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Effect of Manufacturing Stresses to Die Attach Film Performance In Quad Flatpack No-Lead Stacked Die Packages

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Abstract: Problem statement: Repeated heat cure during assembly processes affected the Die Attach Film (DAF) material properties and the effectiveness touched area that leads to weak die bonding and delamination. Suitable die attached condition and DAF material selection had been evaluated to achieve required reliability performance in the manufacturing of the 3D Quad Flat No-Lead (QFN) stacked die package. **Approach:** During this study, special attention was given to the development of the residual stresses due to mismatch in the coefficients of thermal expansion of different DAF materials. Both experimental and finite element method were employed to gain a better understanding in a stress development induced between two different type of DAF, different die attach temperature and during the manufacturing process. Differential scanning calorimetry (DSC) was used to measure the changes of heat flow characteristics for both types of DAF. The die bond strength results measured using shear testing machine were compared with the finite element method prediction. **Results:** Although both DAF samples achieved good reliability performance and passed the Moisture Sensitivity Level 3 test (MSL3) at reflow 260°C without any sign of delamination, numerical simulation had demonstrated that the stress development were increased exponentially as the die attach temperature increased. It showed that different DAF gave different values of stresses but presented the same trend which the lowest die attached temperature (100°C in comparison with 125°C and 150°C) gave more stress to the die and possibility that the die will have weak adhesion to the substrate was high. **Conclusions/Recommendations:** Therefore for this case, stress can be relieved by having higher die attached temperature with an adequate bonding force and time, however die attached temperature for both DAF must be used above the glass transition temperature (128°C for DAF A and 165°C for DAF B) and being controlled not to exceed the crystallization temperature (203°C for DAF A and 204°C for DAF B) of both DAF.

Key words: QFN stacked die, die attach film, finite element analysis

INTRODUCTION

As the consumer demand continue to push towards miniaturization of wireless devices, more functionality and high performance QFN 3-dimensional packaging has been introduced to accomplish all this goal. This innovation introduced the third or Z height dimension by stacking another die on the base die using Die Attach Film (DAF) as shown in Fig. 1. 3D packaging offers attractive way to reduce transmission delays, since its configuration provides much shorter access to several surrounding chips[1]. However, as the number of die stacks increases, DAF on the top die would experience decrease heating temperatures during top die attach process, higher power dissipation and higher thermal resistance between bottom and top die which may lead to weak adhesion and delamination due to high stress concentration[2,3].

There are two common adhesive material used for die stacking in the microelectronic packaging i.e., epoxy paste and DAF. Difficulties in controlling of resin bleed, fillet height, die tilt and adhesive bond-line thickness, has lead to the consideration of DAF as a suitable die attach adhesive for stacked-die applications[4].

By comparison to epoxy, the DAF requires some bonding delay and temperature to allow the DAF to melt, solidifies and stick to the leadframe or die. Previous study has indicated that most of the die stress is developed during die attach and curing process[2,3,5-7]. When the die stress in the assembly processes is

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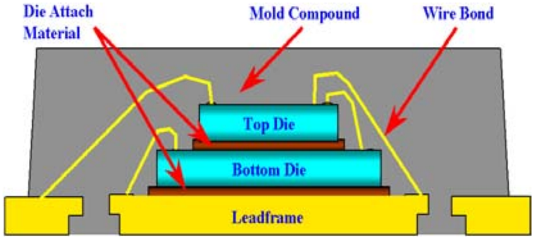


Fig. 1: Stacked die QFN package

compared, it is found that DAF showed 42% lower stress than epoxy[7]. After die attach process, the curing reaction of DAF should be stable in the subsequent process before mold, to increase the effective touched areas and prevent weak interface or delamination in the stack die product[8].

