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SOUND ABSORPTION OF LOW-TEMPERATURE REUSABLE SURFACE INSULATION CANDIDATE MATERIALS

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Sound absorption data from tests of four candidate low-temperature reusable surface insulation materials are presented. Limitations on the use of the data are discussed, conclusions concerning the effective absorption of the materials are drawn, and the relative significance to Vibration and Acoustic Test Facility test planning of the absorption of each material is assessed.

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J. D. Johnston
Lyndon B. Johnson Space Center
Houston, Texas 77058

CONTENTS

Section	Page
SUMMARY	1
INTRODUCTION	1
TEST PROGRAM	2
Test Specimens	2
Test Method	3
Test Apparatus	4
RESULTS AND DISCUSSION	5
CONCLUSIONS AND RECOMMENDATIONS	8

TABLES

Table | Page

I IDENTIFICATION, CONFIGURATION, AND PROPERTIES OF LRSI CANDIDATE MATERIALS . . . 9

II NORMAL-INCIDENCE SOUND ABSORPTION OF CANDIDATE LRSI MATERIALS AND OF SOLID ALUMINUM 10

III COEFFICIENT OF AVERAGE ABSORPTION MEASURED OVER TESTED FREQUENCIES FOR EACH MATERIAL 11

FIGURES

Figure | Page

1 Test specimens viewed from above sealed outer surface 12

2 Test specimens viewed from above unsealed surface 13

3 Absorption measurement test setup

(a) Complete test apparatus 14
(b) Detail of test specimen mounting 14

4 Normal-incidence sound absorption of sealed LRSI candidate materials and of solid aluminum 15

5 Normal-incidence sound absorption of sealed and unsealed surfaces of LI-900 16

6 Normal-incidence sound absorption of sealed and unsealed surfaces of SAM 17

7 Normal-incidence sound absorption of sealed and unsealed surfaces of PD-200 . . . 18

SOUND ABSORPTION OF LOW-TEMPERATURE REUSABLE SURFACE INSULATION CANDIDATE MATERIALS

By J. D. Johnston
Lyndon B. Johnson Space Center

SUMMARY

Initial planning for acoustic tests of Space Shuttle orbiter components revealed the need for sound absorption measurements of the four materials that are candidates for use as low-temperature reusable surface insulation on the orbiter aft fuselage. The normal-incidence sound absorption characteristics of the candidate materials were determined for both the sealed and unsealed surfaces. These data indicate, generally, that the unsealed surfaces have higher absorption than the sealed surfaces and that nonrigid materials have higher absorption than rigid materials. The data also indicate that the Space Shuttle orbiter will be much more sound absorptive than previous spacecraft. As a result of these determinations, the noise generation capability of the Vibration and Acoustic Test Facility at the NASA Lyndon B. Johnson Space Center will have to be increased for testing large orbiter components. Additional conclusions are drawn from the data concerning the relative effects of the various low-temperature reusable surface insulation materials and their configuration on acoustic testing of the orbiter aft fuselage.

INTRODUCTION

Manned spacecraft preceding the Space Shuttle orbiter had dense, locally noncompliant outer surfaces. The orbiter, however, will have a porous, compliant thermal protective material covering most of its surface. This configuration will be more sound absorptive than were previous spacecraft surfaces. Two inferences relative to acoustic environments can be drawn from the higher surface absorption.

1. The thermal protective material may shield the structure to some extent from flight fluctuating pressures so that in-flight vibration levels will be less severe than they would be without the material.

2. The sound power-generation capability required to achieve a given acoustic pressure specification in a ground test will increase in direct proportion to an increase in acoustic absorption.

As a result of the second inference, sound absorption measurements of the orbiter thermal protective material were needed to determine the Vibration and Acoustic Test Facility (VATF) sound generation capability required for orbiter testing. Because a test of the orbiter aft fuselage would be a more severe test of the VATF sound generation system (because of a higher test pressure specification) than tests of other orbiter segments, the four candidate low-temperature reusable surface insulation (LRSI) materials (thermal protective materials) for the aft fuselage were chosen for sound absorption tests. Although the first inference is not directly discussed in this report, the sound absorption test results may be usefully applied, to a limited extent, in studying that deduction.

This report contains sound absorption data from tests of the four candidate LRSI materials. Limitations on the use of the data and conclusions concerning the effective absorption of the materials are discussed. Finally, the relative significance to VATF test planning of the absorption of each material is assessed.

As an aid to the reader, where necessary the original units of measure have been converted to the equivalent value in the Système International d'Unités (SI). The SI units are written first, and the original units are written parenthetically thereafter.

TEST PROGRAM

Test Specimens

Four LRSI materials, identified in table I, are candidates for use on the Space Shuttle aft fuselage. The LRSI material will be bonded in sheet or tile form to the metallic panels of the orbiter. The outer surface of the LRSI will be sealed by a thin moisture-control coating material. The pertinent material, coating, and orbiter application data for each of the candidate materials are given in table I.

Each test specimen was 5 centimeters (2 inches) square; three specimens were 2.5 centimeters (1 inch) thick, and the PD-200 specimen was a fraction thicker at 2.72 centimeters (1.07 inches). All test specimens are shown in figure 1 from above the sealed surfaces. A similar view of the back surfaces is given in figure 2. Before the selection of absorption test specimens, cylindrical plugs had been removed from the PD-200, silicone ablative material (SAM), and polybenzimidazole (PBI) specimens for other tests. These plugs were carefully replaced for the absorption tests. The PBI plug did not penetrate the coating material; however, the PD-200 and SAM plugs were cut completely through the specimens. The replaced plugs fitted so well that it is unlikely that they influenced the absorption measurements. All the specimens except the PBI were suitable for absorption measurements on both the sealed and unsealed surfaces. As can be seen in figure 2, even the unsealed surface of the PBI has a thin, hard, fibrous coating. The cylindrical plug for this specimen did not have the coating; therefore, no meaningful measurements on the unsealed side of the PBI specimen could be made.

Test Method

The size of the available test specimens, only 5 centimeters (2 inches) square, precluded the use of a random noise reverberant-room test technique (a minimum test specimen area of 6.7 square meters (72 square feet) is required to meet accepted test standards), which would have approximated the conditions to be used in testing the aft fuselage and produced less uncertainty in applying the resultant data. The specimens were therefore tested at single frequencies for perpendicular incident plane waves. Sound absorption values measured by the perpendicular-incidence method are always less than or equal to values measured by the reverberant-room method; but for closed-surface specimens such as LRSI materials (except the unsealed side of PD-200), the differences should be small.

