Ultrasonic NDE of Materials Grain Size and Hardness

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ABSTRACT

Ultrasonic techniques can be used for qualitative or /and quantitative evaluation of physical and elastic properties of materials. This paper proposes non destructive methods , which were the work object at the Welding and Control Research Center (CSC), for a qualitative evaluation of the steel hardness and grain size by ultrasonic.This evaluation is based on the measurement of sound velocities and attenuation coefficients of different wave modes in the material. These measurements were taken on samples of suitable nature , shape and dimensions and heat treated in order to obtain the required properties. The experimental results obtained are compared with those obtained by classical methods or quoted from the literature, discussed and analyzed and in taking into account the scattering phenomena influence on ultrasonic parameters in polycrystalline materials, in order to develop non destructive techniques for materials characterization by ultrasounds. This experimental work shows the possibility to assess the qualitative hardness and grain size of a steel only from its longitudinal velocity wave.

Key Words: ultrasonic, grain size, hardness, attenuation, velocity.

Introduction :

By the propagation of acoustical waves through a material, the received signal gives several informations on mechanical or the physical aspect of the medium to explore. The acoustic waves crossing a material come out from it modified. These modifications are directly dependent on the mechanical or structural aspect of the explored matter. This article describes the experimental work done in the Welding and Control Centre which relate the relation between some ultrasonic parameters and the steel hardness and grains size The experimental study of the mechanical characteristics such as the hardness and the grains size influence on the velocities and the attenuation coefficients in polycrystalline materials requires to take into account the scattering of the ultrasonic waves. The attenuation coefficient α is a relative parameter composed of the absorption coefficient α_A plus the scattering coefficient α_s [1]. The attenuation coefficient is a function of the frequency and the mean grain diameter D compared to the wavelength λ [2]. In the Rayleigh region (λ>>D), stochastic region ($\lambda \approx D$) and scattering region (λ<<D), the attenuation coefficient α is respectively proportional to $D^3 f^4$, Df^2 et Df. The scattering of ultrasounds in contact with grains and interfaces in polycrystalline materials are the cause of the attenuation and create dispersive velocities[3]. The amplitude of the backscattered signal A_b , for a given depth z, can be described for homogeneous materials [4] as:

$$A_b=A_0.\,\alpha_S(f).\exp(-2\alpha(f).z) \quad (1)$$

where A_0 is the initial amplitude, $\alpha(f)=\alpha(z,f)$ is the global attenuation coefficient and $\alpha_S(f)=\alpha_S(z,f)$. In general, grain scattering losses are large compared to absorption losses.

In the Rayleigh region (our case), we have [5]. :

$$\alpha(f)=a_1 f+a_2 D^3 f^4 \quad (2)$$

The scattering coefficient shows a high sensitivity to the grain size variation.

The losses by scattering affect much more the shear waves than the compression waves . In the Rayleigh region, we have an upward shift in the expected frequency. Furthermore the term exp(-2α(f).z) in eqn.(1) causes a downward shift in frequency . We have here two opposing phenomena (i.e. upward shift due to scattering and downward shift caused by attenuation). However the sound path length z is high, the downward shift is preponderant, and the velocity decreases . The equation 2 shows that the down shift frequency decreases α whereas the increase in mean grain size diameter makes increase α_S.

Ultrasonic measurements

Ultrasonic measurements are undertaken in immersion technique by using a focused probe . In normal incidence and thereafter in oblique incidence, are measured successively the time of flight and the amplitudes of the back-wall echoes of L and T waves in the specimen .