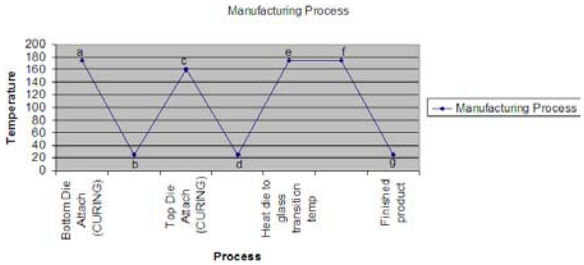
Results from a study by[9] showed that process condition and material properties related to polymeric materials give high impact to the surface mount adhesion. This study reports present work on the evaluation of the material, process and design factors which were studied by scanning acoustic microscopy and finite element analysis. The finite element analyses were implemented to address the stress distribution in the stacked die package and verified by the scanning acoustic microscopy.

MATERIALS AND METHODS

In this study, two types of DAF (A and B) have been simulated and examined. Temperature for manufacturing process was used as the environment load in the simulation. Fig. 2 shown the standard manufacturing process and corresponding temperature used in this study. The normal curing process was simulated because at this temperature, the cross link process happened. Comparison between two types of DAF was done to see the stress for each process.

Samples were prepared using thin film of Al die with the package size of $7\times7\times0.9$ mm^3, QFN 48 leads package (Fig. 3). The base die size is 5×5 mm^2 and the top die size is 3.3×3.3 mm^2, where thickness for both dies are 0.15 mm. Two type of DAF (DAF A and B) were used to stack up the top die on the bottom die using ESEC 2008HS die bonding machine.

This experiment was designed to evaluate the die bonding reliability of the DAF and to understand the sources that affect the manufacturing variation during die attach process. A common parameter set was established for the DAF system that allowed both DAF to produce die bonding process that met standard production physical and visual inspection quality.



Manufacturing process	Temperature °C
Bottom die attach (curing)	175
Cool to room temperature	25
Top die attach (curing)	160
Cool to room temperature	25
Heat die to glass transition temperature	175
Mold compound	175
Finished product	25

Fig. 2: Standard manufacturing process and corresponding temperatures used in this study

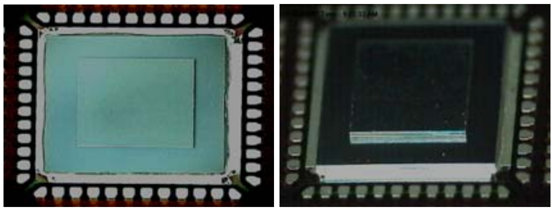


Fig. 3: Top view and side view of the unmolded, 48 leads QFN stacked die package

Based from the data sheet given by the supplier, the recommended temperature range for die attach process are within 100~150'C. Thus, in the next simulation will compare three different top die attach temperatures which are 100, 125 and 150°C. Each of the combinations was run as a separate assembly lot randomly.

In the previous study, evaluation on die pick up condition have been made to observe the effect of pick up force, needle size and height on the die crack and needle mark. The study is important to ensure that any failure at pick up process will not affect the bonding while running the die bond evaluation. The Final result concluded that 5 mil needle type with force 50 gf and 0.6 mm needle height is able to give good pick up condition with no needle mark or die crack for both types of DAF.

Completely flat contact surface is very important to ensure maximum adhesion between DAF and bottom die. It was observed that the contact area between DAF and bottom die surface which affected by needle mark can create voids and lead to delamination. During encapsulation process, air will be trapped in between the needle mark at DAF surface and bottom die that will results in delamination after prolonged reliability test. Fig. 4 illustrated the comparison of poor and good DAF surface after die pick-up process.


(a) (b)

Fig. 4: Die pick up results (a) needle mark observed (b) no needle mark observed with optimized pick - up condition

Differential Scanning Calorimetry (DSC): Mettler Toledo DSC 821e was used to determine the glass transition temperatures (T_g), crystallization temperature (T_c) and melting temperature (T_m) of DAF. The studies were carried out for 30-350°C with heating rate of 20°C $\min^{-1}$.

