

Fórum Técnico Deterioração pelo Hidrogênio.

Técnicas para Detecção de Danos pelo Hidrogênio

JMA Rebello

Universidade Federal do Rio de Janeiro





Main Objectives

The objective of this work is to present some techniques for the ultrasonic detection of hydrogen cracks.



Ultrasonic Spectroscopy

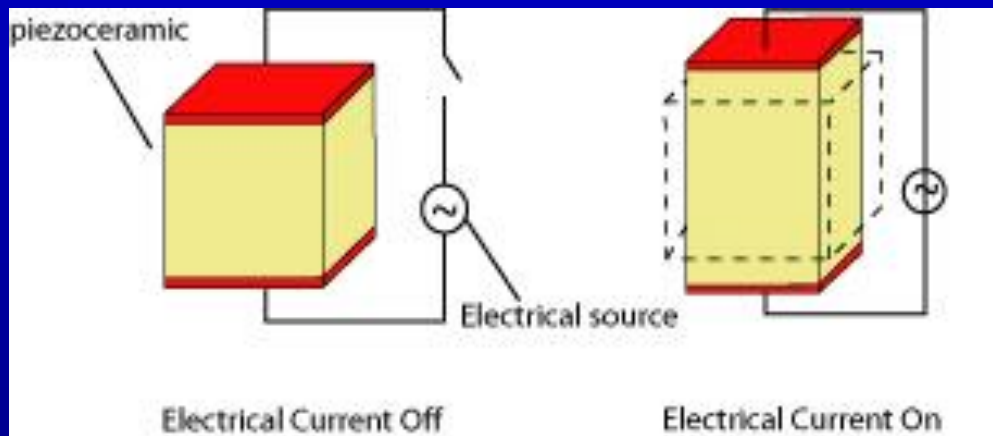
The primary use of ultrasonic spectroscopy is to evaluate the effect of changing wavelength during UT beam and materials interaction.

It allows two main important issues to be attained:

- To increase resolution of crack detection and dimensioning,
- Materials characterization.



Ultrasonic





Ultrasonic Inspection

Probe



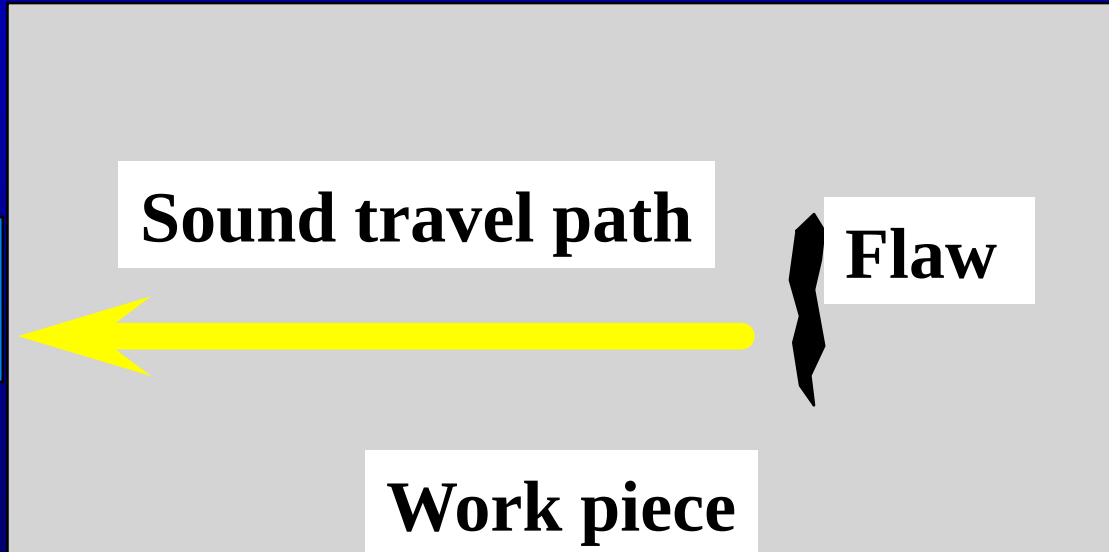
Sound travel path



Flaw

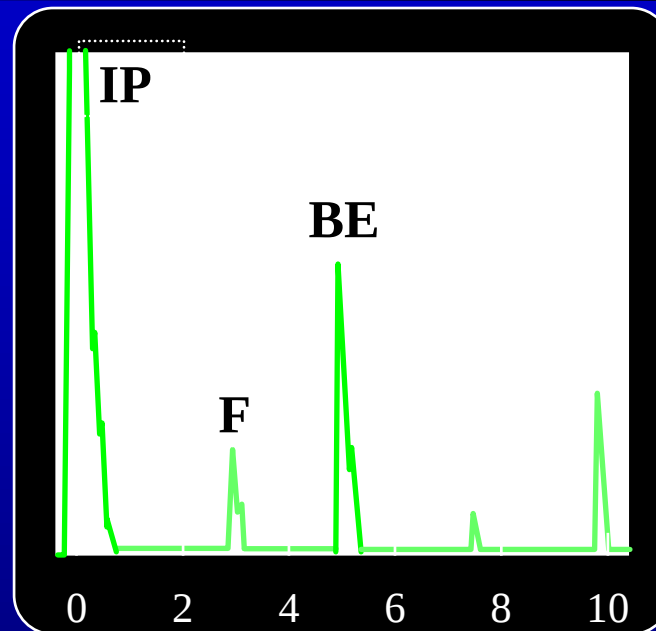
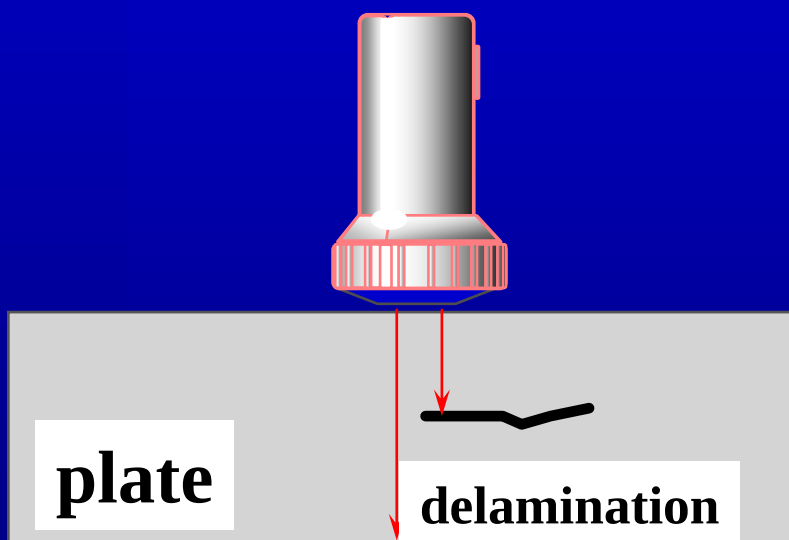


