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Ultrasonic Inspection Techniques Possibilities for Centrifugal Cast Copper Alloy

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Abstract

The article deals with ultrasonic testing possibilities of the copper alloy centrifugal casts. It focused on the problems that arise when testing of castings is made of non-ferrous materials. Most common types of casting defects is dedicated in theoretical introduction of article. Ultrasonic testing technique by conventional ultrasound system is described in the theoretical part too. Practical ultrasonic testing of centrifugal copper alloy cast - brass is in experimental part. The experimental sample was part of centrifugally cast brass ring with dimensions of Ø1200x34 mm. The influence of microstructure on ultrasonic attenuation and limitations in testing due to attenuation is describes in experimental part. Conventional direct single element contact ultrasound probe with frequencies of 5 MHz, 3.5 MHz and 2 MHz were used for all experimental measurements. The results of experimental part of article are recommendations for selecting equipment and accessories for casting testing made of non-ferrous metals.

Keywords: Non-destructive testing, Centrifugal casts, Ultrasonic attenuation, Copper alloy, Brass microstructure

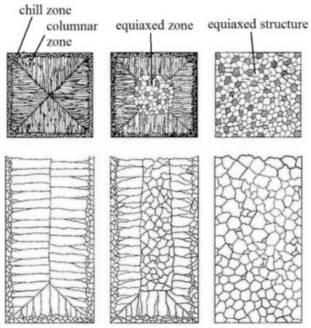
1. Introduction

The art of casting metal into specific shapes goes back thousands of years, but it is only in recent decades that modern ultrasonic NDT tools have been available to help insure product integrity. In ancient times, a foundryman might tap a casting with a hammer to judge its quality by the sound of the ring. Today, microprocessor-based instruments that also utilize sound waves can provide much more information about the hidden internal structure of both ferrous and non-ferrous castings [1, 2].

Ultrasonic testing in foundry practice is most often used as a production of non-destructive testing. Testing is mainly used for identification of relatively large dimensions volume and surface defects such as shrinkage cavities, porosity, hot cracks, cold shuts, etc. Ultrasonic testing of castings made of non-ferrous metals, is quite demanding. 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 fundamental 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, 5].

2. Attenuation of ultrasound

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 (Figure 1) [4, 7, 9].



a.) b.) c.)

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]

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. Attenuation in the material is expressed by the formula:

$$\alpha = \alpha_p + \alpha_r \ [dB.mm^{-1}] \qquad (1)$$

where:

α_p - material absorbing attenuation,

α_r - dispersion attenuation.

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 $\overline{D}$. 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, 8].

3. Experimental measurements

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

Table 1.
Chemical composition of brass ring in [%]

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

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 value is describes in the first part. The second part of the article deals with dependence of ultrasonic attenuation by brass grain size.

3.1 Change of attenuation depending on the frequency

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. Three probes with frequencies 5 MHz, 3.5 MHz and 2 MHz were used in experiment for illustration.

Probes type Acuscan was used for experiment. These are probes with narrow frequency band and long pulses. The probe with a frequency of 5 MHz has a type designation SM-A551, 3.5 MHz probe has designation A550S-SM and probe with frequency 2 MHz has designation PN20-20. The experiment was conducted on the outer surface of the ring in the seven points (Figure 2).

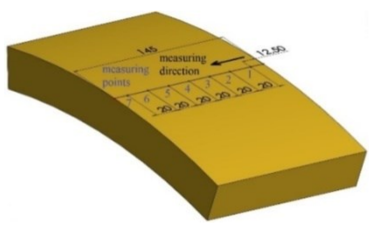


Fig. 2. Scheme of measuring direction and probe position for experiment

Probe and system calibration was performed directly at the test object in the place with the lowest attenuation, 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 MX2.

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 travelled 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 (Figure 3).

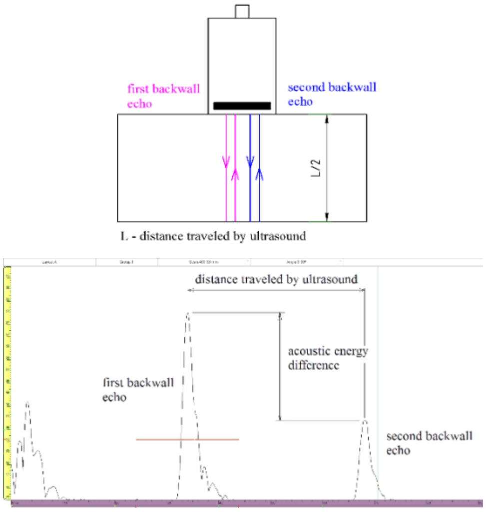


Fig. 3. The principle of attenuation determining

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 MHz and 3.5 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 being measured at all points with probes with frequency of 2 MHz. Velocity of longitudinal ultrasonic waves was also measured in experiment. Results of attenuation and velocity measurements are listed in Table 2.

