Implementation Study of Intelligent system for IC Transfer Molding Process

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ABSTRACT

Various problems occurred in encapsulation of plastic IC packages are the results of improperly handling of the many process parameters, lack of understanding of material properties, and immature mold design. The traditional way to get rid of these problems is to adjust the process parameters of the transfer molding machine. However, the optimization of these parameters is usually based on past experiences or obtained by trial and error. This approach is time consuming and less accurate. A program is developed to help users to choose an appropriate initial machine setting based on the machine, material and mold design information. The detail of its application to IC encapsulation process is described in the paper.

keywords: IC encapsulation, transfer molding process, expert system

1. IC ENCAPSULATION PROCESS

More than 85% integrated circuits (ICs) are encapsulated by plastic. The encapsulation of plastic IC packages is usually accomplished by either conventional or multi-plunger transfer molding machine. It is discovered that a lot of reliability issues arose during and after this encapsulation process. The problems are not only related to the manufacturing process, but also the properties of the epoxy molding compound (EMC) and the design details of the mold and the IC package. Therefore, the relationship between manufacturing process parameters, epoxy molding compound characteristics and the geometrical information of mold and package should be studied carefully.

2. TRANSFER MOLDING PROCESS PARAMETERS²

A typical transfer molding process begins with loading of leadframes into the mold, placing and preheating performs and closing the mold. The heated and molten EMC is then transferred by the ram into the mold system which is composed of runners, gates, mold cavities, ejector, and heating elements. The packages are ejected out once the packing and curing process have completed.

There are basically three types of setting in transfer molding process: temperature, pressure and timing (velocity).

- Temperature setting: top and bottom heater temperature.
- Pressure setting: mold clamping pressure, transfer pressure and packing pressure.
- Timing and velocity setting: ram velocity profile, transfer time and curing time.

Different type of packages (Plastic Quad Flat Pack - PQFP, Thin Small Outline Package - TSOP, Dual Inline Package - DIP, etc.) working with different materials (conventional or fast curing EMC) will result in different machine setting. In general, a typical transfer molding machine setting is shown in table 1.

3. MOLD AND PACKAGE DESIGN CONSIDERATION

Goosey³ suggested that the following parameters should be taken into consideration in mold design: % shrinkage of molding compound, draft angles of mold, gate location, runner systems (the shape and geometry of primary and secondary runners), location of parting line, degree of venting, ejector pin requirements, and mold surface finish.

The important factors in package design are mainly the die position and the die-pad design (recessed, level or elevated). In particular, the wire characteristics such as its length, bonded loop height, diameter and stiffness should be carefully considered in order to eliminate the wire sweep issue.

Table 1. Typical Transfer Molding Machine Settings	
Mold Temperature	175 - 180°C
Transfer Time	15-20s for conventional molding compound <15s for fast curing molding compound
Ram Pressure	~1000 psi
Packing Pressure	~1200 psi
Pre-heating Time	1-2s for automold
Pre-heat Temperature	~90°C

4. EPOXY MOLDING COMPOUND CONSIDERATION

The study of rheology of the molding compound is vital in dealing with the mold filling process. Especially, the viscosity behavior is of great importance. The value of molding compound viscosity is usually high at the very beginning. It then drops significantly because enough heat is absorbed and finally increases drastically as molecular weight increases infinitely because of the conversion approaching to the gel conversion. It is therefore required to set the transfer time (transfer velocity profile) so that the molding compound can flow into the mold cavity with low viscosity.

The major components of epoxy molding compound include epoxide resins, hardener resin, catalyst or accelerator and fillers whereas releasing agents, pigments, flame retardants, and additives are minor components. It was shown by Goosey³ that the filler content plays an important role in EMC.

- $\uparrow$ filler content $\rightarrow$ $\downarrow$ spiral flow length $\rightarrow$ $\uparrow$ viscosity
- $\uparrow$ filler content $\rightarrow$ $\downarrow$ cure shrinkage
- $\uparrow$ filler content $\rightarrow$ $\downarrow$ coefficient of thermal expansion, α
- $\uparrow$ filler content $\rightarrow$ $\uparrow$ thermal conductivity, k

where the symbols $\uparrow$, $\rightarrow$, $\downarrow$ are defined as INCREASE, IMPLY and DECREASE respectively.