When a discrete frequency plane wave strikes a surface perpendicularly, interference of the incident and reflected waves creates pressure amplitude oscillations along the line of wave motion (a line perpendicular to the surface). The pressure amplitude reaches an absolute maximum at the surface, and the first pressure minimum (an absolute minimum) occurs one-fourth wavelength from the surface. The normal-incidence absorption coefficient at a single frequency α can be expressed in terms of the maximum and minimum pressure amplitudes (P_{max} and P_{min}, respectively) by the following relationship.

$$\alpha = \frac{4}{\left(P_{max}/P_{min}\right) + \left(P_{min}/P_{max}\right) + 2} \qquad (1)$$

To obtain the results given in this report, sound pressure level (SPL) was measured rather than pressure; therefore, the actual working formula was

$$\frac{P_{max}}{P_{min}} = \text{antilog}_{10}\left(\frac{SPL_{max} - SPL_{min}}{20}\right) \qquad (2)$$

where the SPL for a pressure P, given some reference pressure P_{ref}, is defined as

$$SPL = 20 \log_{10} \frac{P}{P_{ref}} \qquad (3)$$

Test Apparatus

The test apparatus and the specimen mounting conditions are depicted in figure 3. The complete test apparatus is shown schematically in figure 3(a). The test specimen was mounted in one end of a tube; a speaker was mounted at the other end. Discrete frequency sound controlled by an electronic oscillator was directed from the speaker into the tube, and the resultant maximum and minimum sound pressure levels nearest the test specimen for each frequency were measured using a probe microphone and a readout device (one-third octave band frequency analyzer).

The specimen mounting arrangement is shown in figure 3(b). The 5-centimeter (2 inch) square specimens did not completely cover the end of the 5.25-centimeter (2.07 inch) inner tube diameter; therefore, rubber strips were tightly taped to the specimen edges to augment the specimen area enough to fill the tube opening. Any remaining cavity around the specimen in the expanded inner area of the tube was filled with a pliable acoustic sealing material so that the test specimen was held firmly in place. The entire end of the tube was then closed by bolting on a thick aluminum cap. Although a small portion of the test area (only 1 percent) was filled by the rubber strip material, the data probably were not significantly affected.

RESULTS AND DISCUSSION

The absorption data for the LRSI specimens and for a solid aluminum surface are presented in table II. The solid aluminum surface absorption was measured to demonstrate that the lower limit of the test apparatus measurement capability was low enough that it would not interfere with accurate measurements of the LRSI specimens. Absorption data were determined for the sealed and unsealed surfaces of the PD-200, SAM, and LI-900 specimens, for the sealed surface of the PBI specimen, and for the solid aluminum surface at the center frequency of each one-third octave band from 63 to 2500 hertz. All tabulated data are given in plotted form in figures 4 to 7. The data are plotted in terms of absorption coefficient, which is the measured absorption percentage divided by 100. The data for the sealed surfaces of LRSI specimens show clearly that the elastic material PD-200 is significantly more absorptive throughout most of the test frequency range than are the three rigid specimens. The SAM material has minimum sound absorption for most of the test frequencies. Generally, the unsealed surfaces have higher absorption than the sealed surfaces. The coefficient of the average absorption measured over tested frequencies for each material is listed in table III. These absorption data lead to the conclusion that the orbiter will have much greater sound absorption as an acoustic test article than previous spacecraft tested at the VATF.

Test-article sound absorption can be classified as two major types: (1) surface absorption, attributed to porous or locally compliant materials, and (2) structural absorption, due either to damping inherent in the motion of large structural segments or to energy losses from sound transmission through the structure.

Previous test articles had dense, noncompliant surfaces and therefore had negligible surface absorption. Structural absorption dominated the absorption of these test articles. The average sound absorption attributed to structural motion was 10 percent for the Skylab orbital workshop and 6 percent for the Apollo spacecraft (consisting of a command and service module and a spacecraft/lunar module adapter).

In addition to the two sound energy loss characteristics mentioned previously, the orbiter test articles include a third absorption mechanism. Acoustic energy impinging on the test-article surface can be absorbed by damped vibration of the LRSI tiles (rigid tiles only) on the elastic bondline between the tiles and the supporting panel. The data in this report show that the surface absorption alone (measured in the absence of structural motion) of all the LRSI materials is much greater than the structural absorptions measured on the Skylab orbital workshop and the Apollo spacecraft. Direct sound absorption measurements cannot be made of the third absorption mechanism (vibration of tiles on the elastic bondline). This absorption mechanism would have potential significance at frequencies near the resonance frequency of a tile mass on the bondline stiffness. Existing vibration data indicate that such resonance frequencies will be in the vicinity of 2000 hertz for aft fuselage tiles. Because VATF noise generation control capability does not exist above approximately 1400 hertz, this latter absorption mechanism is considered to be out of the frequency range of interest for the purposes of this report. After the final bondline configuration is determined, the importance of the bondline absorption mechanism should be reassessed.

Because the orbiter aft fuselage will have significantly more absorption than previous test articles and must be tested to more intense fluctuating pressures than were previous test articles, the VATF noise generation capability must be increased. This conclusion is based on the fact that the noise generation capability (on a power basis) required in the test facility is directly proportional to the absorption within the facility and to the square of the sound pressure within the facility.

The LRSI surface absorption data presented in this report only approximate the amount of surface absorption to be expected of the orbiter spacecraft for several reasons.

1. The test specimens are nominally 2.5 centimeters (1 inch) thick, but the expected orbiter application thicknesses (see table I) vary from 0.64 to 4.04 centimeters (0.25 to 1.59 inches). The absorption of the rigid materials will probably not be greatly influenced by material thickness. The PD-200 absorption, however, would be expected to change drastically with changes in thickness. The shape of the absorption curve and the peak absorption would remain constant, but the peak absorption would shift according to the frequency at which the peak occurs. For the unsealed surface, the absorption characteristic should increase in frequency in direct proportion to decreases in material thickness; whereas, for the sealed surface, the absorption peak should increase in frequency in proportion to the square root of decreases in thickness.

