Die Attach Film Performance in 3D QFN Stacked Die.

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Abstract:- Consumer demand for smaller and lighter products in wiresless application with maximum functionality had drive the semiconductor industries toward the developement of 3-dimensional stacked die. One of the key technology is relies on die stacking process. A suitable bonding condition and material set are essential to achieve required reliability performance. This study is to relate the effects of variables bonding parameter on the mechanical adhesion and delamination of the die attach film in QFN stacked die. Samples are deliberately built with nine combination sets of die attach parameters including bonding temperature, force and time to achieve a minimum reliability performance under IPC/JEDEC Moisture Sensitivity Level 3 at reflow 260°C. Characterisation of die attach film was carried out using differential scanning calorimetry whereas it performance was carried out using shear testing machine and scanning acoustic test (SAT) is used to detect the interfacial delamination between DAF and die. The best die attach process is characterized by stable values of die attach film thermal resistance properties and optimum touch area between die/die attach film and die attach film/die.

Key-words:- Die attach film, QFN, delamination

1 Introduction

The trend towards miniaturization of wireless devices, more functionality and high performance can be described by QFN 3-dimensional packaging. This innovation introduced the third or Z height dimension by stacking another die on the base die using die attach film (DAF). 3D packaging offers attractive way to reduce transmission delays, since 3D packaging configuration provides much shorter access to several surrounding chips [1]. Schematic cross section of the stack QFN package can be seen in Fig. 1.

There are two common adhesive material used for die stacking in the microelectronic packaging of high-density surface mount i.e epoxy paste and die attach film (DAF). The application of epoxy paste for die stacking is well documented as a standard die bonding material. Challenge in controlling the resin bleed and creeping effect to the die edge especially for stacked die need an advanced solution for optimum performance. To overcome this problem, the usage of DAF was introduced in the development of 3-D stacked die. Evaluation of different die attach film (DAF) and paste for stacked die package has been performed using both experimental and modeling works [2].Table 1 shows the usage comparison of DAF and epoxy paste.

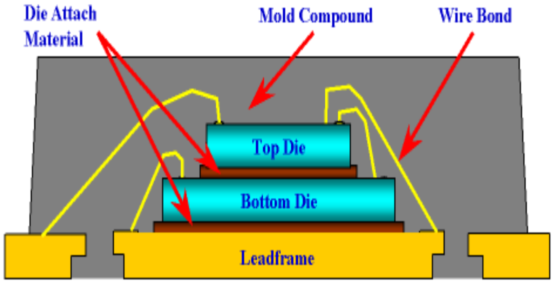


Fig. 1 Stacked die QFN package

Table 1. Comparison of DAF and epoxy paste.

Item	Die Attach Film	Epoxy Paste
Storage Condition	Room Temperature	Freezer
Adhesive formation	Uniform amount	Dot patterning

Die mounting Method	Direct bonding	Dispenser system
Die mounting Temperature	Required	Not necessary
Bleeding	No	Possible
Bond line Thickness	Uniform	Varied

Compared to epoxy, the DAF requires some bonding delay and temperature to allow the DAF to melt, solidifies and stick to the leadframe. One of the important discussion focuses in the stack QFN process flow is on die to die bond process. Basically, when choosing the DAF there are two considerations need to be taken into calculation. First consideration is on the DAF material repeated heat cure during the die attach, wirebond and moulding process. If the DAF is cured before moulding process, chance of delamination between die and DAF interface is high [3]. Secondly, the optimization on the methods of the die attach process, to ensure the robustness and reliability of the package. Theoretically, it is well agreed that process condition and material properties related to polymeric materials give high impact to the surface mount adhesion. Results from the engineering study shows water absorption and work of adhesion between silicon die and substrate interface decreased with increasing filler [4] resulted to excellent resistance to package cracking during reflow soldering by prevented “popcorn“ phenomenon [5]. When the die stress in the assembly processes is compared, it is found that highest stress occurred after molding and DAF showed 42% lower stress than epoxy [6]. On the other hand, it is clear that after die attach process, the curing reaction of DAF should be stable in the followed process before mold, to increase the effective touched areas and prevent weak interface or delamination in the stack die product [7].

