Ultrasonic Evaluation of a Beta-C Titanium Alloy

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Beta-C Titanium Alloys are widely used in aerospace industry. Components of such alloy need to be inspected due to in-service conditions and ultrasonic technique can provide a thorough evaluation. In order to understand the behavior of ultrasonic waves in these media, a set of low power transducers, with center frequencies between 1.5 and 10 MHz, were used to determine the wave velocity, attenuation and broadening of ultrasonic pulses traversing Ti-3Al-8V-6Cr-4Zr-4Mo plates. Spectral analysis performed on the returned pulses provided the necessary information to understand a pulse broadening observed at low frequencies. The ultrasonic pulses were generated by a modern ultrasound field equipment, whereas the spectral analysis was performed by a computer connected to a fast oscilloscope that was capturing the signal returning from the plates. The experimental data is presented as well as a discussion on the effects of the interaction of longitudinal ultrasonic waves in the alloy.

Keywords: Pulse-echo technique, β-titanium alloys, ultrasonic velocity, ultrasonic attenuation, spectral response.

1 Introduction

Ultrasonic nondestructive testing is a versatile technique that can be applied for analysis of several materials. This is useful for characterization of microstructures, assessment of defects, and evaluation of material properties. By virtue of this, ultrasonic measurements during fabrication and heat treatment allow ensuring the absence of unacceptable discontinuities and the presence of a particular microstructure with desired properties [1].

The interaction of ultrasound with microstructure is important for many material problems. Attenuation and backscattering reduce the detectability of flaws, especially in materials with coarse grains or complex microstructures such as titanium alloys. Besides, quantification of these wave propagation properties provide information about the microstructure that can be used in materials characterization studies, e.g. nondestructive determination of grain size [2].

Wave propagation velocity is another key factor in ultrasonic characterization, which in conjunction with attenuation can provide important tools in understanding, the inspectability of materials [3, 4]; for example, it can provide information about crystallographic texture.

Since conventional ultrasound equipments do not give detailed information on the interaction between the pulse and the inspected material, a signal postprocessing is necessary in order to determine the spectral response and hence, better understand the ultrasonic behavior of the material [5].

Main application of Beta-C titanium alloys have been focused in aircrafts manufacture which require sheets of these ones for their structure and skin. Therefore, looking for improve the properties of these alloys and the inspection procedures of components along their life in service, have kept the attention in their study.

In this research, specimens of Beta-C titanium alloy have been used with the purpose of evaluate the behavior of longitudinal ultrasonic waves in such material. Ultrasonic measurements have been carried out by means of the pulse-echo technique, using contact type probes with center frequencies ranging from 1.5 to 10 MHz and the spectrum of returned pulses was analyzed.

2 Experimental procedure

A plate of Ti-3Al-8V-6Cr-4Zr-4Mo alloy with the dimensions shown in Figure 1 has been employed for carry out the study.

![Figure 1: Dimensions of plate specimen.](image_url)

Nominal chemical composition of the acquired material is indicated in Table 1. A sample of this one was cut and metallographically prepared in its extrusion direction and cross-section with the objective of evaluate the microstructure of the titanium alloy. Both sections were observed by optical microscopy using an image analyzer.

### Table 1: Chemical composition of the Beta-C titanium alloy.

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>V</th>
<th>Cr</th>
<th>Mo</th>
<th>Zr</th>
<th>Fe</th>
<th>Other</th>
<th>Ti</th>
</tr>
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<tbody>
<tr>
<td>Min (wt. %)</td>
<td>3.0</td>
<td>7.5</td>
<td>5.5</td>
<td>3.5</td>
<td>3.5</td>
<td>-</td>
<td>-</td>
<td>Bal</td>
</tr>
<tr>
<td>Max (wt. %)</td>
<td>4.0</td>
<td>8.5</td>
<td>6.5</td>
<td>4.5</td>
<td>4.5</td>
<td>0.3</td>
<td>0.4</td>
<td>Bal</td>
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</tbody>
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The titanium alloy has been previously solution treated...
and aged.

Ultrasonic attenuation and velocity were simultaneously measured on each sample using the conventional pulse-echo method. Thus, constant force was applied to the probe against the specimen surface so as to have a constant thickness layer of coupling, specifically glycerin, at the interface. Time-of-Flight (TOF) values were measured using a Krautkramer USN 52L equipment and a Tektronix TSD 3000 oscilloscope, for frequencies of 1.5, 2.25, 5, 7.5, 10.

Longitudinal ultrasonic velocity of the wave was estimated in base to TOF values for each probe.

Ultrasonic velocities were calculated by two ways. The first procedure, indentified as Method A, has been based in the widely used expression:

\[
\text{Velocity (m/s)} = \frac{2 \times \text{thickness (m)}}{\text{Time (s)}}
\]  

Another procedure, identified as Method B, consisted in the application of the Pulse Superposition Method, according to ASTM standard E494 [6]. This method uses a radio frequency (RF) pulse applied to the material at intervals approximately equal to the round-trip delay time of waves across the specimen. Some pulses are omitted periodically to observe the superimposed echoes just after the last applied pulse.

