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Acoustic behaviour of plastics for medical applications

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The rectangular and square samples of bio-plastic materials namely, polymethyl methacrylate (PMMA), polycarbonate (PC), polystyrene plastic (PS material), polypropylene (PP), polyvinyl chloride (PVC), bakelite (G-10), nylon, Y-dent and teflon (PTFE) used for different applications in hospitals have been studied. These samples collected from different hospitals in Delhi (Safdarjang Hospital, Batra Hospital, AIIMS) have been studied for ultrasonic velocity, elasticity, acoustic impedance etc. at room temperature (24ºC). The average values of ultrasonic velocity and elasticity are found to vary directly with the density. The ultrasonic parameters measured at 2.5 MHz are reported here.

[**Keywords:** Ultrasonic properties, Acoustic impedance, Medical plastics, Transmission coefficient]

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1 Introduction

The term plastic refers to a family of materials, which includes nylon, polyethylene and PTFE. The plastics are a relatively recent development but in fact, as part of the larger family called polymers, these are basic ingredient of animal and plant life. During the early 20th century there was a considerable interest in these new synthetic materials. Phenol-formaldehyde (bakelite) was introduced in 1909, and at about the time of the Second World War materials such as nylon, polyethylene and acrylic (perspex) appeared on the scene. The range of plastics available, the type of behaviour, which they exhibit and the design process involved in selecting the best plastic for a particular application[1] were taken into consideration.

The thermo-plastic materials are used in mould room technology for making moulds for cancer patients of head and neck to give them immovability during their radiotherapy treatments. When this material is heated the intermolecular forces are weakened so that it becomes soft and flexible and eventually, at high temperature, it is viscous melt[2]. When the material is allowed to cool, it solidifies again. Examples of thermo-plastics are polyethylene (PE), polyvinal chloride (PVC), polystyrene (PS), nylon, cellulose acetate, acetal, polymethyl methacrylate (PMMA) and polypropylene (PP). Thermosetting materials are characteristically quite rigid materials and their mechanical properties are not heat sensitive. Examples of thermosets are phenol formaldehyde, melamine formaldehyde, urea formaldehyde and some polyesters.

Typical applications of nylon include small gears, bearings, surgical stitching threads, bushes, sprockets, housing for power tools, terminal blocks and slide rollers. The major advantages of polytetra-fluoroethylene (PTFE) material are its excellent chemical resistance and its extremely low coefficient of friction. It is widely used in areas such as insulating tapes, gaskets, pumps, diaphragms and non-stick coatings on cooking utensils. Polyethylene terephthalate (PET) as a moulding material has replaced glass in beverage bottles. The popularity of polyvinyl chloride (PVC) in hospitals is due to its use in artificial prosthesis leg and hand frames. Polymethyl methacrylate (PMMA) has exceptional optical clarity and resistance to outdoor exposure. Its peculiar property of total internal reflection is useful in advertising signs and some medical applications like lenses, lighting diffusers etc. Polystyrene (PS) being of non-pigmented grades have crystal clarity and overall their low cost coupled with ease of processing makes them used for such things as model aircraft kits, vending cups, coils, disposable syringes, phantom for dosimetry in radiotherapy[1-18] etc. Acoustic behaviour of such materials has been studied here.

2 Experimental Details

In the present study, rectangular and square samples of bio-plastic materials namely, polymethyl methacrylate (PMMA), polycarbonate (PC), polystyrene plastic (PS material), Polypropylene (PP), polyvinyl chloride (PVC), bakelite (G-10), nylon, Y-dent and teflon (PTFE) used for different applications in hospitals have been studied. The number of samples of each type used in this study is given in Table 1 with their characteristics and medical applications. These were collected from different hospitals in Delhi (Safdarjang Hospital, Batra Hospital, AIIMS, New Delhi). Their medical applications and chemical compositions are also given in Table 1.

The samples selected for the study are flat and rectangular type. These materials are used for moulding different types of items for hospital use. These samples are cleaned and dried and then clamped in vertical position. Two transducers are kept perpendicular to the surface of the sample and fixed with clamps in two different stands kept on both sides of the sample. The transducers are kept very close to the sample. The position of these transducers is kept just facing to each other. Separate transmitting and receiving transducers on opposite side of the sample are used (in through transmission mode)[13]. The method used for the study of the samples of plastics and solids/metals is the same.

A double-probe (pulse-echo) method[3] has been used to find out the ultrasonic velocity of the hard plastic and solid bio-material samples. The whole set-up was calibrated and standardized for standard iron block for the measurements of bio-plastic and solids bio-materials. An ultrasonic pulser-receiver (Panametric model 5052 PR) was used with 2.5 MHz transducers. Ultrasonic gel was used for good contact of samples and transducers surface. The thickness of the sample is a distance covered by transmitting wave. The received pulse was displayed on cathode ray oscilloscope (model 05-300C-20 MHz L and T Gould make)[7]. Fig. 1 shows the block diagram of whole experimental set-up. The distance between transmitting pulse and received pulse was measured from CRO screen as transit time *t*.