2. The material properties given in table I are nominal properties. Significant density and strength differences occur from batch to batch of each material. Furthermore, because all the materials have been undergoing

continual development, the final materials can be expected to differ to some degree from the specimens tested.

3. The sound field used for the testing was perpendicular to the surface of a specimen, but the most probable orbiter incidence acoustic test condition will result in exposure of the material from all angles of incidence. All acoustic materials display some variation in absorption in accordance with the type of sound field imposed; however, the relationships between absorption values for a material determined by different techniques are known only approximately.

If the previously mentioned limitations of these data are considered, some conclusions on acoustic test planning can be drawn with respect to the particular LRSI material chosen for use on the aft fuselage. Planning for the aft fuselage acoustic test is highly dependent on the LRSI material selected for use on the aft fuselage because the noise generation capability required in the test facility is directly proportional to the absorption within the test facility. Cost-effective planning requires that the noise generation capability created in the test facility be just sufficient to perform the aft fuselage test. Therefore, as an initial planning step, the LRSI candidate materials can be categorized for a general comparison of their absorptive properties. As bases for comparison, the LRSI materials are classified according to their bulk properties (rigid or nonrigid) and their surface-sealing condition (sealed or unsealed). In each of the following conclusions, it was assumed that bondline absorption effects are small or above the frequency range of concern for test planning purposes.

1. A rigid-type, sealed LRSI material (for use on the aft fuselage) will absorb approximately 35 percent less acoustic energy than if the surface is unsealed and will also absorb less acoustic energy than the nonrigid, sealed PD-200 material.

2. The nonrigid, unsealed PD-200 material will absorb less acoustic energy than a sealed surface and also less than any of the rigid, unsealed materials. This conclusion is based on the prediction that the PD-200 material on the production configuration will be thinner than the material tested. (Hence, the frequency at which maximum absorption occurs will be shifted out of the frequency range of test planning.)

CONCLUSIONS AND RECOMMENDATIONS

Preliminary planning for acoustic testing of the orbiter aft fuselage disclosed the need for sound absorption measurements of the four candidate low-temperature reusable surface insulation materials. The resultant data, which are given in this report, show that the Vibration and Acoustic Test Facility noise generation capability must be increased because both the absorption and the pressure test specification of the aft fuselage will be higher than for previous test articles. Furthermore, the data indicate that the increase in noise generation capability will be sensitive to the nature of the low-temperature reusable surface insulation material that will cover approximately 50 percent of the aft fuselage surface. This sensitivity results from the fact that the various candidate materials have different absorption characteristics and, therefore, imply different magnitudes of increase in the facility noise generation capability. (Economy requires that the increase in noise generation capability be just sufficient to perform the testing.)

For initial planning purposes, the low-temperature reusable surface insulation absorption data have been categorized according to gross properties of the materials. The data show that a rigid material with a sealed surface will require less increase in noise generation capability than would the elastomeric PD-200 material with a sealed surface. If the material has an unsealed surface, the elastomeric PD-200 will require less increase in noise generation capability than that for any of the rigid alternate materials.

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas, December 19, 1974
986-15-11-00-72

ORIGINAL PAGE IS OF POOR QUALITY

TABLE I.- IDENTIFICATION, CONFIGURATION, AND PROPERTIES OF LRSI CANDIDATE MATERIALS

Descriptor type	Material			
	PD-200	Silicone ablative material (SAM)	Polybenzimidazole (PBI)	LI-900
Basic material				
Manufacturer	General Electric	General Electric	Aerotherm/Whittaker	Lockheed
Descriptive class	Elastomer, flexible	Ceramic, rigid	Foam, rigid	Ceramic, rigid
Composition	Open-cell foamed RTV-560[1]	Silica monofilaments bonded in silicone resin	Closed-cell plastic foam	Sintered silica fiber composite
Density, kg/m^3 (lbm/ft^3)	256 (16)	160 (10)	96 (6)	144 (9)
Tensile modulus, kN/m^2 (psi)	90 (13)	103 420 (15 000)	12 410 (1800)	241 320 (35 000)
Service temperature, K (°F).	<616 (<650)	<728 (<850)	<728 (<850)	<616 (<650)
Seal coating				
Identification	PD-147	PD-147	Chem-ceram	Ceramic
Descriptive class	Silicone rubber	Silicone rubber	Ceramic	Ceramic
Composition	RTV-511 base[1]	RTV-511 base[1]	Ceramic over fibrous foil[2]	Borosilicate glass
Thickness, cm (in.) . . .	0.046 (0.018)	0.025 (0.010)	0.036 (0.014)	0.038 (0.015)
Application size				
Length and width, cm (in.)	46 by 46 (18 by 18)	30 by 30 (12 by 12)	61 by 61 (24 by 24)	15 by 15 (6 by 6)
Thickness,[3] cm (in.)	1.04 to 1.93 (0.41 to 0.76)	0.79 to 2.69 (0.31 to 1.06)	1.3 to 4.04 (0.5 to 1.59)	0.64 to 1.65 (0.25 to 0.65)
Bond to structure				
Description	Silicone rubber	Strain isolation pad and silicone rubber	Silicone rubber	Strain isolation pad and silicone rubber
Thickness, cm (in.)	0.025 (0.010)	0.318 (0.125)	0.038 (0.015)	0.312 (0.123)

[1]A methyl phenyl silicone product of General Electric.
[2]Both sides of PBI material have a thin fibrous coating.
[3]Thickness varies with location on the orbiter and with the assumed flight trajectory.

