Flow Behavior Analysis of Emc in Molded Underfill (Muf) Encapsulation for Multi Flip-Chip Package

M.A. Azmi¹, M.K. Abdullah¹,*, M.Z. Abdullah², Z.M. Ariff¹, M.A. Ismail³, M.S. Abdul Aziz²

¹School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Penang, Malaysia
²School of Mechanical Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Penang, Malaysia

Corresponding author: mkhalil@usm.my

Abstract. This paper present a numerical analysis of molded underfill (MUF) for multi flip chip package during encapsulation. Castro Macosko model is used in ANSYS fluent to describe the flow behavior of the EMC. The physical quantities such as viscosity, shear rate and velocity is plotted to analyzed the flow behavior of EMC during encapsulation. The EMC flow behavior at flip chip (FC) and free passage (FP) region in cavity are been compared. The viscosity profile of EMC is inversely proportional to the shear rate and velocity profile at FC and FP region. The tendency of "frozen skin" layer occur in cavity package have been predicted with velocity profile during encapsulation.

1. Introduction

Transfer molding is used in MUF to fill the epoxy molding compound (EMC) in a mold during encapsulation process, a part of it is MUF. However, the behavior of EMC flow in the mold is very important to study since it will affect the performance and reliability of electronic package. There are many factors affect the EMC flow behavior and void formation during encapsulation process like transfer speed injection in transfer molding and effect of stacking [1-2]. The EMC flow behavior at the free and chip areas in a mold are different each other [3]. The possibilities of defect such as void, crack, etc occur at in the electronic package.

The flow behavior is dominated mainly by the viscosity and depends on the generalized shear rate in Generalized Newtonian Fluid (GNF) [4]. In addition, the physical quantity such as velocity is used to describe and analyze the EMC behavior during encapsulation process [5]. It is being more exacerbate, the
EMC is thermally cured during or after encapsulation process. For example, when the EMC fills the cavity and the molecules chain in EMC start to cross linking each other. As a consequences, the viscosity creases rapidly and the EMC transform into a gel, solidified and it becomes a highly cross-linked network [6-7].

In the present study, the numerical analysis of MUF encapsulation is carried out on multi flip chip package. The ANSYS Workbench 14.5 software is used to simulate the EMC flow and analysis EMC behavior during encapsulation process.

2. Mathematical model

The governing equations for continuity, momentum and energy for the three-dimensional mold filling are given as:

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{V}) = 0$$  \hspace{1cm} (1)

Where \( \mathbf{V} = (u, v, w) \) is the velocity vector.

Conservation of momentum in \( x \), \( y \) and \( z \)-direction in an inertial:

$$\rho \left( \frac{\partial u}{\partial t} + \frac{\partial u}{\partial x} + \frac{\partial u}{\partial y} + \frac{\partial u}{\partial z} \right) = -\frac{\partial P}{\partial x} + \eta \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right)$$  \hspace{1cm} (2)

$$\rho \left( \frac{\partial v}{\partial t} + \frac{\partial v}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial v}{\partial z} \right) = -\frac{\partial P}{\partial y} + \eta \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right)$$  \hspace{1cm} (3)

$$\rho \left( \frac{\partial w}{\partial t} + \frac{\partial w}{\partial x} + \frac{\partial w}{\partial y} + \frac{\partial w}{\partial z} \right) = -\frac{\partial P}{\partial z} + \eta \left( \frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right)$$  \hspace{1cm} (4)

where \( \rho \) is the fluid density, \( u, v \) and \( w \) is the fluid velocity components, \( P \) is the pressure respectively. The energy equation can be written as

$$\rho c_p \left( \frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z} \right) = k \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) + \eta \dot{\gamma} + \dot{\alpha} \Delta H$$  \hspace{1cm} (5)

where \( T \) is the temperature, \( k \) is the thermal conductivity, \( c_p \) is the specific heat, \( \eta \) is the viscosity, \( \dot{\gamma} \) is the shear rate, \( \dot{\alpha} \) is the conversion rate and \( \Delta H \) is the exothermic heat of polymerization. The EMC material is assumed to be a GNF and it was expressed by the Castro Macosko rheology model.
\[ \eta(T, \dot{\gamma}, \alpha) = \frac{\eta_o(T)}{1 + \left( \frac{\eta_o(T)}{\tau^*} \right)^{1-n} \left( \frac{\alpha_g}{\alpha_g - \alpha} \right)^{c_1+c_2\alpha}} \]  

(6)

with

\[ \eta_o(T) = B \exp \left( \frac{T_b}{T} \right) \]  

(7)

where \( \eta_o \) is the zero shear rate viscosity, \( \tau^* \) is the parameter that describes the transition region between zero shear rate and power law region of the viscosity curve, \( B \) is exponential-fitted constant and \( T_b \) is the temperature fitted-constant. Meanwhile \( \alpha \) is conversion of reaction, \( \alpha_g \) is degree of conversion of gel point and \( c_1 \) and \( c_2 \) are fitting constants. This model will use in EMC material as rheology model, the present of curing reaction which is rate of conversion, \( \alpha \) have change the viscosity and shear rate of material during encapsulation in simulation.

