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VOL. 1, NO. 5 • PUBLISHED BY KEMET ELECTRONICS CORP. • P. O. BOX 5928 • GREENVILLE, SC 29606 • (864) 963-6300 • SEPT 1991

Leads and encapsulants provide multilayer ceramic capacitors (MLCs) used in through-hole board technology with plenty of protection from thermal and mechanical stresses. Thus, the development of ceramic dielectrics for leaded capacitor applications initially concentrated on achieving optimum electrical properties. Surface-mount technology changed the rules, and for more than a decade KEMET ceramic development engineers have worked under the admonition "Think Like a Mechanical Engineer." This focus has resulted in physical property studies, the use of finite element analyses in capacitor design, and new acceptance criteria for dielectric developments.

The paper which follows provide some basic information on two of the important mechanical properties of MLCs: fracture toughness and modulus of rupture. For those readers who wish to learn more on this subject, a list of KEMET technical publications follows the paper.

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Mechanical Properties of Ceramic Capacitors

by C. R. Koripella

Due to their brittle nature, ceramic chip capacitors are susceptible to fracture from mechanical and thermal stresses during surface-mount processing. Characterizing the mechanical strength and thermal shock resistance of both dielectric materials and the capacitors made from them is useful in predicting the reliability of surface-mount applications and designing new and tougher products. In this study, the fracture toughness (FT) and modulus of rupture (MOR) of commercial ceramic dielectric materials were measured with and without internal electrodes. This report briefly discusses the results

Fracture Toughness (FT)

FT is a measure of the energy consumed during differential extension of flaws or cracks determined at the critical stress. It can be regarded as a material constant, but is a function of the stress and the critical flaw size (1). In this study, FT measurements were made by the indentation-strength method (2), in which the sample is pre-cracked using a micro indentor and then the strength is measured in a four-point flexure mode. The FT values for X7R and Z5U dielectrics are about same: 0.8 MPa $m^{1/2}$ (without electrodes) and 1.5 MPa $m^{1/2}$ (with electrodes). Slightly higher values are measured on COG dielectrics: 1 MPa $m^{1/2}$ (without electrodes) and 1.5 MPa m½ (with electrodes). FT values for lead-based (relaxor type) and barium titanate-based Z5U dielectrics are very similar. The FT values collected in this study (Table 1) agree with those reported in literature for ceramic dielectric materials (3).

Modulus of Rupture (MOR)

MOR is a measure of the mechanical strength of the material and is typically obtained by the three-point bend test method (1). Fracture strength is the applied stress necessary to initiate fracture in the brittle material. Fracture strength is variable; thus, MOR is not a material constant but instead depends on various material and sample properties as well as the method of loading. Weibull analysis is the most commonly used statistical method for analyzing the fracture strength of ceramic materials (4). In this method, the probability of failure is a function of stress and the volume of the sample.

Tables 1 and 2 contain the Weibull modulus "m" (reflecting the degree of variability in strength) and the strength value corresponding to the 50% probability of survival for different dielectrics. Weibull analysis indicates that MOR values are significantly higher for samples of 30 mils thickness, and that the presence of electrodes slightly increases the strength of the dielectric. Of the dielectrics sampled, COG samples were particularly affected, followed by X7R and Z5U (see the data in Figures 1 and 2).

Table 1.
Modulus of Rupture and Fracture Toughness Measured on 5819 Size Samples for Different Dielectrics

Dielectrics	Modulus of Rupture				Fracture Toughness			
	Without Electrodes		With Electrodes		Without Electrodes		With Electrodes	
	σ(MPa)	m	σ(MPa)	m	Ave	(std)	Ave	(std)
COG	198	4.1	175	4.8	1.07	(0.15)	1.5	(0.13)
X7R	168	5.4	166	6.5	0.81	(0.09)	1.03	(0.15)
Z5U	114	4.2	116	3.9	0.81	(0.1)	1.01	(0.17)
Z5U(relaxor)	59	3.2	109	6.8	0.81	(0.19)	1.0	(0.14)

Table 2.
Modulus of Rupture and Fracture Toughness Measured on 1206 Size Samples for Different Dielectrics
Modulus of Rupture

Dielectrics	30 mils (0.76mm) thick				50 mils (1.27mm) thick			
	Without Electrodes		With Electrodes		Without Electrodes		With Electrodes	
	σ(MPa)	m	σ(MPa)	m	σ(MPa)	m	σ(MPa)	m
COG	268	5.8	285	4.9	206	3.2	218	2.4
X7R	195	4.4	254	8.1	195	3.0	215	2.9
Z5U	149	3.4	181	3.0	144	2.9	143	2.9
Z5U(relaxor)	96	13.8	128	5.6	89	2.6	90	4.0

The samples at 30 mils thickness did not yield significant differences in strength either with or without electrodes. Weibull modulus values were very low, indicating a large scatter in the data. In the three-point bend test, these samples actually failed in the shear mode rather than the bend mode. Therefore, the MOR values calculated for these samples are not as meaningful.

