

## POSSIBILITY OF DETERMINING STEEL GRAIN SIZE USING ULTRASONIC WAVES

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Properties of steel depend also on its internal structure. In practice, one can distinguish between primary structure (obtained during solidification) and secondary structure (being a result of the  $\gamma$  phase transition into the  $\alpha$  phase during hot working or heat treatment). The grain refinement degree obtained is assessed with microscopic examination. In this work an alternative method is proposed in the determination of the steel microstructure refinement degree. The method is based on the dependence between the high frequency sound attenuation coefficient and the average grain diameter. Sound in steel increases when the average steel grain diameter approximates the ultrasonic wave length, because of the scattering of waves on grain boundaries.

*Key words:* steel; microstructure; ultrasonic wave

**Mogućnost određivanja veličine zrna u čeliku rabljenjem ultrazvučnih valova.** Svojstva čelika ovise također od unutarnje strukture. U praksi može se razlikovati između primarne strukture (dobivena primarnom kristalizacijom) i sekundarne strukture (kao rezultat pretvora  $\gamma$  faze u  $\alpha$  fazu tijekom obradbe deformiranjem ili toplinskom obradbom). Poboljšavanje stupnja veličine zrna utvrdi se ispitivanjem mikroskopom. U ovom radu predložena je alternativna metoda za određivanje oplemenjivanja mikrostrukture u čeliku. Metoda se temelji na ovisnosti između visokofrekventnog koeficijenta prigušivanja i prosječnog promjera zrna. Prigušenje se povećava kada je veličina čeličnih zrna približna dužini ultrazvučnih valova glede rasipanja valova po granicama zrna.

*Ključne riječi:* čelik; mikrostruktura; ultrazvučni valovi

### INTRODUCTION

The microstructure of steel is decisive for its chemical, physical and mechanical properties. Depending on the parameters characterising liquid metal as well as the parameters of the steel casting influencing the crystallisation process, the macrostructure of casts and ingots consist of three, two or only one crystallisation zone. In steel ingots, its most frequent by consist of three zones: chill, columnar and equiaxed grains. The structure of finished hot worked steel depends to a considerable extent on the primary structure of cast steel. Therefore, the knowledge of the microstructure of cast steel is very important on each stage of the steel products manufacturing.

### METALLOGRAPHIC EXAMINATIONS

Metallographic examinations are used in a wide range of applications for determination of the steel macrostructure and microstructure. They enable to assess the impact of the technological treatment methods applied on the of macro and microstructure and stress changes. Importance of macroscopic and microscopic examinations applying the optical and the electron microscope.

K. Nowacki, Faculty of Materials Science and Metallurgy, Silesian University of Technology, Katowice, Poland

Macroscopy consists of visual observation of natural surfaces or specially pre-treated metallographic specimens (ground and etched with special agents). The reagents used for etching of the specimens include e.g. nital, Baumann's solution, Jacewicz's solution (especially for macroetching of alloy steels) or a solution of ammonium persulphate used for determination of the grain size in brittle timber low-alloy steels.

Observation with the optical microscope constitute the basic tool used for metallographic examinations and require the use of the full range of magnifications. In order to reveal the grain boundaries it is necessary to etch the metallographic specimen. Etching reagents attack primarily the grain boundaries. The incident light is diffused and the microscope can be used to observe the grain boundaries as dark lines. Surfaces of the individual grains of one phase can be etched more or less deeply depending on their crystallographic orientation of the examined surface. Using the optical microscope, it is possible to determine the grain size, grains shape and the dislocation distribution in metals and single-phase alloys.

Examinations in the electron microscope enable to observe the steel microstructure down to the atomic level. Generally, electron microscopes can be divided into transmission and scanning electron microscopes. Standard microscopes are used to simultaneously ana-

lyse a large area of the surface. Scanning microscopes enable analysis of a small area treated as a point [1].

## ULTRASONIC TESTS

The individual grains of polycrystalline materials have directional properties. Ultrasonic waves passing through the material of such a structure are diffused both as a result of reflections and refractions of the grain boundaries. Also small inclusions, pores, etc. contribute to the diffusion. Furthermore, diffusion in steels also depends on the beam direction relative to the direction of the grain orientation. Diffusion of waves is the main reason for attenuation of the ultrasonic waves beam in polycrystalline materials [2].

An alternative was proposed for the commonly applied metallographic examination methods, i.e. ultrasonic testing. These tests enable determination of the grain size based on the value of the attenuation coefficient or the ultrasonic waves diffusion coefficient as well as the of velocity longitudinal and transverse wave.