Velocities and attenuation coefficients measurements

Velocities are measured from the wave times of flight in the sample thickness which is measured mechanically with a high accuracy. For the attenuations, the amplitudes of the three first back-wall echoes are measured. The attenuation coefficients of the L and T waves are:

$$\alpha_{LP} = \frac{1}{2y} Ln\left(R_p^{\,2}\left|\frac{E_n - E_{n+1}}{E_{n+1} - E_{n+2}}\right|\right) \quad (3)$$

$$\alpha_{Tp} = \frac{1}{4y} Ln\left(R_p^2.R_e^2\left|\frac{E_n - E_{n+1}}{E_{n+1} - E_{n+2}}\right|\right) \quad (4)$$

E_n : n^{th} echo amplitude, y : sound path, R_p : reflection coefficient at normal incidence (sample - water) , R_e : reflection coefficient at oblique incidence .

Experimental device

The generator delivers excitation pulses. In reception, it contains an amplifier with a large adjustable gain[6].The probe displacement , in a water tank , is performed by two step by step engines .The numerical scope allows a sampling and storage in microcomputer memory for processing. The sample is fixed on a goniometer (fig. 1).

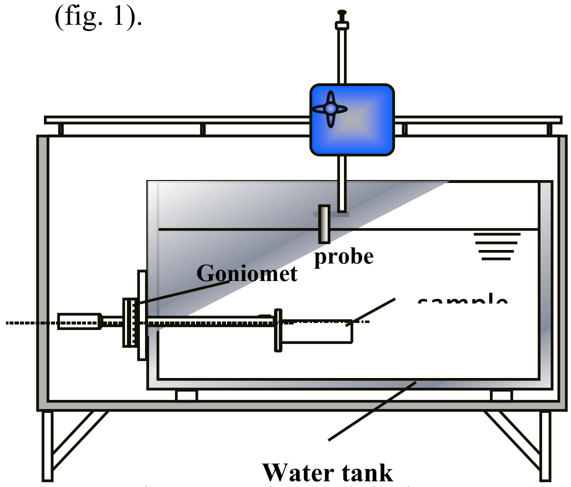

Fig.1. experimental device

Samples

The half cylinder shaped samples (fig. 2) allows to obtain two propagation modes (L and T) in the same sample.

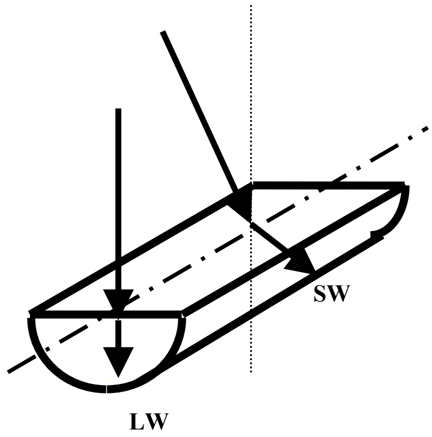

Fig.2 ultrasonic course in the sample

Characterization of the steel hardness

The hardness is the material resistance to a local penetration . It is a property which depends on material characteristics .We have examined 3 identical half cylindrical shaped samples XC38H2 steel.

Thermal processing

The principle (fig.3). consists in heating the sample until the austenitization temperature and then watering on one side . This treatment has given a great hardness gradient along the sample.

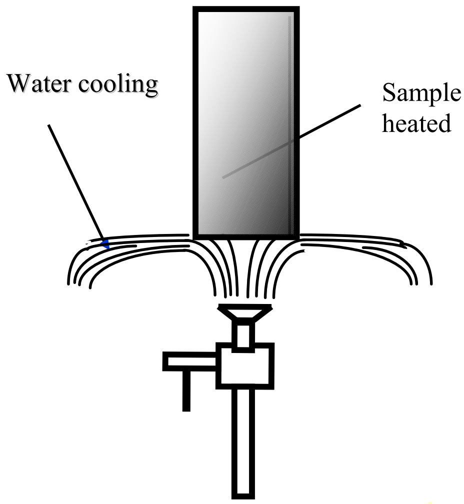

Fig.3 heat treatment device

Hardness measurements

The Vickers hardness is given by:

$$HV = \frac{2p\sin(\frac{\theta}{2})}{D^2} \quad (5)$$

where p: applied load in kgf, D: impression diagonal in mm and θ: angle between two opposed faces. Hardness measurements have been made on four samples. Results obtained are similar and an example is presented (fig.4). The hardness is more highest on the cooled face side then decreases to stabilize to a value of 35 mm that corresponds to the material hardness before processing. We can therefore consider that beyond this value the samples did not have notable modifications in their mechanical characteristics. The metallographical analysis have shown a ferritic-perlitic structure. After the thermal processing, we have a martensitic structure at x =1 mm , a ferritic-perlitic structure at x =35 mm , passing by the bainitic and bainitic-perlitic structures.

