Noninvasive Evaluation of Special Alloys for Prostheses Using Complementary Methods

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Abstract. Ti-Mo-Si alloys have gained the attention of biomedical industry due to specific strength and corrosion resistance and the best biocompatibility among metallic materials used in medical prostheses. In order to characterize the material, the experimental determination of elastic matrix, mechanical wear and the probability of appearance and propagation of thin cracks are imposed. Thus, resonant ultrasound spectroscopy and acoustic emission as non-invasive methods and complementary methods as SEM, EDX are involved, to choose the best concentration of elements with the aim of mechanical properties improvement.

1. Introduction
Modern medical prosthesis as dental implant, knee prosthesis and hip stem are made from high strength brittle materials such ceramics, intermetallic and their composites for structural applications where cyclical loading is critical. Over the last decades, total hip arthroplasty (THA) has become one of the most successful surgical operations. Symptoms such as pain and loss of functions indicate THA as the solution. These symptoms can appear in different forms, as rigidity, deformity, limb shortening or movement reduction. Candidates for joint arthroplasty include patients who either exhibit excessive pain due to dysfunction in the hip or knee due to fracture of the femoral head, arthritis, or other conditions. THA improves quality of life in patients with end-stage osteoarthritis of the hip [1]. More than 500,000 joint replacements are performed each year in the United States alone, with many more hundreds of thousands being performed worldwide. Due to the change in demographics, the total demand will increase about 30% during the next 20 years. A total hip prosthesis is surgically implanted to replace damaged bone within the hip joint. Most of the implant is nowadays modular[2] (Figure 1a).

That assures the possibility to adapting the geometry of the prosthesis to the joint morphology of the patient. The total hip prosthesis consists of three parts:

- a cup that replaces the hip socket. The cup is usually plastic or ceramic metal
- a metal or ceramic ball that will replace the fractured head of the femur
- a metal stem that is attached to the shaft of the bone to add stability to the prosthesis.

Modularity assures the possibility of adapting the geometry of the prosthesis to the joint morphology of the patient. The femoral head has a spherical shape, slightly flattened both anteriorly
and posteriorly. The femoral head is covered of articular cartilage, with the exception of the fovea. On the acetabular face, fovea covers a horseshoe shaped zone and it is set in the central region. The fovea is thick, not articulated and it is filled with some fat, the sinusoidal membrane and the ligamentum rotundum [3]. The articular capsule is inserted on the acetabular edge proximally and on the femur distally. This solution provides more flexibility during primary surgery and simplified revision procedures[4]. Modular components (metal augments) of various size and shape are used to restore bone defect to contained one capable of supporting a revision cup. The size and placement of augments is highly dependable on the bone loss pattern. Theses augments are secured with multiple screws for rigid bone fixation. In the last decade, revision hip arthroplasty has been the center of orthopedic surgeons’ attention because these difficult and hazardous surgeries are growing in numbers. Nowadays, the research is focused on improving surgical techniques, implants design as well as development of biomaterials and bearing surfaces with a significant contribution for obtaining favorable outcome after revision hip arthroplasty, without having complex solution.

![Figure 1. Hip implants: a) modular principle; b) photo.](image)

Since the 1960s, titanium and its alloys are used as medical devices due their unique properties. Titanium properties (i.e. tenacity, low density, resistance to corrosion, stiffness, etc.) made it together with its alloys, in combination with alloying elements (Fe, V, Mo, through other elements) a good replacement of steel pieces (in automotive industry in engine components –valves, connecting rods, drive shafts, crankshafts) [5-7]. Titanium alloys have the advantage of being lightweight and can be used in the aerospace and naval industry, military use, chemical and petrochemical machinery and other high performance applications [8, 9]. Due the biocompatibility, titanium alloys have broad applications in medical implants and prosthetic devices. The elastic modulus of $\alpha$ and $\alpha+\beta$ Ti alloys is much higher [10] than of natural bone (10-30 GPa). Intense researches are known in the domain of development of new bio-functional alloys based on Titanium [11], considered more appropriate of human bones as mechanical bio-functioning compared with polymers and ceramics biomaterials [12-14]. Development of a microstructure with optimal mechanical properties represents a difficult problem in this type of alloys domain. Methods for improving the properties of titanium alloys have been developed, in order to increase the capacity of joining bone tissue-metal implant and to give longevity to implant.

