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MATERIAL ULTRASONIC ATTENUATION INFLUENCE ON CONVENTIONAL ULTRASONIC NON-DESTRUCTIVE COPPER ALLOY CAST TESTING

Internal casting defects that are detected by radiography may also be detected by ultrasonic method. Ultrasonic testing allows investigation of the cross-sectional area of a casting, it is considered to be a volumetric inspection method. The high frequency acoustic energy travels through the casting until it hits the opposite surface or an interface or defect. The interface or defect reflects portions of the energy, which are collected in a receiving unit and displayed for the analyst to view. The pattern of the energy deflection can indicate internal defect. Ultrasonic casting testing is very complicated in practice. The complications are mainly due to the coarse-grain structure of the casting that causes a high ultrasound attenuation. High attenuation then makes it impossible to test the entire volume of material. This article is focused on measurement of attenuation, the effect of probe frequency on attenuation and testing results.

Keywords: Ultrasonic testing, ultrasonic attenuation, copper alloy casting, centrifugal casting

1. Introduction

Ultrasonic testing is used to detect defects like cracks, voids or porosity within the interior of the casting. The method uses reflection and transmission of high frequency sound waves. Ultrasonic sound waves much higher than the audible range are produced and made to pass through the casting. The time interval between the transmitted wave and reflected wave is recorded by ultrasonic defectoscope (analog or digital oscilloscope). Any crack or void in the casting results in reflection or some of the sound from the crack which appears as an echo between the two echoes representing the thickness of the casting. The depth of the crack from the surface of the casting can be easily calculated from the distance between these echoes.

Ultrasonic testing problems can be divided into two groups. One of the problems is rough casting surface at casting to sand molds, when the surface must be mechanically machined to the desired quality. The second most serious problem is the change morphology and grain size of the castings microstructure. Large grain and morphology causes high attenuation of ultrasound in material, which should be countervailed choosing the right testing methods and accessories for testing [1-3].

Practice ultrasonic testing requires a high does of knowledge and experience for an accurate interpretation of the results, which will affect the cost added to the part for the inspection.

2. Attenuation of ultrasound waves

Ultrasonic testing of castings is difficult because castings have usually a large anisotropic structure grain. The heterogeneous anisotropic cross-sectional structure of a casting is caused by a different cooling conditions during solidification of the casting in the mold (Fig. 1) [4,7,9].

These structures make dispersion of ultrasound energy. The ultrasound dispersion causes significant attenuation of ultrasonic energy in material. Rough surface of castings is also negative for ultrasonic testing, especially for small contact area between the probe and the casting. For these reasons, the ultrasonic testing of castings is not so widespread as in other types of production materials. Ultrasonic testing costs often exceed the cost of casting production of one casting [1,8,9].

The biggest problem in ultrasonic testing of castings is therefore different grain structure of the casting, which cannot be removed without following technological operation (e.g. heat treatment). Different grain size causes different attenuation in volume of the testing material. Material attenuation is also dependent on the use ultrasound probe frequency. General rule is that the higher the frequency the higher the material attenuation is present. Total attenuation in the material is expressed by Eq. 1.

$$\alpha = \alpha_p + \alpha_r \text{ [dB.mm}^{-1}\text{]} \tag{1}$$

where:

α_p – material absorbing attenuation, [dB.mm^{-1}],
α_r – dispersion attenuation, [dB.mm^{-1}].

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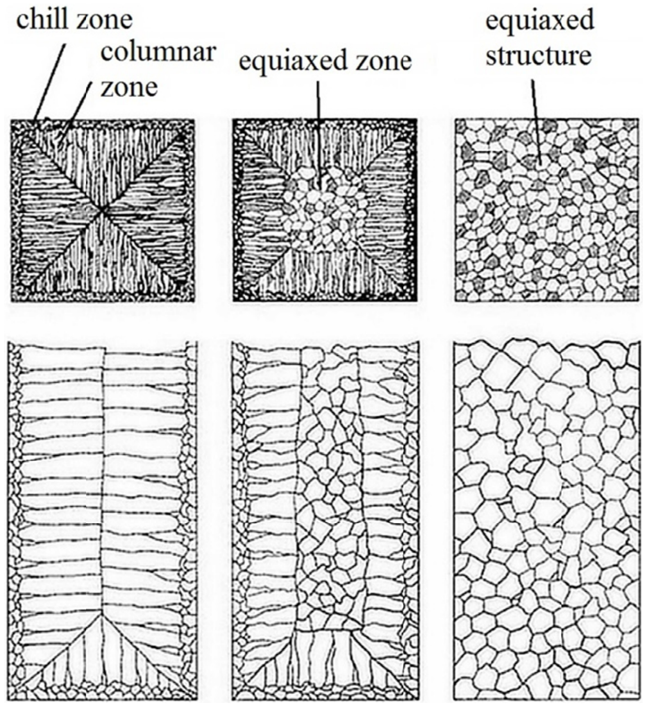

