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On the Facts of the Nanostructure of Zirconia and Its Cracking Mechanism[†]

EL-SHEIKHY Refat ^{*} and KOBAYASHI Akira ^{**}

Abstract

It was found during the investigation that the cracking mechanism, cracking path, crack propagation, cracking speed, and interaction between cracks depend mainly on the nanostructure of the coating material of zirconia. This phenomenon was not clear enough before the detailed fundamental study of fracture of zirconia coating experimentally and theoretically by means of the advanced theory of fracture mechanics and the directional fracture approach.

KEY WORDS: (Cracking) (Mechanism) (Nanostructure) (Zirconia) (Fracture mechanics)

1. Introduction

In this paper the directional fracture mechanics criterion is proposed for application in the field of cracking of gas tunnel plasma spray coatings. Since the cracks of the coating are special cases of fracture based on the technology of plasma spray technique which is very special case and with very special and sensitive materials and analysis, The properties and conditions of plasma science and technology have a great effect on the fracture behavior, crack formation and crack propagation in the coating materials [1]. Therefore, this paper introduces a special application of the directional theory and directional energy approach for thermal stresses and thermal energy [1-4]. This problem of the fracture of the cracks is more complex than any other type of single material or any other composite for many reasons. In addition the mechanical properties of the coating material itself rather than its fracture properties are very difficult to be measured or calculated [1-4]. Thermal fracture properties and thermal fracture energy should be investigated and predicted for studying the cracking and improving the coating material for developing coating material without cracks. This is the aim of this study. Previous studies could not solve this serious problem for the coating technology.

2. Cracks Phenomenon of Zirconia Coating

It is recognized that zirconia coating by GTPS technology has many cracks as shown in **Figs. (1-4)**. These cracks includes tensile mode I, in plane mode II shear, out of plane mode III shear, debonding crack and mixed mode cracks.

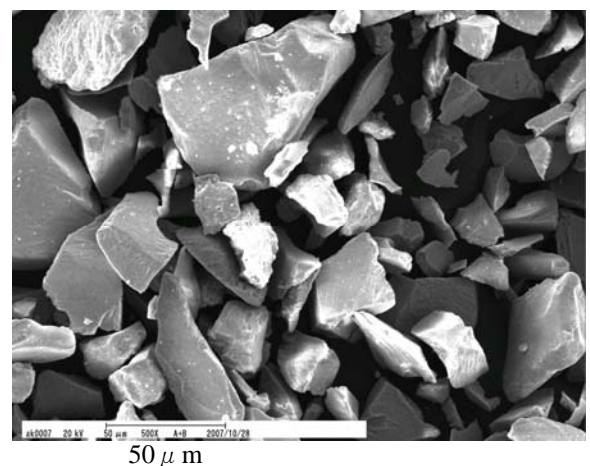


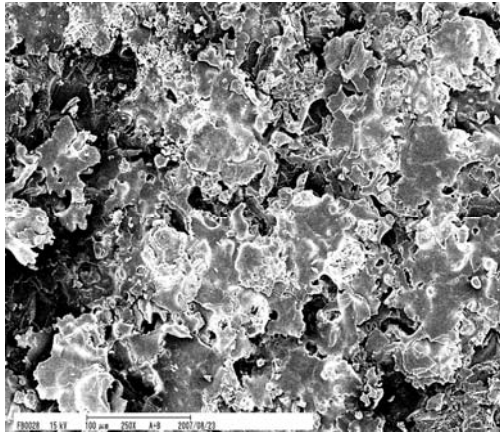
Fig.1 Zirconia powder before coating.

