Experiment Study on Elastic Indicator of Thermal Shock Ceramic Materials

——Implementation of students' innovative research project of Shandong University of Science and Technology

Yanxia Wang[a], Tiantian Sun, Yongli Bao, Xiaomin Ma

School of Traffic and Vehicle Engineering, Shandong University of Technology, Zibo 255049, china

[a]wangyx200@163.com

Keywords: ceramic materials, elastic modulus, shear modulus, poisson's ratio, thermal shock.

Abstract: In order to improve the quality of undergraduate education and combine theory and practice, Shandong University of science and technology organized innovative research activities project for undergraduates. Combined with the characteristics of engineering mechanics course, teachers of engineering mechanics teaching and research section guided students to take an active part in scientific research and innovation practice teaching, which has obtained a good teaching effect. This paper introduces the concrete implement process of the college students' innovative scientific research project "Experiment Study on Elastic Indicator of Thermal Shock Ceramic Materials", which measures elastic indicator of ceramics using the ultrasonic method. This paper studies elastic indicator change rule of the mullite ceramic samples under different factors such as temperature difference, thermal shock times and so on. Studies have shown that in the condition of air-cooling, with the increase of thermal shock temperature difference and thermal shock times, the elastic modulus value, shear modulus and Poisson's ratio are in a falling trend. The project implementation have proved that implement undergraduate innovation research projects could effectively arouse students' learning enthusiasm, cultivate students' scientific research innovation and analytical abilities to solve practical scientific research problems.

Introduction

In order to strengthen students' innovation consciousness and practical ability, Shandong University of Technology launched a college student innovation research project since 2009, and by 2015 it has been successfully held for consecutive 7 sessions. Through the implementation of this project, leading undergraduate student to participate innovation activities, not only could help the students to understand the theoretical knowledge and improve their practical skills, but also could let them access to the most advanced knowledge of the subject and increase their interesting in learning. It will be very helpful for the students' further research training. For this purpose, Department of Engineering Mechanics with their own characteristics applied a program: Thermal shock resistance of ceramic materials-Determination of elastic parameters and it has been successfully completed [1,2].

Mullite ceramics, with a unique combination of properties including high temperature resistance, oxidation resistance, corrosion resistance, low creep rate and other excellent characteristics, is widely used in metallurgy, energy, electricity, chemical industry, aerospace and so on. In the use process, mullite ceramic structure is induced thermal stress due to heat shock, and led to crack, flake, fracture and other thermal shock damages [3-6]. These damages will directly affect the service life of the structure, so the study of thermal shock resistance on ceramic materials is great significance to the practical application. At present, the research of thermal shock resistance on ceramic material, is mostly concentrating on the determination of critical temperature difference [7], thermal shock cycles [8], residual strength [9, 10] and the occurrence and extension of crack [11-13]. However, few papers had a systemic research in the influence of temperature difference, thermal shock cycles and cooling medium on the materials in the process of thermal shock. This paper focused on the changing rule of the mechanical properties indexes on the mullite materials in the thermal shock process, and then cultivates students the research ideas and research methods of fatigue failure.

To measure the sample's elastic index, an ultrasonic method is introduced which calculates the material's elastic performance indicators such as Young's modulus, shear modulus and Poisson's ratio by determining the density of materials, speed of propagation of transverse waves and longitudinal waves in the material. This method has a lot advantages, like no pasting of strain gauge, low cost, short cycle and multipoint measurement. It will be helpful for fostering students' independent thinking and hands-on ability.

Experiments Method

Thermal Shock Experiments. The specimen made by high temperature solid method, the size of the test piece for $10\times20\times100$ mm. Table 1 shows the experiment design.

Table 1 Thermal Shock Experiment

Temperature difference [℃]	Air cooling cycles
400	60
600	60
800	60

Ultrasonic Experiments. Elastic index is measured by ultrasonic method under the condition of air-cooling. Wave velocity measurement system is shown in Fig.1.

Principle of operation: firstly, the pulse generator sends signals (through wire 1 and wire2) to two different transmitting probes which will send transverse waves and longitudinal waves respectively and at the same time the signals are send to a digital oscilloscope (through wire 6). Secondly, the ultrasound goes into the sample through coupling agent and reflects multiple times. Thirdly, each echo signal that reaches probe will be received and transferred to amplifier (through wire 2 and wire 3) and then send back to digital oscilloscope (through wire 4 and wire 5). At last, current sent pulse signal and multiple echo signal is showed on numerical oscilloscope and once the time difference is calculated the propagation time will be obtained [14,15].