Fig. 1. Schematic illustration of three cast structures of metal: a) pure metal, b) solid-solution alloys, c) structure obtained by using nucleating agents [1]

Both attenuations occur in all types of ultrasonic waves. Generally, increasing anisotropy of the structure causes an increase dispersion attenuation. The biggest impact on attenuation is relationship between the wavelength λ and medium inhomogeneity dimension of $\bar{D}$. Dispersion attenuation is usually higher in the transverse waves than in longitudinal. Therefore the overall attenuation of transverse waves is usually higher than in the longitudinal waves at the same wavelength. Any evaluation curve cannot be used for casting testing by the diversity of attenuation in the volume of material. When evaluation of the defects is based on the commonly used curves, the effects of differential attenuation in material lead to incorrect information about the defect size. Consequently, where the castings are tested, we identify only the presence of defects, its location and approximate size [2,5,13].

3. Experimental attenuation measurements

Material of casting

Experimental part of this article describes the typical problems in practical ultrasonic testing of copper alloy castings. Chemical composition of brass ring is in Tab. 1.

Ring shaped casting was centrifugally cast with vertical axis of steel form rotation. The diameter of ring was Ø 1200 mm and its thickness of 34 mm. The experimental part is divided into two parts. The experimental methodology for measuring the material attenuation for the longitudinal ultrasonic wave using contact direct probe and also effect of frequency probe to attenuation

TABLE 1

Chemical composition of experimental brass ring (in wt.%)

Chemical element	**Zn**	**Pb**	**Sn**	**P**	**Mn**	**Fe**	**Ni**	**Si**
wt. %	46.09	4.98	0.80	>1.32	0.89	0.88	0.27	0.66
Chemical element	**Al**	**S**	**As**	**Bi**	**Se**	**Sb**	**Cu**	**—**
wt. %	0.14	>1.16	>0.60	<0.01	>1.68	>1.44	33.11	—

value is described in the first part. The second part of the article deals with dependence of ultrasonic attenuation by brass grain size [1,2,4,13].

The effect of frequency on the attenuation change

The first experiment was focused on determine the effect of attenuation depending on the used frequency. Material attenuation mainly depends on the size and shape of the grain structure. Therefore the choice of the frequency and the position of the probe on casting is very important. Four probes with frequencies 5.00 MHz, 3.50 MHz, 2.25 MHz and 1.00 MHz were used in experiment for illustration [4,10].

The probe with a frequency of 5.00 MHz has a type designation SM-A551, 3.50 MHz probe has designation A550S-SM, probe with frequency 2.25 MHz has designation C606 and probe with frequency 1.00 MHz has designation C603. The experiment was conducted on the outer surface of the ring in the seven points. The measurement line was positioned parallel to the axis of the ring. The measurement scheme is illustrated on Fig. 2.

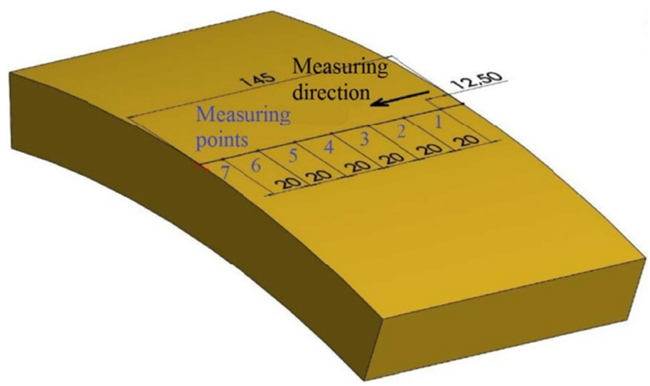

Fig. 2. Scheme of measuring direction and probe position for experiment

Probe and system calibration was performed directly at the test object in the place with the lowest attenuation (in point No. 1), which was on the edge of the casting. Calibration was performed based on the position of the first and second end echo on the screen flaw of defectoscope Olympus OmniScan MX2 using the setting wedge delay and velocity [4,11].