3. Simulation model and boundary condition

The cavity has 3 x 3 flip chip package in matrix array arrangement. The cavity have four inlet and seven outlet. The geometry of flip chip is summarized in Table 1 and its arrangement in the cavity is shown in Figure 1. The total tetrahedral element of meshing for cavity is 1,326,483. Hitachi CEL-9200 (LF) is defined as EMC material and its properties is summarized in Table 2. Castro Macosko model is used as rheology model of material with the rate of conversion (\( \alpha = 0.01 \)). The cavity temperature (\( T_w \)) is set as 448 K and inlet temperature (\( T_{in} \)) set as 343 K. The inlet pressure during encapsulation process is 70 kg/cm\(^2\)[8].

| Table 1. Geometry of flip chip |  
|-------------------------------|  
| **Flip chip parameter**        | **Dimension (mm)** |
| Substrate size                | 7 (W) x 7 (L) x 0.1 (H) |
| Solder bump diameter          | 0.45 |
| Solder bump count             | 64 |
| Bump standoff height          | 0.15 |
| Pitch size                    | 0.80 |

| Table 2. Material Properties  |  
|-------------------------------|  
| **Parameter**                 | **Value** |
| \( \rho \) (kg/cm\(^3\))     | 1856 |
| \( c_p \) (J/kg.K)            | 1078 |
| \( k \) (W/m.K)               | 0.74 |
| \( T_b \) (K)                 | 4810.3 |
| \( B \)                       | 0.042168 |
| \( n \)                       | 0.7773 |
| \( \tau^* \) (N/m\(^2\))     | 0.0001 |
4. Result and discussion

Figure 2 shows velocity versus Z-direction of EMC in cavity package at 5 s of filling stage during encapsulation. The graph was plotted half of the cavity, since another half is symmetry. The velocity of EMC is high at FP region and lower at FC region. When EMC flow through FC, the retardation flow occur due obstacle from flip chip package, it is caused the velocity of EMC drop at FC region. Besides that, the velocity of FP at middle area of cavity is higher than FP at side area. This is because the effect of inlet position at the middle area of cavity package. The shear stress also occurred between EMC and flip chip wall which contain substrate and solder bump.

Figure 3 shows the shear rate versus Z-direction of cavity package. The shear rate of EMC at FC is lower than FP region. The shear rate of EMC reduced because the velocity of EMC drop due to obstacle from flip chip. When the EMC flow through flip chip, the effect of wall stress from substrate and solder bump have reduce the velocity and shear rate of EMC.
Figure 3. Shear rate versus Z-direction of cavity package

Figure 4 shows the viscosity versus Z-direction of cavity package for FP and FC during encapsulation process. From the figure, the viscosity of EMC is higher when it flow through the FC region while low through the FP region. The difference of these values is due to the flow obstruction by the flip chip package. The viscosity is inversely proportional to shear rate. When the shear rate of EMC is decreased, the viscosity of EMC will increase. In non-Newtonian fluid, the viscosity mostly dependent on shear rate. Besides that, the shear stress also occurred between EMC and flip chip. The velocity, shear rate and viscosity of epoxy is an important factor in encapsulation process. Improper handling of these factors will contribute the imperfection of board package such as incomplete filling and void formation.

Figure 4. Viscosity versus Z-direction of cavity package

Figure 5 (a) shows the velocity profile for single multi flip chip package at y-direction of cavity package. The velocity profile of EMC before reach the flip chip is narrow with highest peak of velocity at the middle area of cavity package. When it reached at flip chip, the velocity profile have the curvature at the region (a gap between flip chip and cavity). The velocity of EMC is increased after the EMC flow past the flip chip. At flip chip, the velocity range is higher than velocity at free passage due to effect of
obstacle from flip chip which it limit the EMC flow through the flip chip. As the results, the EMC flow will move toward top region of flip chip package and increase the velocity of EMC flow. The position of EMC flow which is far from the inlet can be seen start to cure from cavity wall, this call as the frozen skin layer effect, the increasing of frozen skin layer at cavity wall tend to increase the EMC flow velocity at the middle area of cavity package. The rectangle shape as shown in Figure 5 (b) shows the position of velocity profile along x-direction during encapsulation.

(a)

(b)

Figure 5. Velocity profile distribution of EMC at multi flip chip package.

5. Conclusion

The numerical investigation was been studied on molded underfill of multi flip chip package. The velocity, shear rate and viscosity profile have been plotted to analyze the flow behaviour of EMC in molded underfill of multi flip chip package during encapsulation. The viscosity profile of EMC is inversely proportional to the shear rate and velocity profile at FC and FP region. Furthermore, the velocity profile of EMC is used to describe the prediction of frozen skin layer during encapsulation in cavity package. The frozen skin layer tend to occur at the end of cavity package which is far from pressure inlet of cavity package.

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