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EVALUATION OF ELASTIC CONSTANTS OF MATERIALS USING THE FREQUENCY SPECTRUM

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ABSTRACT

The characterization of materials made with the support of non-destructive techniques has great importance in industrial applications. The ultrasonic techniques are distinguished by good resolution to measure small variations of wave velocities as a result of changes in the character suffered by a particular material. In general these ultrasonic techniques are studied in the time domain, which represents an experimental difficulties when thin materials are analyzed, as well as to attenuate the ultrasonic signal drastically. An ultrasonic technique that uses the frequency domain is used in this study aiming to provide good time measurements to calculate the elastic constants of the first order in an aluminum alloy 6351. With the aid of a statistical approach was possible to have good results of tests performed when compared by a time domain technique already well explored in Ultrasound works produced in the Nuclear Engineering Institute Laboratory (LABUS / IEN) and also presented in most of the package, in good agreement with the theoretical model established in literature and used to validate the experiment, which was found in the results with good approximation. The relevance of this work in the nuclear area is associated with the interest to know the mechanical properties of structural components of the nuclear industry, which is currently studied as a rule, resorting to the computer simulations or previously during the operation of the system.

Key-words: 1. Frequency domain; 2.elastic constants; 3. Time domain; 4. stress problem

1. INTRODUCTION

The objective of this paper is compare elastic constant values of traditional literature [1] and obtained speeds of longitudinal and transverse ultrasonic waves in a 6351 aluminum alloy tested on physical model [2]. As non-destructive technique, ultrasound is extremely relevant in the nuclear and industrial area in general, it promotes capacity dimensional evaluation and presence of discontinuities.

the ultrasonic technique for measuring time covered in this work was first observed [3] to be able to recognize qualitatively material with an advantage of being unrestricted for large attenuation or thin, which would imply difficulty in the acquisition of at least two echoes to perform the measurement by cross-correlation, compared with the applied methodology , which uses the frequency domain with FFT. this way, this work is also proposing a form of validation by comparing two time measurement techniques, which in stress analysis work [4], [5] has well presented results both qualitatively and quantitatively. Currently responses of time measurements (and therefore speed) of ultrasonic waves path are obtained by techniques in the time domain, and the aim is to techniques with frequency domain could become an interesting option in the study of ultrasonic phenomena

Based in literature references we will be obtained elastic modulus, shear modulus and Poisson's modulus by calculation on the basis of transverse and longitudinal velocities of ultrasonic waves of two different techniques and compared with values tabulated in the literature.

2. MATERIALS AND METHODS

2.1. Considerations about the tested material

The aluminum block was constructed with 70 mm edges, which favored the positioning of the transducers in engagement with the block, by reference marking drawn on the geometric centers of the faces, as seen in Figure (1).

The choice of aluminum is justified because of the versatility of metal and their alloys and also to fulfill an additional purpose of illustrating not only the steel alloys have satisfactory mechanical properties for use in nuclear power plant designs.

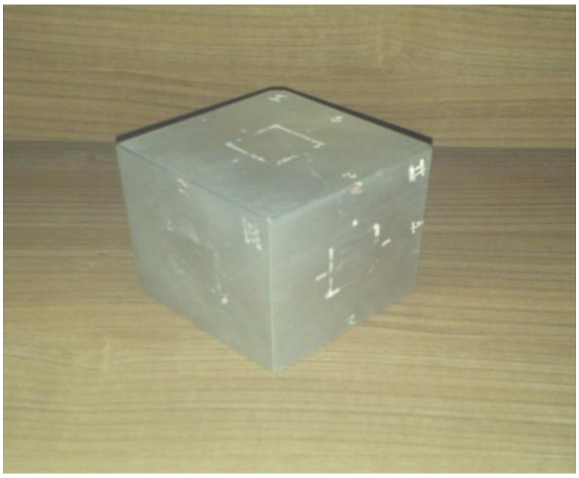


Figure 1: Block standard aluminum, size 70x70 mm.

