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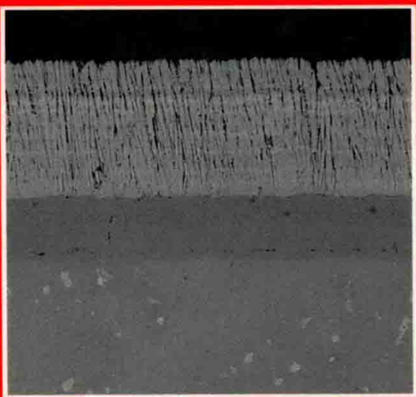

Thermal barrier coatings

Edited by Huibin Xu and Hongbo Guo

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Contributor contact details

(* = main contact)

Editors

H. Xu and H. Guo
School of Materials Science and Engineering
Beihang University
37 Xueyuan Road
Beijing 100191
China

E-mail: xuhb@buaa.edu.cn
guo.hongbo@buaa.edu.cn

Chapter 1

D. Zhang
School of Energy, Power and Mechanical Engineering
North China Electric Power University
Beijing 102206
China

E-mail: zhangdb@ncepu.edu.cn

Chapter 2

W. Ma* and H. Dong
School of Materials Science and Engineering
Inner Mongolia University of Technology
49 Aimin Road
Xincheng district
Hohhot 010051
China

E-mail: wma@imut.edu.cn

Chapter 3

X. Peng
State Key Laboratory for Corrosion and Protection
Institute of Metal Research
Chinese Academy of Sciences
72 Wenhua Road
Shenhe district
Shenyang 110016
China

E-mail: xpeng@imr.ac.cn

Chapter 4

C. G. Zhou* and Q. H. Yu
School of Materials Science and Engineering
Beihang University
37 Xueyuan Road
Beijing 100191
China

E-mail: cgzhou@buaa.edu.cn

Chapter 5

J. Xu* and K. A. Khor
School of Mechanical and Aerospace Engineering
Nanyang Technological University
50 Nanyang Avenue
Singapore 639798

E-mail: jlxu@ntu.edu.sg

Chapter 6

S. Gong* and Q. Wu
School of Materials Science and Engineering
Beihang University
37 Xueyuan Road
Beijing 100191
China

E-mail: gongsk@buaa.edu.cn

Chapter 7

L. Chen
Department of Material Science and Engineering
China University of Petroleum
18 Fuxue Road
Changping
Beijing 102249
China

E-mail: liqiang_chen@sohu.com

Chapter 8

H. Guo*, R. Yao and L. Zhou
School of Materials Science and Engineering
Beihang University
37 Xueyuan Road
Beijing 100191
China

E-mail: guo.hongbo@buaa.edu.cn

Chapter 9

P. Ke*
Surface Engineering
Ningbo Institute of Materials Technology and Engineering
Chinese Academy of Sciences
519 Zhuangshi Road
Zhenhai district
Ningbo 315201
China

E-mail: plkeimr@hotmail.com
kepl@nimte.ac.cn

Y. Wu and C. Sun*
State Key Laboratory for Corrosion and Protection
Institute of Metal Research
Chinese Academy of Sciences
72 Wenhua Road
Shenhe district
Shenyang 110016
China

E-mail: yingnawu@gmail.com
csun@imr.ac.cn

Chapter 10

C. G. Zhou and Y. X. Song
School of Materials Science and Engineering
Beihang University
37 Xueyuan Road
Beijing 100191
China

E-mail: cgzhou@buaa.edu.cn

Chapter 11

C. Zhang*
Baosteel Group Corporation
Pu Dian Road 370
Pudong New District
Shanghai 200122
China

E-mail: zcx_buaa@163.com

C. Chen
AVIC Commercial Aircraft Engine Co., Ltd
Building 3
Dongchuan Road 555
Minhang District
Shanghai 200241
China

E-mail: chenchen@mse.buaa.edu.cn

Chapter 12

G. Chen
Shaanxi Key Laboratory of Friction Welding Technologies
Northwestern Polytechnical University
127 Youyi Xilu
Xi'an
Shaanxi Province 710072
China

E-mail: gfchen@gmail.com

Chapter 13

R. T. Wu
International Center for Young Scientists (ICYS)
National Institute for Materials Science (NIMS)
1-2-1 Sengen
Tsukuba
Ibaraki 305-0047
Japan

