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ULTRASONIC ATTENUATION MEASUREMENT AS THE CONTROL METHOD FOR STEEL EVALUATION

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ABSTRACT
The method of evaluation of a steel loading capabilities by means of ultrasonic attenuation measurement (AM) is briefly described. Results of AM obtained on a Mn-V steel vary with the change of the measurement point and thus are statistically analyzed. The influences of surface preparation, ultrasonic frequency and ultrasonic probe size on ultrasonic attenuation values (AV) for the first time are investigated. Good agreement between mechanical test results and AM was found, which encourages the application of AM.
Keywords: ultrasonic attenuation, mechanical testing, echograms

1. INTRODUCTION
Changes in material microstructure can modify the resistance of the material to crack growth and/or fracture. The phrase mechanical properties is often used to describe particular parameters quantifying this resistance to deformation and failure, a notable example being the fracture toughness. This is but one of a number of mechanical properties, others being yield stress, bond strength, hardness and others. In many applications in which one wishes to characterize the material, rather than discrete flaws, it is the determination of one of these mechanical properties that is the user's end objective, thus defining a second major objective of non-destructive testing [1]. It should be noted that this is an area that is likely to become important in the coming decades. The aging of much of the world's structural infrastructure, including bridges, highways, railroads, power generating stations, and aircraft, all require periodic assessment of serviceability. Assessment of mechanical properties is a crucial step in this approach.
The Standard Practice of the ASTM E 664-78 (1989) describes a procedure for measuring the apparent attenuation of ultrasonic in materials or components with flat, parallel surfaces using conventional pulse-echo ultrasonic flaw detection equipment. The Standard Practice is concerned with the attenuation associated with L-waves introduced into the specimen by the immersion method [2]. It can be used for the determination of relative attenuation between materials.
This paper refers to ultrasonic attenuation in a Mn-V pipeline steel when imperfections of steel structure that can diffuse, absorb or reflect ultrasonic waves are present. The work was done to investigate the application of attenuation method to detect low strength of the steel as a result of an inappropriate production technology and/or corrosion, before it could lead to failure.

2. THE MATERIAL EVALUATED
The pressure vessel A for hydrogen transport was made from a Mn-V steel which meets required content of chemical elements ($C \leq 0,32\%$, Mn 1,1%-1,4%, S, P max 0,035% and Si max 0,4%),

except that it was alloyed with V (0,16-0,22%) instead with Mo (0,18%) and also contains Cu (0,24%). It is of tubular form with inside diameter $2R_i$=300 mm and wall thickness t=8,8 mm. After a few years of vessels use, the wall thickness was increased to 10 mm. The minimum measured wall thickness for the pressure vessel A was 7,5 mm, thus it was rejected, cut and used for liquid penetrant and fluorescent magnetic particle testing, as well for mechanical testing, hardness measurement and AM. The steel is normalized with minimum yield strength 560 MPa, tensile strength 700 MPa and minimum elongation of 14%.

The cylindrical part of pressure vessels is hot rolled and their ends are formed by forging. Working pressure is 15 MPa and working temperature is the ambient temperature. The International Gaseous Committee recommends Cr-Mo steels instead of Mn-V steels for the same application [3].

3. PROCESSES AND METHOD

Since the working pressure is high, it is allowed the possibility of hydrogen penetration into metall lattice in accordance with [4]. The AM method is applied to reveal both HA and/or irregular material structure. Here are considered some factors influencing AV values, while the possible reasons for high AV are investigated in the other paper on AM for this Conference.

Hydrogen attack is a process produced in plain carbon and low alloy steels exposed to a high-pressure hydrogen environment at high temperatures. A chemical reaction between hydrogen and carbides in the steel produces methane gas bubbles in the grain boundaries. The reaction may occur at the surface, resulting in decarburization with an attendant loss in strength. As the bubbles grow, they interlink to form intergranular fissures or microcracks, which result in a loss in both strength and ductility.

Hydrogen blistering occurs when atomic hydrogen deposits as molecular hydrogen at a defect, such as a lamination or band of nonmetallic inclusions. High pressures of molecular hydrogen can build up at that site as atomic hydrogen continues to enter the steel, ultimately forming a blister. Blistering generally occurs in more ductile steels under conditions where hydrogen embrittlement does not occur [4].

