PENGISIAN ACUAN DALAM PEMBUNGKUSAN ELEKTORNIK

(MOULD FILLING IN ELECTRONIC PACKAGING)

Oleh

HENG CHAI WEI
65408

Penyelia

PROF. K. N. SEETHARAMU

MARCH 2005

Disertai ini dikemukakan kepada
Universiti Sains Malaysia
Sebagai memenuhi sebahagian daripada syarat untuk pengijazahan dengan kepujian

SARJANA MUDA KEJURUTERAAN MEKANIK

Pusat Pengajian Kejuruteraan Mekanik
Kampus Kejuruteraan
Universiti Sains Malaysia

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree

Signed……………………………………………………………………………(candidate)
Date ……………………………………………………………………………

STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

Signed…………………………………………………………………………… (candidate)
Date ……………………………………………………………………………

STATEMENT 2

I hereby give consent for my thesis, if accepted, to be available for photocopying and for interlibrary loan, and for the title and summary to be made available to outside organizations.

Signed……………………………………………………………………………(candidate)
Date ……………………………………………………………………………

ACKNOWLEDGEMENT

I wish to take this precise opportunity to express my sincerest appreciation to Prof. K. N. Seetharamu for his guidance and moral support in my final year project. I am very fortunate to be associated with him in pursuing my research interest.

I am grateful to Mr.Venkatesh M.Kulkani for many fruitful discussions, encouragement and valuable suggestions. Without his guidance, I will not be successfully accomplished my final year project.

My sincere thanks to Mr. Tan Chun Wai, for many constructive, useful suggestions and moral support.

I would like to thank to all my fellow colleagues and friends for their support and help throughout the course of this work.

My infinite love and thanks are due to my parents, because all what I have accomplished in life is granted by their unconditional love and years of sacrifice. I will ever be thankful to my sisters and brother for their affection and encouraging words during the pursuit of this course.

Chai wei

TABLE OF CONTENTS

CHAPTER 3

CHAPTER 4

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

A	Area
$[C_E]$	Convection matrix
F	Pseudo-concentration
$[G_1]$, $[G_2]$	Gradient matrix
$[K_{ME}]$	momentum diffusion

$\left[K_{SE}\right]$	stabilization matrix
$\left[K\right]$	K-matrix
$\left[M\right]$	Mass matrix
$\left[M_{LE}\right]$	lumped mass matrix
N_{i}, N_{j}, N_{k}	Shape function
t	time
$\bar{u}$	Volume averaged velocity in x-direction
u_{∞}	free stream velocity
$\bar{v}$	Volume averaged velocity in y-direction
$\upsilon_{a.d}$	Artificial diffusivity
P	Pressure
ρ	Density
τ	Shear stress
μ	Fluid viscosity
Ω	Domain

ALIRAN ACUAN

DALAM PEMBUNGKUSAN ELEKTRONIK

ABSTRAK

Projek tahun akhir ini tertumpu kepada kajian ke atas aliran bendalir dalam proses enkapsulasi yang khas digunakan dalam industri pembungkusan elektronik. Program yang berasaskan kepada Matlab telah digunakan dalam kajian ini. Kaedah Characteristic Based Split (CBS) yang digunakan dalam program ini bertujuan untuk menganalisis dan membuat model bagi aliran bendalir dalam satu acuan yang tunggal bagi proses enkapsulasi. Taburan halaju bendalir yang diperolehi daripada kaedah CBS akan digunakan dalam algorithm pseudo-kepekatan, di mana teknik VOF juga terlibat untuk mengesan muka hadapan bendalir bagi setiap masa tertentu. Kaedah berangka tak terhingga digunakan untuk meringkaskan persamaan-persamaan pemerintah pembezaan separa kepada persamaan-persamaan algebra. Kajian paramater telah dijalankan untuk meninjau bagaimana parameter atau dimensi acuan dan “die atau chip” mempengaruhi sifat-sifat aliran bendalir dalam acuan. Hasil daripada kajian parameter menunjukkan bahawa masa pengisian penuh bagi bendalir dalam kes-kes tertentu adalah berbeza. Hal ini adalah disebabkan oleh rintangan hidraulik dan tekanan di kawasan kemasukan bendalir adalah berbeza. Tujuan kajian parameter ini dibuat adalah untuk mencapai pengisian yang seimbang dalam acuan bagi proses enkapsulasi.

ABSTRACT

This final year project focuses on the study of flow in encapsulation processes of electronic packaging in an industry. The present study is using a program, which is written in Matlab language. Characteristic Based Split (CBS) method is utilized in this program to analyze and model the fluid flow in a single cavity mold of the encapsulation process. The velocity field obtained from CBS method is thus used in pseudo-concentration algorithm, which uses the VOF technique to track the fluid front for each time step. Finite element method (FEM) is employed in all the analyses to reduce the governing partial differential equations to algebraic equations. Parametric studies have been carried out to study how the dimensions and parameters of the gate and die/chip affect the flow filling's behavior. Parametric studies showed by altering the dimensions of the mold tools, the filling time for certain cases would be different due to different hydraulic resistances and pressure at the entrance of the mold cavity. These parametric studies conducted for the purpose to achieve balanced mold filling in the encapsulation process.

Chapter 1

INTRODUCTION

1.1 Electronic Packaging

Electronic packaging plays an important role in the electronic industry. Due to the development of technologies nowadays, the electronic packaging design performs tasks of ever increasing importance in the electronic industry. The continuous trend towards the miniaturization of electronic equipment has revolutionized the assembly and packaging of electronic components. More user friendly and wider variety of functions is provided in these electronic devices. This means that more interconnections will have to be made in less space. The key functions of an electronic packaging are to protect those active electronic components from electrical, mechanical and chemical hazards. It also protects the devices from outside environment. Besides that, it also provides heat dissipation, signal timing and power distribution. The challenge for the package is to provide all distinct functions required by the microelectronic part without limiting the performance of the part. As the semiconductor technologies progresses towards higher levels of integration and high performance increases functionally, the design and fabrication of the package that will meet the requirements of the modern and future microelectronic system become more complex and challenging.

There are several types of package material are used for silicon integrated circuits. The electronic packages are classified as ceramic packages, refractory glass packages and plastic packages. Plastic packaging is more efficient since the assembly and process are conducted on lead frames, which typically grouped four to twelve devices together. This configuration facilitates handling and makes the process more amenable to automation and also helped to keep the costs low and market share high. Plastic packaging utilizes a metal lead frame and metallized circuit pattern to mount the silicon device and a fanout pattern of leads to the pins of the package. The function of molded plastic material is to protect the chip and lead frame from physical damage and contamination.

