Three-Dimensional Flow Analysis of a Thermosetting Compound during Mold Filling

Junichi Saeki and Tsutomu Kono

Production Engineering Research Laboratory, Hitachi Ltd.
292, Yoshida-cho, Totsuka-ku, Yokohama, 244-0817 Japan

Abstract

Thermosetting molding compounds are widely used for encapsulating semiconductor devices and electronic modules. In recent years, the number of electronic parts encapsulated in an electronic module has increased, in order to meet the requirements for high performance. As a result, the configuration of inserted parts during molding has become very complicated. Meanwhile, package thickness has been reduced in response to consumer demands for miniaturization. These trends have led to complicated flow patterns of molten compounds in a mold cavity, increasing the difficulty of predicting the occurrence of void formation or gold-wire deformation.

A method of three-dimensional (3-D) flow analysis of thermosetting compounds has been developed with the objective of minimizing the trial term before mass production and of enhancing the quality of molded products. A constitutive equation model was developed to describe isothermal viscosity changes as a function of time and temperature. This isothermal model was used for predicting non-isothermal viscosity changes. In addition, an empirical model was developed for calculating the amount of wire deformation as a function of viscosity, wire configuration, and other parameters. These models were integrated with FLOW-3D® software, which is used for multipurpose 3-D flow analysis.

The mold-filling dynamics of an epoxy compound were analyzed using the newly developed modeling software during transfer molding of an actual high performance electronic module. The changes in the 3-D distributions of parameters such as temperature, viscosity, velocity, and pressure were compared with the flow front patterns. The predicted results of cavity filling behavior corresponded well with actual short shot data. As well, the predicted amount of gold-wire deformation at each LSI chip with a substrate connection also corresponded well with observed data obtained by X-ray inspection of the molded product.

1-Introduction

The number of electronic parts encapsulated in an electronic module has increased in response to the demands for higher performance. As a result, the configuration of inserted parts during molding of the electronic modules has become very complicated. Due to the demands for miniaturization, package thickness has also been reduced. These trends lead to complications in the flow of molten thermosetting compounds, such as epoxy, in the mold cavity, thus increasing the difficulty of predicting the occurrence of void formation or gold-wire deformation.

2- Method of flow analysis

2.1- System of analysis

Figure 1 shows the system used for three-dimensional (3-D) flow analysis of thermosetting compounds. The figure shows the constitutive equation models for isothermal viscosity changes as a function of time and temperature[1),2)]. In addition, the figure also shows an empirical model for calculating the amount of wire deformation as a function of viscosity, wire configuration, and other parameters. These models are integrated into FLOW-3D® software, a multipurpose three-dimensional flow analysis software package.