Table 2.
Material attenuation and longitudinal wave velocity in brass ring

	Ultrasonic probe frequency					
	5 MHz		3.5 MHz		2 MHz	
Point	c_L [m.s^{-1}]	Attenuation [dB.mm^{-1}]	c_L [m.s^{-1}]	Attenuation [dB.mm^{-1}]	c_L [m.s^{-1}]	Attenuation [dB.mm^{-1}]
1	4384	0.2456	4418	0.2231	4409	0.1029
2	4384	-	4418	-	4409	0.1426
3	4384	-	4418	-	4409	0.1882
4	4384	-	4418	-	4409	0.2235
5	4384	-	4418	-	4409	0.1750
6	4384	0.2647	4418	0.2250	4409	0.1000
7	4384	0.2235	4418	0.2103	4409	0.0691

The results confirmed the theoretical assumption that with decreasing frequency attenuation decreases. Attenuation at 5 MHz frequency is about 2.5 times larger as at 2 MHz. The use of a lower frequency probe therefore makes it possible to test the materials of greater thickness.

3.2 Change of attenuation depending on the grain size

Samples for microstructure evaluation was taken from locations of attenuation measurement of ultrasonic energy 1, 2, 3, and 4. Grain size was measured on the prepared samples. The measurement points 5, 6 and 7 was not evaluated by microstructure because it is symmetrical structure sample. The images of the microstructure are shown in Figure 4. – Figure 7.

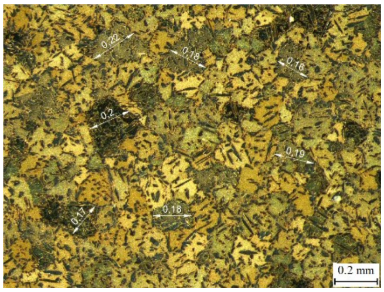


Fig. 4. Brass microstructure in point No. 1

Fig. 5. Brass microstructure in point No. 2

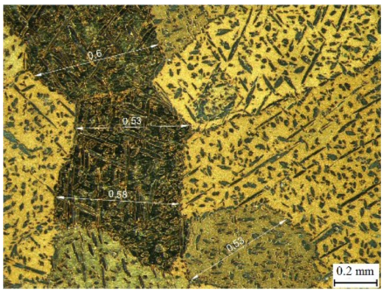


Fig. 6. Brass microstructure in point No. 3

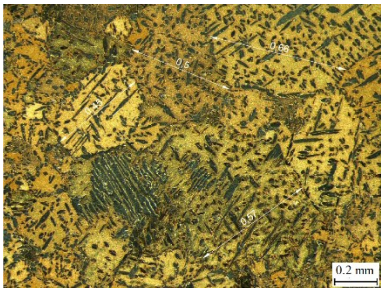


Fig. 7. Brass microstructure in point No. 4

Table 3 shows the average grain size in the individual points of measurement. Measurement of average grain size was graphically done.

Table 3.
Average grain size and attenuation

Measuring point	Attenuation 2 MHz [dB.mm^{-1}]	Average grain size [mm]
1	0.1029	0.19
2	0.1426	0.24
3	0.1882	0.56
4	0.2235	0.62

Comparing grain size and attenuation it was confirmed that with increasing of grain size increases attenuation material too (Figure 8).

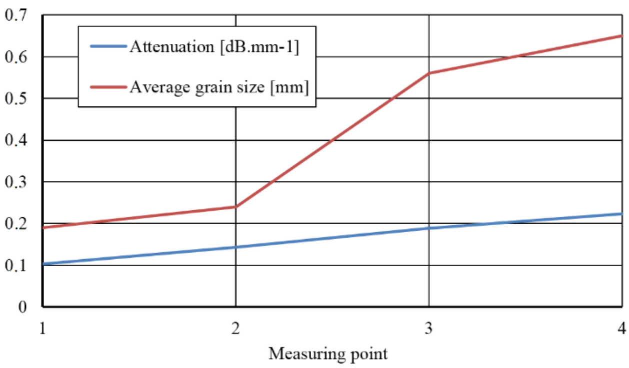


Fig. 8. Attenuation and average grain size in measuring points

Comparing grain size and attenuation it was confirmed that with increasing of grain size increases attenuation material too.

Attenuation in castings causes problems when the evaluation curves are used for defect evaluation. It's because during their formation a constant material attenuation is considered. Constant attenuation is not retained when castings are tested. Incorrect determination of equivalent defect size may occur when evaluation curves are used in testing.

In practical testing castings for not considering attenuation could become the unacceptable defect due to attenuation reflecting energy corresponding to the acceptable defect. For this reason, it is very difficult to use evaluation curve for ultrasonic testing of such castings.

4. Conclusions

The article deals with real problems when testing of castings with large grained structure is performed. The results of experiments show that attenuation of the ultrasound in the material cross-section is different and depends mainly on the frequency and size of the grains. The results also confirmed the assumption that it is not appropriate to use the evaluation curve for casting testing. Probe with low frequency (1-2 MHz) is suitable to use for ultrasound test castings, however the testing sensitivity decreases. The compromise between these facts should always be done when testing castings.

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