The method for measurement attenuation was based on the comparison of the spectral components of two successive echoes, as proposed by Kumar et al. [7]. Then the ultrasonic attenuation coefficient \( \alpha \) was calculated by means of the equation:

\[
\alpha (\text{dB/mm}) = 20 \cdot \log \left( \frac{S_1}{S_2} \right) \frac{2 \times \text{thickness (mm)}}{}
\]  

where \( S_1 \) and \( S_2 \) are, respectively, the first and second backwall echoes.

Also, the graphs corresponding to relative loss of amplitude were obtained for each frequency, which gives a qualitative idea of the attenuation of the signals.

Transmitted signals, for all cases were detected and recorded in the digital oscilloscope TDS 3000 Tektronix, then downloaded to a computer where the fast Fourier transform (FFT) of the time domain signals was performed, using MATLAB 6.5. The signal was digitized at 100 MHz and averaged for about 25 signals. These frequency spectrums were used for analyze the behavior of the pulse at each frequency.

3 Results and discussion

The microstructure of the two sections evaluated on a Beta-C alloy sample can be appraised in the following figure (Figure 2).

![Figure 2: Optical micrographs of the Beta-C titanium alloy microstructure, in its a) extrusion direction and b) cross-section.](image)

It can be observed that the microstructure of the material is constituted by metastable beta with precipitated alpha mainly distributed throughout grain boundaries. Also should be noted that the microstructure shows a clear similarity with bainite in steels.

Results concerning the wave velocity are shown in Figure 3. These were obtained employing each transducer and both methods (A, B) previously explained. The mean value of velocity obtained by Methods A and B, were 6033.8 m/s and 6038 m/s, respectively.

![Figure 3: Change in the longitudinal ultrasonic velocity with the probe frequency.](image)
Insignificant variation of the ultrasonic velocity as function of the transducer frequency allows inferring that the titanium alloy is a nondispersive media for ultrasound in the range of frequencies considered. Mathematically this can be explained in terms of the following expression:

\[ \lambda \cdot f = C_s \]  

where \( f \) is the wave frequency, \( \lambda \) is the wavelength and \( C_s \) is a constant value that represents the ultrasonic velocity. The material fulfilled the above relation, so that, the ultrasonic velocity does not change at different frequencies, i.e. is nondispersive.

About relative attenuation of the pulses, the Figure 4 contains the values found for the probes of 1.5, 2.25, 5, 7.5 and 10 MHz. Differences of amplitude are due to the range of frequencies evaluated.

Figure 5: Change in the attenuation coefficient with the probe frequency.

Figure 6: RF signal of the 1.5 MHz probe on the Beta-C Ti alloy (time domain of the first backwall echo).

Figure 7: Fourier spectrum of the first backwall echo corresponding to 1.5 MHz probe.

RF signal of the 5 MHz probe can be appreciated in the Figure 8. This pulse has greater attenuation than obtained for 1.5 MHz, but on the other hand is better defined.
Figure 8: RF signal of the 5 MHz probe on the Beta-C Ti alloy (time domain of the first backwall echo).

Figure 9 shows FFT of the 5 MHz signal, whose bandwidth is smaller than resultant for 1.5 MHz and frequency of highest amplitude is approximately 4.8 MHz.

Figure 9: Fourier spectrum of the first backwall echo corresponding to 5 MHz probe.

The RF signal and frequency spectrum found for 7.5 MHz are respectively presented in Figures 10 and 11.

Figure 10: RF signal of the 7.5 MHz probe on the Beta-C Ti alloy (time domain of the first backwall echo).

Figure 11: Fourier spectrum of the first backwall echo corresponding to 7.5 MHz probe.

Consistent with the relative attenuation of its ultrasonic pulse, 7.5 MHz signal has even smaller amplitude than for 5 MHz. Its frequency of highest amplitude is around 7.6 MHz. Due to the considerable distortion and scatter that exhibits, this could hide some defects during certain inspection procedures.

The Figures 6, 8 and 10 show complete patterns of the ultrasonic echo for the Beta-C titanium alloy, at 1.5, 5 and 7.5 MHz, respectively. It can be seen that the attenuation varies strongly with the frequency, but the transit time does not show a significant variation. Spectral analysis of frequencies allows characterize the behavior of each transducer with the specimen, showing the frequencies with better resolution for development of inspection procedures.

4 Conclusions

Ultrasonic velocity and attenuation measurements, as well as spectral analysis of the corresponding first backwall echoes have been used for the characterization of Ti-3Al-8V-6Cr-4Zr-4Mo alloy (beta-c).

After consider a couple of pulse-echo methods for measuring ultrasonic velocity, has been found that its mean value is about 6035 m/s for considered material. Small difference between both methods implies its accuracy for the estimation of the parameter. Furthermore, reduced influence of the frequency makes the titanium alloy a nondispersive media.

Results of attenuation measurements allow presuming that titanium alloy tends to act as a low pass filter, attenuating and scattering the higher frequency components of ultrasonic waves.

Although the frequency of 1.5 MHz undergoes the lowest attenuation, 5 MHz signal has a less distortionated pulse on the time domain and is independent of frequency components associated to the bandwidth. On this basis, is possible to suggest the use of 5 MHz as
inspection frequency for the Beta-C titanium alloy.

References