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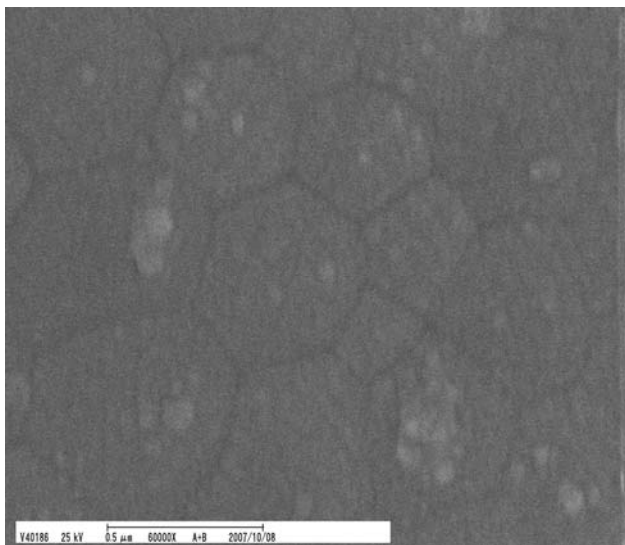


100 μ m

Fig.2 Zirconia coating after spraying.

3. Zirconia Nanostructure, Fracture Interaction, Mechanism of Fracture and Failure of Zirconia

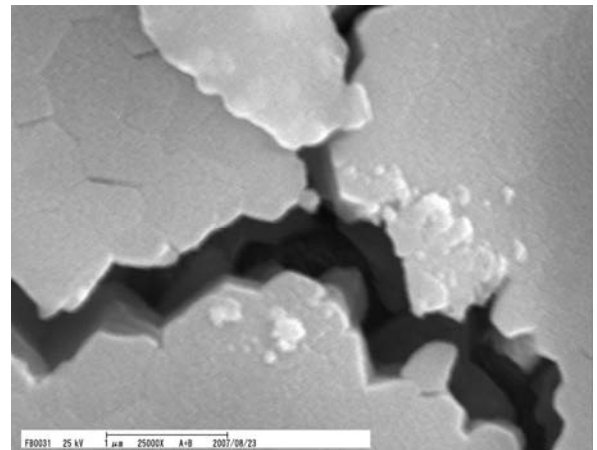
The coating cracks may be associated with full or partial debonding between the coating layer/layers and substrate or between coating layers themselves. This case produces in addition to the other type of cracks, out of plane mode III cracks. These cracks are due to thermal stresses. They will be in single or group cases, intersected, connected or branched cases. Although Zirconia powder particles are of irregular shape with sharp edges the coating microstructure is fine honeycomb structure (**Fig.3**). The cracks usually start by debonding between the particles of the honeycomb under local stress concentration producing new crack surfaces in the same direction of bonded separated particles edges.



0.5 μ m

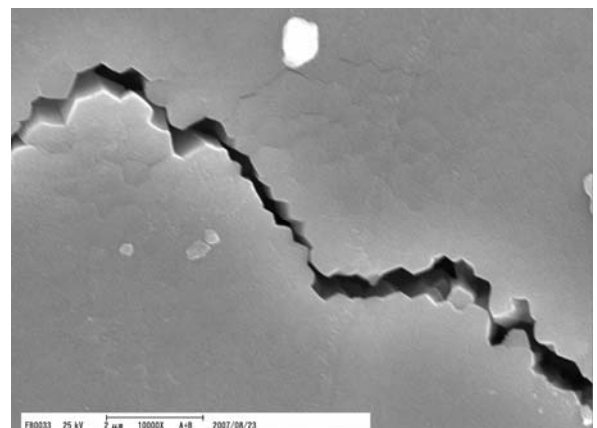
Fig.3 Microstructure of Zirconia coating as Honeycomb.

Therefore, the propagation direction is pre-predicted locally. This local crack will extend in one or more directions between the adjacent particles producing new surfaces and so on until the end of the fracture path. Finally the fracture direction globally will be different from the local directions. The global direction can not pre-predict. It should be predictable by a suitable fracture theory [1-4]. The fracture load locally and globally should be predicted by the suitable fracture theory [1-4]. So, the Global – Local fracture theory is developed (KR-GL theory).As shown, (**Fig.4.a,b,c**) indicates a cracking model with the crack path locally and globally under tension or compression stresses producing irregular crack like zigzag.



