

# Fracture of Filled Epoxy Molding Compound Compact Tension Specimens

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## Abstract

This paper reports the results of fracture toughness tests performed on a highly filled epoxy molding compound in the form of compact tension specimens. The temperatures examined ranged from -93°C to 150°C, and over this range the fracture toughness increases gradually with temperature to the neighborhood of 100°C and then diminishes rapidly as the glass transition temperature is exceeded. The data are compared favorably with earlier results from 3-point-bend specimens. Steady state crack propagation was observed and analyzed. Some observations on the effect of loading rate and sensitivity of the results to specimen cure are also made.

## Introduction

A common failure mode for encapsulated electronic packages is for a crack to emanate from either a sharp corner at an interior structure (e.g., the die or lead frame) or an interior interface and propagate to the package surface, thereby compromising the package's resistance to moisture, which is necessary for long-term viability. Thus, fracture toughness of molding compounds is an important design parameter in package design. It may be used as a comparative measure of a molding compound's resistance to cracking. In more detailed analysis, becoming ever more common as the sophistication of package design advances, the fracture toughness is a necessary parameter for finite element analysis of a package's resistance to crack growth.

Previously, we have evaluated fracture toughness of molding compounds using a three-point-bend specimen configuration [1,2], as have others [3]. In this paper the results of tests on compact tension (CT) specimens are reported. These smaller specimens are easily tested in a miniature test facility developed recently in our laboratory. This test facility provides advantages in that 1. Crack growth may be easily monitored by video camera through a microscope and 2. The environment may both be readily controlled and easily changed, e.g., from elevated to sub-ambient temperatures. These features allowed for tests to be conducted over a temperature range from -93°C to 150°C. Steady crack growth, which was observed at certain temperatures, was studied quantitatively with the aid of the crack length vs. time record provided by the video recording.

## Experiments

Sumitomo EME 7320 fracture toughness specimens were obtained in the form of compact tension (CT) specimens which were 31.8 mm long by 25.4 mm high by 3.18 mm thick. Previous test data for three-point-bend fracture toughness testing of this material were available [1,2] so that the opportunity was available to assess the transferability of the fracture toughness data. The specimens were molded at 175°C and then postcured for four hours at this temperature. A few specimens were tested without the postcure. After molding, the specimens were pre-cracked to achieve a natural crack. This was

done by, first, cutting a 90 degree chevron at the end of the molded notch using a diamond saw. The specimens were then pulled in a servohydraulic test machine in conjunction with the girdle and steel fixture shown in Figure 1 until a crack propagated from the chevron notch. It was found that this procedure permitted the evolution of a precrack which could be arrested rapidly so that the initial crack length to width (a/w) ratio was typically in the neighborhood of 0.5. A disadvantage of this procedure was that the precrack direction sometimes wandered from self-similar as it entered the compressive stress field generated by the girdle. However, this did not appear to significantly affect the data obtained.

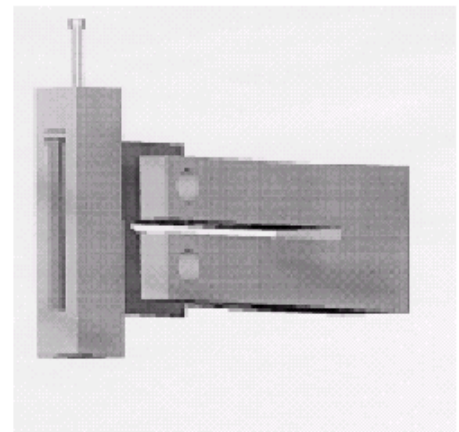


Figure 1. CT specimen prepared for precracking

Tests were conducted using a small screw-driven test machine (microtester) designed to fit underneath a microscope. The microtester has two crossheads which move in opposition so that the center of a symmetric specimen remains fixed, thus facilitating microscopic examination. It is fitted with a small insulated chamber of approximately cubic geometry with dimension 100 mm on a side. For experiments conducted above ambient temperature, heated air was circulated in a closed loop containing a blower, a heater and the test chamber. For experiments at sub-ambient temperatures, the vapor over liquid nitrogen was vented into the chamber. Tests were conducted under displacement control. The usual displacement rate was  $25.4 \times 10^{-4}$  mm/s; several tests were conducted at strain rates both a decade higher and a decade lower to ascertain the sensitivity of the experiments to strain rate.

