China Steel Technical Report, No. 34, pp.66－69, (2021)

Measurement Method of Effective Elastic Modulus for Hot Stove Refractory

TIAO-YUAN WU* and CHING-HENG SHAO**

**Green Energy & System Integration Research & Development Department*
**New Materials Research & Development Department*
China Steel Corporation

The hot stove supplies high temperature air to the blast furnace, with linings composed of multiple refractories. The temperature distribution varies periodically during operation and the lining expands and contracts accordingly. To prevent stove lining damage, it is important to understand the thermal stress in the refractory. Since the elastic modulus of refractories are usually unknown and the mortar between bricks is much thinner compared with brick dimensions, it is difficult to properly simulate the thermal stress in lining. Simulation without mortar influence will predict the refractory structure being very stiff and easy to damage, and result in the wrong design and overestimated the safety margins. This research developed a measurement method to measure the effective elastic modulus of the combined bricks and mortar to simplify the simulation model. The simulation accuracy by a 4-layer refractory structure was validated with a maximum deviation of less than 10%. By this novel method, it is possible to include the mortar influence in the stress simulation of the hot stove refractory.

Keywords: elastic modulus, refractory, mortar, thermal stress simulation

1. INTRODUCTION

In the ironmaking process, hot stoves supply 1200°C hot air to the blast furnace. The main body of the hot stove is a refractory structure with many different geometries and types. During the operation, refractories absorb heat from fuel and release it to the air reciprocatively and their temperatures are always varying. The thermal stress analysis is thus very important to verify the stability of the whole refractory structure. However, the elastic modulus varying with different temperatures, the key parameters for stress simulation, are usually unknown. Vendors don't supply the elastic modulus or only supply that of ambient temperature. Even if we have the modulus of each refractory, it is impossible to simulate the mortar influence due to its thickness being too small. Thus, we need to develop a novel method to measure the effective elastic modulus of bricks and mortar.

The general standard to measure the elastic modulus of refractory is ASTM C885-87[1] by sonic resonance. However, it is used at room temperature which has a large deviation compared to high temperature and large strain regions. Besides, the standard can only be applied to uniform material, but not to the combined mixture, for instance, multi-layers of bricks and mortar. Thus, the static modulus is more suitable for refractories than the dynamic modulus. Miyamoto et al.[2] measured a static modulus under different temperatures by equipment combined with a high-temperature furnace and a testing machine, which applied normal force on a high-temperature refractory sample and measure the deformation. Ramanenka et al.[3] utilized similar equipment to measure elastic modulus of high alumina brick used in a rotary kiln. Yang et al.[4] and Ravi et al.[5] discussed elastic moduli of multi-layers combined with brick and different mortars. But they didn't test the influences of the mortar thickness.

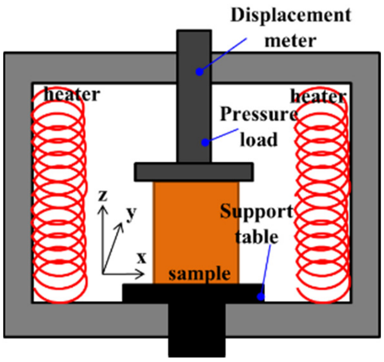
The hot stove lining is composed of multi-layer refractories with different brick/mortar dimension ratios and operates in a temperature range. However, only part of their research discussed the influence of temperature, and a few of them discussed the mortar thickness at the same time.

2. RESEARCH METHOD

2.1 Test Equipment

The test equipment was manufactured and a sketch and photo are shown in figure 1(a) and (b). This equipment consisted of a testing machine to apply normal force, a high-temperature coil to heat and control the sample temperature up to 1100°C, a displacement to measure deformation and a load cell to measure force. The temperature, force, and deformation are certified by

TAF and the expanded uncertainties are 2.7°C, 4.5kgf, 0.006mm, respectively. The highest temperature is 1150°C, maximum force is 600kN and maximum sample dimensions are 100(L)x100mm(W)x135(H).



(a)

(b)

Fig.1. A sketch (a) and a photo (b) of the test equipment

2.2 Test Method

The elastic modulus of bricks could be measured directly by the test equipment. But it is not easy to measure the modulus of mortar because it's difficult to form an independent thin layer of mortar without bricks. An innovative approach is stated below:

(a) To measure the elastic modulus of a brick.

(b) To cut the brick into two parts and apply mortar between them. (This is not clear in meaning)

(c) To measure the effective modulus of the sample (b).

