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Ultrasound application for detection of inhomogeneities in two-layer sheet

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Abstract. The paper presents data on the influence of additives of the pre-treated aluminium oxide powder on the structure of cast lead-tin-based bronzes. Different quantities of the modifier, based on the superdispersed aluminum oxide powder, were added to the bronze melt. The studies have shown that addition of a small amount of aluminum oxide powder (0.07...0.25 %) allows modifying the microstructure of the obtained castings. This modification includes grain refinement, reduction of the matrix dendrites size of tin solid solution in copper, as well as formation of spherical inclusions of the low-melting phase – lead. In this case, the addition of such modifier influences weakly the morphology and the quantity of solid eutectoid inclusions based on electron compound $\text{Cu}_{31}\text{Sn}_8$.

1. Introduction

Equipment made of bimetallic sheet, which consists of two different metals, is increasingly applied in industry. The basic layer (thick) is necessary to assume the loads, and deposited (thin) to protect the base metal from corrosion. The use of bimetals allows saving expensive and rare metals, which significantly reduces the cost-effectiveness of manufactured equipment [1-3].

Russian metallurgy industry produces a diverse range of bimetals, the base of which, in most cases, is made of low-carbon structural steel, and special steels are used as coatings – corrosion or heat-resistant, non-ferrous metals, antifriction alloys, etc. The most widespread ones are double-layer steels, which are used to manufacture critical parts and products. In this regard, the need to control both the bimetal itself and the products made from it is becoming ever more acute [4].

Characteristic defect of a bimetal is a discontinuity in the adhesion of the layers at the boundary of the coating with the base. Improving the reliability of the detection of such defects is an important practical task.

Improvement of methods of control applying conventional methods of non-destructive testing and the use of widely distributed equipment, such as general-purpose ultrasonic flaw detectors, are of particular interest.

2. Ultrasonic Flaw Detection

The ultrasonic flaw detectors of general purpose are designed to control products for the presence (detection) of defects such as discontinuity and homogeneity of materials, products and semi-finished products, welded joints, measuring the ratio of the amplitudes of signals from defects, depth and coordinates of their occurrence. Devices can be applied in mechanical engineering, metallurgy, transport, shipbuilding, energy, construction and other industries [10-13].



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The experimental studies described in the article were carried out using an ultrasonic flaw detector UD 2-70. This is a portable handheld flaw detector implemented on a microprocessor base, designed for the application of non-destructive testing operations for equipment in the oil and gas industry, boiler and transport equipment. The device scanning range is 2-5000 mm with a step of 1 mm, indicating their coordinates. It can work in pulse-echo, mirror-shadow and shadow control modes.

The flaw detector is operated with the help of keys and menus. After switching on the device the screen is illuminated with three fields: the main (central) part of the screen displays the signal information (grids, echo signal, DAC and ADS curves), the work menu is located in the right part of the screen (for example, amplification, width of the control zone, the level of the vertical position are reflected for the strobe, the response setting of the ADS), and at the bottom field - the information zone.

3. Test Bench Description

The test bench is designed for the inspection of bimetal products by ultrasonic flaw detectors. A general view of the test bench is shown in Figure 1.

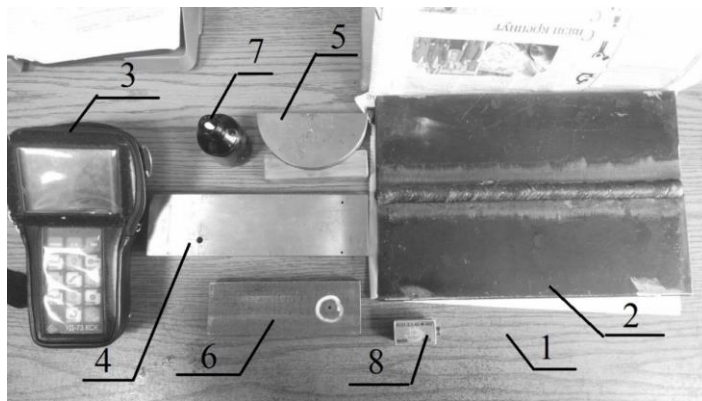


Figure 1. A general view of the test bench:

1 – desktop; 2 – strip; 3 – flaw detector; 4 – standard sample number 2; 5 – standard sample number 3; 6 – standard (production) sample (16 mm); 7 – contact liquid container; 8 – piezoelectric transducer.