This paper proposes to examine mechanical properties of biomaterials based on Ti used in medical prosthetic with different ratios between alloying elements, i.e Mo 10-20%, Zr 6-8%, Si 1-5% to improve the bio-functional characteristics of the materials. For this investigation, we used alternative methods such as scanning electron microscopy and microstructure characterization, acoustic emission (AE) [15] and resonant ultrasound spectroscopy (RUS) [16] as noninvasive methods. EDX are involved, to choose the best concentration of elements with aim of improvement of mechanical properties.
2. Theoretical principle of resonant ultrasound spectroscopy

The elasticity of a material is the predisposition of a material to return to a minimum energy configuration. The change in energy, $\Delta U$, under the influence of deformation strain can be described by an expansion in the size of the deformation strains $e_{ij}$ around the local equilibrium (stress free interval state)[17].

$$\Delta U = \frac{1}{2} C_{ijkl} e_{ij} e_{kl} + \frac{1}{6} C_{ijklmn} e_{ij} e_{kl} e_{mn} + ...$$ (1)

where the $C_{ijkl}$ are constants form the elastic modulus tensor; this is the sum of the effects of the local elastic restoring forces and conforming to the overall symmetry of the system.

The $C_{ijklmn}$ are the third order elastic constants resulting from the third strain derivatives of the second order elastic constants $C_{ijkl}$. The restoration force implied in (1) can be written in a linearized form as Hooke’s law with stress tensor $\tau_{ij}$

$$\tau_{ij} = C_{ijkl} e_{kl}$$ (2)

RUS [18] is based on the fact that the resonance frequencies of an homogeneous object are determined by the geometry, density, and restoring forces of the object, described in (1). The resulting small strain elastic vibrations can be described by the wave equation solution using the linear elastic constants tensor. For a homogeneous and isotropic body, the matrix $C$ can be written as

$$C = \begin{bmatrix}
K + \frac{4G}{3} & K - \frac{2G}{3} & K - \frac{2G}{3} & 0 & 0 & 0 \\
K - \frac{2G}{3} & K + \frac{4G}{3} & K - \frac{2G}{3} & 0 & 0 & 0 \\
K - \frac{2G}{3} & K - \frac{2G}{3} & K + \frac{4G}{3} & 0 & 0 & 0 \\
0 & 0 & 0 & G & 0 & 0 \\
0 & 0 & 0 & 0 & G & 0 \\
0 & 0 & 0 & 0 & 0 & G 
\end{bmatrix}$$ (3)

where $K$ is the bulk modulus, $K = \frac{E}{3(1-2\nu)}$ and $G$ is the shear modulus, $G = \frac{E}{2(1+\nu)}$, $E$ represents the Young’s modulus and $\nu$ is Poisson’s ratio[19].

The calculation of vibration modes of elastic objects with free boundaries is a classic problem in mechanics. Unfortunately, exact analytical solutions exist only for few cases such as isotropic spheres, cylinders and certain models of a parallelepiped [20]. In most cases, approximation methods as finite element method (FEM) or Rayleigh-Ritz method must be used for estimating the eigen-frequencies of normal modes. The Young modulus, shear modulus and Poisson’s ratio were determined based on the propagation speed of longitudinal and transversal ultrasonic waves using impulse - echo method. More on RUS technique can be find in papers of Miglori [21], Zadler [22] and Damarest [23].

