Experiment Study on Thermal fatigue strength of Ceramic Materials ——Implementation of students' innovative research project of Shandong University of Science and Technology

Yanxia Wang, Qinghui Shang, Yongli Bao, Yongqi Liu*

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

[a]Liuyq65@163.com

Keywords: experiment study, mullite ceramic, regenerative materials, bending strength, thermal shock

Abstract. Fatigue failure is very common phenomenon in engineering field, and fatigue problem is more and more prominent with the development of modern social production to high speed, high temperature, high strength load. In this paper, experiments were carried out by the college students to study bending strength change rule of the mullite ceramic specimens under thermal shock, according to the college students' innovation research project of Shandong University of Science and Technology. The experiment results have shown that in the condition of air-cooling, with the increase of thermal shock temperature difference, the bending strength changed little. However, the bending strength value reduced significantly when temperature difference is 200℃ under the condition of water cooling, and the critical temperature difference of the material can be largely determined. Through the above innovative experiments, the students could master the thermal shock fatigue test approaches, and understand the effects of different heat shock factors influence on the mechanical properties of mullite ceramics.

Introduction

With the development of modern science and technology, materials are puts forward high demands on the departments such as space technology, industrial, energy, transportation and so on. Materials are required having high temperature resistance, erosion resistance, good thermal shock, heat preservation, oxidation resistance, excellent comprehensive performance. High temperature structure ceramic material has a series of excellent performance such as high temperature resistance, scouring resistance, corrosion resistance, high hardness, high wear resistance, high strength and oxidation resistance, so ceramic material is the focus and hotspot in the research of the scientific research workers [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]. 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 differences [4], thermal shock cycles [5], residual strength [6, 7] and the occurrence and extension of crack [8-11]. However, few papers had a systemic study in the influence of temperature difference, thermal shock cycles and cooling medium on the materials in the process of thermal shock. This paper focuses on the change laws of the mechanical performance indexes on the mullite samples with thermal shock processes, and cultivates students the research ideas and research methods of fatigue failure.

Experiments Method

Thermal shock experiments. The specimen made by high temperature solid method, the size of the test piece for 10×20×100㎜. Experiment includes thermal shock test and bending strength test.

Design the Thermal shock experiments as shown in Table 1.

Table 1. Thermal shock experiment.

a thermal shock test	temperature difference	cycles
	0, 100℃, 200℃… 900℃	air-cooling and water-cooling each one time
thermal fatigue test	temperature difference (℃)	air-cooling cycles
	200	65
	300	65
	400	65
	500	65
	600	60
	700	60
	800	60

Determination of flexural strength. Bending strength is obtained by three point bending method, which is according to the provisions of GB3001-82. Measuring instrument is the electronic universal testing machine, and the loading rate is 0.5mm/min. The three point bending method is shown in Fig. 1. The flexural strength is calculated according to formula (1):

$$\sigma = \frac{3PL}{2BW} \tag{1}$$

where P is the load of fracture (N) , L is the distance of the two supports (mm), W is the width of specimen (mm) and B is the height of the specimen (mm).

Research Results

The bending strength change curve of a thermal shock. Under the condition of air-cooling and water-cooling, the bending strength change rules of one thermal shock are analyzed, respectively.

The bending strength change curves along with temperature difference in conditions of different cooling medium are shown in Fig. 5. The figure showed: using air and using water as cooling medium, the bending strength variation trend is different. In air-cooling condition, the specimen almost have no thermal shock damage. In the water quenching condition and at 200℃, the bending strength of the materials have obvious downward trend. The reason is that the thermal conductivity coefficient of two cooling mediums is different, namely water thermal conductivity coefficient is bigger than the air thermal conductivity coefficient. A large rate of temperature difference change in the specimen is caused by the big thermal conductivity coefficient of the outside world, so that the big thermal stress is caused, and then the damage of the specimen is large. As a result, specimen damage under water-cooling is bigger than that under the air-cooling. From the Figure 5, it can be seen that the critical temperature difference of the ceramic material is roughly around 200℃.

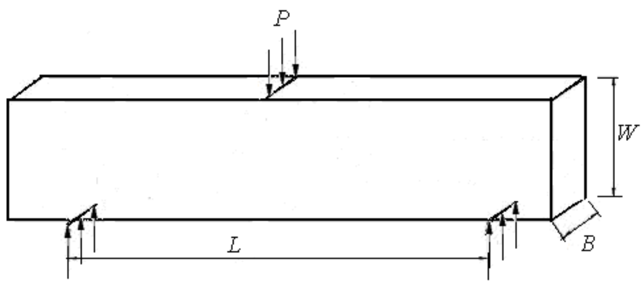


Fig.1. Schematic diagram of three point bending method for measuring the bending strength