The test bench consists of the following elements:

- desktop;
- strips 09G2S + 08H17N13M2T ($300 \times 200 \times 16$);
- two flaw detectors UD2-70 and UD-73;
- standard samples No. 2 and No. 3;
- standard samples (production sample) with thicknesses of 8, 10, 16, 20 mm with two notches;
- container with contact liquid.

4. Processing of experimental data

To obtain experimental data, the device is adjusted before each measurement; therefore, the rejectable level obtained from the notches on the standard production samples and the echo signal from the interface in the bimetal gives different values. The difference between the echo signals from the boundaries of the interface in the bimetal and the rejectable level in dB is determined for the unification of the data obtained in experimental studies. The echo signal “amplification” is recorded at 50% of the flaw detector screen. The echo signal level from the rejectable and phase boundary was displayed on the flaw detector screen in the upper right corner, shown in Figure 2 [14-17].

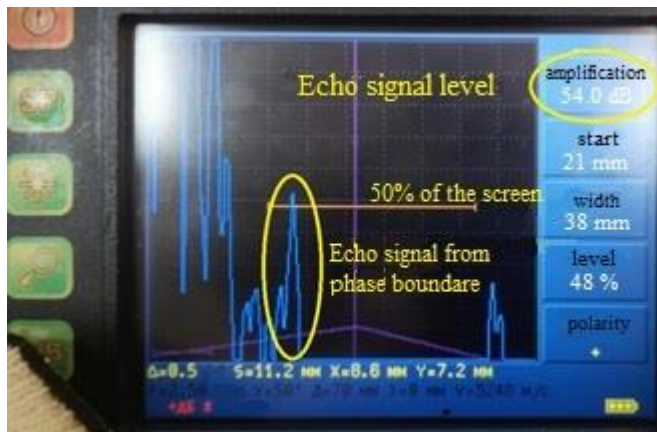


Figure 2. An echo signal from the phase boundary and its level

Studies have been conducted to determine the dependence of the signal amplitude difference on the angle of the prism and frequency of the transducers, as well as on the thickness of bimetallic strips.

5. Results and Discussion

In the course of the experiment, strips ($h = 8, 10, 16, 20$ mm) were sound tested by various transducers with frequencies of 1.8, 2.5 and 5 MHz, with prism angles of $40^\circ, 45^\circ, 50^\circ, 60^\circ, 65^\circ, 70^\circ$. Echo signals from the base metal boundary and the deposited layer were detected. The results of the sonic test are presented in Table 1.

Table 1. Results of sonic test of strips

Prism angle	Ultrasound frequency, MHz											
	1.8				2.5				5.0			
	Strips thickness, mm											
	8	10	16	20	8	10	16	20	8	10	16	20
Signal amplitude difference, dB												
40°	7	9	12	8	8	9	11	15	x	x	x	x
45°	10	10	14	11	9	10	13	16	x	x	x	x
50°	11	11	15	12	11	14	15	17	5	8	16	19
60°	14	10	14	16	16	20	18	21	6	10	20	20
65°	15	10	20	19	18	20	21	22	8	11	23	22
70°	x	x	x	x	17	21	23	25	8	14	24	26

Graphical dependences of the signal amplitude on the prism angle and frequency of the transducer based on the results of sonic tests are plotted. Dependencies are shown in Figures 3-6.

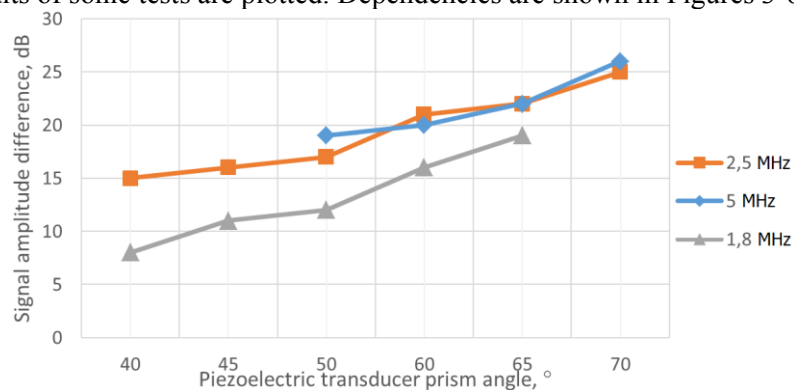


Figure 3. Dependence of the difference of the signal amplitude on the piezoelectric transducer frequency and the prism angle for a 20 mm thickness.