The acoustic velocity *V* in the material is the acoustic path length which is determined by timing the passage of ultrasound. The velocity of the ultrasound in a material depends on elastic constants and density of that material. The ultrasound velocity in the sample is obtained by dividing the measured

Table 1 — Bio-plastics used in the present work

Sample code	No. of samples	Material	Characteristics	Medical applications
PP	15	Polypropylene	Low density, stiffness and excellent fatigue, chemical resistance	Accelerator pedals, forceps/tweezers
PMMA	16	Polymethyl methacrylate	Optical clarity and resistance to outdoor exposure	Face guard, lances, Display models
PC	15	Polycarbonate	Extreme toughness	Compact disc, safety equipment
PS	18	Polystyrene	Its nonpigmented grades have crystal clarity	Disposable syringes, Water phantom
PVC	15	Polyvinyl chloride	Plasticised PVC is flexible. Unplasticised PVC is hard, tough, and strong material	Surgical hand gloves, Artificial prosthesis legs and hand frames
G-10	15	Bakelite (Phenol formaldehyde)	Strong, hard, excellent electric properties, affected by oxidised and alkali agents	
PTFE	15	Polytetra fluoroethylene	Excellent chemical resistant, extremely low coefficient of friction	Diaphragm, insulating tapes
Y-dent	15	Cellulose acetate	At 50-60 ^{o}C it becomes soft and flexible. When it is allowed to cool it solidifies again	Dental application. It is also used in making head and neck mould used in the treatment of cancer patients
Nylon	17	Polyamide	Due to excellent strength, stiffness, and toughness, it is best engineering plastic	Stitching thread (operation)

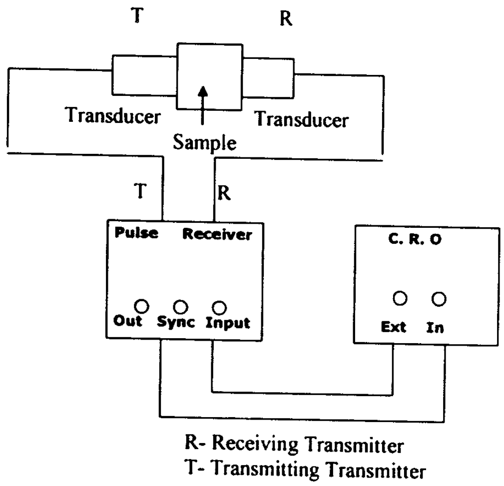

Fig. 1 — Block diagram of ultrasonic system for velocity measurement of solid samples

value of the acoustic path length (*d*) by the time of travel (*t*), as determined from the CRO.

$$V = d/t \text{ m/s} \quad \ldots(1)$$

The acoustic impedance *Z* is equal to the product of the density ρ and velocity *V* of the sound of the material. The value of the acoustic impedance depends on its physical properties.

$$Z = \rho \times V \text{ kg/m}^2\text{s} \quad \ldots(2)$$

where,

ρ is the density of sample and

V is the ultrasonic velocity of sample

density $\rho = m/v$ kg/m^3

where,

m is the mass of the sample and

v is volume displaced or increased.

Dynamic modulus of elasticity E_d is equal to the product of density ρ and square of velocity of sound of the sample.

$$E_d = \rho \times V^2 \quad \ldots(3)$$

3 Results and Discussion

The velocity of sound in a material depends on the elastic constants and density of those materials[11]. Thus, direct measurements of velocity determine the elastic constants provided that the density can be evaluated by another method, e.g. by measuring the volume and weighing or by using a hygrometer. Both the elastic constant and the density vary with temperature, concentration, nature of alloy, structure, and so on, and the measurement of the velocity may yield information about one of these quantities provided that the others remain constant or can be measured independently[5]. The application involves studies of biomedical plastics for ultrasonic velocity, elasticity, acoustic impedance etc. at room temperature (24 ^{o}C) by using a pulse technique.

