Simulation of Balanced Mold Filling in Transfer Molding for Newtonian Fluids

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Abstract

This paper presents the study of flow encapsulation processes as carried out in electronic packaging industry. A two dimensional Hele-Shaw model has been adopted to study the flow of Newtonian fluids into cavities at various distances from transfer ram in the transfer molding process. Velocity field obtained from Hele-Shaw is used in pseudo-concentration algorithm for front tracking with an artificial diffusion term added to allow partial slip at the fluid-wall interface and to damp numerical oscillation to a minimum level. Finite Element Method is employed to reduce the governing partial differential equations to algebraic form. Parametric studies have shown that by altering the dimensions and parameters of the mold tool, which will introduce different hydraulic resistances at the runner, gate and cavity, will lead to balanced filling in transfer molding. All the model dimensions or parameters remain constant except the one which is altered accordingly to allow different hydraulic resistances that will effectively enhance the filling and achieve balanced filling.

Key words

Balanced mold filling, Encapsulation process, Finite Element Method, Front tracking, Hele-Shaw model, Newtonian fluid and transfer molding.

1. Introduction

The electronic packaging design performs tasks of ever increasing importance in electronic industry. Electronic packaging often benefits from technologies developed for the encapsulation of integrated circuits (ICs). The key functions of an electronic package are to protect power and to cool microelectronic chips or components and provide electrical and mechanical connection between the microelectronic part and the outside world. The challenge for the package is to provide all crucial functions required by the electronic part without limiting the performance of the part. As the semiconductor technology progresses towards higher levels of integration, high performance and increasing functionality, the design and fabrication of the package that will meet the requirements of modern and future microelectronic systems becomes increasingly complex and challenging. An electronic device cannot perform its designed function until it is packaged such that it is interconnected with the rest of the system and protected. Encapsulation provides an economical way to protect device packages by isolating the active devices from environmental pollutants and at the same time offering mechanical protection by structural coupling of the device to the constituent packaging materials into a robust package. Majority of encapsulating processes in the IC packaging market are transfer molding [1]. By applying pressure, the heated molten molding compound is transferred from a pot (plunger) through the runners and into the mold cavities. This is a simple mass production and low-cost method for most device encapsulation. For better mold design and optimization of processing, flow analysis during the encapsulation process is important. The objective of the present paper is to establish a general solution algorithm to model the flow of Newtonian fluids in transfer molding and to make parametric studies using finite element method (FEM) developed to obtain balanced filling in transfer molding. The results can be utilized as a design guideline to optimize the encapsulation process prior to fixing up of actual manufacturing setup.

2. Analysis

The present work utilizes models to analyze Newtonian fluid flow in transfer molding. Hele-Shaw approximation has been used to study the filling phase of a transfer molding process. The field variables, pressure and velocity, are obtained as input to a front tracking algorithm, namely pseudo concentration approach to simulate the advancement of fluid front. FEM is employed to reduce the governing differential equations to algebraic form. Assumptions made for the present Hele-Shaw approach are that viscous effects dominates the flow (thus inertia effect is negligible), the mold is thin as compared to its length and width and the flow process is an isothermal process. Researchers [2-5] have attempted to analyze the flow during encapsulation process numerically. Nguyen [4] concluded that transfer molding is more accurately approximated as an isothermal process because at normal and high fill rate, there is insufficient time for the resin conversion due to temperature variation to greatly affect the viscosity of the commercial transfer molding compound. Liu [6] also postulated that the assumption of isothermal flow is reasonable for the injection stage of resin transfer molding process as the resin is usually injected fairly fast and the filling time is much less than the curing time. In fact, it takes hours for the molding compound to be fully cured which is relatively slow when compared to filling time typically in seconds.

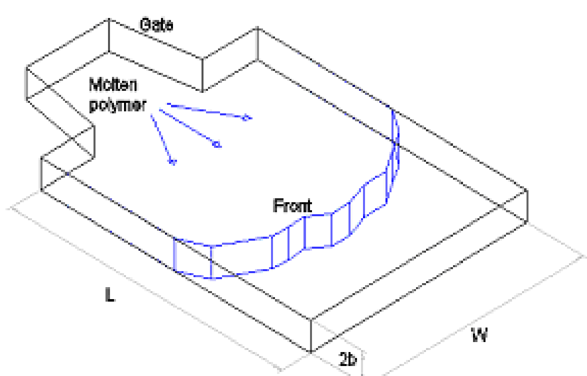

Figure 1. The flow of polymer melts into a thin rectangular mold cavity

The governing equation for the flow derived from Hele-Shaw approximation is expressed as

$$\frac{\partial}{\partial x}\left(S\frac{\partial P}{\partial x}\right)+\frac{\partial}{\partial y}\left(S\frac{\partial P}{\partial y}\right)=0 \qquad (1)$$

where S is the fluidity, which is defined as

$$S = \int_0^b \frac{z^{\frac{n+1}{n}}}{n}\, dz.$$

At $z = \pm b$ (half width), u = v = 0, where u and v are the velocity components along x and y directions. P is the pressure and 'n' is the power law index.

