Prediction of Thermal Stability Behavior of Refractory Specimen: Deterioration Monitoring Using Image Analysis Program

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Abstract. The most important properties usually measured for refractories are working temperature and thermal stability. Thermal stability of the alumina based samples was measured using standard laboratory procedure, water quench test (JUS.B.D.8.319.). ImagePro Plus Program was used for image analysis of deterioration monitoring of the samples before, during and after water quench test. Mechanical characteristics were considered such as strength, dynamic modulus of elasticity resulting from resonance frequency measurements, as well as ultrasonic velocity. In this work correlation between deterioration, ulatrasonic velosity and strength on thermal stability of the samples were investigated. The results were used for validation of the model for the thermal stability behavior prediction of the refractory.

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/or 2) heat transfer conditions [5-7] are used to characterize thermal shock behavior of the refractories. As an alternative, information on the thermal shock behavior of refractories can be obtained experimentally. 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, liquid metal, oil, or fused salts maintained at a lower temperature. Water quench test is usually applied for thermal stability testing. Thermal quenching of the refractories leads to the crack nucleation and/or crack propagation resulting in loss of strength. Since the formation of the cracks has a profound influence on the ultrasonic velocity and the Young modulus of the material, measuring either of these properties may be applied to monitor the development of the thermal shock damage level. The goal of this work is to use non-destructive testing methods and their advantages for prediction of thermal shock behavior. Destruction of the samples was analyzed using Image Pro Plus Program. In this paper relationship between change in mechanical characteristics (strength) and behavior of the samples during thermal shock will be given. Results presented in this paper are a part of investigation dealing with a group of alumina-based refractories. Results for the one type f the material will be presented.

Materials

The alumina based refractories used in the present study were obtained directly from a commercial producer. In this paper damage of the samples was monitored usig ImagePro Plus Programe

These refractories were used in several previous studies in which a number of physical properties related to their thermal shock behavior were measured [8-17]. In Fig.1. samples before (A) and after quench experiments were shown. For the evaluation of thermal stability of sample water quench test was applied (JUS.B. D.8. 319.).

Experimental

The measurement of ultrasonic velocity was performed using the equipment OYO model 5210 according to the standard testing (JUS. D. B8. 121.). The transducers were rigidly placed on the two parallel faces of the cylindrical sample having 5cm diameter and 5 cm height using vaseline grease as the coupling medium. The ultrasonic velocity was then calculated from the spacing of the transducers and the waveform time delay on the oscilloscope. Dynamic Young modulus was calculated using the expression:

$$E_{dyn} = V_p^2 \rho \ \{ (1+ \mu_{dyn}) (1 - 2 \mu_{dyn}) / 1- \mu_{dyn} \} \quad (1)$$

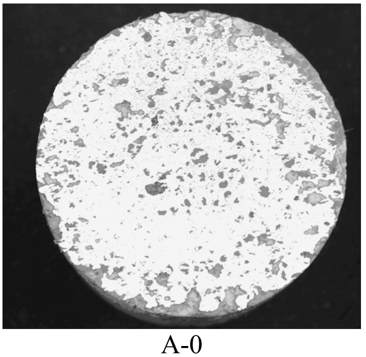
where: V_p – ultrasonic velocity of longitudinal waves (m/s), μ_{dyn} - dynamic Poasson ratio, γ - density (kN/m^3).

Expression for the strength degradation, based on decrease in ultrasonic velocity was used [15]:

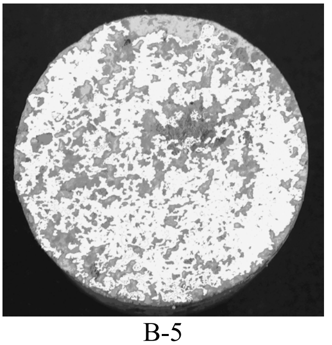
$$\sigma = \sigma_o (V_L/V_{Lo})^n \quad (2)$$

where σ_o is compressive strength before exposure of the material to the thermal shock testing, V_L is longitudinal ultrasonic velocity after testing, V_{Lo} is longitudinal ultrasonic velocity before testing and n - material constant (n = 0.488, ref. 15.)