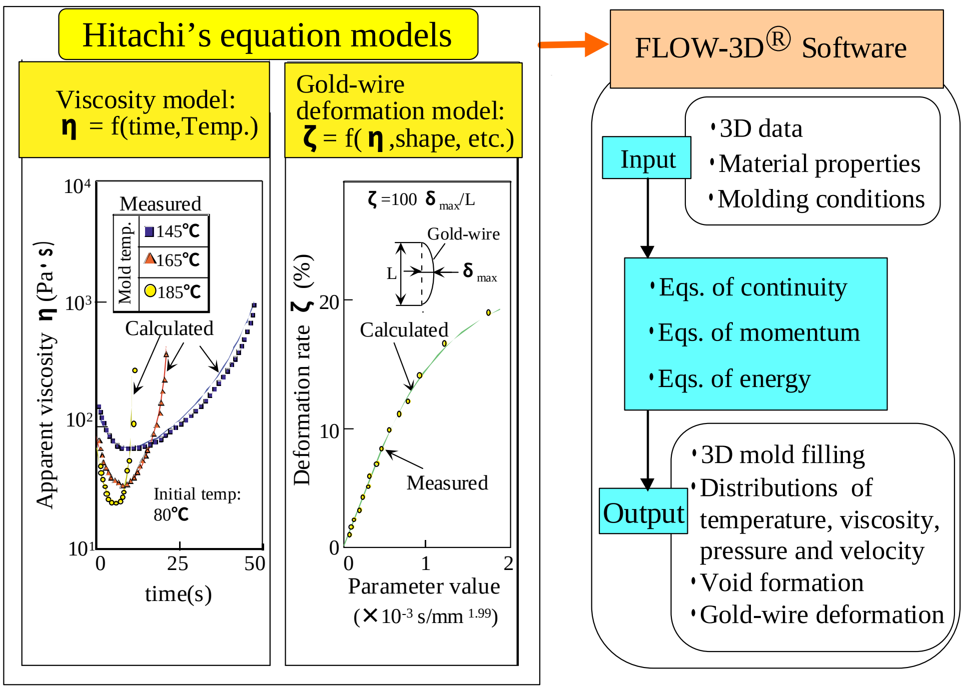


Fig.1 A system of three-dimensional flow analysis for thermosetting compounds

2.2 -Procedure for predicting viscosity changes

Figure 2 shows the procedure for determining the viscosity changes of thermosetting compounds[1),2)]. An empirical model for calculating isothermal viscosity changes has been derived from tests using an epoxy molding compound normally used for encapsulating semiconductor devices. During mold filling, heat conduction mainly from the channel walls causes the temperature of the material to rise. To predict viscosity changes under these non-isothermal conditions, the isothermal viscosity model incorporates a non-dimensional relationship for time and viscosity. Using a master curve produced from the model, non-isothermal viscosity changes can be calculated. The simultaneous conservation equations (mass, momentum, and energy) and the viscosity model are solved numerically to determine rheological changes during mold filling.

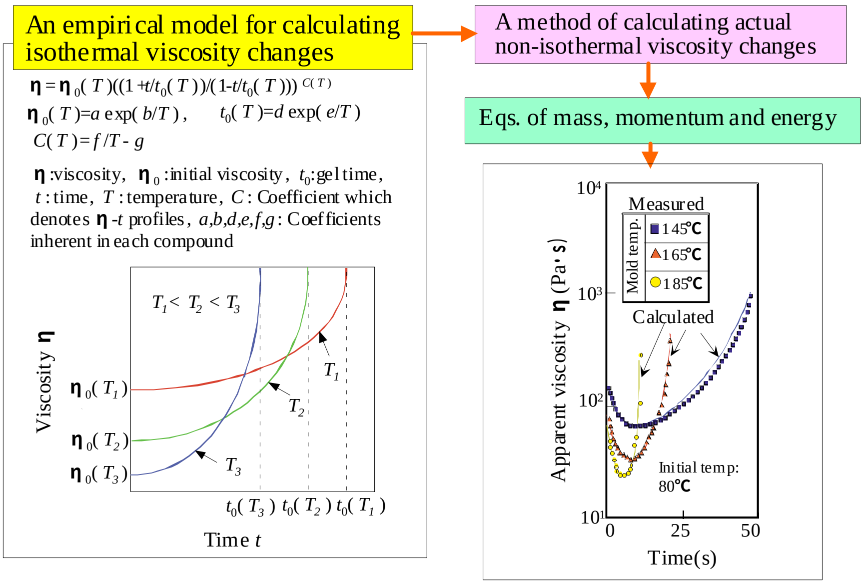


Fig.2 Procedure for determining viscosity changes of thermosetting compounds

2.3 –Method for predicting gold-wire deformation

In semiconductor devices and electronic modules, very thin gold wires are used to connect LSI chips to the terminals of substrates and lead frames. During mold filling, these wires can be deformed due to the flow of molten materials. Predicting the amount of gold wire deformation has thus become important in preventing the occurrence of circuit defects.

Figure 3 shows the empirical model used for calculating gold-wire deformation[3)~5)]. This model is derived from the combination of empirical data and theoretical viscosity values for several semiconductor devices. The horizontal displacement, δ, of each gold wire is found to be similar to that of an elastic beam under three-point bending with a center load. A parameter, ψ, was derived as a function of viscosity, flow direction, flow time, and wire-configuration etc. Using the value of ψ, the deformation rate, ζ, of several semiconductor devices could be estimated accurately.