Work piece





Ultrasonic Inspection



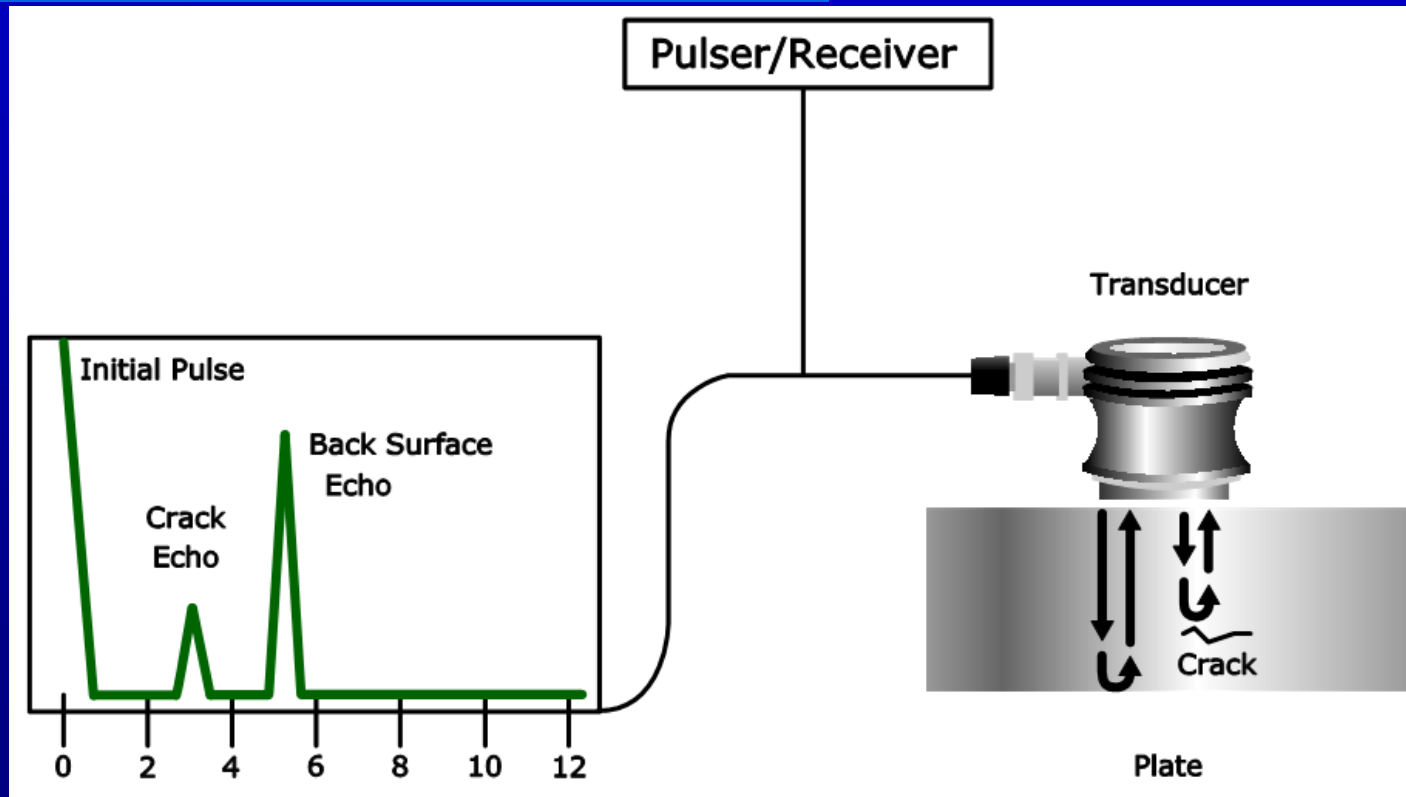
IP = Initial pulse

F = Flaw

BE = Backwall echo

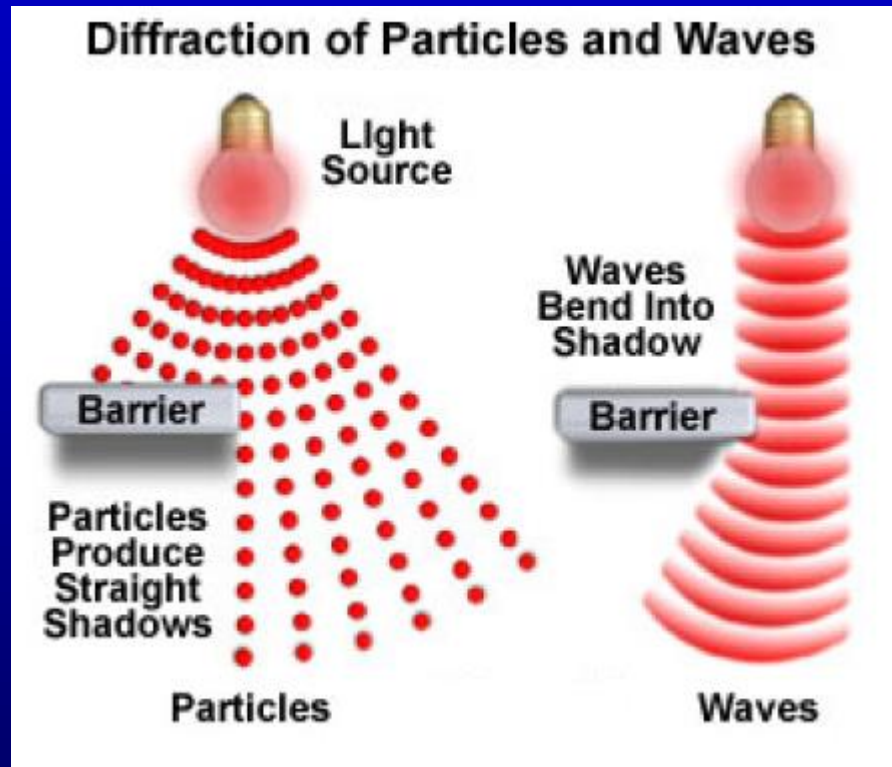


Ultrasonic Inspection



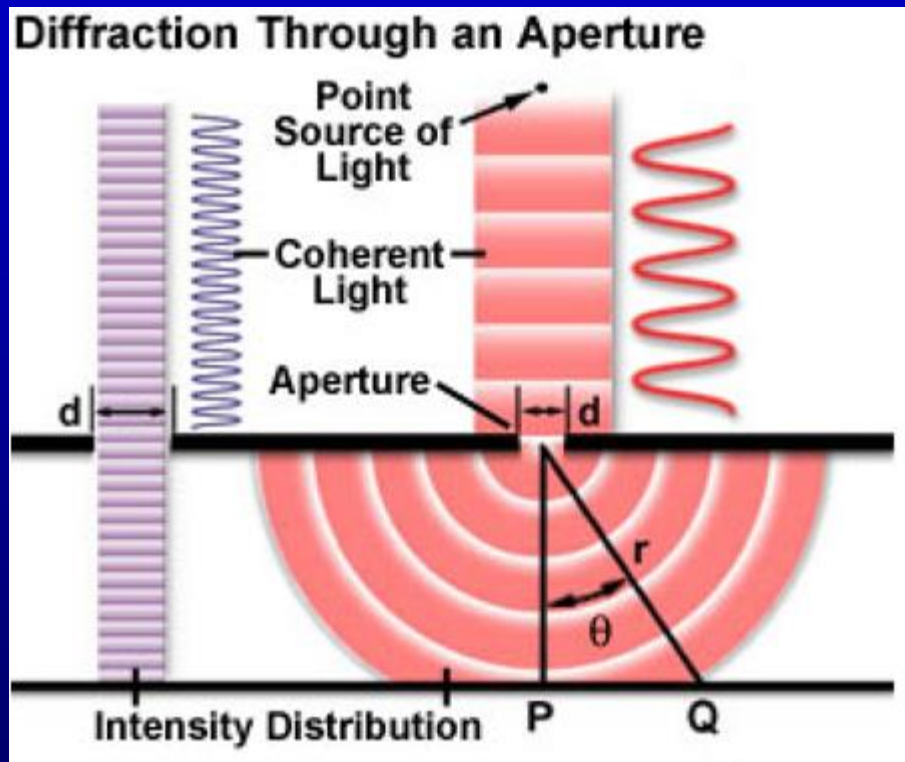


Diffraction



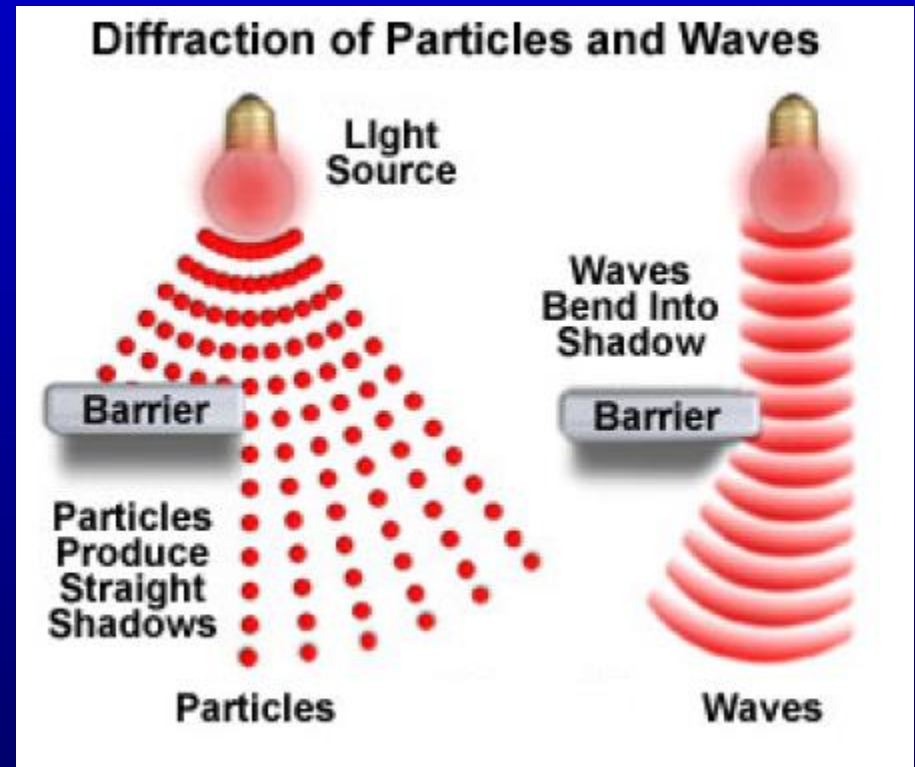
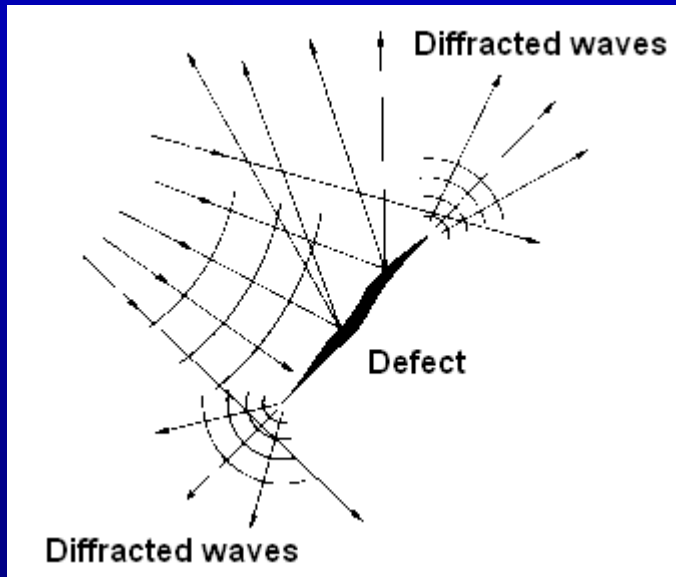


Diffraction



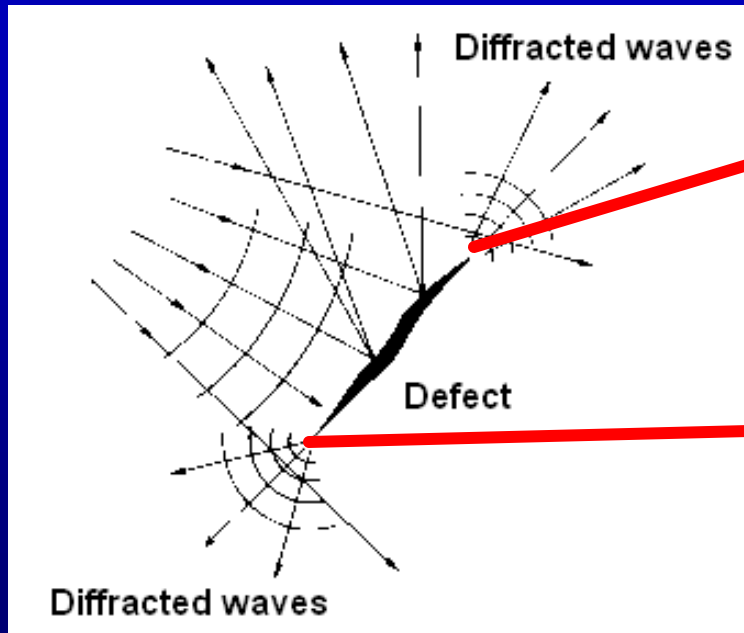


Diffraction

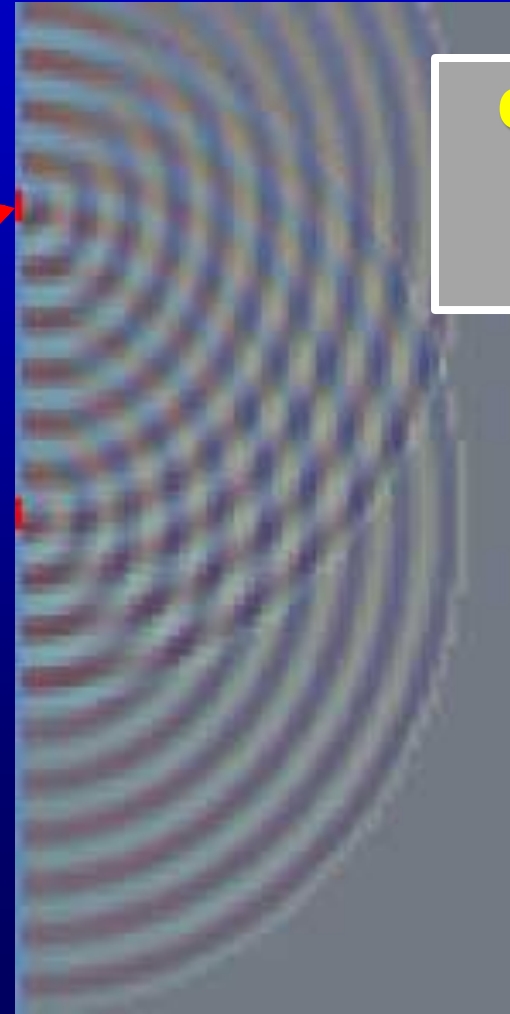




Diffraction



**Como detectar
essas ondas
difratadas?**





Ultrasonics Spectroscopy

The ultrasonic spectral analysis is a frequency domain evaluation of ultrasonic signals and has been successfully applied to materials characterization in many cases . When an ultrasonic pulse propagates through a material, it interacts with the microstructural components (grains, inclusions, porosity, microcracks, etc.), this interaction being quantitatively related to their size and geometry as well as the incident wave length .



