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# Estimation of the Thickness of Refractory Ceramics by the Impact-Echo Method

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## 1. Introduction

Refractory bricks can withstand elevated temperature as high as 1600°C but degradation of its dimension and properties can occur because furnaces normally operate for a long period of time. If the degradation due to a long period of operation is excessive, refractory bricks must be replaced. However, it is difficult to check the degradation from outside of the furnace. Furthermore, the furnace shut down cost is very high for replacement of degraded bricks. Therefore, the survey to evaluate accurate degradation condition of the refractory is mandatory. Acoustic non-destructive testing techniques used for the evaluation of the current refractory structure are acoustic emission (AE), ultrasonic pulse-echo, and impact-echo methods [1].

In this paper, the furnace lining thickness of refractory bricks has been evaluated by the Impact-Echo method [2]. For the purpose, material properties of the refractory were measured first. Then, the vibration characteristics of the refractory specimens were analyzed using the finite element method (FEM). Based on the results, the thicknesses of the bricks were evaluated through the impact-echo tests. The same technique was applied to evaluate a multilayered brick structure.

## 2. Characterization of the Refractory Bricks

Impact-echo is a method to measure the location of flaws and the thickness of specimens through recording the transient stress waves generated by impact and analyzing the waveform in frequency domain [2]. Thickness of the refractory can be measured using Eq. (1):

$$f = \frac{\beta C_p}{2T} \tag{1}$$

where $f$ is the frequency of fundamental mode of vibration, $\beta$ is a shape factor, $C_p$ is longitudinal sound velocity, and $T$ is the thickness of the refractory along the measurement direction. The fundamental mode frequency is found through the impact-echo measurement. Once the $f$ is found, we can determine the $T$ with known values of $\beta$ and $C_p$.

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**Fig. 1** is a photograph of the refractory brick characterized in this study, which has the dimension of 200 mm × 400 mm × 150 mm. The ultrasound wave velocities of the brick were measured by the through transmission method. They are 2974 m/s, 2982 m/s, and 2656 m/s in width (X), length (Y), and height (Z) directions, respectively. These results mean that the refractory specimen has anisotropic material properties.

Fig. 1 Photograph of the refractory specimen.

## 3. Modal Analysis by the FEM

The vibration modes of the refractory were analyzed by the FEM. The bricks were considered to have tetragonal crystal symmetry in its material properties. A commercial FE analysis software PZFlex® was used for the harmonic analysis. The fundamental mode frequency along X, Y, and Z directions were found to be 7.36 kHz, 3.64 kHz, and 8.84 kHz, respectively. Harmonic analysis results along the X direction of refractory are presented in **Fig. 2** as a sample case.

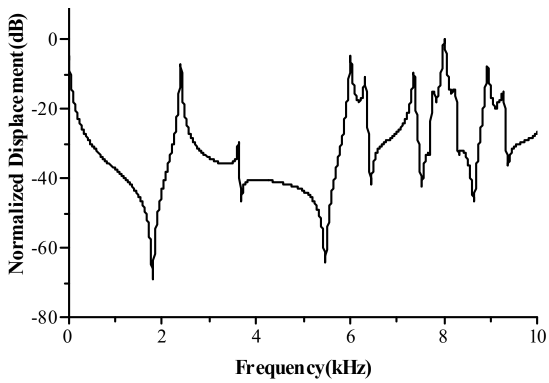


Fig. 2 Frequency response of the refractory in X direction from the FE harmonic analysis.

## 4. Impact-echo Test of the Refractory Brick

Vibration characteristic of the refractory were measured in the three directions using the impact-echo technique. Representative result is presented in **Fig. 3**. **Table I** lists the fundamental frequencies determined from the measurements, the thickness evaluated with Eq. (1), the actual thickness, and the difference between the measured and actual thicknesses. As the difference between the measured and actual thicknesses is less than 4%, the impact-echo technique can be said to be applicable to measure the thickness of refractory specimen within this error range.

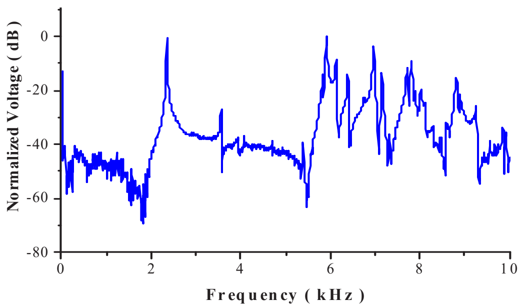


Fig. 3 Measured frequency response of the refractory specimen along X direction.

Table I. Evaluated thicknesses of the refractory brick.

| | Fundamental Frequency (kHz) | Measured Thickness (mm) | Actual Thickness (mm) | Difference (mm) |
|---|---|---|---|---|
| X | 7.16 | 199.37 | 200 | 0.63 |
| Y | 3.56 | 402.07 | 400 | 2.07 |
| Z | 8.86 | 143.89 | 150 | 6.11 |

## 5. Impact-echo Test of a Multilayered Refractory Brick

The methodology used for the single layer refractory specimen was applied to characterize a multilayered structure of the refractory. After attaching an aluminum plate to each direction of the refractory, we checked the change in the fundamental mode frequencies of the layered specimen. First, the fundamental resonant frequency of the specimen for each direction was obtained through FE analysis as 6.77 kHz, 3.53 kHz, and 7.89 kHz, respectively. Experimental frequency response was also acquired like **Fig. 4**. **Table II** shows the fundamental mode frequencies identified from the experimental frequency response, the thickness evaluated with Eq. (2), actual thickness, and the difference between the measured and actual thicknesses. In Eq. (2), variables with the subscript 1 are for the aluminum plate and those with the subscript 2 are for the refractory brick. The results along X, Y, and Z directions show the difference of 4.6% at maximum. Compared with a single layered specimen, the multilayered refractory specimen shows only 0.6% larger difference. Therefore, the impact-echo technique can also be used to measure the thickness of the multilayered structure of refractory.

$$f = \frac{1}{\dfrac{2T_1}{\beta_1 C_{p1}} + \dfrac{2T_2}{\beta_2 C_{p2}}} \tag{2}$$

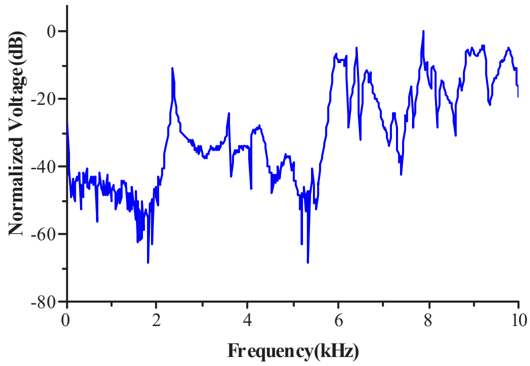


Fig. 4 Measured frequency response of the multilayered refractory specimen along X direction.

Table II. Evaluated thicknesses of the multilayered refractory brick.

| | Fundamental Frequency (kHz) | Measured Thickness (mm) | Actual Thickness (mm) | Difference (mm) |
|---|---|---|---|---|
| X | 6.70 | 203.62 | 200 | 3.62 |
| Y | 3.66 | 381.61 | 400 | 18.39 |
| Z | 7.96 | 151.73 | 150 | 1.73 |

## 6. Conclusions

In this paper, the thickness of refractory specimens was measured for both single and multilayered structures by using the impact-echo technique. The thickness measured in the experiments was confirmed to be accurate within a limited range of error, which showed the efficacy of the impact-echo technique to evaluate the thickness of the refractory.

### Acknowledgment

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### References

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