Transilvania University of Brasov
FACULTY OF MECHANICAL ENGINEERING

ICMS 2019 & COMEC 2019
Brasov, ROMANIA, 21-22 November 2019

DETERMINATION OF ELASTIC PROPERTIES USING ULTRASOUND METHOD IN CASE OF BIOCOMPATIBLE ALLOYS

Adriana Savin[1], Ma Wenbo[2], Gabriel S Dobrescu[1], Bogdan Istrate[3], Corneliu Munteanu[3], Mariana D. Stanciu[4]

[1] National Institute of R&D for Technical Physics, NDT Department, Iasi, ROMANIA, asavin@phys-iasi.ro
[2] Shenyang Jianzhu University, No.25 Hunnan Middle Road,Hunnan district, Shenyang,Liaoning ,CHINA, mawenbodoudou@gmail.com
[3]Gheorghe Asachi Technical University, Faculty of Mechanical Engineering, Iasi, ROMANIA cornelmun@gmail.com
[4] Transilvania University of Brașov, Brașov, ROMANIA, mariana.stanciu@unitbv.ro

Abstract: *The paper focuses on noninvasive experimental method to determine elastic features of a biomaterial based on magnesium and calcium improved with yttrium in different three ratio contents. In first step were measured the sound velocity in longitudinal and transversal direction of samples using the oscilloscope type LeCroy Wave Runner 600MHZ which generate the ultrasounds for transmitter sensor and receive the signals from the receiver sensor. After that, the measured values were integrated in mathematical relation to obtain the mechanical characteristics of studied samples.*
Keywords: *elastic properties of biocompatible alloys, ultrasound method, longitudinal sound velocity, transversal sound velocity*

1. INTRODUCTION

Due to the rapid growth of the world population, accidental injuries such as traffic accidents continue to increase. In particular, the demand for particularly suitable materials has been published in developing countries [1, 2, 3] for the application of biological implants. Therefore, it is a new challenge to develop a material with high biocompatibility for the manufacture of medical prostheses, dental, neck and hip orthoses to meet human needs.
Although some pure metals have excellent properties and can be used as implants, most metal implants are alloys made of metal, namely stainless steel, cobalt-chromium alloy [4-6] in the past few Total Hip Arthroplasty (THA) has become one of the most successful surgical procedures in a decade. However, if THA is used as a solution, there will be adverse symptoms such as stiffness, deformity, and shortened limbs. Between 1980 and 2000, a total of 250,000 hip replacements were conducted annually in the United States [7-9]. Therefore, not only the increased replacement surgery, but also the revision surgery of the hip joint and the knee joint is also greatly increased. However, the revision surgery not only causes pain to the patient, but the price is also very expensive.
In recent years, researchers have shifted their research to the study of magnesium alloys (Mg Ca Y alloy) with different concentration of yttrium [10 - 12]. Therefore, it is necessary to study magnesium alloys with good biocompatibility, long life and good mechanical properties as long-term implants [13-14].
The paper analyses of the influence of yttrium concentration over elastic properties of magnesium alloys (Mg 0.5Ca xY with different ratios composition of Y (x= 0.5; 1.0; 1.5; wt%)) using ultrasound method (as noninvasive methods) to determine the mechanical properties (i.e. Poisson ratio, Young modulus, Shear modulus) [10].

2. EXPERIMENTAL SET-UP

Non-destructive ultrasonic control methods are commonly used in the examination of parts made of various materials, allowing for both the discovery of material discontinuities and the determination of important sizes such as the modulus of elasticity, the Poisson coefficient, and the hardness. It is also possible to obtain qualitative information on the structure and internal porosity of the parts examined. In solid media two types of elastic waves can be propagated: longitudinal where the particle oscillation direction coincides with the wave propagation direction; where the transverse direction to which the oscillation direction is perpendicular to the wave propagation direction. Each type of wave corresponds to its own oscillation velocity.

a) For longitudinal waves, the velocity has the expression (1):

$$C_L = \sqrt{\frac{E}{\rho}\frac{1-\mu}{(1+\mu)(1-2\mu)}} \quad (1)$$

where E is the Young modulus $[E]_{SI}$=GPa, ρ is the density of the material$[\rho]_{SI}$=kg·m^{-3} and μ is the Poisson coefficient, a dimensionless dimension.

b) For transverse waves, the velocity can be calculated based on relation (2):

$$C_T = \sqrt{\frac{G}{\rho}} \quad (2)$$

where G is the shear modulus $[G]_{SI}$=GPa.

