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Young's Modulus Evaluation and Thermal Shock Behavior of a Porous SiC/cordierite Composite Material

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Abstract:

Porous SiC/Cordierite Composite Material with graphite content (10%) was synthesized. Evaluation of Young modulus of elasticity and thermal shock behavior of these samples was presented. Thermal shock behavior was monitored using water quench test, and non destructive methods such are UPVT and image analysis were also used for accompaniment the level of destruction of the samples during water quench test. Based on the level of destruction graphical modeling of critical number of cycles was given. This approach was implemented on discussion of the influence of the graphite content on thermal stability behavior of the samples.

Key words: *Silicon carbide/cordierite, Thermal shock, UPVT, Image analysis, Modeling*

1. Introduction

Application of refractory, ceramic and composite materials in industrial applications such are: thermal insulation, chemical, metallurgical and petrochemical industry, includes knowledge of thermal shock behavior of these groups of materials. The thermal shock resistance is measured in terms of the number of cycles that a refractory material can withstand when subjected to rapid temperature changes [1-10].

In operation conditions, when refractory materials are subjected to the rapid temperature changes, crack nucleation and propagation occurs. When cracks are present in the materials, resulting in loss of strength, material degradation is expected. It is well known that the formation of cracks decreases the velocity of ultrasonic pulses traveling in the refractory. As velocity depends on the density and elastic properties of the material, it is expected velocity degradation of material after thermal shock.

Measuring changes in velocity of Young modulus of elasticity can directly monitor the development of thermal shock damage level, if UPVT is used. Young's modulus of representative samples was calculated using measured values of ultrasonic velocities obtained by ultrasonic pulse velocity technique [6, 10-13]. Results were compared with water quench test data of thermal shock behavior of the investigated materials. The capability of the

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ultrasonic velocity technique for simple, sensitive, and reliable non-destructive characterization of thermal shock damage was demonstrated in this work. Thermal shock damage level could be monitored using image analysis, also. Level of destruction of the sample could be related to the number of water quench experiments [14-22].

In this study, evaluation of Young's modulus and level of degradation of the samples and specifically, characterization of the damage generated was investigated during specific thermal shock cycles.

2. Materials

Group of silicon carbide/cordierite materials was investigated as basis for further investigations in order to obtain porous, but still thermal stable composite materials. For these reasons, materials, with different content and synthesis conditions were investigated, for selection the optimum content of silicon carbide/cordierite material as starting material for porous sample preparation [23-26]. Porosity of the samples was selected by addition of graphite in content of 10%, to the selected SiC/cordierite mixture.

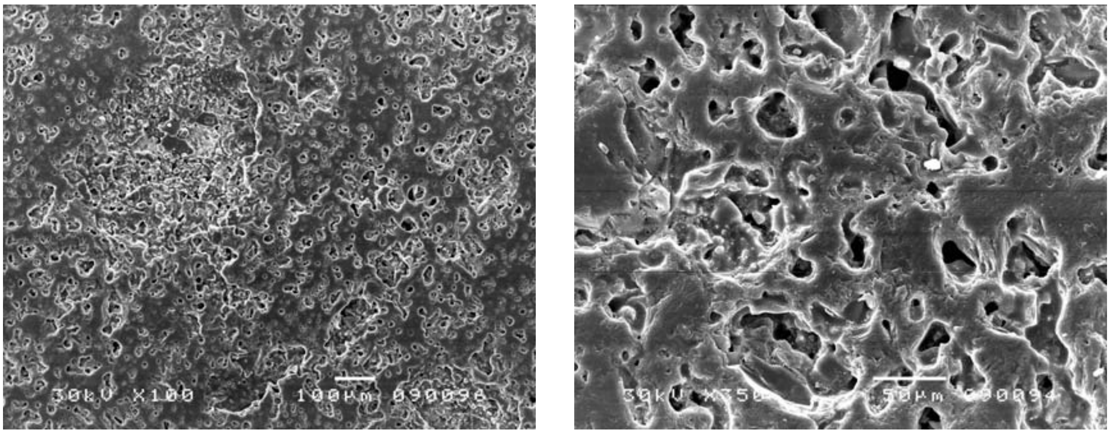

Fig. 1. SEM of S3G1 samples.