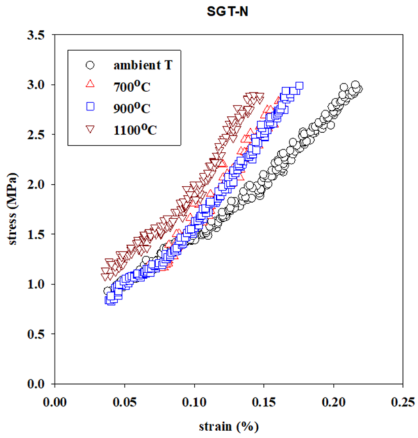
(d) To simulate the stress-strain curve of sample (b) by software ANSYS Structure. In the simulation, the brick modulus and effective modulus are obtained from (a) and (c), the mortar modulus is adjusted until the deviation of simulated effective modulus from the experimental value is <10%. The final adjusted value is the mortar modulus.

(e) To simulate effective moduli of multi-layer structure with different brick and mortar thicknesses by ANSYS Structure and moduli obtained from (a) and (d).

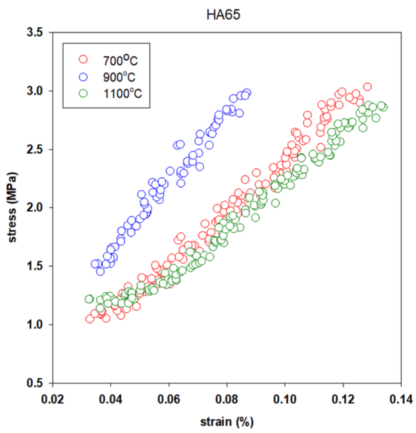
3. RESULTS AND DISCUSSION

3.1 Elastic Modulus Measurement of Refractories

Elastic moduli of some typical refractories used in the hot stove are measured. The stress-strain curves of SGT-N (silica brick) and HA65 (high alumina brick) are shown in Fig.2 (a) and (b) as examples. These curves present that the elastic moduli for various refractories are different and vary with temperatures. Especially, the curves of SGT-N show different slopes at different strain ranges. This means the elastic modulus is not constant and we have to apply different values in the different temperature and strain ranges for the stress simulation. The slopes of Fig.2 (a) are larger than that of (b) which show that HA65 is harder than SGT-N.



(a)



(b)

Fig.2. The stress-strain curves of SGT-N (a) and HA65(b)

More refractories are measured. In Fig.3, five refractories, SGT-N, HA65, L300, CN140G and IC135, show the variations of elastic moduli changed with temperature. The composition of the five refractories is listed in Table.1. The CN140G and IC135 are castable and easier to deform; their elastic moduli is also smaller. L300 is the insulation brick and is usually light and soft; its modulus is between these of castable and hard bricks.

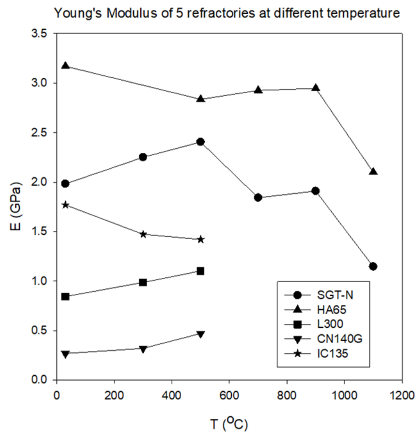


Fig.3. Elastic moduli of the five refractories at different temperatures

The variation trend of modulus for each refractory is not the same. With increasing temperature, it may increase (CN140G and IC135), decrease (HA65 and L300), or be parabolic (SGT-N). In the previous study, the elastic modulus at room temperature is often used for the whole temperature range. However, for instance, the elastic modulus at 1100°C of SGT-N is only 60% of that at room temperature. In the stress simulation it will result the predictive stress of 60% or higher in practical conditions and even higher than the crush strength. The more the safety margin or stronger the bricks with higher crush strength are thus used in design due to the wrong working parameters. On the other hand, for instance the CN140G, the simulation results may show it is safe but actually the refractory is damaged.

