NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report 32-1433

Dielectric Constant and Loss Tangent of Eccofoam PT, at 2.3 GHz, for Various Packing Densities

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Preface

The work described in this report was performed by the Engineering Mechanics Division of the Jet Propulsion Laboratory.

All of the physical and electrical testing, upon which this report is based, was accomplished by A. G. Young.

Contents

Tables

Figures

Abstract

The dielectric constant and loss tangent for Eccofoam PT, at various densities, are determined; the resulting density gradients are provided. The range of densities over which the dielectric constant and loss tangent are determined are from ~20 to 80 lb/ft.^{3}

Dielectric Constant and Loss Tangent of Eccofoam PT, at 2.3 GHz, for Various Packing Densities

I. Introduction

A cavity type of antenna design was used on the Capsule System Advanced Development (CSAD) Lander at the Jet Propulsion Laboratory. The cavity of this antenna design was dielectrically loaded (packed) with a light weight, syntactic, epoxide foam, Eccofoam PT (Emerson and Cuming, Inc., Canton, Mass.), to a nominal density of 28.5 lb/ft^3.

It was determined that, at this packing density, the media would possess a relative dielectric constant ϵ'_r which would satisfy the design requirement of 1.70.

Since Eccofoam PT has the consistency of damp sand, it is difficult to distribute evenly within a cavity and around an antenna probe. Uneven distribution causes density variations; furthermore, the areas of the different densities possess different dielectric constants. For most general applications, the desired situation would be an homogeneous density throughout the loaded device, thereby affording the same dielectric constant in all areas of the cavity.

II. Objectives

The objectives of this program were (1) to determine the dielectric constant and loss tangent of Eccofoam PT when packed at selected densities, and (2) to determine the resulting density gradients at various depths in the packings.

This information will make it possible to selectively tailor the electrical parameters to meet a range of dielectric constants, when required by design. In addition, density gradient data can be used to develop practical and reproducible fabrication procedures.

III. Testing

A. Specimen Preparations

Duplicate sets of cylindrical Eccofoam PT specimens were prepared at densities of 20, 28.5, 40, 50, 60, and 80 lb/ft^3. One of the specimen sets was intended as a spare, to be used in the event of damage to the first set; however, the tests were completed without damage to the first set of specimens.

Table 1. Density vs dielectric constant and loss tangent of Eccofoam PT

Target density, lb/ft^3	Density before machining, lb/ft^3	Density after grinding, lb/ft^3	Uncorrected relative constant dielectric ϵ'_r	Loss tangent, $\delta\epsilon$	Test frequency, MHz	Corrected to 2.3 GHz, ϵ'_{r_f}	Corrected to 2.3 GHz and target density, $\epsilon'_{r_{td}}$
20.0	19.9	20.10	1.489	0.00606	2279.6	1.463	1.455
28.5	28.3	28.57	1.733	0.00696	2284.8	1.710	1.706
40.0	39.7	39.68	2.050	0.00735	2277.6	2.010	2.026
50.0	49.8	50.03	2.390	0.00820	2215.7	2.180	2.179
60.0	59.9	59.92	2.733	0.00815	2071.8	2.218	2.221
80.0	79.3	80.41	3.501	0.00876	1782.1	2.102	2.091

Each specimen was packed in layers to a specified density. In order to accomplish this, an accurately known quantity of Eccofoam PT was placed into a mold and slowly compressed by a ram until the layer was 0.5-in. high. This procedure was repeated for each layer until five layers were compressed, for a total specimen length of 2.5 in.

After packing, all specimens were cured in a forced-draft oven for 1 h at 250°F. After curing and removal from their molds, the approximate density of each specimen was determined (Table 1). One set of specimens was precision ground to the dimensions shown in Table 2. The outer- and inner-diameter dimensions allow the specimens to be lightly pressed into an adjustable reactance line for electrical testing. The specimen length is determined from an anticipated value of dielectric constant and the desired test frequency. In the usual case, the dielectric constant is not exactly as anticipated; the test frequency must be changed slightly to compensate for the error in the specimen length caused by the difference between the anticipated and the actual dielectric constant.

B. Test Procedure

After machining, the density of each specimen was accurately determined by micrometer measurements and by weighing on an analytical balance.