3. Materials and methods

Hip prostheses are presently manufactured from Ti and its alloys due to their superior biocompatibility compared with other representative metallic biomaterials (SUS 316L stainless steel, Co Cr Mo alloys, etc), while the Young modulus is smaller comparatively with those, other characteristics such as corrosion resistance, strength and ductility are superior of other metallic materials. The evaluation of biocompatible materials using nondestructive evaluation techniques (NDE) is often resumed in
literature [24-26]. Fatigue cracks in materials used for implants are characterized by their small opening in incident phase, they begin by the appearance of a small irregular crack located on the border of a crystalline grain and propagate then when the mechanical tension exceeds the threshold value [19]. This behavior of biocompatible materials used in realization of prostheses requires the application of complementary NDE techniques, leading to safety in exploitation.

3.1. Samples
When the prostheses are implanted to reconstruct the bone, to prevent bone resorption and to obtain adequate remodeling, their Young's modulus must be close to that of the bone. An efficient way to obtain a low elastic modulus in metallic materials is to realize a porous structure. The porosity has double effect, beside the one reminded, it allows the thickening of the bone in the pores and transferring the load from implant to the bone, helping the biological fixation. Ti-Mo alloys accomplish this task, solid titanium alloys being a viable alternative for prostheses, compatible biomechanical and biochemical, having mechanical features compatible to the human bones, the best being the βTi alloys with central cubic crystalline structure (bcc), because the titanium atoms are not dense packaged as in the case of α with dense closed packed (hcp) structure. Molybdenum has been selected as alloying element, secondary as ratio, because it not producing toxic reaction and is non allergic, being in balance with the human body. The mechanical properties are improved by alloying Ti with β isomorph stabilizers (i.e Mo), alloying that improve the resistance to corrosion.

Using high purity elements Ti-99.8%, Mo-99.7% and Si-99.2% as starting materials, the Ti 84 Mo 15 Si 0.75 alloy was prepared with vacuum arc melting furnace, in argon atmosphere. The advantages of using this equipment are very high melting temperatures can be achieved, the possibility of vacuum melting the metallic samples under a protective atmosphere and can create alloys with uniform composition. For the acoustic emission and RUS analysis, from the studied probe, a cube sample with 10mm side has been cropped using MAXIEM 1530 device which provides high-pressure water jetting with a precision of 0.1 mm/ml. Cutting quality has not been thermal affected and the material has not been mechanically deformed, nor included internal stresses, micro fissures or structural changes. The sample for metallographic observations was polished with SiC paper and Al₂O₃ particles with water. The polished sample was etched in an erodent with composition of 10 ml HF, 5 ml HNO₃, 85 ml H₂O, requiring 30 s immersion time.

![Figure 2. SEM analysis of TiMoSi alloy.](image1.png)

![Figure 3. EDAX of specimen.](image2.png)

3.2. SEM evaluation
In order to better characterize of the materials, SEM and EDX analysis have been performed. Taking into account the structure of Ti 84 Mo 15 Si 0.75 (TiMoSi), to obtain relevant information about the
influence of Mo concentration over structure, Secondary Electrons (SE) images, as well as BackScattered Electrons (BSE) images have been taken. A Scanning Electron Microscope (QUANTA200 3D) operating at an acceleration voltage of 20 kV has been used of the topographical characterization of the specimens. SEM images emphasize that the Ti alloys is compact (Figure 2). A further confirmation of the local atomic percentage of the elements in sample composition is given in Figure 3.

3.3. Microhardness measurement
The measurements of microhardness were performed by Vickers method, with a load of 100 gF (HV100) in 25 seconds, on faces of the sample after cutting with method mentioned above. The Vickers microhardness remain approximately constant at all faces of the sample (Figure 4).