Galerkin based Finite Element Method [7,8] is used to discretize the partial governing equation. For a Newtonian fluid, shear stress varies linearly with shear rate thus fluidity, S becomes

$$S=\frac{b^3}{3\eta} \qquad (2)$$

The pressure and velocity fields are obtained from Hele-Shaw analysis. Next, front tracking is needed to model the flow of fluid into the tool during the filling phase of transfer molding. *Pseudo-concentration approach [9]*, which is based on Volume of Fluid (VOF) method [10], is used to track the advancement of fluid with velocity field known a priori. The front tracking algorithm is based on a pseudo-concentration function F(x, y, t) which gives a smooth representation of the free surface. F=1 represents the boundary between fluid and empty air space as shown in fig.2.

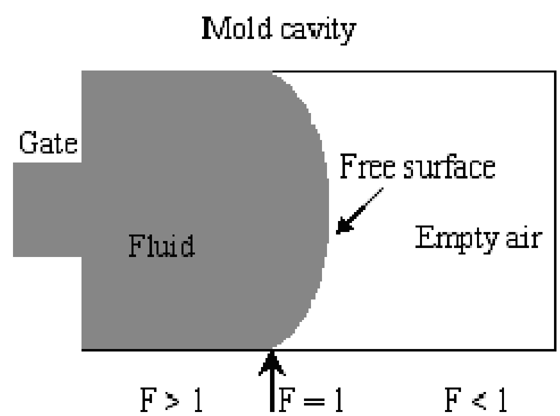

Figure 2. Representation of the free surface for pseudo concentration function F(x, y, t)

The transport of liquid front represented through the Eulerian equation with an artificial diffusion term is given by

$$\frac{dF}{dt}=\frac{\partial F}{\partial t}+u\frac{\partial F}{\partial x}+v\frac{\partial F}{\partial y}-\nu_{ad}\left\{\frac{\partial^2 F}{\partial x^2}+\frac{\partial^2 F}{\partial y^2}\right\}=0 \qquad (3)$$

where ν_{ad} 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 [9].

3. VERIFICATION

For the verification of FEM code developed, realistic problem of filling a flat cavity in xy-plane is considered. In this case, a fluid is forced to enter the cavity as shown in figure 3 with horizontal flow velocity of 1m/s and ventilated at the diagonally opposite corner by assigning zero pressure over this boundary. The domain in this case is discretized into 1408 triangular elements and 769 nodes as shown in figure 4 after grid independent studies.

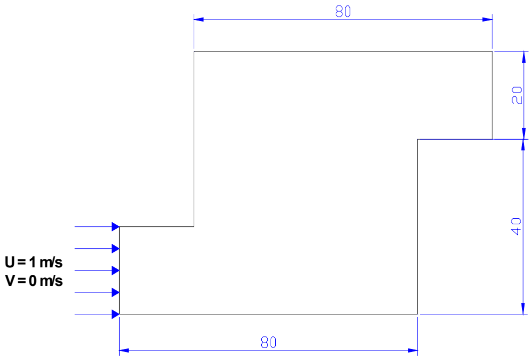

Figure 3. Mold Cavity dimensions (mm) with boundary conditions

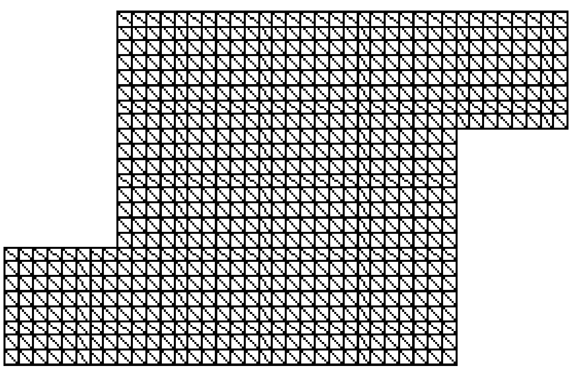

Figure 4. Finite element mesh for mold cavity

The velocity vector plot, as shown in Figure 5 is drawn for the flow through the cavity as. It is observed that axial velocity exists at the entry and at the opposite end zones. When the flow moves progressively, all the velocity vectors at the middle zone are heading towards the upper end with almost same magnitudes in both x- and y-directions. It is also observed that the velocity vectors close to the wall region are parallel to the wall direction. The velocity field will be used in pseudo-concentration approach to track the front of the fluid.