2 Experimental Work

2.1 Sample Preparation of QFN Stack Die

Fig. 2 shows the schematic of the assembly process flow for the QFN stacked die sample preparation, starting from wafer thinning until decapsulation process. To maintain a low-profile stacked die package, the wafers were backgrind to be very thin as ≤0.150 mm in thickness. Wafers of 8 inches diameter, 725 µm thickness and <100> orientation were used in this study. For the mechanical backgrinding step, the abrasive diamond wheels with grit size mesh #1500 were used. After the backgrinding process, some wafers undergo the surface recovery by chemical wet etching at a standard removal rate. The end thickness for wafers undergoing stress relief process was 150 µm.

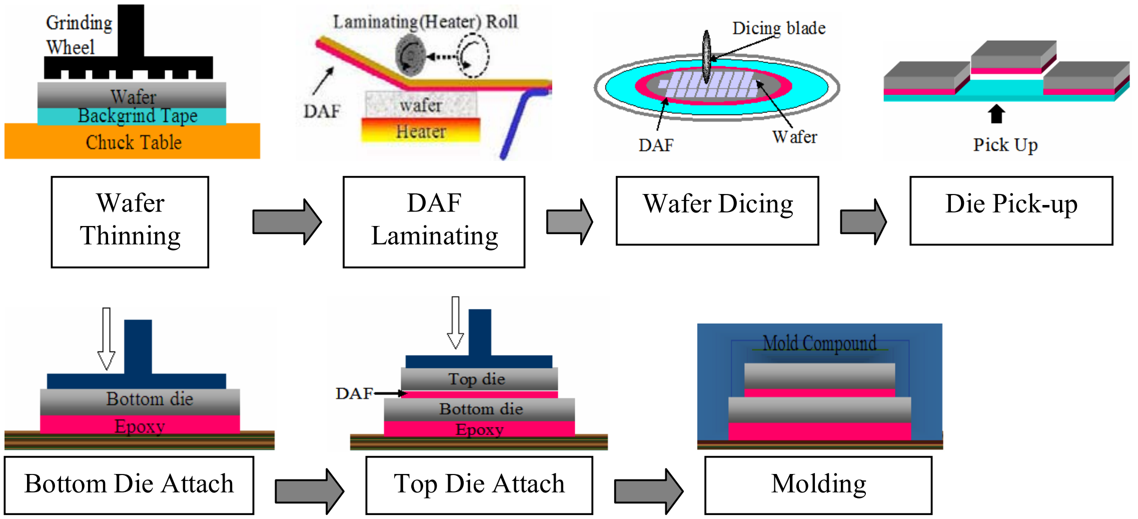


Fig. 2 The schematic illustrate the process flow of QFN Stack Die.

DAF tape was laminated at the backside of thin wafer by applying the same concept as laminating the conventional tape. During lamination inter liner tape will be release and DAF tape will be place on the wafer backside with a roller will be roll on the surface. This is to make sure an even surface with free bubble trap between the tapes and wafer backside. The only response that can be observed was particles exist in between the wafer and the DAF tape. The particles will only affect the dicing process if the particles are in large size but particles size that being observed in the experiment were very small and doesn't give a significant impact to the dicing process such as flying dies.

Double pass dicing method was used to reduce lateral crack and chipping problem in dicing 150µm thickness wafer laminated with DAF as proposed by Jiun et al. [8]. In the dicing process the critical parameter such as spindle rotation, saw speed, and blade grit size has been determined by experimental works and the outcome meet a good agreement with the study done by Abdullah et al [9].

Evaluation on the die pick up conditions has been earlier made to observe the effect of pick up force, needle size and height on the die crack and needle mark. These results are important to ensure that any failure at pick up process will not affect the bonding results while running the die bond evaluation. Final results concluded that 5 mil needle type with force 50 gf and 0.6 mm needle height are able to give good pick up condition on 3.3 x 3.3 mm^2 die size with no needle mark and no die crack observed by visual inspection. Fig.3 illustrate the comparison of the poor and good DAF surface after die pick-up process.


(a) (b)

Fig. 3 Die pick up results (a) needle mark observed (b) no needle mark observed with optimized pick-up condition.

