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# BOARD-LEVEL SOLDER JOINT RELIABILITY AND FINITE ELEMENT MODELING OF CARBON NANOTUBE-FILLED LEADFREE SOLDER ALLOY ON QFN PACKAGES

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## ABSTRACT

*This project aims to solve one of the reliability limitations facing the semiconductor and board mount industry today. Following Moore's law stating that the transistor density of an IC will double every 18 months, translates to an increased power dissipation two folds. With this, an alternative solder alloy composite was developed. This was achieved by impregnating the SnAgCu 405 alloy by 0.8% weight of multi-walled carbon nanotube. This was then applied on an actual QFN semiconductor device that was subjected to thermo-mechanical stressing. Pure SnAgCu and impregnated SnAgCu variants were compared. The findings were validated by Finite Element Method that resulted in an increased latency of 1500 cycles for the solder impregnated by CNT.*

*Keywords: : Quad Flat No-lead, SnAgCu(SAC), Multi-walled carbon nanotube(MWCNT,CNT), Finite Element Analysis (FEA)*

## 1. INTRODUCTION

Greater demand for smaller form factor on semiconductor devices increases the need for package and board level reliability. This has paved the way for further studies on interconnect and silicon technologies as well as in the improvement of packaging and board mounting methods. Because of this, the trend in semiconductor packaging technology shifts from insertion based to surface mount types. Plastic IC surface mount devices are soldered on an automated manner on printed wiring boards (PWB). Thus, size, complexity and costs of printed wiring boards are reduced while facilitating the automation of PCB assembly (1,3). Tin Lead (SnPb) solders have been utilized for various applications on board mount due to their high level of predictability and low cost. Though their efficiency and health risks raise concerns, the repercussion did not fully materialize until July 1, 2006 when the Restriction of Hazardous Substance (RoHS)

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protocol came into effect. This prohibition minimizes and limits the use of Lead containing components. One alternative used by the industry is the SnAgCu solder. In some cases it was seen that SnAgCu is inferior with the SnPb solder alloy. This study is geared towards impregnating the inferior solder alloy with a CNT additive. CNT, a carbon-based material, is widely used as reinforcing agent. One thing that differentiates CNT with other reinforcing agents is its size. Better agglomeration translates to increased material binding; thus, increasing thermo-mechanical stress latency (2).

## 2. METHODOLOGY

The experimental part of this paper focuses on assessing the reliability of SnAgCu+CNT doped solder compared with the existing SnAgCu alloys. Both SnAgCu and SnAgCu-CNT solders were prepared in parallel as well as a QFN (Quad Flat Nolead) test vehicle. This is done to simulate board-mounting conditions. The researcher also procured a commercial grade printed wiring board to mount the device using both variants of solder. The board mounting conditions followed the IPC standard 610 section 8.2.13. It is important to mount the QFN samples consistent to the printed wiring board since this will confirm the theoretical and computational modeling that will be obtained in the FEA results. For this to be implemented, inspection schemes using Scanning Acoustic Tomography, as well as 20X con focal microscope inspections were made in all dimensions of the solder construction. After these collaterals were prepared, the solder connections on the test vehicle should be connected to an event detector sensitive enough to sense slight changes in resistances. IPCSM-785 standards show that a high-resistance spike of approximately above 300 ohms indicates the presence of solder breakdown (4). Once this is done, the researchers load the printed wiring board along with the Quad Flat No lead samples in a temperature cycling oven. This equipment is capable of supplying a temperature variation from -65°C to 150°C. Upon the occurrence of detected resistance readings, the parts were analyzed by a scanning electron microscope, including fault isolation techniques to verify crack initiation and growth.

The results take into consideration the failed cycles for the samples. Finite Element Method validation is necessary to give confidence on the results obtained in the experimental portion. Critical dimensions for Quad Flat No lead samples are taken, cross section measurements are also obtained to be able to plot actual computer model in FEA. The software has the capability of adopting and mimicking thermal and mechanical elements necessary to produce a virtual model of the experiment.