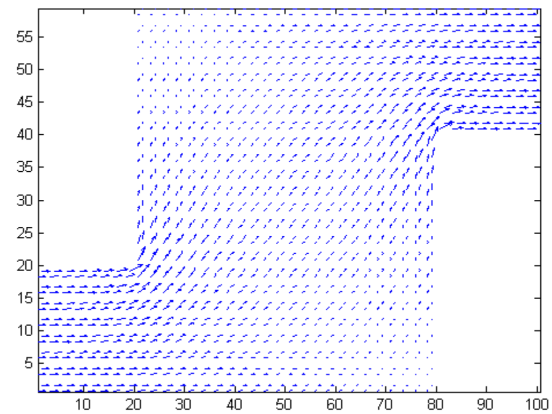

Figure 5. Velocity vector plot for flow in x-y plane cavity

In pseudo-concentration approach,a time step, $\Delta t = 0.001$ second and artificial diffusivity, $V_{ad} = 1.0$ have been used. Comparison of front profiles at different instants of time with the work of Gethin and Abdullah [11] is shown in figure 6.

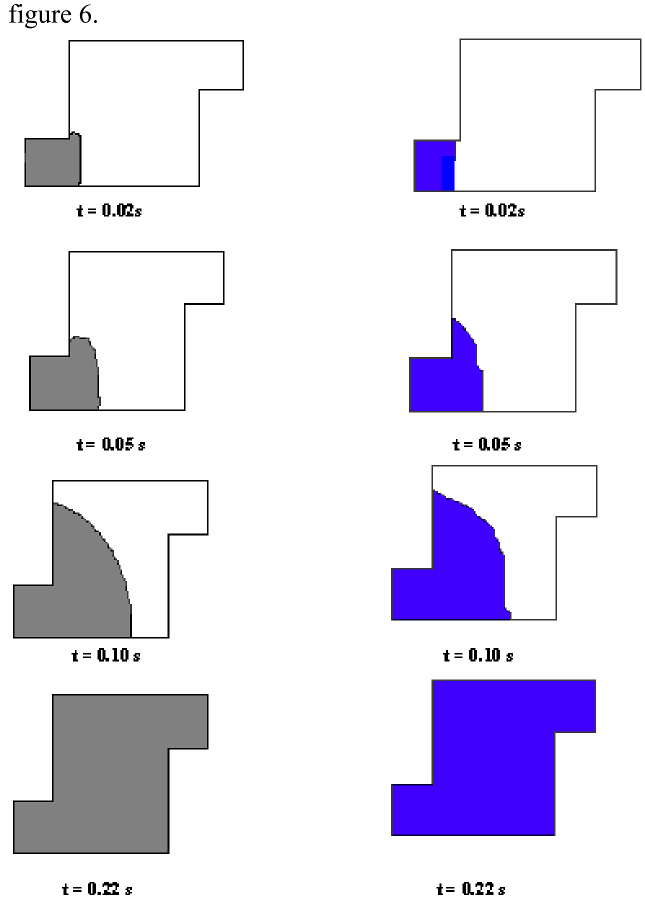

Figure 6. Comparison of front profiles between that of Gethin and Abdullah [11]

It can be observed that at 0.02s, the flow is channeled uniformly into the cavity in the vicinity of entry zone. At 0.05s, the free surface starts to move upward and wets the left sidewall. From 0.05s to 0.10s, the parabolic front pattern advances to the right and up portion of the cavity. The front contours plotted from the FEM analysis conform reasonably well to the datum up to 0.10s. At 0.15s, the flow front has reached the top wall but the front center portion tends to move faster to the upper right direction. As a whole, the simulated filling time is 0.22s as predicted by literature. Thus this serves as the verification to the filling of x-y plane cavity using Hele-Shaw coupled with VOF method.