TABLE II.- NORMAL-INCIDENCE SOUND ABSORPTION OF CANDIDATE LRSI MATERIALS AND OF SOLID ALUMINUM

Frequency, Hz	Percent sound absorption of -							
	LI-900		SAM		PD-200		PBI sealed side	Solid aluminum
	Sealed side	Unsealed side	Sealed side	Unsealed side	Sealed side	Unsealed side		
63	13.5	10.7	14.0	13.2	8.1	6.5	10.7	4.7
80	16.4	12.5	14.7	14.7	9.1	6.9	13.2	4.4
100	19.2	15.5	17.2	17.3	12.5	7.7	18.2	3.9
125	22.8	20.2	19.2	20.6	13.2	8.1	23.5	3.7
160	26.7	25.5	21.2	25.2	18.8	9.6	30.6	3.0
200	31.5	32.1	23.5	30.1	27.3	12.6	35.6	3.0
250	37.3	41.5	24.7	35.6	37.0	16.0	37.3	2.6
315	40.8	49.6	20.9	35.0	51.7	23.5	30.6	1.4
400	40.8	55.5	16.7	32.1	73.9	33.3	24.9	2.4
500	38.3	52.5	15.2	30.6	83.1	50.0	23.2	2.4
630	27.8	46.5	12.6	30.6	72.6	70.4	16.0	1.4
800	22.3	45.3	13.2	30.6	59.8	76.9	13.2	[1]<2.2
1000	21.9	50.0	14.3	29.5	58.1	78.2	14.0	[1]<2.2
1250	19.2	41.5	12.6	25.4	47.6	91.2	12.8	[1]<2.4
1600	14.4	36.3	9.6	24.9	37.0	98.9	11.0	[1]<1.9
2000	11.9	38.3	8.6	25.9	30.1	93.8	9.6	[1]<1.4
2500	8.6	34.0	6.5	30.9	22.3	81.5	7.3	[1]<3.0

[1]Measurement affected by insufficient dynamic range of measurement system.

TABLE III.- COEFFICIENT OF AVERAGE ABSORPTION MEASURED OVER TESTED FREQUENCIES FOR EACH MATERIAL

Material	Absorption coefficient
LI-900	
Sealed side	0.243
Unsealed side	.357
SAM	
Sealed side	.156
Unsealed side	.266
PD-200	
Sealed side	.390
Unsealed side	.450
PBI	
Sealed side	.195
Solid aluminum[1]	.027

[1]Solid aluminum coefficient given for reference.

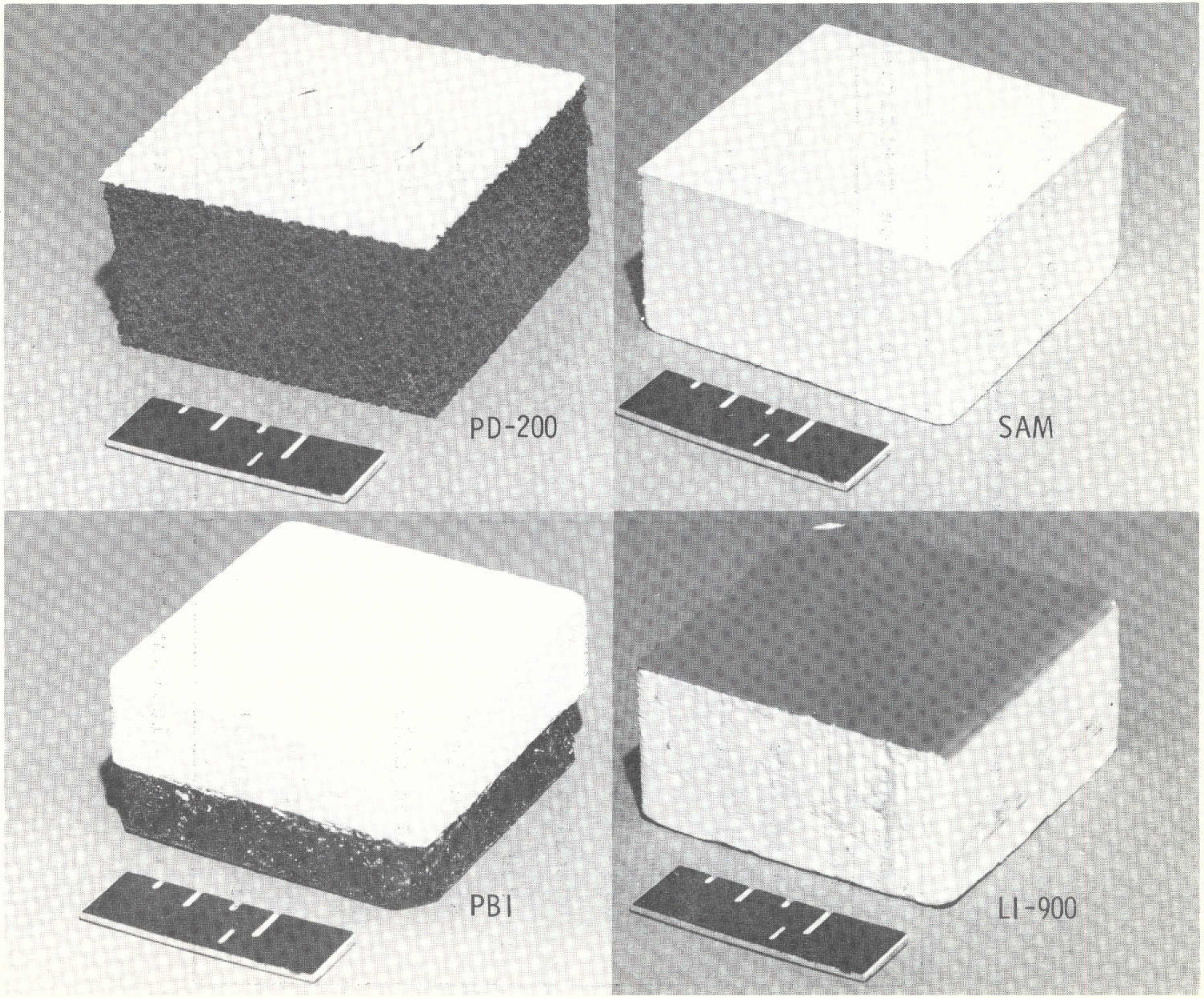


Figure 1.- Test specimens viewed from above sealed outer surface.