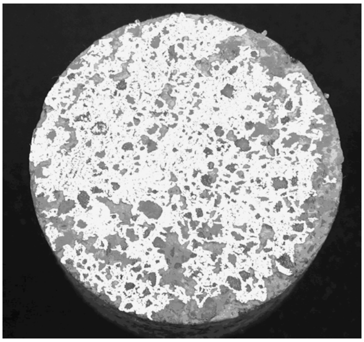
Photographs of the samples were taken, before and after water quench test. Image Pro Plus Program was used for image analysis. When surface damage of the samples was investigated, samples were covered with the thin film made by chalk powder in order to obtain a better resolution and difference in damaged and non/damaged surfaces in the material. In this paper damage of the samples was monitored usig ImagePro Plus Programe, and results for material destruction, were given (Fig.5.).



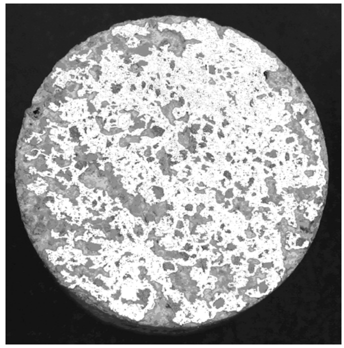
A-0



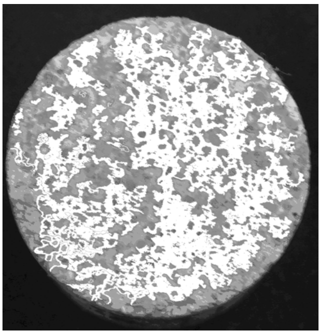
B-5



C-10



D-15



E-18

Fig. 1. *A) Sample before quenching, B) after 5 cycles, C) after 10 cycles, D) after 15 cycles, E) after 18 cycles*

Results

Change of the ultrasonic velocity during water quench test, versus damage surface level is illustrated in Fig. 2. Degradation of strength during water quench test versus damage surface level was given in Fig 3., where the degradation of strength was calculated using equation 2. Fig. 3.a) and Fig. 3.b) represents changes of ultrasonic velocities of longitundinal, V_p and transvesal, V_s waves, respectively, where: V_p – ultrasonic velocity of longitudinal waves (m/s),V_s – ultrasonic velosity of transverzal waves (m/s).

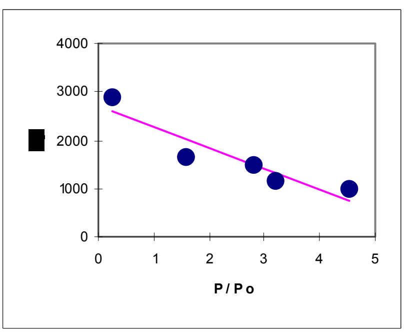


Fig. 2. *a) Ultrasonic velocity (V_p) versus damaged surface level (P/P_o)*

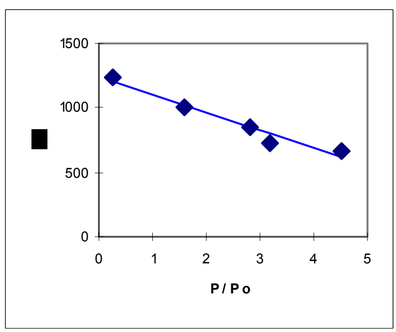


Fig. 2. *b) Ultrasonic velocity (V_s) versus damaged surface level (P/P_o)*

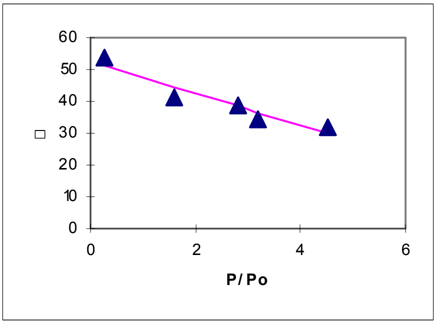


Fig. 3. *a) Strength degradation (calculated with V_p) versus damaged surface level (P/P_o)*