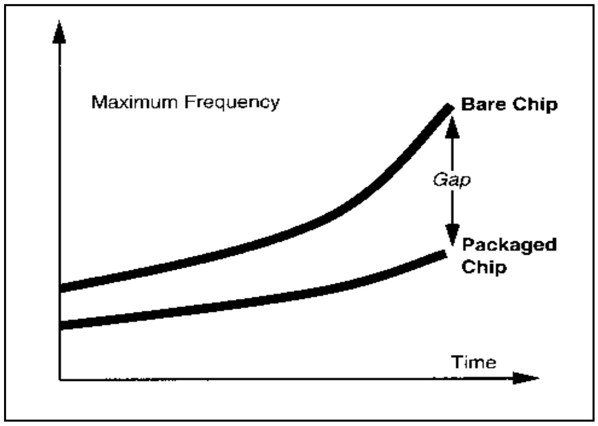
1.2 Encapsulation

Encapsulation is a common packaging technique, which provides an economical way to protect the active device from outside environment pollutants and both chemical and mechanical protection of the IC (Integrated Circuit). It is typically done by means of low temperature polymers. An electronic device has to be packaged in advance so that it is interconnected with the other components of the system before it can perform its designed function. Present encapsulation techniques are based on flip chip process, where the silicon die is attached to the package substrate and electrically connected through an array of solder bumps. Encapsulation materials are molded onto the IC or dispensed under the die, such as with flip-chip BGA packages.

Different type of packages requires either encapsulation or sealing to protect the die in the package. Encapsulation is a type of protection with an organic overcoat. This type of protection is not permanent and is controlled by permeation properties of the polymer resins. Sealing involves inorganic overcoat in protection. This type of protection is permanent and it is hermetic. By comparison, the cost of sealing protection is higher.

1.3 Packaging challenge

Basically, the system performance of an electronic device is influenced by the package itself. It is shown clearly in **figure 1.1** that the package is already the bottleneck to the system performance. The maximum frequency of the bare chip is higher than the packaged IC. Obviously, the package limits the IC technology. The simple fact is that the on-chip silicon system can out-perform the speed capability of the package. As volume production techniques continue to drive the cost of bare silicon chips down, the cost of the packaging constitutes a greater and greater proportion of the total system cost. Due to this, the challenges for electronic packages in the future are becoming extremely complex. An optimum packaging design has to be achieved by considering seriously the aspects that will affect the performance of an electronic packaging.



.

Figure 1.1: IC packaging performance gap (Tumala, 2001)

1.4 Encapsulation processes

Encapsulation process is divided into two major categories: molding and liquid encapsulation.

1.4.1 Molding

Molding is the process of encapsulating the device in plastic material. Transfer molding is one of the most widely used molding processes in the semiconductor industry because of its capability to mold small parts with complex features. The process takes place where the heated molten molding compound is transferred from a pot, through the runners and flow into the mold cavities when applying the pressure. Although this is a low cost method for most device encapsulation but it is hard to apply to some new applications such as flip-chip and cavity fill type PGA (Pin Grid Array). Molding operation can be done individually on a single device as well as in molded array package (MAP). In order to avoid any defects such as wire sweep and void entrapment, spherical silica fillers is used in the molding compound for MAP operation. Besides that, a perfect mold design is also essential to minimize those defects.

1.4.1.1 Transfer molding process

Transfer molding process involves a series of in-line cavities that exists in the transfer mold. Each cavity has very small exhaust channels, called vents, which allow the air to exit the cavity as the molding compound enters. The runner is connected to a small entrance port, called gates, which feeds the molding compound to each cavity. Normally, large molds also contain the primary runners, which connect these strip runners to the main transfer pot. This transfer pot that situated near the center of the mold will receive the molding compound initially. Knockout pins lay flush with the runner and cavity surface during the molding cycle and then extend into those regions to push the molded devices and runners out when the mold opens.

Basically, the operational process is simple and usually automated. In the process, the molding compound is first preheated prior to its loading into the molding chamber. After pre-heating, the molding compound is forced by a hydraulic plunger into the pot where it reaches melting temperature and becomes fluid. The plunger then continues to force the fluid-molding compound into the runners of the mold chase. These runners serve as canals where fluid-molding compound travels until it reaches the cavities, which contain the lead frames for encapsulation. By the time the material starts to enter the cavities, it is fully molten and usually performed at minimum viscosity. This transfer continues at rather near-atmospheric pressures until all cavities fill. There is an increment in pressure to “pack-out” the molding compound and to ensure that the sharp cavity corners fill out completely. The pressure will continue to hold until the molten compound become rigid enough to support the devices. After that, the mold opens and all molded gates and runners eject into collection systems. Brushes are then used to clean away any residue or flash of molding compound and the cycle begins again.

The presses, which hold and operate the mold, have three main functions: they clamp the molds closed, they move the transfer ram and they control the mold temperature. For an automated press, it manages all other functions like device loading and device/runner ejection. This type of press is typically for gang-pot molds. **Figure 1.2** shows the typical transfer molding process.

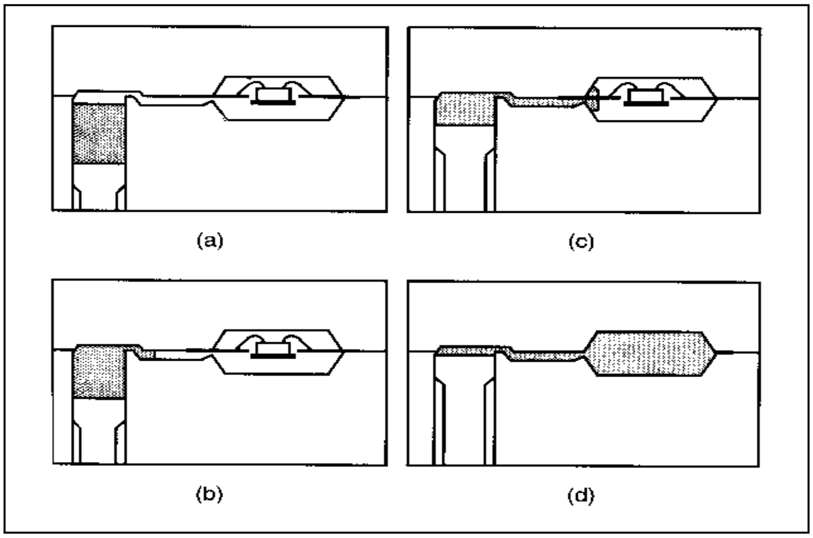


Figure 1.2: A typical transfer molding process (Tumala, 2001)

1.4.2 Liquid encapsulation

Liquid encapsulation is an effective way to make sure that the reliability of fine-pitch, low-gap devices where the encapsulant material is dispensed into a liquid form and then cure to form a solid encapsulated package. By using this process, the utilization of the encapsulation materials can be maximized, as compared to the inefficient use of the molding compounds in the transfer molding operation. The liquid encapsulant can be designed into different viscosity grades to fit into different type of flow requirements. Cavity filling, glob topping and underfilling are the most used liquid encapsulation processes. For the sake of brevity, only the most common process, which is underfillng, will be discussed here. (Tummala, 2001)

