



ARCHIVES

of

FOUNDRY ENGINEERING

ISSN (2299-2944)

Volume 19

Issue 2/2019

9 – 14

10.24425/afe.2019.127108

2/2



Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

# Ultrasonic Control of Ductile Cast Iron Castings by Phased Array Technique

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Received 22.02.2019; accepted in revised form 02.04.2019

## Abstract

The goal of this article is non-destructive ultrasonic testing of internal castings defects. Our task was to cast several samples with defects like porosity and cavities (where belongs mostly shrinkages) and then pass these samples under ultrasonic testing. The characteristics of ultrasonic control of castings are presented in the theoretical part of this article. Ultrasonic control is a volume non-destructive method that can detect internal defects in controlled materials without damaging the construction. It is one of the most widely used methods of volume non-destructive testing. For experimental control were made several cylindrical samples from ferritic grey and ductile cast iron. Because of the form and dispersion of graphite of grey cast iron it was not possible to make ultrasonic records on this casting with probe we used, so we worked only with ductile cast iron. Ultrasonic records of casting control are shown and described in the experimental part. The evaluation of the measurement results and the reliability of the ultrasonic method in castings control is listed at the end of this article.

**Keywords:** Ductile cast iron, Technological casting parameters, Ultrasonic testing, Phased array

## 1. Introduction

Ultrasonic testing has arisen from the need to detect internal defects of forgings and rollers where cannot be used X-Ray testing and where these defects could cause serious damage of machine parts. Ultrasonic testing of castings is difficult because of the rough grain structure on which the ultrasonic beam is usually dispersed. In graphitic cast iron is attenuation of the ultrasonic caused also by the graphite shape and dispersion in the matrix of the base material. Casting defects are usually spatial, and they have a random orientation. For this reason, casting analysis is not as widespread as for other types of metallic materials. Steel castings can be tested by ultrasonic if they made are of low-alloy steels. Most preferred is the testing after normalization annealing which soften the structure. When a reflection method cannot be

used, we need to use transition method, ideal for immersion bonding, which guarantees a good passage of the ultrasonic beam even on the unmachined surface of the casting.

## 2. Ultrasonic control of castings

Non-destructive testing of cast components is not so extended as testing of welds. Cast testing by using ultrasonic methods is quite hard because usually the component consists of a thick anisotropic grain structure on which the ultrasonic beam is heavily dispersed. Anisotropic material is a material which mechanic – physical properties are different in each way. During manufacture of castings, defects like shrinkage, cavities which are filled with gas and porosity occurs so as non-metallic inclusions

from the sand or slag and cracks due to stresses during solidification. Defects except cracks are spatially dissected and have random orientation. That is the reason why UT testing of castings did not expand so much as in other types of construction materials. The other reason is that testing itself is too complicated and expensive in comparison to the cost of the casted component. If the components are tested the only thing that is examined is the presence of defects, their location (position) and approximate size. Casted iron can be tested on at lower frequencies which relies on the shape, size and amount of dissolved graphite. Components with thin walls allow testing by using probes with frequencies 2 MHz at bigger thicknesses frequency 1 MHz is used. In some cases, there is the need to use frequencies from 0,5 to 0,8 MHz. [1–4]

The velocity of ultrasonic expansion is related to the amount and shape of graphite. This leads to the relation of velocity and attenuation depending on the wall thickness of the casted component. At thin wall components that cool down faster the velocity of spreading is higher because the structure has smaller grain size. In Fig. 1 you can see an example of anisotropic material, where the good direction of testing and direction with big attenuation is shown. [5]

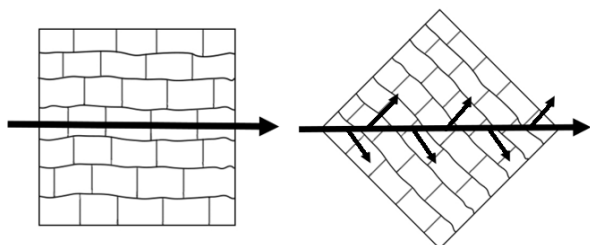


Fig. 1. Testing of anisotropic material – good direction of testing (left), direction with big attenuation (right) [5]

Ultrasonic testing has a sense at evaluating the mechanical properties of casted iron. To be more specific the velocity of ultrasonic waves exhibits good correlation. When it is possible the velocity is measured by using deflection method. Often the dead area of the probe at low frequencies has a significant damping and the testing must be provided by applying transition method. [6, 7]

