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# STUDIES ON THE PROPOGATION OF ELASTIC WAVES IN BOVINE COMPACT BONES AS A FUNCTION OF TEMPERATURE

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**ABSTRACT** To study the physical properties of biomaterials like bony hard tissues through the propagation of elastic waves is one of the most successful method.With the help of internal friction measurement, we can study the processes such as recrystallization, annealing, quenching and tempering, plastic deformation and strain ageing. In the present investigation we calculate and reported the internal friction loss ($Q^{-1}$) for all the six types of bovine compact bones for the first time in a single experiment by using the ultrasonic piezoelectric composite oscillator technique with the help of X-cut crystal in different physiological conditions. Significant variation is observed from bone to bone. This may be attributed to composition and mineral content of the bones. Peak temperature data also is also determined. Temperature variation of logarithmic decrement in X-cut quartz transducer is also verified with mounting of bovine compact bar shaped bone samples. Change of internal friction ($Q^{-1}$) with temperature is also calculated to predict the mechanism of acoustic losses and phase transitions in these bony hard tissues. Internal friction measurements are also useful to obtain the information about imperfections in bony hard tissues. The present investigation constitutes a step towards the application of natural bovine bone ceramic materials for the transducer applications.

**KEYWORDS :** Internal friction loss (Q-1) bovine compact bone, fresh and oven dried decalcified condition.

## INTRODUCTION:

Recently many developments have taken place in ultrasonic methods to study the energy loss associated with the propagation of elastic waves in understanding the physical properties of the biomaterials. The study of propagation of stress waves[1-6] in an elastic bony hard tissue deals with the measurement of the velocity of stress waves and the attenuation or energy loss of these waves.

The information relating the forces that are operative between atoms or ions comprising the bony hard tissue can be assessed with the help of elastic constants and acoustic losses. This information is very much helpful to study the phenomena such as phase transitions and relaxation processes in biomaterials.

The elastic behavior of solids was reported by several investigators as a function of temperature, pressure, magnetic field and also as function of the frequency of stress waves.[7-11] The acoustic parameters such as elastic constants, attenuation coefficients and loss factors are determined for the biomaterials which are in the form of single crystals, polycrystalline composite materials and bio alloys.

When bone tissue is kept completely isolated from its surroundings the mechanical energy of vibrating bony hard tissue gets converted in to electrical or heat energy. For this reason the vibrations of the bone tissue get damped quickly. The damping of the vibrations and the energy transfer are attributed to the internal friction present in the bony hard tissue. The imperfections in the bony hard tissues can be easily estimated by Internal friction measurements. Internal friction makes it possible to examine the tendency of a biomaterial to elastic lag, creep and grain boundary relaxation. A lot of research work and important conclusions were drawn on the internal friction loss behavior of ferrites, ferroelectrics and many different composite materials in solid state physics but the literature review says that very little research work done on the internal friction behavior of bony hard tissues. For this purpose to understand the mechanism of acoustic losses and phase transitions in these biomaterials the author carried out the studies on the internal friction loss measurements of bovine compact bone tissues and the results were tabulated.

## MATERIALS AND METHODS:

The inelastic behavior of different bovine compact bones such as Metacarpus (MC), Metatarsus (MT), Radius/Ulna (R/U), Humerus (H), Tibia (T) and Femur (F) can be estimated by measuring the internal friction $Q^{-1}$.These experiments are performed at resonance where the inertia of the system is applicable. Usually these methods are divided into two types (i) Wave propagation methods and (ii) Methods involving resonant systems vibrating either in free decay or in the steady state. In the present investigation, the composite piezoelectric oscillator method has been used for the study of the internal friction.

### *Experimental Method*

The composite piezoelectric oscillator was constructed by cementing quartz rod to the bovine compact bone specimen (MC, MT, R/U, H, T and F) rods of identical cross-section. The adhesive employed in the present work was a paste containing one part of weight of calcium carbonate and five parts by weight of sodium metasilicate, prepared using little water. This composite system is mounted on a crystal holder as shown Figure. 1 below.

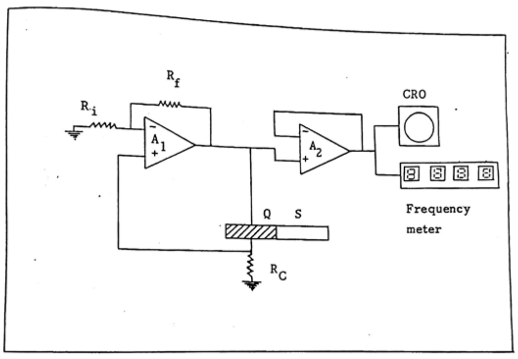



*Figure.1 Electronic set up to detect the resonant vibrations of piezoelectric oscillator*

$R_C$ is altered until the oscillatory condition is achieved. The critical resistance $R_C$ and the resonant frequency $f_c$ were seton using digital multimeter and a frequency counter respectively. By knowing of $R_C$ and $f_c$ internal friction loss of the bovine bone tissues can be calculated. The internal friction of the bone sample is given by

$Q^{-1} = W/2W = \delta/\pi$ where

$\delta = G \pi R_C ( C_c / L_c )^{1/2} = K_1 R_c G$

where $K_1$ is known as proportionality constant.
$K_1$ was first derived by Marx[12], Robinson and Edges[13] give a more detailed derivation for the equivalent electrical circuit of the three-component composite oscillator.