Microstructure of SG1 sample is characterized with pores with different shape, dimensions, and distrbution. Heating on the temperature of 600 °C process of elimination the graphite from the bulk of the sample was observed, and pores were replasing the places where graphite was found. One part of the observed pores is formed from graphite particles, and their dimensions are realted to several microns, but pores with grater dimensions were also observed.

3. Experimental

3.1. Water quench test

Most used experimental method for thermal stability testing is water quench test (ICS 81.080 SRPS B.D8.308 former JUS B. D8. 306 and 319). Samples in our experiments were cylinders with 1 cm diameter and 1 cm high. The specific procedure including heating temperature, as well as cooling conditions is explained in details in literature [14-19]. This water quench test procedure is similar to the test described in PRE Refractory Materials Recommendations 1978 (PRE/R5 Part 2).

3.2. Ultra Pulse Velosty Testing (UPVT)

Ultra Pulse Velosty Testing UPVT was first reported on refractory materials in the late 1950's and it has been subsequently applied frequently to characterize and monitor the properties of industrial refractory materials nondestructively [14-26]. Initial use of sonic velocity was related to specialized applications such as fireclay coke oven shapes, but from the 1980's it has been applied to bulk refractories as well. Moreover, equations have been proposed to correlate the ultrasonic velocity or Young's modulus to the strength or porosity of various refractories [14-26]. The UPVT method has been considered in detail in ref. [4-12].

The measurement of ultrasonic velocity was performed by using the equipment OYO model 5210 according to the standard testing procedure (ICS 81.080 SRPS D. B8. 121.). The transducers were rigidly placed on two parallel faces of the cylindrical sample having 1 cm diameter and 1 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.

By measuring the bulk density, the Poisson's ratio and ultrasonic velocity of a refractory material it is possible to calculate the dynamic modulus of elasticity using the equation below [16, 23-28]:

$$E_{dyn} = V^2 \rho \left(\frac{(1+\mu_{dyn})(1-2\mu_{dyn})}{1-\mu_{dyn}} \right) \tag{1}$$

Where V is the pulse velocity (m/s), ρ is the bulk density (kg/m^3) and μ_{dyn} the dynamic Poisson ratio, defined as :

$$\mu_{dyn} = \frac{(2\alpha^2 - 1)}{(2\alpha^2 - 2)} \tag{2}$$

$$\alpha = \frac{V_L}{V_S} \tag{3}$$

3.3. Image analysis

Image analysis is useful tool for macro and micro structural characterization. Based on the structural analysis and by the correlation of these results with mechanical properties, material behavior in different conditions as well as material reliability could be discussed and monitored [14-20, 27]. Image analysis can be applied to define grain characteristics: maximal, minimal, mean; reinforcement: diameter and length of fibers, ratio of different phase, and degradation of the sample caused by different impact. In this paper image analysis will be applied on the samples to determine level of destruction caused by thermal shock testing.

Image Pro Plus presents special program for treatment and analysis of image. Program recognizes and enables work in all known formats of images (TIFF, JPEG, BMP, TGA...). This program automatically performs image analysis. It automatically measures, counts and classifies all obtained data about analyzed objects [13-20,27]. Program communicates directly with Excel program, what enables statistical and graphical treatment of data. In this study image analysis was used for the determination of damage surface level before and during the testing. Samples surfaces were marked by blue color in order to obtain better resolution and difference in damage and undamaged surfaces of the material. Results were given in percent and they were presented as ratio of P (non damaged surface) and P_0 (ideal surface before quenching).