Basics of transition method is measuring the value of ultrasonic energy which goes thru the tested material. There are two probes where one transmits and the second receives the ultrasonic energy. If the material includes a defect, the defect will create a shadow and the receiver receives less energy. The defect is analysed by comparing the values of received energy from the material without a defect and with a defect. This method is suitable for components with thinner wall thickness. [8–10]

Deflection method is the most common method. Here the probe has a function of transmitter and receiver. Short ultrasonic waves are transmitted into the examined component where they deflect from the surface of the component into his inner defects. After deflection the ultrasonic wave comes back to the receiver (if there is a twin probe the wave is received not by the converter that transmitted the wave but to the converter that works as a receiver). Time trend of the impulse in the material is presented on the screen of the measuring device. The defect echo will show between the source and the end echo. [11, 12]

Defect of the casting is the deviation of shape, appearance, weight, size and macrostructure from related specifications or established technical conditions. They have a negative influence on the manufacturing process and its fluency. The defects of castings can be divided as unacceptable, acceptable and repairable. Unacceptable defect is a deviation from the specifications or established conditions which is not removable, or the repair of the casting is unacceptable or economically not profitable. At acceptable defects the deviation is tolerated, and the use of the casting is possible even with the defect. Repairable defects are deviations where by using a well suitable repair procedure (flattening, annealing, welding) that is according to the specification. [13–15]

However, there are some factors that influence the results of the ultrasonic testing method. Among the device and the probe most significant are acoustic binding, tested surface, tested material, shape of the component and the properties of the defect. [16]

### 3. Experimental part

The experimental part is aimed at identifying internal defects in castings by non-destructive ultrasonic Phased array method. A reflection ultrasonic method was used to test the cast samples. The aim of the experiment was to cast cylindrical test samples, with technological conditions of casting being designed to produce natural defects in the casting volume. Experimental samples were cast into a sand mould. This sand mould was compacted by hand. The inflow system had the intake on the bottom of the mould (Fig. 2). The test samples were made from ductile cast iron (GJS).

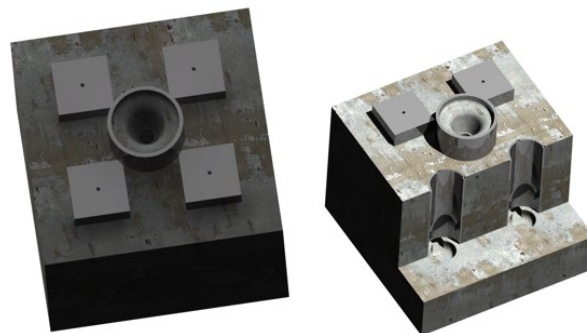


Fig. 2. 3D model of the whole mould (left) and the cut of the mould (right) [5]

Preparation for melting and casting of samples was carried out in the laboratory of casting at the Department of Technological Engineering at University of Zilina. The casting of the cast iron took place in an electric induction furnace in a graphite melting-pot with a protective refractory material. The individual technological parameters casting of the test samples are shown in Table 1. The chemical composition of the test samples is shown in Table 2.

Table 1.

Technological parameters of the test samples casting of ductile cast iron (GJS)

| Material | The casting temperature [°C]<br>(± 5°C) | Pressure [MPa]         | Melting pot temperature [°C]<br>(± 50°C) |
|----------|---|------------------------|--|
| GJS      | 1400                                    | Casted gravitationally | 700                                      |

Table 2.

Chemical composition of cast samples

| Material | Fe (hm. %) | C (hm. %) | Si (hm. %) | Mn (hm. %) | P (hm. %) | S (hm. %) |
|----------|------------|-----------|------------|------------|-----------|-----------|
| GJS      | 91,610     | 4,260     | 3,378      | 0,605      | 0,010     | 0,012     |

For the preparation of cast iron, crude iron, steel scrap, litvar7 type modifier and graphitization inoculant FeSi75 were

used. The chemical composition of litvar7 type modifier and inoculant FeSi75 is shown in Table 3.

Table 3.

Chemical composition of the inoculation and the modifier

| Type    | Fe(hm. %) | C (hm. %) | Si (hm. %) | Mn (hm. %) | Mg (hm. %) | P (hm. %) | S (hm. %) | Al (hm. %) | Ca (hm. %) |
|---------|-----------|-----------|------------|------------|------------|-----------|-----------|------------|------------|
| Litvar7 | 39,5      | 0,49      | 42,0       | -          | 6,91       | -         | -         | -          | 1,2        |
| FeSi75  | -         | 0,1       | 75         | 0,5        | -          | 0,04      | 0,02      | 0,1        | 0,1        |

Then samples were machined to achieve the desired dimensions (Ø50-60 mm and Ø70 - 80 mm) and surface quality (Fig. 3).