## Primary Results

Figures 2 and 3 present representative load vs. load point displacement (P-d) curves for fracture toughness tests of Sumitomo EME 7320 conducted at temperatures above and below ambient, respectively. It is apparent that at temperatures of 75°C and below, failure occurs abruptly although at 75°C there is evident rounding of the P-d curve before sudden failure. At temperatures above 100°C there is no discontinuous jump in P-d curves, and cracks were observed to advance in a stable manner. Maximum loads were observed at 75°C with peak values diminishing gradually with diminished temperature and, above 100°C, rapidly with increased temperatures.

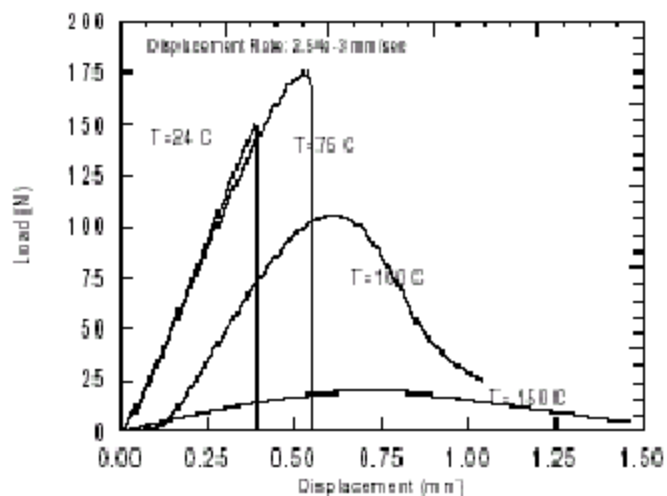


Figure 2. Load vs. Load Point Displacement for Cured (175 °C/4 hrs) Specimens

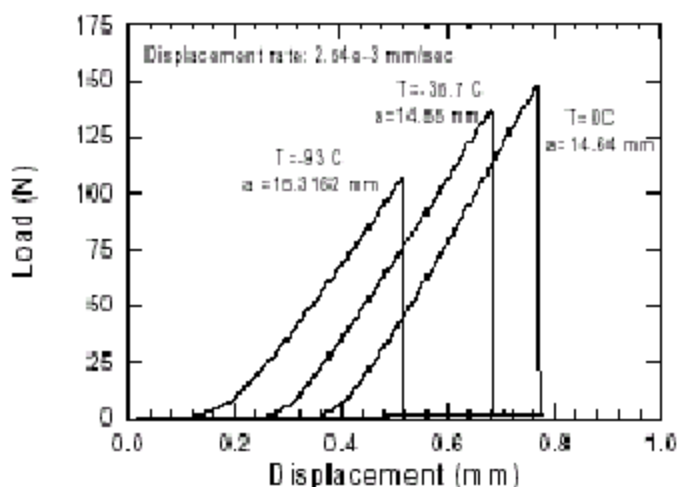


Figure 3. Load vs. Load Point Displacement for EME 7320 Specimens at Low Temperatures

## Discussion and Ancillary Results

This section will discuss and present ancillary data on the effects loading displacement rate and cure on the primary results and will as well present some results on stable crack growth which were developed from the primary data. It will also assess the degree to which transferability is obtained for data from both three-point-bend and CT specimens.

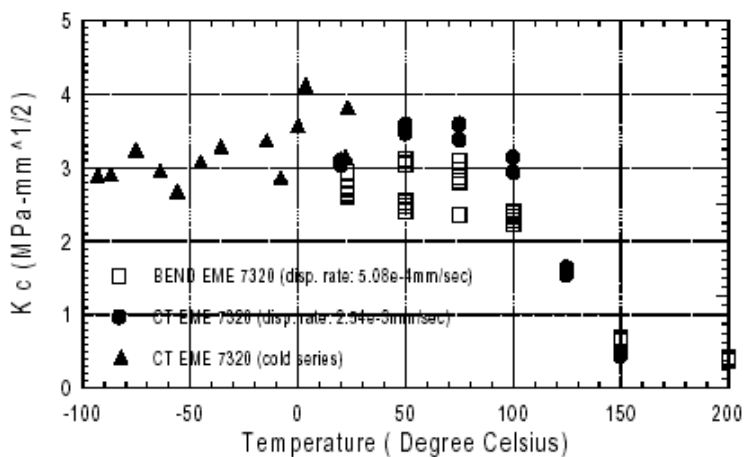


Figure 4. Fracture Toughness of EME 7320 Molding Compound as a Function of Temperature

All data were reduced according to ASTM E399 [4]. For tests at and below 75°C, this resulted in a valid determination of the critical fracture toughness,  $K_{Ic}$ . For tests above this temperature the restriction that the peak measured load be no more than 1.1 times the load found by the intersection of the 95% slope line with the P-d curve is not met. However, as amplified upon below, this deficiency is not associated with an excessive plastic zone size and R-curve behavior so all values of  $K_{Ic}$  are presented against temperature in Figure 4. For comparison, the data from three-point bend tests of EME 7320 are also shown in Figure 4.

