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Mechanical characterization of epoxy moulding compound in pressurized steam

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ABSTRACT

Epoxy Molding Compounds (EMCs), commonly based on epoxy resin, are used widely for encapsulation of chips in electronic devices for protection against mechanical, environmental, and chemical attack. The thermo-mechanical properties of these compounds are important for the assessment of package reliability. These properties are highly dependent on the temperature and moisture.

EMCs absorb water when exposed to a humid environment. The trapped water generates steam in the compounds during the soldering reflow part of the packaging assembly process, which may drastically change the viscoelastic and adhesion behavior of the compound.

The present research focuses on the characterization of mechanical properties of an epoxy molding compound in steam at elevated pressure (temperature above 100 °C and relative humidity equal to 100%). A special steam chamber with a highly accurate tensile setup for force and displacement measurements is designed and manufactured. The chamber is equipped with a 3 Point Bending (3PB) loading setup. The setup can also be modified to mixed mode bending for investigating the effect of temperature and steam on the molding compound-to-lead frame interface strength.

In this paper, the viscoelastic creep compliance of a molding compound in dry and wet environment is measured in 3 point bending mode. It is shown that steam significantly affects the thermo-mechanical properties of the molding compound. The glassy and rubbery modulus of the molding compound were seen to decrease almost by 20%. Furthermore the glass transition temperature decreased by about 30 °C and the creep process was seen to be about a factor 40 faster in a hot steam environment.

1. Introduction

It is well known that polymers and polymer-based composites show strong temperature and time dependent behaviour. These viscoelastic properties are highly dependent on temperature, degree of cure and moisture. The first two factors have been reported in our previous works [1,2] while concerning the issues for epoxy molding compounds. In [1] the thermo-mechanical properties of a series of epoxy resins were studied. It was shown that the filler decreases the cure shrinkage and thermal contraction of epoxy resins. However it increases the modulus below and above the glass transition temperature. Moreover in [2], the changes in viscoelastic properties during cure for commercial molding compounds is monitored. Using a shear tool, a full cure dependent visco-elastic model for the shear modulus of these materials was extracted.

Studies showed that moisture in any form causes swelling and degradation in polymer composites. This factor can also (and generally does) affect the mechanical and physical properties of the polymers and composites, as described in many studies. [3–8] reported the moisture effect on the mechanical properties of a carbon/glass fiber hybrid composite, polyurethane shape memory polymer and EMCs and found out that the absorbed water continuously decreased the mechanical strength and T_g of the materials. Furthermore, Walter et al. and Boehme et al. [9–11] showed that the viscoelastic responses of the EMCs under dynamic loading are highly dependent on the temperature and moisture content of the samples. Similar phenomenon were also observed by Zhou et al., and Ishisaka and Kawagoe [12,13].

Epoxies are widely used in the microelectronic industries as encapsulants, adhesives and underfills. The mechanical properties of these materials and the interface strength of electronic chips are also affected by the generated steam during soldering reflow

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of microelectronic assembly process. However, in studies where the moisture sensitivity of polymers was investigated the highest temperature was limited to the boiling point of water, 100 °C. Therefore, up to now, the thermo-mechanical properties of the molding compounds for the temperature/ humidity regime of temperature above 100 °C and relative humidity near 100% were not established.

The present research focuses on the viscoelastic properties of EMCs in steam at elevated pressure conditions. For the present harsh environment study a special steam chamber (Pressure Vessel) with a highly accurate tensile setup is designed and tested. The functionality and performance of the setup is assessed measuring the viscoelastic creep compliance of an EMC in dry condition and comparing that with creep measurements using a commercial Dynamic Mechanical Analyzer (DMA). Applying the time–temperature superposing principle, the viscoelastic creep compliance master curves and related shift factors are extracted and compared. As the next step, the mechanical properties of the EMC (creep compliance, T_g and corresponding shift factor) are determined for the pressurized steam environment and the effect of the moisture is quantified.

2. Design of the setup

A special steam chamber is developed in order to measure the viscoelastic properties of the EMC in pressurized steam. The simplified schematic diagram of this setup is shown in Fig. 1. The steam chamber with tensile setup initially contains 0.5 l water. This water converts to steam while heating up the setup. The initial air in the system is removed by a pressure release valve in top of the vessel (F in Fig. 1) such that the chamber always contains water vapor at 100% humidity. For temperatures above 100 °C this corresponds to a higher pressure, a relation which is known from standard thermodynamics [14].

