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Numerical simulation of crack propagation in ceramic materials at high temperature

Fengshan Han * [1], Xinli Wu [2], Zhongliang Cui [3]

[1]Research Center for Numerical Tests on Material Failure, Dalian University, Dalian, 116622, China

[2]College of Engineering, The Pennsylvania State University, Pennsylvania, USA

[3]Fourth branch, Dalian Kaijian Municipal Engineering Co Ltd，Dalian,116600，China

*Corresponding author e-mail: 568418541@qq.com

Abstract Ceramic Materials have been widely used in many fields of engineering, It is necessary to research the process of crack propagation of ceramic materials at high temperature by numerical simulation. The numerical model is applied to investigate the formation, extension and coalescence and crack propagation in ceramic materials at high temperature. A numerical model of ceramic materials is proposed to investigate thermally-induced damage and crack propagation at high temperature. The numerical simulations show that when the tensile stress exceeds its phase transition threshold, it produces tensile failure, in the specimen surface more and more the impact cracks are appear, the crack spacing's are basically equal and parallel to each other, with the elapse of time, the main cracks continue to expand, small part of the cracks expansion are subjected to limited, there are the classifications of cracks. With the elapse of time, crack propagation speed gradually slows down, and eventually reaches a steady state. The numerical simulation demonstrates that the model proposed can visually replicate the thermal cracking propagation process of ceramic materials at high temperature. The result of our numerical simulation shows that thermal cracking propagation process in ceramic materials at high temperature is in good agreement with the real experimental thermal cracking result of crack propagation in ceramic materials at high temperature.

1. Introduction

Ceramic materials have been widely used more extensive application in many fields of engineering such as in the field of aerospace, machinery manufacturing, energy, metallurgy, in daily life, etc. due to their with good resistance to high temperature, corrosion resistance, wear resistance. under the conditions of high temperature, ceramic material inevitably suffer from effect of thermal shock. Due to their brittleness, sensitivity to defects and low thermal conductivity, that make ceramic materials easy to Failure under the conditions of high temperature. Therefore, stiffness and thermodynamic in the thermal environment of ceramic materials must be accurately analyzed. In the design of the structure of ceramic materials and to evaluate its service life In the hot environment and corresponding guiding the structure design of ceramic materials and to evaluate its service life. Especially its structure under extreme conditions (high temperature, with the dynamic and complex environment) , the elastic and inelastic behavior and damage and failure mechanism should be researched. Thermal stress caused by thermal shock belongs to the unsteady thermal stress. due to temperature change, the surface or internal in ceramic materials will generate the high stress leading to material damage and failure.

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extensive researches [1–15] have been carried out on the behavior of ceramic materials at high temperature. It is necessary to research the crack propagation process of ceramic materials at high temperature by numerical Simulation.

Thermal shock is an important factor of material Failure. when material is urgently heating or cooling, it results in severe temperature changes, and impacts thermal stress within material. Thermal stress is caused by thermal shock and it belongs to the unsteady thermal stress, due to extreme temperature changes, on the surface of the material or internal material , high stress will be produced. and leading to material failure.

Some useful analytical solutions have been developed, but the analysis was not sufficient to predict crack generation and propagation. It is evident that these analytical solutions are limited to resolve the thermal incompatibility of homogeneous materials. They are unable to take into account the heterogeneity of material properties and the process of cracks propagation, which are important to researchers and practicing engineers.

This paper presents the use of a thermal elastic damage model, Realistic Failure Process Analysis (abbreviated as RFPA) for thermo code, to investigate the formation, extension and coalescence of cracks induced by thermal stress on ceramic materials. to study the thermal cracking process and crack propagation of ceramic material at high temperature. The development of the thermal cracks are discussed. The simulated results provide a better understanding of the mechanisms of thermally induced cracking in ceramic material at high temperature.

2. Numerical Simulation

2.1 Model of Ceramic Materials at high temperature for numerical simulation

In order to simulate thermal cracking behavior of ceramic materials at high temperature,. A numerical model with a geometry of 35mm×10mm, is discredited into a 350×100 (35000 elements) mesh, was established to simulate the process of crack propagation of ceramic materials at high temperature. Numerical simulation model is shown in Figure 1. The model of the left, right, down, on this three sides are fixed and are thermal isolation.. The model of the Up surface is contact surface with environment, and is in a state of freedom. Model of the initial temperature is 300 degrees, and the environment temperature is 20 degrees, model can be treated as the ceramic heating to high temperature condition, then its three surfaces are fixed and model is thermal isolation and it is suddenly put it into the environment temperature, The model of the Up surface is contact with the environment temperature.

The elements are characterized by Young's modulus (E), uniaxial compressive strength, Thermal expansion coefficient, and so on. The physical and mechanical Parameters adopted in the Numerical simulation are listed in Table 1.