Considering the appropriate equivalent circuit for the two component resonator one can get the following expression for $K_1$ as

$K_1 = 4 d^2_{311} l^2_2 / S2_{1111} h f_c M_C$

where $l_2$ = width of the electrode face of the transducer
h = number of harmonic (usually one)
M = Mass of oscillating system ($M_Q + M_s$)
$f_c$ = resonant frequency of oscillating system
$d_{311}$ = piezoelectric constant of the quartz
$S_{1111}$ = elastic modulus of quartz
For quartz crystal at 300 K[50,51]
$d_{311} = 2.28 \times 10^{-12}$ C/N
$S_{1111} = 1.45 \times 10^{-11}$ $m^2$/N

All the internal friction measurements have been performed with strain amplitude of $10^{-6}$ after the bone specimen attained the thermal equilibrium.

***Cementing***

The composite oscillator is formed by cementing the quartz rod to the specimen identical cross section. For room temperature measurements phenyl salicylate commonly known as 'salol' is used as the bonding material. For the high temperature work the adhesive that can be used consists of five parts of sodium metasilicate and one part of calcium carbonate. These chemicals should be thoroughly powdered to micron size and mixed with a drop or two of double distilled water so as to form a very fine paste. A thin layer of this paste is used for bonding the transducer with the bone tissue specimen as shown in Figure. 2 The composite system so formed is to be kept under pressure at least for about 24 hours at room temperature before it is put into use at high temperature.

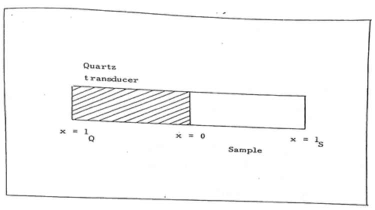


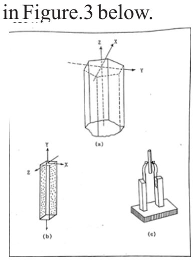

***Figure.2 Two component composite system***

***Quartz Transducers***

The X-cut quartz crystal cut from the natural quartz crystal was used in the present investigation. The measurements of the X-cut quartz crystal used in the present investigation is like this,

Length of 0.0020051 m
Width of the electrode face 0.0003923 m
Natural frequency of 144.460 kHz and
Mass of $0.6299 \times 10^{-3}$ kg.

The electrode faces are silver painted. The details of electrode assembly are presented in Figure.3 below.



(a) Quartz Crystal
Z-axis is optic axis
(b) X-cut crystal
(c ) Crystal holder

***Figure. 3 Electrode arrangement and mounting of X-cut Quartz crystal***

***Piezoelectric composite bone tissue specimens***

The piezoelectric composites viz., bovine compact bone tissue samples of identical cross section, as that of the transducer were prepared employing the method detailed mentioned above.

***Temperature Study***

The composite system with the holder and the bone specimen, was placed at the center of a tubular electric furnace to measure the effect of temperature on the internal friction of the bovine specimens as shown in the above Figure.3 This tubular electric furnace consists of a thick fused silica tube, which is wound non-inductively a nichrome wire of sufficient length at regular intervals. A thick coating of fire cement was coated to the nichrome wire. The temperature of the furnace can be raised from 30 to 400º C. But in the present investigation due to biological bone sample limitations the maximum temperature up to 120º C only is utilized. The set temperature can be able to controlled within ± 0.2º C using Aplab temperature controller-indicator model 9601.

***Accuracy of the method***

The accuracy of the proposed technique in the present investigation depends on the accuracy of finding the parameters involved in determining the decrement δ. The accuracy of decrement δ determined in this present investigation is about ± 5%

**RESULTS:**

The results of the present investigation were tabulated in the following manner. Room temperature internal friction and peak temperature data for bovine compact bone tissues is tabulated in Table No.1 taking five samples each in different physiological conditions.

***Table.1 Room temperature internal friction and peak temperature data for bovine compact bone tissues***

| Bovine Compact Bone Name | Internal Friction Q -1 x 104 | | Peak Temperature ºC | |
|---|---|---|---|---|
| | *In Fresh Condition* | *Oven Dried Decalcified Condition* | *In Fresh Condition* | *Oven Dried Decalcified Condition* |
| *Metacarpus (MC)* | *14 ± 1.35* | *10 ± 2.75* | *68 ± 4.20* | *57 ± 5.50* |
| *Metatarsus (MT)* | *13 ± 0.93* | *9 ± 1.80* | *72 ± 3.30* | *67 ± 4.80* |
| *Radius/Ulna (R/U)* | *16 ± 1.75* | *11 ± 1.35* | *76 ± 2.50* | *68 ± 3.97* |
| *Humerus (H)* | *18 ± 1.93* | *13 ± 2.20* | *70 ± 1.98* | *62 ± 2.50* |
| *Tibia (T)* | *19 ± 2.23* | *14 ± 1.55* | *75 ± 3.30* | *65 ± 3.35* |
| *Femur (F)* | *21 ± 2.27* | *17 ± 0.95* | *77 ± 1.75* | *61 ± 4.45* |