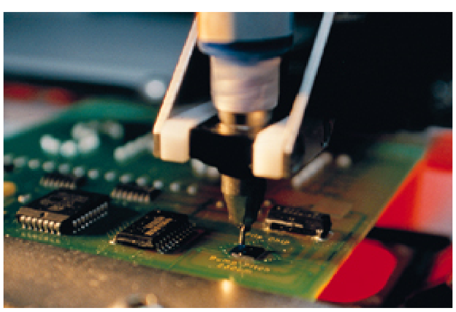
1.4.2.1 Underfilling encapsulation

The underfilling encapsulation in a device serves several purposes. Its most important role is to compensate for the difference in the coefficient of thermal expansion between the substrate and die surface. If there is no underfill, the stress that created by this difference is typically large and would be absorbed by the solder bumps entirely. The total bond area of the solder bumps is always much smaller than the respective areas of the die and the substrate. As a result, the stress on an individual solder bump is relatively great. To reduce these stresses, the stand off region between die and package is encapsulated with epoxy molding compound

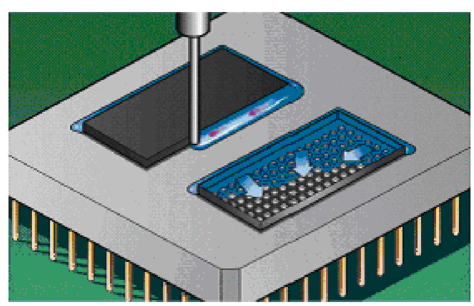
(EMC) using underfill encapsulation process. By absorbing energy during thermal cycling, the underfill reduces this stress by a factor of about 10.

Underfill acts an isotropic compression container around each bump helps to prevent the solder from creeping during thermal cycling. In normal operation, temperatures are sufficient to allow solder to begin to creep if there is an adjacent free space. Such creep would deform the bump and lead to the failure of the interconnection. At the same time, the underfill prevents the initiation of cracks in solder bumps by eliminating free surfaces at grain boundaries where cracks could propagate. Underfill also serves to some degree as a heat sink to dissipate heat from the die. Though for this to happen, it is necessary that all regions of the cured underfill have the same thermal characteristics, as variations can cause overheating in the die.

In order to perform all of these functions, the underfill must possess very specific material properties that are dependent on the two major constituents of the underfill, which are the epoxy and the filler particles. A suitable underfill fluid that had properly dispensed will maintain a homogeneous mixture of epoxy and filler particles as the fluid flows between the die and the substrate. When the fluid underfill is dispensed, it is driven by capillary action are filled at a low speed between the integrated circuit (IC) Chip and the substrate in order to increase the thermal cycle fatigue life and the reliability of the bump interconnect. Because of the capillary effect, the underfiller flows into the voids between the chips, the substrate and the solder bumps. **Figure 1.3(a)** and **figure 1.3(b)** show the flip clip encapsulation process and the way in which the fluid underfill dispensed respectively.



(a)



(b)

Figure 1.3: (a) Flip clip encapsulation process
(b) Sketch of fluid underfill dispense (www.asymtek.com)

The open spaces between the flip chip surface and the board or substrate is filled with a non-conductive adhesive underfill material to protect the bumps and the flip chip surface from moisture, contaminants, and other environmental hazards. More importantly, this underfill material mechanically locks the flip chip surface to the board or substrate, thereby reducing the differences between the expansion of the flip chip and the substrate. This prevents the bumps from being damaged by shear stresses caused by differences between the thermal expansions of the chip and the substrate. **Figure 1.4** shows the place where the adhesive situated between the flip clip and the substrate. Dispensing the correct volume of fluid underfill will ensure that the entire space is filled properly, even during normal variations in production processes. Normally, a cracked die often causes incomplete underfill.

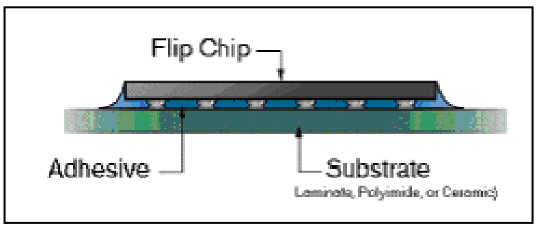


Figure 1.4: Placement of the adhesive in one device (www.asymtek.com)

The adhesive acts in several ways to reduce the overall stresses that related to bump failure. Besides that, the adhesive also used to reduce the onset of crack initiation in the bump substrate interface due to thermal fatigue stresses because no free surface available. Apart from that, the adhesive shrinkage produces a compressive stress on the bump in order to reduce the thermally induced normal stress. (Babiarz. A. J., 1999).

1.5 Objective

The objectives of the present work are listed below:

- Establish a general solution algorithm to model the flow of Newtonian fluid in transfer molding.
- Conduct parametric study using Finite element code available. The results can be used as a design guideline to optimize the encapsulation process prior to fixing of actual manufacturing setup.

Chapter 2

LITERATURE SURVEY

2.1 Introduction

Plastic ICs encapsulation is essential in providing the protection to the IC and enables the packaged IC to perform its desired functions in many different types of environment. Basically, encapsulation can be classified into two major categories: molding and liquid encapsulation (Tumala, 2001). In the manufacturing of plastic packages field, transfer molding of ICs is an important process that has to take into account. Although transfer molding is a well-established procedure in the manufacturing field, but the process still difficult to optimize and remain subject to several manufacturing defects, such as incomplete encapsulation, void formation and excessive deformation of wires and leadframes (Nguyen et al., 2000). Fine pitch wirebonding is the recent advances in other areas of packaging (Nguyen et al., 1998) and molded array package technologies, have increased the risk of defects, and imposed even more demanding requirements on the molding process (Nguyen and Lee, 1998) and the material formulation (Nguyen et al., 1997).

2.2 Flow models in molding

Research efforts have been carried out in flow simulation of low temperature molding compounds used in encapsulation for various package designs ranging from wire bonding, chip carrier with beam leads to direct chip connection (Gilleo, 2001).

The first generation molding analysis was based on the model simplifications. The complicated mold geometry was approximately by the combination of several simple geometry models. The second-generation technique appeared in the early 1980s. The combination of finite element method (FEM) with the Generalized Hele-Shaw (GHS) model was developed successfully to simulate the mold filling in complex geometry and to help optimize the mold design. However, this type of analysis is restricted to thin parts only. Most of the current available commercial molding analysis packages are based on the GHS approximation.

A finite element method based on the Hele-Shaw approximation has been used in the study of Turng and Wang (1993) and Nguyen (1994). A generalized Newtonian fluid model describes the behavior of the epoxy-molding compound. Analysis is carried out for a simplified geometry by treating the leadframe as a solid although the geometry in the chip cavity is complicated.