Table 1. Results of microhardness measurements.

| Zone | HV (GPa) |
|------|----------|
| 1    | 353.9    |
| 2    | 359.8    |
| 3    | 356.6    |

The average values of hardness obtained from three different areas of this, are presented in Table 1. According to the literature [27, 28] and the results obtained from the experimental researches on TiMoSi alloys, a comparative study was carried out also with the classical biomaterials of the Ti6Al4V alloy, respectively the class of CoCrMo alloys (Figure 5).

Figure 4. The fingerprint left by the Vickers microhardness.

Figure 5. Graphical comparison of the hardness values of TiMoSi alloy with other biomaterials.

Compared to other biomaterials, the TiMoSi alloy had a similar hardness value as the Ti6Al4V alloy, which is the most used in implantology [27,29,30].

3.4. Ultrasound characterization of samples
For sample Ti84 Mo15 Si0.75 cube, having 10 mm length, in order to determine mechanical parameters such as Young modulus E, shear modulus G and Poisson ratio, the propagation speed of ultrasound waves were determined using impulse - echo method. Longitudinal velocity wave was measured using a sensor G5KB GE with central frequency of 5 MHz, the coupling being assured by coupling gel. The transversal wave velocity was determined with a sensor MB4Y GE with central frequency of 4 MHz. The PanametricsPR 5073 Pulser Receiver is used for the emission impulses and the reception of the signals. The digitizing of the signals and the measurements of the time of flight was made with the digital oscilloscope Le CroyWave Runner 64Xi.

The mechanical characteristics are presented in Table 2.
Young’s modulus was estimated using the method described above but according with presence of porosity. Future research in this area should concentrate on the porous structures implants with different levels of porosity (15-70%) to reduce the Young’s modulus.

Table 2. Mechanical characteristics of sample taken into study.

| Metallic sample | Length [mm] | Density [kg/m³] | Young modulus [GPa] | Shear modulus [GPa] | Poisson ratio | C₁ [m/s] | Cᵢ [m/s] | Observations |
|-----------------|-------------|-----------------|---------------------|--------------------|---------------|--------|--------|-------------|
| TiMoSi          | 10          | 5.063           | 88.81               | 33.93              | 0.3           | 5514   | 2589   | With cracks detected by cutting and microscopic analyzed |
| Ti84.2 Mo15 Si0.75 | -           | -               | -                   | -                  | -             | -      | -      |             |

4. Experimental Set-up

4.1. Acoustic emission

Acoustic emission (AE) is a passive ultrasonic nondestructive testing and evaluation (NDT / NDE) method for monitoring mechanically, thermally, etc., stimulated materials and structures. Transient elastic waves are generated in material due to the rapid release of energy from localized sources within material. The sources can originate from different mechanisms. The primary sources of AE are mechanical deformation and fracture, phase transformations, and other processes. Elastic waves propagate through a structure from the source to detectors (mostly piezoelectric transducers), which convert wave energy to electric signals. Weak electrical signals are amplified and characterized by parameters of their wave forms like energy, intensity, frequency spectrum and others [31, 32]. Due to the high sensitivity of piezo-transducers is AE technique widely used to identify failure initiation, the initial stages of damage, damage propagation, and catastrophic failure of the material. The recording of values when microcracks are initiated is a more accurate way of predicting the real strength of materials used in critical biomedical applications [33-35].

The sample was subjected to compression loading on INSTRON 1195 electromechanical testing machine with Bluehill 2 control software at the constant displacement velocity rate 0.2 mm/min. The maximal machine loading capacity is 100 kN, thus, the compression test was pre-programmed to stop at 80 kN load. AE was continuously monitored throughout the whole test using two piezoelectric AE transducers DAKEL IDK09 (diameter 9 mm) with sintered alumina wear plate. The experimental setup is presented in Figure 6.

Figure 6. Experimental setup for compression test with AE monitoring: (a) equipment; (b) AE transducers.
The frequency band of transducers was relatively flat (10 dB) in the range of 30 – 500 kHz. Figure 7 presents the detailed layout of the sample and AE transducers.