## 3. RESULTS AND DISCUSSION

From the gathered measurement readings and technical data sheets, model construction was implemented using the ANSYS software. Majority of the aforementioned elements are thermo-solid elements, meaning they can be used in multi-environment simulation (for thermal and mechanical). At the moment, the ANSYS software cannot effectively predict crack propagation because of material and microscopic variability. With this, a parameter known as Stress Intensity Factor (SIF) was compared to the fracture toughness of the specific material (5). Stress gradients were noted and proven to be the most probable cracking locations for the simulation. This was verified thru material cross sections, imaging analysis and fractographic signature for metals exhibiting brittle fracture specifically on the intermetallic surface. The SnACu solder behaved in a way described in literature - elastic, plastic and creep. It is also important to map out temperature gradients since the SnAgCu alloy is sensitive to variations in temperature.

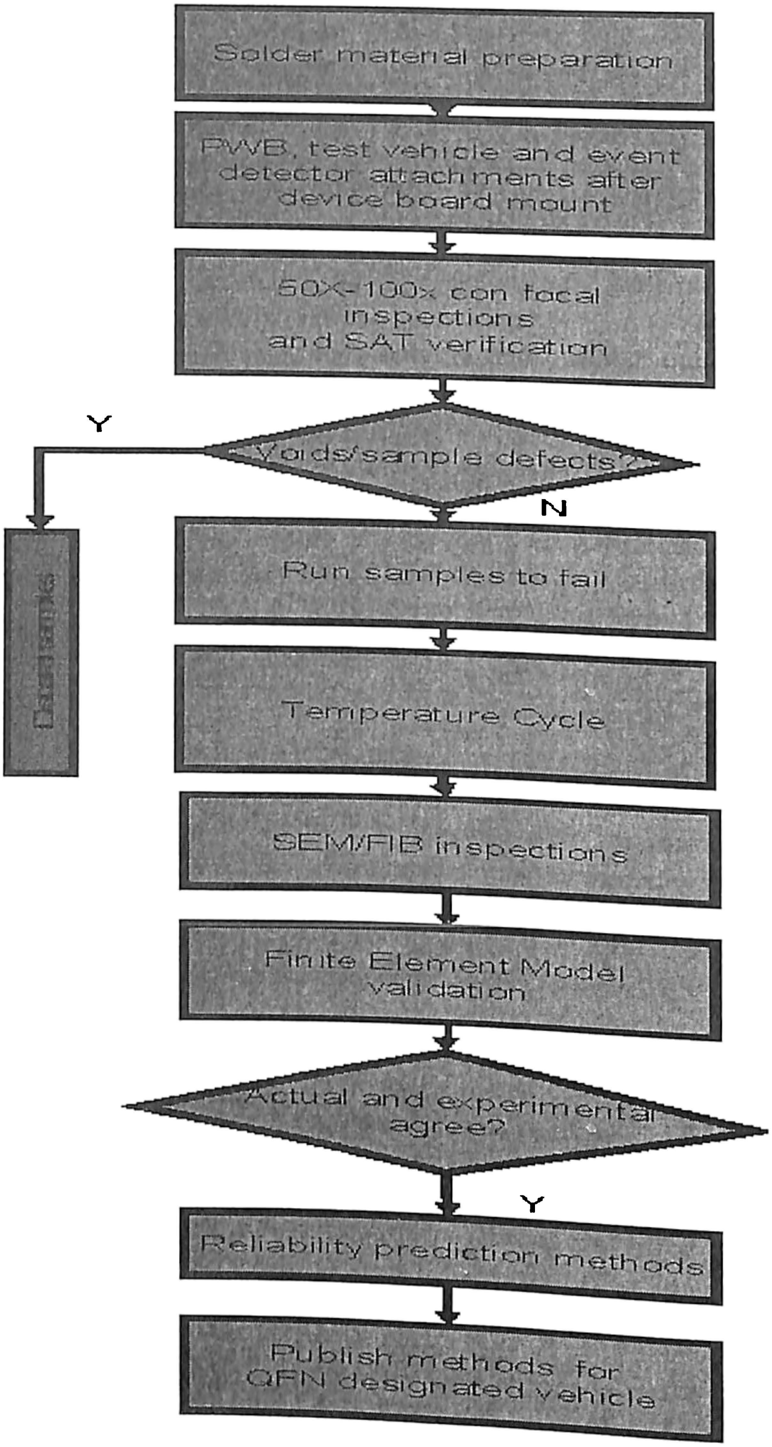

**Figure 1:** Flowchart for methods in solder joint assessments

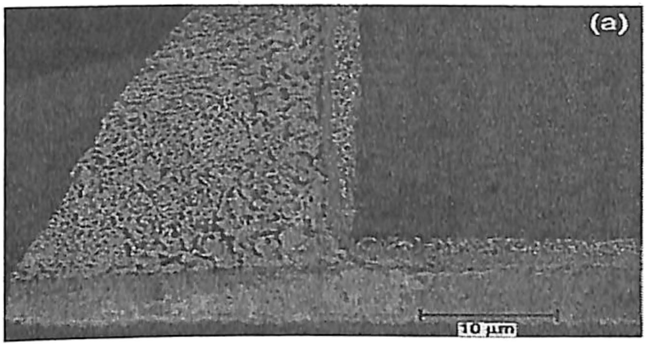

**Figure 2:** SnAgCu CNT solder alloy after 2900cycles

The simulation shows that the bulk solder exhibits the start of the crack phenomenon. This is conceived to be a slowly deteriorating factor followed in elastic plastic and creep strains, with breakdown eventually occurring.