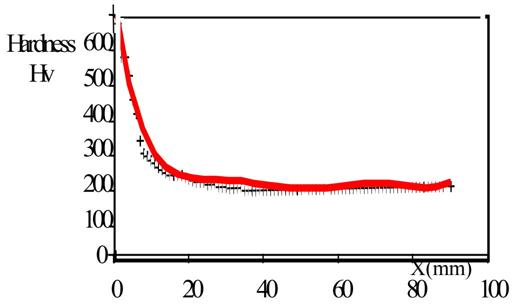

Fig.4 hardness curve

Ultrasonic measurements

Ultrasonic measurements are taken in immersion with a focused probe . The measured ultrasonic parameters are the velocities of longitudinal V_L and transverse V_T waves and their attenuation coefficients (α_L et α_T) along the sample. All these curves have the same way and are similar to the hardness evolution. As an example we give the L wave attenuation coefficient curve (fig. 5). They start with a maximum and decrease to stabilize with a constant value at a distance 35 mm from the cooled face exactly like the hardness curve. We can deduce that from the curves of V_L, V_T, α_L and α_T, it is possible to assess to the hardness by measuring only one of the these four parameters[7].

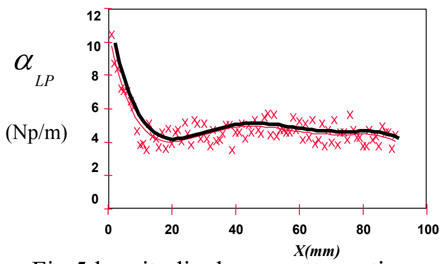

Fig.5 longitudinal wave attenuation coefficient on the axis

Characterization of the steel grains size

We have studied the velocities and attenuation coefficients evolution according to the grains size on steel E24 samples. The identical samples underwent the same treatments previous . The metallographic analysis showed the same structure on all the samples. Only the grains size changed.

Grain size measurements

The average grain size of 3 samples is measured by the method called " by counting " (fig. 6). The image linear magnification g must be such that at least fifty grains can be inside the area limited by a 79.8 mm diameter circle .
The average grains diameter D in mm is:

$$D = \frac{1}{\sqrt{m}} \quad (6) \quad \text{where} \quad m = 2\left(\frac{g}{100}\right)^2 n_g \quad (7)$$

and n_g is the total number of grains inside the circle. We can observe that the grains size is weaker on the cooled face side and increases slowly to stabilize at 40 mm distance value which corresponds to the material grain size before processing.