The ultrasonic wave attenuation coefficient  $\alpha$  is the value of the wave pressure amplitude decreases with regard to the length of the path section. The attenuation coefficient is expressed in decibels per metre. The factors influencing the attenuation coefficient for the given frequency include the material microstructure, and the changes with the frequency, i.e. with decrease of the wavelength [2]. This dependence is depicted on Figure 1 and it has been confirmed by the author's own examinations.

The relation between the attenuation coefficient measurements by constant frequency and the polycrystalline material's (Figure 2) mean grain size shows that the strongest diffusion takes place when the grain diameter is 3 to 4 times smaller than the wavelength. In other cases, when the grain size value is several times higher or lower than the wavelength, the coefficient in question exerts no significant influence on the attenuation coefficient.

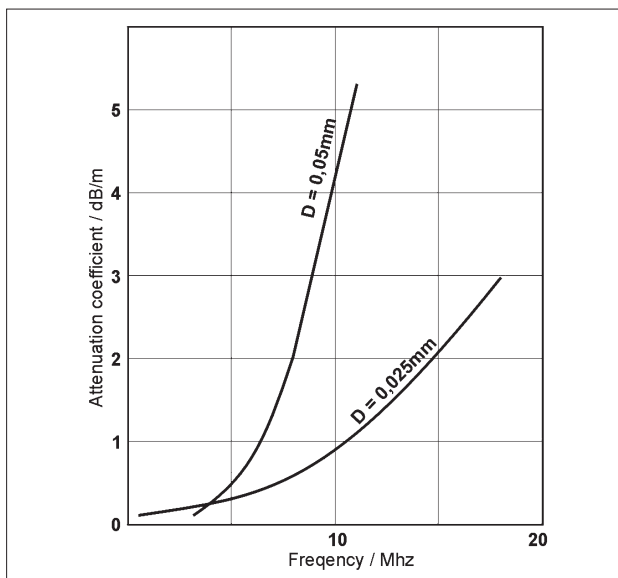


Figure 1. Dependence between the attenuation coefficient and frequency for steel grade "15" [2].

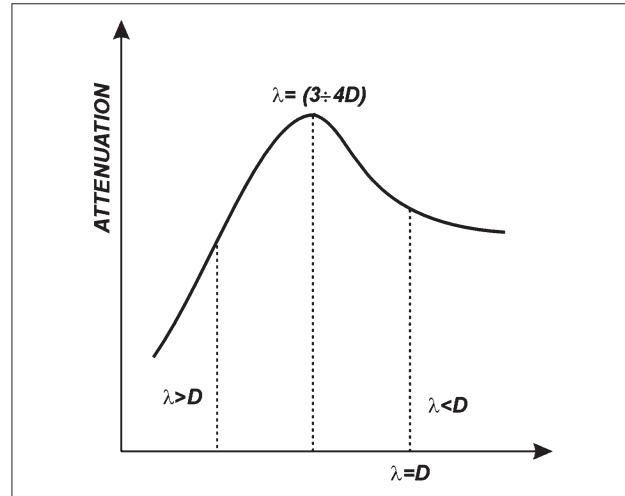


Figure 2. Dependence between the attenuation and the mean grain size  $D$  on constant frequency [2].

The extent of diffusion of waves characterised by the given length depends on the properties of adjacent grains, the type of the intercrystalline material and of the grain size. The diffusion increases considerably with wavelength decrease, i.e. the frequency increase. Significant changes taking place in the material analysed can be the reason for the so-called structural noises caused by the grain echo on the oscilloscope display. In order to avoid the structural noises, one must use ultrasonic waves of appropriate length, at least six times larger than the mean grain size. In the cases of wavelength for ca. 10 times larger than the grain diameter, the dependence between the attenuation coefficient  $\alpha$  and the mean grain size  $D$  can be expressed with the formula (1) [2].

$$\alpha = C \frac{f^4}{D^3} \quad (1)$$

where:  $f$  – frequency / MHz,  $C$  – material constant value.

The mean velocity of a longitudinal ultrasonic wave in steel at the room temperature is ca. 5950 m/s, whereas one of a transverse wave – ca. 3250 m/s. The author's own examinations of alloy steels imply that values of the both velocities for the said group of steels fall within the following ranges: 5850 – 5980 m/s for longitudinal waves and 3180 – 3240 m/s for transverse waves [3,4].

The analytical method proposed in this paper is based on the determination of the relation between the steel grain size and the attenuation and diffusion coefficients as well as the ultrasonic waves velocity measured applying the impulse method. The examinations discussed in [5] (Figure 3) suggest a considerable conformity between the steel test results obtained with application of ultrasonic methods and metallographic a grain size assessment.