Examples of UT Microstructure Interaction

**UT wave propagation in
a homogeneous media**



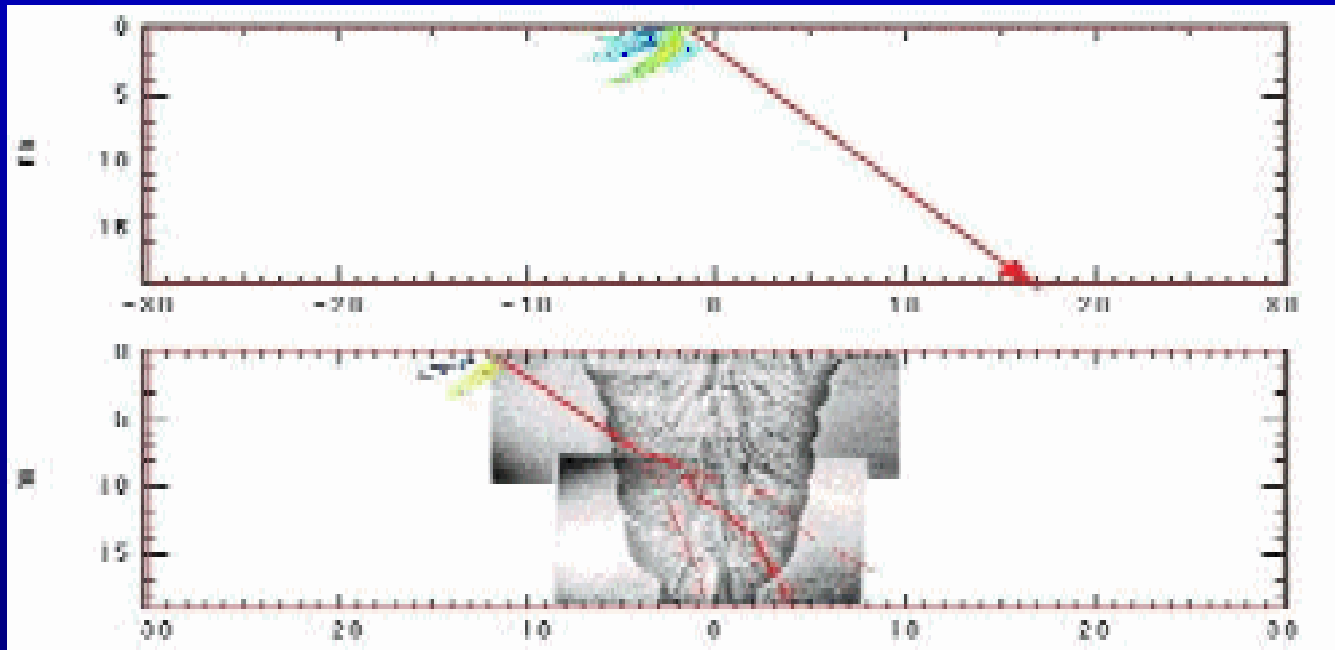
UT wave reflection in a hole



**Credits: Japan Society of Maintenology,
eJournal of Advanced Maintenance, Vol.2,
No.2, NT25**



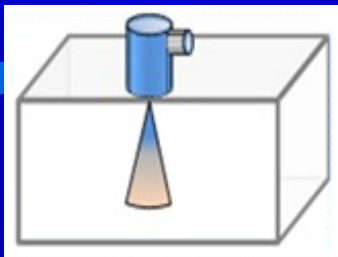
Examples of UT Microstructure Interaction



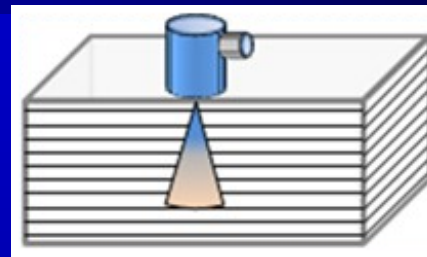
Credits: Japan Society of Maintenology,
eJournal of Advanced Maintenance, Vol.2,
No.2, NT25



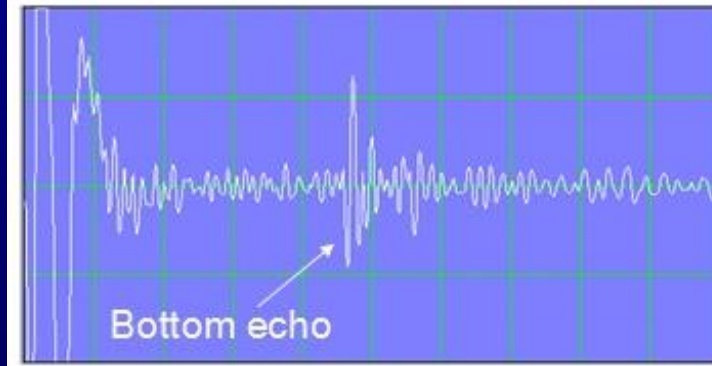
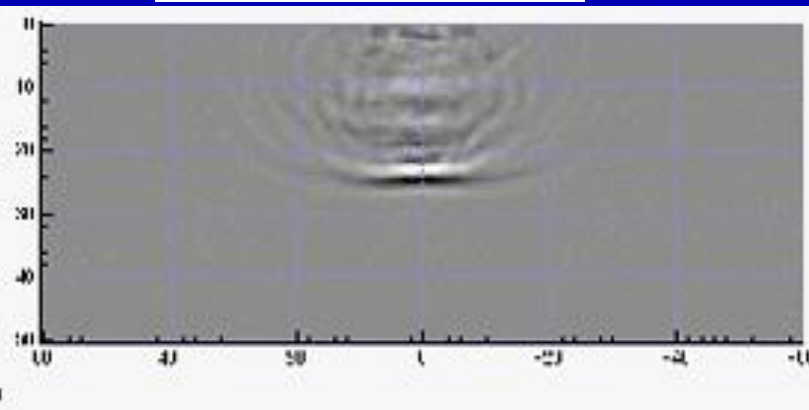
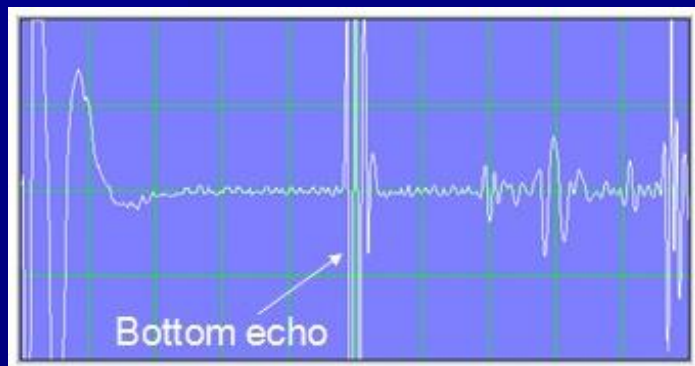
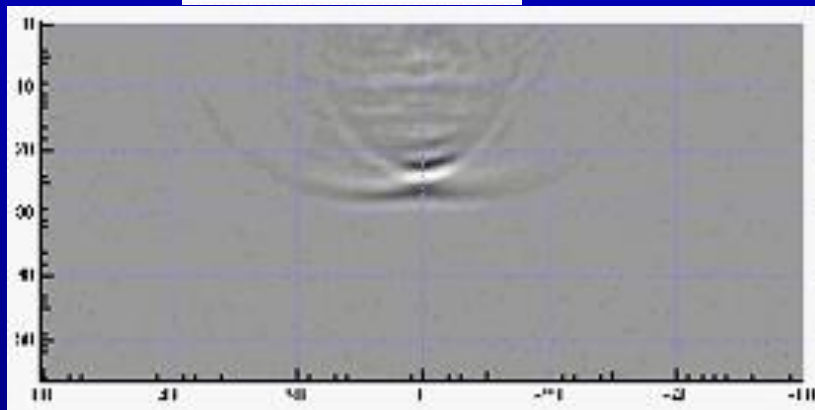
Examples of UT Microstructure Interaction



SUS316
Base metal



Alloy 600 type
Buttering





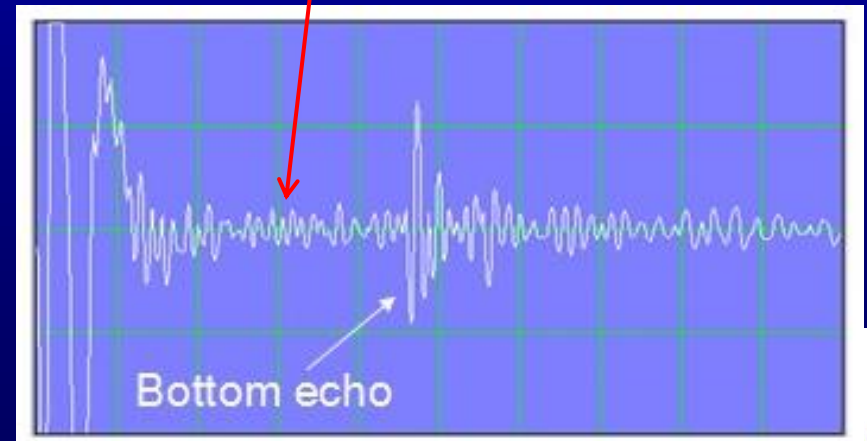
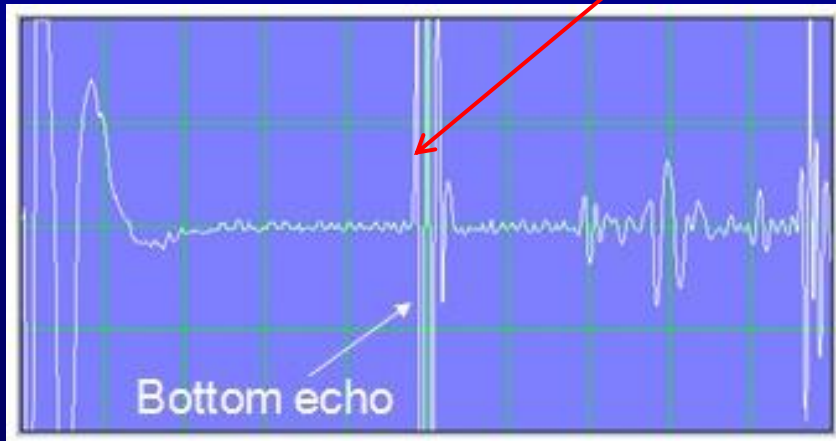
Examples of UT Microstructure Interaction

This interaction could be evaluated as a change in the frequency distribution of the transmitted pulse (echo spectral analysis) or of the scattered signal (e.g. backscatter spectral analysis). The ultrasonic spectral analysis of echoes has been applied to non destructive characterization of materials since the end of the 1960s



Examples of UT Microstructure Interaction

This interaction could be evaluated as a change in the frequency distribution of the **transmitted** pulse (echo spectral analysis) or of the **scattered** signal (e.g. backscatter spectral analysis).





Microstructure Interaction Fast Fourier Transform

- Generalization of Fourier Series for infinite domains

$$x(t) = \int_{-\infty}^{\infty} \mathcal{F}(f) e^{-2\pi i f t} df$$

$$\mathcal{F}(f) = \int_{-\infty}^{\infty} x(t) e^{2\pi i f t} dt$$

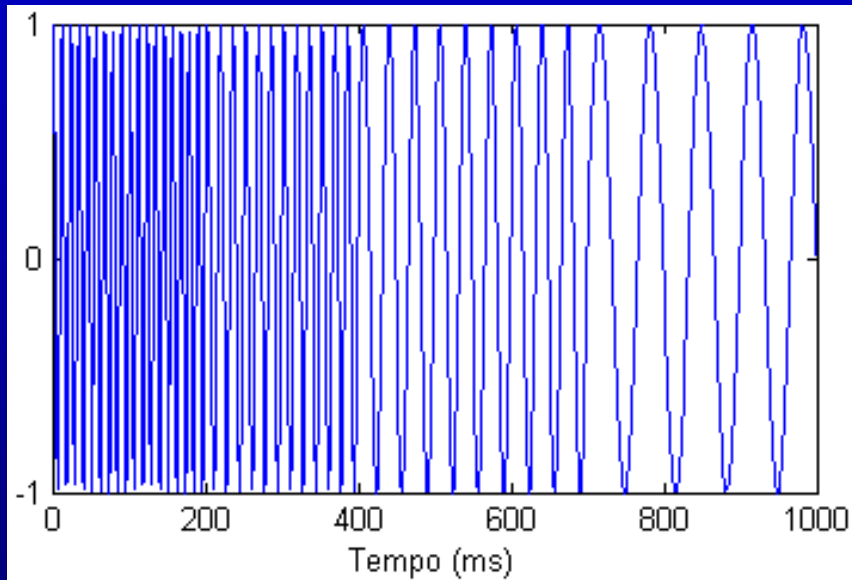
- Can represent continuous, aperiodic signals
- Continuous frequency spectrum