The dielectric constant and loss tangent determinations were performed using two SLRD Generators and an LMD Precision Slotted Line (Rohde and Schwarz, Inc., Munich, Germany). The generators and slotted line were operated in a typical heterodyne set-up with an MRAL Mixer and a Type 1236 I-F Amplifier Detector (General Radio Co., West Concord, Mass.). The specimen container was an Adjustable Reactance Line (Rohde and Schwarz).

Table 2. Machined dimensions of Eccofoam PT specimens

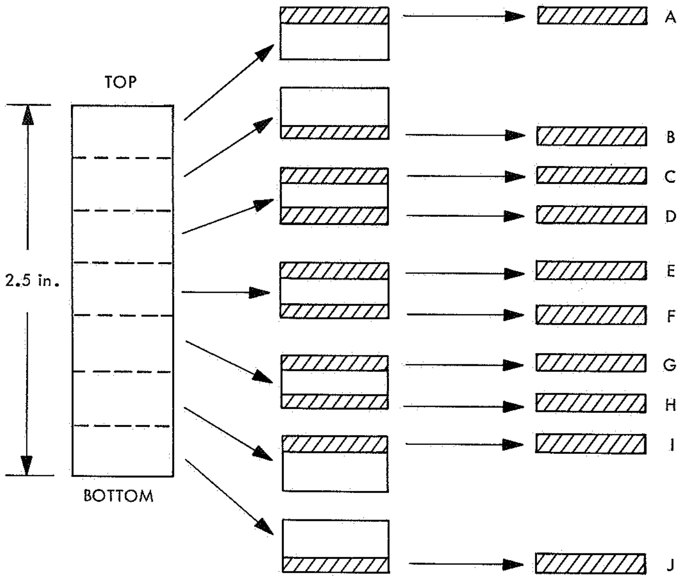
Target density, lb/ft^3	Anticipated dielectric constant ϵ'_r	Outer diameter, in.	Inner diameter, in.	Length, in.
20.0	1.45	0.8250 $^{+0.0000}_{-0.0003}$		2.130 ±0.005
28.5	1.70		0.3603 $^{+0.0003}_{-0.0000}$	1.970 ±0.005
40.0	2.00			1.815 ±0.005
50.0	2.10			1.775 ±0.005
60.0	2.20			1.730 ±0.005
80.0	2.40			1.730 ±0.005

After the electrical determinations were completed, each specimen was sectioned, as shown in Fig. 1, and the densities of each piece were accurately determined. Table 3 presents the density of each sectioned piece versus the dielectric constant, as taken from the corrected curve in Fig. 2.

Graphs representing uncorrected test data and the test data after corrections for both the target densities and the target frequencies of 2.3 GHz are shown in Fig. 2 and enumerated in Table 1.

Table 3. Density gradients vs dielectric constants

Target density, lb/ft^3	Section location in specimen (Fig. 1)	Density, lb/ft^3	Corresponding dielectric constant for corrected curve in Fig. 2
20.0	A	19.96	1.450
	B	20.03	1.469
	C	19.81	1.448
	D	20.09	1.488
	E	19.97	1.456
	F	19.53	1.444
	G	20.08	1.484
	H	20.11	1.494
	I	20.05	1.481
	J	19.91	1.438
28.5	A	29.98	1.756
	B	29.48	1.737
	C	29.93	1.750
	D	28.50	1.710
	E	29.25	1.731
	F	27.75	1.687
	G	28.65	1.708
	H	29.25	1.731
	I	29.49	1.738
	J	27.66	1.685
40.0	A	41.28	2.050
	B	38.24	1.981
	C	40.33	2.031
	D	39.02	2.003
	E	38.39	1.976
	F	38.41	1.980
	G	40.30	2.030
	H	39.48	2.006
	I	40.96	2.047
	J	38.63	1.991
50.0	A	51.02	2.178
	B	49.82	2.171
	C	49.50	2.165
	D	49.59	2.168
	E	51.28	2.183
	F	48.80	2.161
	G	50.17	2.175
	H	49.91	2.173
	I	49.18	2.163
	J	49.97	2.174
60.0	A	62.53	2.211
	B	60.86	2.215
	C	59.81	2.216
	D	58.75	2.215
	E	59.05	2.216
	F	58.11	2.214
	G	59.46	2.215
	H	59.72	2.215
	I	62.76	2.210
	J	60.48	2.216
80.0	A	81.40	2.080
	B	79.47	2.098
	C	79.53	2.096
	D	79.16	2.099
	E	81.84	2.073
	F	78.91	2.101
	G	81.28	2.079
	H	79.91	2.090
	I	81.90	2.072
	J	79.47	2.098



