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Comparative Analysis of Mechanical Properties in Ox and Camel Bones: Insights from Tensile and Compressive Strength Testing

Abdul Rauf

Department of Physics, College of Science, Jazan University, P.O Box. 114, Jazan 45142, Kingdom of Saudi Arabia
Email: *abdul_rauf148[at]yahoo.com*

Abstract: ***The paper presents data on Mechanical properties of femur, rib and scapula of ox and camel. The study utilized a Universal Testing Machine (UTM) to conduct tensile and compressive strength tests on these bone samples. The results indicate that rib bones exhibit higher tensile strength compared to femur and scapula bones, while spongy bones demonstrate lower compressive strength than compact bones. Additionally, the study highlights how decalcification affects bone strength, showing an increase in tensile strength for decalcified bones. This research underscores the simplicity, cost-effectiveness, and accuracy of the testing method, providing valuable insights into the mechanical behavior of bone tissues.***

Keywords: Tensile strength, Compressive strength, Femur, Rib, Scapula, Ox, Camel, Decalcification

1. Introduction

Bone is a composite, formed by the mineralization of an organic matrix, *the collagen*, by the nucleation and growth of calcium hydroxyapatite within the matrix. The study of some important parameters like, size, distribution and orientation of crystallites of bone mineral are very much useful in understanding mechanical behavior of bone and constituents.

Soft and hard tissues of vertebrate body provide a support against the gravitational force to the body. Most of the soft tissues are flexible and highly elastic. In general, their behaviour is viscoelastic. In contrast, hard tissues are more compact, rigid and less elastic and serve as endoskeleton and exoskeleton of the vertebrate body. Bone is a hard tissue. It contains both organic (collagen) and inorganic (calcium phosphate) materials. Hence, the bone can be considered as viscoelastic composite material. The organization of composite varies from animal to animal and is strongly influenced by anatomical and physiological alterations, unlike engineering composite materials.

Since bone tissue is a part of biological structure and its mechanical properties can only be fully appreciated if one understands how the structural organization functions as a whole.

Extensive studies have been made, in the past, on the mechanical properties of biological macromolecules, cells, tissues and organs in order to understand the mechanical behaviour of different living systems

Ikai and Fukunaga [1] employed ultrasonic photography to estimate the cross sectional area of the muscle and determined the tensile strength of the muscle of the arm.

Mohan Radhakrishna et. al., [2] studied the mechanical properties of collagen fibers from mammalian, avian and reptilian sources. Wids variation in the mean breaking strength was observed in different samples. The tests were carried out under identical conditions.

Adeel Ahmad and Basharat Ali [3] reported young's Modulus of flight muscle, heart, liver, intestine, stomach, kidney and brain of the bird, corvus splendens vieillot, employing variable path ultrasonic interferometer.

Bhima Shanker [4] and reports a modulus E = 24.10^6 Ib in^{-2} for fluorapatite along the axis, the value for hydroxyapatite apparently has not been determined. On the other hand, collagen does not obey Hook's law exactly; its tangent modulus of elasticity seems to be about 180,000 Ib in^{-2}. and concludes that two-phase materials can function efficiently only if there is very firm bonding between the fibers and the matrix. But the nature of bonding between the collagen and the appetite is uncertain.

Roy [5], for the first time, showed that a piece of artery behaves like a rubber band by measuring the strain in it.

Wohlisch et. al., [6] measured the degree of stretching and breaking point in animal tissues like human hair, skin and corium, tendons, cartilage, frog muscle, cocoon fibers. These values were compared with those of volcanised rubber.

Bar Ernst [7] determined the elasticity of cartilage, covering the heads of various long bones of man and ox, by using a modified man gold elastometer and Gildemeister ballistic elastometer.

Price [8] showed that the elastic properties of wood depend upon its internal structure. According to him the anisotropic character of elasticity is due to the fact that wood is built up of cells, which are long hollow cylinders, arranged parallel to the axis of the stem or branch.

Pfeiffer [9] developed an apparatus to measure the deformability of protoplasts without the risk of injuring the protoplasm and concluded that plasmalemma possesses elasticproperties.

Saxton John [10] studied the elastic property of rabbit aorta of different age andobserved that it does not age so rapidly as compared to other organs and is still a relatively young structure even at the end of the life span.

Treitel Otto [11] measured the elasticity of the rhizomes of equisetum fluviaticle together with other plant and animal tissues and in 1945 reported that stress strain curves of certain rhizomes become flatter with increasing age while breaking stress and strain decreases with increasing age due to decreasing respiration.

Brust Hanfred [12] determined the viscosity and elasticity of striated muscle.