Holm and Langtangen (1999) presented a simulation model for injection molding. A 2-dimensional Hele-Shaw approximation is adopted for the polymer flow between two flat plates, whereas the moving polymer-air front is handled by a level-set-like method. The 3-dimensional heat equation is solved using finite difference in time domain. The main advantage of this model is that a common 2-dimensional finite element mesh can be used for all the equations.

Kuah (1999) used commercial software C-MOLD to design the gate and runner systems in order to achieve a balance flow and thus can minimize the wire sweep during the encapsulation of the QFP IOOL ultra fine pitch wire bonded package. The software models the mold filling by assuming a Hele-Shaw flow of an incompressible viscous polymeric melt under non-isothermal and symmetric thermal boundary conditions. The numerical scheme is a hybrid finite element/finite difference method, which solves pressure and temperature fields. The moving melt fronts are tracked by a control volume method. The numerical results have been compared to actual short shot sample and the results are compared well.

Hang and Wang (2000) used Hele-Shaw approximation to analyze the flow in the chip cavity, particularly the flow through the openings in the leadframes. There are two methods to model the cross flow through the openings of the leadframes. For the first method, the cross flow has been modeled using a cross-flow element that connects the lower and upper chip cavity. The analytical equations for the pressure drop during flow through the opening are used to determine the thickness of the cross-flow element. For the second method, the flow through the leadframe opening has been modeled as a source term in the continuity equation. The value of the source term in the continuity equation was calculated using analytical equations for the pressure drop during flow through openings. The two types of methods will give the same results but the second method is more suitable for the package with many small openings in the leadframe.

2.3 Flow models in underfilling encapsulation

The development of simulation capabilities for the analysis of underfill encapsulation process is of primary importance to understand the effects of the various process variables in the final underfill properties. Underfilling is an electronic packaging technology used to reinforce the solder joints between chip and the substrate to reduce stresses developed due to mismatch of thermal expansion coefficient between the silicon die and package substrate.

The fluid flow in underfilling process has been simulated by C.W.Tan et.al (2004). He used generalized porous medium approach to study disperse or injection of fluid into an underfilled area within the standoff gap of a flip-chip without actually modeling the geometry of the solder joints. The underfill area (flow domain) is treated as a porous media represented by a porosity, ε value which accounts for volume fraction of underfill region available for flow.

Turng and Wang (1993), Nguyen (1994) and Tan *et.al.*(2004) have attempted to analyze the flow during the encapsulation process numerically. Daniel *et.al*.(2003) have presented large-scale numerical models for underfill encapsulation process. The numerical formulation consists of the finite element method coupled with the volume of fluid technique and is based on generalized Hele-Shaw equations.

Sejin and Wang (1997) had carried out studies about the flow of the encapsulant during the flip clips underfill encapsulation process. They developed the models for both capillary driven encapsulation and forced injection encapsulation processes. The numerical analysis used a finite element method based on Hele-Shaw method for solving the flow field. Sejin and Wang have also developed a process to study the pressurized underfill encapsulation of flip chips. The process used a special mold to surround the chip to be encapsulated and injects the encapsulated material at elevated pressure. This pressurized encapsulation process reduced the fill time, which was able to perform the encapsulation at room temperature, filled the cavity completely without any voids and increased the capability of handling viscous encapsulants relative to the customary dispensing process for the particular case used in the experiment.

Characteristic Based Split (CBS) Method has been used by Kulkarni et.al (2004) to analysis the fluid flow of the underfilling process. They used CBS method to model this fluid flow in chip cavity. Velocity and pressure fields are thus obtained from CBS scheme, which uses Finite Element Method to solve the governing partial differential equations. The velocity field is then used in pseudo-concentration algorithm to track the fluid front. The pseudo-concentration method is based on Volume of Fluid (VOF) technique.

2.4 Front tracking

The primitive variables, i.e. velocity and pressure fields, obtained from flow analysis have to be coupled with front tracking algorithm making the advancement of fluid in a cavity traceable at any instance before the cavity is filled. When modeling the free surface, consideration may be given for either the VOF (Volume of Fluid) method or the Lagragian method (Hirt et al., 1974). The latter approach has an advantage since it naturally gives the position of the free surface via its moving boundary as the fluid fill the cavity. However, as the mesh keeps changing in size and position, a robust unstructured automatic mesh generator is required since frequent remeshing is needed owing to rapid distortion and movement of the free surface. Hence, it is more economical to use the Eulerian approach, which only requires a fixed mesh, and therefore the VOF method has been adopted for free surface tracking.

Generally the algorithm for tracking free surface, based on volume of fluid (VOF) method, has been introduced by Hirt and Nichols (1995). This method has been used in conjunction with the continuity and Navier-Stoke equations by many authors in the literature to solve mold-filling problems. Gethin and Abdullah (1997) presented a finite element formulation for filling thin sections. The formulation is based on analogy that the local velocity profile across the thin section mimics the laminar Poiseuille flow between two surfaces. The velocity and the pressure fields were coupled with the VOF method to predict the free surface. The VOF method is written in the form of a first-order pure advection forming pseudo-concentration equation.

Prasad (1999) has used a front tracking technique namely Pseudo-concentration method with an additional artificial diffusion term. The functions of the artificial diffusion are to allow partial slip at polymer-wall interface and to damp numerical oscillation in the algorithm. This technique is based on the volume of fluid method (VOF), employs a well-known marker and cell (MAC) technique. A particular value of the pseudo-concentration variable, F was chosen to represent the free surface demarcating the polymer and air regions, which can be tracked for each time step. The main advantage of this method is that the location for the moving front and the front boundary conditions need not be explicitly accounted for.

Studies have been carried out by Kang and Lee (1999) using a modified control volume finite-element (CVFE) method along with fixed-grid method to the process of mold filling during resin-transfer molding. It used to handle the problems associated with the moving resin front. The fixed grid was refined in an adaptive manner, which dividing the flow-front elements into two regions using the estimated flow front. New ‘imaginary nodes’ are placed at the intersections between the original element border and the temporary flow front. The pressure at these new ‘imaginary nodes’ represented the pressure at the old ‘real nodes’ by using the mass conservation of resin. The ‘imaginary nodes’ do not affect the size of the global matrices and thus do not increase the computational time. A proposed method called FINE, provided smoother flow fronts and reduced the error in the pressure at the flow front that plagued the conventional fixed-grid methods.

The fluid front tracking is carried out using Volume Of Fluid (VOF) technique. The velocity field obtained from CBS scheme is used in pseudo-concentration approach to track the advancement of fluid front. A particular value of the pseudo-concentration variable is chosen to represent the free fluid surface demarcating the mold compound and air regions that can be tracked for each time step. Simulation has been carried out for a particular geometry of a flip chip package.

