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DETERMINATION OF ACOUSTIC PROPERTIES OF SOME BUILDING MATERIALS FOR BUILDING DESIGN

NIGERIAN BUILDING AND ROAD RESEARCH INSTITUTE

Foreword

Due attention is now given to the acoustical performance of buildings especially conference, concert and cinema halls, theatres and auditoria. To achieve good acoustical performance, it is necessary to identify and properly use materials with good acoustic performance.

This report contains the acoustic properties of various local materials which were determined by the standing wave method. Special attention is given to fibre boards developed by the Nigerian Building and Road Research Institute from local palm and coir fibres and rice husks. Other materials considered are some locally manufactured conventional boards from rigid and flexible polyurethane foams, expanded and extruded polystyrene, fibre cement and mineral fibres.

It is hoped that this report will encourage Nigerian architects and engineers to a greater use of locally manufactured and developed acoustic building materials.

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1. INTRODUCTION.

Lack of proper sound treatment in functional enclosures leads to excessive noise level and reverberation, creating the difficulty of speech communication. The adverse effects of noise — the unwanted sound or signal — on man's ability for concentration can be reduced using acoustic or sound insulation materials. Acoustic design methods and materials are developed for schools, auditoria, concert halls, churches, mosques, cinemas and other places where acoustical consideration play important roles. Such enclosures, interior walls and ceilings designed using functional architectural geometry, if treated with suitable sound absorbent materials, help to avoid reverberant behaviour with a resultant considerable reduction in the noise level. The sound absorption characteristics of a material depends on its thickness, density, flow resistance and porosity. It also depends on the frequency and angle of incidence of the sound, air absorption, the effects of pattern, area, edge and diffraction; and the mounting conditions of the material (1–4).

In this paper, the acoustic properties of some local building materials developed at the Building Materials Section of the Nigerian Building and Road Research Institute and some other locally manufactured boards from expanded polystyrene, polyurethane rigid foams, fibre cement and mineral fibres are determined. The standing wave method is used for determining the sound absorption coefficient and the acoustic impedance of the materials while a locally fabricated flow resistance apparatus is used to find the *dc* acoustic impedance of the materials. The acoustic properties and the pattern of behaviour are presented in this paper.

2. SOUND ABSORPTION AND STANDING WAVE THEORY

2.1 Sound Absorption.

For rigid walls of a complete enclosure, all the incident waves are reflected setting up a standing wave pattern with non-uniform distribution of acoustic energy density. If the walls are porous and soft, a substantial part of the incident wave is absorbed and the distribution of mean-square pressure is reduced and uniform.

The properties (1,5) which make a material suitable for sound absorption are:

(i) Surfaces that are relatively transparent to sound waves. Such acoustic transparency may be in the form of a porous surface, an integral mechanical perforation or fissured openings into the body of the porous material or a perforated board. Perforated hard surface acts as a positive or mass-series acoustic reactance and show decreasing transparency with increasing frequency.

(ii) A means for the vibratory energy of the waves to be completely transformed into heat energy by friction. The frictional element in the form of a layer of highly porous material at least 12mm (½ inch) thick, in which the pores must intercommunicate throughout, accounts for the dissipation of sound energy.

(iii) The total depth of air volume between the face of the material and the rigid backing surface behind it (this includes air in the pores of the material). When the total depth of air is less than ¼ wavelength, it acts as a series-negative or stiffness acoustic impedance whose value increases with decreasing frequency and decreasing depth of air volume. Inside a porous material, the amplitude of vibration of the incident sound wave energy or air molecules is progressively damped out by friction against the fibres forming the pores. This friction whose value depends on the resistance of the material to direct air flow is called the *dc* acoustic resistance or flow resistance (F) and defined as the ratio of the pressure drop across a sample of material to the volume velocity of air (flow rate) passing through it. It is expressed in MKS rayls as

$$F = \frac{dp}{dt} / U \text{ ....} \qquad (1)$$

where dp/dt is the pressure difference across a thickness d_t and U is the volume current through the porous material. The value of the flow resistance is a function of the thickness and density of the material, fibre diameter, percentage binder and the average orientation of fibre with respect to the direction of air flow. The optimum value varies with frequency, thickness and method of mounting.

Acoustical materials display a peaked absorption — frequency curve, the shape at low frequency being largely determined by the depth of air volume, in the peaked region by the flow resistance and at the high frequencies by the amount of surface opening.

2.2 Absorption Coefficients

Three variations of the absorption coefficient parameter can be distinguished.

(a) Sound absorption coefficient for a given angle of incidence, α_θ :— This is the ratio of the sound energy absorbed by the surface to the sound energy incident upon the surface at a given angle θ. Note that $0 < \alpha_\theta < 1$.

(b) Statistical (energy) sound absorption coefficient, α :— defined as the ratio of sound energy absorbed by the surface to the sound energy incident upon the surface when the incident sound field is perfectly diffused for an infinitely large absorbing surface. It is sometimes called the random incidence sound absorption coefficient which can be determined using the Reverberation Chamber method.

(c) Sabine Absorption Coefficient, α_{sab} :-This is obtained by measuring the time rate of decay (reverberation time) of the sound energy density in an approved reverberation room with and without a patch of the sound-absorbing materials under test laid on the floor. α_{sab} so obtained may exceed α by as much as 50% at low frequencies and 20% at high frequencies. This is the value usually published by manufacturers.

The standing wave method employed here measures α_θ for $\theta = 90^o$ and this result is normally referred to as the normal incidence absorption coefficient.

2.3 The Standing Wave Theory

The standing wave method is used in determining the absorption coefficient and acoustic impedance of the building material samples (1–3, 5–9).

For an acoustic plane wave incident normally on a sample in the standing wave tube of Figs. 1 and 2 at a point or distance x, the total sound pressure is:

$$P_x(x,t) = P_i(x,t) + P_r(x,t)$$

where $P_i(x,t) = A \cos 2\pi ft$ is the incident sound pressure and

$$P_r(x,t) = B \cos 2\pi f(t-2x/c)$$

is the reflected sound pressure.

The Root Mean Square (RMS) maximum and minimum pressures measured are $P_{max} = (A+B) \cos 2\pi ft$ occuring at $x = \lambda/2$

and $P_{min} = (A-B) \cos 2\pi ft$ occuring at $x = \lambda/4$

The sound absorption coefficient (α) defined as the ratio between the energy absorbed by the sample and