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MONITORING THE DAMAGE LEVEL DURING THERMAL STABILITY TESTING OF REFRACTORY SAMPLE USING SONINIC MEASURMENT

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ABSTRACT

Thermal stability of the refractory material with the content of 28 % Al_2O_3 was investigated. Water quench test (JUS.B.D8.319.) was applied as experimental method for thermal stability testing. Dynamic Young modulus of elasticity was calculated using measured values of longitudinal (Vp) and transverzal (Vs) velocites. Values of dynamic Young modulus and changes of in compresive strength during testing were presented as function of the measured number of quench experiments. Changes in resistance parameters caused by thermal shock was presented, also. Analysis of the thermal shock behavior of the samples based on the obtained results was given.

Key words: refractories, sonic measurment, dynamic Young modulus, resistance parameters, thermal stability

1. INTRODUCTION

Thermal shock resistance dictates refractory performance in many applications. In many instances, a two -fold approach, i.e. 1) material properties [1-4] and / 02) heat transfer conditions [5-7] is taken to characterize thermal shock behavior of the refractories. As an alternative, information on the thermal shock behavior of refractories can be obtained by experimental means. One test for this purpose, which is highly popular because of its simplicity, consists of quenching appropriate specimens from an oven temperature into a medium such as water [8-10], liquid metal [11], oil [12], or fused salts [13] maintained at a lower temperature.

Thermal quenching of the refractories leads to the crack nucleation and/or propagation resulting in loss of strength. Since the formation of the cracks has profound influence on the ultrasonic velocity and the Young modulus of the material, measuring either of these properties can directly monitor the development of the thermal shock damage level.

2. MATERIALS

The refractories used in the present study were obtained directly from commercial producer. These refractories were used in several previous studies in which a number of physical properties related to their thermal shock behavior were measured [17-25].

3. EXPERIMENTAL

Thermal stability of the refractories was measured by water quench test (JUS. B. D8. 319.) as experimental method. Cylindrical specimens 5 cm diameter and 5 cm high were used in experiment. The samples were dried at 110 °C and then transferred into electric furnace at 950°C, the temperature being adrieved in to 15 minutes, and held for 15 minutes. The pieces were then quenched in into water and left for 3 minutes before returning to the furnace at 950°C. This was repeated until failure. The number of quenches to failure was taken as a measure of a thermal shock resistance.

Table1 - Thermal and Mechanical Properties

Parameter	value
Al_2O_3, (%)	28
Density, ρ (g/cm^3)	2.62
Thermal conductivity, k (W/mK)	1.7
Specific heat, c (kJ/kgK)	1.05
Thermal expansion coefficient, α (%)	0.7
Compressive strength, σ_p (MPa)	51
Young modulus, E (GPa)	25.5
Thermal stability (number of quench experiments, N)	6

The measurment of ultrasonic velocity was done using the equipment OYO model 5210 according to the standard testing (JUS. D. B8. 121.). The transducers were rigdly placed on the two paralel faces of the cylindric specimen using vaseline grease as the coupling medium. The ultrasonic velosity was then calculated from the spasing of the transducers and the waveform time delay on the osciloscope. Dynamic Young modulus was calculated using the expression [14, 26]:

$$E_{dyn} = Vp^2 \rho \; \{ (1+ \mu_{dyn}) (1 - 2 \mu_{dyn}) / 1- \mu_{dyn} \} \qquad (1)$$

$$\rho = \gamma / a \qquad (2)$$

$$\alpha = Vp/Vs \qquad (3)$$

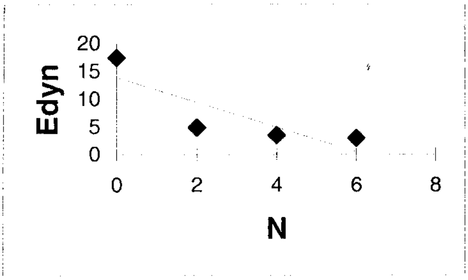
$$\mu_{dyn} = (2\alpha^2 - 1)/(2\alpha^2 - 2) \qquad (4)$$

where:

Vp – ultrasonic velocity of longitudinal waves (m/s), Vs – ultrasonic velosity of transverzal waves (m/s), μ_{dyn} - dynamic Poasson ratio, γ - density (kN/m^3)

4. RESULTS AND DISCUSSION

The effect of the thermal shock fatique on the Young modulus is shown on the figure 2. The good agreement between decrising the Young modulus and number of cycles suggests that thermal shock damage could also be quantitatively evaluated nondestructively by measuring the dynamic Young modulus. Unfortunatly, coefficient of correlation (is in this case lower than it was in comparison the ultrasonic velocity with the number of cycles [24].