**Transformada de
Fourier dos Sinais**

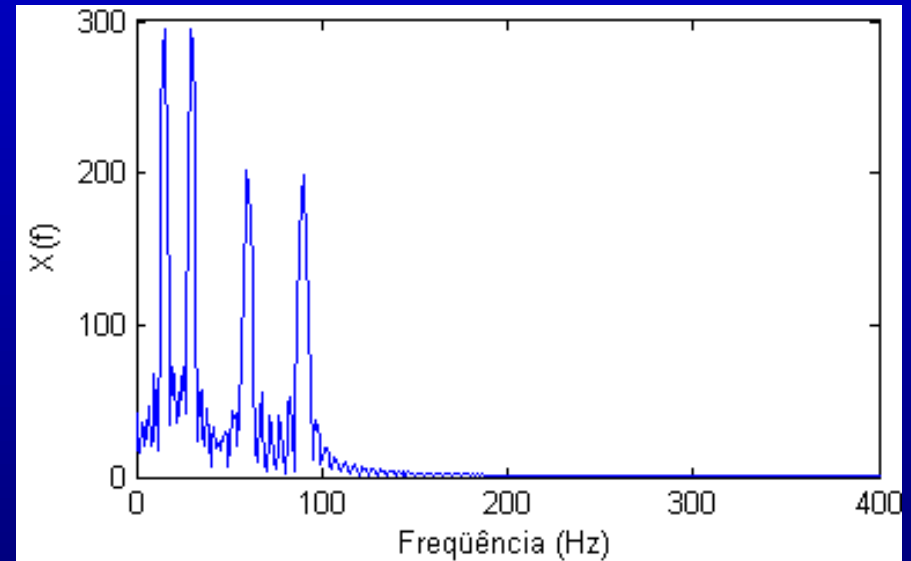


Microstructure Interaction

Fast Fourier Transform



Time Domain UT Signal



Frequency Domain



Examples of UT Microstructure Interaction

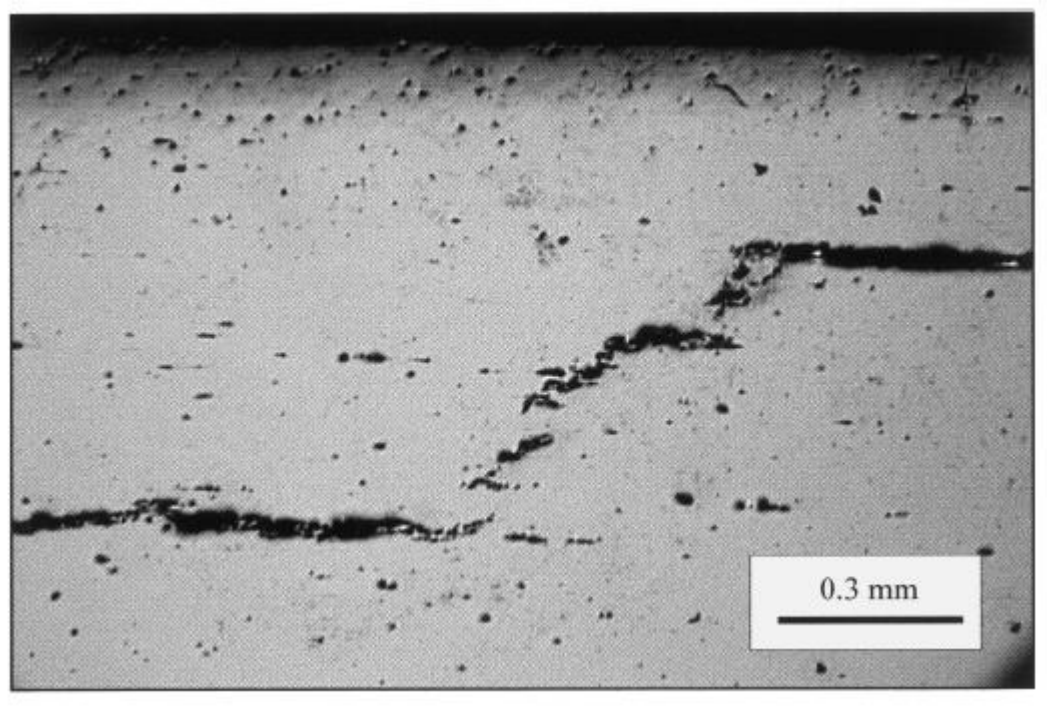
This interaction could be evaluated as a change in the frequency distribution of the transmitted pulse (echo spectral analysis) or of the scattered signal (e.g. backscatter spectral analysis).

**Como detectar
essas ondas
difratadas?**

**Transformada
de Fourier dos
Sinais**



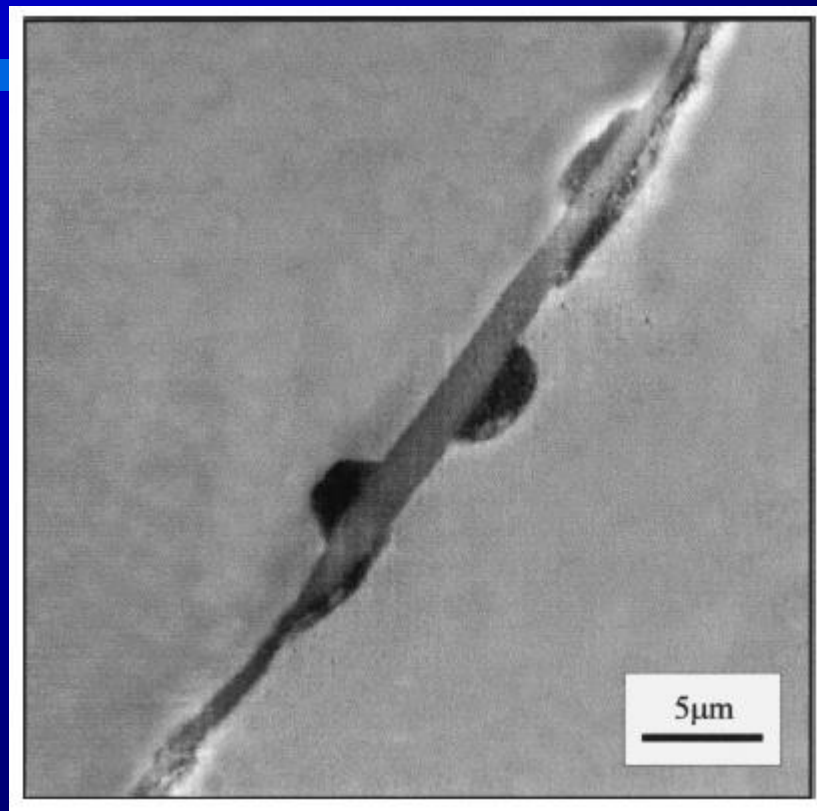
Hydrogen cracks detection



Optical micrograph of a typical stepwise crack of the analysed surface of a hydrogen attacked sample



Hydrogen cracks detection



Inclusion of a hydrogen attacked sample showing disbonding



Hydrogen cracks detection

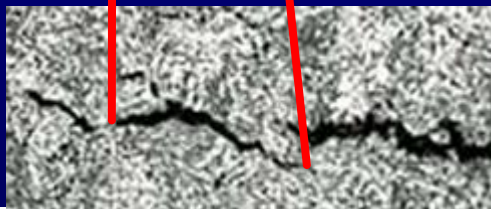
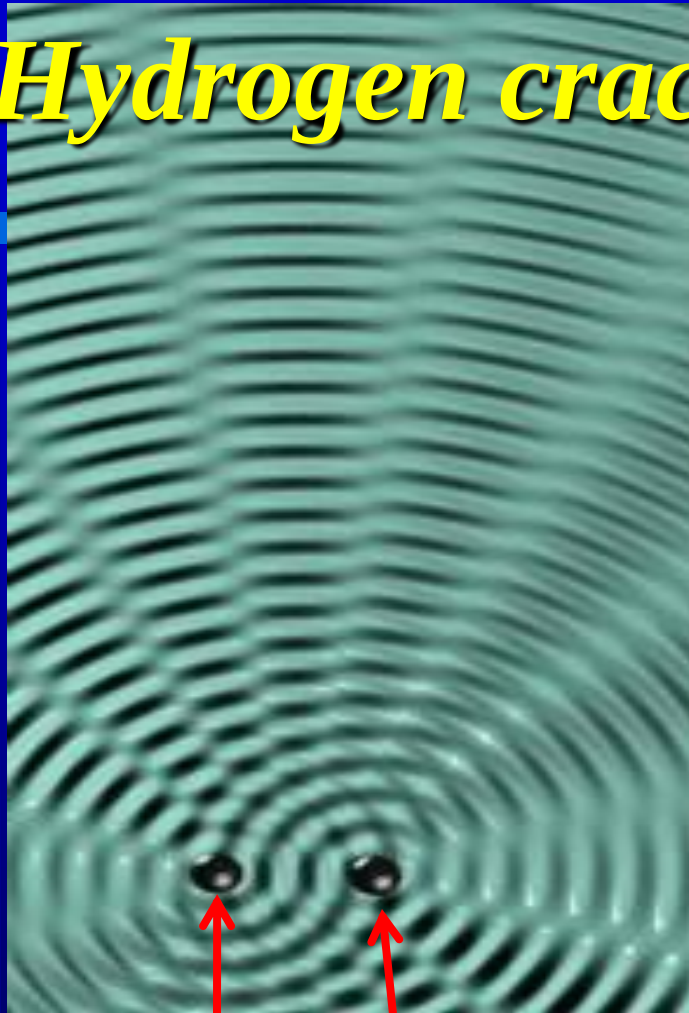


Hydrogen cracks

**Hydrogen cracks are too small to reflect UT waves.
Detection is only possible using UT spectroscopy**



Hydrogen cracks detection

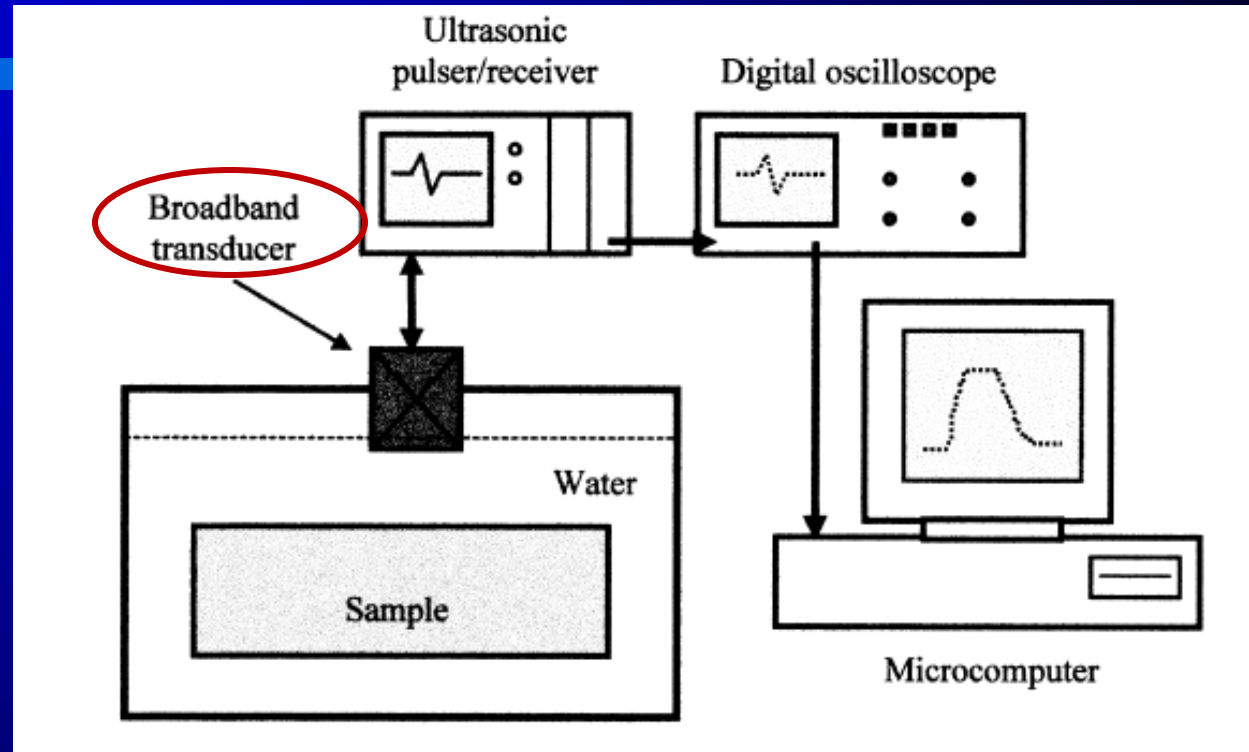


Hydrogen cracks are too small to reflect UT waves. Detection is only possible using UT spectroscopy of the diffracted waves from the crack tips.



