Development of an ultrasonic method to determine the residual thickness of refractory blocks

Short Communication

Development of an ultrasonic method to determine the residual thickness of refractory blocks

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An ultrasonic method was developed to measure the residual thickness of refractory blocks at an operating glass melting furnace. This ultrasonic measuring method was used to determine the thickness of zirconia-based refractories on a small laboratory glass melting furnace. Two ultrasonic transducers with a silica delay and a coupling media were used to measure the transition time, that the ultrasonic signal needs with the applied echo method. The results of the thickness measurements at cold and hot refractory blocks were compared. The investigations prove the possibility to employ the ultrasonic device for determining the residual thickness of refractory blocks.

Entwicklung einer Ultraschallmeßmethode zur Bestimmung der Restwanddicke von feuerfesten Steinen

Eine Ultraschallmeßmethode ist entwickelt worden, um die Restwanddicke von feuerfesten Steinen an einer laufenden Wanne zu bestimmen. Diese Ultraschallmeßmethode wurde benutzt, um die Dicke von feuerfesten Steinen auf der Basis von Zirkonoxid in einem kleinen Laborglasschmelzofen zu ermitteln. Zwei Ultraschallköpfe mit einer Vorlaufstrecke und einem Koppelmittel wurden eingesetzt, um die Schallaufzeit zu messen, die das Ultraschallsignal bei der angewandten Echomethode benötigt. Die Ergebnisse der Dickenmessung an kalten und heißen feuerfesten Steinen wurden verglichen. Diese Untersuchungen zeigen, daß die Meßanordnung zur Ultraschallmessung der Restdicke von feuerfesten Steinen anwendbar ist.

1. Introduction

Until now no precise method for the determination of the residual wall thickness of refractories is available. Visual inspection and temperature monitoring in the infrared region with thermovision equipment lead only to inaccurate and estimated results. The idea to achieve this determination with ultrasonic methods is not new, but the progress in the development of ultrasonic sensors, ultrasonic and electronic equipment makes it more feasible nowadays.

There is the need to measure the actual wall thickness of refractory material at operating glass tanks in view of an optimum assessment of the remaining lifetime of the furnace, the minimization of downtime for inspection and repair, the minimization of the risk of a leak and as a help for constructive changes at a running furnace (for example: setting supplementary electrodes).

2. Experimental set-up

Figure 1 shows the experimental set-up of the test equipment. A personal computer is equipped with two supplementary boards for controlling the ultrasonic equipment and for data acquisition, respectively. Two ultrasonic transducers (one as transmitter and one as receiver) with a silica delay each are necessary. The transducers generate a broadbanded ultrasonic signal with a nominal frequency of 500 kHz. The transition time of the ultrasound is determined with the software of the data acquisition board and the thickness of the block is calculated.

The silica delays act as a buffer material to protect the transducers against the heat of the refractory blocks (cooled soldier blocks: 180 to 300 °C; without cooling: up to 600 °C) and to guide the ultrasonic signal. Other delay materials could be used to protect the piezoelectric transducer against heat [1], but considering acoustic properties, availability and processing, silica seems to be the best.

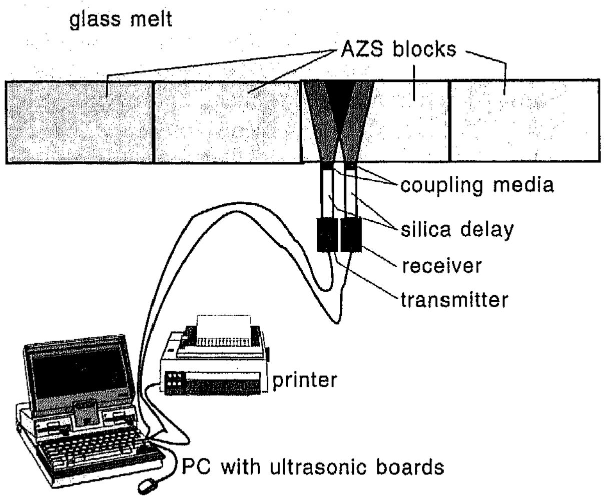

Figure 1. Experimental set-up.

