ANALYSIS OF THE MOULD VOID PROBLEMS BY STATISTICAL PROCESS CONTROL ON A 28x28 mm QUAD-FLAT-PACKAGE INTEGRATING CIRCUIT

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Abstract

Transfer molding of thermoset plastics has proven to be an economical and effective way of packaging microelectronic devices. This project analyzed the mold void defects found on the surface of integrating circuit (IC) packages. While the technique of Statistical Process Control (SPC) employed in this analysis enabled "the single problem" to be exploded into five major problem areas, some selected root causes were classified into either special variability or random variability using the concept of variability. It was demonstrated that using the SPC approach, the number of defects was greatly reduced over the testing period of 12 months. This work also included [I] the Taguchi method on design of experiment for chipped pellet investigation, [II] the long term method for measuring thermometer Gauge Repeatability & Reproducibility study, and [III] the short term method on mold temperature process capability study.

Introduction

Transfer molding of thermoset plastics has proven to be an economical and effective way of packaging microelectronic devices. While thermoset materials meet the engineering requirements necessary for this application, the molding technique is capable of encapsulating the devices under pressure which is low enough not to cause any significant damage to the gold wire bonded between the die and the leadframe of a plastic encapsulation integrating circuit. One of the high integration density package families, namely 28x28 mm Quad-Flat-Package (QFP) which has 120, 128, 144, 160 and 208 leads, is currently the most popular chips in the market.

During the process of transfer molding, a number of molding defects may occur which are to be unacceptable. Among the defects, mold void appears to be the most common one. This project concentrated particularly on this mold void defect found on the surface of IC packages. The main objective of this work was to reduce the scrap rate caused by this mold void defects from 6600 defects per million (DPM) to 3500 DPM over a target period of 12 months. In order to attempt to achieve this objective, the technique SPC was adopted. Employing the SPC preliminary problem solving technique - cause and effect diagram (fish-bone analysis), the single problem was exploded into five major problem areas, ie methods, materials, machines, manpower and environment. Many possible root causes of these problem areas were subsequently identified.

The concept of variability was used in this work to classify the selected root causes into either special variability or random variability. Besides, other problem solving tools such as flow chart, run chart, and control chart were used to identify the timely conditions. The Taguchi method on design of experiment for chipped pellet investigation, the long term method for measuring thermometer Gauge Repeatability & Reproducibility (GRR) study, and the short term method on mold temperature process capability study were also conducted to quantify the study subjects.

SPC analytical tool

Plastic molding (encapsulation) is the first process among the End-Of-Line (EOL) operations. Among 120 different types of identified EOL defects, only some of them are found frequently and of great significance on cost impact. Using the Pareto chart analysis on these EOL defects and comparing their potential degree of difficulties of resolution, the investigation on the reduction of mold void defects was chosen and the indicator is expressed as Defects Per Million (DPM = [No. of defective units found / No. of units inspected] x 10^6).

The purpose of SPC program is to establish a standard approach towards continuous process improvement through SPC. The first real step in quality improvement is to accept the concept that quality is intimately associated with variation. Its objective is to maintain all critical processes and their variation under tight statistical control in order to enhance quality, reduce scrap and reduce production cost through identification of process variation, and through the reduction of these variations by means of real time corrective action. In the other words, the SPC technique utilizes a proactive approach to problem solving in contrast to the conventional reactive approach of inspecting out defects.

Special variability comes and goes in the system causing time-related variations in yield, performance or reliability. Deviation due to special variability result from changes in external conditions that are controllable. Operator training and experience, changes in temperature or raw materials, variations in test equipment, variations in machine conditions and material properties are examples of special variability. A process can be considered to be statistically controlled only when such special variability have been eliminated or adequately reduced. Their detection and elimination are the primary functions of statistical process control procedures. Traditionally special variability have often appeared to be random because they were never examined closely enough (**figure 1**).