Regression Statistics	
Multiple R	0.841262
R Square	0.707722
Adjusted R Square	0.561583
Standard Error	4.557211
Observations	4

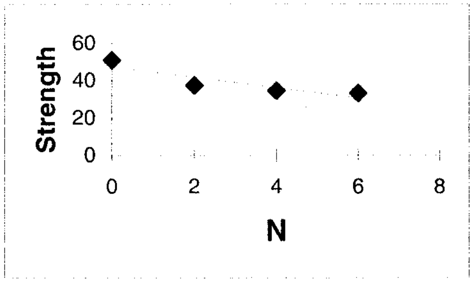
Figure 1 - Dynamic Young modulus as function of number of cycles of the quench experiment (N)

Since very good results were obtained by monitoring changes in ultrasonic velocites, these were used for the correlation of strength degradation caused by thermal shock. Expression for the strength degradation was used [14], described as:

$$\sigma = \sigma_o (V_l/V_{Lo})^{n} \qquad (6)$$

where

σ_o - is compressive strength of the material before exposure of material to the theraml shock testing, n - material constant (n = 0.488, ref. 14.)



Regression Statistics	
Multiple R	0.888526
R Square	0.789479
Adjusted R Square	0.684218
Standard Error	4.540466
Observations	4

Figure 2 - Compressive strength (σ, MPa) degradation as function of number of cycles of the quench experiment (N)

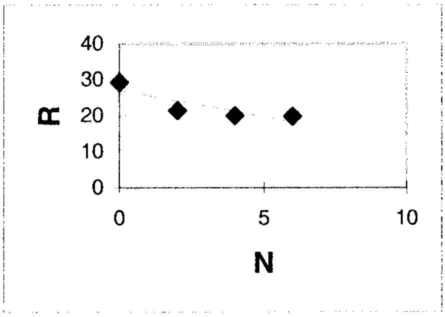
High values of coefficient of correlation suggests that degradation in strength during thermal stability testing is in strong correlation with the water quench test experiment results.

Thermal shock stability of the refractories could be presented using resistance parameters [1-4]. Fracture and damage resistance parameters were calculated from thermal and mechanic properties listed in Table I., and usual equations are presented :

$$R = \sigma(1 - \nu)/E\alpha \tag{7}$$

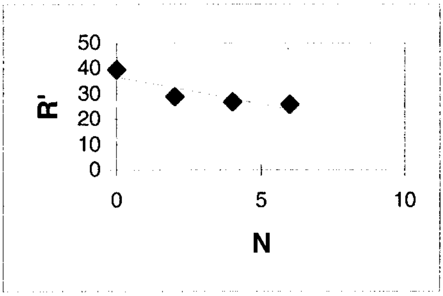
$$R' = kR \tag{8}$$

The first fracture resistance parameter (R) accounts for the cases of steady temperature distribution in a specimen and/or the cases of thermal shock with an infinite heat transfer coefficient. The second fracture resistance parameter (R') is for the cases of thermal shock under the condition where the Biot number is comparatively low. Both fracture resistance parameters describe the relative resistance against the nucleation of fracture. Degradation of resistance parameters due to the degradation of strength, were also presented in Figures 3. and 4.