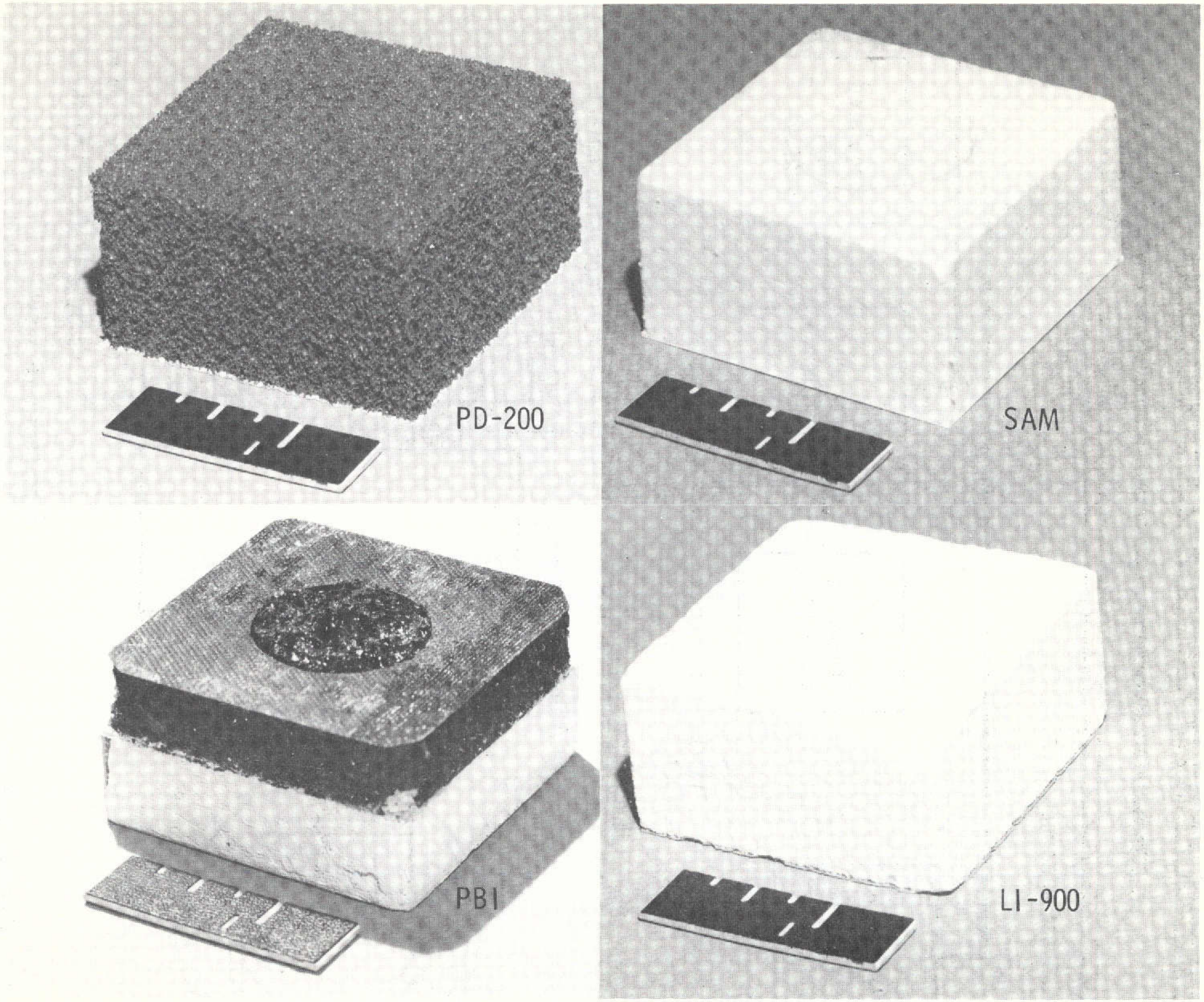
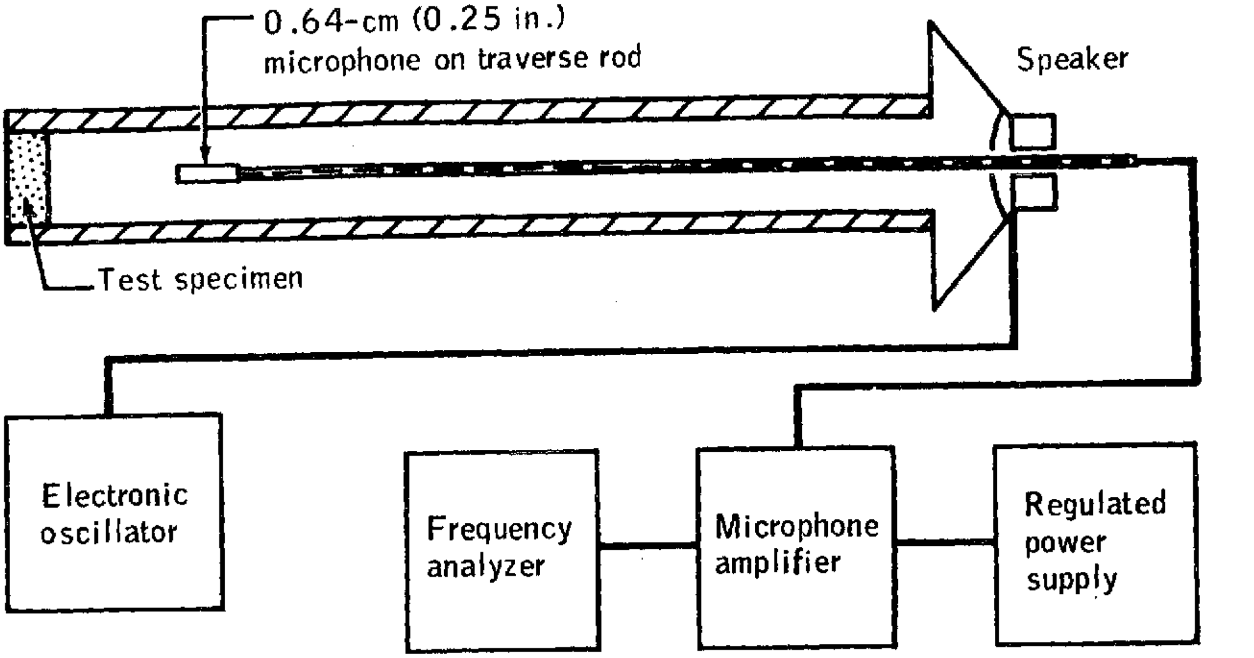
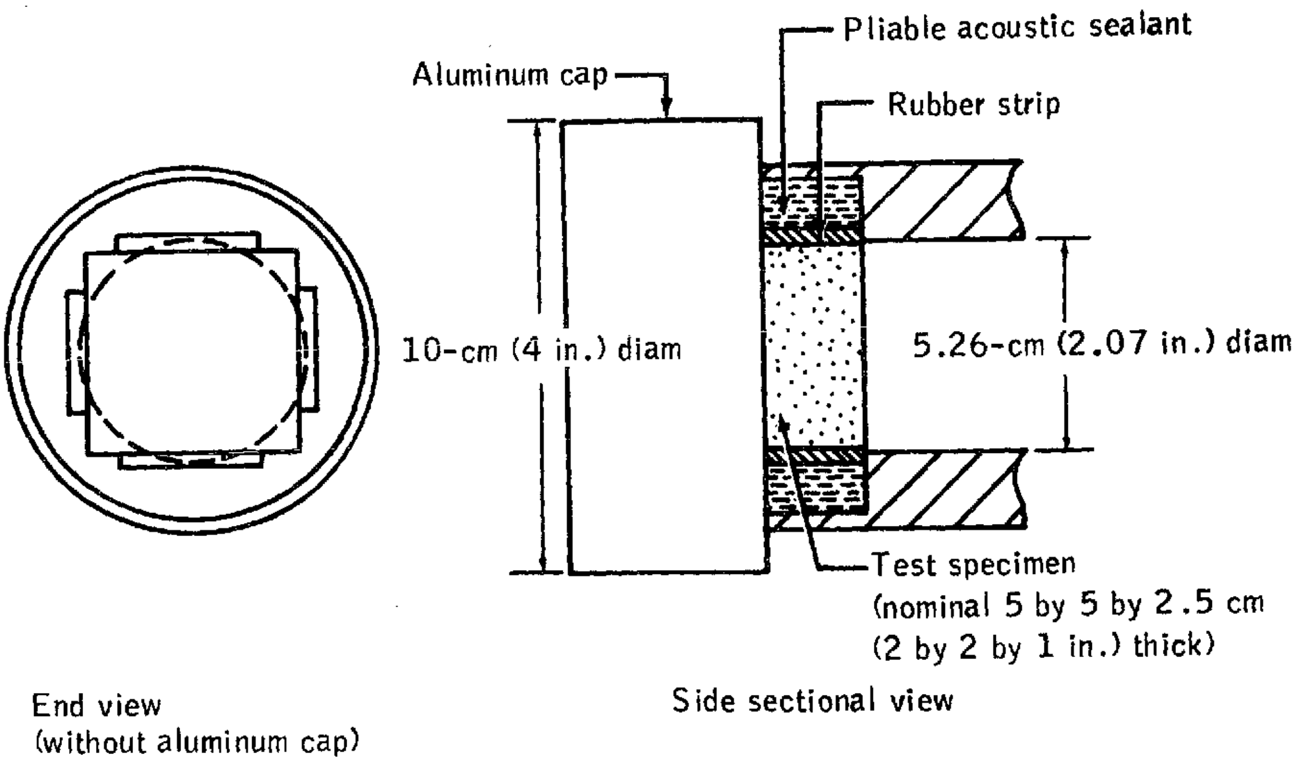