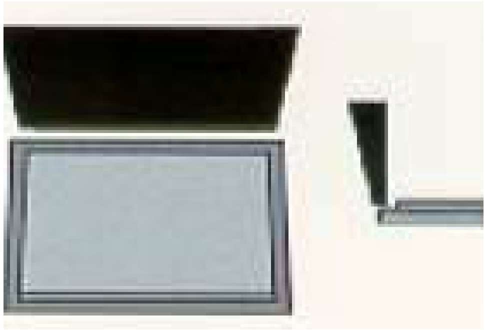
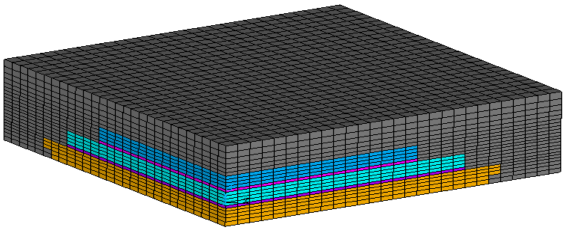


Fig. 5: Correct position of shear tool for top die shear test.

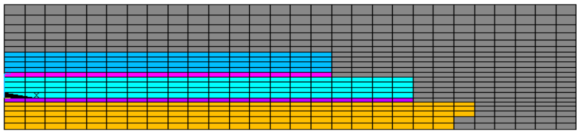
Die shear: Mechanical adhesion strength of DAF was obtained using a XYZTEC Condor shear testing machine. Correct position of shear tool is as shown in Fig. 5. In this study, only the top die was sheared or forced to move while the base die was kept stationary. Results from this study presented the adhesion strength for DAF die attach condition.

Scanning acoustic test: Scanning Acoustic Microscope (SAM) EVO II was used by performing G-scan mode for image analysis and signal amplitude was verified by A-scan mode to detect air gap or interfacial delamination between mold compound and top die, bottom die and leadframe on more than 70 samples of DAF A and B.

Finite Element Analysis (FEA): Finite element technique is a method of finding approximate mathematical solutions of physical problems. It is also used to predict the failure caused by package warpage in semiconductor industry[10]. In this study, three dimensional solid models were generated to determine the thermally induced stresses under different conditions of assembly processes. Ansys® software was used for finite element analysis. As the geometry of package is symmetry, only one-quarter of the package is needed to be modeled with symmetrical boundary conditions. The FEA model of package unit is shown in Fig. 6. The model used eight node 3D brick elements and 200 mesh elements to generate quad meshing. The symmetrical boundary conditions were applied to the surface at x = 0 and y = 0 and node at bottom of substrate to prevent free rigid body motion. Thermal loading is applied to simulate the cooling after molding process, i.e., from 175°C to room temperature. Element birth and death option was used to simulate the manufacturing conditions.