Fig. 1. Model of Numerical simulation

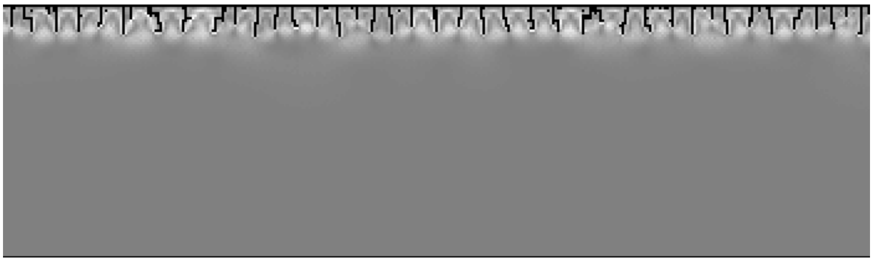
Table 1 Rock parameters of surrounding rock used for numerical simulation

Homogeneous Index	Modulus elasticity /Mpa	Compressive strength /Mpa	Thermal expansion coefficient /α/K^{-1}	Specific heat /J/kg ^{0}C	Heat transfer coefficient / W.(mK)$^{-1}$
10	243000	700	8.5×10^{-6}	300	8

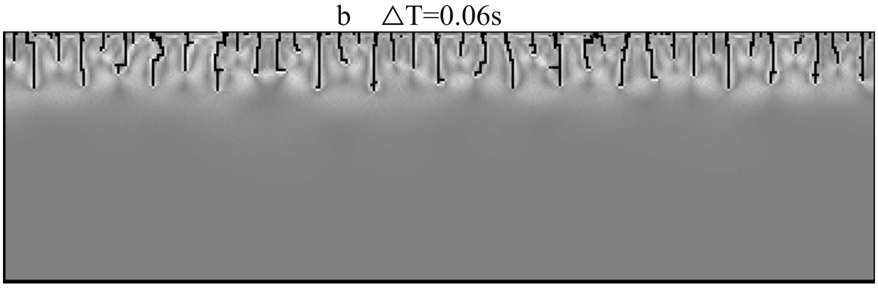
2.2 Process of Crack Propagation in Ceramic Materials at high temperature by numerical simulation

Process of crack propagation in ceramic materials at high temperature by numerical simulation is shown in Figure 2.

