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A New Method to Measure Lateral Confining Pressure in Passively Confined Kolsky Compression Bar Experiments

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ABSTRACT

Electronics packaging in the form of potting or encapsulation is critical for component protection against shock and vibration loads. Encapsulation is usually achieved by filling the space inside an electronic component with resins or rubbery materials (called “potting materials”) to mitigate high-g and/or high-frequency mechanical shock. The encapsulation may also be subjected to various environmental temperatures from cold to hot during application. Though modeling and simulation are routinely used for component design and survivability assessments, little work has been done to experimentally evaluate the performance of potting materials under triaxial confinement over a wide range of temperature conditions and strain rates which would mimic application use. This gap exists due to the challenges associated with *in-situ* measuring the specimen confining pressure during the experiment. In this study, a new instrumental confining tube design and diagnostic method was developed to provide a calibrated measurement of the radial confining pressure generated by a sample subjected to an axial stress pulse using a Kolsky bar. This method provides more comprehensive and quantitative understanding of triaxial compressive response of material under dynamic loading.

Keywords: Kolsky compression bar, confined response, triaxial, potting materials

INTRODUCTION

Encapsulation or “potting” of electronics packages is a key step in protecting sensitive components from the environment. Potting is accomplished by filling the space surrounding electrical subcomponents usually with either a thermoset plastic or epoxy resin. From an electrical standpoint, potting provides electrical insulation as well as protection against dust and moisture which can lead to corrosion. From a mechanical standpoint, potting materials can improve resistance against shock and vibration loads which can improve survivability. Depending on the thermal operating envelope of the electronics package, the potting material may be subjected to a wide temperature range while being mechanically loaded. Simulations to evaluate survivability of systems requires accurate material data. Because of the encapsulated configuration, the potting material is not allowed to freely expand when mechanically loaded, but triaxially confined. Hence, the material response must be measured in a manner like the application. Few studies are available that provide experimental techniques to in-situ measure both axial and radial components of passively confined materials. When such measurements of radial confining pressure have been made, a solid confining tube with a strain gage mounted on the exterior is placed over the sample [1]. The internal pressure is calculated based on the strain-gage measurement of the hoop strain of the confining tube [2]. This method is somewhat limited in the information that it provides and depends on the precise location of the strain gage relative to the specimen during experiments. First, assumptions must be made about the tube geometries and mechanical properties. Second, and most importantly, precise positioning of the strain gage over the sample is critical since any change in positioning would affect the measured hoop strain. This method may work for thick specimens, such as the sand tested in [1], which is longer than the strain gage for the hoop strain measurement. However, for the samples with only a few millimeters in thickness, the positioning of the strain gage becomes critical.

In this study, we created a new sensor made of polyvinylidene fluoride (PVDF) film to measure *in situ* the radial pressure produced by a passively confined specimen in a Kolsky bar experiment. Working principal, design, and calibration of the sensor are discussed. Example material response for EPON 828, a typical potting material, is presented.

MATERIALS AND SENSOR DESIGN

In this study, a new PVDF-based confining pressure sensor was used to record in-situ radial pressure produced by a potting material specimen subjected to dynamic axial compression with a Kolsky compression bar. EPON 828 potting material was used as an example to demonstrate the new diagnostic technique. The specimens had dimensions of approximately 4 mm thick by 25.4 mm in diameter which is the same as the diameter of the pressure bars. The instrumented confining tube consists of a thin-walled inner confining tube and a relatively thick-walled outer confining clamp, as shown in Fig. 1. Both parts were made of 4340 steel. A layer of 110 µm thick PVDF film is sandwiched between the two confining tubes.

Figure 1. Confining tubes with confinement clamp (right) and without confinement clamp (left)

The entire tube arrangement is slid over the sample in a compression Kolsky bar setup. When subjected to axial compression, the sample expands in the radial direction, generating a radial pressure against the confining tube. Such a radial pressure is sensed by the PVDF placed between the inner confining tube and the outer confining clamp. The radial force is calculated by time integration of the PVDF output

$$F(t) = \int_0^t \frac{U(t)}{kR} dt \tag{1}$$

where U is the output voltage, R is the discharge resistor in the circuit, and k the piezoelectric constant of the PVDF film. One downside of this approach is that the complex tube geometry becomes a factor as well as precise knowledge of the piezoelectric constant. A way to circumvent this problem is to directly calibrate the PVDF sensor using internal pressurization against a conventional pressure sensor. This approach was used in this study to develop an empirical relationship between the charge produced by the sensor and the internal pressure. The calibration process was completed at different temperatures of approximately -50 ºC ("cold"), ambient, and 75 ºC ("hot") to cover a wide temperature range used in potting material experiments.

The voltage output of the sensor was integrated to obtain the charge produced by internal pressure. A relationship between the PVDF output and internal pressure at different temperatures was determined and described as "K_prime", using exponential functions as shown in Fig. 2 at different temperatures. Importantly, this direct calibration of the pressure sensor accounts for the structural response of the tube and clamp arrangement.