The principle of attenuation measurement by direct contact ultrasonic probe (longitudinal wave attenuation) is established to measure the acoustic energy difference of the first and second backwall echo in dB. This value is divided by the actual distance traveled by ultrasound in mm. The result is the attenuation value of material for a given frequency in the units dB.mm^{-1}. Thus, the attenuation is ultrasound energy loss per unit of length (Fig. 3).

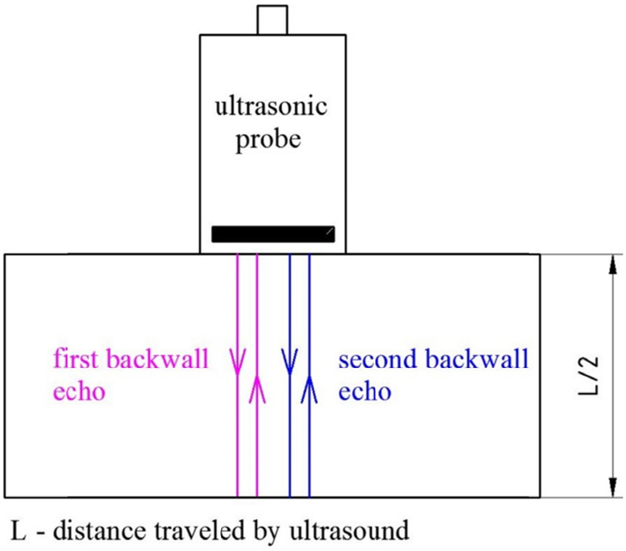

Fig. 3. The principle of attenuation determining

The results have confirmed the expected change of attenuation along the line of measurement. In some cases it was even impossible to identify the second backwall echo on the defectoscope display. This is the case of the probes with frequencies of 5.00 MHz and 3.50 MHz. The second echo was identifiable only in the position of the probes on ring in points 1, 6 and 7. In the remaining points it was not possible to identify the second backwall echo, therefore could not be determined material attenuation. Attenuation was be measured at all points with probes with frequency of 2.25 MHz and 1.00 MHz. Velocity of longitudinal ultrasonic waves was also measured in experiment. Results of attenuation and velocity measurements are listed in Tab. 2.

The results confirmed the theoretical assumption that with decreasing frequency attenuation decreases. Attenuation at 5.00 MHz frequency is about 2.3 times larger as at 1.00 MHz. The use of a lower frequency probe therefore makes it possible to test the materials of greater thickness. Probe with maximal frequency of 2.25 MHz can be used to testing of this ring. However, with decreasing frequency, control sensitivity on internal defects decreases [1,6,11].

Change of attenuation depending on the grain size and its effect on the echoes shape

Samples for microstructure evaluation were taken from locations of attenuation measurement of ultrasonic energy 1, 2, 3, and 4. Grain size was measured at the prepared samples. The measurement points 5, 6 and 7 were not evaluated by microstructure because it is symmetrical structure sample (microstructure in point 1 = 7, 2 = 6, 3 = 5). The images of the microstructure with echoes (5.00 MHz and 1.00 MHz) are shown on Figures 4-7.

Microstructure photo in point 1 with echoes obtained with 5.00 MHz and 1.00 MHz probes is on Fig. 4. The average grain size in point 1 is 0.19 mm. This grain size causes a significant attenuation at the 5 MHz frequency. Significant attenuation is visible on the echogram as the ultrasonic signal noise from microstructure located between the transmitting pulse and the backwall echoes. Only two echoes are present on an echogram at a 5.00 MHz frequency. The attenuation noise from microstructure is not visible when using a 1 MHz frequency probe, which is due to a lower attenuation due to a lower frequency. Three backwall echoes are on echograme.

The average grain size in point 2 is 0.24 mm. The increasing grain size is caused by increasing attenuation at the 5 MHz frequency. The increasing ultrasonic signal noise from microstructure is visible on the echogram located between the transmitting pulse and the backwall echoes again. Only one backwall echo is present on an echogram at a 5.00 MHz frequency, second backwall echo is invisible, due to high attenuation. The 1.00 MHz echograme is without visible attenuation from microstructure.