The small dimensions of the sample didn’t allow direct attaching of transducers. The transducers were glued with cyanoacrylate onto a hard metal plate cover playing the role of wave guide from transducers, toward the sample. A support plate was also used on the bottom, to avoid damage the surface of loading clamps by the small and very hard specimen.

Instead of standard AE analyzer for AE signals treatment, two AE transducers with different signal amplification and USB HS5 oscilloscope connection were used for AE signals treatment in order to entire processing of their large dynamic range (more than 80 dB). Signals from both transducers S1 and S2 placed on opposite sides of the waveguide were amplified in PAC 20-40-60 preamplifiers (PA1 by 20 dB, and PA2 by 40 dB, respectively) and then were input to two channels of the 14 bit ADC’s of the USB digital oscilloscope Tie-Pie HS5 for continuous signal sampling by 2.5 MHz frequency without thresholding. This assembly allows to record AE signals with full dynamic range including noise. The full ranges of both oscilloscope channels were adjusted differently: channel with S1 at 2 V and S2 at 400 mV respectively, enabling variable threshold settings of AE hits and events definition [32] in post-processing of AE signals, which is not possible with standard analyzers.

![Diagram](image)

**Figure 7.** Detailed layout of the sample and AE transducers: (a) scheme; (b) photo.

### 4.2. Resonant Ultrasound Spectroscopy - RUS

According with [18] sample geometry affects data acquisition. In this case the used sample was a cube with 10 mm length. For this we have few excitation modes and the spectrum requires more analysis than at a long bar. The increasing of spectral complexity supposes adjacent analyses of the sample before concluding about this sample.

In order to determine parameters, more resonance frequencies must be searched. This requires large time of computational calculation and repeated tests. The same number of normal modes for a short sample comparing with another long requires a narrow frequency range. The measurements are carried out with transducers in contact. The coupling of the transducer with the specimen influences which modes are measured. When the sample is pinned on its edge, more modes are excited and the modes are better defined than when the transducers are placed at the cube surface (Figure 8).

The probe is fixed between the emission transducers (excites an elastic waves with constant amplitude and variable frequency for specimen) and reception transducers (that detects response in US frequency of sample) in order to accomplish the condition of stress free surface. The equipment allows the setting so that for the established position of the cylindrical sample, the contact on the edge assures the excitation of a maximum number of possible resonances for the fixed geometry.

A Network/Spectrum/Analyzer Agilent 4395A generates a sweep frequency between 120 kHz and 200 kHz in 1 kHz step. The signal is amplified by Power amplifier AC 1012 AG&TC Power Inc. USA and applied to an US transmitting transducer P111.O.06P3.1 type, selected for the large bandwidth. The signal from receiving transducer, identical to the transmitting one, is applied to the B port of the 4395A Agilent, the spectrum being acquired by a PC that is used also to program the functioning of
the equipment with a numerical code developed in Matlab, via PCIB interface. The command of the power amplifier is made with the same PC via RS232 interface.

![Diagram](image)

**Figure 8.** Experimental set-up for RUS: a) scheme; b) sample placement.

5. Experimental results

The presence of microcracks inside the materials used in the construction of medical prostheses has long been controversial due to the disturbing factors and the fact that it is difficult to observe and quantify their dimensions. The novel non-destructive techniques as RUS and AE have improved detection capability by increasing the confidence coefficient in the test analysis. The micro cracks accumulate with cyclic loads, the preexistence of a pore can be transformed into the propagation crack. Transient reduction of bone mass involves the use of a prosthetic material that can bear the loads by slowing the accelerated remodeling in response to loads. The weakening of a prosthetic implant is also generated by the ratio between porosity and damage. It is very important to know, in order to obtain and characterize the materials that the perturbations of material properties (density and especially the elastic constants tensor) affect the resonance frequencies and especially how they affect. In the manufacturing process, it is necessary to investigate the pore geometry, which has a strong effect on cell attachment and matrix formation, especially in the conditions of their realization in 3D technology. To evaluate what resonances will be observed in an experiment of the sample is very important to anticipate the theoretical response. The real case shows that it is useful to use resonance eigenvalues and eigenvectors in prediction.