3.2 Elastic Modulus Simulation of Mortar

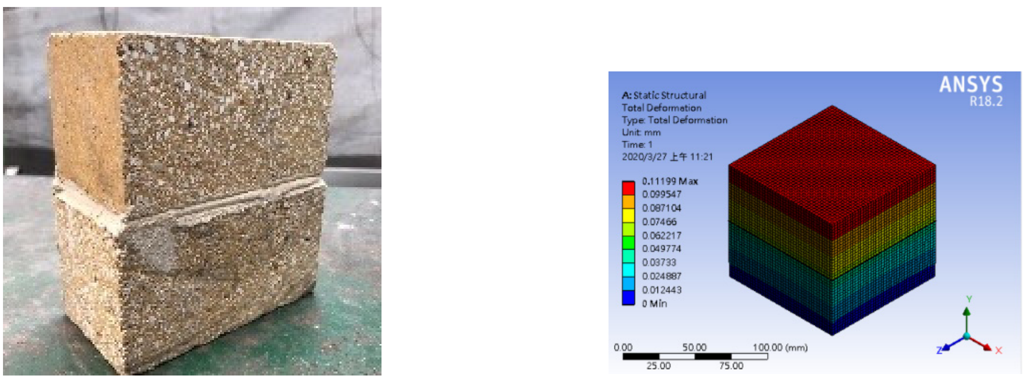
To follow the approach of 2.2, the moduli of SGT-N and SGT-N with mortar MK950 (Fig.4(a)) at different temperatures were measured; those of mortar MK950 were also obtained by simulation (Fig.4(b)). The total height of SGT-N with MK950 is 122mm and a thickness of MK950 is about 3mm. The results listed in Table.2 show that the moduli of MK950 is constant at different temperatures and thus the predicted effective elastic moduli have small deviations (<4%) to experimental values.

3.3 Validation of Effective Elastic Modulus Simulation

A four layer structure composed of SGT-N (38mm), MK950 (3.6mm), L300 (30.4mm) and CN140G (37.8mm) (Fig.5) was utilized to validate the test method in section 2.2. The simulated effective elastic moduli of SGT-N and MK950 were 1.4, 1.5, and 1.55 at room temperature, 300°C, and 500°C. The measured and predicted effective moduli are listed in Table. 3 and the maximum deviation is about 8%. The results validate the test method is feasible and present it having enough accuracy to apply effective elastic modulus in the stress simulation.

Table 1 The Composition of the five refractories

Composition	SGT-N	HA65	L300	CN140G	IC135
Al_2O_3	0.9	65	75	49	37.5
Fe_2O_3	0.5	1.0	0.8	1	2.2
SiO_2	95.5	35	21	42	46
CaO	2.6	0.9		6	11
TiO_2	0.5	0.3			



(a) (b)

Fig.4. The photo (a) and simulation model (b) of brick SGT-N with mortar MK95.

Table 2 The elastic moduli of mortar MK950 and effective elastic moduli of brick SGT-N with mortar MK950

Temperature (°C)	RT	300	500
Exp. E of SGT-N (Gpa)	2.00	2.25	2.40
Sim. E of MK950 (Gpa)	0.20	0.20	0.20
Exp. effective E of SGT-N+MK950 (GPa)	1.60	1.75	1.84
Sim. effective E of SGT-N+MK950 (GPa)	1.66	1.70	1.89
Dev. (%)	-3.6	2.9	2.5

Table 3 The effective elastic moduli of a 4-layer structure.

Temperature (℃)	RT	300	500
Sim. effective E of SGT-N+MK950 (GPa)	1.40	1.50	1.55
E of L300 (GPa)	0.84	0.92	1.1
E of CN140G (GPa)	0.48	0.54	0.47
Exp. effective E (GPa)	0.76	0.84	0.82
Sim. effective E (GPa)	0.81	0.84	0.89
Dev. (%)	-6.4	0.6	-8.3

Fig.5. The 4-layer structure was used to validate the test method of effective elastic modulus.

4. CONCLUSIONS

(1) The elastic modulus of refractory changed with temperature is a fundamental parameter in thermal stress simulation. But venders usually don't supply it. The test equipment helps us to obtain it by ourselves.

(2) The function of mortar absorbing brick deformation can't be neglected in the thermal stress simulation. Thus, the simulation method of effective elastic modulus which represents the overall stiffness of refractory was developed.

(3) This method is easy and effective. The effective elastic moduli of refractory structures with different thicknesses can be obtained quickly and accurately without many experiments.

REFERENCE

1. ASTM C885-87, Standard Test Method for Young's Modulus of Refractor Shapes by Sonic Resonance, 2012.
2. M. Miyamoto, T. Onoye, and K. Narita, Deformation and Failure Behavior of Refractories for the Blast Furnace at Elevated Temperatures, Transactions ISIJ, 1981, vol. 21, pp. 887-894.
3. D. Ramaneka, M-L. Antti, G. Gustafsson, and P. Jonsen, Characterization of High-alumina Refractory Bricks and Modelling of Hot Rotary Kiln Behaviour, Engineering Failure Analysis, 2017, vol. 79, pp. 852-864.
4. K-H. Yang, Y. Lee, and Y-H. Hwang, A Stress-Strain Model for Brick Prism under Uniaxial Compression, Advances in Civic Engineering, 2019.
5. S. Ravi, S. Viswanathan, T. Nagarajan, V. Srinivas, and P. Narayanan, Experimental and Numerical Investigations on Material Behaviour of Brick Masonry, ICRSET 2014, Mar 21-22, Dubai.