Hydrogen cracks detection

Ultrasonic spectroscopy is the study of ultrasonic waves resolved into their Fourier frequency components.

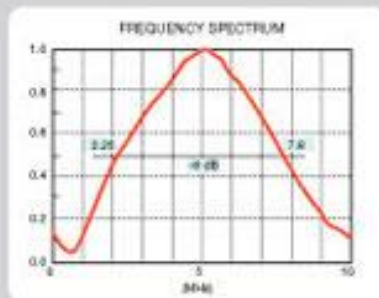
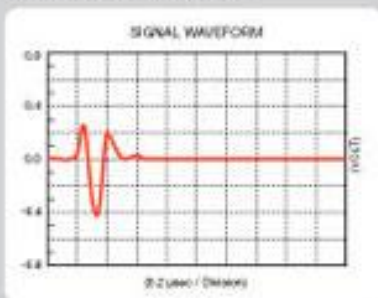


Experimental system used to perform the ultrasonic spectral analysis.

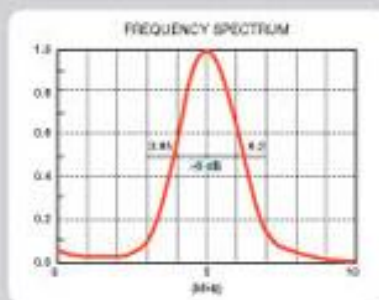
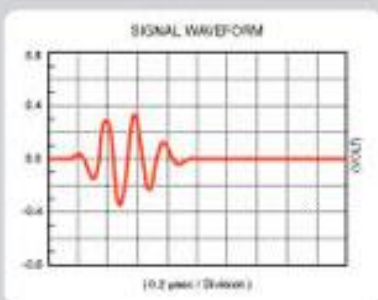


Hydrogen cracks detection

Broadband



Narrowband

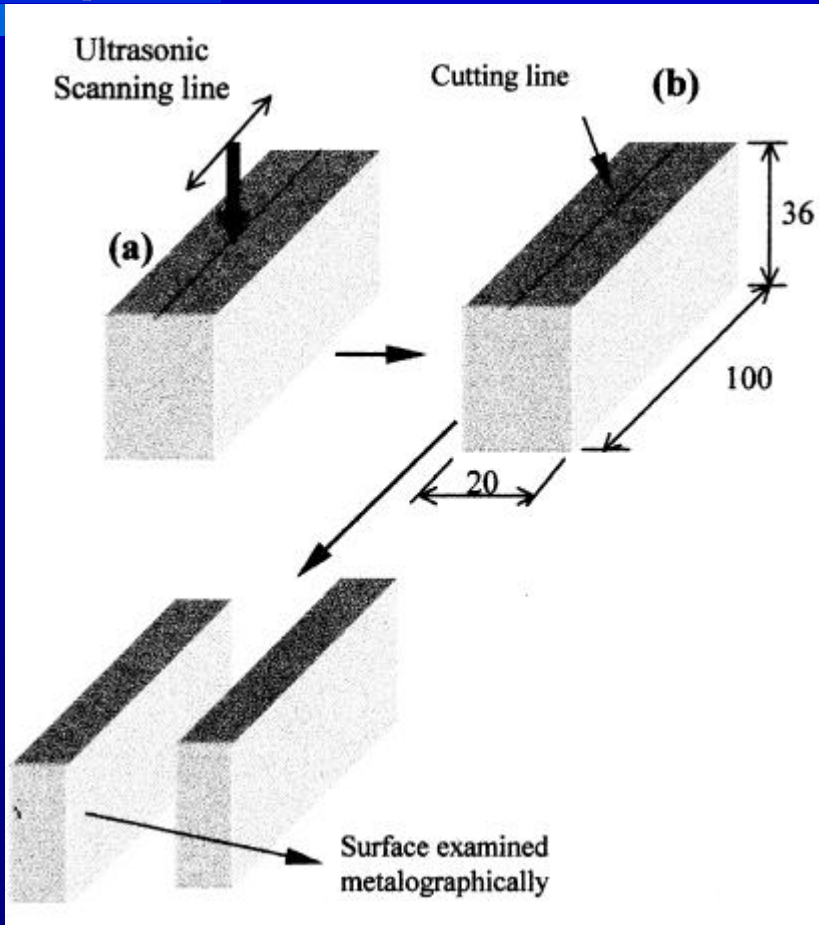


Broad band transducers for spectral analysis do not generate sound waves at a single pure frequency, but rather over a range of frequencies centered at the nominal frequency designation.

WHY??



Hydrogen cracks detection

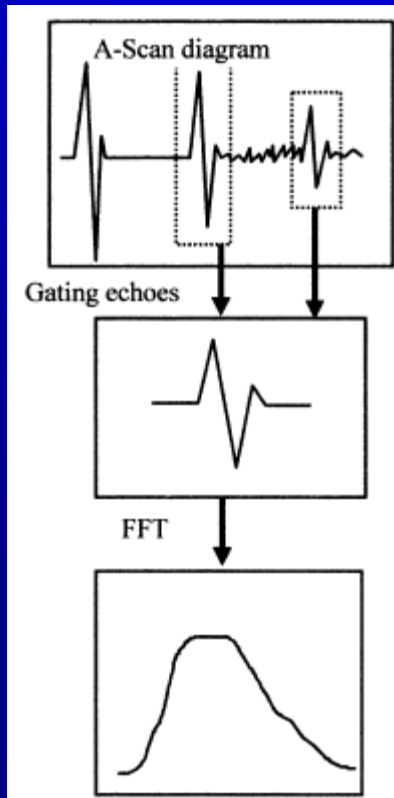


Steel Samples:
ASTM A516 gr 60.

Hydrogen attack:
NACE TM 0177 standard, used to test the resistance of steels in H₂S environments, for 96 h at room temperature without external loads.



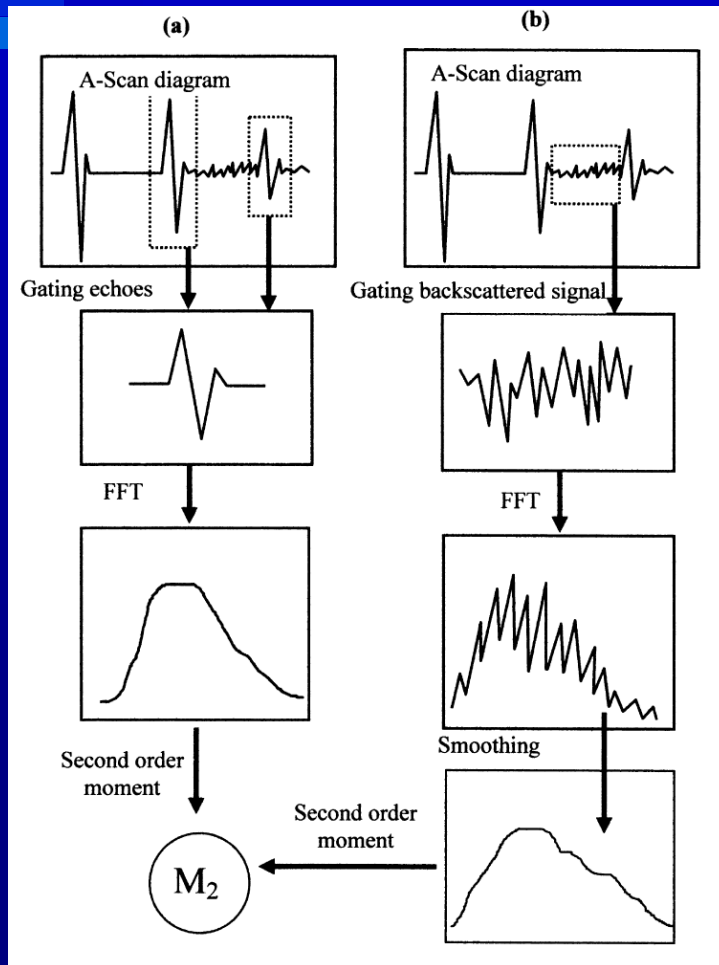
Hydrogen cracks detection



UT Spectral analysis was performed for the back wall echo gated (rectangular window) by the oscilloscope.



Signal processing

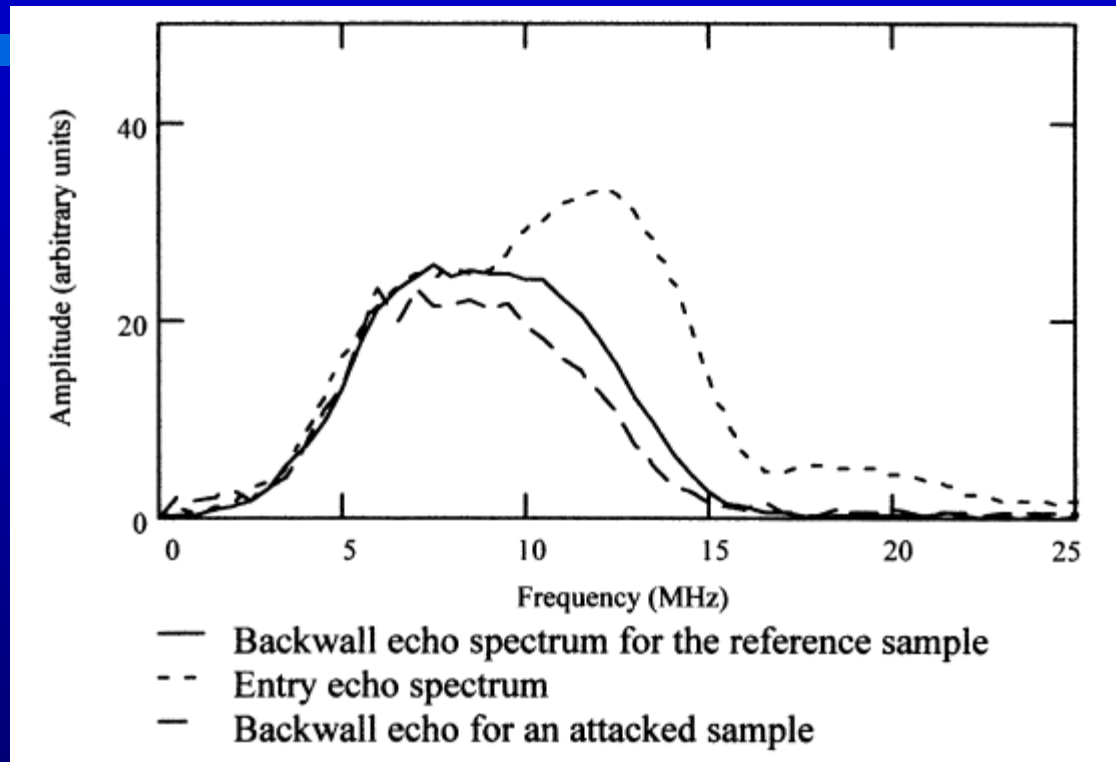


$$M_2 = \sum_{i=0}^I E_i i^2$$

Signal gating and processing of (a) echo and (b) backscattered signal. The processing consists basically of the time to frequency transformation (by FFT) and the extraction of a feature of it (the second order momentum).