Simonson et. al., [13] measured the elastic constants of skeletal muscle in situ. They reported the differences in elastic properties between natural and synthetic rubber, between rubber andmuscle, and between relaxed and muscle under tension.
King and Lawton [14] reported a formula to evaluate the elasticity of different soft body tissues of different age.

Hillav [15] showed that the muscle exhibits rubber – like and normal type of elasticity under different conditions.

Burton [16] determined the young’s modulus of elastin and observed that a single fiber would appear to be stiffer than the aggregate. He also reported the elastic modulus of smooth muscle of arterial wall.

Hayashi Khiro [17] carried out tests on shell lines to find elongation, elasticity and breaking strength.

Shimizu et al [18] studied the viscous flow and elastic modulus of typical noodles from Japanese domestic wheat flour.

Craig and Peyton [19] described suitable experimental techniques to evaluate the elastic modulus of human dentin and its ultimate compressive strength.

Plausak [20] determined the elasticity of human skin.

Smith and Walmsley [21] studied the various factors affecting the elasticity of bone of ox, horse, sheep, dog and human and reported that Young’s modulus varied with duration of applied stress, the fluid content ofthe tissue and temperature.

Karaisonyi and Andrews [22] designed and constructed an apparatus for measuring the torsional strength of macaroni. A highly significant correlation was found between torsional strength and bending strength of 25 samples.

A search of literature reveals that in spite of extensive investigations on the mechanical properties of soft tissue and muscle no information is available on tensile and compressive strength of bone material. In view of this, in the present investigation studies on these properties have been made on normal and decalcified femur, rib and scapula bone of Ox and camel.

2. Material and Methods

The animals Ox and Camel were selected for the study of tensile and compressive test of their bones, as both the animals are from different environmental conditions.

Fresh samples of bovine bone were obtained from slaughter house. They were boiled for two hours after removing flesh material and then kept exposed to air for seven days. They were then cut into rectangular bars of suitable dimensions along the bone axis

For the determination of tensile strength, specimens were prepared from bone samples of femur, rib and scapula of ox and camel, in the form of rectangular bars of suitable breadth and thickness (Fig. 1)

For the determination of compressive strength, specimens were prepared from bone samples of femur, rib and scapula of different animals in the form of cylinders in the range of length between 8 to 10 mm (Fig.2).

For decalcification test, specimens were decalcified by treating them with 0.9% nitric acid for 24 hours and then suspended in running tap water for 24 hours. The mass of specimens was determined before and after the decalcification process.

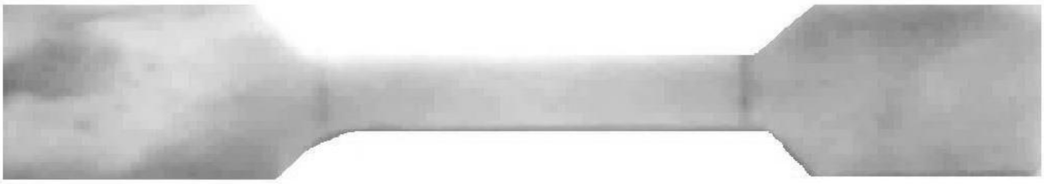

Figure 1: Sample for the determination of tensile strength

Figure 2: Sample for the determination of compressive strength

2.1 Description of UTM

The UT3000 is a computerized servo controlled tensile, compression testing machine with nominal loads from 5 kg to 30 ton. The UT3000 system is a sophisticated computerized control unit with a perfectly matched servo controlled double screw drive load frame. The test area is made of the stationary lower crosshead hard chrome plates of 2 screws and 2 guide bars and a movable upper cross head. The load cell which is directly attached to the upper cross head compliments is made up of extremely rigid load frame. Specimen grip is the most important function in material testing procedures. Specimen grips, with various clamping principles, is used to ensure optimum gripping for every type of specimen. Printing of the results was achieved by the easy to use control panel. (Fig.3)