Three dimensional view

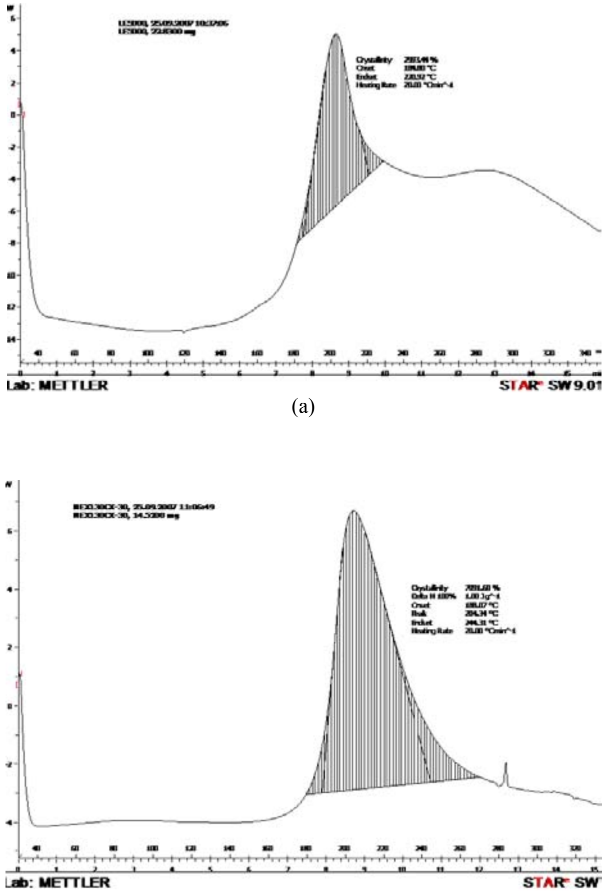


Side view

Fig. 6: The FEA model of QFN stacked die package unit used in this study

RESULTS

DAF curing properties: DSC was run in dynamic mode to measure the changes of heat flow characteristics for both types of DAF when they were heated under controlled temperatures. The DSC curves in Fig. 7a and b, present the glass transition temperature, starting point of polymerization temperature, maximum of reaction temperature and rate of cristalinity of DAF A and B.



(a)

(b)

Fig. 7: (a): DAF A DSC trace at 30-350ºC with heating rate of 20 min^{-1} (b): DAF B DSC trace at 30-350°C with heating rate of 20°C min^{-1}

Die shear result: Fig. 8 shows the comparison of shear strength results for DAF A and B at different die attached processing temperature. Two failure modes were observed during die shear test which were 50% to 100% silicon remains on die pad and no silicon remain or less than 10% on die pad as shown in Fig. 9.

Delamination result: Scanning Acoustic Microscopy (SAM) with G-scan and A-scan mode works by directing focused sound from a transducer on a target object and the transmitted sound was measured. G-scan mode images of DAF A and B after Moisture Sensitivity Level 3 (MSL3) test at reflow 260°C are shown in Fig. 10.

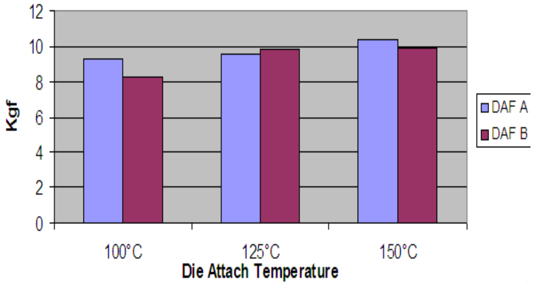
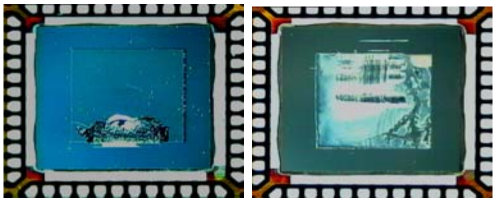


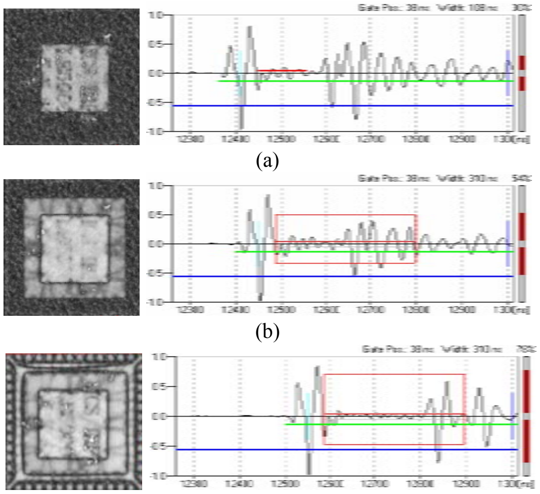
Fig. 8: Die shear measurement results of DAF A and B



(a) (b)

Fig. 9: Specified modes for die shear (a) 50% to 100% silicon remains on die pad (b) no silicon remain or less than 10% on die pad

DAF A

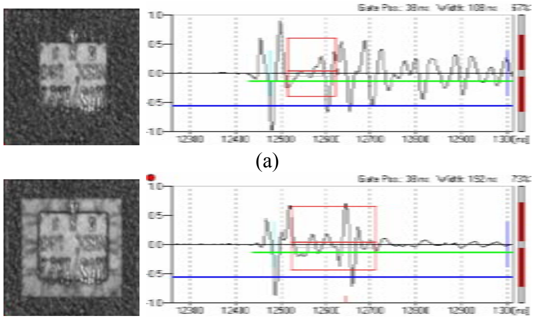


(a)