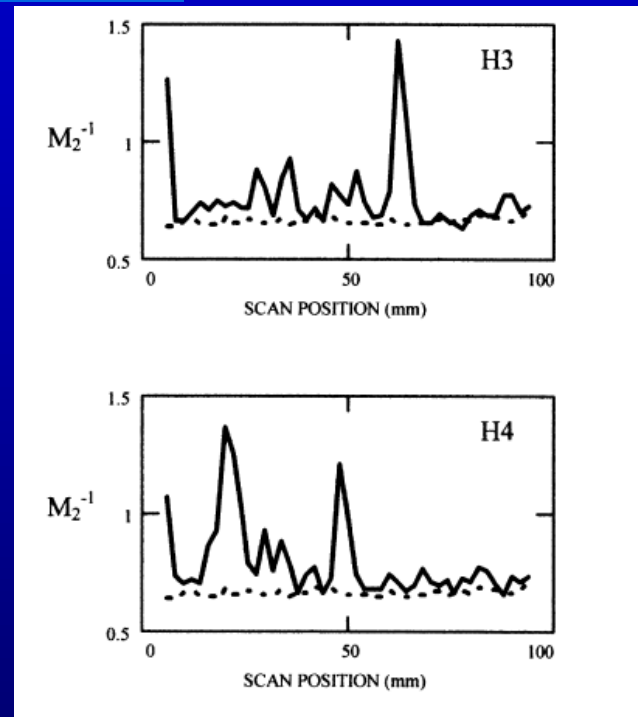
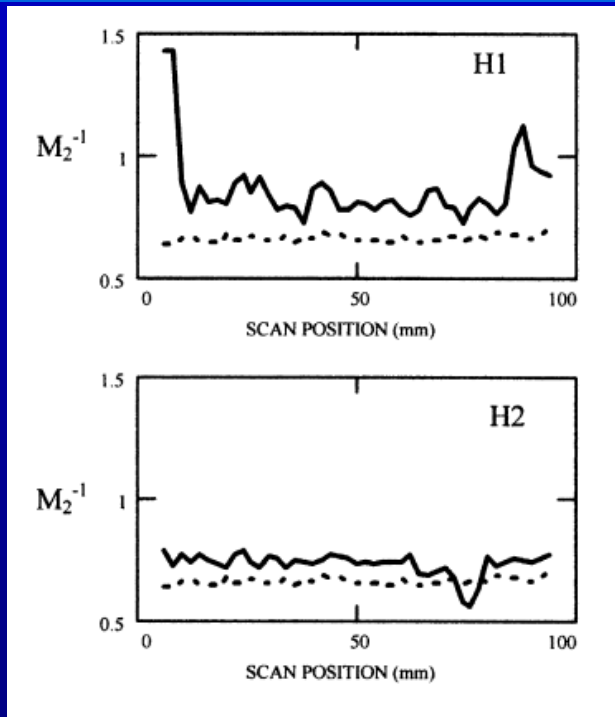
Signal processing



FFT of several signal from the UT technique



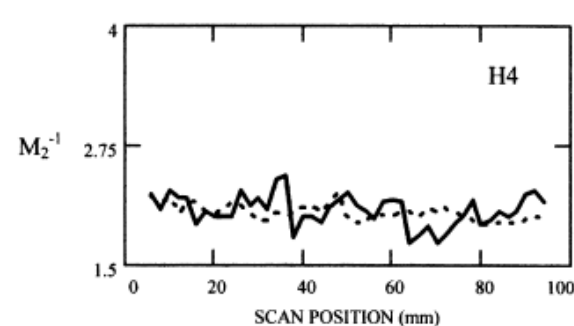
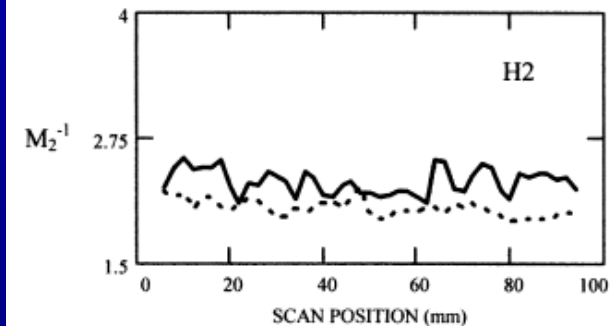
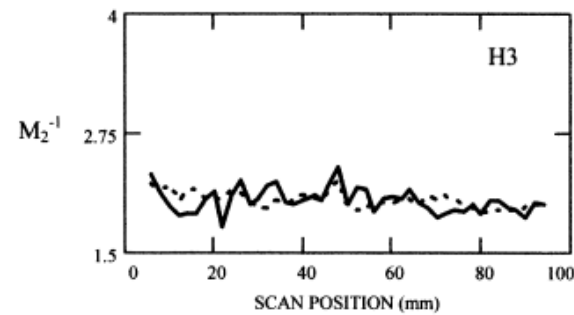
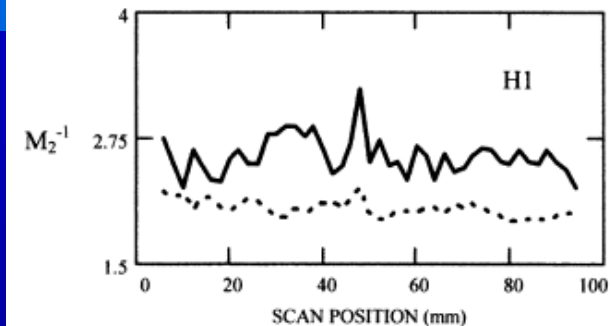
Signal processing



Inverse of the second order momentum. Bach wall echo.



Signal processing



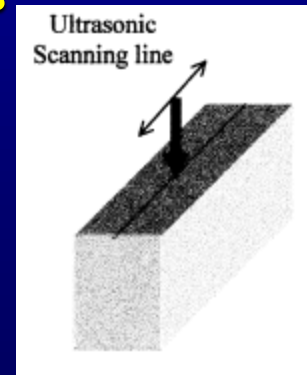
Inverse of the second order momentum. Back scattered echo.



Conclusion

FFT of UT signal can be an useful tool to detect hydrogen cracks.

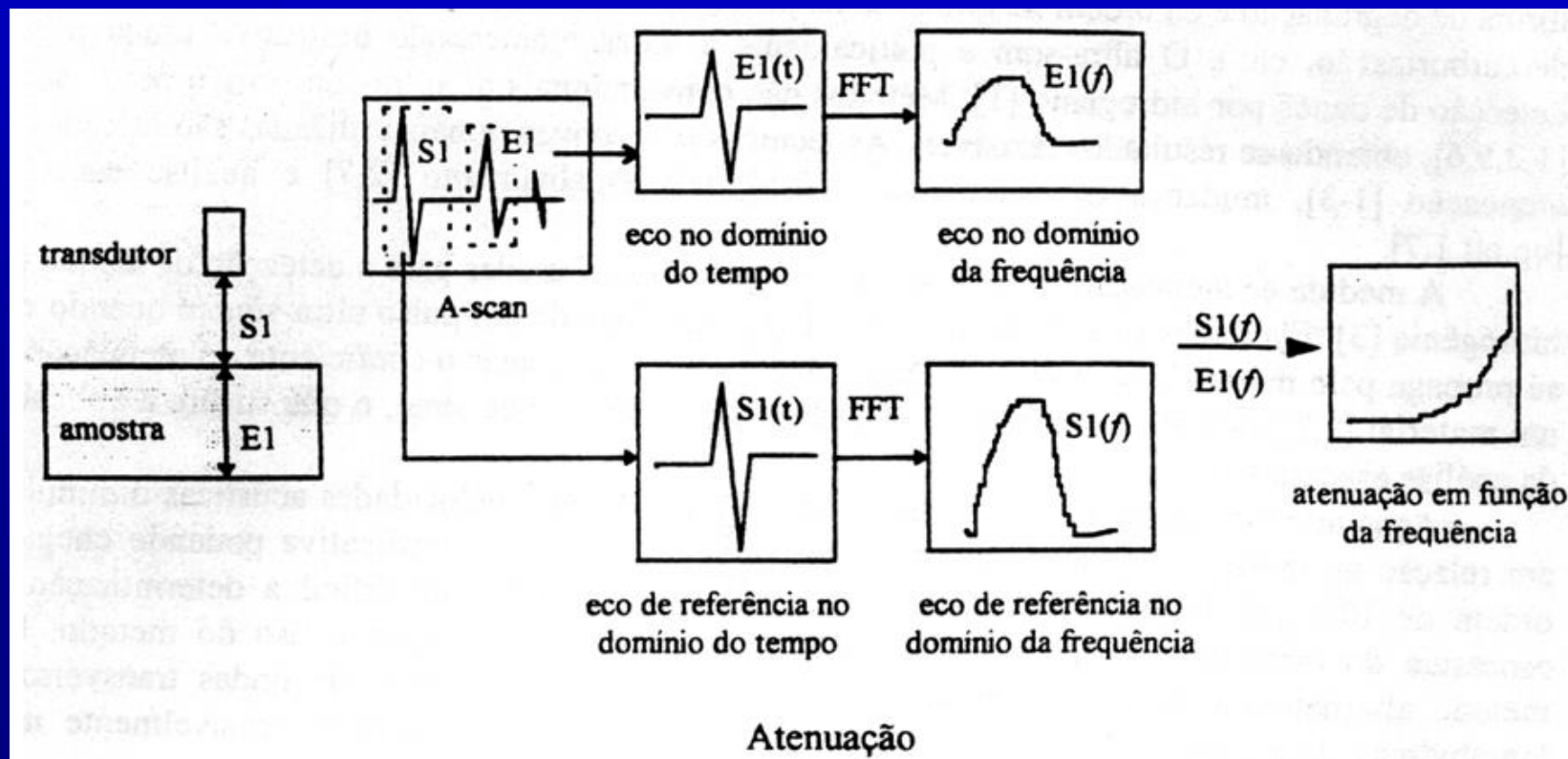
However is necessary some further analysis in order to recover the points where these cracks are located along the test piece width.





Signal processing UT

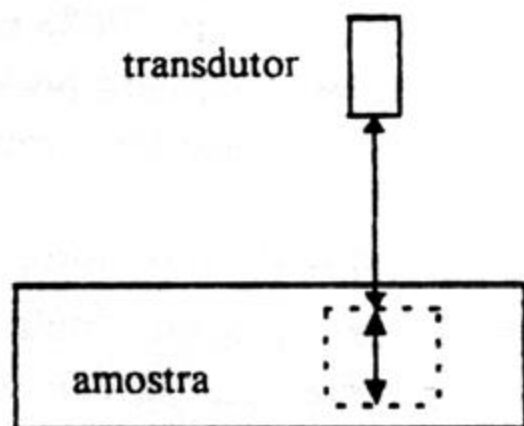
Attenuation Measurements





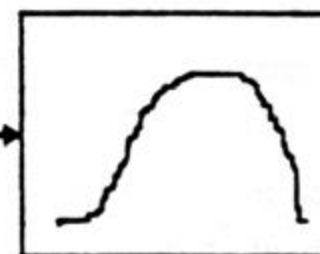
Signal processing UT

Attenuation Measurements



A-scan do sinal
retroespalhado

FFT



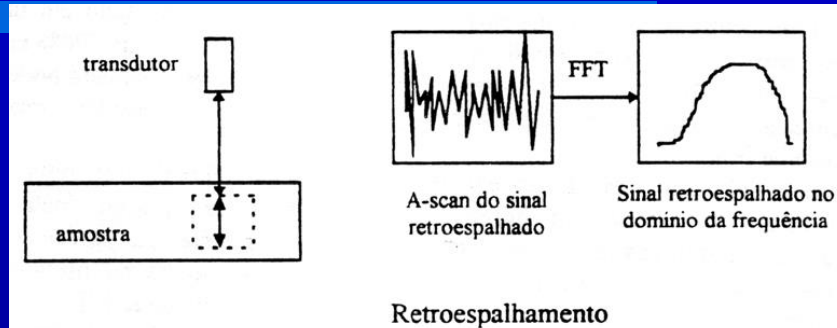
Sinal retroespalhado no
domínio da frequência

Retroespalhamento



Signal processing UT

Attenuation Measurements



Análise do sinal retro-espalhado se tem teoricamente um sinal com conteúdo em frequência parecido com o que foi perdido pela atenuação devida ao espalhamento. A grande vantagem da análise por retro-espalhamento é que não é necessário o eco de fundo. Isto permite a avaliação micro-estrutural por ultra-som de materiais com grandes espessuras e com superfícies de fundo bastante corroídas.