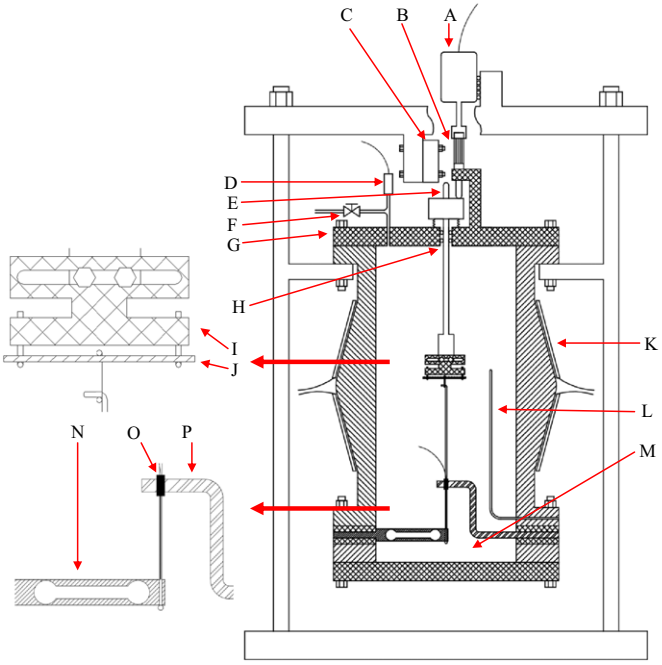

Fig. 1. Schematic drawing of pressure vessel apparatus (not to scale). A: programmable stepping motor with guiding fixture; B: controllable micrometer; C: displacement transducer (laser sensor); D: pressure transducer; E: shaft; F: pressure release valve; G: top flange; H: pressure seal; I and J: 3PB setup with sample; K: heating elements; L: thermocouple; M: water reservoir; N: force transducer (loadcell); O: Differential Variable Reluctance Transducer (DVRT); and P: DVRT holding fixture.

The designed and developed Pressure Vessel (PV) consists of a thick walled steel housing and a loading section. The loading section includes a 3 point bending set up (I and J), force transducer (N) and displacement measurement part. (B and C in Fig. 1)

The moving set up consists of a controllable micrometer (B), a step motor with holding fixture (A) and a shaft (E). The controllable micrometer is positioned on top (=outside) of the vessel in the relatively cool area and is driven by a programmable stepping motor. The movable shaft enters the upper flange plate through a hole with appropriate pressure seal. The upper side of the shaft is clamped by the guiding fixture, moving the shaft vertically. The movement of the shaft is captured by the displacement transducer (Laser sensor, 2820 KEYENCE Co.) mounted outside of the vessel.

As Fig. 1 shows the 3PB setup along with the sample are positioned at the lower part of the movable shaft. The 3PB setup can be used for specimen with various dimensions. It is also possible to replace it with a mixed mode bending setup for doing delamination measurements [15,16].

A rigid rod connects the sample to the load cell positioned on the lower flange plate inside the vessel. The load cell consists of a hollow beam (N) of which the deflection is measured using a Differential Variable Reluctance Transducer (O in Fig. 1, type: M-DVRT-1.5 mm, high resolution, Microstrain Co.). This DVRT is especially chosen for this application as it can operate at temperatures up to 170 °C in humid environments, while strain gauges are unreliable under these extreme conditions.

For a 3PB experiment the sample is loaded by moving the shaft upwards. The applied load and displacement of the load cell are monitored by recording the voltage differences of the DVRT. These voltages are converted to load and displacement of the DVRT using a calibration curve. The calibration data is obtained by applying known loads and displacement to the load cell at different temperatures, ranging from 100 to 180 °C. The force and displacement calibration factors turn out to be 1.13 N/V and 0.406 mm/V and are slightly temperature depended. Calibration factors in wet conditions are much more involved and were performed at only two temperatures (120 °C and 135 °C) which agreed well with dry condition.

The load cell is designed for relatively low forces (up to 2 N). Therefore the beam of the load cell has a non-negligible displacement which must be considered. The displacement of the sample is defined as the difference between the shaft and loadcell displacement.

The chamber of the pressure vessel includes three parts: top, middle and lower. The lower section contains the water reservoir and is made from a bolted flange with flange plate. This section also comprises the loadcell and DVRT. The middle section has two removable glass windows for sample mounting and observation. Condensation of steam on the glass windows is effectively prevented by a thin coating (Rain-x, Anti- rain, Shell Car Care International Ltd.) and by external heating of the windows using a hot air blower. Furthermore, this section is equipped with heating elements (6000 W, WATLOW Co.) and thermocouple (K and L in Fig. 1). The top part is made up from a bolted flange with flange plate on which the motion part with laser sensor is installed. This section also entails the pressure transducer (0–10 bar, WIKA Co.) measuring the inside steam pressure. All signals are analyzed using a dedicated Lab View program.

3. Experiments

3.1. Material

A commercial epoxy molding compound (MP8000, Nitto Co.) was molded into strips of $38 \times 5 \times 2$ mm^3 by NXP Semiconductor