4. Analysis for Newtonian Flow

Studies have been carried out for a Newtonian flow in a simple transfer molding tool as shown in figure 7. Viscosity, η of the fluid is taken as $0.05 Ns/m^2$. It is assumed that the upper half and lower half of the mold are symmetric and only one half of the geometry is modeled in the simulation. The thickness of all cavities and runner is 3.6 mm. So, the thickness of the half model is 1.8 mm. The tool configuration or parameter for this case will be same as that for the trial/first case except one configuration or parameter changed in order to reduce filling time and achieve balanced mold filling. The tool is subjected to a flow with constant horizontal velocity, u of 111.11 mm/s and zero flow vertical velocity as shown in figure 7.

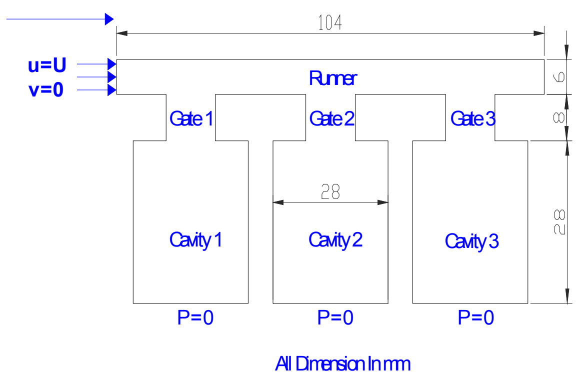

Figure 7. Dimensions for in-line mold cavity.

The boundaries opposite to the gates, where normally air vents reside, are applied with zero pressure. Based on several trials, an artificial diffusivity, V_{ad} =10 which produced the pseudo-concentration distribution with minimum numerical oscillation and a time step, Δt = 0.01s are used in the pseudo-concentration algorithm. The first case has been tried out on a model with uniform gate dimension with a thickness of 1.8mm and a width of 12mm for all gates, runner dimension with a thickness of 1.8mm and 6mm in width. The domain is discretized into 1632 elements and 950 nodes as depicted in figure 8.

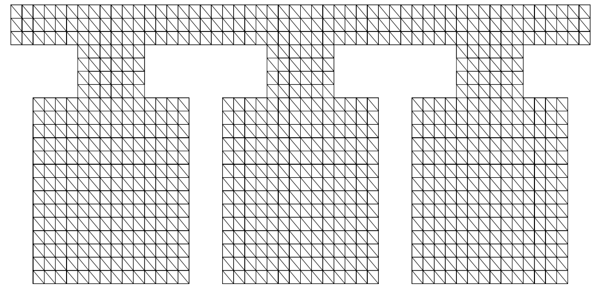

Figure 8. Finite element mesh for gate (12 x1.8mm thick) and runner (6 x 1.8mm thick).

Figure 9 shows the velocity vector plot from the Hele-Shaw analysis on a transfer molding tool with uniform gates dimension.

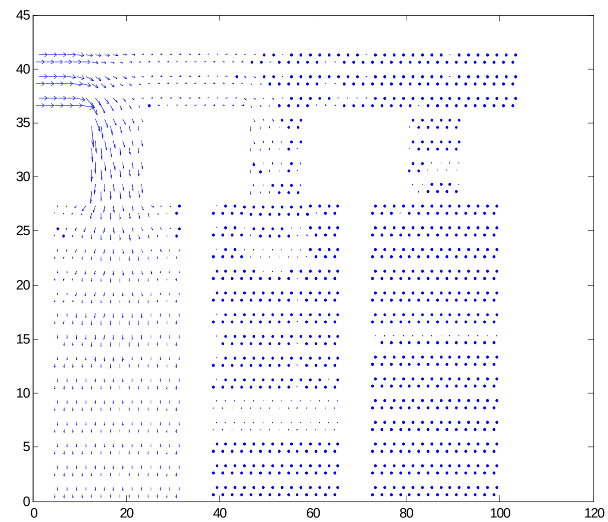

Figure 9. Velocity vectors plot for gate (12 x 1.8mm thick) and runner (6 x 1.8mm thick).

It is observed that the material is dispensed into the first cavity much faster that the others. The velocity vectors reduce in size substantially once it diverges into first cavity through the first gate 1. Losses are significant as the flow change its direction at the right angle. It is also observed that the magnitude of the vectors at the gate nearest to the flow inlet is approaching the largest magnitude at flow inlet. The sizes of the vectors reduce as the flow progressively distributes into the second and the end cavity. The front profiles for different instants are shown in figure 10. The simulated filling time is 27.1s.