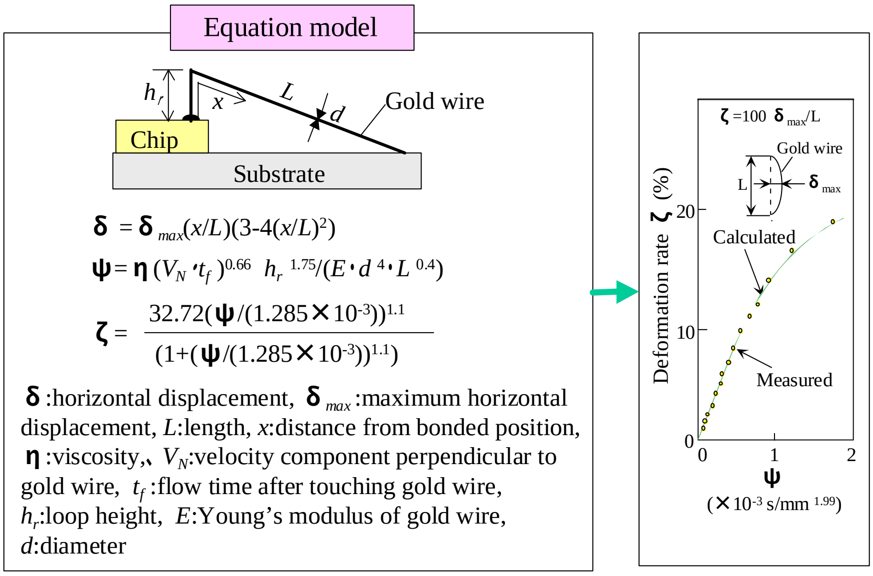


Fig.3 An empirical model for calculating gold-wire deformation

3 –Mold filling simulation during encapsulating of electric module

3.1-Schematic of a package and a mold

Figure 4 shows the schematic diagram of the package used in this study. The electronic parts were encapsulated using a commercial epoxy molding compound.

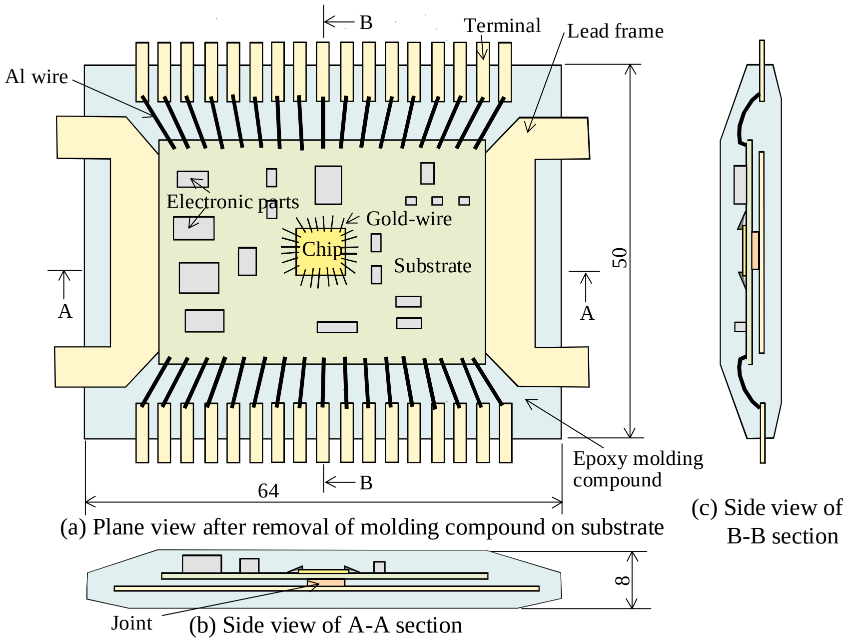


Fig.4 Schematic of a package structure

Figure 5 shows the schematic of the packaging mold. The various electronic parts were fixed between the upper and lower mold. Mold temperature was maintained at 180℃. The molding compound was placed in a pot after dielectric preheating. By driving a plunger downward, the molten compound flows through runners and a gate to fill the cavity.