Fig. 3. Created experimental samples

### 3.1. Ultrasonic testing of test samples

Produced experimental samples were tested using UT deflection method. As a device the OmniScan MX2 modular defectoscope from Olympus was used.

The EchoMix ultrasonic gel was used as the binding medium and testing amplification was set up to 80 dB. Evaluation of the measured data was provided on the OmniPc 4.2 software. Measurement itself took place on the front of the cylinder and Phased array probe which specification and dimensions are shown in Table 4 was used.

Table 4.

Probe Specifications and Dimensions

| Probe    | Item number | Frequency (MHz) | Number of Elements | Pitch (mm) | Active Aperture (mm) | Elevation (mm) | External Dimensions L, W, H (mm) |
|----------|-------------|-----------------|--------------------|------------|----------------------|----------------|----------------------------------|
| 5L64-A12 | U8330593    | 5,0             | 64                 | 0,60       | 38,4                 | 10,0           | 45, 23, 20                       |

Using this probe, we were able to capture the linear E-scan from the defects found in the casting volume. For the ultrasonic testing a 64-element Phased array probe which can display the entire sample volume on one record was used. The casting conditions were set so that the occurrence of the shrinkage in the casting volume was assumed. In two cases the assumed defect in the casting volume was not created, in two cases in the sample volume the defect was created. Samples were cut in the measuring line after the ultrasonic testing and we took a photo of the macrostructure defects from the cut. The photo of the macrostructure of the individual samples is assigned to the ultrasonic recordings. On Fig. 4 is shown microstructure of experimental cast samples.

In ES Beam Tool 5, the position of the probe before the ultrasonic testing was simulated. Experimental measurement was performed on two samples. The measurement was performed along the selected line through which the samples were cut to obtain the macrostructure. On Fig. 5 we can see the macrostructure of sample no. 1 and on Fig. 6 position of the probe when checking the sample no. 1 as well as location the defects in the castings.

On macrostructure it's possible to see the shrinkages in the sample volume. These are cavities, which in this case do not lead to the surface the experimental sample but are enclosed inside the casting. They arise in places which solidify last, that is, in the hot spots. Cavities are caused by loss of volume due to solidification and cooling of the metal. On Fig. 7 is located ultrasonic record of experimental sample no. 1 using a PA probe.