Signal processing UT

Attenuation Measurements

Por meio de comparação entre a curva amplitude x frequência de um material são (amostra padrão) e a do material submetido ao encharque (amostra hidrogenada) pode-se caracterizar a região do espectro que foi sensível ao dano .

A curva atenuação x frequência pode ser obtida relacionando-se o espectro de frequência (curva amplitude x frequência) do corpo de prova não encharcado (amostra padrão) e o corpo de prova encharcado (amostra hidrogenada), empregando a seguinte equação:

$$\alpha = \frac{1}{2t} \times 20 \log 10 \frac{A_{ref}}{A_{hid}} \quad \text{em dB/mm}$$



Signal processing UT

Attenuation Measurements

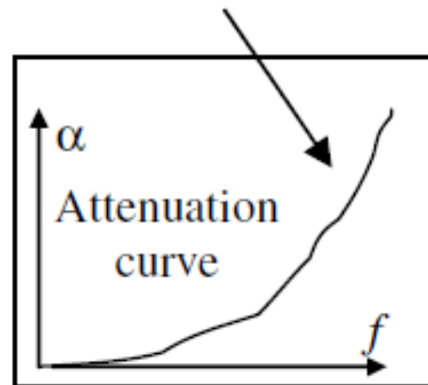
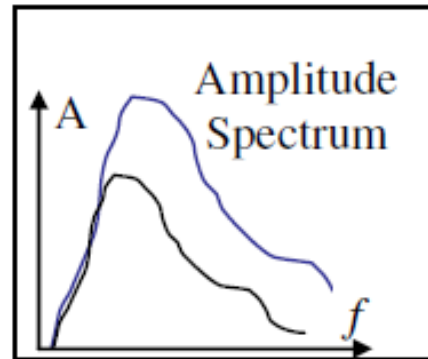
onde A_{ref} é a amplitude do pulso proveniente da amostra padrão e A_{hid} é a amplitude do pulso proveniente da amostra hidrogenada e t é a espessura da amostra.

$$\alpha = \frac{1}{2t} \times 20 \log_{10} \frac{A_{ref}}{A_{hid}} \quad \text{em dB/mm}$$



Signal processing UT

Attenuation Measurements



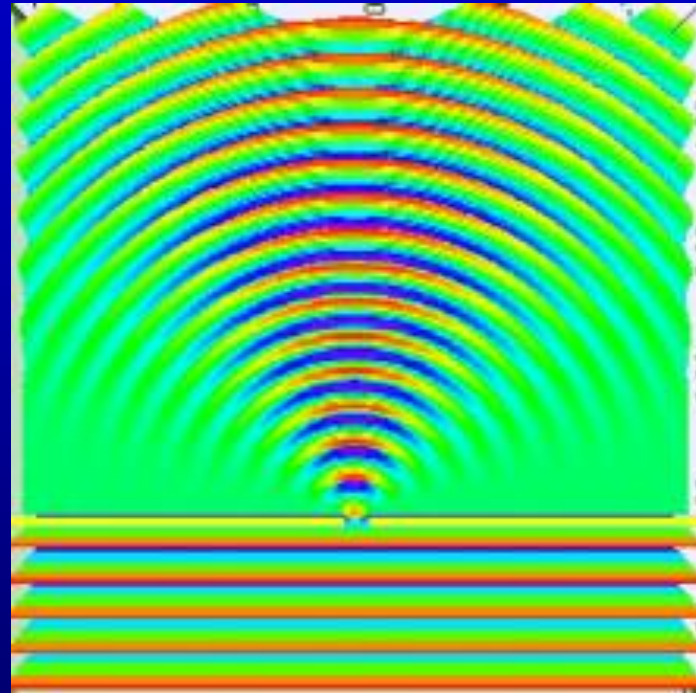
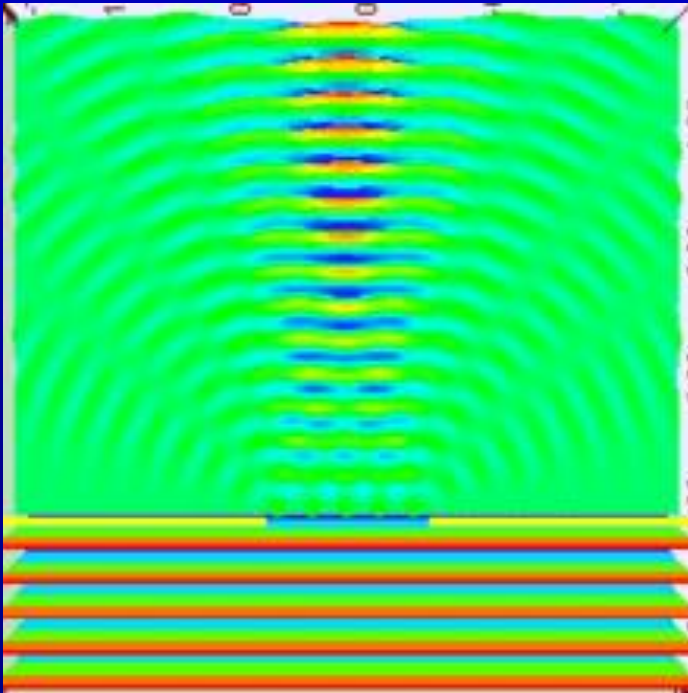
Por que o coeficiente de atenuação é uma função de valor crescente com a frequência do espectro?

$$\alpha = \frac{1}{2t} \times 20 \log 10 \frac{A_{ref}}{A_{hid}} \quad \text{em dB/mm}$$



Signal processing UT

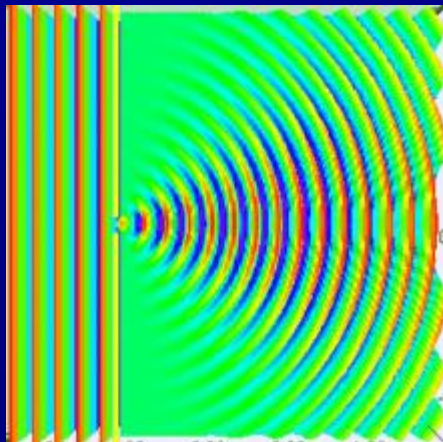
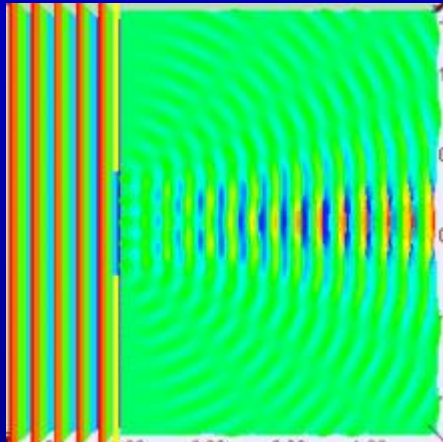
Attenuation Measurements





Signal processing UT

Attenuation Measurements

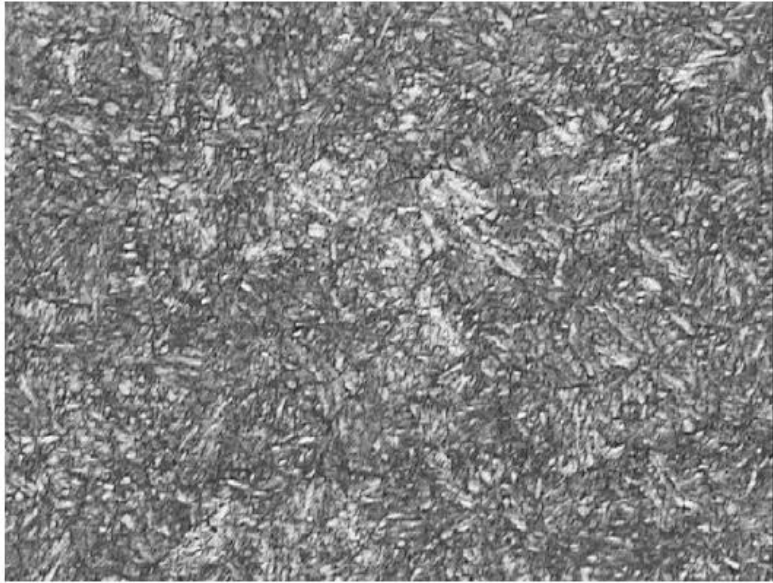


Espalhadores de pequenas dimensões são mais eficazes em produzir o fenômeno de difração. Altas frequências de ondas UT correspondem a menores λ e portanto interagem com grande número de espalhadores, aumentando assim a atenuação sônica.



Signal processing UT

Attenuation Measurements



b)

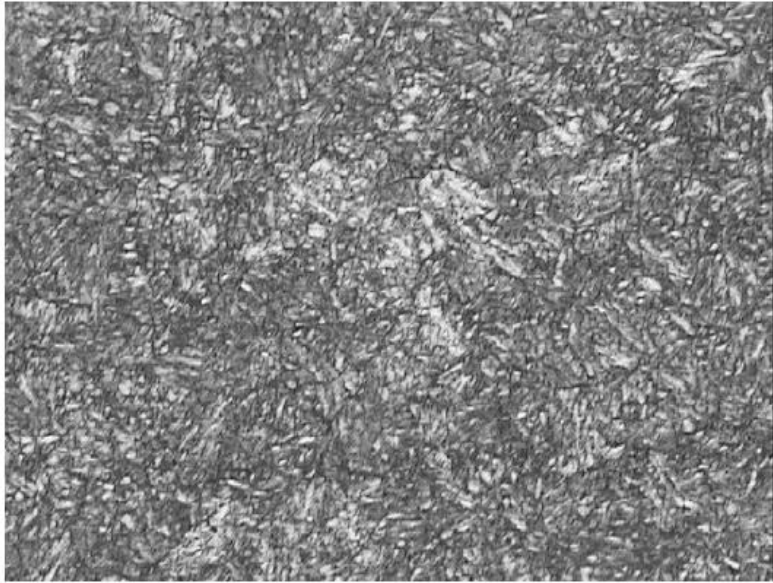
Micrografia ótica. Reagente Murakami. Aço supermartensítico 200x.