1 μ m

Fig.4.a Honeycomb structure of zirconia indicating the local and globl fracture directions.



2 μ m

Fig.4.b Honeycomb structure of zirconia indicating the local and globl fracture directions.

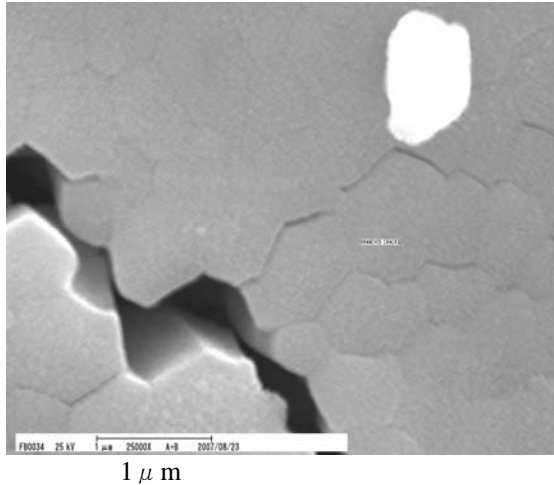


Fig.4.c Honeycomb structure of zirconia indicating the local and global fracture directions.

4. Approach and Theory of the Mechanism

A developed fracture criterion is proposed called Global- Local fracture theory (KR-GL theory). This theory depends on directional fracture theories [1- 4]. It includes two steps as the following:

- 1- The first step is to calculate global fracture direction (θ_c) and global fracture load (σ_c) by means of directional volumetric-distortional strain energy theory [1-4] in addition to other global fracture properties.
2. The second step is to calculate the local fracture direction or directions at the same points. These directions are already pre-determined by the directions and locations of the bond between each two particles. The local fracture load should be determined. So, the local bond strength will be calculated in the core region near the global crack tip to find which bond will start fracture first or start together. Usually at each crack tip there are two or at least one, bond. The fracture direction and fracture load will be calculated by volumetric distortional strain energy theory. New crack surfaces will be produced.

5. Relation between Zirconia Coating Structure and Cracks

Figures 6 and 7 show some results for fracture directions and fracture load under thermal stresses in bi-directional stresses as shown in the model of (Fig.5). Figures 6 & 7 shows the results of fracture direction and fracture load for the two cases of thermal stresses in heating stage as tensile stresses and cooling stage as compression stresses. The results show that there are three types of bond. One bond is between the particles and each other in the same coating layer. Another bond is between the particles in one layer and particles in another layer. The last bond is located between the substrate and

particles of adjacent layer. Complete results will be published soon.

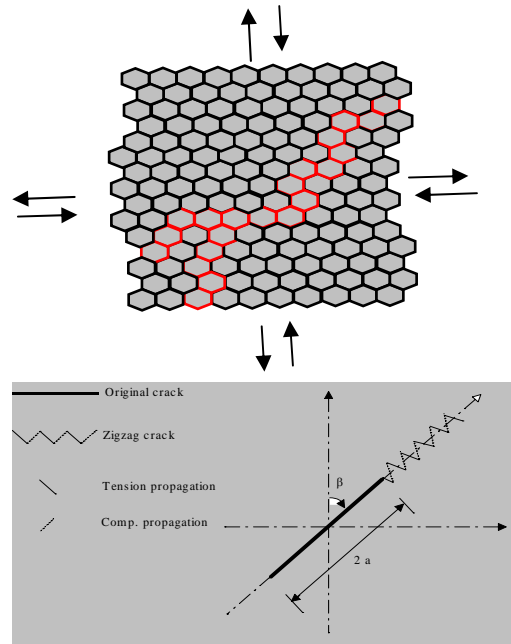


Fig.5 Fracture model and applied thermal stresses.