Figure 2.- Test specimens viewed from above unsealed surface.



(a) Complete test apparatus.



(b) Detail of test specimen mounting.

Figure 3.- Absorption measurement test setup.

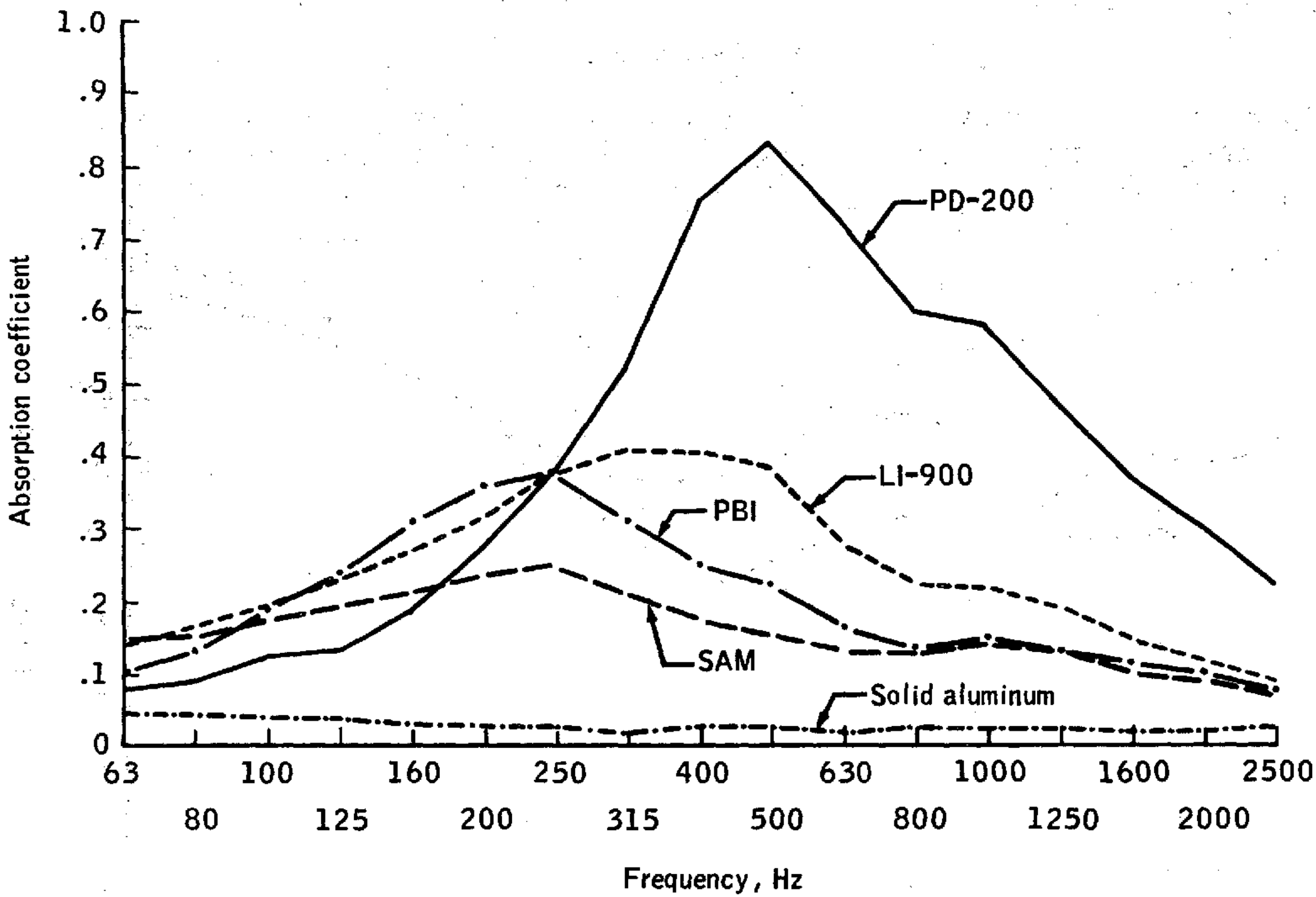


Figure 4.- Normal-incidence sound absorption of sealed LRSI candidate materials and of solid aluminum.