(b)

(c)

DAF B



(a)

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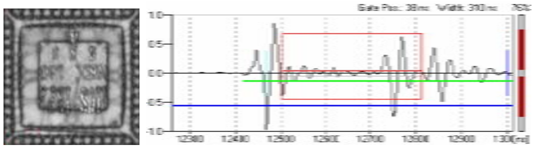
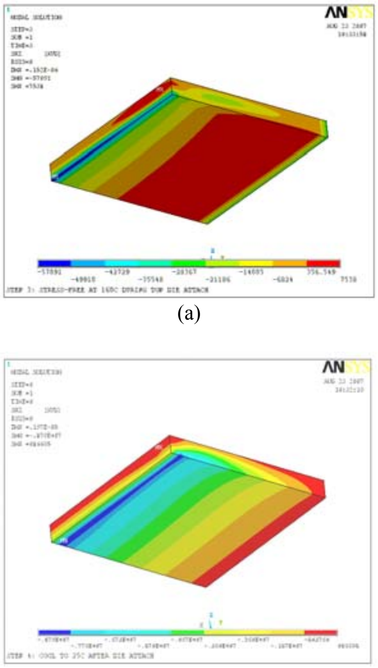


(c)

Fig. 10: G-scan images and A-scan signals show non-defect area and good amplitude (positive-negative-positive) signals for units of DAF A and B after MSL3 test

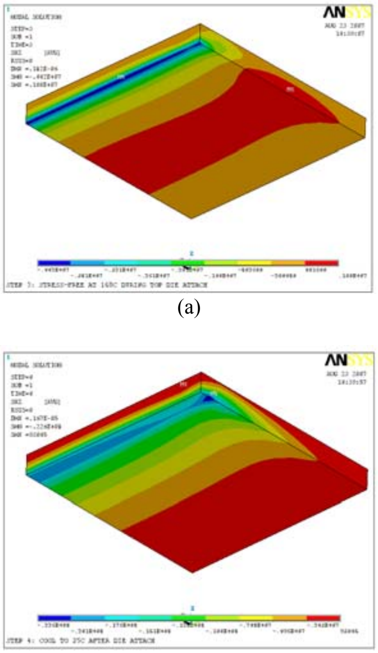
Stress analysis in FEA technique: Stress distribution on top die laminated with DAF A and B during curing process at 160°C and after curing process at room temperature (25°C) was shown in Fig. 11 and 12. While Fig. 13 presents the stress level experienced along manufacturing process for top die shear stress and top die 1st principal stress of both DAF A and B. Effect of die attach temperature towards top die shear stress and top die 1st principal stress for both DAF A and B were also evaluated as represents by Fig. 14 and 15. Stress values were summarized in Table 1.



(a)

(b)

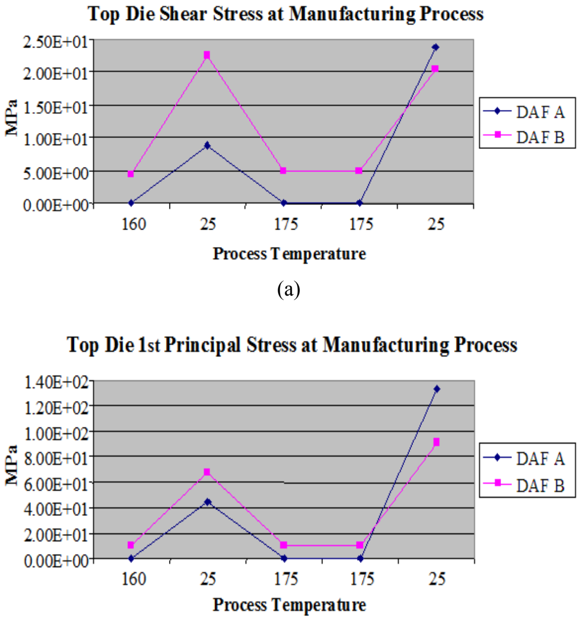
Fig. 11: Stress distribution on top die laminated with DAF A at (a) curing process, 160°C and (b) room temperature (25°C) after curing process