The average grain size in point 3 is 0.56 mm. Ultrasonic noise echoes have already reached half the height of the backwall echo in 5.00 MHz probe frequency echogram. High ultrasonic noise from microstructure (up to 30% full height screen - FSH)

TABLE 2

Material attenuation and longitudinal wave velocity in brass ring

Measuring point	Ultrasonic probe frequency							
	5.00 MHz		3.50 MHz		2.25 MHz		1.00 MHz	
	c_L [m.s^{-1}]	α [dB.mm^{-1}]	c_L [m.s^{-1}]	α [dB.mm^{-1}]	c_L [m.s^{-1}]	α [dB.mm^{-1}]	c_L [m.s^{-1}]	α [dB.mm^{-1}]
1	4384	0.2456	4418	0.2231	4415	0.1566	4430	0.1303
2		—		—		0.2427		0.1678
3		—		—		0.2492		0.1779
4		—		—		0.2466		0.2018
5		—		—		0.2108		0.1859
6		0.2647		0.2250		0.1055		0.1399
7		0.2235		0.2103		0.1055		0.0954

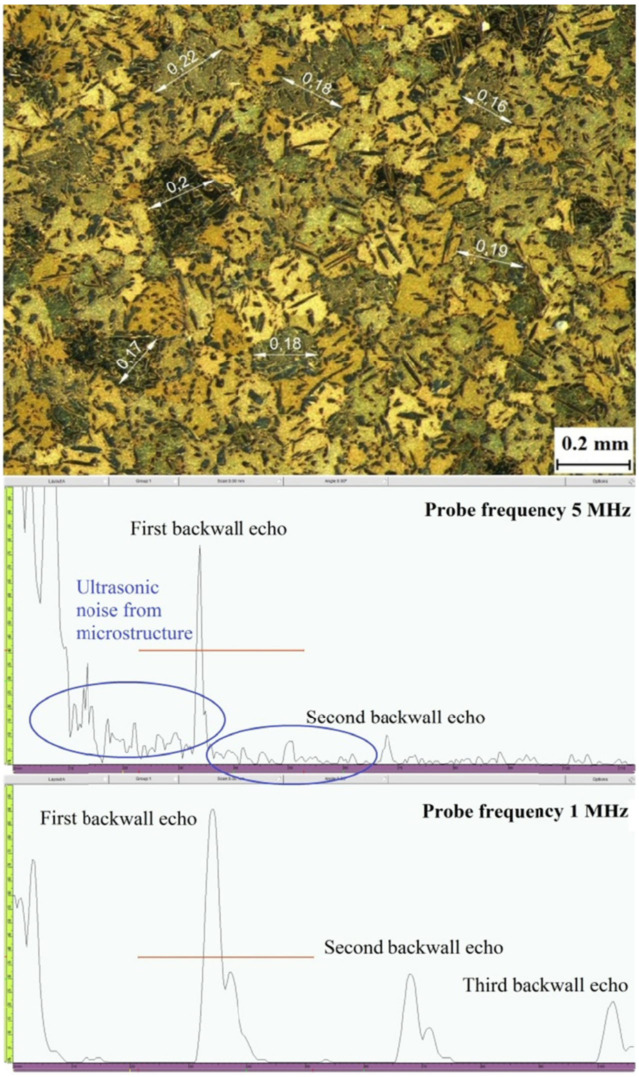

Fig. 4. Brass microstructure in point No. 1 (top), 5 MHz echogram (middle) and 1.00 MHz echogram (bottom)

