

# Thermal Behavior of Animal Bone: A Biomaterial Review

Abdul Rauf

Department of Physical Sciences, College of Science, Jazan University, P.O. Box. 114, Jazan 45142, KSA

**Abstract:** *Animal bone, a natural composite of collagen and calcium phosphate, exhibits distinct thermal behavior vital for biomedical applications. This review discusses specific heat, thermal conductivity, and diffusivity within the context of biomaterials science, focusing on their role in bone tissue engineering, implants, and thermal therapies. Earlier experimental findings are reinterpreted to highlight the influence of structure and composition on thermal response. By bridging classical studies and modern biomedical needs, this article provides a fresh outlook for researchers working on bone-mimetic materials.*

**Keywords:** Animal bone, thermal conductivity, specific heat, bone cements, hydroxyapatite

## 1. Introduction

Bone is a multifunctional biological material that provides mechanical support, protects vital organs, and serves as a reservoir for minerals. From the perspective of biomaterials research, bone is a natural composite consisting of an organic collagen matrix reinforced with inorganic mineral phases, mainly hydroxyapatite. This unique composition results in remarkable mechanical, thermal, and biological performance, making bone an important reference material for the design of synthetic and hybrid biomaterials.

Thermal properties of biomaterials are particularly important in biomedical applications involving heat generation or transfer, such as orthopedic implant fixation, polymerization of bone cements, laser and radiofrequency therapies, cryopreservation, and sterilization processes. Shifts in temperature may affect cellular viability, protein stability, and the integrity of mineralized tissues. Therefore, understanding how heat is stored and transferred in bone is critical for both fundamental biology and applied biomaterials research.

In living organisms, thermal regulation is closely linked to metabolism and tissue structure. While extensive studies have examined thermal behavior in soft tissues and biological fluids, comparatively fewer investigations have focused on mineralized tissues such as bone. Earlier studies on animal bone, though not previously viewed in the context of biomaterials, provide valuable experimental data on thermal conductivity and specific heat. Reinterpreting these findings through the lens of modern biomaterials science can offer insights into structure–property relationships and guide the development of bone-mimicking materials.

### Thermal Properties of Biological Tissues: A Biomaterials View

Thermal properties such as specific heat capacity and thermal conductivity govern how biological materials respond to temperature changes. In biomaterials, these parameters affect how heat is dissipated near implants, how well synthetic materials match native tissue, and the safety margins during thermal procedures.

Early calorimetric studies on plant tissues and food materials established the role of bound and free water in determining

thermal behavior. Similar principles apply to bone, where water content, porosity, and mineralization strongly affect heat transfer. Studies on gelatin gels, fats, and biological fluids laid the experimental foundation for understanding heterogeneous biological materials, which is directly relevant to bone as a porous, hydrated composite.

Extensive past studies have examined thermal properties of biological macromolecules, cells, tissues and organs in order to understand the mechanical and thermal behavior of different living systems. The review aims to provide a refreshed and application-oriented perspective.

## 2. Review

Keshin et. al. [1] determined the specific heat of bound water of plants calorimetrically. Plant tissue contains at least three forms of water, firmly bound, loosely bound and free water. The ratio of firmly bound to loosely bound water in the seeds is 1:2. Seed germination occurs only when free water appears. The maximum amount of firmly and loosely bound water is observed in the leaves of mesophytes and xerophytes and minimum amount in hydrophytes and succulents. The specific heat of living leaves is minimum in xerophytes, rises in mesophytes and hydrophytes and reaches a maximum value in succulents.

Moline et. al. [2] developed a rapid method for the determination of specific heats of some food materials between temperatures - 160°C and - 40°C. Their method utilized a polystyrene cell with a known heat leak between - 196 C and + 20 C into which an aluminium specimen holder containing the sample pre cooled to - 196°C was placed. They presented the specific heat data on gelatin, ice, some meat, fish and dairy products.

Lentz [3] reported the data on thermal conductivity of ice gelatin gels of different concentrations, different kinds of meat including fish and poultry, several kinds of fats and mixtures of gelatin gels and fats at different temperatures from - 25°C to 5°C. He found that above freezing temperatures, the conductivities of meats were equal to each other and slightly lower than water, while the variation in conductivity of fats with temperature is small.

Poppendiek et. al. [4] measured thermal conductivity in a large number of normal and frozen samples of biological fluids and tissues using a special unidirectional heat flow apparatus. The thermal conductivities of all the biological fluids and tissues studied were also predicted using mathematical heat conduction models.

Similarly, Jonderko et. al. [5] studied the effect of tobacco smoking on skin blood flow parameters by determining thermal conductivity co-efficient using Hensel's instrument. They selected 15 non-smokers and 25 smokers who consume at least 10 cigarettes daily for the study.