SECTIONS A THROUGH J ARE 0.100 ±0.005-in. THICK

Fig. 1. Sectioning of specimens after electrical determinations

Recalling the relationship as the inverse of the square root of the dielectric constant to frequency and the direct relation of density to the dielectric constant, the corrections can be calculated by either of the following:

$$\epsilon_2 = \frac{(f_1)^2\left(\frac{\epsilon_1 \cdot d_2}{d_1}\right)}{(f_2)^2} \qquad \text{or} \qquad \sqrt{\epsilon_2} = \frac{f_1\left(\sqrt{\frac{\epsilon_1 \cdot d_2}{d_1}}\right)}{f_2}$$

where

ϵ_1 = dielectric constant at a known frequency

ϵ_2 = dielectric constant at the desired frequency

d_1 = measured density

d_2 = desired density

f_1 = actual test frequency

f_2 = desired test frequency

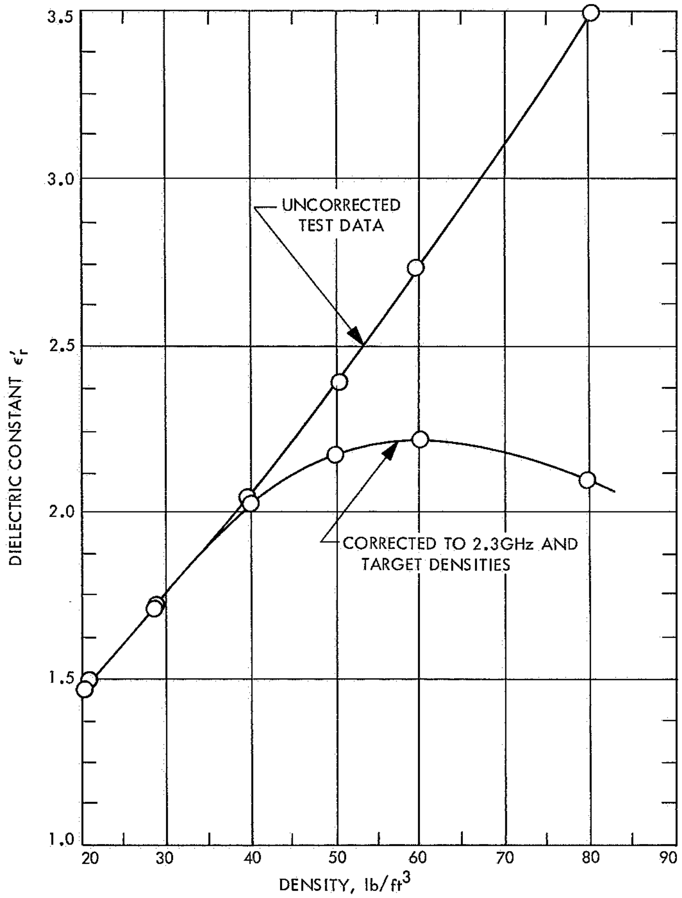


Fig. 2. Dielectric constant vs density of Eccofoam PT

IV. Conclusions

Within the selected density ranges of this program, and at 2.3 GHz, there are two distinct ranges of obtainable dielectric constants for Eccofoam PT (Fig. 2). The dielectric constants in the first range increase linearly with increasing densities between approximately 20 and 34 lb/ft^3. The dielectric constants within the second distinct range increase nonlinearly with increasing densities from approximately 34 lb/ft^3 to a maximum dielectric constant of 2.216, at a density of approximately 60 lb/ft^3, and decrease nonlinearly with increasing densities from 60 to 80 lb/ft^3.

The tangent of the loss angle for Eccofoam PT increases with increasing density, as shown in Table 1.

An analysis of the data in Table 3 indicates that practical deviations of dielectric constants (caused by density gradients) can be expected to be less than 0.074 for each of the packing densities between ~20 and 80 lb/ft^3.