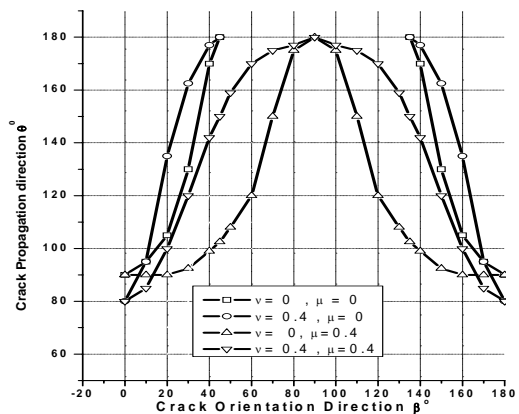
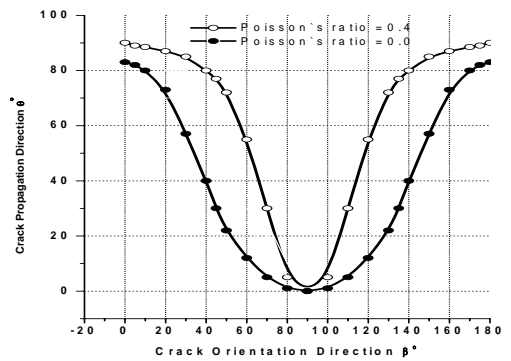


Fig.6 Fracture directions and critical stresses due to heating as tension stresses.

6. Conclusions

As shown the fracture problem of zirconia coating is a very complicated problem. It has different phenomena than other materials and composites from many views. It needs very special methods of analysis. The fracture directions and fracture loads are of different types regarding the local and global analysis. The fracture increment length can be estimated as the length of the side length of the zirconia particles. Then, the fracture properties, fracture energy and fracture path can be calculated and pre-predicted by the applied theory. A safe life time can then be estimated. The fracture can be controlled and may be prevented. The next step of the research will concentrate on more specific studies of the fracture analysis for these reasons.

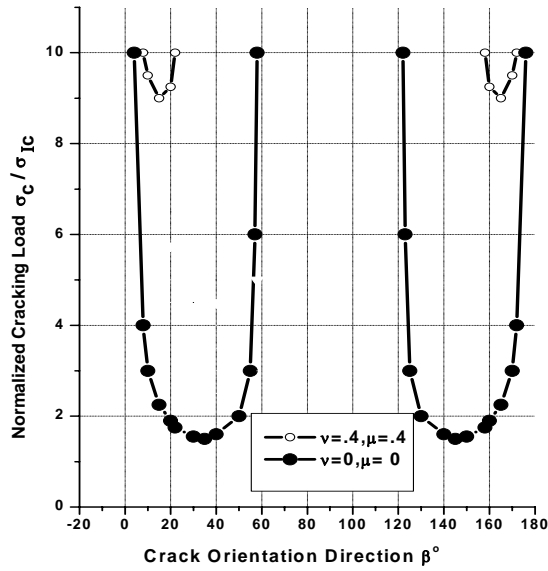
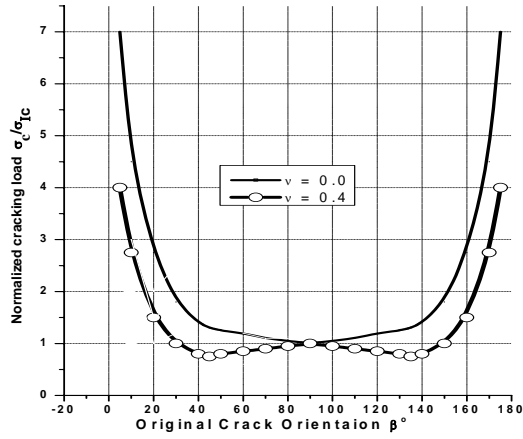


Fig.7 Fracture directions and critical stresses due to cooling as compression stresses.

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