5. TYPES OF DEFECT³⁻⁵

The most commonly seen problems in the transfer molding process are flash, incomplete fill, voids formation, wire sweep, warpage, and mold sticking.

- a. Flash: This refers to the molding compound flowing out of the mold cavity and, in particular, on the lead fingers at the parting line region.
- b. Incomplete Fill: This occurs when the molding compound cannot fill the mold cavity completely. Incomplete fill is also known as short shot.
- c. Voids formation: Voids are the imperfections inside the molding compound. The formation is usually due to the gases trapped inside the molding compound during packing.
- d. Wire sweep: This phenomenon appears as the melt front entering the mold cavity. The bonded wires are displaced by the flow momentum. In the worse case, the wire bonding may be broken if the momentum is large enough.
- e. Warpage: Package warpage refers to the deflection caused by uneven thermal contraction of the different materials of the package and the chemical shrinkage of molding compound.
- f. Mold sticking: Sticking refers to the adhesion of molding compound on the surface of mold cavity or molding tools. This not only requires extra time for cleaning the mold but also causes the package cracking on removal it from the mold.

6. CAUSES OF DEFECTS

The listed problems are basically due to the miss-handling of machine setting, the lack of understanding of material properties and the immature design of package and mold. Among these factors, the usual practice is to adjust the machine parameters since it is time-consuming and very expensive to perform material characterization and mold / package re-design. In order to calibrate the involved parameters efficiently and properly, we should first know the inter-relationship between the key parameters and the defect modes. Their relationships are summarized as below^{3,5}:

6.1 Flashing / Resin bleeding

process parameters

- ↑ transfer pressure → bleeding
- ↓ clamping pressure → flashing

material

- ↑ amount of external release agents → resin bleeding
- ↓ resin viscosity → resin bleeding
- ↓ melt viscosity compound → flashing
- ↓ filler size → flashing

mold / package design

- worn molds (especially in parting line area)
- ↑ thickness of leadframe → bleeding
- ↓ thickness of leadframe → bleeding

6.2 Incomplete fill

process parameters

- ↓ transfer pressure → incomplete fill
- ↓ molding temperature → incomplete fill
- ↑ molding temperature → incomplete fill
- long transfer speed → incomplete fill
- short transfer speed → incomplete fill
- too high preheat temperature → incomplete fill
- too low preheat temperature → incomplete fill
- insufficient clamping pressure → flashing → incomplete

material

- ↑ amount of molding compound → incomplete fill
- ↓ amount of molding compound → incomplete fill
- ↑ variation in perform density → incomplete fill
- cold insert → ↑ viscosity → incomplete
- heat insert to the mold temperature
- material with the correct spiral flow should be selected

mold / package design

- partially blocked or completely blocked gate → incomplete fill
- oversized filler particles → gate blockage → incomplete fill
- partially cured molding compound → gate blockage → incomplete fill
- dirty in mold → partially cure molding compound → gate blockage → incomplete fill
- vents are located opposite to gate position
- are the vents deep enough ?

6.3 Voids formation

process parameters

- ↑ transfer speed → void
- ↑ molding temperature → blisters

material

- excessive volatiles
- low melt viscosity → void
- cold insert → ↑ melt viscosity

mold / package design

- inadequate venting

6.4 Wire Sweep

process parameters

- ↓ transfer velocity → wire sweep in end cavity
- ↑ transfer velocity → ↑ flow momentum → wire sweep in front cavity
- switch over between velocity control to pressure control

material

- ↑ resin viscosity → wire sweep

mold / package design

- ↑ wire length → wire sweep
- ↓ wire diameter → wire sweep
- ↑ downset of die pad → racing effect between two fronts → wire sweep