## ULTRASONIC IMPULSE METHODS

Measurements of the parameters of ultrasonic waves can be conducted using one of the most commonly applied analytical methods. In accordance with the basic division

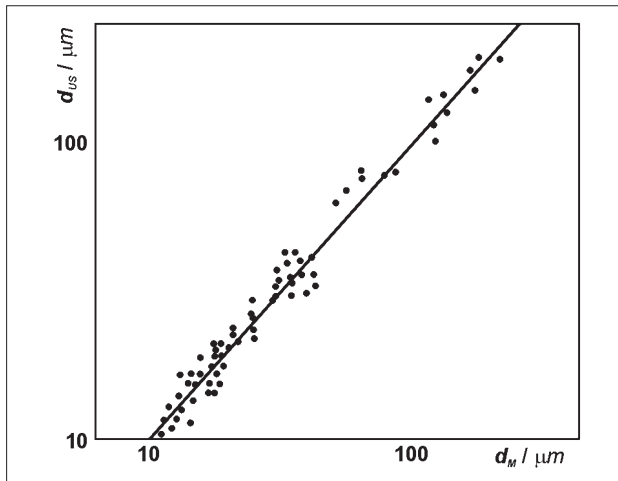


Figure 3. Comparison of grain sizes determined with application of an ultrasonic  $d_{US}$  and a metallographic  $d_M$  method [6].

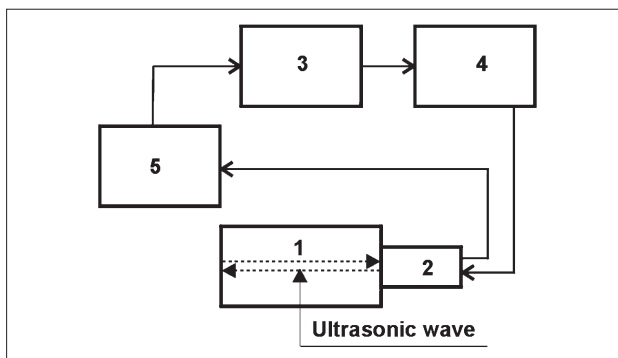


Figure 4. Measurement principle in accordance with the reflected wave method; 1 – sample, 2 – ultrasonic transducer (transmitter and receiver), 3 – computer with oscilloscope card, 4 – impulse generator, 5 – amplifier.

of analytical methods, they are classified as reflected waves methods (echo methods) or passing waves methods.

In the echo method (Figure 4), the measurement is conducted using one ultrasonic transducer functioning both as transmitter and as receiver, whereas the ultrasonic wave travel the distance of specimen double length. In practice, the reflected wave method is used in several ways, e.g. with the head directly contacting with the specimen analysed or with the delay line as a layer of liquid or solid material between the head and the specimen. The advantage of the reflected wave method is the use of one head, only. In media of low dispersion, the measurement of time between the successive echoes is a basis for the determination of the wave propagation velocity in the specimen analysed. Moreover, the attenuation measurement with application of the reflected wave method require to consider the fact that, at the boundary between the individual media, some part of the wave energy passes through the specimen whereas its other part is reflected [7].

By the passing method (Figure 5) the measurement is conducted using two transducers, the transmitter and the receiver. The transducers are positioned one in front of the other on both sides of the specimen. The transducers

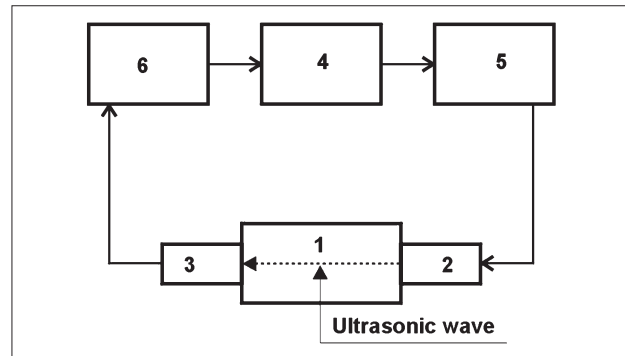


Figure 5. Measurement principle with the passing wave method; 1 – sample, 2 – ultrasonic transducer (transmitter), 3 – ultrasonic transducer (receiver), 4 – computer with oscilloscope card, 5 – impulse generator, 6 – amplifier.

can contact with the specimen or they can be placed in a certain distance by using delay lines. With regard to the single wave passage through the specimen, the advantage of the passing wave method is the possibility of examining materials with high attenuation [7].

## SUMMARY

The steel structure microexaminations conducted are primarily based on the macroscopic or microscopic metallographic methods. In the paper the possibility of determining the steel structure with application of an indirect method based on the dependencies between the steel grain size and some of the ultrasonic wave parameters is presented. The test conducted imply the possibility of empirical identification of such dependencies for individual steel grades.

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**Note:** The responsible for english language is Frane Vodopivec, Ljubljana, Slovenia.