Microelectronics Reliability 80 (2018) 42–46

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel

Experimental and modeling study on viscosity of encapsulant for electronic packaging

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ARTICLE INFO

Keywords:
Jet dispensing
Electronics packaging
Curing
Droplet consistency

ABSTRACT

In electronics packaging manufacturing, the adhesive materials are delivered on the microelectronic products using the dispensing technology. In the dispensing process, the dispensed volume of adhesive will be affected by its viscosity. The adhesive viscosity will be affected by many factors, such as shear rate, temperature and curing. In order to have good dispensing consistency, the adhesive viscosity should be studied and modeled. In this paper, a viscosity model is constructed to characterize the effects of shear rate, temperature and curing. The experiments verify that this model can well estimate the viscosity variation, and the droplet consistency can be improved significantly when the jetting temperature is set using this model.

1. Introduction

The adhesive materials used in microelectronic packaging mainly include epoxy, polycarbonate, polymethylmethacrylate and glass [1]. For the advantages of high adhesion, high purity, high water resistance, high thermal stability and high transmittance, bicomponent epoxy is one of the most widely used adhesive materials in microelectronic packaging.

Commonly the adhesive materials are delivered on the microelectronic products using the dispensing technology [2], such as jet dispensing [3]. During the dispensing process, the dispensed volume will be affected by the properties of adhesive materials, such as viscosity, surface tension and compressibility. And the dispensed volume can be affected severely by the viscosity variation. For the bicomponent epoxy, the curing time, temperature and shear rate will affect its viscosity significantly [4]. After mixing the curing agent into the epoxy, the curing reaction begins which leads to the increase of viscosity with curing time. The epoxy is non-Newtonian fluid with shear-thinning property, so its viscosity will decrease with the increase of shear rate. Also the epoxy belongs to high-molecular polymer. The activity ability of its molecular chain will improve with the increase of temperature, and the interaction force between molecules will reduce leading to the decrease of epoxy viscosity [5]. In order to control the dispensed volume preciously, a simple and efficient adhesive viscosity model should be proposed to characterize the comprehensive effects of curing time, temperature and shear rate.

Currently, there are many kinds of rheological models to describe the adhesive viscosity. Considering the effects of shear rate, the generalized power-law model is the most widely used to describe the relationship between the viscosity and shear rate [6,7]. In this model, only the shear rate is considered, and it is hard to describe the complex variation of adhesive viscosity in dispensing process. Considering the shear rate and temperature, the viscosity model is developed which can be used to predict the dispensing performance [8]. However, this model is only suitable for the adhesive with very slow curing process or no curing process. Considering the curing degree and temperature, the adhesive viscosity model is developed. In this model, the curing degree model should be established first, and the curing degree is complex to compute [9]. It is not very suitable for the real application. For the fluid with thixotropic or rheopectic behavior, the shearing time should be considered. Based on the generalized power law equation, an empirical viscosity model is proposed [10]. This model is not valid to describe the viscosity recovery and the equilibrium state. Based on the structural theory, a model is developed to characterize the time-dependent rheological behavior caused by shearing [11]. However, the structural theory is not suitable to describe the curing process.

In this paper, a novel viscosity model is proposed to characterize the epoxy viscosity variation under the effects of curing time, temperature and shear rate. So as to obtain the viscosity variation in dispensing process accurately, the thermostat and rotary rheometer are used to simulate the dispensing environment. Then the epoxy viscosity is measured under different condition. Using the measured viscosity data, the parameters in the proposed viscosity model are identified. The validation experiment shows that this calibrated model can well predict

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https://doi.org/10.1016/j.microrel.2017.11.011
Received 18 August 2017; Received in revised form 24 October 2017; Accepted 15 November 2017
Available online 22 November 2017

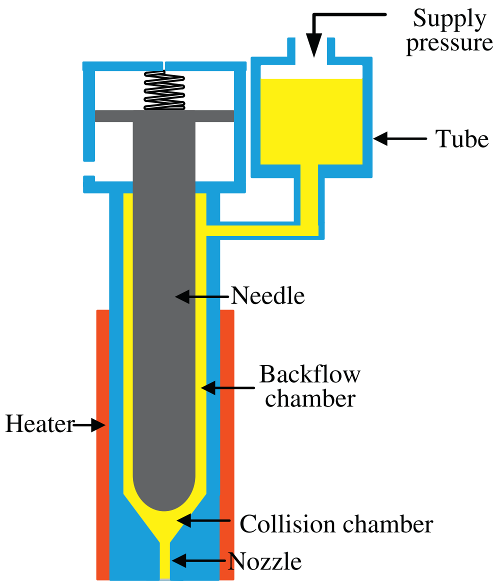

Fig. 1. Configuration of jetting dispenser.

the viscosity variation. Then the jetting experiment shows that this model can efficiently improve the droplet consistency.

2. Problem description

The configuration of jetting dispenser is shown in Fig. 1. In the dispensing process, the adhesive is stored in the tube after mixed up with the curing agent, and its curing temperature is room temperature ($T_c = 28\ ^\circ C$). During each dispensing process, the adhesive in the tube will be pumped into the dispenser by the supply pressure. Then it will be pushed out of the dispenser from the nozzle for the needle squeeze. In the nozzle and chamber, the adhesive will be heated to high temperature making it more smoothly to flow out of the nozzle. In such process, the adhesive cures slowly in the tube and the temperature will change when it flows into the nozzle and chamber. In the batch dispensing process, the adhesive viscosity will change for the curing effects. Thus, the dispensed volume will be changed and the packaging quality will be affected. To improve the droplet consistency, the adhesive viscosity variation should be as smaller as possible. So the viscosity model should be proposed to characterize the viscosity variation. Using this model, the adhesive viscosity can be stable by adjusting the temperature to compensate for viscosity variation.

