indicate the highest contributing factor to the variability in measurement data comes from part-to part variation inherent to the specimens.

Reported Total Repeatability & Reproducibility contribution to total variation:

7.69 % < 9% (quality standard acceptance criteria). Thus, experimental setup is considered to be an adequate measurement system.

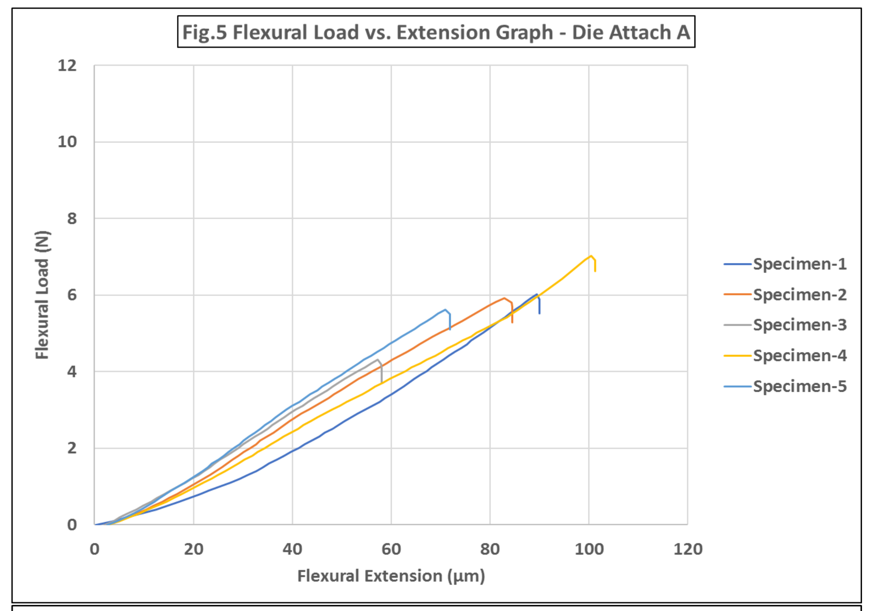


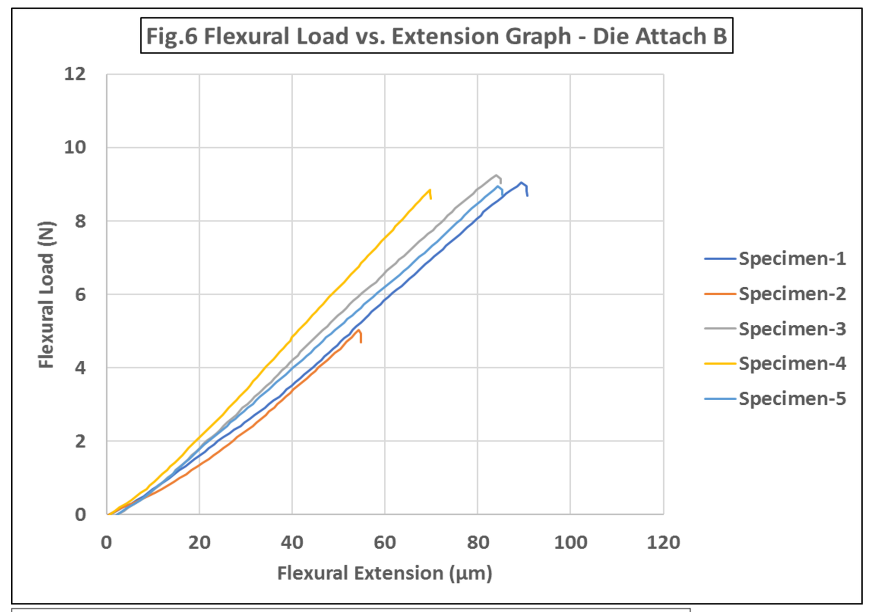
Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0047148	7.69
Repeatability	0.0047148	7.69
Reproducibility	0.0000000	0.00
Day	0.0000000	0.00
Part-To-Part	0.0565827	92.31
Part(Day)	0.0565827	92.31
Total Variation	0.0612975	100.00

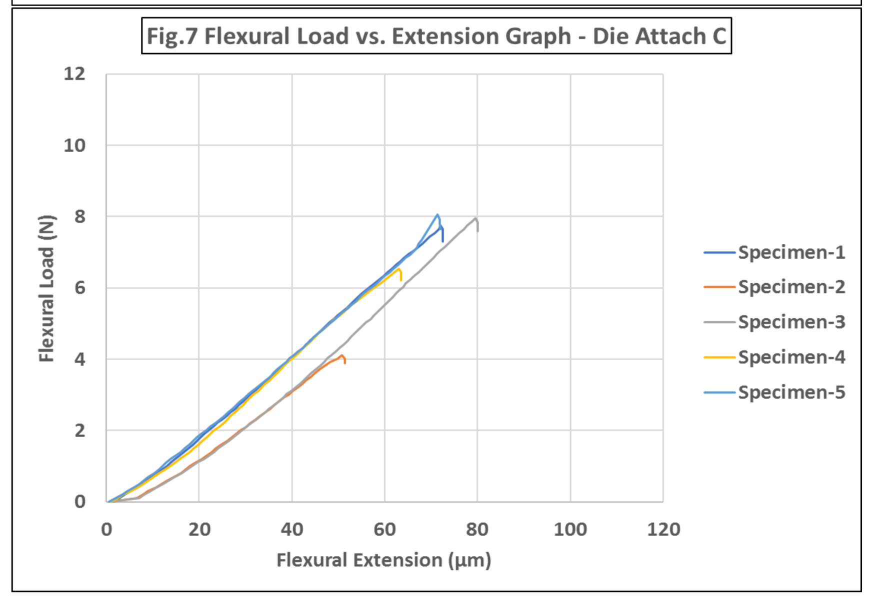
Fig. 4 – Nested (Expanded) Gage R&R output