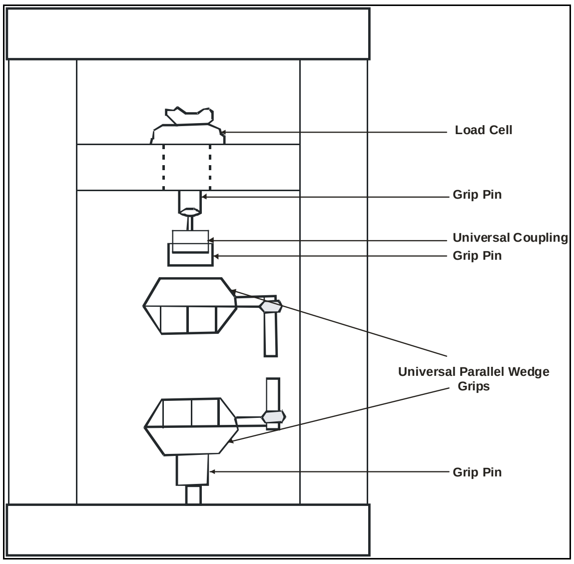

Figure 3: Block diagram of UTM machines

2.2 Experimental method for Tensile strength

Sample identification was done by material code and batch name. Once test parameters are set for a material, system automatically sets test parameters, like testing speed, gauge length (sample length i.e., the distance between the two grips), units, graph type (stress vs strain), required, when same material code is specified. The whole test data is synchronously recorded and then processed. The specimen is placed in the machine between the holders. Once the machine is started it begins to apply a slowly increasing load upon the specimen. The measurement accuracy was decisively improved via automatic offset correction, temperature and long term drift. The digital sensor and zero point setting, minimizes the time required for settings and optimizes the test data for long term stability. The measurement range is used to an optimum and the values of all sensors are monitored. The weight of specimen holders is compensated automatically. It was observed from the specimen that as load increases, the length of the specimen increases. At some level the load becomes constant and the specimen fails. The results of tension test are collected in the form of a stress - strain curve.

2.3 Experimental method for compression test

The compression test is performed with a specially designed compression cage (where a specimen under test is compressed between two flat plates) having measuring gauge to measure the compression and recovery with an accuracy of 1/100 mm. All test data is synchronously recorded. Compression cage with electronic displacement sensor required no human intervention during the test. The sensor automatically measures the displacement and forward data to the computerized testing machine and machine displays the complete test result on the PC screen. Test result represented graphically as stress Vs strain.

The experiment was repeated for normal and decalcified bone. Data was tabulated for femur, rib and scapula of ox and camel.

3. Results

Table1 presents the data on tensile strength of animal bone, obtained using universal testing machine. The requisite parameters of the bone specimens namely gauge length, breadth, thickness, cross sectional area, breaking load, peak load and safety factor are presented for normal and decalcified specimens of femur, rib and scapula of animal ox and camel.

The data reveals considerable variations in the values of tensile strength with respect to type of bone, animal and calcium content. Fig. 4 shows the plots drawn between tensile stress on Y-axis and strain on X-axis for *Six* samples, each of normal and decalcified femur, rib and scapula bones of the animals – ox and camel. The plots reveal *three* regions – initially linear, then non-linear and a peak.

Table 2 presents the data on compressive strength of animal bone, obtained using universal testing machine. The requisite parameters of the bone specimens namely, gauge length, diameter, cross sectional area and peak load are also presented which may help in the calculation of compressive strength.

Fig.5 shows the plots drawn between compressive stress on y-axis and strain on x-axis for the samples of animal bone such as femur, rib and scapula of ox and camel, in normal and decalcified condition. The stress strain curves are non-linear. The plots show a peculiar behavior.

4. Discussion

Soft and hard tissues of vertebrate body provide a support against the gravitational force to the body. Most of the soft tissues are flexible and highly elastic. In general, their behaviour is viscoelastic. In contrast, hard tissues are more compact, rigid and less elastic and serve as endoskeleton and exoskeleton of the vertebrate body.

Bone is a hard tissue. It contains both organic (collagen) and inorganic (calcium phosphate) materials. Hence, the bone can be considered as viscoelastic composite material. The organization of composite varies from animal to animal and is strongly influenced by anatomical and physiological alterations, unlike engineering composite materials. However, bone has fibrous structural component (collagen) and exhibits a composite behaviour microscopically as well as macroscopically. Since bone tissue is a part of biological structure and its mechanical properties can only be fully appreciated if one understands how the structural organization functions as a whole.

The mechanical strength is an important property of the living systems. Hence, it must be sufficient to meet the forces that fall upon them. The forces that tissues must resist are nothing but the external forces. The tensile strength of rib (ox: 12.05, ±1.48 x 10^5 g/sq.cm; camel: 8.48, ±1.72 x 10^5 g/sq.cm) is found to be more than that of scapula (ox: 5.49, ±1.72 x 10^5 g/sq.cm; camel: 5.9, ±0.5 x 10^5 g/sq.cm) and femur (ox: 8.01, ±0.83 x 10^5 g/sq.cm; camel: 4.47, ±0.55 x 10^5 g/sq.cm) as latter is more brittle than the former.