During stacked die attach process, samples were prepared using thin film of Al die with the package size of 7 x 7 x 0.9 mm^3, QFN 48 leads package. The bottom die size was 5 x 5 mm^2 and the top die size was 3.3 x 3.3 mm^2, with thickness for both dies were 0.15 mm. The samples were deliberately built with nine combination sets of die bonding parameters for top die laminated with DAF while bottom die attach process were performed using commercial epoxy with only maintain at one optimized die attach parameter as shown in Table 2.

Table 2. Parameter matrix for top die attach.

Die Bond M/C	ESEC2008HS								
Run	1	2	3	4	5	6	8	7	9
Epoxy & DDAF Type	Epoxy A & DAF Y								
Pick Up Force (gf)	50								
Needle Type (mils)	5								
Needle Height (mm)	0.6								
Bonding Temp (°C)	125	100				150			
Bonding Force (gf)	120	100		140		100		140	
Bonding Time (sec)	1	0.15	2	0.15	2	0.15	2	0.15	2
DDAF Cure Condition	150 °C 1 Hrs								
Wirebonding Temp (°C)	210								

The die attach process started with attachment of the bottom die by following the normal epoxy dispenser process and then cured in the oven at 160°C for one hour. DAF Y was used to stack up the DAF laminated die on the top of the bottom die by using the same ESEC2008HS but equipped with the Heated Process Positions (HPPS). At this stage the dispenser system which used in the mounting method for epoxy was eliminated and the DAF die bonding process was assisted by the heater or HPPS system and need some bonding delay to allow the DAF to melt, solidifies and stick to the leadframe. Stacked die samples were cured in the oven at 150°C for one hour. All the samples were then past through the molding process using commercial mold compound with optimized parameter. Molding temperature was set at 175°C.

2.2 Finite Element Analysis (FEA)

FEA was used to simulate three different temperatures of manufacturing processes for top die laminated with DAF Y to determine the die stress at each stage. From the data sheet given by the supplier, the recommended temperature range for die attach process using DAF Y are within 100~150'C. Thus to support the experimental results, simulation was run between three different die attach temperatures at 100'C, 125'C and 150'C.

Both experimental and simulation was designed to evaluate the die bonding reliability of the adhesive tape and to understand the effects of likely sources of manufacturing variation. Therefore three factors were evaluated: bonding temperature, bonding force and bonding time. A common parameter window was established for the DAF system that allowed the DAF to produce die bond that met established production physical and visual inspection criteria. Each of the combinations was run as a separate assembly lot in a completely randomized order.

2.3 Differential Scanning Calorimetry

Mettler Toledo DSC 821e is used to monitor changes in cured properties of DAF depends upon temperature. DAF is subjected to temperature in ranges of 30 - 350ºC and 130 - 500ºC with the heating rate of 20º/min.

2.4 Die Shear

Results of mechanical adhesion for each DAF was obtained using a DAGE 4000 series shear testing machine. Correct position of shear tool is illustrated in Fig. 4.

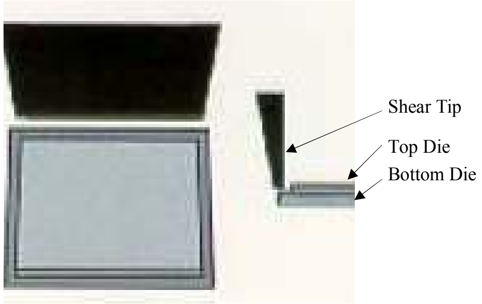


Fig. 4 Correct position of shear tool.

30 units of die were sheared for each run. For the purpose of this study, only the top die was sheared or forced to move while the base die was kept stationary. Thus the DAF layer will move relatively between the dies and present the adhesion strength for the DAF and die attach condition.

2.5 Scanning Acoustic Test

Scanning Acoustic Test (SAT) is perform by using SONIX@ HS-1000 with the transducer pulse echo scanning frequency of 25MHz to detect the air gap or interfacial delamination between DAF and die. G-Scan mode is used to investigate the interfaces between mould compound and (a) first die, (b) second die and (c) leadframe.

3 Results and Discussion

3.1 Visual Inspection

Visual inspection on every stage of QFN stacked die process were done to make sure no any defects occurred to the samples during the assembly process that will influence the final reliability especially due to delamination of the package when subjected under heat and pressure. Fig. 5 illustrated the top and side view of the unmolded package which showed good condition of stacked dies. Monitoring results on the fillet height, resin bleed and bond line thickness of the DAF and epoxy were in controlled as shown in Fig. 6.