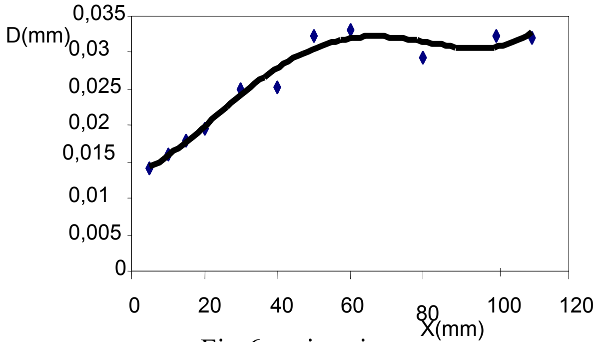

Fig.6 grains size curve

Ultrasonic measurements

The measured ultrasonic parameters are: V_L, V_T, α_L and α_T . The curves V_L and V_T (fig. 7and 8) have the same way. They start with a maximum and decrease until at a value of 40mm to stabilize at a constant value of 90 mm of the cooled face ,except for V_T which becomes stable after 40mm. If we compare these curves to the one giving average grains diameter , we note that there is an opposite effect on the cooled face side. In the Rayleigh region we have seen that the down shift frequency decreases the attenuation coefficient whereas the increase in mean grain size diameter makes increase the scattering coefficient. However the downward shift caused by attenuation is preponderant, and velocity is decreasing [8]. For the attenuations, we have a great scatter in the experimental data which does not allows their exploitation. This experimental work shows that it is possible to assess qualitatively to a material grains size from its longitudinal or transverse velocity. However, it is important to study the frequency influence which is a promising tool in this type of investigation.

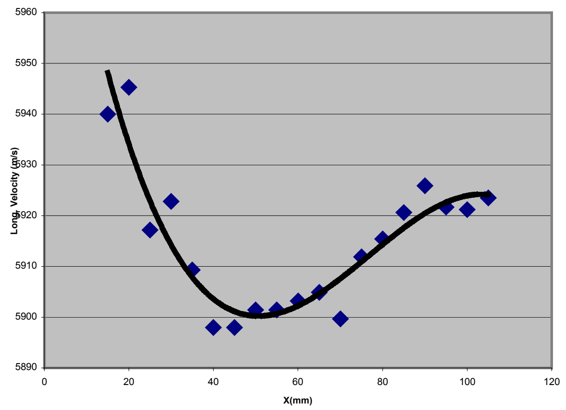

Fig.7 longitudinal velocity on the axis

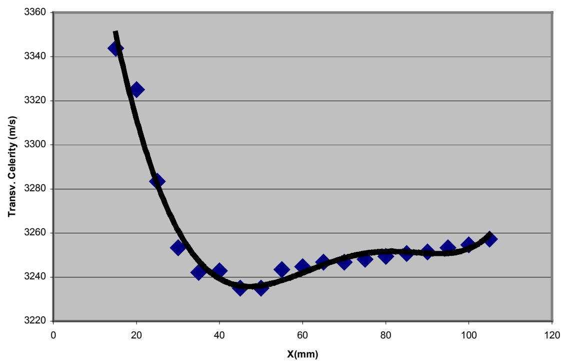

Fig.8 transverse velocity on the axis

Conclusion

The evolution analysis of the ultrasonic parameters and the hardness and grains size curves of steel shows the possibility to assess to these characteristics by the simple measurement of the velocity or the attenuation coefficient of one propagation mode. The results obtained are compared with those obtained by traditional techniques and literature and showed a good agreement. This work opens the way with the development of quantitative and / or qualitative non destructive characterization techniques of materials by ultrasounds.

References

[1] S. Hirsekorn & al, “Ultrasonic Methods to Detect and Evaluate Damage in Steel”, NDT&E 15(2000)373-393.

[2] F.E. Stanke & G.S. Kino,J. Acoust .Soc. Am., 75(3) (1984) 665

[3] J. A. Turner, R.L. Weaver, J. Acoust .Soc. Am., 96, 3675-3683 (1994)

[4] J.Saniie & al, spectre evaluation of ultrasonic grain signals, IEEE Ultrason. Proc., 1987, 1015-1020

[5] A.B.Bathia, J. Acoust .Soc. Am., 31(1), (1959) 16

[6] A. Badidi Bouda & T. Meksen ,The study of the ultrasonic transducers influence on the materials non destructive testing quality by ultrasonics, CESA 98, IEEE Systems, 259-264,1998

[7] A. Badidi Bouda, & al , Ultrasonic characterization of materials hardness, Ultrasonic (38), 2000, 224-227

[8] A. Badidi Bouda, A. Benchaala & S. Lebaili, Grain Size Influence On Ultrasonic Velocities and Attenuation », NDT&E International Elsevier, volume 36, number 1, pp1-5 , January 2003