The piezoelectric transducer with a frequency of 1.8 MHz is optimum for a thickness of 20 mm according to the graphical dependence presented in Figure 4, since the difference in the amplitudes of the echo signals from the phase boundary is the smallest. The echo signal from the phase boundary can be detected easier with a frequency of 1.8 MHz than that of 2.5 and 5 MHz. The reason is a large amount of noise at 2.5 and 5 MHz.

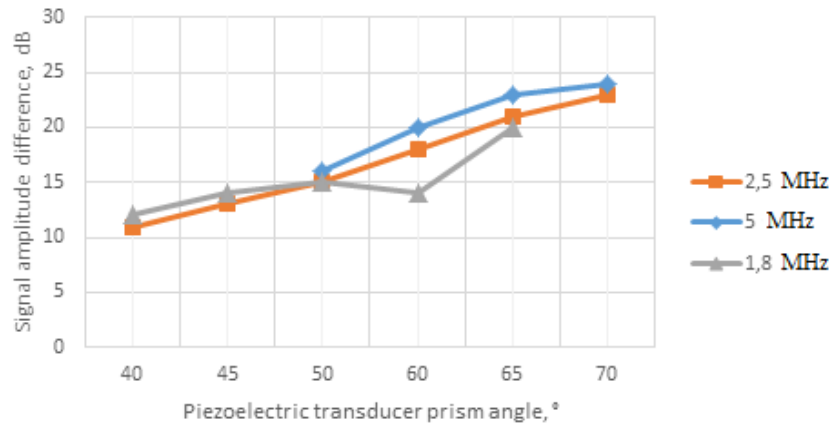


Figure 4. Dependence of the difference of the signal amplitude on the piezoelectric transducer frequency and prism angle for a thickness of 16 mm.

According to Figure 4, the piezoelectric transducer with frequencies of 2.5 and 1.8 MHz is optimum for a thickness of 16 mm since the difference in the amplitudes of echo signals from the phase boundary is the smallest. But the echo signal from the phase boundary can be detected easier with a frequency of 2.5 MHz than that of 1.8 and 5 MHz. The field direction of the searcher of the piezoelectric transducer with a frequency of 2.5 MHz is narrower than that with the frequency of 1.8 MHz.

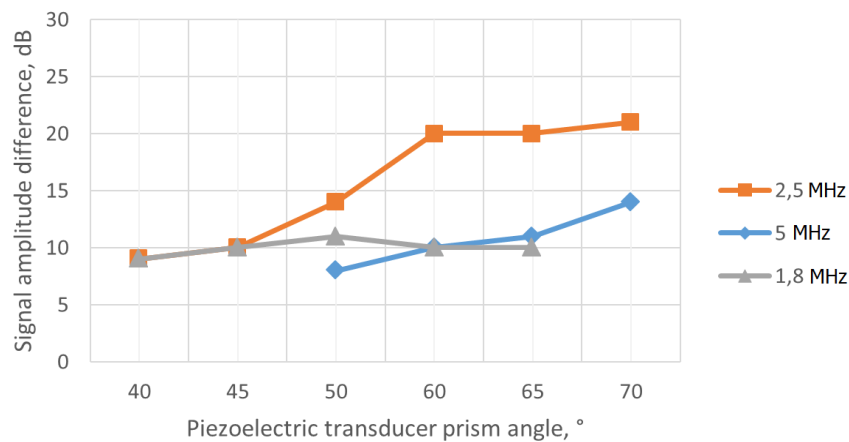


Figure 5. Dependence of the difference of the signal amplitude on the piezoelectric transducer frequency and prism angle for a thickness of 10 mm.