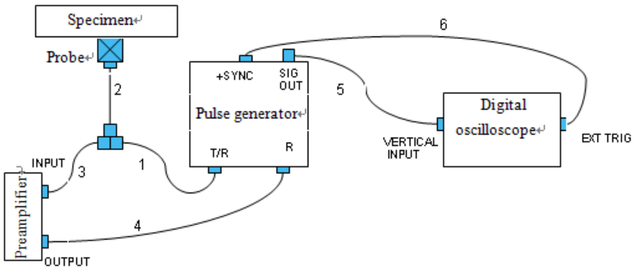

Fig. 1 Ultrasonic wave velocity measurement schematic diagram

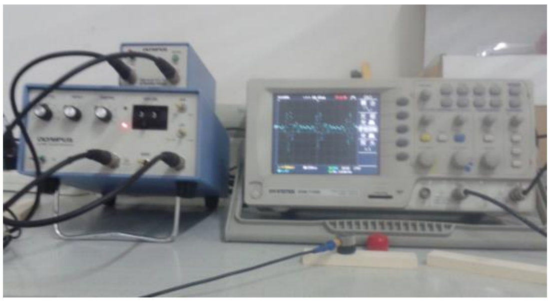

Fig.2 Working scheme of testing instruments

In short, the working process is that pulse signal generated by pulse generator is conversed into high-frequency mechanical energy and then transferred to specimens through coupling agent, propagate, reflect, refract, attenuate to death and finally the propagation time is shown on oscilloscope [16]. Wave velocity measurement device consists of OLMPUS-ultrasonic pulse generator, preamplifier, probe and digital oscilloscope. Fig. 2 shows the instruments.

Research on Elastic Index

Research Principle. The elastic modulus E, shear modulus G and Poisson's ratio μ of materials are calculated according to the following formulas [17]:

$$E = \rho c_T^2 \left[3 - \frac{1}{(c_L/c_T)^2 - 1} \right] \tag{1}$$

$$\mu = \frac{1}{2} \frac{c_L^2 - 2c_T^2}{c_L^2 - c_T^2} \tag{2}$$

$$G = \rho c_T^2 \tag{3}$$

Where c_L is the velocity of longitudinal waves (m/s), c_T is the velocity of shear waves (m/s), ρ is density.

Research Results.

The curve of elasticity modulus E changing with thermal shock cycles are showed in figure 3. It shows that elasticity modulus gradually decrease with the increment of thermal shock cycle times, and when the temperature difference of thermal shock is small, the change of elasticity modulus is small. But the change will be bigger when the temperature difference grows to 600℃ and 800℃ showed in the figure. The decline of elastic modulus indicates that the shape changing capacity of the material has become weak, so the thermal shock has caused much more damages to the sample's elasticity modulus.

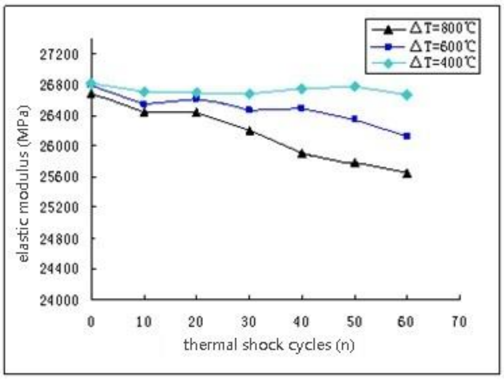

Fig. 3 Elastic modulus changing with the thermal shock cycles times

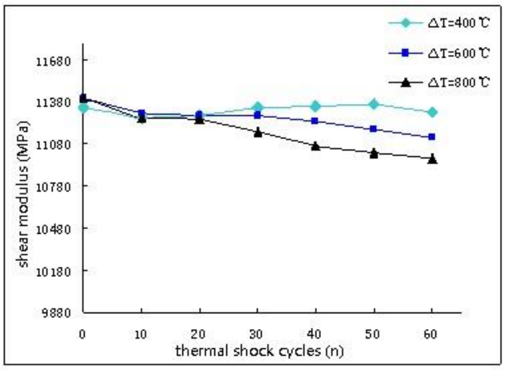

Fig. 4 Shear modulus changing with the thermal shock cycles times

Shear modulus G also changes with thermal shock cycles times, see figure 4. When the temperature difference of thermal shock is 400℃, shear modulus will change like a wave. But when the temperature difference rises to 600℃or 800℃, Shear modulus will go down with the growth of thermal shock cycles times.