The ultrasonic properties of plastics were investigated using a double probe through transmission method. The ultrasonic velocity and density were measured. The acoustic impedance, elasticity (Young's modulus), transmission coefficient and reflection coefficient have been calculated[13,14]. The average values of ultrasonic parameters are given in Tables 2 and 3. At least ten readings were taken at

Table 2 — Average values of ultrasonic parameters of bio-medical plastics

Sample code	Material	Density kg/m^3 $\rho \times 10^3$	Velocity (m/s) V	Acoustic Impedance 10^6kg/m^{2}s $Z = \rho V$	Elasticity 10^9kg/ms^2 $Ed = \rho V^2$
PP	Polypropylene	0.905	2100	1.9	3.99
PS	Polystyrene	1.050	2450	2.52	5.43
Nylon	Polyamide	1.140	2750	3.13	8.62
G-10	Phenol formaldehyde	1.40	3473	4.86	16.89
PTFE (teflon)	Polytetrafluo-roethylene	2.10	5400	11.34	61.24
PC	Polycarbonate	1.15	2800	3.22	9.02
Y-dents	Cellulose acetate	1.28	3100	3.97	12.3

Table 3 — Average values of transmission and reflection coefficients of bio-medical plastics at 24 °C and at atmospheric pressure

Sample	Density $\times 10^3$ kg/m^3	Transmission Coefficient $a_T = \frac{4Z_1Z_2}{(Z_1+Z_2)^2}$ kg/m^{2}s	Reflection Coefficient $a_R = \left(\frac{Z_2-Z_1}{Z_1+Z_2}\right)^2$ kg/m^{2}s
Polypropylene (PP)	0.95	0.90275×10^{-3}	0.999097
Polystyrene (PS)	1.050	0.68071×10^{-3}	0.999319
Polyamide (Nylon)	1.14	0.54809×10^{-3}	0.999725
Phenol formaldehyde (G-10)	1.40	0.35302×10^{-3}	0.999646
Polycarbonate (PC)	1.15	0.53277×10^{-3}	0.940172
Teflon (PTFE)	2.1	0.15131×10^{-3}	0.999848
Cellulose acetate (Y-dent)	1.28	0.43214×10^{-3}	0.999567

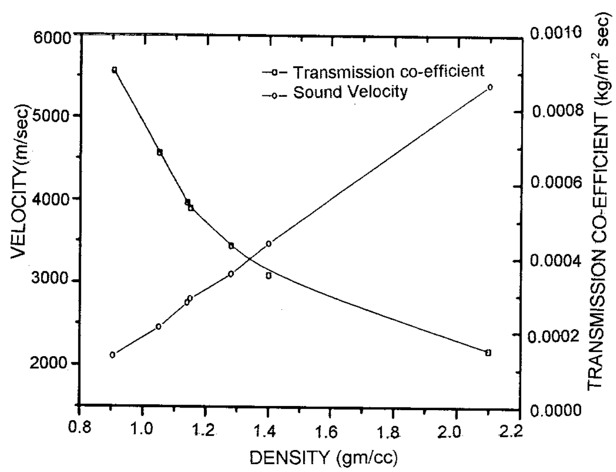

Fig. 2 — Variation in sound velocity and transmission coefficient as a function of density in plastics

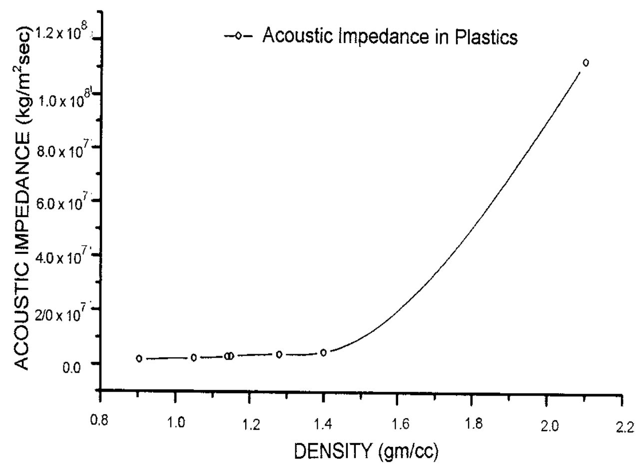

Fig. 3 — Variation in acoustic impedance as a function of density in plastics

different voltages in different directions and then calculated to get the average value to reduce the errors in the results. It is concluded that ultrasonic velocity varies with the density. In hard materials, ultrasonic velocity was higher than that of soft materials. A graph of density versus velocity and transmission coefficient is shown in Fig. 2. The present paper shows that as the density of the bio-plastic materials increases the velocity of sound increases but the transmission coefficient in plastic materials decreases with increase in the density. Fig. 3 shows the variation in acoustic impedance as a function of density.

4 Conclusion

The velocity of sound in plastics varies linearly with increase in density, whereas transmission coefficient decreases with the increase in density[10]. Young's modulus and shear modulus in homogenous, non-dispersive materials have been calculated from longitudinal wave and shear wave velocity (along with material density). In plastics and other polymers, the variation in molecular structure such as length or orientation of polymer chains often resulted in the corresponding changes in sound velocity and/or attenuation[15]. Changes in grain size or orientation in steel, silver and other metals would cause changes in the amplitude, direction, and/or frequency content of scattered ultrasound[9]. Variation in sound velocity, scattering, and/or attenuation across different axes of a solid can be used to identify and quantify anisotropy.

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