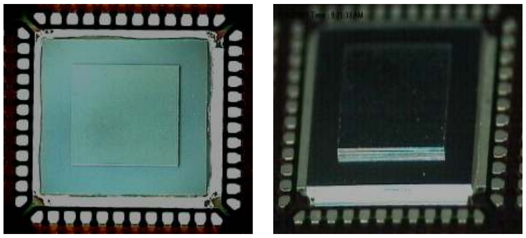
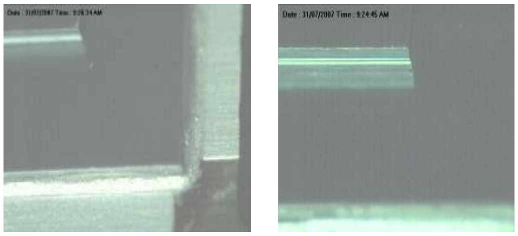


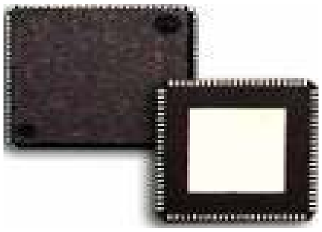
Fig. 5 Top view and side view of the unmolded, 48 leads QFN package.



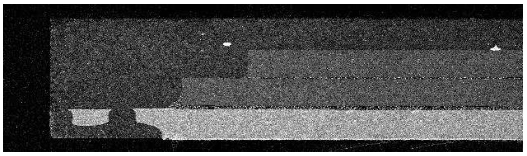
(a) (b)

Fig. 6 Fillet height, resin bleed and bond line thickness of the (a)epoxy and (b)DAF were in controlled.

Completely flat contact surface is very important to ensure maximum adhesion between DAF and bottom die. It is observed that minimum contact area between die surface which effected by needle mark can create voids and prone to delamination. During "sealing" process by bond force, air will be trapped in between the needle mark at DAF surface and bottom die that will results in delamination propagation after prolonged reliability test. Specification for void inspection is that the void must lower than 10%. From the results, all runs were passed the void inspection. Fig. 7(a) and (b) shows the image of molded samples and cross-section analysis on the stacked die configuration.



(a)

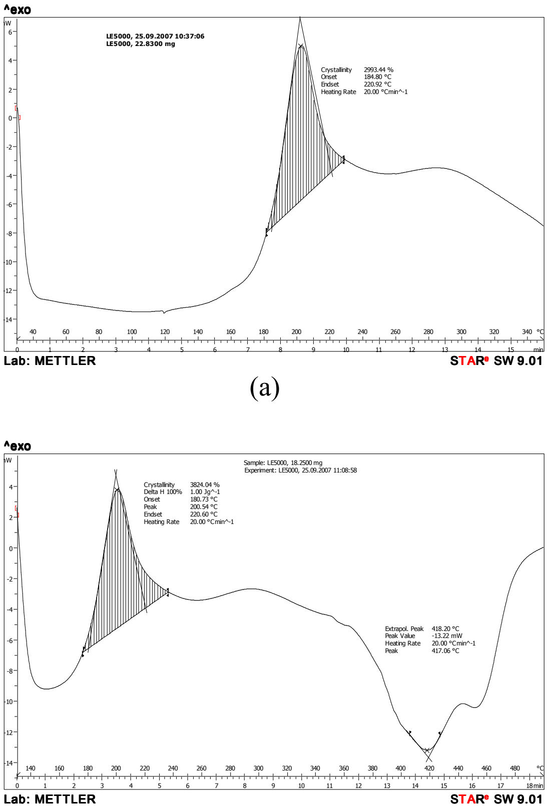


(b)

Fig. 7 (a)molded samples and (b)cross-section analysis on the stacked die configuration.

3.2 DAF Curing Properties

Change in DAF curing properties is known depend upon the temperature. Knowledge on how these changes occur over a range of temperature can guide to better understanding and help to define the processing technique that need to be used. In this study the DSC was run in dynamic mode to measure the changes in the heat flow characteristics for DAF adhesive tapes when the material was heated under controlled temperature. Results for dynamic DSC trace are shown in Fig. 8 (a) and (b).