MOR results given in Tables 1 and 2 show lower values for the relaxor-type Z5U lead dielectrics than the $BaTiO_3$ based Z5U dielectrics. However, the FT values, as shown in Table 1, are about the same for both dielectrics. Similar FT values are also reported in the literature (3), which implies equal mechanical strength for both the dielectrics. The low MOR values measured here may be due to the unique method of intergranular fracture and the extensive porosity in the lead-based dielectrics, compared to transgranular fracture and minimal porosity in the $BaTiO_3$, dielectrics.

Realizing the importance of the mechanical strength of the dielectric materials, KEMET has incorporated mechanical strength requirements along with the electrical requirements for new dielectric material development. Using this approach, a new Z5U formulation was developed with a higher dielectric constant and superior mechanical properties. Figure 3 shows the comparison of MOR results measured on the old and new Z5U materials without internal electrodes. Not only is the MOR higher for the new Z5U material, but the Weibull modulus "m" is also higher, indicating a narrow distribution of strengths.

Fig. 1 MOR Data for Different Dielectrics

5819 Size, without Electrodes, 30 mils

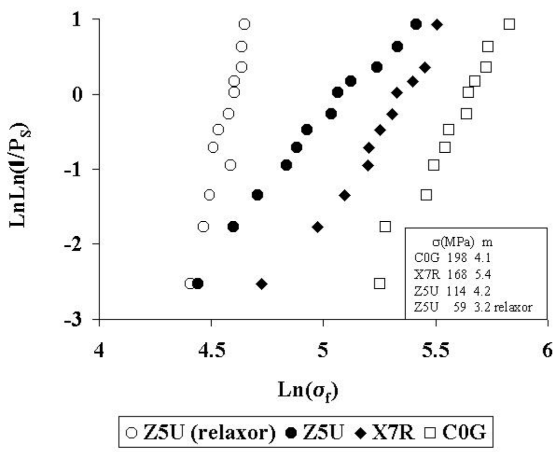


Fig. 2 MOR Data for Different Dielectrics

1206 Size, without Electrodes, 30 mils

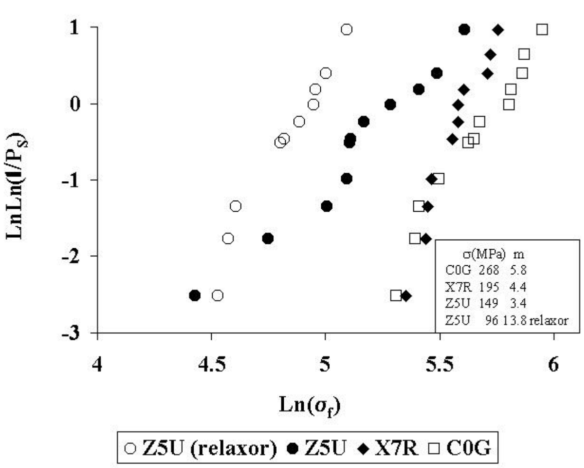
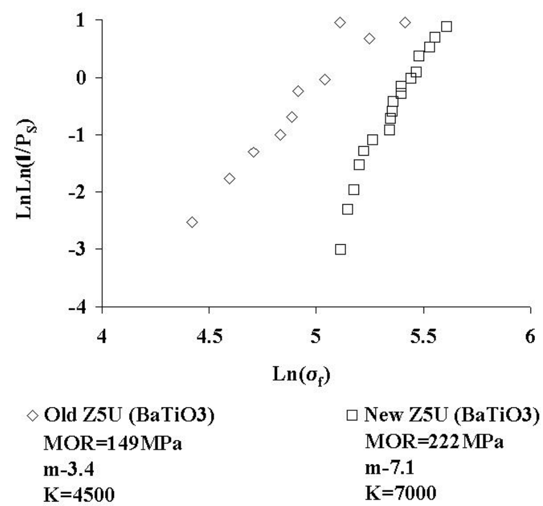


Fig. 3 MOR Data for Different Dielectrics

1206 Size, without Electrodes



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4. G. Weaver, "Engineering with Ceramics Part 1: The Weibull Model," *J. Mat. Edu*., 5, 677-804 (1983).

Additional KEMET Technical Literature

KEMET contributions to the technical literature on the mechanical and thermal properties of surface-mount MLCs include:

1. F-3072 - H. V. DeMatos and C. R. Koripella, "Crack Initiation and Propagation in MLC Chips Subjected to Thermal Stresses," *Proceedings of the Eigth (CARTS) Capacitor and Resistor Technology Symposium*, 25-31. San Diego, CA, March 1988.
2. F-2104 - C. R. Koripella and H. V. DeMatos, "Fractography of Thermal Shock Cracked Multilayer Capacitors," *J. Am. Cer. Soc*., Vol. 72, No. 12,2241-2246, December 1989.
3. F-2106 - J. B. Bergenthal, "Mechanical Strength of Multilayer Ceramic Chip Capacitors," *Proceedings of the Eleventh (CARTS) Capacitor and Resistor Technology Symposium*, 124-135, Las Vegas, NV, March 1991.
4. F-2107 - C. R. Koripella, "Mechanical Behavior of Ceramic Capacitors," *Proceedings of the Electronic Components and Technology Conference*, 457-462, Atlanta, GA, May 1991.