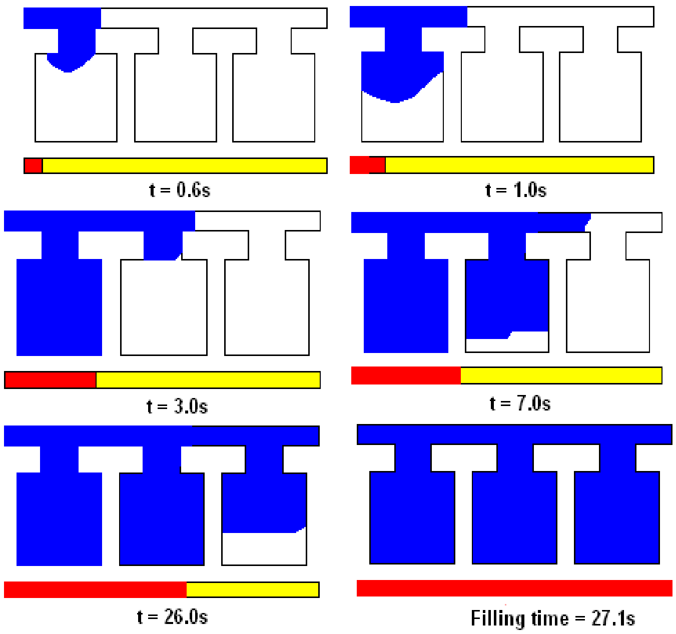

Figure 10. Front profiles for gate dimension (12 x 1.8mm thick) and runner (6 x 1.8mm thick)

After several trials, the balanced mold filling for a Newtonian flow into a 3-cavity toll is achieved for the configuration of mold tool as shown in figure 7 with the thickness of gates in proportion of 0.7: 0.9: 1.5mm, and a uniform length of 12mm is applied to all gates in the model. The domain is also discretized into 1840 elements and 1056 nodes as shown in figure 8. The velocity field and front profiles are presented in figures 11 and 12.

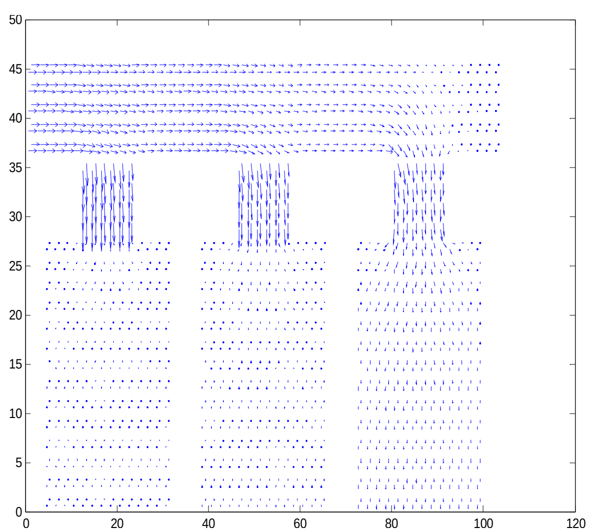

Figure 11. Velocity vector plot for gate dimension (12 x thickness 0.7: 0.9: 1.5mm) and runner dimension (10mm in width and 1.8mm in thickness).

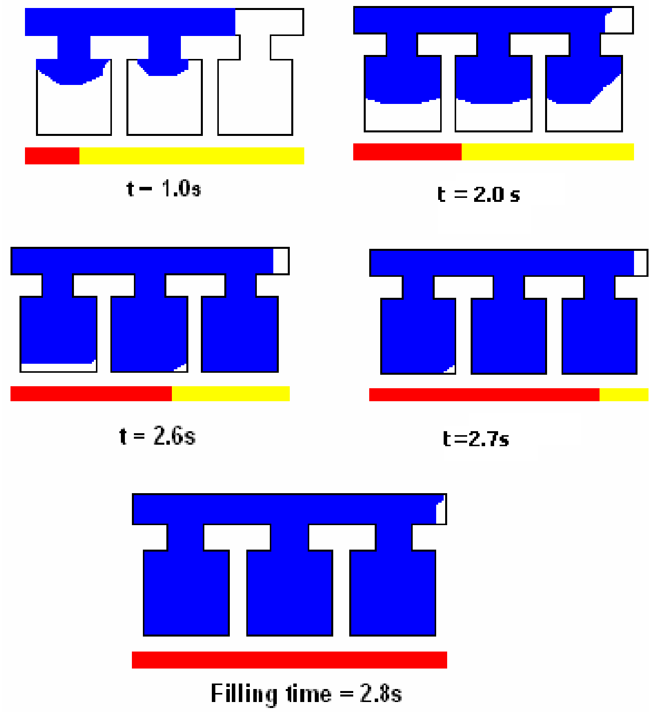

Figure 12. Front profiles for gate dimension (12 x thickness in ratio 0.7: 0.9:1.5mm) and runner dimension (10mm in width and 1.8mm in thickness).