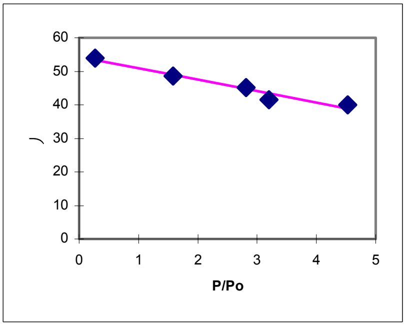


Fig. 3. *b) Strength degradation (calculated with V_s) versus damaged surface level (P/P_o)*

The degradation of the dynamic Young modulus versus damage surface level is shown in the Fig.4. Damaged surfaces of the sample originate from the missing grains mostly and in a less extent from the crack nucleation and crack propagation during quenching. Obtained results for the surface decrease are given versus number of quench experiments in the Fig. 5. These results could be used for the comparison of the damaged surface level or number of quench experiments with other parameters usually used for thermal stability.

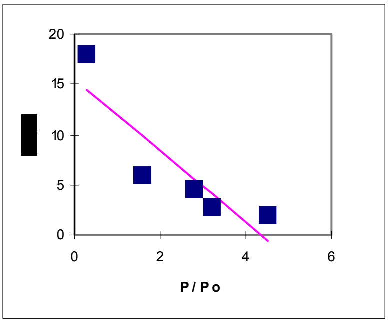


Fig. 4. *Dynamic modulus of elasticity degradation versus damaged surface level.*

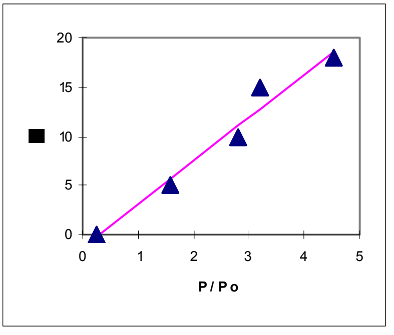


Fig. 5. *Number of quench experiments (N) versus damaged surface level (P/P_o).*

Discussion

In the privious work change in mechanical characteristics, which was mostly reduction, as well as in ultrasonic velocity, was conected with number of quench experiments [12-17]. Obtained results for damaged level of samples showes strong correlation with the number of quench experiments (Multiple R =0.98). Degradation of measured ultrasonic velocites correlated to the damaged surface level pointed out excellent coeffitient of correlation for longitudinal vawes, Vp (Multiple R = 0.93) and transversal vawes, Vs (Multiple R =0.97). According to presented results, strength degradation of the samples, calculated using equation 2. and presented at Fig. 4. showed also strong correlation with damage level using Vp (Multiple R = 0.94) and Vs (Multiple R = 0.98) for calculation. In values obtained with treansvesal waves, better results were obtained for strength degradation correlated with the damaged sufrace level. Behavior of dynamic Young modulus durig thermal shock (Fig.5.) showed lower coefficient of correlation (0.88), but with enough high value,allowing the use of this type of correlation for further applications.

Conclusion

The goals of this paper were to use image analysis for the verification of the model of prediction and monitoring the changes in the material behavior in condition of thermal shock.

Two groups of parameters were measured during testing:

– Monitoring changes in mechanical characteristics (strength and dynamic modulus of elasticity) as well as ultrasonic velocity,

– Changes of sample surface during testing.

Results showed that surface damage could be correlated with the number of quench experiments with high coefficient of correlation. This result could be used for lifetime prediction of specimen during thermal shock testing presented as the number of quench experiments. Taking into account that number of cycles of thermal shock does not explicitly describe the damage level, which is one of the most important information for lifetime prediction.

Change of the mechanical characteristics during thermal shock is very important for the prediction of the material behavior. When this change is related to the damage level, it has better confidence for prediction of the material behavior in conditions of thermal shock. Also, from the proposed equation (2) it is possible to calculate the velocity of decreasing strength of the material.

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