The elastic behaviour of animal bone is noteworthy as evident from tensile strength – strain curves (Fig. 4). The tensile loading response of a bone is peculiar. The stress-strain curves show *Three* regions – initially *linear*, then *non-linear* at the end *Peak*. As is known, the major components of a bone are *Collagen matrix* and *Apatite*. Hence, stress-strain curve represents the collective response of collagen fibers and inorganic material – the apatite to the applied load, whether it may be tensile or compressive load. The spongy bones like rib and scapula have compressive strength value of (ox: 2.48, ±1.18; camel: 5.19; ±1.92) and (ox: 7.36, ±2.29 x 105 g/sq.cm; camel: 4.46, ± 0.81 x 10^5 g/sq.cm) while the compact bone like femur bears the value of about (ox bone: 16.55 ±1.8; camel bone: 19.8 ±2.5). This result is confirmed from the data on compressive strength of normal and decalcified bones (Table 2). The data shows that the compressive strength of spongy bones is very less than that of compact bone.

It is observed that the spongy bone expanded in lateral direction as compressive load increases. This shows that the spongy bones are less brittle and are of ductile nature. This ductile nature of the material enables it to resist almost indefinitely large forces without fracture. The specimen in contact with *plate* expanded less because of friction between surfaces of plates and specimen. The stress for an arbitrarily chosen deformation is indicated as compressive strength of a ductile material. While in the case of compact bone, it shows the brittle nature during the compressive test. The ultimate compressive strength of most brittle material is different than the ultimate tensile strength. For example, in concrete, the ultimate compressive strength is about ten times its ultimate tensile strength.

5. Conclusion

The data and above discussion proves that the compact bone like femur shows brittle nature when compared with spongy bones during the compressive test, and the camel bone is more brittle in nature when compared with ox bone and has more compressive strength. The bone contains crystalline calcium phosphate. Due to decalcification process bone loses its toughness, and its compressive strength decreases considerably. The effect of decalcification is different for different type of bones. The spongy bones lose its half of the compressive strength after decalcification, while compact bone shows comparatively less effect of decalcification.

A brittle material in general fails due to tensile stresses or is weak against tensile stresses. Camel bone is found to be more brittle than ox bone, as the tensile strength of camel bone is found to be less than ox bone. It is found that the tensile strength of decalcified bone is higher than that of normal bone (Table 1)

The compressive strength of ox femur is two times more than that of tensile strength and three times more in the case of camel femur.

The plots (Fig. 5) between stress and strain at compressive loading for all bones reveal *Four* regions – horizontal, non-linear, and linear and peaks (at the end or at different positions).

Table 1: A Comparison on average values of tensile strength of normal & decalcified animal bone

Animal	Bone	Tensile strength (x 10^5 g/sq. cm)	
		Normal	Decalcified
OX	Femur	8.01 ± 0.83	8.07 ± 2.58
	Rib	12.05 ± 1.48	12.32 ± 3.27
	Scapula	5.49 ± 1.72	7.77 ± 1.55
Camel	Femur	4.47 ± 0.55	8.31 ± 0.68
	Rib	8.48 ± 1.72	12.15 ± 2.23
	Scapula	5.9 ± 0.5	5.02 ± 0.48

Table 2: A Comparison on average values of compressive strength of normal & decalcified animal bone

Animal	Bone	Compressive strength (x 10^5 g/sq. cm)	
		Normal	Decalcified
OX	Femur	16.55± 1.8	13.92 ± 1.48
	Rib	2.48± 1.18	1.52 ± 0.48
	Scapula	7.36 ± 2.29	5.39 ± 1.89
Camel	Femur	19.85 ± 2.57	13.2 ± 3.8
	Rib	5.19 ± 1.92	1.26 ± 0.86
	Scapula	4.46 ± 0.81	1.9 ± 1.16