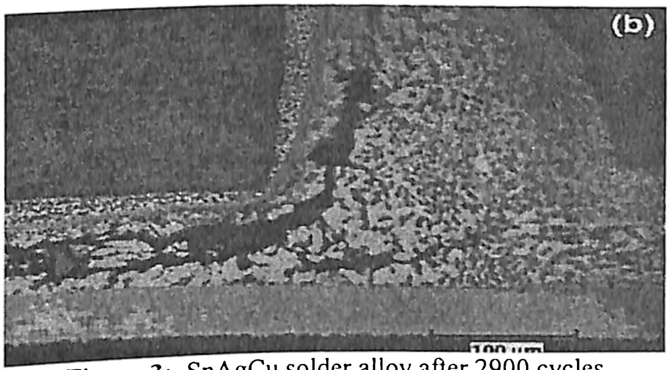

**Figure 3:** SnAgCu solder alloy after 2900 cycles

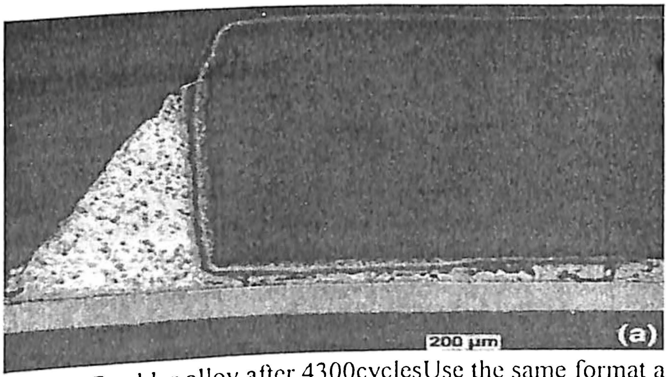

**Figure 4:** SnAgCu CNT solder alloy after 4300cyclesUse the same format as the main text.

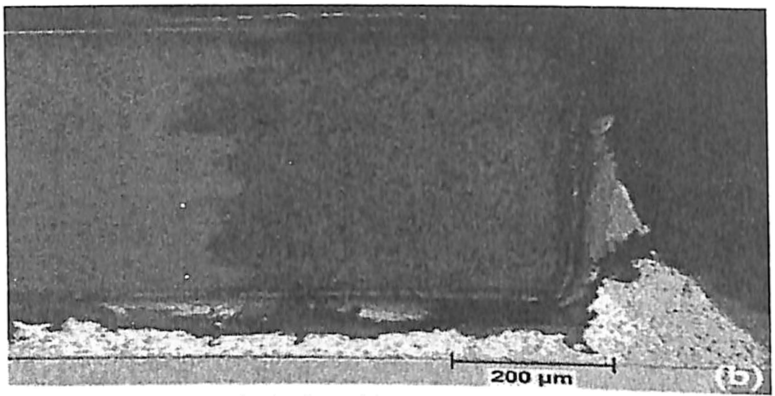