Measuring equipment is subjected to variation. An analysis of a process cannot be meaningful unless the measuring instruments used to collect data are both accurate and repeatable. If instruments are not properly calibrated for "accuracy", a systematic variation or bias may result. A similar condition could occur if different individuals use the same equipment to perform similar measurements (reproducibility). Another type of variation called random variation, is generally caused by conditions built into the instrument itself such as internal friction and backlash. This can cause variation of measurement in a series of repeated, identical checks (repeatability). All these factors - accuracy, repeatability and reproducibility combined to affect the overall performance of the measuring equipment. Gauge Repeatability and Reproducibility (GRR) should be conducted to verify the accuracy and appropriateness of the measuring equipment. "Gauge repeatability" is the variation in measurements obtained when one operator use the same gauge for measuring the identical characteristics of the same parts. "Gauge reproducibility" is the variation in the average of measurements made by different operators using the same gauge when measuring identical characteristics of the same parts.

The "long term method" of GRR study can determine errors of gauge repeatability and reproducibility separately. Study results can also provide information concerning the causes of gauge error. Ideal instrument should have zero GRR. In general if GRR is found to be less than 0.3, the instrument is said to be appropriate for the purpose.

"Short term method" of capability studies are conducted to determine the central tendency and variation of a machine in a very compressed time period under controlled conditions. Data are recorded in a frequency distribution manner. The average and standard deviation are calculated to estimate the actual centring and amount of variability. A more meaningful Cp (spec width / process width) and Cpk (2 x [target value - process mean] / spec width) values can be achieved if the data follows normal distribution tested by 95% Lilliefors bounds at 5.0% significance level.

The foundation of Taguchi method [1, 2, 3] is to accept the concept that quality is intimately associated with variation. A process usually consists of some basic functions. It is the product function which is important to the consideration of variation. There are three basic design steps to optimize a process against functional variation. These steps are : (A) system design, (B) parameter design and (C) tolerance design. System design draws on knowledge from specialized fields. Designers at this stage often build into a design automatic feedback loops and controls to stabilize variation and functions. This can be very effective but also quite costly. Dr. Taguchi suggests to control variation by introducing a drastic change to the system. That is done through parameter design.

Parameter design is the technique of establishing the optimum parameter levels of a system, the drastic change that inherently resists variation. This is probably the most overlooked step in research and development in general. Most people tend to be satisfied in finding a solution that works, rather than finding the best solution. Through the trial and error approach, the immature system is modified repeatedly until it converge. This is obviously inefficient and does not guarantee an optimum design.

Tolerance design is the last basic design. The tolerance of the input parameters are adjusted to obtain the desired output variation. However without an understanding on how the input parameters affect the output function, this step is somewhat arbitrary. How much should the input tolerance be reduced and what parameters should be changed become the key question.

Molding

Molding process. The fully automatic transfer molding system for QFP encapsulation is different from the conventional molding machine. The leadframe which are initially aligned inside the carrying magazine are being transferred to the leadframe preheating station. After preheating at 110 C° for about 140 seconds, the leadframe are transferred to the top surface of the bottom mold die. The bottom die together with the preheated leadframes move up until fully matching with the top mold die. Transfer molding is then started and it takes about 9 to 12 seconds at 170 C° to finish. Followed is another 120 seconds for curing. After curing the four encapsulated leadframes together with solidified runner will then be transferred to the de-gating station at where the gates between the runners and the corresponding encapsulating units are broken.

Molding die. Basically it is the same as conventional transfer molding die. Main difference is the existence of the delicate leadframe being clamped at the parting line of the top and bottom mold dies. The plastic pellets, which are initially stacked inside the pellet stacker, and are transferred for preheating for 22 seconds at about 90 C°, become molten are pushed from top-down into the dies by a plunger.

Mold void specification. Mold void is defined as the unwanted opening at any external surface of a plastic package. The top and bottom surfaces is divided into nine zones, designated zone 1 to zone 9 (**figure 2**).

(A) Any void size on the die area (zone 5), top and bottom side of the package is a reject.

(B) Any void outside the die area (zone 1 to 4 and zone 6 to 9) greater than 10 mils is a reject.