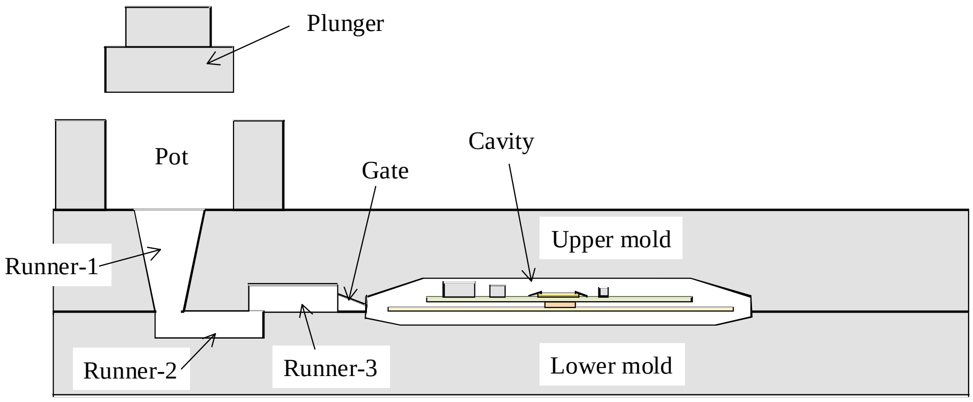


Fig.5 Schematic of a mold

3.2-Input data

Table 1 shows the input data for the 3-D flow analysis. Several boundary conditions are simplified to save computing time. An analysis of the mold filling dynamics is made using the input data and the initial conditions of the mold, gold-wire, and epoxy.

Table1 Input data and modeling for three-dimensional flow analysis

Material	Coefficients of the viscosity model	a=2.3×10^{-10}(Pa･s), b=10270(K), d=5.57×10^{-6}(s), e=6975(K), f=2092(K), g=1.0(-)	
	Thermal properties	Thermal conductivity : λ	0.963(W/(m･K))
		Specific heat at constant pressure : C_p	879(J/(kg･K))
		Density : ρ	2020(kg/m^3)
Molding conditions		Preheat temperature of the compound	80℃
		Temperature of the mold and the inserted parts	180℃
		Transfer time	7s
Modeling		･Cross section of the runnner-1 is rectangle ･Slope of the package surface is neglected ･The terminal frames are not separated	

3.3-Results and discussion

3.3.1-Filling behavior in the runner

Figure 6 shows the calculated results of filling behavior and the temperature distribution in the various runners of the packaging mold. The mold filling dynamics are calculated from the temperature obtained from the heat conduction of the epoxy through the wall of the mold. These results are set as a function of time.

