Effect of Molding Cure Time on High Density Quad-Flat-No Lead Sawn Package

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Abstract. Quad Flat No Lead (QFN) is part of an integrated circuit (IC) products that required wire bonding and molding as part of its packaging process. There are many types of QFN packages thickness available in the market and 0.75 mm thickness is one of the highest in demand. The wireless (WLSS) QFN package was used in this research for the mobility of electronics devices especially for wireless technology such as mobile phone and laptop. The objective of this paper is to study the effect of molding cure time at 100 and 130 s of WLSS QFN package. Besides, two variations of package size of 2.5 mm x 2.5 mm and 7.0 mm x 7.0 mm were undergoing each process in QFN packaging stages to adhere to the real manufacturing environment. For characterization, 4 types of QFN package were examined for its moldability through C-CSAM, reliability and electrical test were also carried out according to the Joint Electron Device Engineering Council (JEDEC) requirements. From the result, it was found that the optimum molding cure time is 100 s is suitable for molding the WLSS QFN package. This new curing temperature can be can increase productivity for about 8% for QFN packaging.

Keywords: Molding Cure Time; Quad-Flat-No-Lead Sawn (QFNs) Package; Transfer Molding; IC Package Type; Electronic Packaging

1. Introduction

There are numerous integrated circuits (IC) or microchip surface mounted packaging method worldwide. Among famous package is Quad Flat No Lead (QFN), Thin Small Outline Package (TSOP), Quad Flat Package (QFP), Flip Chip-Chip Scale Package (FCCSP), Ball Grid Array (BGA) etc. QFN package is one of the fastest growing integrated circuit (IC) surface mounted packaging methods. It is developed in the mid-1990s by Motorola, Amkor, Toshiba and some other leading IC manufacturer. QFN package may consist of one or more devices to be connected with bear wire and leadframe as its base. Then, the connected devices are encapsulated with epoxy resin through molding process to protect the devices for long lasting IC [1].

The major difference between QFN and other package is QFN has no external lead or pin or leg. It is to be soldered directly on to printed circuit board (PCB) by soldering method [2]. So, the PCB does not need the hole to mount QFN devices and can be filled by more IC or the PCB size can be minimized. QFN has complex wire bonding to connect its entire internal devices components where the
The diameter of the wire is about 0.7 to 1.0 mils. QFN package is using epoxy molding compound (EMC) to encapsulate the wire bonded IC. EMC are thermoset material which means it will change form when heated from solid state to liquid state and will change back to solid state. The molecules will form cross-linked networks that are no longer to be reversible when heated thus it does not melt even at very high temperature. This process, however, is non-reversible. EMC is used not only for QFN but also used in other IC packages that require molding. It is used due to lower cost, good wear, and tear resistance and ability to withstand high temperature and pressure. The advantage of EMC it has fire resistance capability [3], [4].

In the packaging stage, there are many processes involved to produce the end product. The wafer needs to be ground until about 8 mils in thickness and singulated by sawing or laser cutting. Singulated wafer is called die. This process is called die preparations. The die is then attached to leadframe by die attach epoxy in a process named die attach (DA) process. The leadframe with die attached to it is then bond with wire to create electrical connection between the die and leadframe. This process is called wire bonding process. After bonded with wire, the connected die is entirely molded with EMC. The molded leadframe is then clean with chemical through chemical deflash process and plated with Sn to increase solderability. Afterwards, the leadframe is singulated through sawing process to form units of IC or microchips. These units shall then undergo visual inspection for rejecting external defects. The general packaging flow is presented in Figure 1.

Molding process is the process to encapsulate wire bonded IC in order to provide protection and the harden mold resin will act as a body for the package. Since molding process located in middle of line (MOL) stage, it is an important process that connects the product from front of line (FOL) to end of line (EOL). Thus, its processing time is very essential and has high impact on overall productivity of QFN packaging. Reduction on molding processing time may increase the overall QFN productivity. Basically, molding process has five basic parameters which is curing time, molding temperature, transfer sequence, transfer pressure and clamping pressure. Among these parameters, mold curing time is the only one directly affecting mold processing time. Thus, mold curing time need to be reduced in order to reduce mold processing time.

In any manufacturing company, time is most essential as time will directly impact the productivity and cost of manufacturing. Manufacturing cost will increase proportionally with manufacturing time. Each of every process need process improvement to further reduce wastage and increase productivity. Since molding process is the process that connects FOL and EOL. For this reason, there are several study done such as molding material [5], [6], post mold cure process [7], but, very few considering the molding cure time mainly for QFN packaging. The main objective of this paper will cover the study on effect of molding cure time on WLSS QFN package. As part of JEDEC requirements, QFN reliability test will be performed. If reduction of cure time produced good result, the cure time reduction effect on mold processing time and productivity will also be investigated.