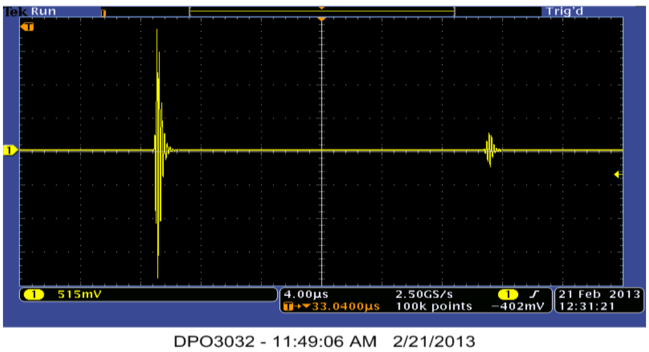
2.2. Density determination.

It was used a 1000 ml capacity Becker, digital scale precision mark Shimadzu 0,001g capacity 6200g, water and the aluminum block. The process was to initially weigh the materials individually to obtain reference values. After checking the block was submerged in Becker with known water volume. The difference between the volume of water displaced in Becker and the initial volume was used as an experimental result of the volume occupied by the aluminum block.

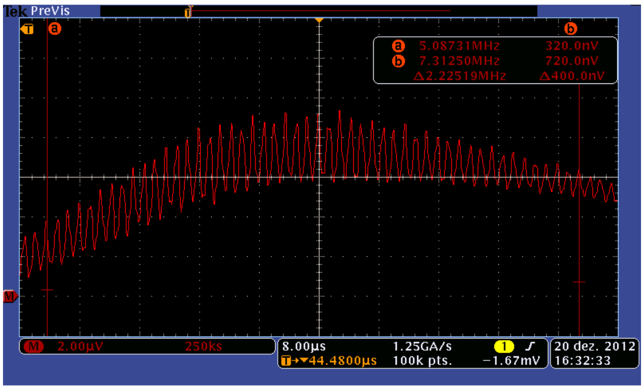
2.3 . Considerations on the techniques used time measure

The main motivation of the experiment was to compare two techniques of ultrasonic waves travel time measure inserted into an aluminum block. To this end, in a first step, these waves time measurements were taken (longitudinal and shear) in the directions of three axes of symmetry block reiterating that the measurement time is a primary way to calculate the travel speed of the ultrasonic waves , used as inputs in physical models to obtain the elastic constant. The techniques used were those called the cross-correlation technique, which consists of processing the ultrasonic signal based on the picture time (second) v.10 CHRONOS by software, and the technique of frequency, Figure (2b), where in the ultrasonic signal based on the time is transformed (FFT) and is mathematically converted frequency to time, that is, in this technique the distance between the peaks, corresponding to a frequency range, to calculate the inverse of this value (1/f) obtained if the value of travel time. An advantage that can be seen is that the time base have two echoes.

For this reason, after repeated measurements, the cross-correlation shown an important aid. Now the signal in the frequency base have about 50 peaks, which can calculate the travel time by the inverse of the average frequency ranges.



(a)



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(b)

Figure 2: (a) cross-correlation; (b) frequency technique.

By the way signals are present, it can be inferred that the attenuation of the ultrasonic beam in the material is essential for a good reading and interpreting the course of time, since they have only two echoes obtained with good resolution even when applied cross correlation .

The same is not true of the signal transformed by the FFT, which can calculate the journey time with an average involving more frequency peak, namely in each signal there is a "population" embedded greater travel times in the frequency spectrum generated by the FFT.

2.4. Measures of times ultrasonic wave course in aluminium cube

The travel times of the ultrasonic waves were obtained using an experimental apparatus as illustrated in Figure 3, at Qualival's Mechanical testing Laboratory common to all stages, which are listed below:

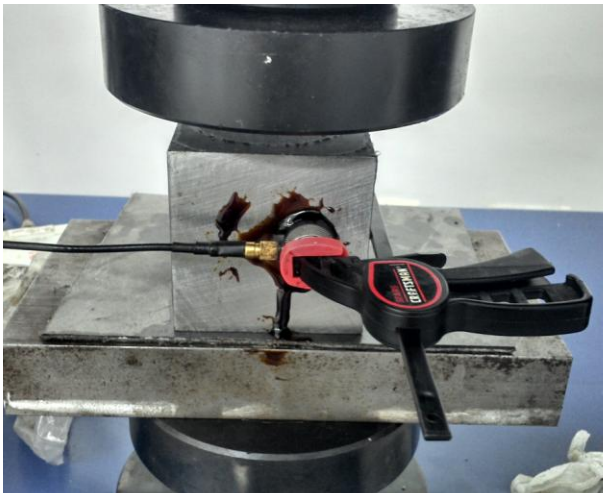
- Resolution Oscilloscope 300MHz, Tektronix brand, DPO-3032 model;
- OpenChoice Tek software that communicates the oscilloscope and the computer;
- Chronos Software v.10;
- Apparatus ultrasonic wave generator, brand Panametrics, model xxx;
- longitudinal ultrasonic wave transducer, Panametrics brand, model A109S;
- transverse ultrasonic wave transducer, Panametrics brand, model V155;
- Signal Filter;
- Computer;
- Digital Thermometer, TESTO brand, model 177-T3;
- Wiring to specific union of elements;

Figure 3: Experimental Apparatus - Mechanical Testing Laboratory (Qualival).

Specifically on the transducers (longitudinal and transverse), these are similar in appearance, but with the difference that the longitudinal wave transducer provides polarized wavefronts, ie with well-defined direction of vibration. For this reason times given were taken in two orthogonal directions. In the case of longitudinal wave, because it is compression wave has spherical symmetry, not interfering with the position or orientation of the transducer corresponding to this wave.

Figures 4a and 4b below show the head positioning plugs of transverse wave data.

(a)



(b)

Figure 4: Polarization directions (a) direction of polarization 1 (b) direction of polarization 2

3.RESULTS AND DISCUSSION

A physical model found in the literature was the basis for using the measured travel times of the ultrasonic waves [2]. Below are the equations corresponding to the physical model which will be used:

$$E = \rho VT^2 \frac{\left[4-3\left(\frac{VL}{VT}\right)^2\right]}{\left[1-\left(\frac{VL}{VT}\right)^2\right]} \quad (1)$$

$$G = \rho VT^2 \quad (2)$$

$$v = \frac{\left[2-\left(\frac{VL}{VT}\right)^2\right]}{\left[2-2\left(\frac{VL}{VT}\right)^2\right]} \quad (3)$$

where:

E - elastic modulus

G - shear modulus

ν - Poisson module

ρ - density of the analyzed material (aluminum block);

v_L - speed longitudinal ultrasonic wave; and

v_T - speed transverse ultrasonic wave

Use of this model was a way to check the validity of the data collected. To complete all quantities composing the equations it was necessary to measure the distance traveled by the ultrasound waves in one direction (axis) of aluminum figure block 1, the block density (as seen at 2.2), and the time values are taken from the route of longitudinal ultrasonic waves (since the time measurements of shear waves had already been obtained), as shown in Table 1.

The travel times of longitudinal waves were obtained with the help of Chronos v.10 software in amount of 30 measures, set this to be considered for calculating the average value in the presentation of results.

Table 1: Average Times longitudinal wave path.

Position	Face I	Face II	Face III
Average Times	2,20E+00	2,20E+00	2,20E+00

From the data collected from travel times of longitudinal and transverse ultrasonic waves, and the supplementary experimental measurements, it could be verified the validity of the equations that describe the chosen physical melo. The results calculated by the two techniques (cross-correlation and FFT) are shown in Table 2, and can be compared with this values.

The data set is considered as referring to the face II, taking into account the two directions of polarization, and no further charging. It is important to mention that at this stage of the experiment measurements were taken on three sides, namely along the three axes of symmetry of the aluminum block, ie the faces I and III. Face II was chosen for having presented, in general, the smallest variations in the sets of measures, which was considered as an important aspect, since the main objective is to analyze the variations resulting from voltages applied to the load.

It is noteworthy that they are used transverse wave velocity values in the calculations of mechanical properties, there was a concern to solve the two equations times, taking into account two orthogonal directions of polarization of these waves, which provided us with additional results that valued the compared with the tabulated values.

Table 2: Results of physical properties obtained with the method of cross-correlation and FFT compared with the literature.