3. Modeling of adhesive viscosity

There are many kinds of empirical models to describe the viscosity variation. To fit the epoxy viscosity well, the Bird-Carreau model is used to describe the relationship between the adhesive viscosity and shear rate which is shown as follows [12]:

$$\mu(\dot{\gamma}) = \mu_{\text{inf}} + (\mu_0 - \mu_{\text{inf}})[1 + (\varphi_0\dot{\gamma})^2]^{(n-1)/2} \tag{1}$$

where μ is the viscosity; $\dot{\gamma}$ is the shear rate; μ_0 is zero-shear-rate viscosity; μ_{inf} is infinite-shear-rate viscosity; φ_0 is natural time; n is power-law index.

According to the pre-analysis of the experimental data, it is found that the value of μ_{inf} is about $6*10^{-5}$ Pa*s, which is much smaller than the adhesive viscosity. So Eq. (1) can be simplified as follows:

$$\mu(\dot{\gamma}) = \mu_0[1 + (\varphi_0\dot{\gamma})^2]^{(n-1)/2} \tag{2}$$

In the jetting process, the adhesive viscosity can be affected by curing time and temperature. So their effects should be considered in Eq. (2). According to the pre-analysis of the experimental data, both curing time t and jetting temperature T have slight effects on the natural time φ_0 and power-law index n. So φ_0 and n can be assumed to be constant. But the zero-shear-rate viscosity μ_0 is affected by t and T significantly. So the model of μ_0 with t and T should be established. When the polymer is in viscous state, the relationship between polymer viscosity and temperature can be described by Arrhenius equation [13]. So model of μ_0 can be assumed to be as follows:

$$\mu_0(T,t) = K(t)e^{E(t)/RT} \tag{3}$$

where R is the gas constant ($R = 8.314$ J/mol/K), $E(t)$ is the flow activation energy (J/mol), $K(t)$ is the pre-exponential factor. Both $K(t)$ and $E(t)$ are curing time dependent variables. From Eqs. (2) and (3), the multi-variable model of adhesive viscosity can be constructed as:

$$\mu = K(t)e^{E(t)/RT} \times [1 + (\varphi_0\dot{\gamma})^2]^{(n-1)/2} \tag{4}$$

where $K(t)$, $E(t)$, φ_0 and n are unknown variables which should be identified using experimental data.

4. Experimental study of adhesive viscosity

In these experiments, a Kinexus rheometer (manufactured by Malvern) is used to measure the adhesive viscosity. The adhesive used in this paper is epoxy-150B produced by Ausbond. Using this rheometer, the adhesive temperature can be adjusted in the range of 10–100 °C with the accuracy of 0.01 °C. And the range of shear rate is 0.1–3000/s. The thermostat is used to simulate the adhesive curing process in the tube.

From the viscosity model Eq. (4), the temperature, curing time and shear rate are coupled to affect the adhesive viscosity. It is hard to identify the unknown variables in this multi-variable model. So the following decoupled experiments are conducted to identify the unknown variables separately.

4.1. Analysis of shearing rate

The zero-shear-rate viscosity can be regarded as constant if the temperature is constant and the variation of curing time is very small. Under this condition, the adhesive viscosity can be described using Eq. (2), where the unknown variables are μ_0, φ_0 and n.

To obtain μ_0, φ_0 and n, the experiment parameters are set as:

$$T = 301.15\quad K(28^\circ\text{C});\ t = 20\quad \text{min};\dot{\gamma} = 0.1\text{~}1600/\text{s}.$$

This experiment is conducted when the epoxy is mixed after 20 min, and the shear rate $\dot{\gamma}$ varies from 0.1/s to 1600/s within 2 min. During this measuring process, the curing effects can be ignored for the measuring time is only 2 min. To minimize the measuring error, the viscosity is measured for three times, and the average value is used to identify the unknown parameters. The parameters are obtained as $\varphi_0 = 0.00135$ s; $n = 0.30226$. And the corresponding fitting curves are shown in Fig. 2.

4.2. Analysis of curing time and temperature

In the real jetting process, the adhesive will be used for 50 min after mixed with curing agent. So the curing effects to the adhesive viscosity cannot be ignored. To obtain $K(t)$ and $E(t)$ in Eq. (3), the experiment parameters are set as:

$$\dot{\gamma} = 200/\text{s};\ T_c = 301.15\quad K\,(\text{room temperature});\ T = 298.15\quad K\text{~}333.15\quad K;$$
$$t = 10\quad \text{min},\ 20\quad \text{min},\ 30\quad \text{min},\ 40\quad \text{min},\ 50\quad \text{min and } 60\ \text{min}.$$

In this experiment, the mixed epoxy is stored under the room temperature. The temperature T varies from 298.15 K to 333.15 K within 2 min. This process is repeated for six times when the epoxy is mixed after 10 min, 20 min, 30 min, 40 min, 50 min and 60 min