Figure 1. General packaging flow
2. Experimental

2.1 Material
The total thickness of the product is 0.75mm (WLSS) and the leadframe layout is 250 mm x 70 mm. The thickness is inclusive of mold cap thickness and leadframe thickness. Mold cap thickness is 0.55 mm while leadframe thickness is 8 mils which were about 2.0 mm. There are 4 panels in each leadframe in this design. Two different package size of 2.5 mm x 2.5 mm and 7.0 mm x 7.0 mm with the same thickness 0.75 mm WLSS available for WLSS package were used in order to investigate the effect of molding cure time for all body sizes.

2.2 Mold Encapsulation Process
In this study, epoxy molding compound (EMC) was supplied by a local supplier in a spherical shape and the details properties of EMC as tabulated in Table 1. Two types of wires consisted of gold and copper wires with a diameter of 0.7 mils were used in this study. Leadframe to be used was copper leadframe and die attach epoxy was conductive silver epoxy resin. The molding technology was used in this study is transfer molding process and the parameter involved in this study as in Table 2. Thermocouple mechanism was used for heating and temperature controls. Both top and bottom mold chase has 4 heating rods each. The heat was well distributed across the mold chase assembly and pot and plunger assembly. The output of mold QFN strips encapsulation as shown in Figure 2.

| Table 1: Properties of epoxy mold compound |
|-------------------------------------------|
| Epoxy Mold Compound Properties            |
| Content (wt.%)                             | 88.0 |
| Filler sieving size (mm)                   | 75.0 |
| Shape (Spherical / Flake)                  | 100 / 0 |
| Spiral flow (cm)                           | 110.0 |
| Gel time (s)                               | 32   |
| CTE1 (10^-6/°C)                            | 0.8  |
| CTE2 (10^-6/°C)                            | 3.7  |
| Tg (°C)                                    | 130.0 |
| Flammability (UL-94)                       | V-0  |
| Water Absorption (%)                       | 0.15 |
| Flexural Strength at RT (N/mm²)            | 170.0 |
| Flexural Strength at 260°C (N/mm²)         | 17.0 |
| Flexural Modulus at RT (N/mm²)             | 26000.0 |
| Flexural Modulus at 260°C (N/mm²)          | 600.0 |

Figure 2 Molded QFN strips
Table 2. Transfer Molding Process Parameter

| Machine Parameter | Unit                | MCT₁ | MCT₂ |
|-------------------|---------------------|------|------|
| Cure Time         | s                   | 100  | 130  |
| Clamp Pressure    | tonne               | 28   | 28   |
| Transfer Time     | s                   | 17   | 17   |
| Transfer Pressure | tonne               | 1.2  | 1.2  |
| Temperature       | ℃                   | 175  | 175  |
| Package Size      | length (mm) x width (mm) | 2.5 x 2.5 | 2.5 x 2.5 |
|                   | length (mm) x width (mm) | 7.0 x 7.0 | 7.0 x 7.0 |

3. Characterization

3.1 Moldability Test
The mouldability test was measured through C-SAM to capture any defect upon the epoxy mold compound. In this test 4 samples were submitted for preconditioning and examined in C-mode Scanning Acoustic Microscope (C-SAM) to check for any interfacial delamination.

3.2 Reliability and Electrical Test
Reliability of the product is also part of characterization and considered as the most important test to validate two different curing time. Reliability test to be run is the Precondition Test at Moisture Sensitivity Level 1 (MSL 1) and Level 3 (MSL 3) to test the workability of the product. Temperature Cycling (T/C) to check the product durability in temperature changing environment and lastly, Pressure Cooker Test (PCT) to know the existence of a gap between EMC and leadframe. All the reliability test was done is part of JEDEC requirements. Before and after the reliability test, the electrical test was conducted to detect any open or short failure.

4. Result and Discussion

4.1 Moldability Properties
Moldability properties are the most important indicator of the possibility of reducing molding cure time. Molding cure time shall first affect the moldability qualities such as delamination, mold void, crack and sticking. The first moldability test result to be discussed is the result of dummy units. Leg 1 and Leg 2 are tested on the smallest body size for WLSS package which is 2.5 mm x 2.5 mm. Leg 3 and 4 are tested on the biggest body size which is 7.0 mm x 7.0 mm. On the contrary, 2 units were affected with mold flash on the control lots of biggest body size which is molded with 130 s cure time as shown in Figure 3. The mold flash is very light but it covers the lead more than 5% of its area as shown in Figure 4. Thus, it is still considered a reject sample. Reducing molding cure time does not produce any mold flash defect. The post CSAM for both WLSS QFN package (2.5 mm x 2.5 mm & 7.0 mm x 7.0 mm) is shown in the following Figure 5.