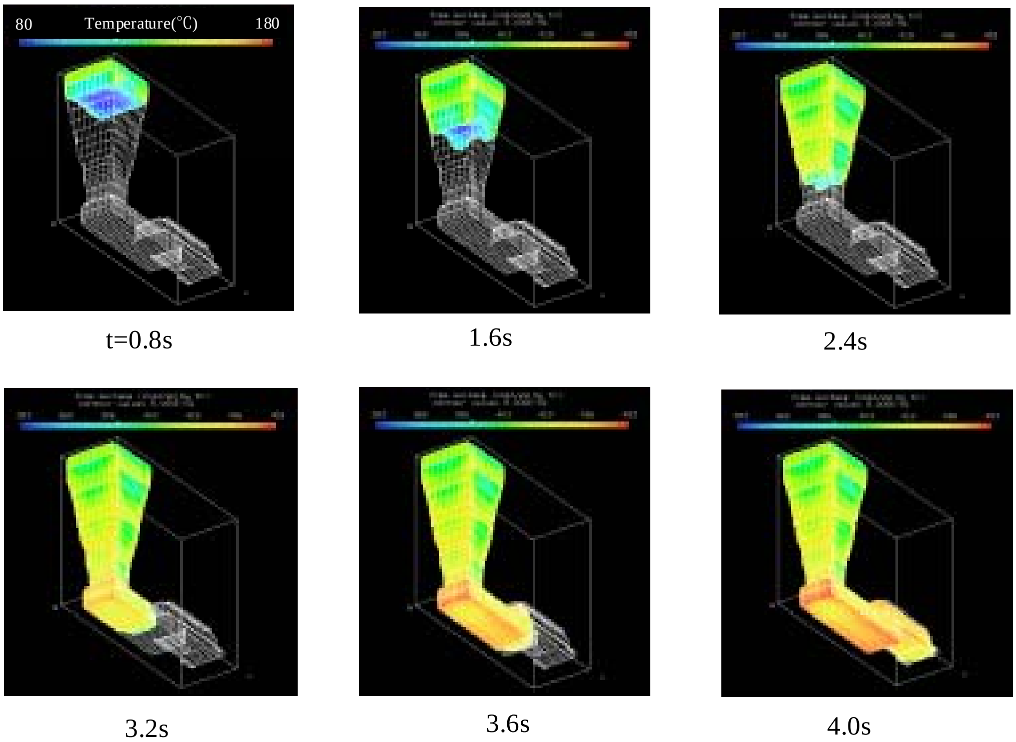


Fig.6 Calculated results of filling behavior and temperature distribution in the runner

3.3.2-Cavity filling behavior

Figure 7 shows the calculated results of the cavity filling behavior and the temperature distribution of the cross section of the substrate at the height of 0.73mm from the upper surface of the substrate. Due to complicated boundary conditions, the flow behavior in the cavity changes over time, as shown by the time-lapse sequence. The temperature on the substrate is higher than that at other areas due to the high thermal conduction from the substrate.

Figure 8 shows the cavity filling behavior. Fig.8a shows the calculated results at 6.15s and the viscosity distribution at the same cross section shown in Figure 7. The viscosity at the substrate is lower than that at other portions due to the quick temperature rise. Figure 8b shows a photo of the short shot. The theoretical flow front pattern predicted by the model corresponds well with the actual short shot data.

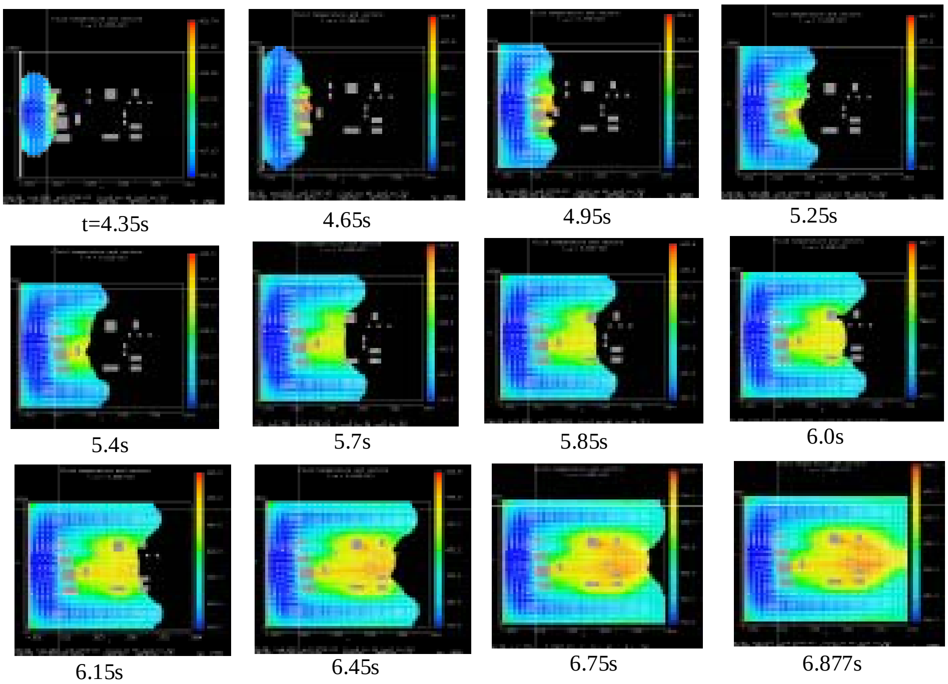
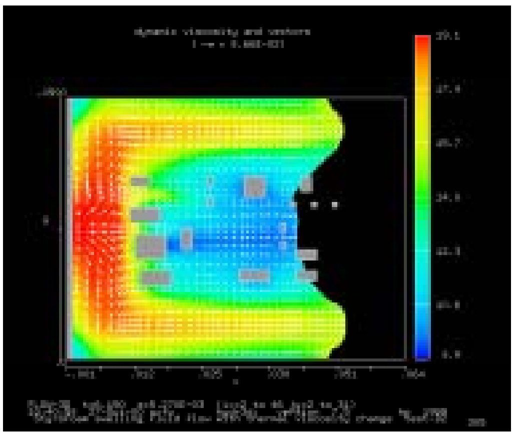
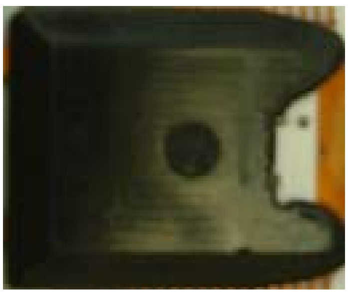


