



Dielectric Studies of Acrylic Resin, Alginate, Dental Plaster, Dental Stone, Glass Ionomer and Silver Amalgam

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ABSTRACT

The study on physical properties of biomaterials now-a-days plays an important role in understanding the nature and its constituents. On one hand, their importances in medical field leading to diagnosis of a particular disease and on another hand bio-material are commercially important in daily life. In view of the importance of biomaterials the researchers thought that it is worthwhile to pursue research on Physical properties of biomaterials. In the present investigation dielectric studies on Acrylic resin, Alginate, Dental plaster, Dental stone, Glass ionomer and Silver Amalgams dental materials were taken up to study the various dielectric parameters like dielectric constant, dielectric loss and electrical conductivity, which show significant difference from one material to another material. Dielectric parameters are very sensitive to moisture content, mineral content in the material. The results of the present investigation are critically discussed in terms of its biocompatibility.

Keywords: Dental materials, dielectric constant, dielectric loss and electrical conductivity

1. INTRODUCTION

Biomaterials are non-viable materials used in a material device intended to interact with biological systems. They may be distinguished from other materials in that they possess a combination of properties, including chemical, mechanical physical and biological properties that render them suitable for safe, effective and reliable use within a physiological environment. Key factors in a biomaterial usage are its biocompatibility, bio-functionality, and availability to a lesser extent. Ceramics are ideal candidates with respect to all the above functions, except for their brittle behavior. A synthetic material is placed within the human body; tissue reacts towards the implant in a variety of ways depending on the material type [1]. The mechanism of tissue interaction if any depends on the tissue response to the implant surface. In general, there are three terms in which a biomaterial may be described in or classified into representing the tissues responses. These are bio inert, bioresorbable, and bioactive. Dielectrics are the materials in which electrostatic field can persist for a longer time and offer a very high resistance to the passage of electric current under the action of the applied direct current voltage and hence sharply differ in their basic electrical behavior from conductive materials. Much may be known about the structure of matter from measurement upon

polar liquids and solids, at extremes of frequency and often involving absorption of electrical energy as shown by the measured dielectric loss and frequency dependence of the dielectric constant [2]. Types of dental materials chosen in the present investigation and their compositions are given below.

Acrylic Resins:

This dental material is available in the form of powder and liquid form. The powder contains Polymethyl methacrylate-as beads or grindings, Benzoyl peroxide (0.3 to 3%)-Initiator, Colour pigments. Liquid contains Methyl methacrylate monomer, Ethylene dimethacrylate (5%) - cross linking agent, Hydroquinone (0.006%)-Inhibitor.

Alginate:

Alginate dental material consists of Ester salts of alginic acid, sodium or potassium or triethanolamine alginate, Calcium sulphate, zinc oxide, potassium titanium fluoride, diatomaceous earth, sodium phosphate, coloring and flavouring agent.

Dental plaster:

Dental plaster is composition of Sodium citrate, sodium tetraborate decahydrate, potassium sulphate, and potassium sodium tartrate which is used as cementing the teeth.

Dental Stone:

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Dental stone is used as one the dental material that contains Sodium citrate, sodium tetraborate decahydrate, potassium sulphate, potassium sodium tartrate and 2 to 3 % -coloring matter.

Glass ionomer:

Glass Ionomer is available in the form of powder and liquid. Powder form contains silica, alumina, sodium fluoride, cryolite, calcium fluoride, calcium phosphate or lime and Liquid contains phosphoric acid, aluminum phosphate, zinc phosphate, water.

Silver Amalgam:

Silver Amalgam consists of Silver, tin, copper and zinc composition used for the dental material as teeth transplantation.

The dielectric loss angle is an important parameter both for the material of a dielectric and an insulated portion. All other conditions being equal, the dielectric losses grow with this angle. This parameter is usually described by the so-called loss tangent ($\tan\delta$) sometimes the quality factor of an insulation portion is determined which is the reciprocal of loss tangent.

$$Q = 1/\tan \delta = \cot \delta = \tan \phi$$

The influence of frequency on the dielectric constant of an ionic crystal is related to the variation of polarizability. At low frequencies of the order of a few H_z , the dielectric constant is made up of contributions for electronic, atomic and space charge polarization. As the frequency increases to MH_z region, the dielectric constant decreases and then becomes independent of frequency [3-4]. The D.C. conductivity term becomes predominant and conductivity would normally be independent of frequency. The conduction loss may be defined explicitly as being due to motion of free vacancies, whereas the Debye loss due to relaxation effects is not explicitly defined.

2. EXPERIMENTAL

2.1 Materials

Dental material samples namely Acrylic resin, Alginate, Dental plaster, Dental stone, Glass ionomer and Silver Amalgams were collected from different dental hospitals in Bangalore. The dental material samples were brought to laboratory within 24 hours. Care was taken while collection of specific dental material samples and kept them separately.