The AV are inferred from a rate of decay of multiple echoes, corresponding to multiple reflections of ultrasonics. The apparent attenuation in decibels per unit length, *V*, is given by the relationship [2]

$$V = \frac{dB}{2(n-m)t} \quad (dB / mm) \tag{1}$$

where dB=20 $\log_{10} (A_m/A_n)$ is the apparent attenuation in dB

m and *n* are ordinal numbers of back multiple reflections (n>m)

A_m and A_n are corresponding (*m*-th and *n*-th respectively) echo-amplitudes

t is specimen thickness (mm).

The values of the attenuation at 5 MHz for unattacked steel are less than 0,16 dB/mm, for 94% of unattacked steel specimen 0,16 dB/mm and the average attenuation level for attacked specimens is 0,35 dB/mm, according to [5]. The value 0,16 dB/mm is taken here as a reference value for a sound material.

Average AV for examined ferrite-perlite steels (C 0,42-0,51 %, Mn 0,5-0,8 %, Mo 0,15-0,30 %, Cu 0,5-0,75 %, no V) range between 0,054 dB/m and 0,065 dB/m in the heat non-treated condition, while in the heat treated condition of these steels average AV range between 0,059 dB/m and 0,084 dB/m [1].

The ultrasonic backscatter examinations of carbon steel specimens with different thermal history, show systematic variation of backscattered energy with phase structure at constant grain size [6]. For comparison, here it is referred that typical mean value of backscatter amplitudes and their range (in parentheses) for bainite and tempered martensite are 35,5 (23,5-42) and 34 (32-37,5), given in dB, for steel En25. The range is broad compared with backscatter amplitudes and it is concluded that the differentiation between bainite and tempered martensite is difficult for examined steel En25. It should be noted that statistics is here very helpful because variations of properties are inevitable.

The examination described in this paper applies the contact technique to the AM method and attempts to evaluate some influences, e.g. probe diameter, on AM values for given pressure vessels.

4. ATTENUATION MEASUREMENT

Samples cutted from the pressure vessel A were prepared from outer and inner vessel side as follows:
-surface ground by abrasive paper No 400 (the preparation 1)
-surface cleaned by sand blasting (the preparation 2)
-surface fine ground by diamond paste (the preparation 3)
-surface fine ground by abrasive paper No 600 (the preparation 4).
Series (sets) of *n* measurements, are performed from outer surface with the ultrasonic probe of diameter ϕ 6,3 mm and frequency 5 MHz. Results are given for different surface preparations in table 1.

Table 1. Mean attenuation values α for 5 MHz/ϕ 6,3 mm probe and vessel A (in dB/mm)

Series No	Preparation No outer/inner	n	α dB/mm	σ_{n-1} dB/mm	Interval for measured values expected with probability 0,95
1	1/2	33	0,245	0,058	0,129 - 0,361
2	3/2 or 4/2	6	0,392	0,044	0,304 - 0,480
3	3/4 or 4/4	10	0,177	0,035	0,107 - 0,248

For each series of *n* measurements it is given the arithmetic mean of AVs, α, with standard deviation σ_{n-1} as well the confidence interval for probability 0,95 in table 1. If both surfaces are finer polished, σ_{n-1}, the interval and mean value are decreased, while rougher back (inner) surface increases α.
The measurement with the 2,25 MHz/ϕ 6,3 mm ultrasonic probe has shown similar influences of surface preparation, only AV scatter is much less when both surfaces are rough, indicating lower sensitivity of smaller frequency probe to surface condition. Mean AV are also greater than 0,160 dB/mm for all surface preparations and surprisingly are comparable to AV for a fine grain steel and a 2 MHz/ϕ 6,3 mm probe [7].
Additional AM by using 5 MHz/ϕ 12,5 mm probe on test pieces cutted from the pressure vessel A wall, were performed on outer surface after the preparation 1 and the results for test piece 2 are given in table 2.