2.5 Summary

Various flow models and front tracking algorithms for mold filling and underfill encapsulation processes have been presented in this chapter. Many authors have extensively used the application of Finite Element Method in Hele-Shaw approximation to solve the field problem of mold filling and underfilling. The use of Hele-Shaw model in commercial package like C-MOLD and FLUENT has been reported in the literature as well. Various factors, which can adversely affect the reliability and performance of encapsulated packages during filling stage like voiding, incomplete encapsulation etc., have been discussed. Several authors validated their simulation results by using experimental data from short shot in transfer molding process. Although many model for curing kinetics and rheology of polymeric flow reported in the literature, it was found that one cannot use the available model for verification purposes without knowing all the coefficients and curve fitting parameters derived empirically.

The present trend to produce faster, smaller and cheaper electronics products is driving the packaging technology towards higher packaging density with thinner and smaller profile. This makes the plastic encapsulation process much more complicated and is difficult to analyze. The conventional Hele-Shaw approximation is inadequate to analyze such a complex process. So the multipurpose solution algorithm such as characteristic based split method can be used to solve the problems with complex nature.

Characteristic Based Split (CBS) Method has been used to analysis the fluid flow in the chip cavity and to solve the flow-governing equations by using finite element method (FEM). Finally, Volume of Fluid (VOF) method and Finite Element/ Control Volume (FE/ CV) method are two most popular front tracking methods employed in the literature due to their simplicity and only one fixed mesh is required initially to simulate the advancement of fluids (Newtonian and Non-Newtonian) in mold filling or underfilling problems.

Chapter 3

METHODOLOGY

3.1 Introduction

The development of simulation capabilities for the analysis of encapsulation technologies is essential in order to understand the effects of different process variables in the final encapsulation process. All these models can utilize to develop an optimal underfilling process. In this work, the underfilling process is modeled and analyzed by using Characteristic Based Split (CBS) Method and Volume of Fluid (VOF) technique. By using CBS method, the pressure field and velocity field of the fluid flow can be determined. The velocity field obtained is thus used in pseudo-concentration algorithm, which uses the VOF technique to track the fluid front for each time step. Thus, the cavity filling time can be known easily from the simulation model. This model serves as an useful tool for mold design and also for process optimization.

3.2 Characteristic Based Split Method

The finite element method (FEM) has been used for the solution of the Navier-Stokes equations since early seventies. In the last decade, several FEM algorithms have been introduced in the flow problems numerically. Characteristic Based Split (CBS) Method is an algorithm, which was proved to be very efficient and is unified approach for computational fluid dynamics applications. This algorithm used to solve many problems of fluid dynamics, which included the general compressible, and incompressible flow problems, shallow water, thermal and turbulent flows. The procedure of CBS method is developed from the principles of characteristics. A particle is tracked along its characteristics in this procedure. Characteristic Based Split (CBS) scheme is an alternative to finite volume method. It also takes care of numerical oscillations in space, which usually occur in convection-diffusion problems.

In this project, CBS method is used to analyze the fluid flow in encapsulation process, which is used in electronic packaging industry. Semi-implicit time stepping method is used for time domain discretization. Implementation of CBS scheme is then shown after presenting the governing equations of fluid flow.

The governing equations in two-dimensions may be written as follows: (Lewis et.al. 2004)

a. Continuity equation

$$\frac{\partial u_1}{\partial x_1} + \frac{\partial u_2}{\partial x_2} = 0 \tag{3.1}$$

b. x_1 momentum equation

$$\frac{\partial u_1}{\partial t} + u_1 \frac{\partial u_1}{\partial x_1} + u_2 \frac{\partial u_1}{\partial x_2} = -\frac{1}{\rho}\frac{\partial p}{\partial x_1} + \nu\left(\frac{\partial^2 u_1}{\partial x_1^2} + \frac{\partial^2 u_1}{\partial x_2^2}\right) \tag{3.2}$$

c. x_2 momentum equation

$$\frac{\partial u_2}{\partial t} + u_1 \frac{\partial u_2}{\partial x_1} + u_2 \frac{\partial u_2}{\partial x_2} = -\frac{1}{\rho}\frac{\partial p}{\partial x_2} + \nu\left(\frac{\partial^2 u_2}{\partial x_1^2} + \frac{\partial^2 u_2}{\partial x_2^2}\right) \tag{3.3}$$

The Characteristic Based Split (CBS) Method consists of three main steps.

1. An intermediate velocity field will be calculated once the pressure term from the momentum equation dropped.
2. Calculation of pressure from Pressure Poisson equations.
3. Calculation of velocity correction to get actual or real velocities.

3.2.1 Time discretization

For time discretization of above equations, semi discrete method is used. The above equations in their semi-discrete form can be written as below:

Step 1: Intermediate velocity

Intermediate x_1 momentum equation

$$\frac{\tilde{u}_1 - \tilde{u}_1^{\,n}}{\Delta t} = -u_1\frac{\partial u_1^{\,n}}{\partial x_1} - u_2\frac{\partial u_1^{\,n}}{\partial x_2} + \nu\left(\frac{\partial^2 u_1}{\partial x_1^{\,2}} + \frac{\partial^2 u_1}{\partial x_2^{\,2}}\right)^n - u_1\frac{\Delta t}{2}\frac{\partial}{\partial x_1}\left[u_1\frac{\partial u_1}{\partial x_1} + u_2\frac{\partial u_1}{\partial x_2}\right]^n$$

$$-u_2\frac{\Delta t}{2}\frac{\partial}{\partial x_2}\left[u_1\frac{\partial u_1}{\partial x_1} + u_2\frac{\partial u_1}{\partial x_2}\right]^n \tag{3.4}$$

Intermediate x_2 momentum equation

$$\frac{\tilde{u}_2 - \tilde{u}_2^{\,n}}{\Delta t} = -u_1\frac{\partial u_2^{\,n}}{\partial x_1} - u_2\frac{\partial u_2^{\,n}}{\partial x_2} + \nu\left(\frac{\partial^2 u_2}{\partial x_1^{\,2}} + \frac{\partial^2 u_2}{\partial x_2^{\,2}}\right)^n - u_1\frac{\Delta t}{2}\frac{\partial}{\partial x_1}\left[u_1\frac{\partial u_2}{\partial x_1} + u_2\frac{\partial u_2}{\partial x_2}\right]^n$$

$$-u_2\frac{\Delta t}{2}\frac{\partial}{\partial x_2}\left[u_1\frac{\partial u_2}{\partial x_1} + u_2\frac{\partial u_2}{\partial x_2}\right]^n \tag{3.5}$$

Step 2: Pressure calculation

$$\frac{1}{\rho}\left(\frac{\partial^2 p}{\partial x_1^{\,2}} + \frac{\partial^2 p}{\partial x_2^{\,2}}\right)^n = \frac{1}{\Delta t}\left(\frac{\partial \tilde{u}_1}{\partial x_1} + \frac{\partial \tilde{u}_2}{\partial x_2}\right) \tag{3.6}$$