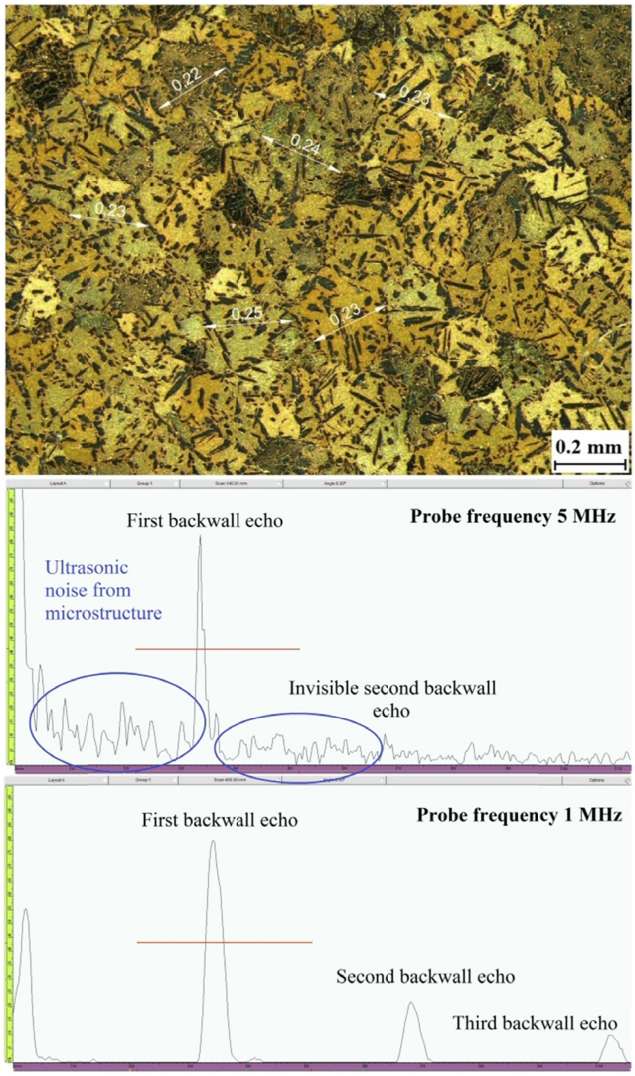

Fig. 5. Brass microstructure in point No. 2 (top), 5 MHz echogram (middle) and 1.00 MHz echogram (bottom)

will cause the defect echoes to be merged with noise echo and defect will not be indicated in this case. The 1.00 MHz echo-grame is clear with only three backwall echoes.

The average grain size in point 4 is 0.62 mm. The 5.00 MHz probe cannot be used for this grain size because the high noise level is presented on the echogram. It is possible to use max. 2.25 MHz for ultrasonic testing of castings of this grain size. The 1.00 MHz echogram is on Fig. 7. Echogram is without noise from microstructure with three distinct backwall echoes.

The average grain size and attenuation is shown in Tab. 3.

TABLE 3

Average grain size and attenuation

Measuring point	Average grain size [mm]	Attenuation [dB.mm^{-1}]	
		2.25 MHz	1.00 MHz
1	0.19	0.1566	0.1303
2	0.24	0.2427	0.1678
3	0.56	0.2492	0.1779
4	0.62	0.2466	0.2018

The results of attenuation measurements and microstructure evaluation confirmed that increasing grain size increases ultrasound attenuation, which is directly proportional to the used probe frequency. The dependence of the attenuation on the grain size is on Fig. 8.

4. Conclusions

The article deals with real problems when testing of castings with large grained structure is performed. The topic is focused on the effect of frequency and grain size on the attenuation of ultrasound energy. Probe frequencies 1.00 MHz, 2.25 MHz, 3.5 MHz and 5.00 MHz were used to determine dependence frequency, grain size and ultrasound attenuation. Ultrasonic attenuation increases with the increase in frequency and grain size. There must always be a good compromise between frequency and attenuation for reliable ultrasonic testing. Ultrasonic probes with a maximal frequency of 2.25 MHz can be recommended for ultrasonic testing based on experimental measurements.