### Displacement Rate

In order to evaluate the effect of strain rate on the experimental results, tests were conducted at ambient temperature and 125°C for displacement rates both a decade higher and a decade lower than the nominal rate of  $25.4 \times 10^{-4}$  mm/s. The results of these experiments are summarized in Table 1.

Table 1. Dependence of  $K_{Ic}$  on Displacement Rate

Displacement Rate (mm/s)	Fracture Toughness ( $\text{MPa}\cdot\text{m}^{1/2}$ )	
	(20°C)	(125°C)
$25.4 \times 10^{-3}$	3.03	2.25
$25.4 \times 10^{-4}$	3.03	1.64
$25.4 \times 10^{-5}$	3.10	1.03

At ambient temperature the difference in observed fracture toughness was insignificant. At 125°C a two decade decrease in loading displacement rate resulted in diminution in  $K_{IC}$  by greater than 50%. These observations are consistent with the results of both relaxation experiments [5] and dynamic mechanical analysis [6] of a similar molding compound, which exhibited its greatest rate dependence for temperatures in the same neighborhood.

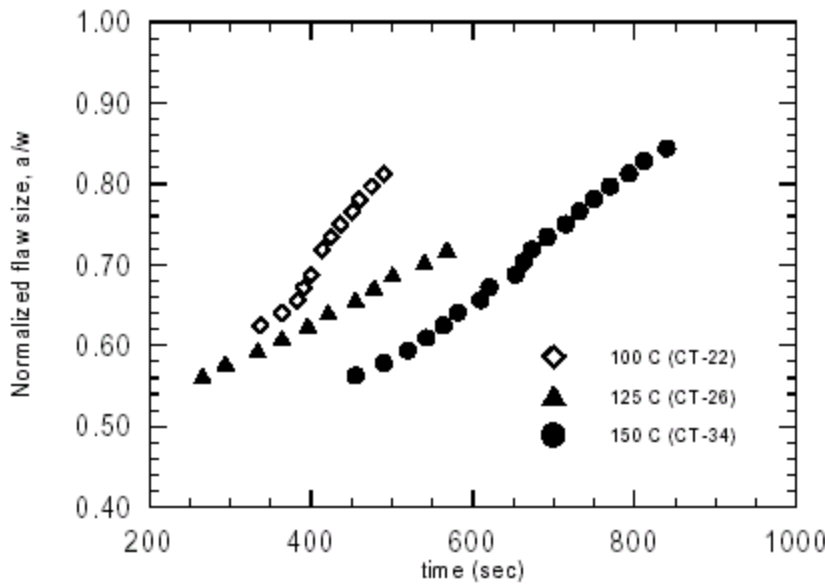
Cure

It was found that the postcure was necessary to develop the fracture toughness values presented in Figure 4. Specimens not post-cured were found to exhibit fracture toughness values significantly lower. This decrease was by an average of 53% at

100°C; at ambient temperature the decrease was by 20%.

Stable Crack Growth

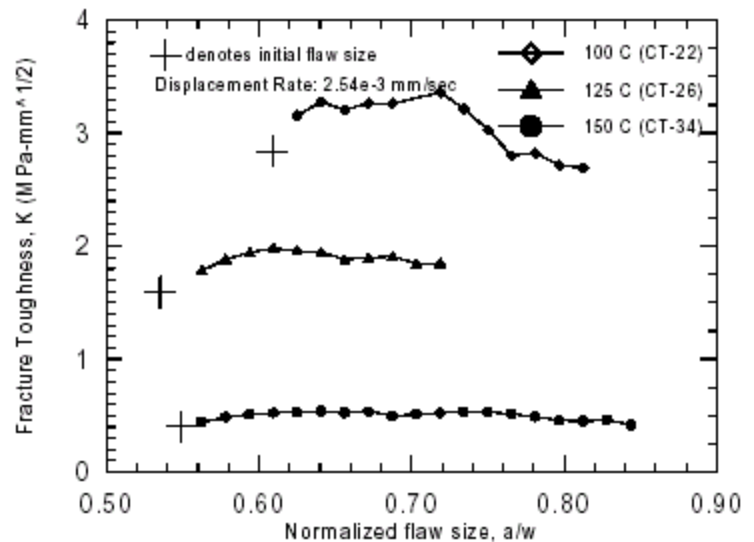
As already noted, at temperatures above 100°C stable crack growth was observed. In all cases this behavior was observed in conjunction with a smooth diminution in load subsequent to the maximum value (Figure 2) as contrasted to the discontinuous decrease observed at lower temperatures. Stable crack growth has also been reported for three-point-bend test specimens [3]. The availability of a continuous video record of the magnified specimen image permitted some analysis of this phenomenon in the present study. Plots of crack length vs. time were developed, as shown in Figure 5.