Step 3: Velocity correction

$$\frac{u_1^{\,n+1} - \tilde{u}_1}{\Delta t} = -\frac{1}{\rho}\frac{\partial p^n}{\partial x_1} - u_1\frac{\Delta t}{2}\frac{\partial}{\partial x_1}\left(\frac{1}{\rho}\frac{\partial p}{\partial x_1}\right)^n - u_2\frac{\Delta t}{2}\frac{\partial}{\partial x_2}\left(\frac{1}{\rho}\frac{\partial p}{\partial x_1}\right)^n \tag{3.7}$$

$$\frac{u_2^{n+1}-\tilde{u}_2}{\Delta t}=-\frac{1}{\rho}\frac{\partial p^n}{\partial x_2}-u_1\frac{\Delta t}{2}\frac{\partial}{\partial x_1}\left(\frac{1}{\rho}\frac{\partial p}{\partial x_1}\right)^n-u_2\frac{\Delta t}{2}\frac{\partial}{\partial x_2}\left(\frac{1}{\rho}\frac{\partial p}{\partial x_2}\right)^n \tag{3.8}$$

3.2.2 Spatial discretization

On assuming linear interpolation functions for all the variables, the spatial variation for a linear triangular element may be written as below (refer to **figure 3.1**):

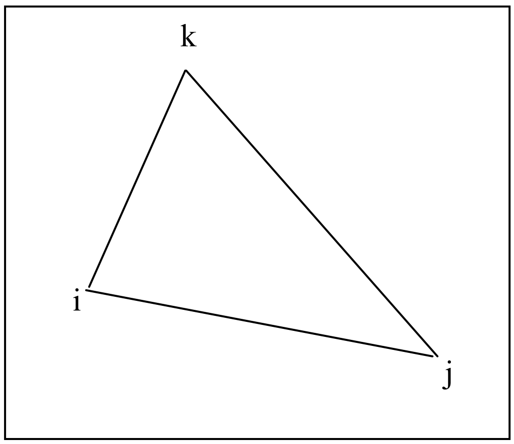


Figure 3.1: Two-dimensional triangular element

$$u_1 = N_i u_{1i} + N_j u_{1j} + N_k u_{1k} = [N]\{u_1\} \tag{3.9}$$

$$u_2 = N_i u_{2i} + N_j u_{2j} + N_k u_{2k} = [N]\{u_2\} \tag{3.10}$$

$$p = N_i p_i + N_j p_j + N_k p_k = [N]\{p\} \tag{3.11}$$

The final form of equations in matrix form can be written as:

Step 1: Intermediate velocity calculation

for x_1 component,

$$[M]\frac{\Delta\{\tilde{u}_1\}}{\Delta t}=-[C]\{u_1\}^n-[K_m]\{u_1\}^n-[K_s]\{u_1\}^n \tag{3.12}$$

for x_2 component,

$$[M]\frac{\Delta\{\tilde{u}_2\}}{\Delta t} = -[C]\{u_2\}^n - [K_m]\{u_2\}^n - [K_s]\{u_2\}^n \tag{3.13}$$

Step 2: Pressure calculation

$$[K]\{p\}^n = -\frac{1}{\Delta t}\left[[G_1]\{\tilde{u}_1\} + [G_2]\{\tilde{u}_2\}\right] \tag{3.14}$$

Step 3: Velocity correction

$$[M]\{u_1\}^{n+1} = [M]\{\tilde{u}_1\} - \Delta t[G_1]\{p\}^n \tag{3.15}$$

$$[M]\{u_2\}^{n+1} = [M]\{\tilde{u}_2\} - \Delta t[G_2]\{p\}^n \tag{3.16}$$

where

$[M]$ = Mass matrix

$[M_{LE}]$ = lumped mass matrix

$[C_E]$ = convection matrix

$[K_{ME}]$ = momentum diffusion

$[K_{SE}]$ = stabilization matrix

$[K]$ = K-matrix

$[G_1]$ and $[G_2]$ = Gradient matrix

For the details of element mass matrix, lumped mass matrix, convection matrix, momentum diffusion matrix, stabilization matrix, K-matrix, gradient matrix and force matrix, one can find by refer to Lewis et.al (2004).

3.3 Pseudo-concentration approach

Pseudo-concentration approach, which is based on the Volume of Fluid Method (VOF), is used for front tracking in transfer molding and underfill encapsulation simulation. This method employs well-known marker and cell technique. In order to represent the free fluid surface demarcating the polymer and air regions, which can be tracked for each time step, a particular value of the pseudo-concentration, variable, F is chosen.

The reliability and efficiency of the mold filling model depends significantly on the choice of technique used for the advancement of liquid front. A fixed mesh approach is employed, where the liquid front progressively fills various elements of the mesh during filling period. The front tracking algorithm is based on

(a) a pseudo-concentration function F(x, y, t) which gives a smooth representation of the interface region.

(b) the transport of liquid front through the Eulerian representation.

$$\frac{dF}{dt} = \frac{\partial F}{\partial t} + u\frac{\partial F}{\partial x} + v\frac{\partial F}{\partial y} = 0 \qquad (3.17)$$

This equation allows the function F(x, y, t) to move with the flow. A particular value of F is associated with the fluid free surface and plotting the contour of that particular value gives the position of the free surface. In the present work, $F = 1$ is used to denote the free surface, while $F > 1$ indicates the fluid region and $F < 1$ indicates the empty region.

The success of the front tracking algorithm depends on a proper choice of F and evaluation of the melt front from the predicted value of F. For this purpose, it is desired that the solution of equation 3.18 be obtained without any oscillations. In order to smoothen the numerical oscillations, an artificial diffusion term is added. The transport equation for F is further modified as:

$$\frac{dF}{dt} = \frac{\partial F}{\partial t} + u\frac{\partial F}{\partial x} + v\frac{\partial F}{\partial y} - \upsilon_{a.d}\left\{\frac{\partial^2 F}{\partial x^2} + \frac{\partial^2 F}{\partial y^2}\right\} = 0 \qquad (3.18)$$

where $\upsilon_{a.d}$ is the artificial diffusivity which has to be selected suitably. In addition to that, the artificial diffusion term has an important effect to cause partial slip of the liquid-air interface at the wall (Prasad, 1999).

3.3.1 Finite Element Formulation

Finite difference solution in time (Forward difference method) has been employed for temporal discretization of equation 3.19 (Segerlind, 1984). Discretization of the equation with the application of the Galerkin weighted residual method leads

$$\int_{\Omega}[N]^T F^{n+1} d\Omega = \int_{\Omega}[N]^T F^{n} d\Omega - \int_{\Omega}[N]^T \Delta t\left[\left(u\frac{\partial F}{\partial x} + v\frac{\partial F}{\partial y}\right) - \upsilon_{a.d}\left(\frac{\partial^2 F}{\partial x^2} + \frac{\partial^2 F}{\partial y^2}\right)\right]^n d\Omega \qquad (3.19)$$

where Ω is the volume of the domain.