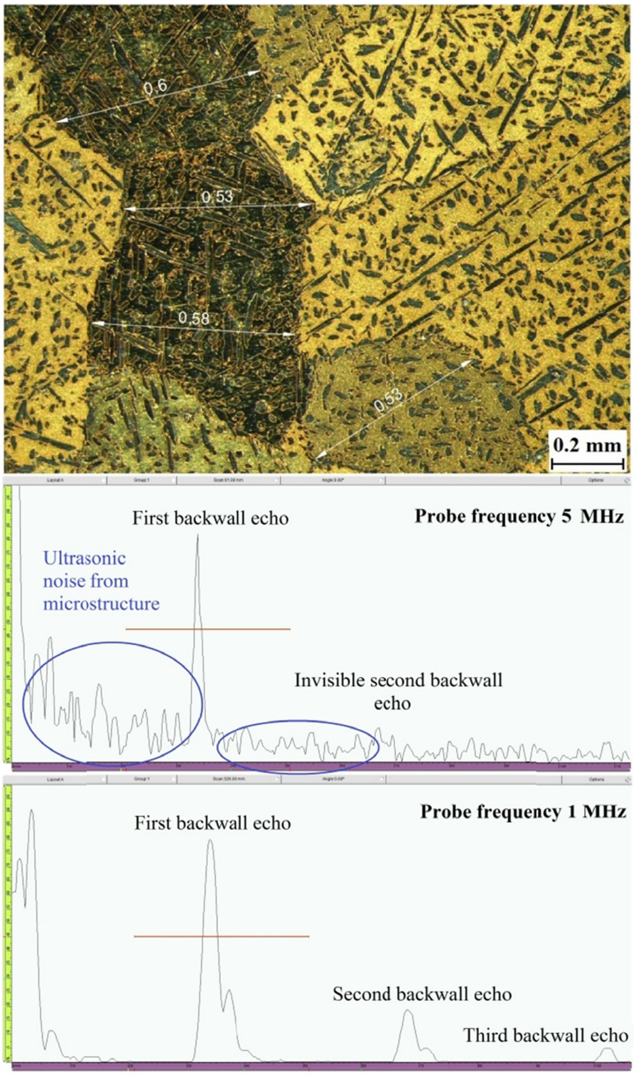

Fig. 6. Brass microstructure in point No. 3 (top), 5 MHz echogram (middle) and 1.00 MHz echogram (bottom)

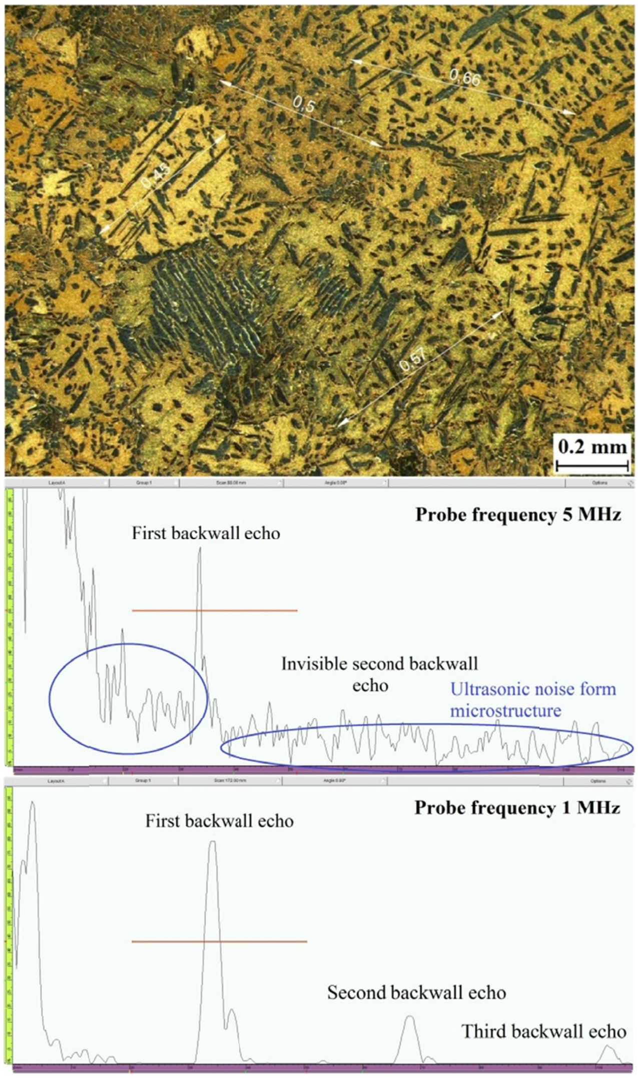

Fig. 7. Brass microstructure in point No. 1 (top), 5 MHz echogram (middle) and 1.00 MHz echogram (bottom)

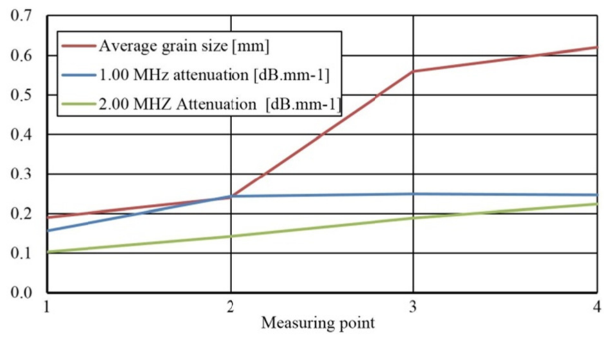

Fig. 8. The dependence of the attenuation on the grain size

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