4. Results and Discussion
4.1. UPVT

Changes in the ultrasonic velocities due to the water quench test are given at the Fig. 2.

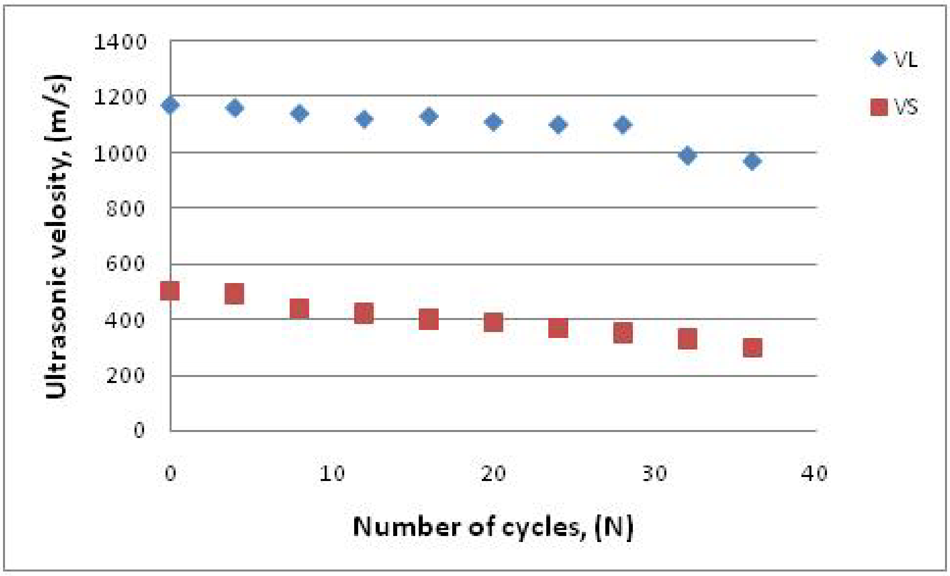

Fig. 2. Changes in the ultrasonic velocities during experiment.

During the water quench test, ultrasonic velocities were decreasing (Fig. 2.), which was expected, as crack nucleation and propagation, as well destruction of the samples during testing was expected.

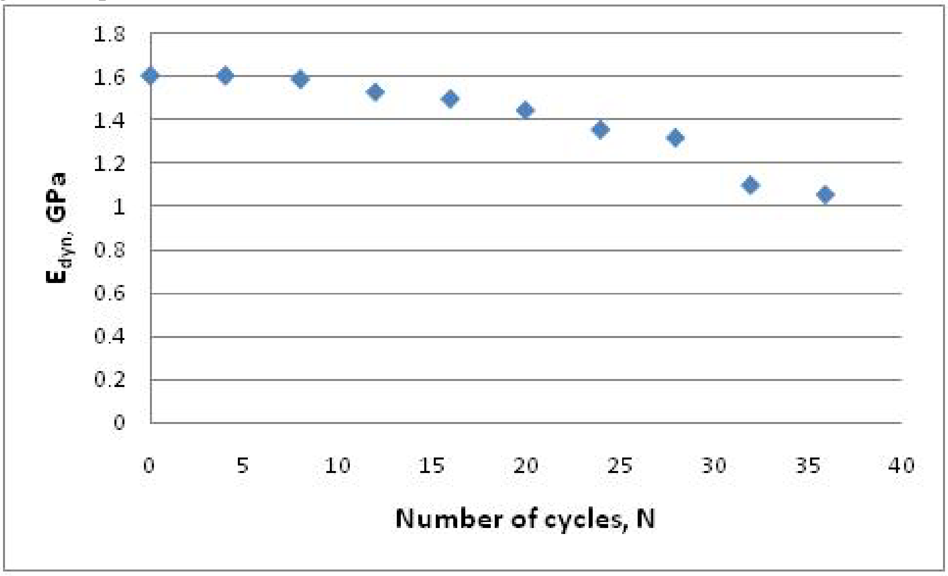

Fig. 3. Young modulus of elasticity degradation during experiment.