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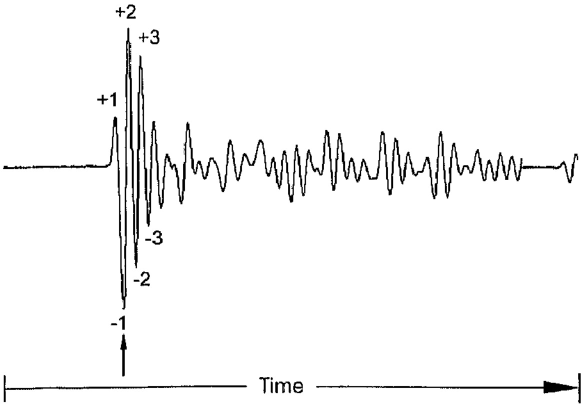
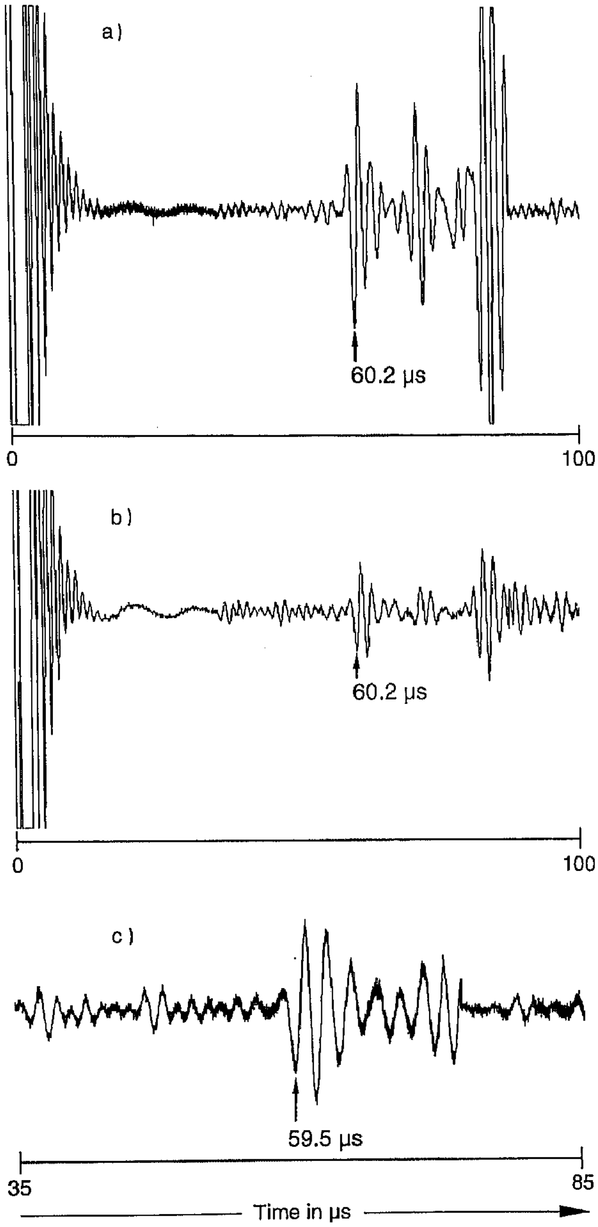


Figure 2. "Original" ultrasonic signal (A scan), with the typical 3 positive (marked with +1 to +3) and negative (marked with −1 to −3) peaks.



Figures 3a to c. Ultrasonic signal measured at a fused-cast AZS block with 32 wt% zirconia, a) cold block, b) hot block with flue gases of about 1400 °C inside the furnace, c) hot block in contact with glass melt of about 1350 °C.

To minimize the loss of sound energy, occurring with the transition of the ultrasonic signal from the delay into the refractory material, coupling media are used. Different coupling media have been selected in laboratory test, depending on the temperature of the refractory block at the outside:

- 20 to 200 °C: commercial coupling media,
- 180 to 300 °C: nickel- or copper paste,
- 300 to 470 °C: commercial high-temperature coupling media,
- above 450 °C: solder glass (lead borate glass),
- above 520 °C: solder glass (alkali phosphate glass).