Fig.7 Calculated results of cavity filling behavior and temperature distribution at the cross section of the height of 0.73mm from the substrate upper surface



(a) Calculated results at 6.15s and Viscosity distribution



(b) A photo of short shot

Fig.8 Comparison of cavity filling

3.3.3-Gold-wire deformation

The theoretical values for gold-wire deformation are calculated using the method already described. The actual values of gold-wire deformation were measured using X-ray inspection of the molded package. Figure 9 shows a comparison of gold-wire deformation. The deformation rate at each position differs due to differences in the velocity component perpendicular to gold wire. The calculated values of gold-wire deformation at each position correspond well with the observed data.

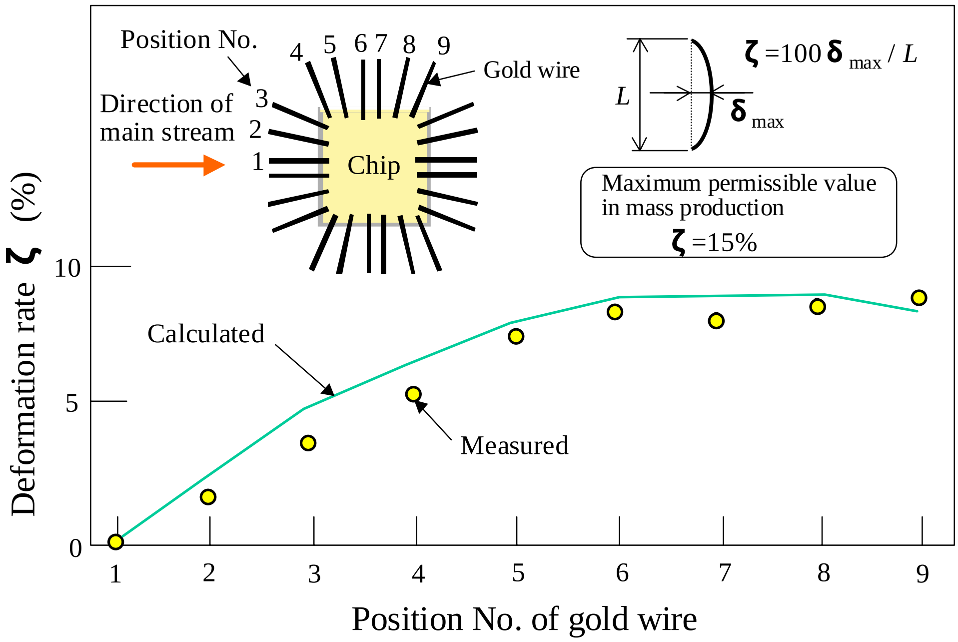


Fig.9 Comparison of gold-wire deformation

4-Conclusions

A model for analyzing the three-dimensional mold filling dynamics of thermosetting compounds such as epoxy during package encapsulation was successfully developed for thin package electronic modules. The theoretical calculations of both cavity filling behavior and gold-wire deformation were found to be in good agreement with actual data observed in electronic modules.

References

1)J.Saeki et al. ,6th annual meeting of PPS, 12KN1(1990)

2)J.Saeki et al. , *JSME* International Journal Series Ⅱ, **33**,486(1990)

3)J.Saeki et al.,SEIKEI KAKOU,**12**,67(2000)

4) J.Saeki et al.,SEIKEI KAKOU,**12**,788(2000)

5) J.Saeki et al.,SEIKEI KAKOU,**13**,49(2001)