(a)

(b)

Fig. 12: Stress distribution on top die laminated with DAF B at (a) curing process, 160°C and (b) room temperature (25°C) after curing process



(a)

(b)

Fig. 13: Stress level at manufacturing process (a) top die shear stress (b) top die 1st principal stress

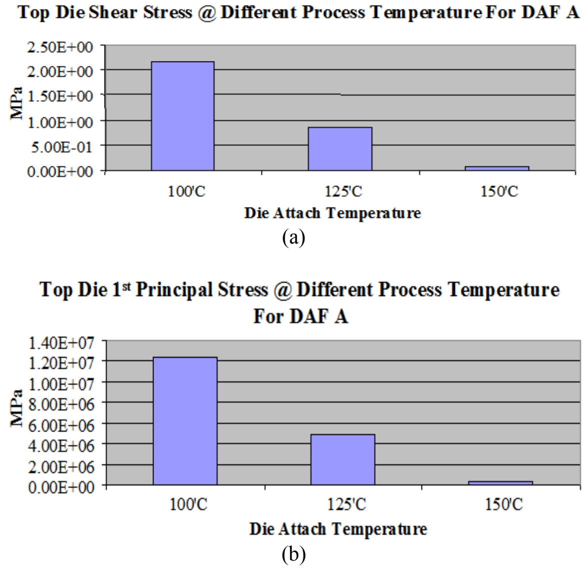


Fig. 14: Stress level for DAF A at different die attached temperature (a) top die shear stress (b) top die 1st principal stress

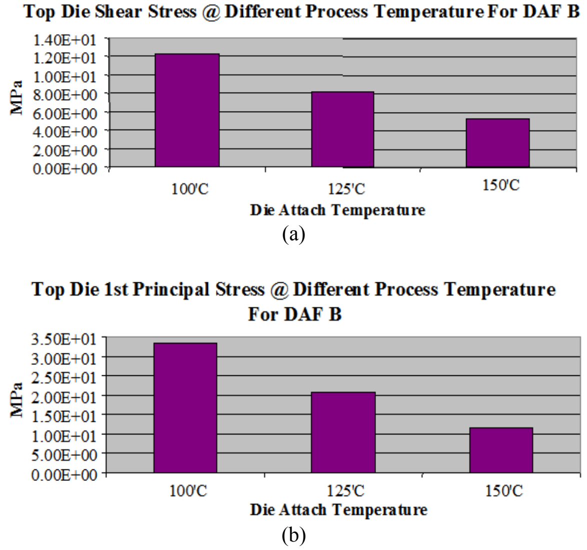


Fig. 15: Stress level for DAF B at different die attached temperature (a) top die shear stress (b) top die 1st principal stress

Table 1: Stress values of top die shear stress and top die 1st principal stress for DAF A and B

Shear stress	DAF A	DAF B
100'C	2.17 Pa	1.23×10^{1} Pa
125'C	8.43×10^{-1} Pa	8.15 Pa
150'C	6.55×10^{-2} Pa	5.25 Pa
1st principle stress	DAF A	DAF B
100'C	1.24×10^{7} Pa	3.33×10^{1} Pa
125'C	4.86×10^{6} Pa	2.08×10^{1} Pa
150'C	3.56×10^{5} Pa	1.18×10^{1} Pa

DISCUSSION

DAF curing properties: Change in DAF curing properties is depending upon the processing temperature (Fig. 7a and b). Knowledge on how these changes occur can guide to a better understanding and help to define the required processing technique. As the temperature increases to some point, the DAF material experienced change in heat capacity and caused the glass transition to occur. The glass transition temperatures (T_g) of DAF A and B are 128 and 165°C respectively. Further heating beyond this temperature caused the DAF materials become less viscous where molecules of the materials gained sufficient energy to spontaneously arrange themselves into a crystalline form. The crystallization temperature (T_c) of DAF A and DAF B are at 203 and 204°C respectively. The transition from amorphous to crystalline solid is an exothermic process and results in a peak in the DSC signal[11]. Ideally, the recommended cure conditions should be followed, with the understanding that the true bondline temperature of the DAF may not necessarily be identical to the oven set temperature[12].