**Figure 5**: SnAgCu solder alloy after 4300 cycles

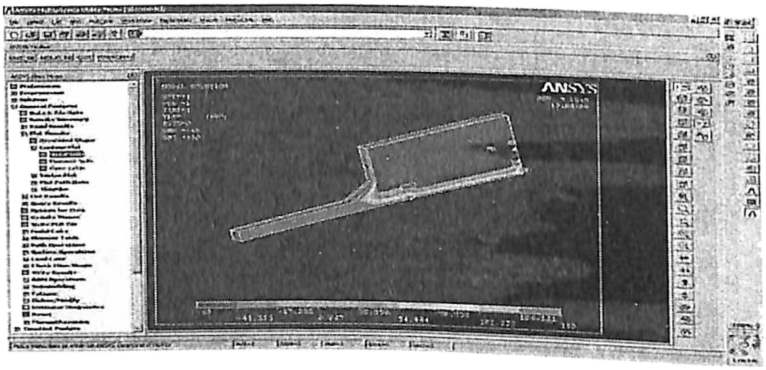

**Figure 6:** Quarter Model representation for solder joints

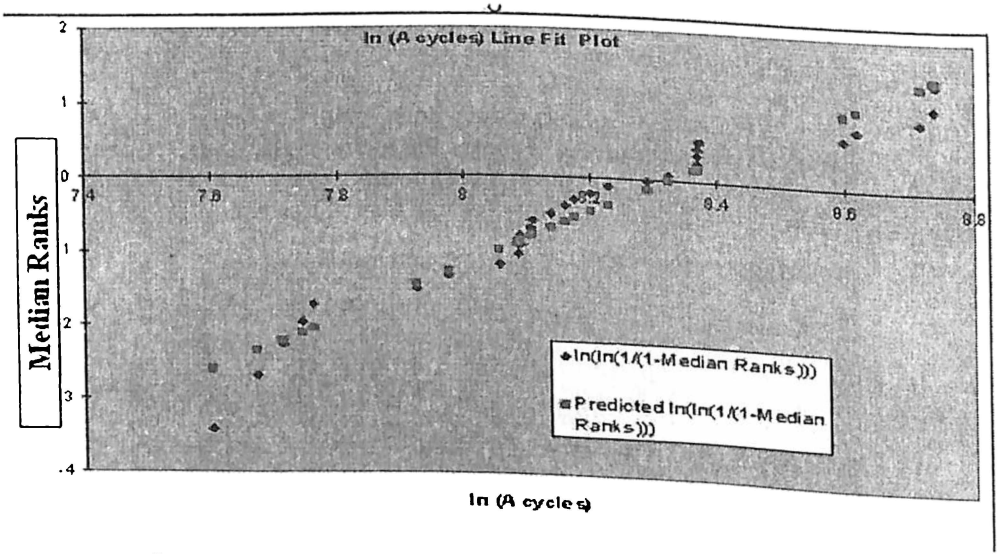

**Figure 7:** SnAgCu CNT Weibull Plot 38.2% of the population will theoretically survive 2615 cycles based on the actual experiments