5. CONCLUSION

The present work focuses on the study of flow in encapsulation processes in electronic packaging industry. A 2-D Hele-Shaw approximation has been used to model the flow in the transfer molding process. Pseudo-concentration algorithm is used for front tracking. Numerical solutions of flow governing partial differential equations are obtained using finite element method. The studies are presented for Newtonian fluid flow of transfer molding The balanced filling is achieved for a flow (viscosity, u = 0.05 kg/s) into a 3-inline-cavity tool at constant rate of 2.4cm^3/s with the gate 12mm in width and 0.7mm:0.9mm:1.5mm in thickness.

REFERENCES

[1] Rao R. Tummala, "Fundamentals of Microsystems packaging ", Mc.Graw-Hill Professional Publishing , 2001.

[2] C.W.Tan, P.A. Aswastha Narayana, M.Z. Abduallah, T.J.Goh, "Mold filling and underfilling simulation during semiconductor encapsulation", The 14th Int. Symp. On Transport Phenomena, Bali, Indonesia, 6-10 July, 2003.

[3] L.S.Turng, and V.W.Wang, "On the simulation of microelectronic devices", Van Nostrand Reinhold, NewYork.,1993.

[4] L.Nguyen, "Flow simulation in IC chip encapsulation",Electronic Components and Technology Conference, Buena Vista, 1994.

[5] S.Han,and K.K.Wang, "Flow analysis in a chip cavity during semiconductor encapsulation" Journal of Electronic Packaging, 122(2), pp160-167, 2000.

[6] B.Liu, S.Bickerton and S.G.Advani, "Modeling and simulation of resin transfer moulding (RTM)–gate control, venting and dry spot prediction", Composite Part A, 27A, pp135-41, Elsevier Science Ltd., 1996.

[7] R.W.Lewis, K.Morgan, K.N.Seetharamu and Thomas H.R., " Finite Element Method in Heat transfer analysis" , John Wiley & sons, England, 1993.

[8] L.J.Segerlind, "Applied Finite Element Analysis", second edition, John Wiley and sons, 1984.

[9] B.S.Prasad, "Solidification simulation of casting using finite element method", MS thesis, Indian Institute of Technology, Madras, 1999.

[10] C.W.Hirt, and B.D.Nichols, "Volume of fluid (VOF) method for the dynamics of free boundaries", Journal of Computataional Physics, 1993.

[11] D.T.Gethin, and S.Abdullah "Finite element formulation for filling a thin section cavity. Int.JNumerical Methods for Heat & Fluid Flow. 7(4), pp 344-366,1997.

BIOGRAPHIES

Chu Wee Liang received his B.Eng.degree from University Science Malaysia in March 2004. Presently, he is doing M.Sc. in "International Production Management" at Technical University of Hamburg-Harburg (TUHH), Germany. His areas of interest include Production Management Quality Engineering and Statistical Quality control.

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Prof K.N Seetharamu graduated from Mysore University in Mechanical Engineering in the year 1960. He obtained his Masters Degree in Power Engineering in the year 1962 from Indian Institute of Science, Bangalore, India. He obtained his doctoral degree in 1973 in the field of heat transfer from Indian Institute of Technology, Madras, India.

He joined Indian Institute of Technology, Madras in the year 1968 as a lecturer and rose to the level of Professor in the year 1980. In 1998 he joined University of Science Malaysia on invitation. Prof. Seetharamu has supervised 25 students for PhD Degree and 31 students for Masters Degree by research. Currently he is supervising about 20 students in the area of Electronic Packaging.

He has published more than 100 papers in International Journals and about 200 papers in International and National Conferences. He has published several books on the application of FEM to heat transfer and fluid flow and has contributed a chapter on thermal management in the book *"Fundamentals of Microsystems Packaging"* edited by Rao Tummala and published by McGraw-Hill in 2001.

Prof. Seetharamu established IMAPS Malaysia Chapter in the year 1998 and IEEE-CPMT Malaysia Chapter in the year 2000 and continues to be active in this area. Marquis book "Who is who in the world" makes a reference to Professor K. N. Seetharamu.