Action plan

(A) **Problem identification**

1. Generate form for data collection
2. Data collection regarding void location
3. Review data
4. Cause and effect analysis

(B) **Analysis and elimination of special variability**

1. Sealing of mold pellet for second restore
2. Mold defects criteria identification
3. Use of combined 2 spiral flow range pellets
4. Evaluate the effect of chipped pellets

(C) **Analysis of random variability**

1. Addition of air vent on centre cull block
2. Machine capability study on top & bottom temp.

Cause and Effect Analysis

All possible and potential factors were extracted through brainstorming and a cause and effect analysis was drawn as shown in **figure 3**. Six potential significant factors were selected and classified into either special or random variability.

Special variability

Restorage of used molding compound. Prior to production, the molding compound EME-6300H was allowed to warm up to room temperature for 24 hours before opening the metallic air-tight container such that the compound was ensured to reach thermal stabilisation. After opening the compound was exposed to room temperature and sometimes humid atmosphere. If re-sealed improperly the moisture might be condensed if the temperature inside below dew point. No re-sealing and re-packing handling procedure supplied from supplier, before and after upon request. *Solution.* A detail molding compound fast thawing procedure was figured and written and implemented. A paper of "desiccant for plastic surface mount components" was found and followed. As this quality improvement action was executed and accomplished with other action, the exact advantage of this action would not be evaluated. However it was believed this special variability was removed.

Understanding of mold defects criteria. Due to various reason such as high labour turnover rate, many direct production and QA staff did not fully understand the mold void specification. Over-rejection or under-rejection might probably be resulted. As 70% of the engineering staff were foreigner, all specification were written in English. However all production staff were Chinese and they knew very little about English. Communication problem arose. *Solution.* All direct line staff had to be trained by the SPC department and qualified by Process Engineering department before they were released to the line. Better defects demonstration by introducing visual aids. Key information were translated into Chinese for training and reference. Concrete assessment could not be made with this sole factor.

The best way to deal with special variability that came from human and procedural related problem was to establish a good counter-checking documentation system, to train and examine the responsible operator in a timely manner, and to assess continually the problem awareness of the qualified operators. Also some physical tools could be used to compensate the incapability of a documentation system.

Use of 2 combined spiral flow rate pellets. Mold compound viscosity, which is expressed in spiral flow - cm, would significantly affect the filling and curing properties during encapsulation. Suppler's specification was 75-120 cm. Finding the best spiral flow rate without adverse to other important properties, such as wire sweep and lift-pad, so as to reduce the mold void defects was the objective. After experimentation, it was found that compound with higher spiral flow rate, from 90-120 cm, would create lesser amount of mold void defects than with lower reading. *Solution*. The supplier Sumitomo Bakelite was requested to ship with higher spiral flow compound but they refused. Sorting the incoming compound with required spiral flow was impractical as this created high administrative and scraping cost. Other compatible or better mold compound could not be sourced. Such special variability was verified but could not be eliminated as the control was on supplies' hand.

Chipped pellets on void. The ideal shape should be a pure cylindrical pellet of diameter 40 mm and length 21 mm. However the incoming compound was always chipped at some portion along its circular circumference. It was thought that this chipped volume allowed more air to be entrapped during the molding compression cycle and hence such chipped pellet might be one of the special variability (**figure 4**). *Solution*. Taguchi's method on design of experiment was chosen. 3 experimental factors were to be manipulated at 2 defined levels.

Experimental factors	Level (1)	Level (2)
A - 1st pellet which flow into cavity	0-1/8	> 1/4
B - 2nd pellet which flow into cavity	0-1/8	> 1/4
C - 3rd pellet which flow into cavity	0-1/8	> 1/4

Level (1) : chipped out within 0-1/8 of the pellet circumference
Level (2) : chipped out greater than 1/4 of the pellet circumference

As the interaction between the experimental factors were also required to investigate, a total of 8 runs were necessary. Taguchi's orthogonal array $L8(2)^7$ was chosen. Experiment was done and response curves were plotted (**table 1**). It was concluded that there had no significant difference between level (1) and (2) of factor A and B. However for factor C, the mold void DPM was significantly increased once the chipped pellet was used. A validation run was conducted so as to verify the truth of the previous conclusion. Validation result basically the same as predicated previously. After completing the evaluation, a temporary engineering change notice with allowable chipped out within 0-1/8 of the pellet circumference was generated and implemented. Unlike the previous section that there had only 1 factor and 2 levels to be considered, the proposed special variability of this section required 3 factors and 2 levels, and also their interaction, to be evaluated so as to get a clearer picture. Taguchi's method on the design of experiment was one of the best and quick means to achieve such a meaningful result.