Temperature variation of logarithmic decrement in quartz transducer is tabulated in Table No.2

***Table.2 Temperature variation of logarithmic decrement in quartz transducer***

| *Temperature (T) º C* | *$\delta_C \times 10^4$* |
|---|---|
| *25* | *1.13* |
| *30* | *1.23* |
| *35* | *1.32* |
| *40* | *1.44* |
| *45* | *1.60* |
| *50* | *1.73* |
| *55* | *1.91* |
| *60* | *2.32* |
| *65* | *3.05* |
| *70* | *3.58* |
| *75* | *3.41* |
| *80* | *3.15* |
| *85* | *2.56* |
| *90* | *2.00* |
| *95* | *1.83* |
| *100* | *1.75* |
| *105* | *1.70* |
| *110* | *1.66* |
| *115* | *1.62* |
| *120* | *1.51* |

Temperature variation of internal friction ($Q^{-1}$) in bovine compact bones (MC, MT, R/U, H, T, and F) taking five samples each are tabulated and graph is plotted between change of Internal friction ($Q^{-1}$) with temperature as shown in Figure. 4 below.

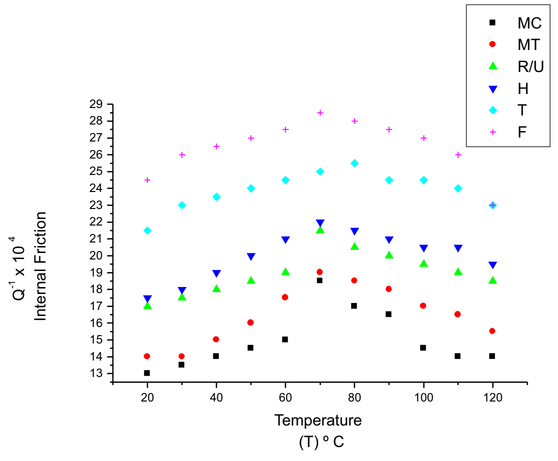



*Figure. 4 Variation of Internal friction Q-1 with temperature (T) for bovine compact bones*

## DISCUSSION:

As mentioned earlier, evaluation of internal friction of the bovine compact bone sample demands the knowledge of temperature dependence of the logarithmic decrement of quartz transducer $\delta_c$ and transducer resonant frequency $f_c$ Hence the temperature variation of logarithmic decrement of quartz transducer was studied and the data are presented in Table.2 To test the reliability of the experimental technique developed in the present work, the internal friction measurements on bovine compact bones (MC, MT, R/U, H, T and F) has been investigated in the temperature variation from 20º C to120ºC and the experimental values are tabulated. The change of internal friction ($Q^{-1}$) with temperature (T) for different bovine compact bones is graphically shown in Figure.4 along with literature data[14-15] for comparison. In general, the agreement between the present work and the literature data is quite good.

In the temperature range of the present investigation, the internal friction ($Q^{-1}$) is found to increase with further rise of temperature. The temperature dependence of internal friction of different bovine compact bones was studied. The value of internal friction at room temperature obtained in the present work is presented in Table. 1 along with the data of other workers in different physiological conditions. The agreement between the present data and the literature data[16] indicates the reliability of technique for the calculation of internal friction of bony hard tissues. An examination of the data presented in Table.1 shows that there is good agreement between the values obtained in the present investigation and those observed by the other investigators.

The compositional change of internal friction ($Q^{-1}$) for different bovine compact bones (MC, MT, R/U, H, T and F) in different physiological conditions at room temperature is given in Table.1 From the examination data it is evident that the internal friction loss shows a maximum for Femur (F) bone and least for Metatarsus bone (MT) both in different physiological conditions. It can be inferred from this observation that the acoustic energy losses are minimum in those bovine compact bone specimens. However in the present work no measurements were carried out in the bovine spongy type bone specimens due to their limitation in the dimensions.

From the present investigation it is observed that the peak temperature for bovine compact bones lies in between 63.80º C to 78.75º C in fresh condition where as for oven dried decalcified condition the peak temperature lies in between 51.50º C to 71.97º C

## CONCLUSIONS:

The internal friction loss studies on these bovine compact bone composites reveal that acoustic losses are low in the fresh compact bones than their oven dried decalcified bovine compact bones indicating their usefulness for the transducer applications. From these studies it is found that the internal friction loss ($Q^{-1}$) in six different type of bovine compact bones is as fallows

F > T > H > R/U > MC > MT

The peak temperature for bovine compact bones lies in between 63.80º C to 78.75º C in fresh condition where as for oven dried decalcified condition the peak temperature lies in between 51.50º C to 71.97º C It is found from the present studies that it is possible to develop natural bovine bone ceramic materials with mechanical strength independent of temperature.

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