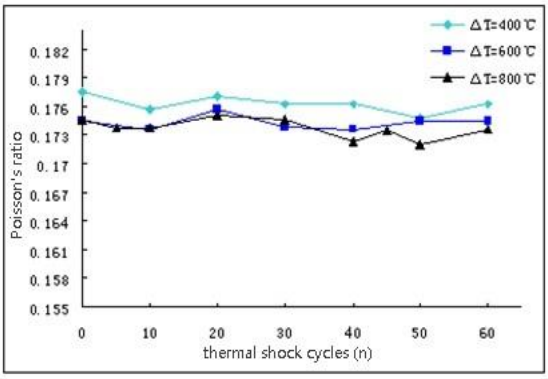

Fig. 5 Poisson's ratio changing with the thermal shock cycles times

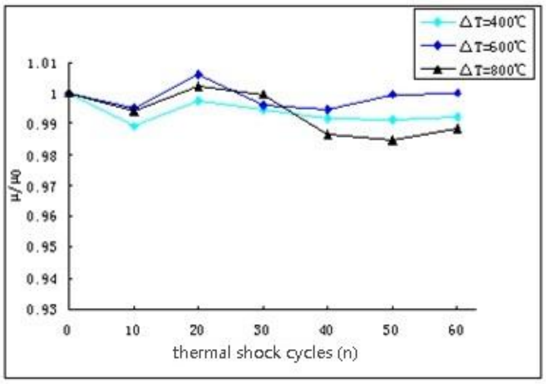

Fig. 6 Normalized processing of Poisson's ratio data

Figure 5 is the curve of Poisson's ratio variation under thermal fatigue. As showed the Poisson's ratio change is not obvious with increasing thermal shock cycle, the changing curves also look like a wave. Figure 6 is the Poisson's ratio variation under 60 times thermal shock. It tells that the bigger thermal shock temperature difference is, the bigger fluctuation Poisson's ratio will have. That means the Poisson's ratio of 400℃ and 600℃ will be smaller than the 800℃. And when the temperature difference is 800℃ and thermal shock cycle is 60, Poisson's ratio decreased by 1.17%.

Research Conclusion.

Through experiment, the changing curves of the elasticity indexes under different temperature differences and different thermal shock cycles are measured, and the extent of damages of thermal shock mechanical properties of the mullite ceramics are obtained.

In the thermal fatigue experiment, the value of the elastic modulus E, shear modulus G and Poisson's ratio μ were reducing gradually with increasing of the thermal fatigue cycles, so that the damage degree of the samples increased.

Summary

Department of Engineering Mechanics at Shandong University of Technology has always put raising student's innovation ability and practical problems solving skills at the first place. Considering the current Engineering Mechanics experiment course contain a little knowledge of optics and acoustics, the department launched the project: the ultrasonic method for measuring the elastic properties of materials. The results show that by connecting practice teaching with theory teaching could expand students' knowledge, enhance students' learning interest and enthusiasm, enable students to learn theoretical knowledge well and master basic experiment skills, and cultivate and enhance their innovative capacity, which lays a good foundation for the subsequent teaching activities.

Acknowledgements

This work was financially supported by the excellent course in Shandong Province "Engineering Mechanics", a grant from National High Technology Research and Development Program of China (863 Program) (2009AA063202) and the Shandong Province Natural Science Fund (ZR2009FQ023, ZR2011EL017, ZR2013EEQ008).

References

[1] Zhao G G, Rao P G, Lu M. China Ceramics, Vol. 42(9) (2006), p.13-17.
[2] Chen B, Ding P D, Cheng C. Nai Huo Cai Liao, Vol. 38(4) (2004), p. 234-237.
[3] Liu H W. Material Mechanic. Beijing: Higher education press, (2011).
[4] Xu Z L. Elasticity Mechanic. Beijing: Higher education press, (2010).
[5] He Z Y, Zhao Y F. Basical Theory of Sonic. Beijing: Defense industry press, (1981).
[6] Shi Y W. Ultrasound Detection. Beijing: Mechanical industry press, (2005).
[7] Osterstock F. Mater. Sci Eng, Vol. A168 (1993), p. 41-44.
[8] Faber K T, Huang M D, Evans A G. Quantiative studies of thermal shock in ceramics based on movel test technique. Journal of the American Ceramic Society, Vol. 64(5) (1981), p. 296-301.
[9] Li J K, Zhou J, Liu X. Journal of Ceramics, Vol. 31(1) (2010), p.101-104.
[10] Li T T. Preparation, characterization and thermal shock resistance of Spodumene ceramics. Wuhan: Wuhan institute of technology, (2012).
[11] Lu J, Zheng Z X, Jin Z H. Material Composite Science, Vol. 18(4) (2001), p.76-81.
[12] Chen B, Ding P D, Cheng C. Journal of the Chinese Ceramic Society, Vol. 32(6) (2004), p.718-722.
[13] Andersson Tomas, Rondiffe David J. Indentation Thermal Shock Test for ceramics. Journal of the American Ceramic Society, Vol. 79(6), (1996).
[14] Lu J, Zheng Z X, Ling Z H. Indentation-quench method to determine the thermal shock resistance for toughing AL2O3 ceramic matrix composites. PTCA, Vol. 39(1) (2003), p.14-18.
[15] Li J W. NDT handbook. Beijing: China Machine Press, (2012).
[16] Hu J K, Zhang Q L. Principals and methods of ultrasound test. Anhui: University of Technology of China press, (1993).
[17] Paul M, Albert S B, Robert E G. Nondestructive Testing Handbook—Ultrasonic Testing. (1996), p.224.