3. Calculation of the thickness

To calculate the thickness d of the refractory block, the transition time t_t of the fastest longitudinal wave, the transition time of the delays t_d and the sound velocity of the longitudinal wave v_l in the investigated refractory material are necessary:

$$d = \frac{(t_t - t_d)\, v_l}{2}\,. \qquad (1)$$

The "original" ultrasonic signal is shown in figure 2. This signal can be received when the two delays are held together. As the signal is then determined with the transmission technique, the positive and negative half-waves are phase-inverted in comparison to the reflected signal. Figure 2 shows the transmission signal with a phase alternation, so that it looks like the signal that is received with the echo technique for the residual thickness measurement. This typical signal with its 3 positive (+1 to +3) and 3 negative (−1 to −3) peaks, strictly speaking the first negative peak (figure 2, peak −1), is looked for in the ultrasonic measurements. The transition time t_t is the time of the first negative peak. The time difference from one peak to another may be an additional help to distinguish the signal of the fastest longitudinal wave from the noise, which originates from scattering and reflection of ultrasound and electrical interference.

The transition time of the silica delays depends on their length. With the used silica delays of 100 mm each, the transition time of the delays adds up to 36.7 µs.

Laboratory tests and tests on a small laboratory glass melting tank showed that the temperature dependence of the sound velocity is not as important as the variation of the sound velocity from block to block and within one block, respectively, due to the conditions of the production of the refractories. If

Table 1. Calculated thicknesses of different fused-cast refractory blocks

AZS block	thickness in mm	calculated thickness in mm		
		cold block	hot block, flue gases inside the furnace	hot block in contact with glass melt
no. 1	75	70.5 ± 7.0	70.5 ± 7.0	68.4 ± 6.8
no. 2	120	116.1 ± 11.6	111.9 ± 11.2	109.2 ± 10.9
no. 3	120	125.2 ± 12.5	114.7 ± 11.5	109.7 ± 11.0

former investigations [2 and 3], laboratory tests and investigations on the small glass tank are taken into account, the following values of sound velocity v_l of different fused-cast AZS refractory materials can be assumed:

- AZS with 32 wt% ZrO_2: 6000 m/s,
- AZS with 41 wt% ZrO_2: 5850 m/s.

The deviation of the sound velocity (±10 %) limits the accuracy of the ultrasonic determination of the residual wall thickness. This can theoretically be eliminated with a different arrangement of transducers using 3 of them.

4. Results of ultrasonic investigations

Figures 3a to c show ultrasonic signals, signal amplitude versus time (A scan), of a fused-cast AZS block with 32 wt% of zirconia determined on a laboratory glass melting unit. First the cold block was examined (figure 3a). After heating up the glass tank the hot block with flue gases of about 1400 °C inside the furnace was tested (figure 3b). After filling the furnace with cullet the hot block in contact with glass melt of about 1350 °C was at last investigated (figure 3c). Figures 3a and b show the ultrasonic signal in the range between 0 and 100 μs whereas figure 3c shows the ultrasonic signal between 35 and 85 μs.

An additional signal of the same shape as shown in figure 2 may be seen, sometimes even with a higher amplitude than the first signal that characterizes the thickness of the block (see figure 3a). This second signal is probably due to the surface wave that finds its direct way from the delay of the transmitter to the delay of the receiver on the surface of the block. The signal of the surface wave is seen later than the signal of the reflected longitudinal wave, because the sound velocity of the surface wave is about half as fast as the velocity of the longitudinal wave. As the attenuation of the longitudinal beam passing the block is high, the amplitude of the surface wave may be higher than the amplitude of the "real" signal.

Table 1 compares the real thicknesses of different investigated fused-cast blocks with the calculated thickness determined with the ultrasonic method. Figures 3a to c show the ultrasonic signals received through the investigation of block no. 1. Block no. 2 contains 32 wt% zirconia like block no. 1 whereas block no. 3 contains 41 wt% zirconia. The variations of the calculated block thicknesses as recorded in table 1 are due to the deviation of the sound velocity mentioned in section 3.

5. Summary

An ultrasonic method and an arangement of ultrasonic and electrotechnical equipment, that could be used to determine the residual wall thickness of refractory blocks, were tested on refractory blocks on a small glass melting unit. These investigations proved the possibility to employ this method and the corresponding equipment. Further investigations will be carried out to develop a device that will work under industrial conditions.

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