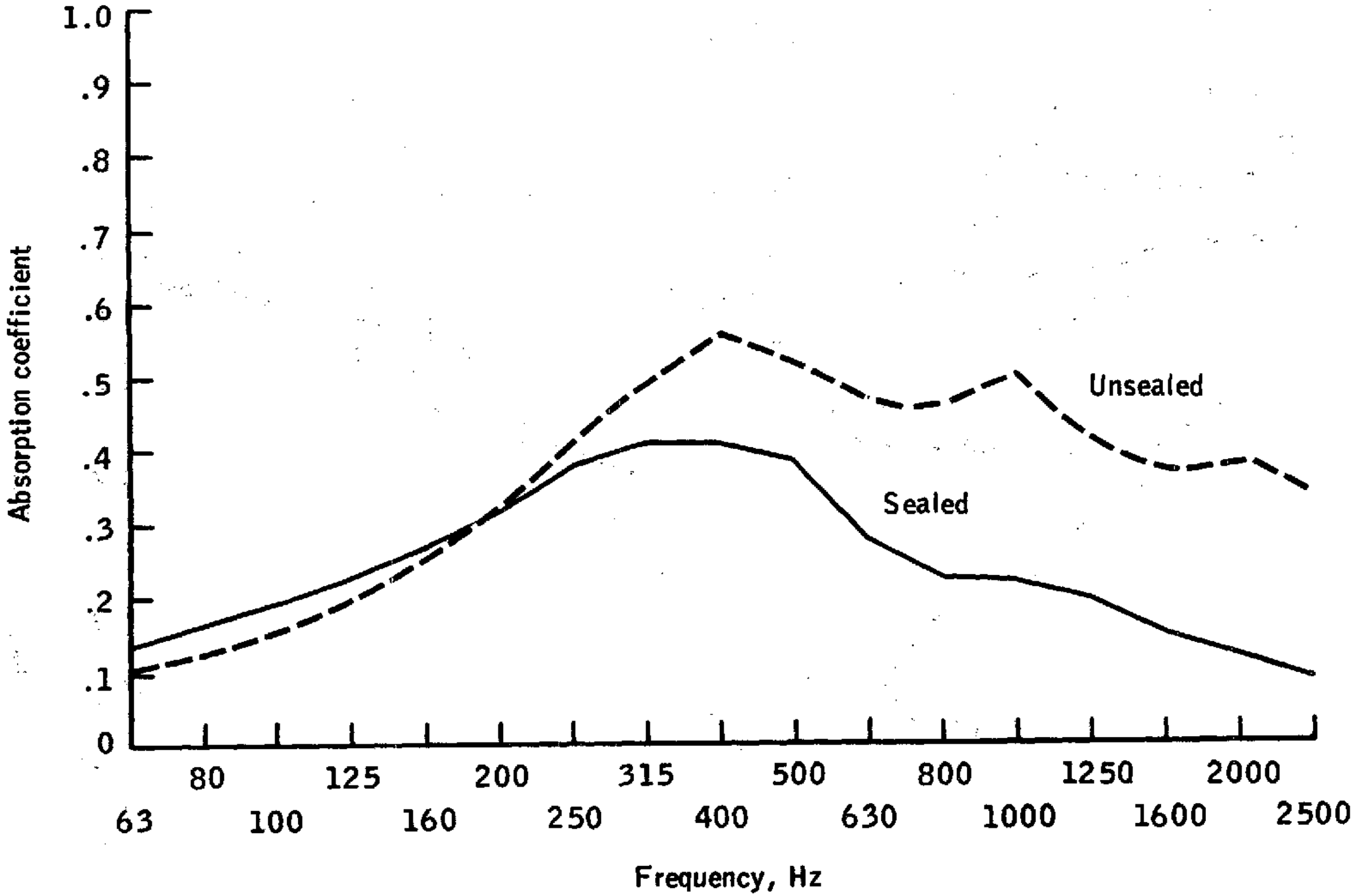


Figure 5.- Normal-incidence sound absorption of sealed and unsealed surfaces of LI-900.