Based on the results obtained by ultrasound method, it can be calculated the elasticity characteristics such as Poisson coefficient μ (relation 3); Young's Modulus (longitudinal elasticity modulus) E (relation 4); the shear modulus G (relation 5).

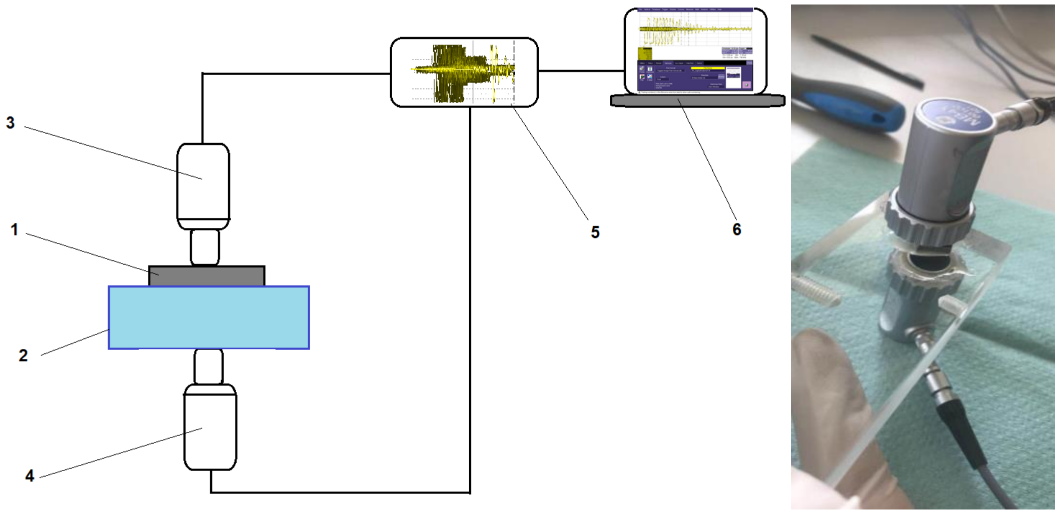
$$\mu = \frac{\left(\frac{C_L}{C_T}\right)^2 - 2}{2\left[\left(\frac{C_L}{C_T}\right)^2 - 1\right]} \quad (3)$$

$$E = G\left[2(1+\mu)\right] \quad (4)$$

$$G = C_T{}^2 * \rho \quad (5)$$

2.1. Experimental principle

The method consist of contact emission of ultrasound waves with a transducer and reception of them with the second transducer, the longitudinal and transverse wave propagated in samples materials. In Figure 1 is presented the principles of experiment. The transducers are coupled to the oscilloscope type LeCroy Wave Runner 600MHZ which generate the ultrasounds for transmitter sensor and receive the signals from the receiver sensor.



a) b)

Figure 1: The experimental set-up: a) principle of tested method (Legend: 1 – samples; 2 – Plexiglas's piece; 3 – transmitter transducer; 4 – receiver transducer; 5 – oscilloscope; 6 – computer); b) capture image during the experiment

The transducers are coupled to the oscilloscope type LeCroy Wave Runner 600MHZ which generate the ultrasounds for transmitter sensor and receive the signals from the receiver sensor. In Figure 4 are presented some signals acquisitioned during the experiments.

a) b) c)

Figure 2: The ultrasound signals visualization on the oscilloscope display

2.2. Materials

The tested samples were obtained from alloys of magnesium (Mg), Calcium (0.5Ca) and yttrium (Y) with different ratios composition of Y(x= 0.5; 1.0; 1.5; wt%). Mg alloys used in medical applications is appreciated for their biocompatibility degree. Once released into the body by the alloy degradation process, the alloying elements must be completely reabsorbed without producing local or systemic toxic effects. Ca shows the best biocompatibility, no toxic effects, being, as Mg, an element present naturally in the human body. The yttrium has the role to increase the mechanical properties of the others components [15].
The composition of samples was determined using EDX using SEM Quanta 200 3D DUAL BEAM coupled with an EDS-EDAX detector (Table 1).