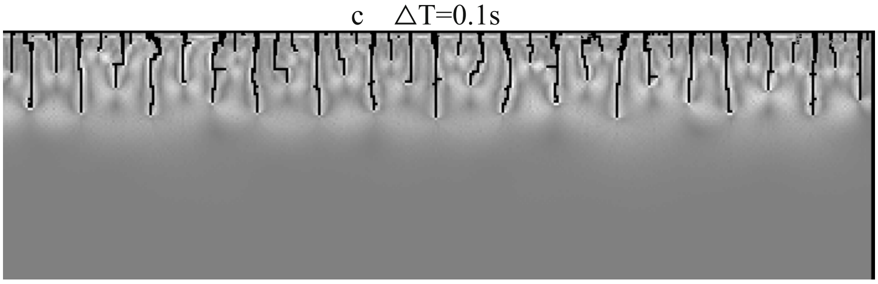
a △T=0.01s



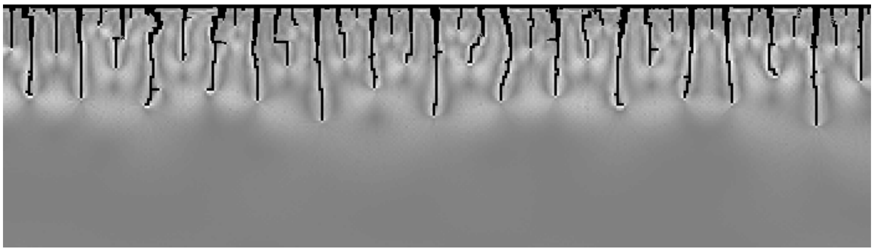
b △T=0.06s



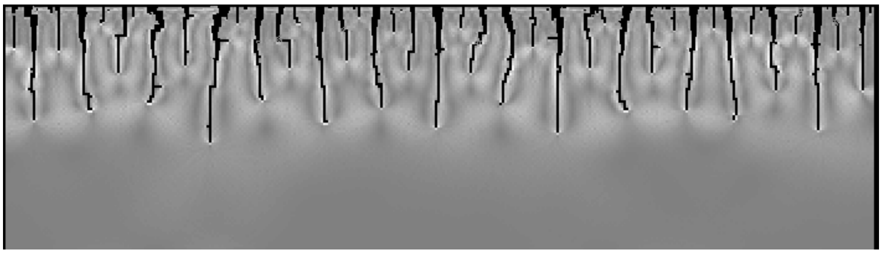
c △T=0.1s



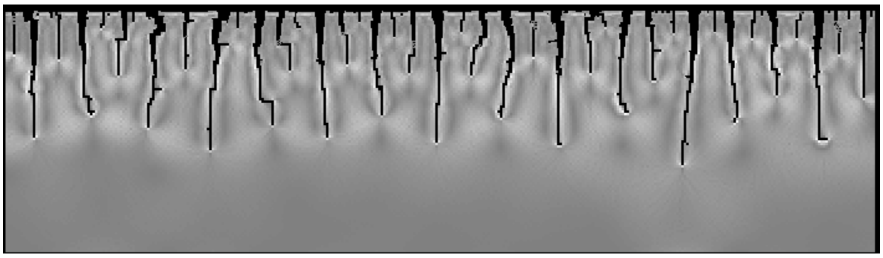
d △T=0.4s



e △T=0.6s



f △T=0.8s

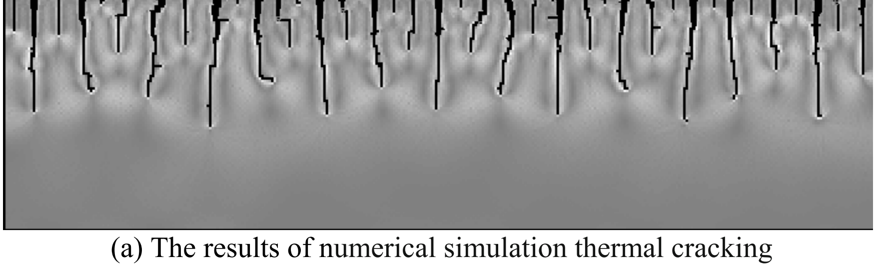


g △T=1s

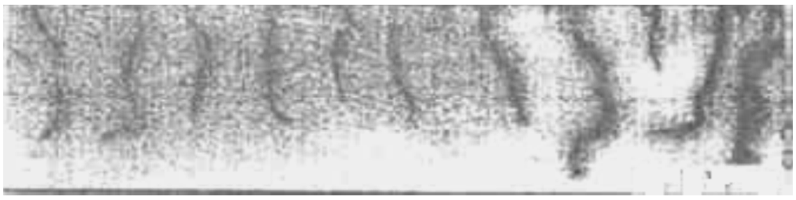
Fig. 2 Process of crack propagation in ceramic materials at high temperature by numerical simulation

As described above, the numerical Simulation show that the crack propagation behavior in ceramic materials at high temperature is developed at the interface, as is shown in Fig.2a. When the simulated sample specimen is subjected to thermal shock, In the specimen surface tensile stress is produced, when the tensile stress exceeds its phase transition threshold, it produce tensile failure. The initial cracks on the surface of thermal shock are formed, When the △T = 0.1s, specimen surface produce tensile failure, When the △T = 0.2s, The specimen surface appears more and more the impact crack, the crack spacing is basically equal and parallel to each other. When the △T = 0.3s, ,With the elapse of time, the surface tensile stress increases, prompted the cracks continue to expand, When the △T=0.4s, Most cracks continue to expand, but there are a small part of the cracks expansion, are subjected to limited. When the △T = 0.6s,With the elapse of time, The main cracks continue to expand, small part of the cracks expansion are subjected to limited, there are the classifications of cracks. with the elapse of time, crack propagation speed gradually slow down, and eventually reach a steady state, as is shown in Fig.2

The result of our numerical simulation the thermal cracking propagation process in ceramic materials at high temperature is in good agreement with the real experimental thermal cracking result of crack propagation in ceramic materials at high temperature [14,15]. as is shown in Fig.3



(a) The results of numerical simulation thermal cracking



(b) The results of real experimental thermal cracking [14,15].
Fig. 3 The results of numerical simulation and real experimental thermal cracking

3. Conclusions

This paper briefly describes the application of numerical model of thermal induced damage and failure of process of crack propagation in ceramic materials at high temperature, the crack formation and extension process of crack propagation in ceramic materials at high temperature were investigated using the RFPA-Thermo model. the simulated thermal cracking pattern in ceramic materials at high temperature agrees well with the real experimental results. the presented method provides an opportunity to investigate the effect of fracture initiation, propagation and coalescence due to thermal cracking, and it also provides an easy way to investigate damage appearing simultaneously, The numerical study reveals the failure process induced by thermal shock. numerical simulations show that when the tensile stress exceeds its phase transition threshold, it produce tensile failure, the specimen surface appears more and more the impact crack, the crack spacing is basically equal and parallel to each other, with the elapse of time, the main cracks continue to expand, small part of the cracks expansion are subjected to limited, there are the classifications of cracks. with the elapse of time, crack propagation speed gradually slow down, and eventually reach a steady state. the numerical simulations show that the cracks initiated rule less on the surface where it subjected to thermal shock at the beginning of thermal shock. however, as the further thermal conduction produced some cracks gradually growth following the inner normal direction of the surface while the propagation of other cracks was restrained. It is useful for studies on the thermal induced failure mechanism of ceramic materials at high temperature.

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