2.2 Methods

In the present investigation two types of important artificial dental powders materials collected in dental hospital, Bangalore for study of dielectric properties. Dental materials i.e. powders is converted into specimens in the form Pellets or discs by using Ball Milling apparatus tree for

dielectric measurements. The dental material samples surface is painted with silver paste for electrode attachment (Figure1). The reagent powders were mixed and ball milled using Restch PM 200 planetary ball mill in agate bowls with agate balls. It was then ground well in an agate mortar once till a fine powder was obtained. Intimate mixing of the materials was carried out using agate mortar for 4 h and then ball milled using Restch PM 200 planetary ball mill in acetone medium for 20 h with agate balls of different sizes in diameter in agate bowls. The slurry was dried and the dried powder was pressed into disc shape of size 2.5 cm diameter and 1 cm height using suitable. A small amount of saturated solution of 3% polyvinyl alcohol was added as a binder. The powder was then pressed in to pellets of 1.2 cm diameter and 2 mm thickness and toroids of dimensions 1.2cmx0.8cmx0.4cm ($D_o \times D_i \times h$) using a hydraulic press at a pressure[4]. Pellets of 1.2 cm diameter and 2 mm thickness and toroids of dimensions 1.2cmx0.8cmx0.4cm ($D_o \times D_i \times h$) using a hydraulic press at a pressure of 150MPa (Figure2).The samples obtained after sintering from both the techniques were polished on fine carborundum powder to remove a thin layer from the surface regions.



Figure1: Instrument used to prepare desired orientation and to the shape required sample.



Figure2: Different specimens in the form of pellets used for the present investigation.

2.3 Measurements of Dielectric parameters

For the study of dielectric Properties two types of dental materials are taken in the pellet form. After that dental samples in the form of pellets are painted with silver paste for electrical conductivity. These samples are used to measure dielectric parameters. The dielectric measurements are taken from HIOKI LCR Hi Tester Model 3532-50 (Figure 3). The experimental cell for the determination of the dielectric behavior of the dental materials of different species at different temperature was housed in a programmable tubular furnace. The experimental cell was positioned in such a way that the specimen lies exactly at the center of the furnace. The temperature of the furnace could be controlled through an RS232 computer interface. The computer program was so designed to maintain the desirable temperature for a required time through the computer controlled (Divya Process Temperature controller, Model DPI-1100). The pellet samples were well polished to remove any roughness and the two surfaces of each pellet were coated with air-dried silver paste (Du Pont) as contact material for electrical and dielectric measurements. The capacitance of the cell with the specimen and the loss factor ($\tan \delta$) of the samples were measured by the computer using the low frequency impedance analyzer Hioki 3532-50 LCR-Hit ester operating in the frequency range 100 Hz to 1MHz [5]. For the purpose of temperature controlling another thermocouple was used. The two thermocouples were individually calibrated under identical conditions to avoid errors in temperature measurements. A dc voltmeter (Philips Model PM 9004) was used to calibrate the thermocouples.

The thermocouples are kept approximately at a distance of 0.1 to 0.2 cm away from the test specimen to avoid voltage pick-ups. In the present work, the error in the measurement of dielectric constant and loss factor were 3% and 5% respectively. From a knowledge of the dimension of the samples and the values of the capacitance determined at any given temperature or frequency the dielectric constant of the sample could be evaluated using this relation.

$$\epsilon' = \frac{Cd}{\epsilon_0 A}$$

Where 'C' is the capacitance of the pellet in Pf, 'd' the thickness of the pellet, 'A' the cross-sectional area of the flat surface of the pellet and ϵ_0 the constant of permittivity for free space ($\epsilon_0 = 8.854 \times 10^{-12}$ F/m). The dielectric constant ϵ' and loss factor $\tan \delta$, measurements were carried out in the frequency range of 100 Hz to 1 MHz at room temperature [6-7].



Figure 3: Experimental setup for dielectric measurements.

3. RESULTS AND DISCUSSION

A glance at table 1-3 shows that the values of dielectric parameters have decreased with the increase of frequency. In the present investigation, the results of dielectric parameters of different types of dental materials Acrylic resin, Alginate, Dental plaster, Dental stone, Glass ionomer and Silver Amalgams when measured 100Hz to 1MHz. frequency range, reveals that the significant variations which may be attributed to the extent of hydration, molecular architecture and chemical compositions of dental materials. Each of the dental material has its own physiological individuality. From table 4 and 5, it seen that the percent decrement in dielectric constant values is different with different materials and the comparative data of the dielectric parameters such as dielectric constant, dielectric loss and electrical conductivity are obtained at normal dried conditions are different with different materials because the dielectric parameters mainly depends on the density and the chemical content [4-5]. The dielectric properties of biomaterials have both theoretical and practical importance. Theoretically, they give a better understanding of the molecular structure of biomaterial and their interactions. The practical applications of the dielectric properties are that the density and moisture content of biomaterial can be determined nondestructively. It has also been reported that knots, spiral grain, and other defects can be detected by measuring dielectric properties [6-7].