With both the load and crack length histories available, time was eliminated and the fracture toughness calculated and plotted as a function of non-dimensional crack length, as presented in Figure 6. The fracture toughness as calculated per E399 and the known initial flaw size is also noted in Figure 6.

Figure 5. Plot of Flaw Size as a Function of Time for Three Test Temperatures

Figure 6.



It is observed that, generally, the cracks propagate at a substantially constant stress intensity value which is the same as that calculated for initiation. The 100°C record eventually shows a modest decrease in  $K$ . In any event, it is clear that the initiation  $K_{IC}$ , as calculated per ASTM E399 is a critical load for crack propagation, be it either unstable or stable in nature.

It is noted that the ability of the molding compound to support stable crack propagation, i.e., crack growth in a constant  $K$ -field, at elevated temperatures implies that this material is certainly capable of supporting creep crack growth, i.e., crack

growth in an increasing  $K$ -field. Thus, creep crack growth as a failure mode for electronic packages is a possibility.

Transferability

The ability of  $K_{IC}$  to serve as a valid parameter for determining conditions which are critical for crack growth in different geometries is central to its utility as a design and analysis parameter. Figure 4 shows the extent of transferability of two geometries, namely, three-point-bend and CT fracture toughness specimens. It is seen that the CT specimen tends to give somewhat higher values of  $K_{IC}$  over most of the temperature

range spanned by both data sets although, at both ends of this range agreement is within experimental scatter. These end points--ambient temperature and 150°C--are temperatures where the amount of viscoelastic behavior exhibited by a like molding compound has been observed to be relatively small.

While load point displacement rates cannot be directly compared for the tests because of the different specimen geometries, the time rate of change of the stress intensity factor is a quantity which directly compares stress rates in the K-dominant zone. At temperatures below 75°C in the present experiments, P-d curves are reasonably linear prior to crack initiation, and, for this situation, it is easily determined that

$$\frac{dK}{dt} = \left(\frac{\dot{\delta}}{\delta_c}\right)K_c \quad (\text{Eq. 1})$$

Here  $\dot{\delta}$  is the load point displacement rate and  $\delta_c$  is the load point displacement at peak, or critical, load. For ambient temperature data, Equation 1 produces SIF rates of 0.013 MPa-m<sup>(1/2)</sup>/s and 0.019 MPa-m<sup>(1/2)</sup>/s, for three-point-bend [2] and the present CT tests, respectively. Since the ratio of these values will be comparable for results at other temperatures as well, it is seen that the CT data of Figure 4 are associated with a somewhat higher strain rate than are the three-point-bend data. In view of the rate sensitivity exhibited by the data of Table 1 (at 125°C), it appears that the geometry-dependent differences in  $K_c$  at selected temperatures which are seen in Figure 4 are largely associated with rate effects. Consequently the evidence is that transferability for critical stress intensity factor between CT and three-point-bend specimens is excellent.

In concluding this section, it must be noted that the effect of specimen thickness is unclear. The CT specimens were 2.5-mm-thick as compared to a thickness of 6.3 mm for the bend specimens. The thickness to width ratio, B/w, for the three-point-bend specimens met the E399 requirement for a valid plain strain fracture toughness test by equaling 0.5. For the CT specimens, this was not the case, with B/w = 0.1. Since at certain temperatures the agreement shown by Figure 4 is good, it appears that the results are relatively insensitive to the degree to which plane strain is achieved, but this issue was not systematically addressed by the present test program.

## Conclusions

A series of fracture toughness tests has been conducted on the filled epoxy molding compound EME 7320 at temperatures ranging from -93C to 150C. Fracture toughness values have been found which are consistent with previously obtained data from three-point bend specimens. For tests conducted at and above 100°C the failure was by steady state crack growth and occurred at a substantially constant value of K. Strain rate was significant in determining the initiation fracture toughness in these cases. The absence of postcure was also found to significantly affect fracture toughness.

## Acknowledgment

John Sauber of DEC and Steve Groothuis of Texas Instruments provided molding facilities and material, respectively, for specimen preparation. Mr. T.C. Harper of OSU was responsible for subsequent preparation of the specimens. This work was supported by the Semiconductor Research Corporation.

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