Regression Statistics	
Multiple R	0.855885
R Square	0.732539
Adjusted R Square	0.598809
Standard Error	2.843266
Observations	4

Figure 3 - First fracture resistance parameter degradation as function of number of cycles of the quench experiment (N)



Regression Statistics	
Multiple R	0.886629
R Square	0.786111
Adjusted R Square	0.679166
Standard Error	3.538177
Observations	4

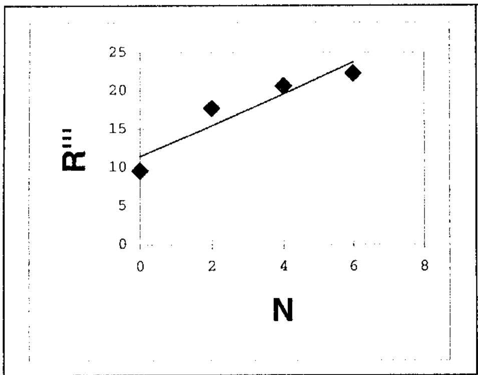
Figure 4 - Second fracture resistance parameter degradation as function of number of cycles of the quench experiment (N)

From the Figures 3. and 4. strong correlation between fracture resistance parameters degradation and the number of cycles of the quench experiment was oserved.

$$R''' = E/\sigma^2(1-\nu) \tag{9}$$

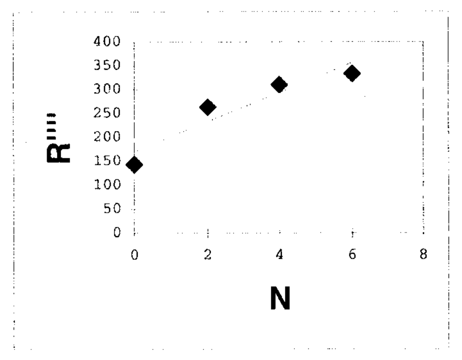
$$R'''' = \gamma R''' \tag{10}$$

The second damage resistance parameter R'''' , describes the relative resistance against the propagation of cracks once nucleated [1-4]. This parameter is representing the resistance of the refractory to thermal shock damage by kinetic crack growth. The first damage resistance parameter R''', is a simplified formula derived from R'''' by eliminating the term of fracture energy.



Regression Statistics	
Multiple R	0.939982
R Square	0.883566
Adjusted R Square	0.825349
Standard Error	2.362469
Observations	4

Figure 5 - First damage resistance parameter change as function of number of cycles of the quench experiment (N)



Regression Statistics	
Multiple R	0.939549
R Square	0.882752
Adjusted R Square	0.824127
Standard Error	35.51952
Observations	4

Figure 6 - Second damage resistance parameter change as function of number of cycles of the quench experiment (N)

From the Figures 5. and 6. excellent correlation between damage resistance parameters degradation and the number of cycles of the quench experiment was oserved. In case of monitoring damage resistance parameters changes due to the thermal shock, higher values of coeficient of correlation were observed, comparing to the fracture resistance parameters.

5. CONCLUSION

Monitoring of thermal shock damage development in refractories by nondestructive method is of high industrial significance in relation to productivity as well as safety. Sonic measurment is very usefull tool to solve this problem since the advantages are:

- instrument is small in size, portable, and very easy to use on site, if necessary,
- results of the method could be obtained very fast, and as they are related to damage, the damage level in material could be predicted with very good accurancy.

Results presented in this study suggest that of the sonic measurments could be used for prediction of damage level in specimen due to the thermal shock. Monitoring the damage level could be obtained using the decreasing of the ultrasonic velosity. Also, as the results in the Chapter 4. suggest the decreasing of the Young modulus could be also used for the same purpose. The lower values of the coefficient of correlation with the water quench results in that case suggests more acurate analysis, possibly combined with other correlation to get more accurate prediction. Strength degradation in material due to thermal hoking could be also evaluated, with very strong correlation with the number of cycles of the quench experiment (N). Prediction of strength degradation could be a very useful parameter for life time prediction of material.

Results presented in this paper showed that higher values of fracture resistance parameters are expected for the sample before thermal shocking. After shocking both fracture resistance parameters are decreasing, with strong correlation with water quench test.

For the damage resistance parameters higer values were observed after thermal cycling. Calculated values of both damage resistance parameters for the sample were lower before than after quenching. Better results for the correlation with the results of quench experiment were observed for the damage resistance parameters.

Acknowledgements

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