The optimum for the thickness of 10 mm is the piezoelectric transducer with frequencies of 5.0 and 1.8 MHz since the difference between the amplitudes of the echo signals and the interface is the smallest. But the echo signal from the phase boundary can be detected easier with a frequency of 5.0 MHz than with that of 1.8 and 2.5 MHz. As the piezoelectric transducer has a frequency of 5.0 MHz, the directivity of the search field is narrower than that for frequencies of 2.5 and 1.8 MHz. Due to the large amount of noise in the 1.8 MHz piezoelectric transducer, there is an error because of the human factor.

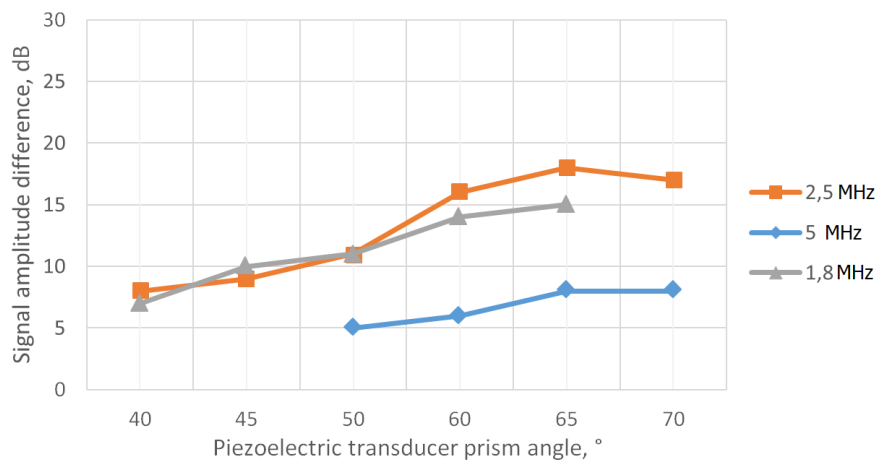


Figure 6. Dependence of the difference of the signal amplitude on the piezoelectric transducer frequency and prism angle with a thickness of 10 mm.

From the graphical dependence presented in Figure 6, it follows that the optimum piezoelectric transducer for a thickness of 8 mm is a transducer with a frequency of 5.0 MHz. Due to the fact that the piezoelectric transducer has a frequency of 5.0 MHz, the directivity of the field of the searcher is narrower than that for the frequencies of 2.5 and 1.8 MHz.

Analyzing the dependence of the echo signal amplitude on the piezoelectric transducer frequency and prism angle for thicknesses of 8, 10, 16, 20 mm, one can observe a general trend of increasing the difference in the amplitude of the echo signal by increasing the piezoelectric transducer prism angle. This is due to the fact that increasing the input piezoelectric transducer angle increases the path of the echo pulse to the phase boundary in the bimetal.

On the basis of the results obtained, the following recommendations on the use of ultrasonic methods for the control of double-layer sheet to detect defects at the boundary of the alloying of metals can be made:

1. For sheets with a thickness of 16–20 mm, piezoelectric transducers with a frequency of 1.8 MHz and an input angle of 40° to 50° are optimal.
2. For bimetals with a thickness of 14–16 mm, piezoelectric transducers with a frequency of 2.5 MHz and an input angle of 40° to 50° will be optimal.
3. For a sheet with a thickness of 8–14 mm, piezoelectric transducers with a frequency of 5.0 MHz and an input angle of 50° to 65° are optimal.

6. Conclusion

This article describes the method of ultrasonic testing of bimetals using a general purpose flaw detector UD2-70.

Ultrasonic testing of strips with thicknesses $h = 8, 10, 16, 20$ mm was carried out using various piezoelectric transducers. The flaw detector was tuned to the required thickness by electronic distance-amplitude compensation (DAC) before each sonic test of a double-layered sheet.

According to the research, it has been found that with an increase in the thickness of the bimetal and the piezoelectric transducer prism angle, the difference in signal amplitude increases, which complicates the selection of the signal from the interface due to noise. As the frequency of the piezoelectric transducer increases, the signal amplitude difference will decrease and the echo signal from the border will be detected easier, but the complexity of the flaw detector tuning will increase.

Based on the results obtained, the optimum characteristics of piezoelectric transducers (oscillation frequency, prism angle) have been selected for the most common bimetal thicknesses from 8 to 20 mm used in machine building.

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