6.5 Warpage

process parameters

- ↑ cooling rate → warpage

material

- ↑ thermal mismatch (α) between leadframe, silicon die and EMC → warpage
- degree of cure

mold / package design

- ↑ package size → warpage
- ↓ package thickness → warpage
- parting line

6.6 Sticking / staining in the mold

process parameters

- undercure of the molding compound → sticking

material

- ↑ amount of agent → ↑ staining of the Mold
- incompatible release agent → sticking

mold / package design

- dry molds → sticking
- poor mold design (draft angle : ~ 8 - 12 °) → sticking

7. INTELLIGENT SYSTEM IMPLEMENTATION

Machine settings are often done by trial and error. Optimization of process parameters for injection molding machine was studied using proportional-integral and proportional-integral-derivative control schemes⁶. On the other hand, building expert systems for injection molding process was attempted by many researchers⁷⁻¹¹. A molding trouble-shooting expert system was built based on a system of questions and answers⁷. This system can provide guidance to operator in correcting the problems step by step. An intelligent system for injection molding operations was developed which gathered and accumulated the experiences (relationship between various parameters) from skillful workers and experts to form a multi-dimensional matrix⁸. This matrix was then used to generate some guidelines for defects correction. Recently, a defect correction intelligent system based on logic formalism for injection molding process has been developed by Tan et al.¹¹. This system represents the knowledge of machine parameters using propositional logic. The optimum machine setting is then obtained with the help of

fuzzy logic. An initial machine setting program for transfer molding process has been developed by us recently¹. The program facilitates the user to select appropriate setting at the beginning of the operation.

Intelligent system for IC transfer molding operation is not available and the system developed for injection molding operation can be adapted. Its inference engine can be combined with IC encapsulation knowledge to solve the problems. The set of initial setting from the initial setting program is used as input into the intelligent system to find out the optimum setting for the IC encapsulation process. The schematic of an intelligent system for defection correction in IC transfer molding process is shown in figure 1. The complete system basically consists of three modules: an initial machine setting program, simulation programs, and a rule-based system.

Fig.1 Schematics of Expert System of IC Transfer Molding Process

- a. Initial machine setting program: This module combines all the information from the material, machine, mold and package design database and then uses simple mathematical assumptions and calculations to generate the initial machine settings¹. For Plastic Quad Flat Pad package with mold cavity dimensions: height=3.2mm, width=28.0mm and length=28.0mm, the output parameters are listed as follows:

Pressure

- Clamping Pressure : 120.0bar
- Transfer Pressure = 68.67bar
- Packing Pressure = 82.74bar

Temperature

- Top & Bottom Mold Heater (1,2 & 3) = 175°C
- Preheat Temperature = 85°C

Velocity/Timer

- Packing duration = 90.0sec
- Curing Time = 90.0sec
- Number of transfer velocity zone = 3
- Velocity of Zone 1= 0.891 mm/s
- Velocity of Zone 2&3= 2.789 mm/s

Benchmarking

The industrial setting of the automold machine is used as a comparison. For the same set of input parameters defined as above, the recommended velocity setting is :

- Velocity of Zone 1= 0.9 mm/s
- Velocity of Zone 2&3= 2.8 mm/s

Fig. 2 Transfer Velocity Profile

- Simulation Programs: With the machine parameters generated by the rule-based system, the simulation programs are used to determine the severity of the defects. The amount of warpage, wire sweep and void content are the key issues to be monitored in the process. On the other hand, flow simulation is also required to study the rheology of the molding compound¹².
- Rule-based system: The knowledge summarized in section 6 can be used to generate a set of rules by using the propositional logic and the optimized machine setting is then searched using the algorithm described by Tan et al.¹¹.

8. FUTURE WORKS

Attempt of applying expert system on transfer molding operation is discussed. Modified machine setting can be obtained through expert system. However, in order to check the existence and severity of the problems, simulation using the generated machine setting should be done. This test run can help the system to further fine tune the process parameters. Simulation programs including calculation the amount of warpage and wire sweep are therefore required to be developed in the future.

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