5.1. AE test results and their interpretation

Figure 9 presents the compression loading diagram with AE activity of Ti alloy sample. Maximal attained compression stress was $\sigma = 800$ MPa as loading machine was automatically stopped at 80 kN, yet before the final fracture exceeding loading force 100 kN. Crosshead displacement controlled by the loading machine (0.2 mm/min) was strictly linear up to its maximum 2.1 mm. Direct measurement of the strain was not realized due to small sample dimensions, so that maximal strain was only estimated after correction on overall machine stiffness as 1.44 %, which implies compression modulus in linear part approx. 89 GPa. AE signals from both channels were continuously sampled with 2.5 MSPS, which resulted in two about 1.6 GB long records. The post-processing of these records was carried out after correction on amplification set at 10 dB$_{AE}$ counting threshold (i.e. approx. 3µV, about 2dB above a noise level) and count rate dNc/dt proportional to the energy of AE activity was
evaluated from higher sensitive second AE channel. A total number of counts $N_c$ was computed by summation of count rates.

AE activity is connected with various processes taking place in the compressed samples. The first AE hits recorded at about the test time $t = 160$ s are caused by the first contact of upper machine clamp with the sample.

![Figure 9. Compression loading diagram of Ti sample with recorded AE activity.](image)

The upper and lower surfaces of the sample were not polished and also not perfectly plan-parallel, which resulted in the fracture of one salient corner manifested by the high AE event at $t = 310$ s marked as #1 in Figure 9. After that begins linear stress growth in the sample. At about $\sigma = 100$ MPa starts formation of small cracking in the sample accompanied by AE activity resulting in bigger event #2 representing probably coalescence of smaller cracks. Internal cracking continues under approx. constant count rate 20 counts/s up to higher energy events ended by the event #3, representing longer crack jumps. Due to the high elastic energy stored in the sample, the following AE activity accompanying further cracking is characterized by the average count rate of 78 counts/s. It was ended with internal crack jump manifested by event #4, which represents release of a large amount of stored energy. The test was stopped at $\sigma = 800$ MPa under continuing smaller AE activity. Additional

![Figure 10. AE signal waveforms of events no. #1 to #4 (up) and their corresponding spectra (down).](image)
compression loading under lower displacement rate was carried up to $\sigma = 900$ MPa (not recorded in Figure 9) when it stops before the overall sample failure signalized by again growing AE activity. Different mechanisms of fracture processes taking place during various periods of compression loading are identified by comparing frequency spectra of individual large events marked in Figure 9 as #1 to #4. The signal waveforms of those events are plotted along with their corresponding spectra in Figure 10. Large event #1 representing the break off of the salient sample corner that exhibits long duration at very low maximal frequency only 40 kHz. It can be interpreted as a vibration resonance of the whole sample clamped in the testing machine due to large energy release and falling down of the broken off part. This resonance is perfectly hearable when the signal of that event is played down-sampled. The event #2 occurred with started internal cracking has the frequency maximum around 140 kHz. A higher crack velocity at higher stored elastic energy in the sample is accompanied with higher maximal frequency 193 kHz of the event #3. A similar feature is observed at event #4 where the frequency maximum is again around 200 kHz but another high peaks are at 300 kHz. The frequency spectra were calculated from signals recorded by the first channel, as amplitudes of signals from the more sensitive second channel were limited.