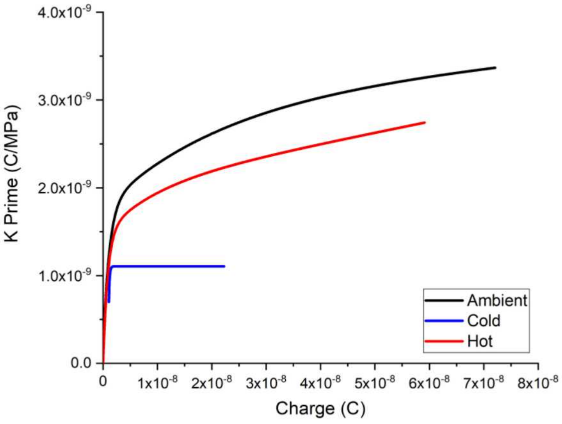


Figure 2. Relationship between sensor output and charge obtained at different temperatures

RESULTS AND DISCUSSION

A typical raw experimental record for confined potting material is shown in Fig. 3. The raw voltage of the potting material signal is integrated to obtain the charge before application of the K_prime exponential function. The integrated charge and resolved radial stress produced by the axially compressed specimen are shown in Fig. 3. As shown in Figs. 3 and 4, the PVDF produces a large signal which corresponds to a radial pressure of approximately 62 MPa.

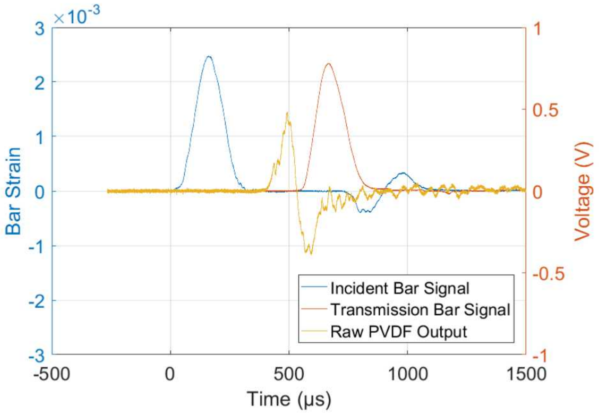
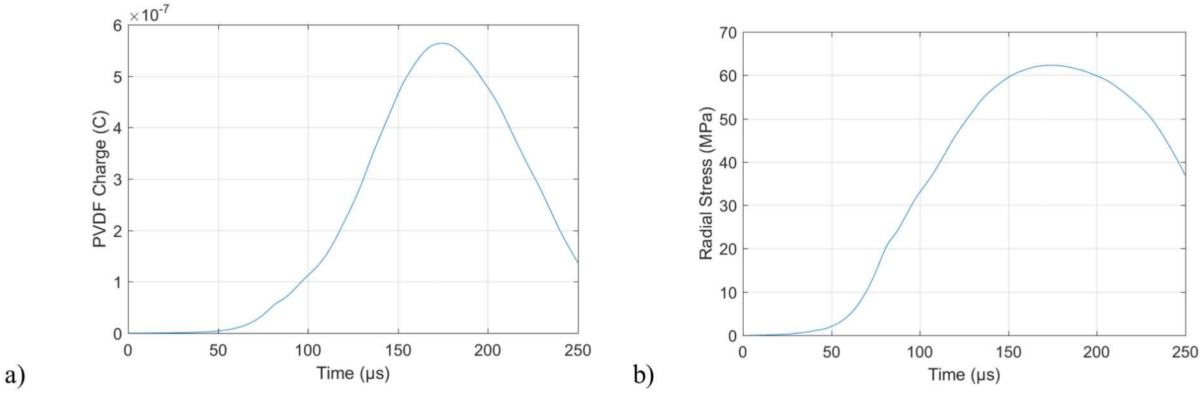


Figure 3. Strain signals and raw PVDF output for a Kolsky compression bar experiment on confined potting material



a) b)

Figure 4. Charge output by PVDF and radial stress produced by axially compressed potting material specimen

Using the radial stress history shown in Fig. 3 along with the axial stress and strain histories, the mean stress and volumetric strain relationship can be found. The mean stress-volumetric strain relationship for an EPON 828 potting material at ambient temperature and a constant strain rate of 1000 s^{-1} is shown in Fig. 5. Fig. 5 shows that a mean stress of approximately 180 MPa was nearly linearly produced up to a maximum strain of approximately 0.085. This provides a relationship that can be used to create constitutive models of potting materials subjected to triaxial confinement.

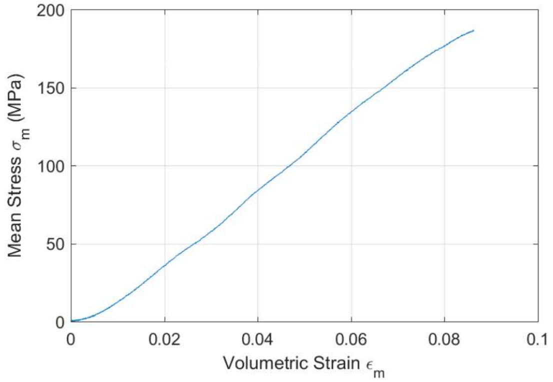


Figure 5. Mean stress – volumetric strain relationship for EPON 828 epoxy

CONCLUSION

A new sensor design was outlined in this study to provide a direct in-situ measurement of radial pressure produced by a passively confined specimen in a Kolsky compression bar experiment. The new sensor design used PVDF film in a unique configuration to directly obtain the radial stress. Importantly, the new sensor does not rely on exact placement of the sensing material with respect to the specimen compared to previous confining designs that used strain gages to measure deformation of the confining tube. The sensor was directly calibrated against a known pressure sensor to acquire a calibration curve at different temperatures to account for temperature effects in the PVDF film. The calibration information is applied to the output from Kolsky compression bar experiments to obtain the radial stress history during the high rate experiment at different rates and temperatures to characterize the confined material behavior. Modeling and simulation teams can use this information for both calibration and validation of potting materials as well as prediction of system-level response of potted components.

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