(a)

(b)

Fig. 8 (a) DAF Y DSC trace at 30 - 350ºC with the heating rate of 20º/min (b) DAF Y DSC trace at 130 - 500ºC with the heating rate of 20º/min.

The curve trace presents the starting point of polymerization temperature, maximum of reaction temperature achieved, rate of cristanility and melting point for both DAF. Results were summarized as in Table 3.

Table 3 DSC results for DAF Y at 30 - 350ºC and 130 - 500ºC

Tempe Rapture	DAF Y		
	T(peak) ºC	Cristanility %	Melting Point ºC
30 - 350ºC	200.20	2993.44 %	-
130 - 500ºC	200.54	3824.04	417.06

The curve traces for DAF Y presents roughly equivalent pattern in the heat flow although exposed at different range of temperature of 30-350ºC and 130-500ºC, which exhibited stable heat flow properties. The DAF present a rapid and sharp cure reaction peak, the initial point is about 125°C and maximum reaction achieved at 200°C. Ideally, the recommended cure conditions should be followed, with the understanding that the true bondline temperature of the adhesive may not necessarily be identical to the oven set temperature [9].

3.3 Die Shear Result

Fig. 9 reported the shear test measurement results for DAF Y on different combination of die bonding parameter. It can be seen that the bond force, bond temperature and bond time give a significant impact to the adhesion strength of the top die.

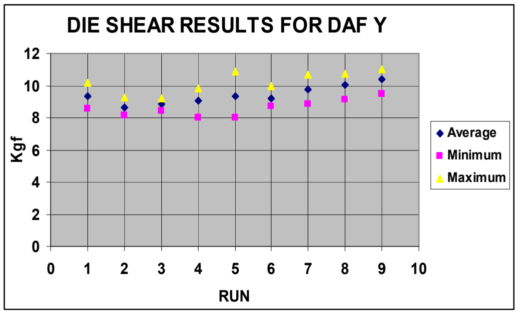


Fig. 9 Die shear measurement results for both DAF.

DAF Y presents increasing in die shear reading as bonding force, temperature and time increase, with failure mode of more than 50% to 100% silicon remains on die pad after shearing and little number of units illustrated no silicon remain on die pad as shown in Fig. 10.

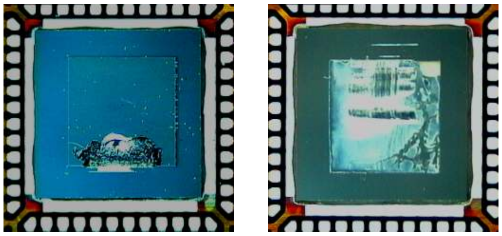
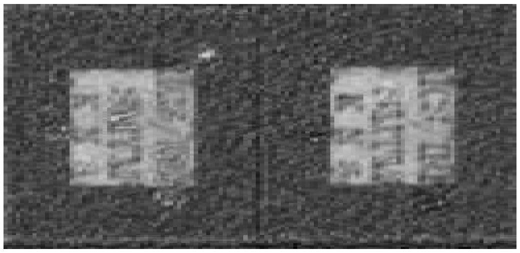
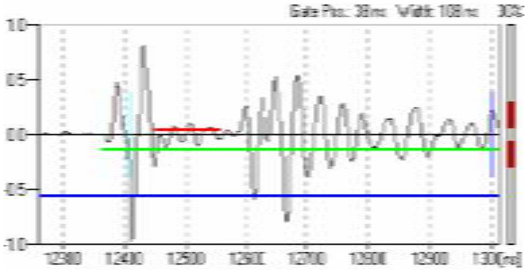

(a) (b)

Fig. 10 Specified modes for die shear (a) more than 50% to 100% silicon remains on die pad (b) no silicon remain or less than 10% on die pad.