Table 2. Mean attenuation values and standard deviations for test piece 2, dB/mm

Probe	Measurement point		
ϕ 12,5 mm 5 MHz	1	2	3
	0,247 (0,037)	0,329 (0,069)	0,174 (0,028)
	0,318 (0,096)	0,228 (0,060)	0,160 (0,028)
Thickness (mm)	7,7	7,45	7,48
Mean values	**0,256 (0,072)**	**0,272 (0,064)**	**0,167 (0,028)**
Probe	**Measurement point**		
ϕ 6,3 mm 5 MHz	1	2	3
	0,350 (0,053)	0,221 (0,056)	0,220 (0,050)
	0,208 (0,018)	0,295 (0,028)	0,167 (0,023)
Thickness (mm)	7,7	7,45	7,48
Mean values	**0,222 (0,040)**	**0,280 (0,044)**	**0,176 (0,039)**

For each measurement point there are two series of three measurements with mean value and standard deviation given in parenthesis. Corresponding mean values-general arithmetic mean (GAM) and mean standard deviation $\overline{\alpha}_{n-1}$ are given below for two probe sizes. For larger probe ϕ 12,5 mm GAM value is 0,191 dB/mm and $\overline{\alpha}_{n-1}$=0,060 dB/mm, calculated using formulae:

$$GAM_{12,5} = \frac{0,256/0,072^2 + 0,272/0,064^2 + 0,167/0,028^2}{1/0,072^2 + 1/0,064^2 + 1/0,028^2} = 0,191 dB/mm \quad (2)$$

$$\overline{\alpha}_{n-1} = \left[\left(0,072^2 + 0,064^2 + 0,028^2\right)/3\right]^{1/2} = 0,060 dB/mm \quad (3)$$

while for smaller probe ϕ 6,3 mm GAM value is 0,222 dB/mm and $\overline{\alpha}_{n-1}$=0,041 dB/mm.

For larger probe GAM is smaller but standard deviation is larger. Student's-test shows that the difference between two given GAM values is not significant statistically. Lower AV at the third measurement point are attributed to more homogeneous structure at that point.
A pair of typical echograms indicating very non-homogeneous microstructures are illustrated in Figures 1 and 2. The echogram taken on cylindrical part of the pressure vessel A with 5 MHz probe and preparation 3 of outer surface (inner surface is sand blasted) is given in fig. 1. The echogram in Figure 2 is obtained using 2,25 MHz probe and the same preparation of surfaces as for the probe 5 MHz.

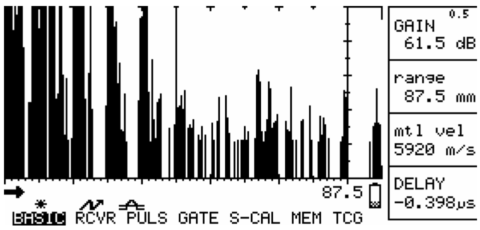

Figure 1. Echogram obtained on vessel A (5 MHz/6,3 mm probe), α_{n-1}=0,453 dB/mm

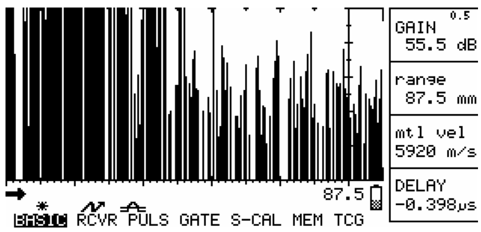

Figure 2. Echogram obtained on vessel A (2,25MHz/6,3 mm probe), α_{n-1}=0,304 dB/mm

5. MECHANICAL TESTING

Hydrogen attack not necessarily has a consequence the deterioration of material mechanical properties. Hydrogen presence in solid solution as well the exposition of a steel to gaseous hydrogen at high pressure and ambient temperature, may result in a decrease of elongation and toughness values [4].
The elongation measured is less than 14%, the required value for steels for these applications. Impact testing results at ambient temperature are satisfying when notch is perpendicular to vessel length: total energy of impact at 20°C is less than 62 J and the energy for crack propagation is less than 31 J. Values of total energy obtained at -20°C with notch in perpendicular direction are less than recommended in [3]. Moreover, the energy for crack propagation is negligible as given in Table 3.

Table 3. Values of impact toughness at - 20 °C with perpendicular notch for vessel A

Specimen No	Total energy of impact J	Energy of crack initiation J	Energy for crack propagation, J
1	32,0	31,0	1,0
2	32,6	31,5	1,1
3	33,1	32,0	1,1

The brittle component of fracture is dominant: the participation of plastic component is only 5% at -20°C in three of total five specimens and 0% in remaining two specimens. At +20°C plastic fracture participates only 20% in three of total six specimens and 5% on three remaining specimens.

6. CONCLUSIONS

Probe diameter is less significant parameter for AM than its frequency if inhomogeneities are very small. It is confirmed that AM gives indirect indications of mechanical property variations.

7. REFERENCES

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