Table 1: The chemical composition of studied samples

Samples	Elements wt%			Physical features	
	Mg	Ca	Y	Density [g/mm^3]	Length [mm]
Sample 1 (Mg 0.5Ca 0.5 Y)	98.52	0.54	0.94	1649.84	9.94
Sample 2 (Mg 0.5Ca 1.0 Y)	98.34	0.89	0.77	1696.77	10.04
Sample 3 (Mg 0.5Ca 1.5 Y)	97.91	0.65	1.44	1603.78	10.19

3. RESULTS AND DISCUSSION

For calculated mechanical parameter was used ultrasound method by echo pulse method, described in [.....] in order to determined Young modulus E, shear modulus G and Poisson ratio of sample using longitudinal velocity wave C_l and transversal velocity wave C_t presented in Table 2. The average values of hardness were obtained from five different areas of faces of sample remain approximatively constant. The small differences are due to the influence of alloying elements that influence compactness. With increasing the yttrium ratio composition, the ratio between longitudinal sound velocity and transversal one increases too (Figure 3).

Table 2: Mechanical properties determined with ultrasound method

Samples	Measured sound velocity		Mechanical properties		
	C_L [m/s]	C_T [m/s]	Young modulus [GPa]	Shear modulus [GPa]	Poisson ratio
Sample 1 (Mg 0.5Ca 0.5 Y)	5282	2948	37.79	14.80	0.28
Sample 2 (Mg 0.5Ca 1.0 Y)	5442	2868	36.50	13.96	0.31
Sample 3 (Mg 0.5Ca 1.5 Y)	5610	2931	36.16	13.78	0.31

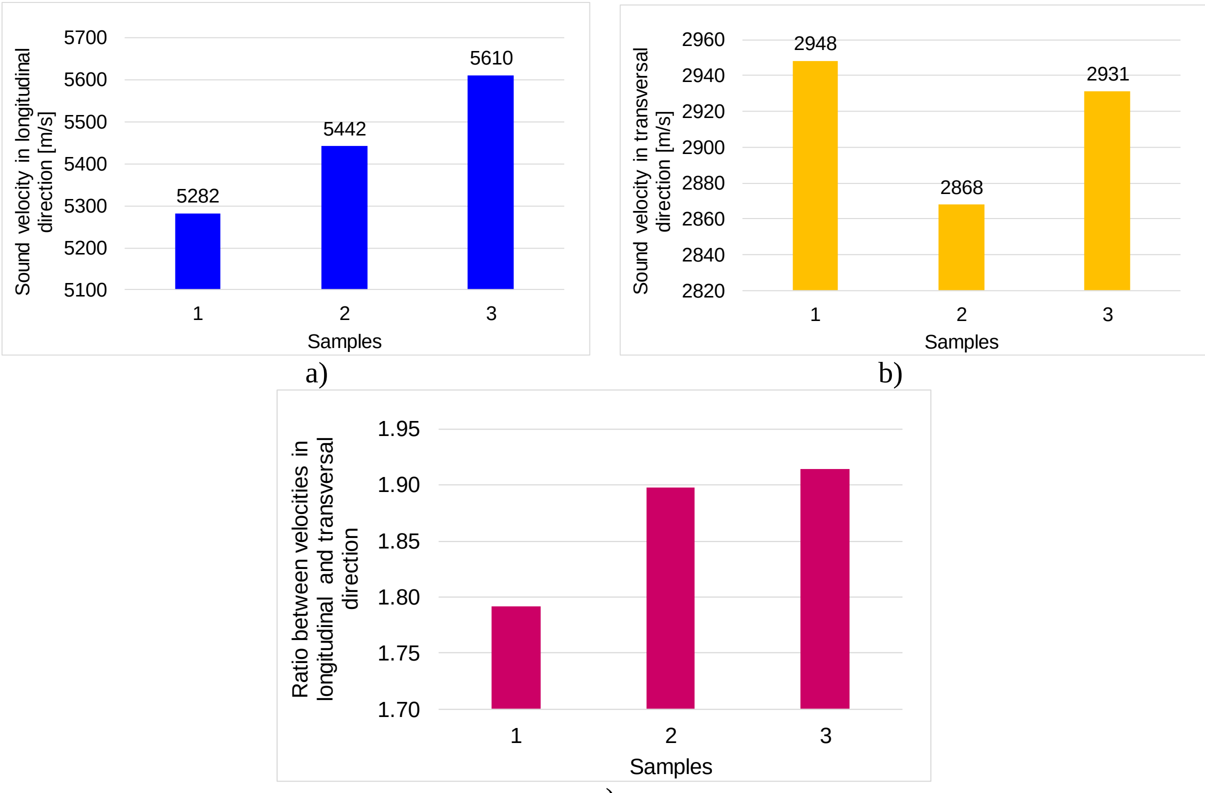


Figure 3: Variation of sound velocity: a) in longitudinal direction; b) in transversal direction

Regarding the elasticity moduli, it can be noticed that increasing the yttrium concentration leads to decreasing the Young's and shear modulus (Figure 4). The Young's modulus decrease with 4,3% in case of alloys with 1.5 yttrium compare to alloys with 0.5 yttrium.