3.4 Delamination

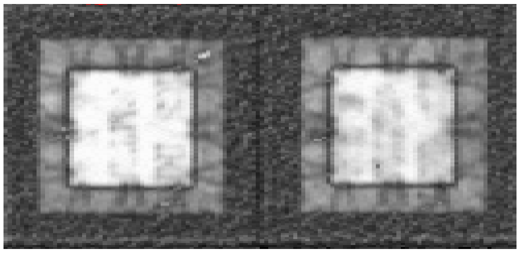
Delamination is basically generated during cooling process from process temperature especially die attach, molding and also thermal reliability test to room temperature. Imbalance in coefficient thermal expansion (CTE) between mold compound, Cu leadframe, die and die attach film and epoxy can be a major cause of delamination in the package. SAT results of G-scan and A-scan mode for the interfaces layer of (a) top die, (b) bottom die and (c) leadframe is shown in Fig. 11 (a)-(c).


G-scan mode

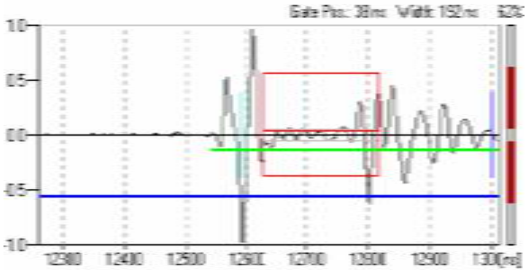


A-scan mode

(a)

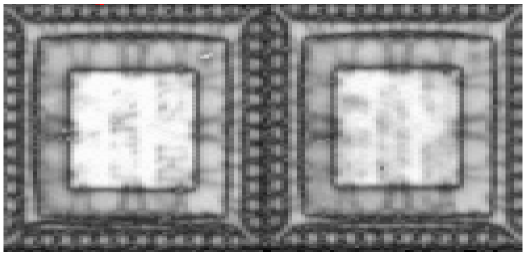


G-scan mode

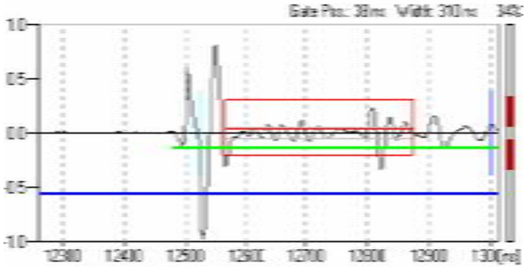


A-scan mode

(b)



G-scan mode



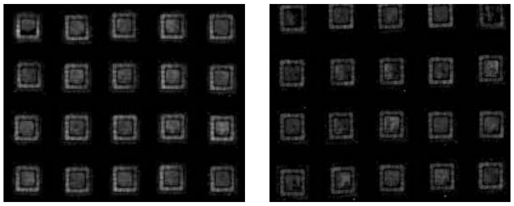
A-scan mode

(c)

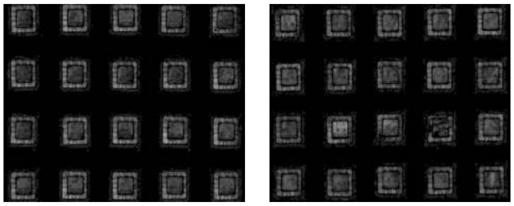
Fig. 11 (a)G-Scan from a gate width of 108ns, the detection on top die layer shows that this unit has no delamination and image has proven with the A-Scan signal. (b)G-Scan from a gate width of 192ns, the detection on bottom die layer shows that this unit has no delamination and image has proven with the A-Scan signal. (c)G-Scan from a gate width of 310ns, the detection on leadframe layer shows that this unit has no delamination and image has proven with the A-Scan signal.

Pulse-echo (reflected) mode image for all nine die attach cases on top die layer before and after MSL3 at reflow 260°C have been well presented in Fig. 12. Any air gap or delamination will show up as a bright area in the SAM image. The scanned image clearly shows the 100 % coverage of the DAF underneath the top die. No any samples failed with no sign of delamination or adhesive voids can be found before reliability test. Equivalent results were also observed for all cases after reliability test and achieve a minimum reliability performance under IPC/JEDEC Moisture Sensitivity Level 3 (MSL3) at reflow 260°C.