When biomaterial is placed in an electric field, the current-carrying properties of the biomaterial are governed by certain properties, such as moisture content, density, grain direction, temperature; and by certain components such as chemical composition, biological matrix of biomaterial. They also vary in an extremely complicated fashion with frequency. The overall effects of these parameters interact with each other and add to the complexities of the dielectric properties [4-11]. A close look at

Table 1: Dielectric constant of dental material with variation of frequency.

Name of the dental sample	Dielectric constant ϵ' at frequency of									
	100Hz	500Hz	1K Hz	1.5K Hz	2K Hz	4K Hz	6K Hz	8K Hz	10K Hz	1M Hz
Acrylic resin	173.85±37.46	55.82±3.07	47.60±3.55	45.13±3.02	43.87±2.31	42.95±9.47	39.93±2.30	39.25±2.11	38.50±2.02	32.22±0.00
Alginate	331205±16356 0.87	20420.55±1 8.55	99070.05±57 31.74	5251±3041.9 7	3355.5±1919. 79	1209.3±661. 43	685.6±356 .95	471.1±236.03	356.7±172.96	18.35±0.35
Dental plaster	259835±96428 .15	32752.55±2 .36	11966.25±44 75.63	7029±3102.2 2	4842.35±2447 .51	2164±1435. 43	1375.91±1 051	998.95±794.2 5	777.55±636.7 5	15.64±1.99
Dental stone	227780.5±144 6.23	46669.6±49 8.83	22710±2646 9.84	14677.95±17 352.33	10597.8±1259 6.12	4645.9±545 4.34	2622.55±3 .52	1903.6±2167. 71	1411.85±158 5.69	14.09±3.10
Glass ionomer	89.76±4.99	55.3±1.70	49.39±.83	48.7±0.99	47.17±1.09	43.93±0.87	42.57±0	41.62±0.87	40.88±0.76	32.85±0.77
Silver amalgam	152396.5±147 90.55	14635±48.08	4502.5±662.56	2973.5±101.12	2013.5±19.09	844.8±74.95	511.9±70. 85	360.55±58.62	275.6±48.82	13.25±2.62

Table 2: Dielectric loss of dental materials with variation of frequency.

Name of the dental sample	Dielectric loss ϵ'' at frequency of									
	100Hz	500Hz	1K Hz	1.5K Hz	2K Hz	4K Hz	6K Hz	8K Hz	10K Hz	1M Hz
Acrylic resin	213.17±159. 37	2509±2.38	13.65±1.23	10.77±0.79	9.05±0.50	6.07±0.55	4.97±0.55	4.41±0.60	3.97±0.72	1.77±0.21
Alginate	3312030±16 35622.84	296869.5±1 68446.27	91179.5±680 75.29	38152±2900 1.28	20386.8±1539 3.43	4839±3528. 46	2153.15±1 502.81	1260±855.60	846.55±562.0 8	8.48±2.57
Dental plaster	1738347±21 80503.75	294657.5±5 3142.61	83133.5±157 26.76	41538±1312 2.49	25658.5±1123 2.39	9507±7065. 41	5555±499 9.24	3807.5±3738. 47	2826±2903.3 8	9.41±2.14
Dental stone	2277802±14 46420.86	450748.75± 520829.89	216961.25±2 79036	139852±183 18...85	100780.65±13 3309.92	43780.05±5 8331.85	24330.65± 32351.48	14817.2±195 67.62	9941.65±130 46.05	10.14±7.06
Glass ionomer	61.53±4.33	15.34±0.09	9.29±0.51	9.10±0.16	8.09±0.15	6.29±0.30	5.42±0.15	4.88±0.23	4.50±0.19	1.99±0.01
Silver amalgam	1523963.29± 147905.11	131583.42± 20402.05	29108.86±32 53.92	16359.49±43 94.66	9720.81±2180. 45	3060.24±11 6.88	156555555 .56±96.36	975.12±111.54	676.10±91.36	5.38±0.24