Cross Correlation				FFT		
ΔS_{US}(m)	t D1(s)	t D2(s)	t_L(s)	t D1(s)	t D2(s)	t_L(s)
	4,43E-02	4,46E-02	2,20E-02	4,41E-02	4,44E-02	2,20E-02
7,00E+01	V_T D1(m/s)	V_T D2(m/s)	V_L(m/s)	V_T D1(m/s)	V_T D2(m/s)	V_L(m/s)
	3,16E+06	3,14E+06	6,35E+06	3,17E+06	3,16E+06	6,35E+06
	E_1 (Pa)	E_2 (Pa)	E_{LIT} (Pa)	E_1(Pa)	E_2(Pa)	E_{LIT}(Pa)
ρ(kg/m^3)	6,71E+13	6,64E+13	7,00E+13	6,75E+13	6,70E+13	7,00E+13
	G_1 (Pa)	G_2 (Pa)	G_{LIT} (Pa)	G_1(Pa)	G_2(Pa)	G_{LIT}(Pa)
2,51E+06	2,51E+13	2,48E+13	2,55E+13	2,53E+13	2,51E+13	2,55E+13
	ν_1	ν_2	ν_{LIT}	ν_1	ν_2	ν_{LIT}
	3,36E+02	3,38E+02	3,30E+02	3,34E+02	3,36E+02	3,30E+02

Where:

ΔSUS - distance traveled by the ultrasonic wave on the block;

t D1 - cross ultrasonic wave travel time in the direction of polarization 1;

t D2 - travel time cross ultrasonic wave in the direction of polarization 2;

tL - travel time of longitudinal ultrasonic wave;

VT D1 (speed transverse ultrasonic wave in the direction of polarization 1;

VT D2 - speed transverse ultrasonic wave in the direction of polarization 2;

VL - speed longitudinal ultrasonic wave;

E1 - yield strength calculated on the value of the transverse ultrasonic wave speed in the direction of polarization 1;

E2 - yield strength calculated on the value of the transverse ultrasonic wave speed in the direction of polarization 2;

ELIT - literature yield strength;

G1 - shear modulus value calculated velocity of ultrasonic transverse wave in the first polarization direction;

G2 - shear modulus value calculated velocity of ultrasonic transverse wave in the second polarization direction;

Glit - shear modulus literature;

v1 - Poisson coefficient calculated on the value of the transverse ultrasonic wave speed in the direction of polarization 1;

v2 - Poisson coefficient calculated on the value of the transverse ultrasonic wave speed in the direction of polarization 2; and

vLIT - Poisson's ratio literature

From the results presented in Table 2 it is suggested similarity of data taken from travel times of the ultrasonic waves in the aluminum block by the two techniques under study with the values found in the classic literature.

The similarity of the results is assumed because the referenced literature cite the league generically aluminum, which is not necessarily identical to 6351 alloy used in this work. Moreover, it is not the power of said manufacturing process in the literature, which is highly relevant for the study of stress. Therefore, the comparison can be assumed to be good for continued work until the findings.

The results were produced and promoted stabilities similar for both techniques, ie, the FFT technique can be considered analogous to the technique of cross-correlation in this work.

This confirms the possibility of calculating the elastic constants determined nondestructively material, ie, without the need for removal of specimen for the execution of a mechanical test, as is usually done.

4. CONCLUSION

The suggested method has the possibility of being made efficiently measured, for example, a material (or part, component or structural) where removal of a part for construction of the test body unavailability account the original material would not be possible.

The techniques of cross-correlation and FFT were able to provide values of the elastic constants of the first order in agreement with literature values, which supports the validity of the FFT technique to produce measurements similar to those found by the technique of cross-correlation.

From the experimental point of view and perspectives for practical applications in the nuclear industry, especially in plants already in operation, the techniques can serve as an aid in work where you can not get a specimen for lifting the elastic constants and the changes over the same time in relation to the sustained efforts by structures that need to be inspected, confirming the advantage of non-destructive.

From the point of view of possible materials to be studied under this approach, the FFT technique has advantages over the use of the ultrasonic signal in the time domain because the number frequency peaks, larger than the echoes, the possibility of promoting measures attenuators much or too thin, materials which generally is more complicated to establish a ultrasonic wave to be read in the time domain, due to the absence of the return echo (the attenuation material) as well excessive proximity or superposition of echoes (in very thin materials), which makes the reading of the travel time, even with software support.

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