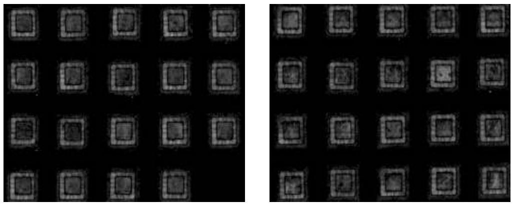
Run 1



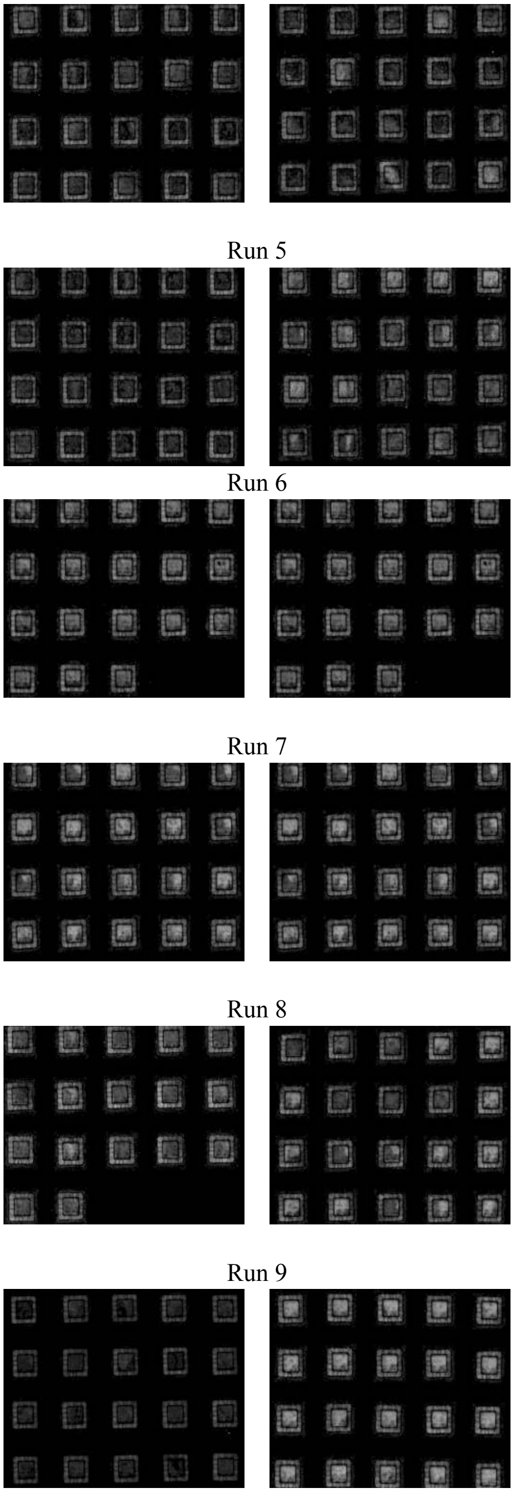
Run 2



Run 3



Run 4



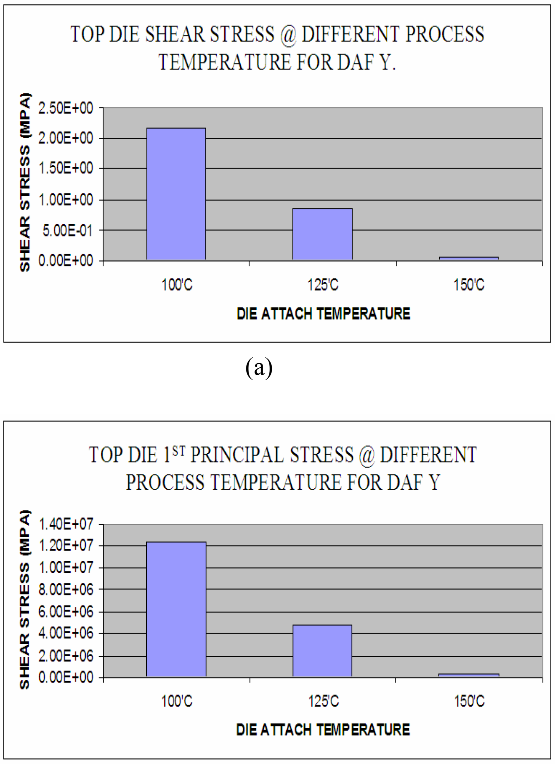
(a) (b)

Fig. 12 SAT scanned image of (a) DAF Y before reliability test (b) DAF Y after reliability test.