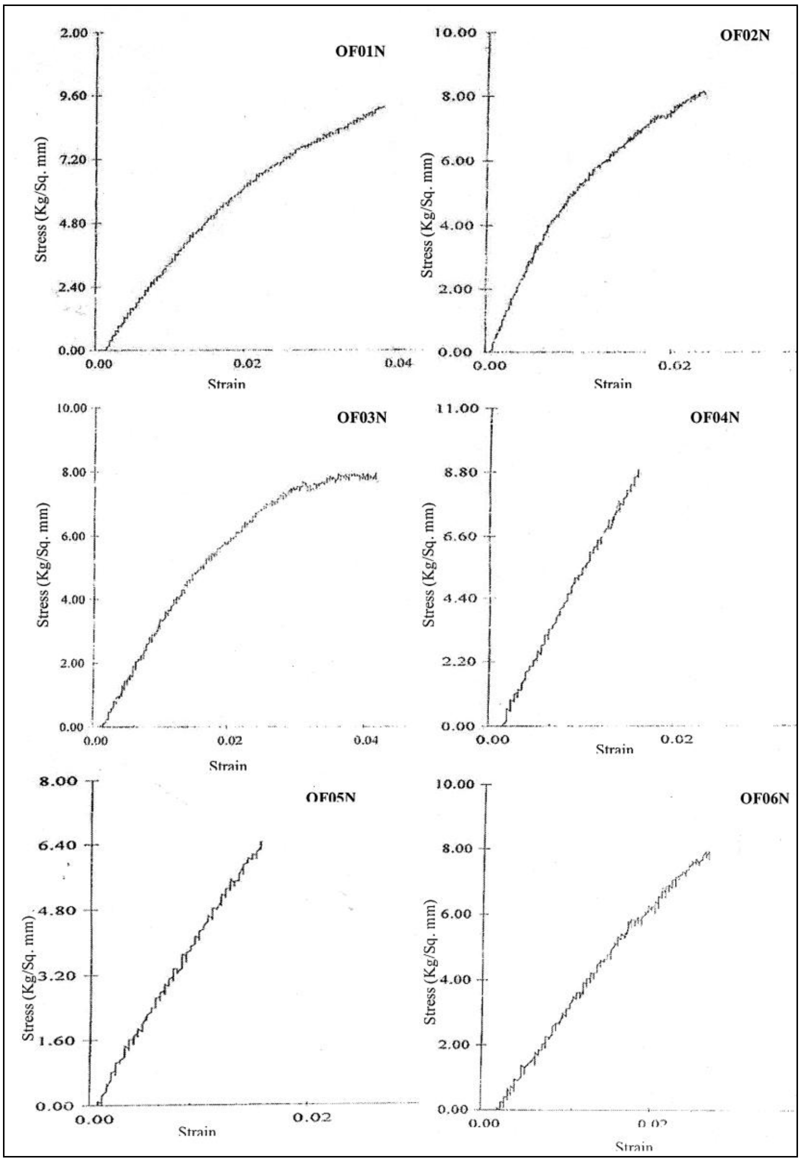

Figure 4: Stress – Strain curve obtained during tensile test

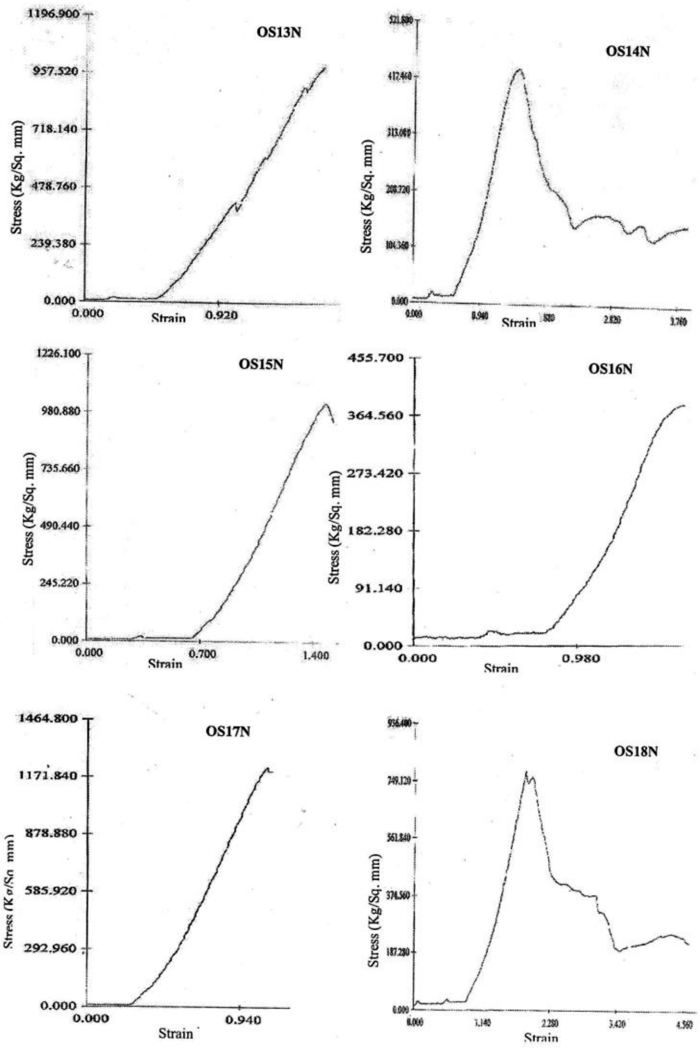

Figure 5: Stress – Strain curve obtained during compressive test

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