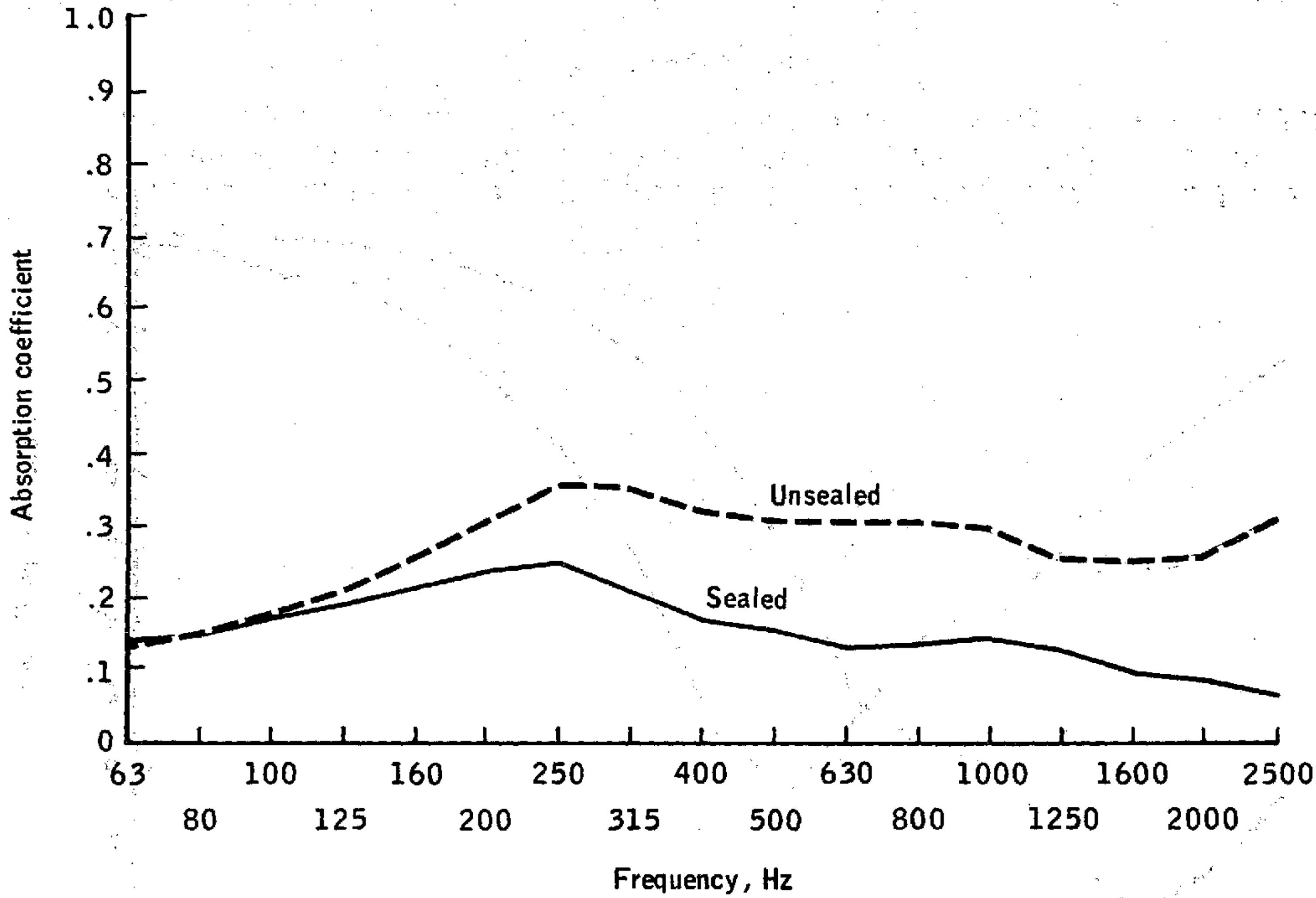


Figure 6.- Normal-incidence sound absorption of sealed and unsealed surfaces of SAM.

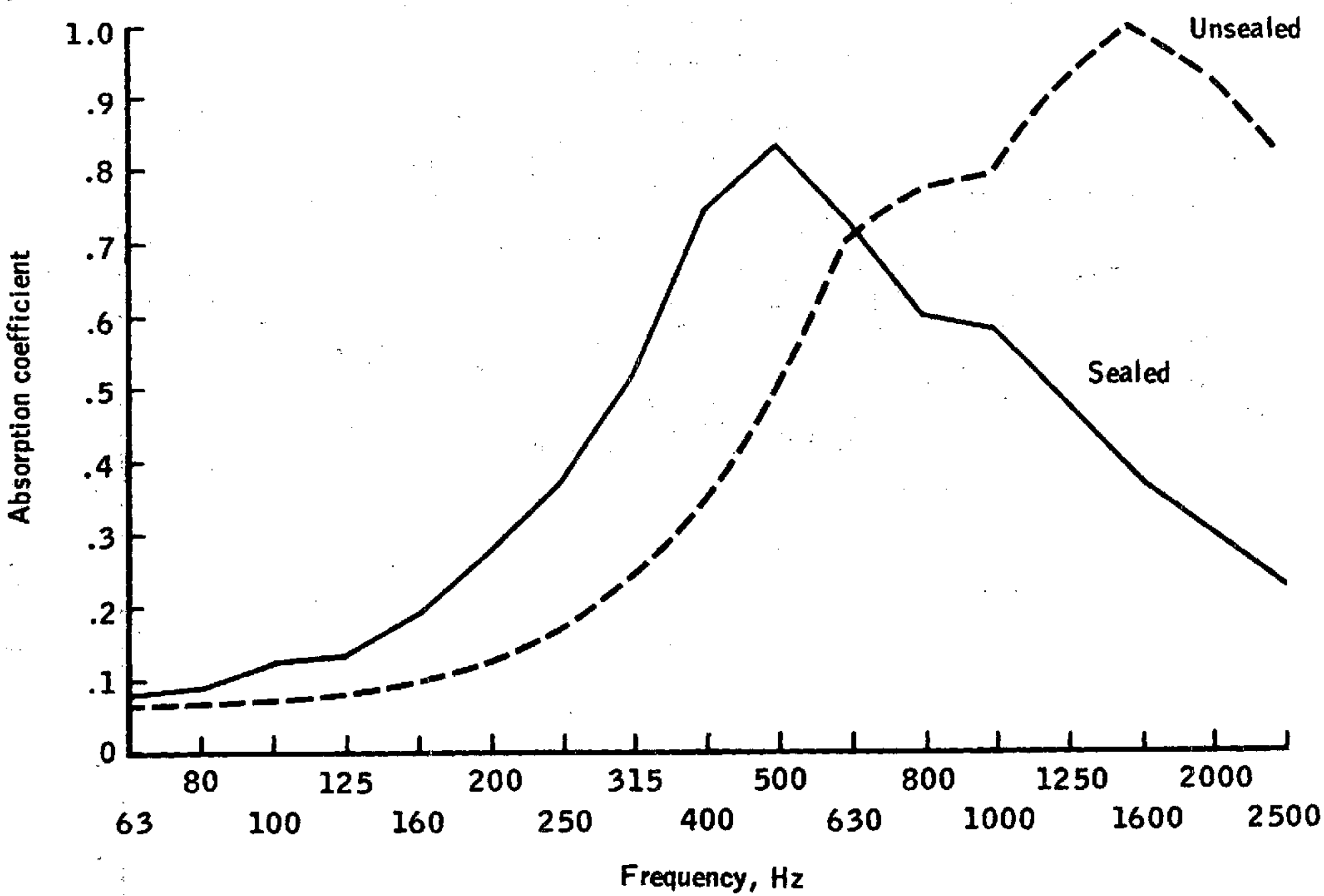


Figure 7.- Normal-incidence sound absorption of sealed and unsealed surfaces of PD-200.