Finally we get the matrix form of equation as: (Chun Wai, 2003)

$$\frac{A}{3}\begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix}[F]^{n+1} = \frac{A}{3}\begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix}\begin{Bmatrix}F_i\\F_j\\F_k\end{Bmatrix}^n$$

$$-\frac{\Delta t.\upsilon_{a.d}}{4A}\left\{\begin{bmatrix}b_i^2 & b_ib_j & b_ib_k\\ b_ib_j & b_j^2 & b_jb_k\\ b_ib_k & b_jb_k & b_k^2\end{bmatrix} + \begin{bmatrix}c_i^2 & c_ic_j & c_ic_k\\ c_ic_j & c_j^2 & c_jc_k\\ c_ic_k & c_jc_k & c_k^2\end{bmatrix}\right\}\begin{Bmatrix}F_i\\F_j\\F_k\end{Bmatrix}^n$$

$$-\frac{\Delta t}{24}\left[\left(b_iF_i + b_jF_j + b_kF_K\right)^n\begin{pmatrix}2u_i + u_j + u_k\\ u_i + 2u_j + u_k\\ u_i + u_j + 2u_k\end{pmatrix} + \left(c_iF_i + c_jF_j + c_kF_K\right)^n\begin{pmatrix}2v_i + v_j + v_k\\ v_i + 2v_j + v_k\\ v_i + v_j + 2v_k\end{pmatrix}\right]$$

(3.20)

Chapter 4

RESULTS AND DISCUSSION

This chapter consists of two parts. The first part covers the methodology verification. The results that obtained from FEM analysis are compared to results of a case taken from Gethin and Abdullah (1997). This will show in detail in section 4.1. The assumptions used by the authors to derive the formulation for filling a thin cross section are the flow is laminar, incompressible and Newtonian. The same assumptions have been used in present analysis.

In the study of Newton's law of viscosity, it states that for simple fluids with low molecular weight, the shear stress is linearly proportional to the shear rate in laminar flow with the constant of proportionality being defined as the viscosity (Manzione, 1990). The formula is shown below:

$$\tau = \mu \frac{\partial u}{\partial y} \tag{4.1}$$

where $\tau =$ Shear stress

$\mu =$ Fluid viscosity

$\frac{\partial u}{\partial y} =$ Velocity gradient

Figure 4.1 shows the velocity distribution profile that takes place in a duct, which is subjected to free fluid stream for a laminar flow. In a real fluid, the velocity adjacent to a solid boundary will be zero or more accurately, equal to the wall velocity. This condition is called 'no slip', which will be true as long as the flow does not separate from the wall. Obviously, it shows that the boundary layer is still developing and growing in thickness up to its maximum. After a few seconds, the flow may said to be fully developed and no further changes in velocity profile are to be expected downstream, provided that the duct characteristics such as diameter and surface roughness remain constant. In other words, the parabolic velocity distribution profile in the duct will remain the same over the remaining length of the duct. Theoretically, the entry length for a particular duct (the distance from the entry at which a laminar boundary layer ceases to grow) is infinite. However, it is normally assumed that the flow has become fully developed when the maximum velocity, at the duct centerline becomes 0.99 of the theoretical maximum. (Douglas, 2001)

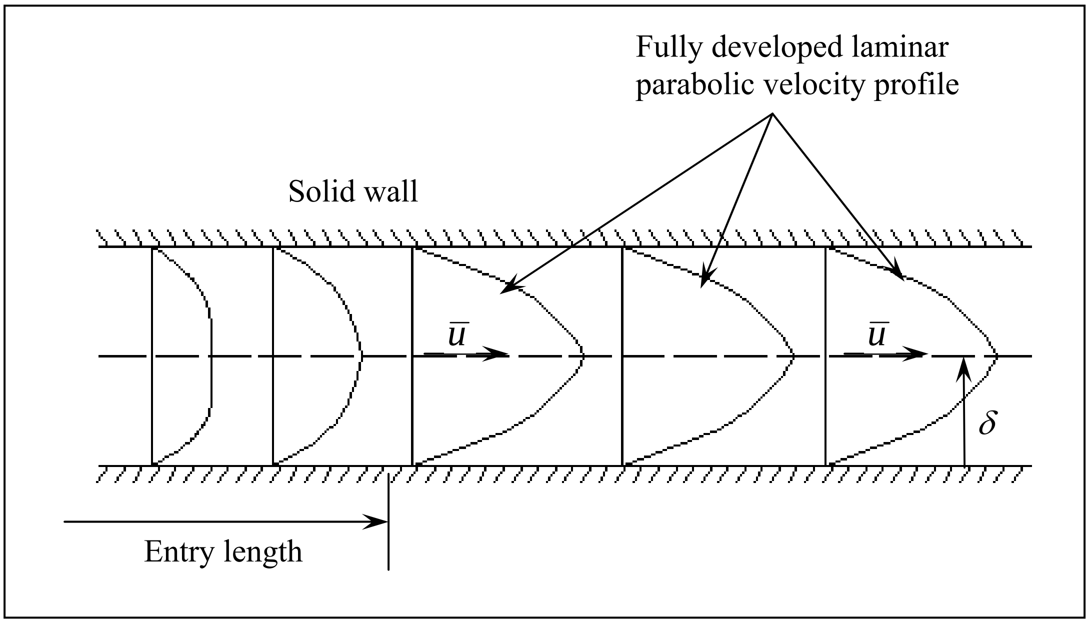


Figure 4.1: Development of fully developed laminar flow in a duct

4.1 Filling a rectangular cavity

Characteristic Based Split (CBS) algorithm is used to study the behavior of flow filling a rectangular cavity, which is shown in **figure 4.2**. This cavity is subjected to a flow with a uniform inflow velocity of 1 m/s in x-direction at inlet and a zero pressure condition is applied at the opposite boundary. The properties of fluid used in this analysis are viscosity, η = 0.05 Pa.s and density, ρ = 1000 kg/m^3. The domain is discretized into 663 nodes and 1200 elements as shown in **figure 4.3**. The pressure and velocity distributions of the domain are first obtained from CBS method. Then pseudo-concentration equation is applied to model the movement of fluid front, which demarcates fluid region from empty air. By using the time step, $\Delta t = 0.5$ ms and an artificial diffusivity, $\upsilon_{a.d} = 1.0$, the simulated flow pattern is shown in **figure 4.4** compare with the results of Gethin and Abdullah (1997).