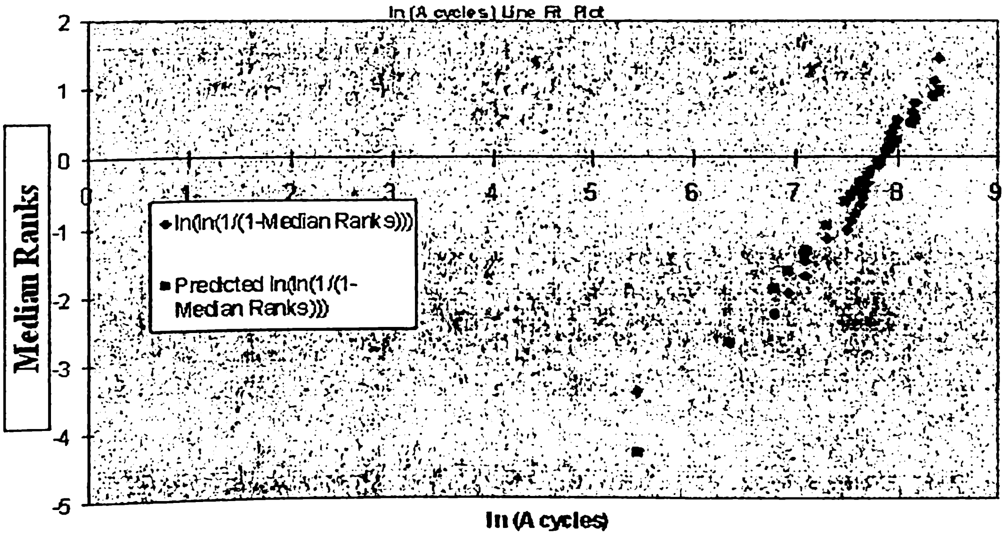

**Figure 8:** SnAgCu CNT Weibull Plot 38.2% of the population will theoretically survive 4138 cycles based on the actual experiments.

## 4. CONCLUSION

Detailed solder joint fatigue models with life prediction capability are established for both QFN packages incorporating SnAgCu 405 and SnAgCu405-CNT solder alloy. Comprehensive design analyses are performed to study the material behavior and each effects contributing to solder joint cracking. Package geometry, material properties, and thermal cycling test condition were also considered. The relative fatigue life predictions are consistent with experimental observations.

For thermal cycling experiment, it is important to set consistent test conditions (e.g. temperature range and cycle time) and test board design (e.g. board thickness) for various cases. The standardization helps make meaningful relative comparison among different cases. Fatigue modeling can be applied for design analysis of solder joint reliability to save cost, time, and manpower in performing the DOE studies by thermal cycling test. This is especially useful for new package development. The fatigue modeling can also be integrated with electrical simulation and thermal analysis for a complete board-level reliability design solution.

Weibull distribution was also utilized to predict reliability performance. The study revealed that 38.2% of the SnAgCu CNT solder population can withstand 4138 cycles, whereas the SnAgCu 405 variant can withstand 2615 cycles. With this data, an additional 1500 cycles was attributed to the presence of SnAgCu CNT as confirmed by the results of Cruz and Basilia. Although the relative data of the FEM and actual data recorded agreed at approximately 60%, a comparison between literatures by Tee of NTU shows agreement at 34% based on actual and simulated results. With the data and simulated results, the researchers determined that the outcome obtained is acceptable leveraging from the findings of NTU and Darveaux. In addition, the researchers were able to translate the results in a 1000TC scale from the gathered data. The study revealed that for the SnAgCu 405 CNT variant, the population will survive at approximately 99.4% of the time whereas the SnAgCu 405 variant will survive at approximately 84% of the time.

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