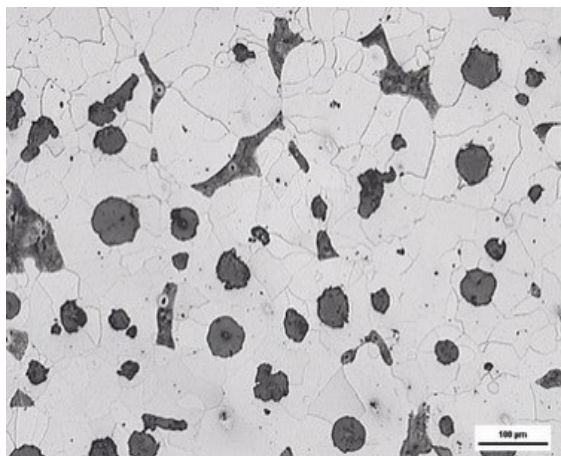


Fig. 4. Microstructure of experimental samples

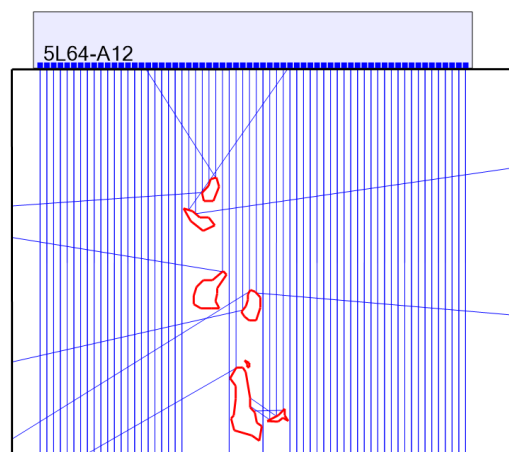


Fig. 6. Probe position at sample check no. 1

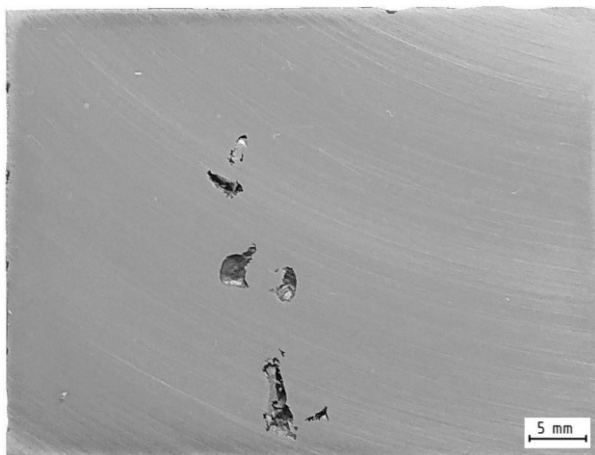


Fig. 5. Macrostructure of the experimental sample no. 1

On Fig. 7 it is possible to see the ultrasonic record using a 64-element PA probe. The probe allowed by its aperture to display the entire sample volume below the measured line at one position. The record contains the A-scan on the left and the linear E-scan on the right. At the bottom of the E-scan you can see the end-echo. By the occurrence of internal defects in the sample on place of the blue cursor on the E-scan, end echo weakens to a minimum. This is due to internal defects that prevent ultrasonic energy transition on the opposite surface. Changing the end echo intensity can be considered as an indirect indication from internal defects. The direct indication, that would arise by direct reflection of the defect, is not visible. Ultrasonic record without the presence of direct indication from defects is caused by inappropriate tilting the areas of the surface of the defects, what caused reflection of the ultrasonic energy outside the probe. On Fig. 8 we can see the macrostructure of sample no. 2 and on Fig. 9 position of the probe when checking the sample no. 2 as well as location the defects in the castings.

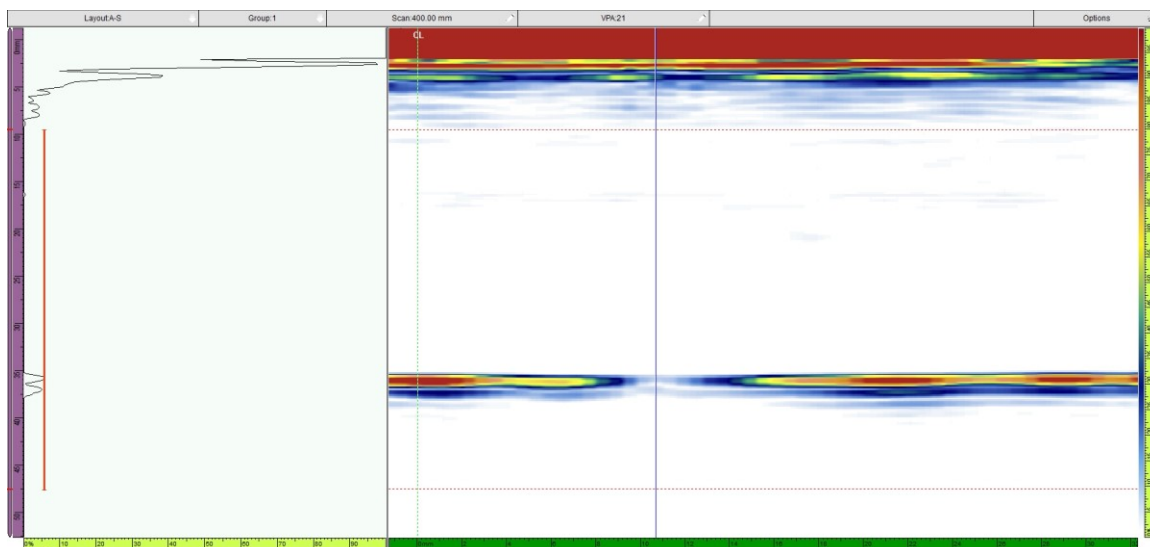


Fig. 7 Ultrasonic record experimental sample no. 1 using a PA probe



Fig. 8. Macrostructure of the experimental sample no. 2

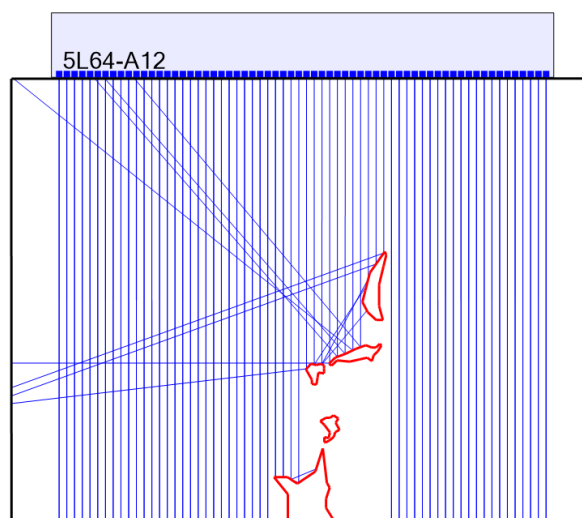


Fig. 9. Probe position at sample check no. 2

On macrostructure is seen again the shrinkages. These shrinkages are enclosed inside the casting, only one leads onto the surface of the casting. Again, applies that shrinkages arises in hot spots. The solution for elimination shrinkages is to improve solidification conditions, proper riser design eventually decreasing amount of gasses in melt. On Fig. 10 is located ultrasonic record of experimental sample no. 2 using a PA probe.