![Figure 3. Effect of mold deflash on package size (2.5 mm x 2.5 mm & 7.0 mm x 7.0 mm)]
Figure 4. Light mold flash covered 1 lead at bottom left corner.
4.2 Reliability and Electrical Properties

Reliability test is part of the JEDEC requirement, the result of the reliability test for both packages as shown in Table 3. Smaller body size is set to withstand higher moisture sensitivity level (MSL) which is MSL level 1. This is due to smaller body size have smaller surface area of bonding between EMC and leadframe. The small size also makes it easier for delamination to propagate from outside to inside or inside to outside in high stress environment. Bigger body size has larger surface area which provides stronger bonding between EMC and leadframe. Bigger body size also makes it harder for delamination to propagate. Thus, bigger body size MSL level is 3.

Table 3. Reliability test for both package size (2.5 mm x 2.5 mm) and (7.0 mm x 7.0 mm)

| Test Item                  | Test Description                        | MCT₁ (2.5 mm x 2.5 mm) | MCT₂ (2.5 mm x 2.5 mm) | MCT₁ (7.0 mm x 7.0 mm) | MCT₂ (7.0 mm x 7.0 mm) | Findings                |
|----------------------------|-----------------------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| Precondition Test (MSL 1)  | Reject if there are any delamination    | 0/77 units              | 0/77 units              | 0/77 units              | 0/77 units              | No delamination observed |
| Temperature Cycling (T/C)  | Reject if there are any delamination    | 0/77 units              | 0/77 units              | 0/77 units              | 0/77 units              | No delamination observed |
| Pressure Cooker Test (PCT) | Reject if there are any delamination    | 0/77 units              | 0/77 units              | 0/77 units              | 0/77 units              | No delamination observed |
| Electrical Test (Post reliability) | No electrical failure allowed        | 0/231 units             | 0/231 units             | 0/231 units             | 0/231 units             | No electrical failure observed |

Figure 5. (a) WLSS molded 2.5 mm x 2.5 mm for 100 s (b) WLSS molded 2.5 mm x 2.5 mm 130s (c) WLSS molded 7.0 mm x 7.0 mm for 100 s (d) WLSS molded 7.0 mm x 7.0 mm for 130 s
4.3 Effect of Molding Cure Time on Mold Processing Time

The effect of molding cure time on mold processing time presented in Figure 6. Total processing time for mold in Fig. 6 is the average mold processing time for 10 mold shots. Original average mold processing time is 338s while 100s molding cure time process in average of 307 s. There is a reduction of 27 s in processing one shot of molding. This gives 9.17 % of processing time reduction. Reduction of mold processing time shall increase the mold process productivity. Productivity for mold is determined by the total strips produced in one hour. The total strips produced per hour are known as unit per hour (UPH). Molding products are in strip form but the productivity indicator is still called as UPH. This is due to the UPH name is common for manufacturing machines. Reduction of molding cure time for 30 s should affect the mold processing time.

![Figure 6. Effect of mold cure time on mold processing time](image1)

The effect modling cure time on number of strips (UPH) was presented in Figure 7. The UPH for 130 s molding cure time is about 21 strips per hour while UPH for 100 s molding cure time is about 23 strips per hour. There is about 8.7 % improvement in productivity. It is more than targeted improvement which is 5%. This shows that reducing molding cure time is beneficial to QFN packaging industry as it can increase its productivity and reduce the processing cost. The actual cost saved may differ between companies depending on their material prices, labour cost, and electric consumption.

![Figure 7. Effect of molding cure time to the productivity](image2)
5. Conclusion
Actual units of QFN are molded with original and proposed molding cure time which is 130 s and 100 s respectively. Both samples went through all the processes in the QFN packaging stage. Same machines and parameter were used on both units throughout the experiment except for molding cure time to ensure no external factor is affecting the results in this study. The results obtained throughout the experiment shows that 100 s cure time able to produce high quality molded WLSS QFN units. There is no visual and moldability defect found through C-SAM figures. The reliability and electrical test which is part of JEDEC requirement confirmed that 100 s molding cure time can be proposed as new molding cure time. The 30 s reduction is needed to save mold processing time for about 9 %. The productivity of molding process also increases by about 8 % using 100 second molding cure time. In conclusion, 30s reduction of molding cure time did not cause any failure to molded WLSS QFN units. Furthermore, the lower mold cure time increases the mold process productivity by up to 8 %. Thus, molding cure time at 100 s is applicable to increase productivity and save processing time and cost.

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Acknowledgement
This work is supported by Universiti Kebangsaan Malaysia (UKM) under Geran Galakan Penyelidik Muda (GGPM-2020-036) and Institute of Power Engineering, UNITEN for research materials and collaboration work.