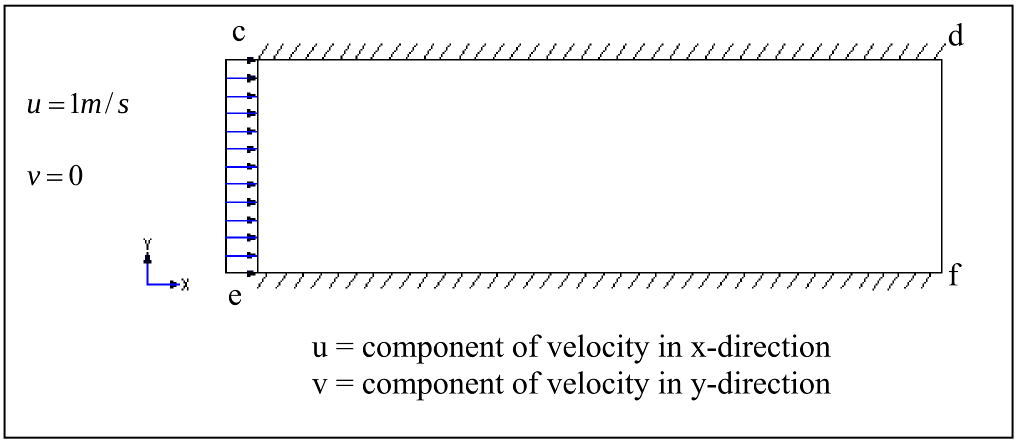


Figure 4.2: Fluid filling a rectangular cavity (all dimensions in mm)

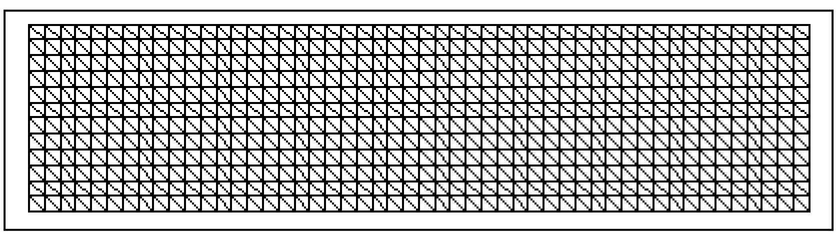


Figure 4.3: Finite element mesh

In **figure 4.2**, the uniform inflow velocity of the flow is 1 m/s and there is no gravitational acceleration. If the slip is permitted on the walls, the position of the free surface, x_c will be

$$x_c = \bar{u}.t \tag{4.1}$$

where t = time and

$\bar{u}$ = velocity

The velocity field is very uniform throughout the domain with the value of $\bar{u} = 1m/s$ and $\bar{v} = 0m/s$. In reality, the predicted free surface will be close to the position of x_c as the boundary layer along the sides cd and ef (**figure 4.2**) is comparatively thin. The simulated front profiles are shown in **figure 4.4**, which agree well with the analytical value described by equation 4.1. Also, the front profiles predicted are comparing well with numerical results from Gethin and Abdullah (1997), (except some minor distortion found at fluid-wall interface), confirming the application of fill simulation in simple cavity types.

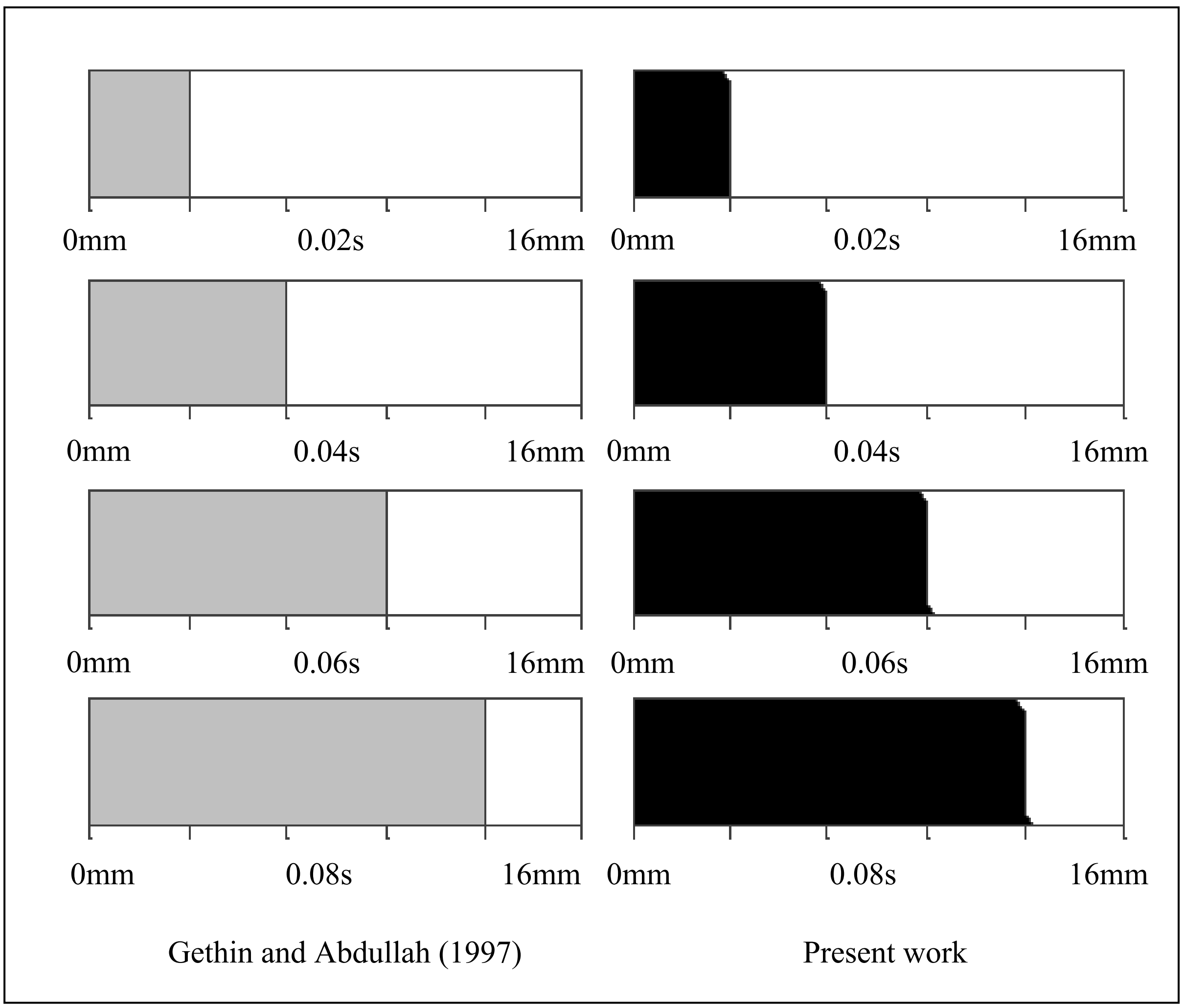


Figure 4.4: Comparison of front profiles between Gethin and Abdullah (1997) and present work