Signal processing UT

Attenuation Measurements



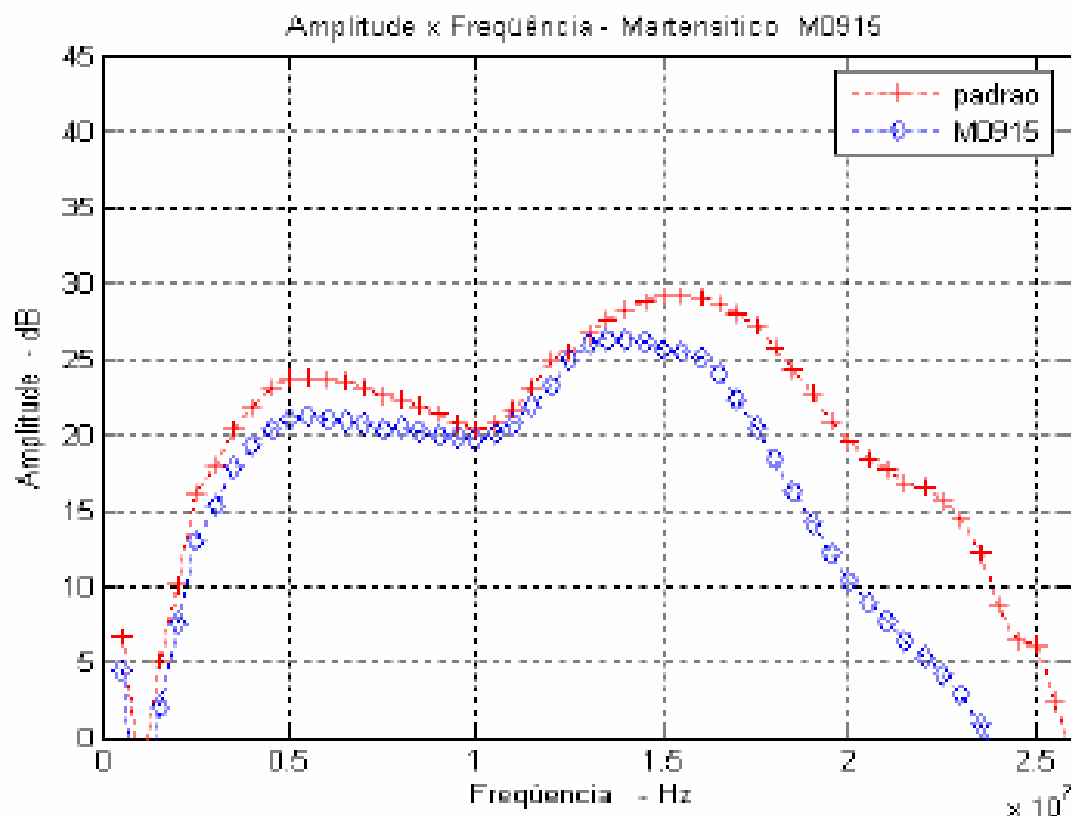
b)

Micrografia ótica. Reagente Murakami. Aço supermartensítico 200x.





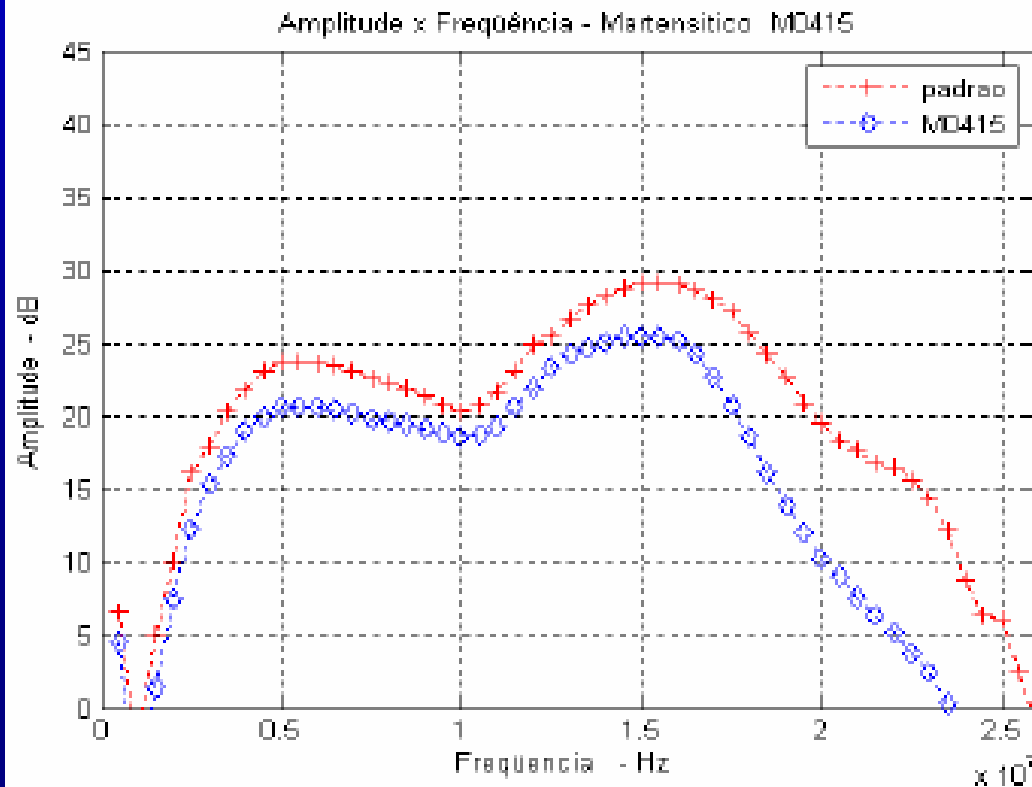
Signal processing UT Attenuation Measurements



**Amostras
padrão sem
trincas e
hidrogenada
por 96 horas.**



Signal processing UT Attenuation Measurements

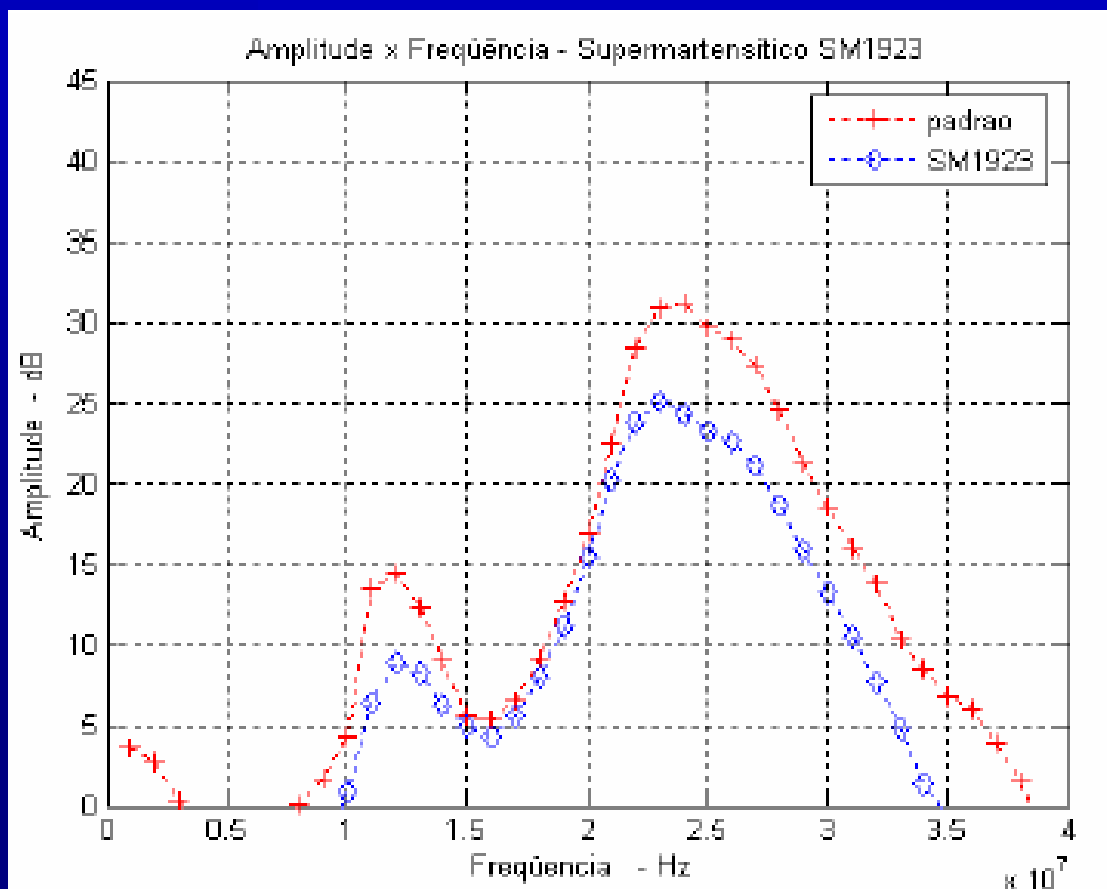


**Amostras
padrão sem
trincas e
hidrogenada
por 96 horas.**



Signal processing UT

Attenuation Measurements

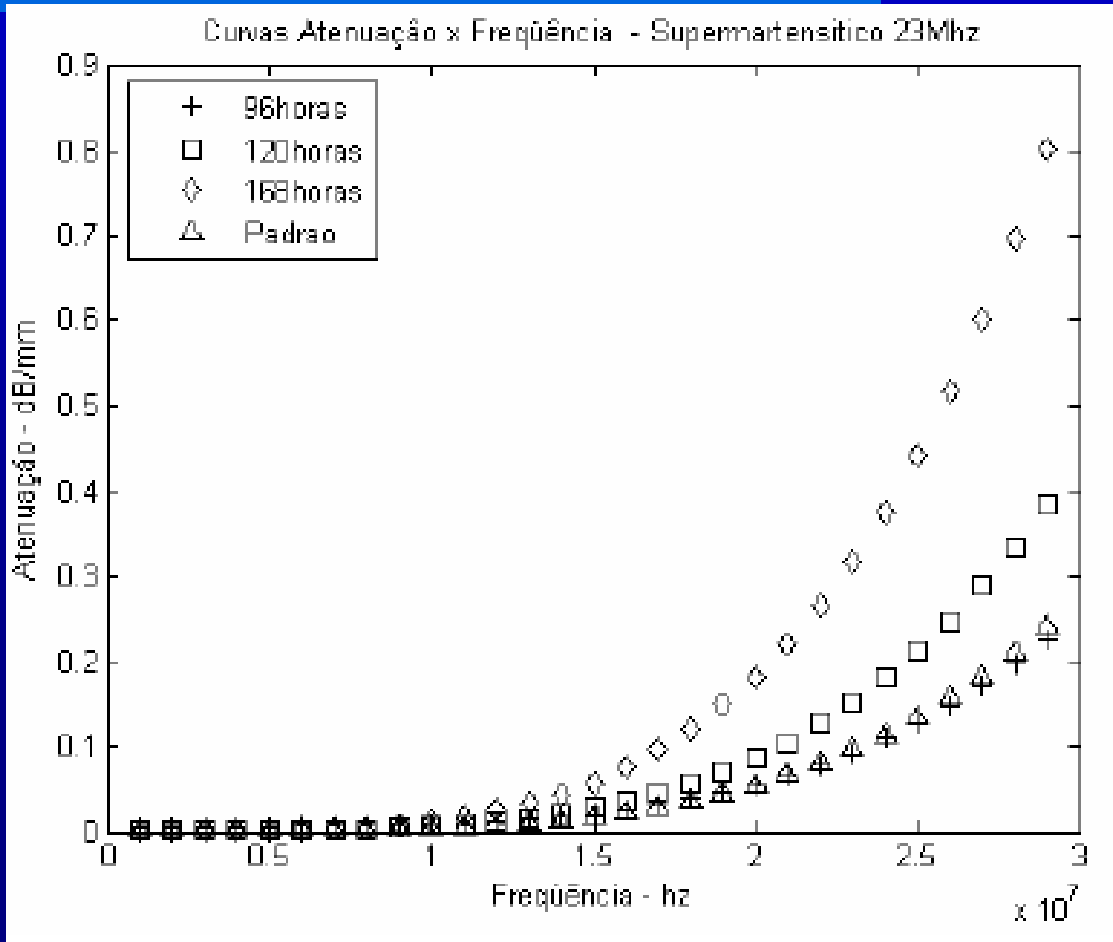


**Amostras
padrão sem
trincas e
hidrogenada
por 168 horas.**



Signal processing UT

Attenuation Measurements



**Amostras
padrão sem
trincas e
hidrogenada
por tempos
variados.**



Conclusion

O efeito do espalhamento da onda ultra-sônica devido à presença das heterogeneidades (trincas ou microempolamentos) decorrentes do dano por hidrogênio, foi um fenômeno preponderante na atenuação da energia sônica introduzida nas amostras empregadas nesta experimentação.

Por meio da análise espectral ultra-sônica foi possível representar o comportamento da atenuação proveniente dos danos por hidrogênio presentes nos aços martensítico e supermartensítico, através do levantamento das curvas $\alpha \times f$.



Muito Obrigado!

Perguntas?