Decreasing of Young modulus of elasticity was also expected, according to the results related to the changes of ultrasonic velocity, as well the literature data which investigate influence of porosity on Young modulus of elasticity. It is well known that increasing quantity of defects (cracks nucleation and growth) and/or porosity will result in decreasing the

Young modulus of elasticity [5-14, 31].

4.2. Image analysis

Level of damage during water quench experiment was monitored by image analysis. Image Pro Plus Program was applied for level of destruction determination. Samples were photographed before and during testing, in order to measure level of destruction and photographs are given at the Fig. 4. Results of the image analysis are given in the Fig. 5. as function of number of cycles of water quench test.

Number of cycles	SG1
0	
24	
32	

Fig. 4. Image of the samples during water quench testing.

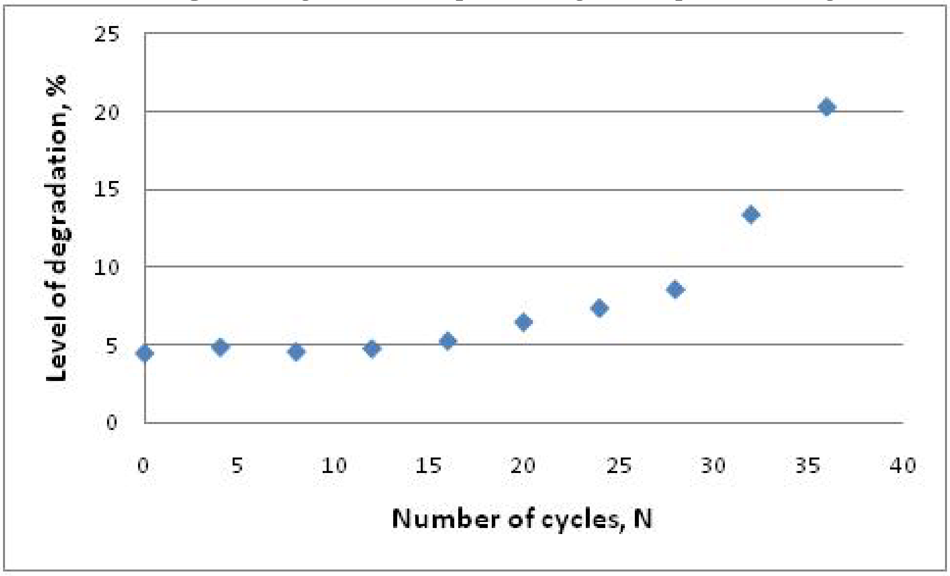

Fig. 5. Level of degradation of the samples during testing.

These results for original surface before testing have to be taken into account, as they affect behavior of the sample during testing. For the lower values of degradation of the original surface, lower values of degradation at the end of the experiment are expected. Also, considerations related to the crack nucleation and crack propagation due to the thermal shock could be correlated to the influence of the original surface. After 28 cycles, more rapid degradation for SG1 samples was observed. Samples SG1 after 36 cycles showed level of degradation of 20.3 %. Results presented at the Fig. 5. where degradation of the samples during thermal shock was monitored, could be used for prediction of critical number of cycles samples could withstand. According to the standard procedure of water quench test [14-18, 23-27] degradation of the surface of the sample could be tolerated till 50 % of degradation of original surface. Applying this approach if critical level of degradation is 50 % of original surface, than linear interpolation could be used for obtaining the critical number of cycles, Nc, and graphical representation is given at the Fig. 6.