Random variability

Addition of air vent on centre cull block. It was thought that during the start of the compression cycle, much air was entrapped along the circular runner when the punch was pushed downward and the straight runner was fully filled with encapsulant before the whole circular runner. This amount of entrapped air would pass through the runner and entre the last molding cavities at the end of the cycle and mold void problem was then resulted. *Solution*. An air vent was added and the depth was increased from 0.0010" to 0.0015" and then to 0.0020". All other molding specification remained unchange. Result showed that the DPM for all modified vented cull block was drastically increased from 2728 to 6166. It seemed that the proposed mechanism was wrong and the suggested explanation was at such high pressure and high compound mobility area that any entrapped air would either find a way to force through the blocked viscous compound and to escape through the normal air vent at the corner of the package cavities, or be pressurized as tiny internal void at the circular runner, or be pressurized as tiny void at the surfaces of the package. Further cull block modification was planned but abandoned due to cost effectiveness. A lot of effort had been paid but no improvement could be made. This was not uncommon as common sense didn't always work as expected.

Machine capability study on top and bottom mold temperature. Each machine would have different process window even of the same type. Top and bottom mold temperatures were believed to be another two critical parameters. Before starting the machine capability study, the characteristics of the measuring instrument - Cormark thermometer had to be identified, or the machine capabilities data could be misleading.

"Long term" GRR study for the Cormark thermometer was performed. Following the standard procedure and the result was 11.9 %, with reproducibility 0% and repeatability 11.9%. The variability was totally coming from the thermometer rather than from operator. It could be concluded that the thermometer was accurate enough for such purpose.

"Short term" machine capability study for 3 automatic molding presses, in terms of top and bottom mold temperature control capability, were performed and summarised as in **table 2**. A SPC software based on the Lilliefors bound theory, 95% bound and 5% significance, was used to check the normality of the distribution. It was observed that 4 out of the 6 distributions were not normal. As a result their Cp and Cpk values were not "general meaningful" and could not be compared directly among themselves and with those that had normal distributed data, as all meaningful capability indices had to be obtained from a normal distribution curve.

Although most of the distribution were not normal, the control limits for these distribution were still established based on the normal distribution theory as it was the simplest to apply. These control limits were calculated from (average $\pm$ 3σ) and still looked reasonable from their actual values.

The difficulty on thermometer handling was identified and this was also verified by the GRR study that the variability was solely coming from gauge variability, a new thermometer with magnetic surface probe was adopted.

The top and bottom mold temperature were controlled by a single temperature controller with output linked to 2 heater in parallel. 2 new heaters would perform differently after using for some time, resulting differential temperature across top and bottom mold. Long term solution was to replace the single controller with two independently calibrated controllers. However this solution was practically impossible because such retrofit involved expensive modification on software and electronic hardware, which was not justified in terms of cost. It seemed that such important random variability, after identification and verification, would only be addressed by top management and no others.

It was interesting to note that there might have many unpredictable random variabilities existing in the production floor and these variabilities were absolutely out of our own control even their existence were realized. The only solution to deal with these variabilities was just "take or leave", depending on the companies' market and financial strength.

Conclusion

Following the SPC approach, all special variabilities including improper restorage of molding compound, misunderstanding of mold void defects criteria, improper control of spiral flow rate and chipped size of molding pellets were largely eliminated and a statistical controlled process was achieved. All random variabilities including addition of air-vent on the centre cull block of the mold die and the incapability of the molding processes to control the top and bottom mold die temperature were found to be largely out of control and remained there. It was mainly due to these remaining random variabilities that composed of the remaining DPM.

The DPM of the mold problem was reduced by 57% over the investigating period of 12 months.

Reference

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