All the specimens were subjected to similar loading conditions. Data were recorded for each specimen until first load drop, i.e., yield point in flexure was observed on the 'Flexural load vs. Flexural extension' plots produced by Instron. Specimens were optically inspected to record preliminary failure mode. Observed failure mode, crack in die 2 of stack, was similar and concentrated to the specific stressed region for all specimens.

RESULTS, CONCLUSIONS, & FUTURE WORK







Summary Descriptive Statistics for N =25

	Flexure Extension (μm)	Flexure Strain (%)	Flexure Load (N)	*Flexural Strength (MPa)
Stack with Die Attach - A				
Mean	87.96	3.63	6.11	6.90
Min	51.47	2.12	4.32	4.88
Max	111.94	4.62	8.45	9.55
Range	60.47	2.49	4.13	4.66
S.D	15.57	0.64	0.85	0.96
Stack with Die Attach - B				
Mean	82.59	3.36	9.10	10.28
Min	54.38	2.24	5.06	5.71
Max	111.28	4.59	12.83	14.50
Range	56.90	2.35	7.78	8.78
S.D	16.40	0.67	1.56	1.76
Stack with Die Attach - C				
Mean	64.63	2.67	6.51	7.35
Min	47.53	1.96	4.12	4.66
Max	82.50	3.40	8.08	9.12
Range	34.97	1.44	3.96	4.47
S.D	9.91	0.41	1.00	1.13

*Flexural Strength = Stress at yield point in flexure test.

Graphs shown above are only for first five specimens out of 25 that were subjected to test.

Conclusion:

- In terms of **flexural strength** of die stack:

  Die attach B > Die attach C > Die attach A

- In terms of stiffness, i.e., resistance to deformation under loading:

  Die attach C > Die attach B > Die attach A

Thus, it is reasonable to conclude that die attach B has greater mechanical strength with moderate deformation allowing greater stack integrity and robustness.

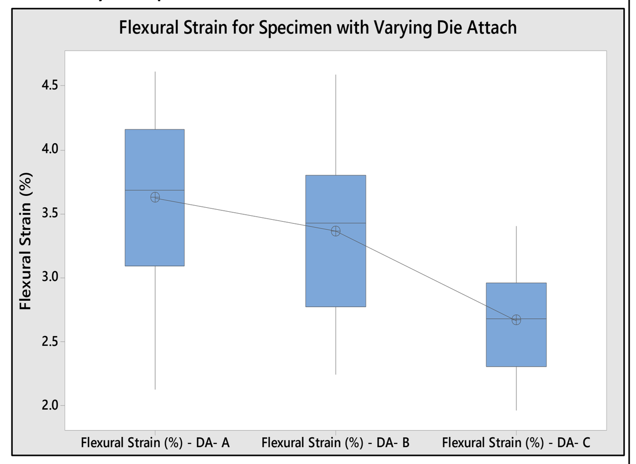


Fig. 8 – Flexural Strain Distribution

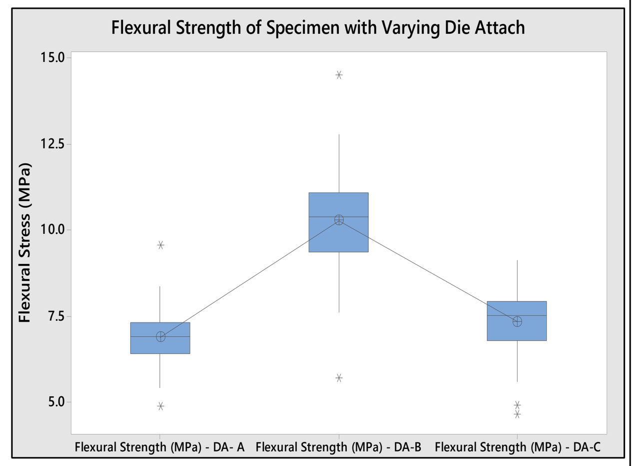


Fig. 9 – Flexural Stress Distribution

Future work:

- Process optimization – Investigate outlier specimen for stack construction.
- Use experimental data to conduct stress simulation and understand stress distribution.

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ACKNOWLEDGEMENTS

Thank you to Shafi Saiyed and team, Analog Devices Inc., for their valuable guidance, support, and funding. Special thanks to Stephen Natale, Analog Devices Inc. for Instron training.

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