4.3. Strength degradation modeling

Strength degradation modeling was calculated using equations (1.) and (2.). These equations were similar to those previously used [23-28]

$$\sigma = \left(\frac{V_L}{V_{L0}}\right)^{0.488} \tag{1.}$$

$$\sigma = 0.1 \cdot \left(\frac{100 - P}{P_0}\right)^{0.488} \tag{2.}$$

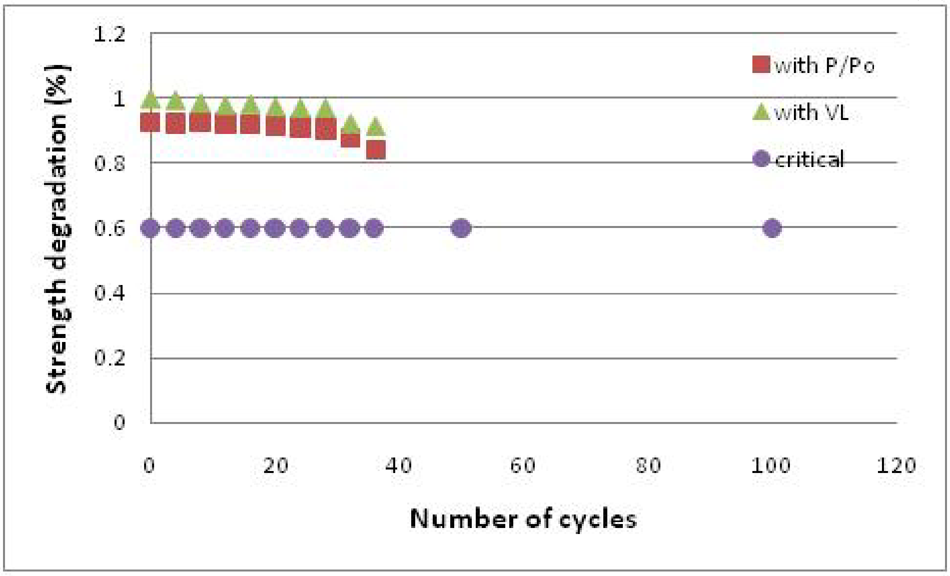

Fig. 6. Critical number of cycles based on the level of degradation model.

Based on the equations 1 and 2, and using the approximation that critical level for strength degradation could be estimated to 60 % graphical results are given at the Fig.5.

Based on the approach from Fig. 5. critical number of cycles for SG1 samples could be around 90 cycles, if interpolation is applied with UPVT approach, if other interpolation is applied, than Nc would be around 70 cycles, approximately with the image analysis approach.

5. Conclusion

Ceramic composite material based on SiC/cordierite material with graphite content (10%) was synthetized in order to get different porosity of the samples, and investigate these effects on thermal stability behavior.

Thermal stability was monitored by:

1. Standard experimental method (water quench test),
2. UPVT applied for ultrasonic velocity and Young modulus of elasticity monitoring and
3. Image analysis for level of degradation during experiment.

Obtained results showed:

- UPVT measurements could be correlated to the thermal shock cycles, either with change of ultrasonic velocity or Young modulus of elasticity. Degradation of the ultrasonic velocity could be used for strength modeling (equ 1.)
- Results for the degradation level measured using image analysis could be correlated with the number of cycles. These results could be used for modeling the strength degradation during testing (equ 2.).
- Results for modeling strength degradation during testing could be used for graphical presentation for critical number of cycles.

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Садржај*: Синтетисани су порозни узорци SiC/кордијерит композитног материјала са додатком графита од 10 %. У току рада ће бити праћена промена Јунговог модула еластичности и термошока. Термошок ће бити праћен коришћењем стандардне методе наглог хлађења у води, као и применом недеструктивних метода испитивања UPVT (метода на бази ултразвучних мерења) и анализе слике на основу које ће бити одређен степен разарања узорка током испитивања термостабилности. На основу степена разарања узорка, као и осталих добијених биће одређен критичан број циклуса, са графичком презентацијом модела.*

Кључне речи: *Силицијумкарбид/кордијерит, термошок, ултразвучна мерења, анализа слике*

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