Die shear strength: From Fig. 8 it can be seen that the bonding temperature give a significant impact to the adhesion strength of the top die where both DAF showed the increase in shear strength as the die attach temperatures increase with most of the failure modes were 50-100% silicon die remained on die pad after shearing and very small number of units illustrated no silicon remain on the die pad (Fig. 9). The adhesion between DAF and bottom die has primarily involved micro interlocking process. Therefore increasing in the die attach temperature above the DAF glass transition temperature caused the viscosity to drop and bonding pressure will force the DAF to achieve intimate contact to the bottom die surface. These influenced the interlocking which lead to the increased in real contact area. As the results, adhesion strength between DAF and bottom die surface had presented high shear strength.

Delamination: Any air gap or delamination will be exhibited as a red area in the SAM image for G-scan mode and negative-positive-negative signal amplitude for A-scan mode. MSL3 test results indicated that most samples of DAF A and B had passed with unsigned of delamination or adhesive voids can be found based on the J-STD-020C Joint IPC/JEDEC Standard for Moisture/Reflow Sensitivity Classification for Nonhermetic Solid State Surface-Mount Devices (Fig. 10).

Stress analysis in FEA technique: The simulation study on evaluation of the stress induced by thermal loading during assembly process showed that a high stress had been detected at both DAF during cooling down to room temperature after curing process during cooling process. The distributed shear stresses on top die laminated with DAF were decrease exponentially (Fig. 11 and 12). Fig. 13 shows DAF A experienced lower stress level compared to DAF B after curing process. However after the curing process, the stress level of them seems reverse where DAF B exhibited lower stress compared to DAF A. This suggested that DAF A has a better integrity compared to DAF B. Based from the data sheet given by the supplier, the recommended temperature range for die attach process are within 100~150'C. Thus, in the next simulation will compare three different top die attach temperatures which are 100, 125 and 150°C. Each of the combinations was run as a separate assembly lot randomly.

Fig. 14 shows that the same trend was obtained between top die shear stress and top die 1st principal stress during processing temperatures of DAF A. Each processing temperatures has presented different stress values. At 100°C of die attached temperature, a high stress was obtained on the top die component. The possibility that the die will have weak adhesion at the bottom die was high. At 150°C of die attached temperature, the die stress was relieved by showing the lowest stress values compared with other two temperatures (100 and 125°C).

Fig. 15 shows that the same trend was obtained between top die shear stress and top die 1st principal stress during processing temperatures of DAF B. Similar with the trend of DAF A, the lowest stress obtained at 150°C die attached temperature and the highest stress obtained at 100°C die attached temperature. However, the stress result for each die attach temperatures did not show approximate values between top die shear stress and top die 1st principal stress as presented by DAF A.

CONCLUSION

The experimental and finite element method is design to obtained suitable die attach condition and DAF characterization to achieve MSL3 reliability performance in the manufacturing of the 3D QFN stacked die package. It is suggested that the die attached temperature for DAF A and B must be used above the glass transition temperature (128°C for DAF A and 165°C for DAF B) and being controlled not to exceed the crystallization temperature (203°C for DAF A and 204°C for DAF B). The best die attach process is characterized by stable values of DAF thermal resistance properties and optimum touched area between DAF and die surface. Although both DAF samples achieved good adhesion and reliability performance, numerical simulation indicates that it is important to control the stress development at the die attach stage, therefore for this case, stress can be relieved by having higher die attach temperature with an adequate bonding force and time.

ACKNOWLEDGEMENT

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