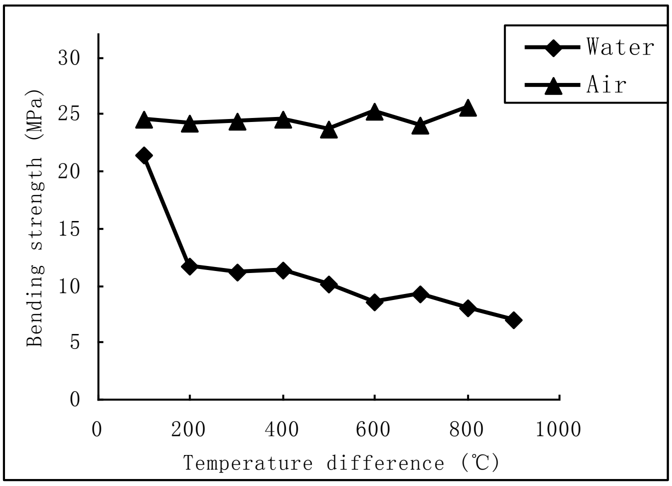
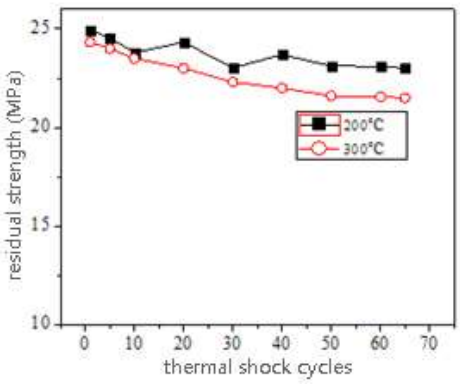
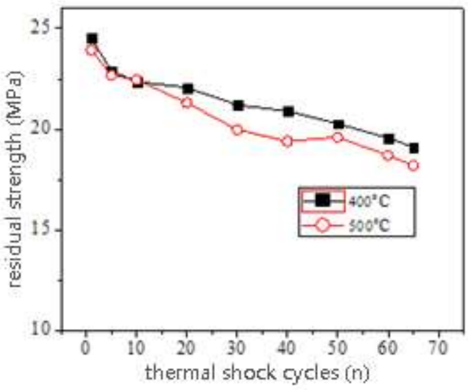


Fig. 2. The bending strength changing with thermal shock temperature difference

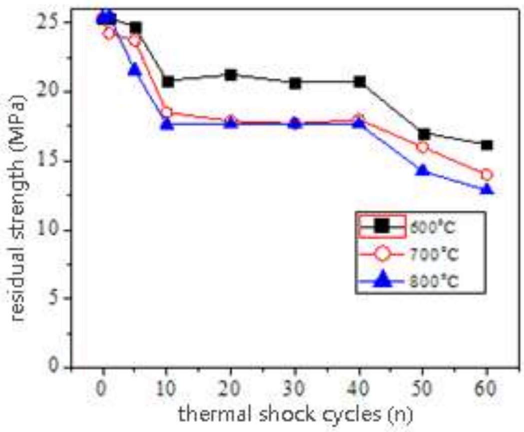
The bending strength change curve of thermal shock fatigue. The samples' residual bending strength curves of various thermal-shock cycles under different temperatures are shown in figure 3. By separated into three groups, the curves show different patterns as below.

In the figure 3, it could be concluded that the material's residual strength will decline with different thermal shock cycles. However, with various temperature differences and thermal shock cycles it shows different attenuation laws. When the temperature difference gets 200 ℃- 300 ℃, the changing is slow compared with 400 ℃- 500 ℃, but when it goes up to 600 ℃-800 ℃ the variety discipline will change totally from low temperature. The residual strength will fall off at first along with increase of thermal shock cycle, and then before it falls again it will keep still for a certain scope. The decline of residual strength is quite rapid in the first ten thermal shocks; it is because of the high thermal stress caused by large temperature difference, and the accumulation of damage. When the strength keeps stand under 10^{th}-40th thermal shocks there is no new cracks formed and the energy is stored in the cracks formed in the first ten shocks which will advance the growth of the cracks depth and length, it is called the sub-critical extension. When energy stored exceeds the critical status, residual strength will continue to drop.





(a) temperature difference of 200 ℃ and 300 ℃ (b) temperature difference of 400 ℃ and 500 ℃



c) temperature difference of 600 ℃,700 ℃,800 ℃

Fig. 3. The bending strength changing with thermal shock cycle times

Research Conclusion

Through experiment, the change curve of the bending strength which were under different temperature, different thermal shock cycles and different cooling mediums were measured, and the damage degree of thermal shock mechanical properties of the mullite ceramics were obtained.

There are different damage degrees of the specimens under different cooling medium. Specimen damage under water-cooling is bigger than that under the air-cooling.

In the thermal fatigue experiments, bending strength decreases gradually with increasing of the thermal fatigue cycles, so that the damage degree of the samples increased.

Summary

In the current engineering mechanics course, the fatigue, especially the thermal fatigue, almost is not involved due to the limitation of school hours. The students almost have not fatigue failure concept, and have not scientific ideas and methods to solve the problem of fatigue. But, in the process of “college students' innovative research project”, by studying bending strength change rule curve of the mullite ceramic specimens, the students' research ideas and research methods of fatigue failure could be cultivated. Practice has proved that implement undergraduate innovation research projects can effectively arouse students’ learning enthusiasm, cultivate college students' scientific research innovation and analytical abilities to solve practical scientific research problems.

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] Osterstock F. Mater. Sci Eng, Vol. A168 (1993), p. 41-44.

[4] 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.

[5] Li J K, Zhou J, Liu X. Journal of Ceramics, Vol. 31(1) (2010), p.101-104.

[6] Li T T. Preparation, characterization and thermal shock resistance of Spodumene ceramics. Wuhan: Wuhan institute of technology, (2012).

[7] Lu J, Zheng Z X, Jin Z H. Material Composite Science, Vol. 18(4) (2001), p.76-81.

[8] Chen B, Ding P D, Cheng C. Journal of the Chinese Ceramic Society, Vol. 32(6) (2004), p.718-722.

[9] Andersson Tomas, Rondiffe David J. Indentation Thermal Shock Test for ceramics. Journal of the American Ceramic Society, Vol. 79(6), (1996).

[10] 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.

[11] Li J W. NDT handbook. Beijing: China Machine Press, (2012).