5.2. RUS

The resonance spectrum has been measured on the cube of alloy taken in this study. In the range 10 kHz-100 kHz, the obtained results are in conclusive and therefore, only the resonance spectrum in the range 120 kHz-200 kHz will be described. For a better understanding of the alloy used in manufacturing of femoral heads vibration modes, the eigen vibrations have been calculated using Solid Works 2014, Simulations Toolbox. For titanium alloy sample, axisymmetric, isotropic and homogeneous, a mesh of 62280 nodes and 43215 elements has been used. Therefore it can be concluded that every mode must fall into one of the three classes according to [22]: extensional axisymmetric mixtures of compression and shear motions, flexural modes through along pass that are tilted with respect to the axis, (the flexural modes occur in pairs named doublets, both members of which have the same resonance frequency) and torsional (the frequencies of these modes depends entirely upon the samples shear velocity) mode. The oscillation eigenfrequencies were calculated using/based on the parameters set presented in table 1. Figure 11 shows the vibration modes obtained by simulation, for the frequencies between 120kHz and 200kHz.

These figures represent the results of simulation of deformations for two extensional modes (a, b), and two flexural modes (c, d), for the cube obtained using the finite element method using SolidWorks 2014. The amplitude of signal in the swept frequency range is in tight connection with properties (especially to the density) of the sample. Red color represents maximal displacements and the minimal ones are presented in blue. The simulated information is very important to determine which of the resonances are observables for an investigated spectrum.

Figure 11. RUS spectrum for the main vibrational modes:(a) extensional mode – 122 kHz; (b) extensional mode – 190 kHz; (c) flexural mode – 197 kHz; (d) flexural mode – 200kHz.

The resonance frequencies obtained by simulations correspond to those experimentally obtained.
The inhomogeneities inside the material can be identified from the resonance spectrum, by changes of the resonance frequency, splitting of peaks/increasing of their width, and modifications in amplitude. In order to determinate, in the basis of experimentally measured resonance spectra, of the main elastic properties of the sample, the inversion of data was used, implying conjugate gradient method [22], minimizing the objective function.

\[
F = \sum_i w_i \left( f_i^{(p)} - f_i^{(m)} \right)^2
\]  

Where \( f_i^{(p)} \) are the computed frequencies, \( f_i^{(m)} \) are the measured frequencies, \( w_i \) are the weights, which characterize the confidence we have in the measurements. Using Matlab 2014 and because the number of peaks corresponding to the frequencies is small, the data inversion could be achieved for determination of elastic modulus and shear modulus. The variation of element concentrations from sample modifies the position of the peaks from spectrum as well as their amplitude. The presence of other discontinuities leads to modification of the signal phases. Figure 12 presents the resonance spectrum between the 120 kHz and 200 kHz, where d1 to d4 are cube’s diagonals.

The resonance spectrum is specific for each object, comparing the resonance spectrum for two elastic objects, a difference between the elastic parameters of each object can be observed. For the studied sample, the cube having 10 mm sides, 4.467 g mass, the shape of the spectrum, depends on the position of discontinuities with respect to diagonal contact direction of transducers (polarization orthogonal or parallel to discontinuity).

![Figure12. Resonance ultrasound spectra of the sample.](image)

6. Conclusions

The compression test results may be concluded by an ascertainment that compressive strength of Ti alloy sample is higher than 900 MPa. Never the less, its internal cracking manifested by accompanying AE activity begins at the stress about 300 MPa and more rapid cracking starts at stress about 600 MPa, which may be considered as an application limit. AE at higher compressive loading means warning before the catastrophic failure of a component. The frequency information and other parameters from AE data are useful for identification of failure mechanism.
RUS has been employed to detect the presence of discontinuities at surface/inside the sample. In both situations, the results are different beside the material without discontinuity. For the studied sample with dimensional ratio around 1, the interpretation is favorable because the torsion modulus is smallest, well separated by the rest for $\nu > 0$, allowing the determination of shear modulus. In the case in which the elements are incorrect alloyed, with a smaller density than the prescribed one, and the elastic and shear modulus are smaller, important modification in the spectrum shape and resonance frequencies appear. The changing in resonance frequencies towards elements concentrations and the dependency of vibration modes by the alloy’s base element will be following.

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