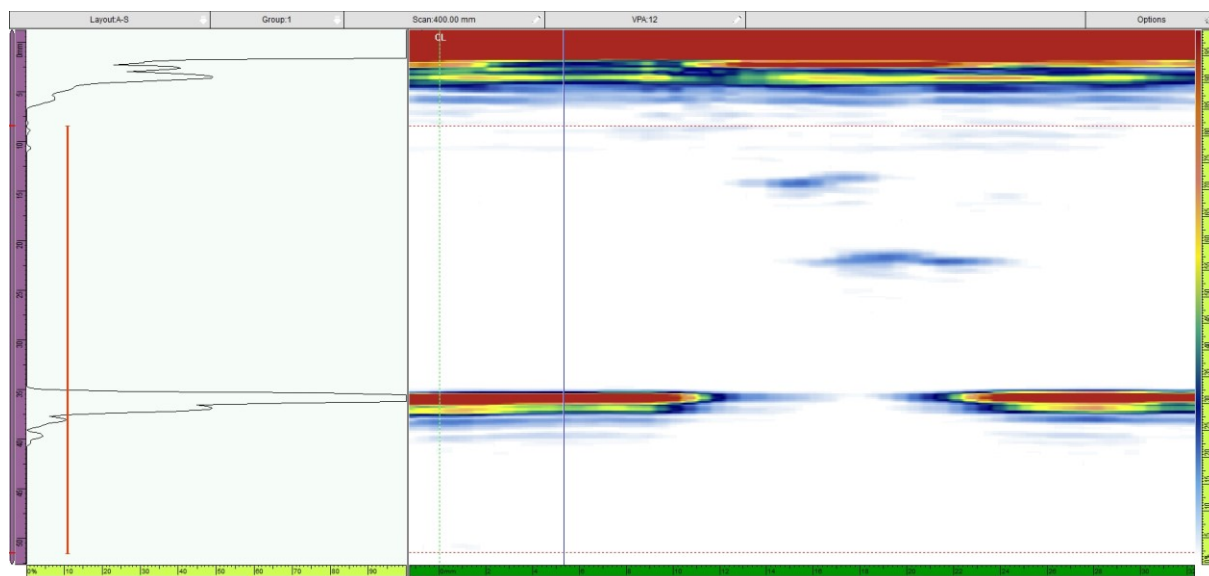


Fig. 10. Ultrasonic record experimental sample no. 2 using a PA probe

On Fig. 10 it is again possible to see the ultrasonic record using a 64-element PA probe. Even in this case, the probe also allowed the whole sample volume to be displayed below the measurement line. The ultrasonic record contains the A-scan on the left and the linear E-scan on the right. At the bottom of the E-scan, it is possible to see the end echo, whose intensity even in this case at the defect sites is also attenuated. There are direct

indications too on the ultrasonic record, from which the defect position under the probe can be determined.

At sample no. 2, direct indications were also found on the ultrasonic measurement record. This is mainly due to the shape, orientation and arrangement of the defects in the sample.

When controlling castings by ultrasonic testing, the control should be performed from several nonparallel surfaces of the

casting. In this case, when checking the casting from the cylindrical surface (small area diameter), there was insufficient acoustic bond, so it was not possible to make a record with enough sensitivity.

## 4. Conclusions

Castings testing by ultrasonic Phased Array technique is mainly dependent on attenuation of the casting material, the surface quality and its geometry. The experimental part of the article focuses on the ultrasonic testing castings of ductile cast iron. The dispersion and globular graphite form allow for the use of higher frequencies (5-15 MHz) for testing, what ensure a higher sensitivity of control compared to grey cast iron, which can be tested by frequencies at 1-2 MHz. It is clear from the experimental results when ultrasonic testing of the castings can be considered as a defect-indication also decrease of the end echo without the presence of a direct indication. Obtaining direct indications is dependent on the shape and orientation of the castings defect. The shape and orientation of castings defects is almost always random, so it is not possible always to predict direct indication, which was also confirmed by experimental results.

## Acknowledgements

The research was supported by the Slovak Research and Development Agency under the contract no. APVV-16-0276 and no. APVV-17-0310.

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