Table 3: Dielectric Conductivity of dental materials with variation of frequency

Name of the dental sample	Dielectric Conductivity K (mho-cm ⁻¹)X10 ⁻⁹ at frequency of									
	100Hz	500Hz	1K Hz	1.5K Hz	2K Hz	4K Hz	6K Hz	8K Hz	10K Hz	1M Hz
Acrylic resin	1242.83±929.11	146.29±13.87	79.57±7.15	62.83±4.61	52.76±2.91	35.39±3.19	28.98±3.18	25.71±3.48	23.14±4.20	8...54±1.21
Alginate	19309134.99	1736579.18±535681.14	531576.48±396878.95	222426.16±169077.45	118855.04±89743.71	28211.37±20570.94	12552.86±8671.41	7345.8±4988.14	4935.38±3276.92	49.43±15.01
Dental plaster	10134563.01±12712336.9	1717853.22±309821.42	484668.30±91687.02	242166.54±76504.10	149589.05±65484.84	55425.81±4191.35	32385.65±29145.6	22197.72±21795.30	16475.58±16926.71	54.86±12.45
Dental stone	13279585.66±8432633.63	2627865.21±3036438.28	1264884.08±1626779.90	815337.16±1068748.88	587551.18±77196.85	255237.69±340074.71	141847.68±188609.12	86384.27±114079.25	57959.81±76058.47	59.11±41.14
Glass ionomer	358.72±25.23	89.46±5.24	54.20±2.99	53.08±0.95	47.19±0.87	36.67±1.73	31.62±0.87	28.47±1.36	26.26±1.11	11.92±0.29
Silver amalgam	8884705.99±862.28	767131.37±1894.9	169704.69±18970.3	95375.85±25620.87	56672.32±12712.02	17841.23±681.40	9127.25±561.	5684.99±650.	3941.66±532.	32.77±3.37

Table 4: Data on Percentage Decrement in Dielectric Constant in Different Dental Materials.

Name of the dental material	v ₁ (Hz)	v ₂ (Hz)	ε ₁	ε ₂	(Δε / ε ₁)X100	
Acrylic resin		100	1M	173.85±37.46	32.22±0.00	81.47
Alginate		100	1M	331205±163560.87	18.35±0.35	99.99
Dental plaster		100	1M	259835±96428.15	15.64±1.99	99.99
Dental stone		100	1M	227780.5±144642.23	14.09±3.10	99.98
Glass ionomer		100	1M	89.76±4.99	32.85±0.77	63.4
Silver amalgam		100	1M	152396.5±14790.55	13.25±2.67	99.99

Where $\Delta\epsilon = \epsilon_1 - \epsilon_2$, $\epsilon_1 =$ dielectric constant at the frequency v_1 , $\epsilon_2 =$ dielectric constant at the frequency v_2

Table 5: A Comparison of Dielectric Properties of Different Dental Materials at Normal Dried Condition

Name of the dental material	Dielectric parameters		
	Dielectric constant ε'	Dielectric loss ε''	Conductivity K (mho-cm ⁻¹)X10 ⁻⁹
Acrylic resin	47.60±3.55	13.65±1.23	79.57±7.15
Alginate	99070.05±5731.74	91179.5±68075.29	531576.48±396878.95
Dental plaster	11966.25±4475.63	83133.5±15726.76	484668.30±91687.02
Dental stone	22710±26469.84	216961.25±279036	1264884.08±1626779.90
Glass ionomer	49.39±0.83	9.29±0.51	54.20±2.99
Silver amalgam	4502.5±662.56	29108.86±3253.92	169704.69±18970.33

the tables reveals that the significant variation in dielectric parameters with variation of frequency from 100Hz to 1 MHz in tangential direction varies with density, mineral present in the sample and chemical content and its microstructure of dental materials Acrylic resin, Alginate, Dental plaster, Dental stone, Glass ionomer and Silver Amalgams. It is interesting to note that glass ionomer has low dielectric constant value compared to other materials (Table.4 & table.5).

4. CONCLUSIONS

In order to understand dielectric behavior of dental materials of six types namely Acrylic resin, Alginate, Dental plaster, Dental stone, Glass ionomer and Silver amalgam were operated by different types of polarization mechanisms, dielectric constant (ϵ'), dielectric loss (ϵ''), and conductivity (K) were measured as a function of frequencies 100Hz to 1MHz. The following characteristic features can be observed.

1. The dielectric parameter mainly depends on moisture content and orientation of molecules, chemical composition with respect to applied electric field.
2. The dielectric parameters are high in the case of Alginate normal dried dental samples in the form of pellets, when compared to Acrylic resin dental samples. This may be attributed to partly size of the cells and change in structure and chemical composition.
3. Dielectric constant (ϵ'): decreases with frequency from 100Hz to 1MHz. Alginate have higher values.
4. Dielectric loss (ϵ''): decreases with frequency from 100Hz to 1MHz. Alginate have higher values, and others having intermediate values.
5. Conductivity (k): decreases with frequency from 100Hz to 1MHz. Alginate have higher values and others having intermediate values.

Hence, it can be concluded that structural constituents and moisture content of dental materials have integrated activity in influencing the dielectric properties of dental materials. However, within the same dental sample, the dental parameters (density, moisture content etc) are more or less the same. The increase in the hydration increases the dielectric loss and dissipation factor. The dielectric constant is more in Alginate.

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