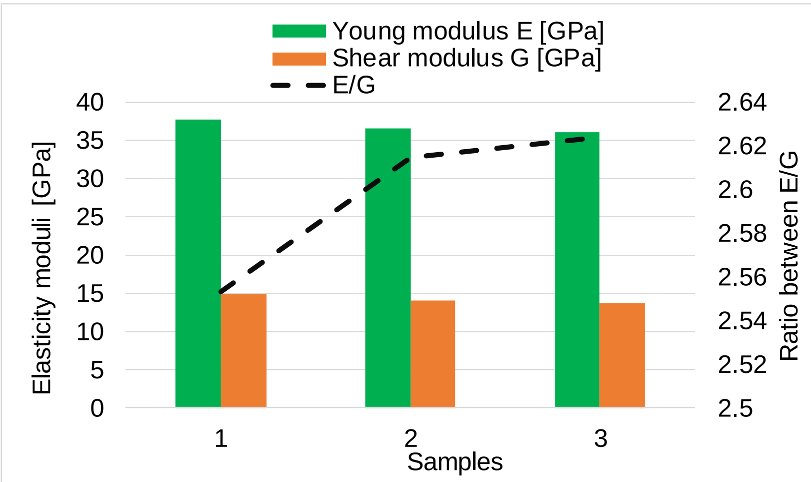


Figure 4: Variation of elasticity moduli

4. CONCLUSION

The experimental determination of the Young modulus, the shear modulus and Poisson ratio of the sample using ultrasound method has been presented, starting from data characterizing the material in the entire volume, not only at the surface, using longitudinal velocity wave and transverse velocity waves. The obtained values for Young modulus are closed to those of human bones assuring the good compatibility. Addition of calcium and yttrium at magnesium alloys improve the mechanical properties, yttrium contributed to obtained special corrosion resistance.

ACKNOWLEDGEMENT

This work was supported by the Romanian Ministry of Research and Innovation, CCCDI – UEFISCDI project PN-III-P1-1.2-PCCDI-2017-0239/ 60PCCDI 2018.

REFERENCES

[1] Wiliams DF 1999 *The Williams dictionary of biomaterials* (Liverpool, UK: Liverpool University Press)
[2] Prakasam M, Locs J, Salma-Ancane K, Loca D, Largeteau A, Berzina-Cimdina L 2017 *J. Funct. Biomater.* **8**(4), 44
[3] Palacio-Mancheno PE, Larriera AI, Doty SB, Cardoso L, Fritton SP 2014 *J Bone Miner Res* **29**(1) 142-50
[4] Witte F, 2010 *Acta biomaterialia* **6**(5) 1680-92
[5] Chorny V, Yatsun Y, Golovakha M 2014 *Orthopaedics, Traumatology and Prosthetics* **1** 105-9
[6] Lupescu S, Munteanu C, Istrate B, Stanciu S, Cimpoesu N, Oprisan B 2017 *IOP Conf Ser: Mater Sci Eng* **209**(1) 012018
[7] Staiger MP, Pietak AM, Huadmai J, Dias G. 2006 Biomaterials **27**(9) 1728-34
[8] López HY, Cortés-Hernández DA, Escobedo S, Mantovani D 2006 *Key Engineering Materials* **309** 453-6
[9] Lupescu S, Istrate B, Munteanu C, Minciuna, M G, Focsaneanu S, Earar K 2017 *Revista de Chimie* **68**(6) 1408-1413
[10] A Savin et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 572: 012017
[11] Savin A, Craus ML, Turchenko V, Bruma A, Dubos PA, Malo S, Konstantinova T, Burkhovetsky V 2015 *Applied Sciences* **5**(4) 1665-82
[12] Savin A, Vizureanu P, Prevorovsky Z, Chlada M, Krofta J, Baltatu MS, Istrate B, Steigmann R. 2018 *IOP Conf Ser: Mater Sci Eng* **374**(1) 012030
[13] Myasnikov DV, Konyashkin AV, Ryabushkin OA 2010 *Tech. Phys. Lett.* **36**(7) 632-5.
[14] Jaglinski T, Lakes RS 2011 *Rev. of Sci. Instrum.* **82**(3):035105
[15] Savin, A., Iftimie, N., Steigmann, R., Dobrescu, G.S., Istrate, B. and Munteanu, C., 2019, *IOP Conference Series: Materials Science and Engineering* (Vol. 572, No. 1, p. 012017).