A review was given on different blood flow measurements including thermal conductivity by Fischer Herbert [6]. He discussed the thermal conductivity in regard to its clinical applicability for the determination of blood flow in limbs (muscle and skin).

Levy et. al. [7] studied blood flow in the brain of cat by the continuous direct measurement of thermal conductivity.

Brand and Chesues [8] studied the physical properties such as density, thermal conductivity and specific heat of foam in order to understand the role played by it for protecting plants against cold weather.

Ogle Thomas [9] observed changes in thermal conductivity of the integuments in non hibernating 13- lined ground squirrels with the ambient temperature.

Hamano et. al. [10] made temperature measurements on cornea and determined the thermal conductivity and diffusivity of corner in order to understand heat transfer.

Soorkoosk [11] made specific heat measurements on isozyme chymotrypsinogen and ovalbumin in aqueous solutions.

Fernandez and Montes [12] worked with creams to find the thermal conductivity of about 20, 30 and 40% fat at several temperatures between 5°C and 75°C.

Khodas et. al. [13] studied the possibility of multiple increase in thermal conductivity of liver and muscle tissue of human, cadaver in vitro and also muscle tissue of dog in vivo in a powerful acoustic field.

Hearting and Pfeiffenberger [14] determined the thermal conductivity of bovine and Pig retina. An experimental study was presented.

Ferez and Celvelo [15] measured thermal conductivity of cooked meat under different thermal treatments and developed a mathematical model for its prediction.

Kemal Serbetci [16] studied mechanical and thermal properties of Hydroxyapatite – impregnated bone cement. The aim of this study was to develop new bone cement compositions that would have low setting temperature and high mechanical strength and be comparable with the commercially available ones. They concluded that the hydroxyapatite decreased the polymerization temperature for 111°C to 81°C and increased the compressive strength from

110 Mpa to 122 Mpa of the resultant cement.

Gaberid et. al. [17] measured the thermal diffusivity of bone, Hydroxyapatite and metals for biomedical application. They reported that the porosity and its orientation in the bone are two important factors for the heat flux through the bone. The hydroxyapatite in compact powder form, presents a thermal diffusivity value very near to those obtained for the bone samples which gives thermally consistent results between these materials.

Matter et. al. [18] investigated the influence of cryopreservation of cancellous bone at different temperatures and different storage periods for mechanical changes. They conclude that different cryo- preservation temperature do not have any influence on the mechanical properties of cancellous bones, also storage duration upto 2 years has no effects on the mechanical strength of the bone.

Abdul Ghani et. al. [19] (2003) studied the effect of the inclusion of triphenyl bismuth (TPB) on the thermal properties of (PMMA) based bone cements using both conventional DSC. The glass transition temperature determined by DSC showed that the value decreased with the addition of increasing amount of TPB through both blending and dissolution methods.

Kubisz et. al. [20] examined the changes in thermal and electrical properties of bone as a result of IMGY dose gamma irradiation. They reported that modification of bone structure of high doses of gamma radiation changes the electrical and thermal properties of the bone.

Patrick et, al. [21] studied the thermal properties of some biomaterials such as zinc poly-carboxylate, zinc phosphate and glass ionomer, used as dental restorative materials. The specific heat has been determined by the principle of method of mixture. The thermal conductivity has been determined by an apparatus

devised in the laboratory, which is a modification of Lee's apparatus. They reported that the specific heat of glass ionomer is maximum and the thermal conductivity of zinc poly carboxylate is minimum. The thermal diffusivity of zinc poly carboxylate is comparable to glass ionomer. The study also reports the specific heat value of milk tooth.

Patrick and Adeel Ahmad [22] studied electrical resistivity and temperature coefficient of resistivity of some biomaterials such as zinc poly carboxylate cement, zinc phosphate cement, glass ionomer and milk tooth. The measurements were carried out using a sample holder fabricated in the laboratory. They reported that the electrical resistivity of is high order (order of  $10^8$ ) in the case of zinc poly carboxylate, low in case of zinc phosphate and glass ionomer (order of  $10^8$ ), when compared with that of milk tooth (order of  $10^8$ ). The temperature coefficient of resistivity is the same irrespective of the dental material studied.

Abdul Rauf et. al. [22] described a method to determine the thermal conductivity of animal bone. In this method thermal conductivity of bone samples of different animals were

determined by using Lee's apparatus. The investigations suggest that thermal conductivity of bone after decalcification increases. The data shows that the thermal conductivity increases with the variation of percentage of decalcification.