The different coefficient of thermal expansion (CTE) values of different DAF or epoxy formulations and assembly process condition are considered as the main cause of the package delamination. At the beginning of the delamination, a large amount of energy exists at the interface due to CTE mismatch. This energy has to be released through interface crack growth or die cracking [11].

3.4 Effect of Die Attach Process Temperature.

From the data sheet given by the supplier, the recommended temperature range for die attach process are within 100~150'C. Thus, the simulation results showed the comparison of top die shear stress and top die 1st principal stress between three different die attach temperatures (100'C, 125'C and 150'C) for DAF Y as shown in Fig. 13(a) and (b).



(a)

(b)

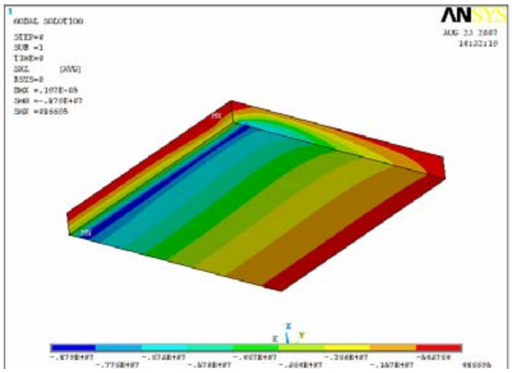
Fig. 13 comparison of (a)top die shear stress and (b)top die 1st principal stress between three different die attach temperatures (100'C, 125'C and 150'C) for DAF Y.

From the graph shown, both the stresses have shown the same trend. Different temperature process gave different stresses. The stress at 100'C for die attach temperature gave more stress to the die. The possibility that the die will not attached to the substrate is high. But for 150'C for die attach temperature, the die stress is lowest compared with other two temperature. Both results of top die shear stress and top die 1st principal stress is summarize in Table 4.

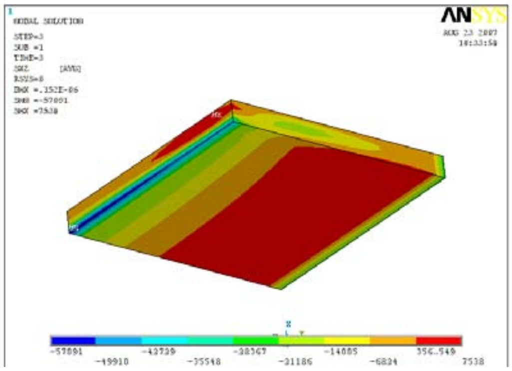
Table 4 summary of (a)top die shear stress and (b)top die 1st principal stress between three different die attach temperatures (100'C, 125'C and 150'C) for DAF Y.

Shear Stress	DAF Y
100'C	2.17E+00
125'C	8.43E-01
150'C	6.55E-02
1st Principal Stress	DAF Y
100'C	1.24E+07
125'C	4.86E+06
150' C	3.56E+05

Fig. 14(a)-(c) shows the comparison of die shear stress at the top die location between room temperature (25°C) and curing temperature (150°C) after die attach process. The results show that beside die attach temperature, DAF curing temperature will induce high stress. Thus, special attention must be given at the die attach process condition to make sure the package can withstand extreme condition and have high reliability.



(a)



(b)

Fig. 14 comparison of die shear stress at the top die location between (a)room temperature (25°C) and (b)curing temperature (150°C) after die attach process.

4 Conclusion

The results from this investigation shows that all the units have passed IPC/JEDEC MSL3 and indicate that the best die attach process is characterized by stable values of DAF thermal resistance properties and optimum touched area between die/DAF and DAF/die. For this case, where the bonding temperature used is equal to 150°C and below, good adhesion and reliability performace was achieved by the combination of the highest bond force, temperature and time. But, if higher process temperature is required, short process time will need to be used with an adequate force. Based on DSC curve results, it is suggested that bonding temperature for DAF Y must be used below than 200°C to make sure the DAF not fully cured after die mount. It is because, after die-mount process, the curing reaction of DAF must be stable in the followed process before moulding. The DAF should only be completely cured under transfer pressure and elevated temperature during moulding process to ensure the DAF will be compressed to fill the gap between top die and bottom die interface.

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