Abdul Rauf et. al. [23] studied the specific heat of animal bone using the principle of method of mixture. Samples of bones of different animals were cut into small pieces of irregular shape suitable to heat in a steam generator. The investigation suggests that the specific heat of bone after decalcification decreases. The data shows that the specific heat of samples varies with variation of percentage of decalcification.

### 3. Conclusions

Animal bone serves as an excellent model system for studying thermal behavior in composite biomaterials. Findings from earlier experiments suggest that while thermal properties are relatively consistent across species, significant variations exist among different bone types due to differences in mineral content, structure, and function. Recasting earlier thermal studies within a biomaterials framework highlights their relevance to modern biomedical applications.

A comprehensive understanding of bone thermal properties can contribute to the rational design of bone substitutes, cements, and implants with improved thermal and biological compatibility. Future studies may benefit from combining advanced thermal analysis with microstructural techniques with microstructural analysis will further enhance the development of next-generation biomaterials inspired by natural bone.

### References

- [1] Keshin A F, I A Shulgin and M M Bokovaia Dok lady Akod. Nauk SSSR (Bot. Sci. Sect), Vol.,122, No. 6, pp. 252-256, 1958.
- [2] Moline S W, J A Sawdye A J Short and A P Rinfret, Food Technol., Vol. 15, No.5 (1961), pp.228- 231.
- [3] Lentz C P, Food Technology, Vol. 15, No. 5(1961), pp. 243-247.
- [4] Poppendiek H F, R Randall J A Breeden, J E Chambers and J R Murphy, Cryobiology, Vol. 3, No.4 (1966), pp. 318-327.
- [5] Jonderko Gerard, Jozef Podkowka, Zozislaw Dabrowski, Anto Wegiel and Andrzej, Poltyg. Lek., Vol. 21, No.12(1966), pp. 422-425.
- [6] Fischer Herbert Arztlische Forsch, Vol. 21, No.9 (1967), pp. 340-347.
- [7] Levy L L, J A J Stolwijk and H Graichen, Royal Academy of Engineering, Stockholm Swed., 1967, pp. 217
- [8] Brand Harry J and Jerry L Chesucss, Trans. Asae. Amer. Soc. Agr. Eng., Vol. 13, No.1 (1970), pp. 1-5.
- [9] Ogle Thomas F, Physil. Zooel., Vol. 43, No.2(1970), pp. 98-108.
- [10] Hamano Hikaru, Kiyogi Miyabe and Sachiko Mitsunaga, J. Jap. Contact Lens Soc., Vol. 13, No.8 (1971), pp. 65-72.
- [11] Soorkoosk J, Acta Chem. Scand. Ser. B Cig. Chem.

- Biochem., Vol. 28 No. 4 (1974), pp. 409- 417.
- [12] Fernandez Martin E and F Montes J. Daviy Res.,Vol. 44, No.1(1977), pp. 103-109.
- [13] Khodas Ma, SA E Fimovon, O L Kuznetsov, V E Lemberg and E M Simkin, Z H Eksp. Klin.Med.,Vol. 17, No.5 (1977), pp. 94-98.
- [14] Hearting F and V Pferffenberger Graefei, Arch. Clin. Exp. Ophthalmol., Vol. 219, No.6 (1983), pp. 290-291.
- [15] Ferez M G R and A Calvel, J. Food Sci., Vol.49, No.1 (1984), pp. 152-156.
- [16] Kemal Serbetci, Feza Korkusuz Nesrin Harisci, J. Biomaterials Polymer, Vol. 12, No. 8 (2000), pp.893-910.
- [17] Gaberiad P R, Antonio, C A and Rocia A M, Analytical Sciences Vol. 17 (2000), pp.357-360.
- [18] Matter, H P Garsel, T.V. and Bilderbeek, J. Biomedical Materials, Vol. 55, No.1(2001), pp. 40-44.
- [19] A. Ghani, Nazhat Behiri and Deb, J. Biomaterials, Vol. 14, No.11 (2003), pp. 1229-1242.
- [20] Kubisz, Leszek, Mielcaiek and Jaroszyk Felik, J. Biological Micromolecular, Vol. 33, No.1-3 (2003), pp. 89-93.
- [21] Patrick G and Adeel Ahmad, J. Pure & Applied Physics, Vol. 17, No.1 (2005), pp. 37-41.
- [22] Patrick G, Kaleem Ahmed Jaleeli and Adeel Ahmad,J. Pure & Applied Physics, Vol. 17, No.1, (2005), pp. 15-22.
- [23] Abdul Rauf, B S Bellubbi and Adeel Ahmad, J. Pure & Appl., Vol. 22, No. 2(2010), pp.335-346.
- [24] Abdul Rauf, B S Bellubbi and Adeel Ahmad, J. Pure & Appl., Vol. 22, No. 3(2010), pp.575-579.