E-mail: wu.rudder@nims.go.jp

Chapter 14

H. Y. Qi* and X. G. Yang
School of Jet Propulsion
Beihang University
37 Xueyuan Road
Beijing 100191
China

E-mail: qhy@buaa.edu.cn

Chapter 15

H. Xu* and J. Wu
School of Materials Science and Engineering
Beihang University
37 Xueyuan Road
Beijing 100191
China

E-mail: xuhb@buaa.edu.cn

Preface

Thermal barrier coatings (TBCs) are finding increasing application in the most demanding high-temperature environment of aircraft and industrial engines. They have the capability to improve the durability of engines by reducing the surface temperature of the underlying components. The use of TBCs, along with internal cooling of the underlying superalloy components, has thus enabled advanced gas turbine engines to operate at temperatures even above the melting temperature of the superalloy, thus achieving a remarkable increase in the efficiency and performance of engines. This technology has been regarded as one of the most important and effective developments in efforts to improve the propulsion efficiency of advanced aero engines.

The TBC components must withstand the harsh environment coupled with high temperature, large temperature gradient, complex stress condition and corrosive atmosphere. No single coating component is able to satisfy these multifunctional requirements. As a result, a complex TBC structure has been developed. Research since the 1970s has been focused on a preferred coating system primarily comprising three separate layers on the substrate, so as to achieve long-term effectiveness in oxidative and corrosive environment at high temperatures, i.e. a ceramic top coat layer with low thermal conductivity to provide excellent thermal insulation for the hot components, a bond coat layer above the substrate to hold the ceramic coat on the substrate, and a thin thermally grown oxide (TGO) layer to provide adhesion between the ceramic top coat and the bond coat. The TBC component is expected to last over thousands of take-offs and landings in aero engines. However, the complexity and diversity of TBC structures and the severity of operating conditions give rise to premature TBC failure. This premature failure has slowed down the use of TBCs and compromised the ability to take full advantage of the energy efficiency and service lifetime potentially offered by TBCs. In view of this, fundamental investigations into TBC materials and processing principles and assessments of TBC performance, lifetime prediction and failure mechanisms have been systematically conducted. The multidisciplinary subjects of materials science, physics, chemistry, mechanics, computation science and thermodynamics are involved in this research field.

At present, the TBC industry is key in the field of aero engines worldwide. It is necessary to make the theory and the applications of TBCs known to both researchers and graduate students, and this is the purpose of this book. The aim is not only to provide a clear and thorough presentation of both fundamental principles and applications of TBC systems in the aero engine industry, but also to prepare the way for future TBC systems by reviewing previous achievements. There are 15 independent chapters in this book, in which progress in TBC materials, advanced processing technologies, physical and chemical phenomena such as oxidation, diffusion, fatigue, thermal conduction and sintering, failure mechanisms and non-destructive evaluation of TBCs and their life prediction have been described.

A general description of the background, processing technology of electron beam physical vapor deposition (EB–PVD), oxidation and thermal cycling performance of TBCs manufactured by EB–PVD is given in Chapter 1. The selection principles and the progress of ceramic top coat materials in TBC systems are introduced in Chapter 2. Several proposals on the development trends in ceramic top coats are raised in this chapter. In Chapter 3, the emphasis is placed on a comparison of the processing and oxidation resistance of various metallic coatings. As a newly developed TBC system, the nanostructured TBCs are introduced in Chapter 4, including the fundamental principle of formation of nanostructure, microstructure features and associated properties, and several potential applications of nanostructured TBCs are suggested.

Two main processing technologies are generally used in the manufacture of TBCs, namely plasma spraying (PS) and electron beam physical vapor deposition (EB–PVD). The principles, microstructure characteristics and applications of PS and EB–PVD are addressed in Chapters 5 and 6, respectively, giving guidance in the selection of processing technology for the production of TBCs to meet different industrial purposes. In Chapter 7, plasma-sprayed TBCs are presented with the emphasis on thermal physical properties, mechanical properties, durability and failure mechanisms. The properties of plasma-sprayed TBCs can be further improved by modifications to the TBC structure. This fact was particularly evident in Chapter 8, in which a modified TBC structure with high segmentation crack density is proposed. In Chapter 9, the structure, characteristics and properties of TBC systems prepared by a so-called detonation plasma spray method are presented.

One of the primary tasks for TBCs is to effectively protect the underlying superalloy substrate from hot corrosion and high-temperature oxidation. The high-temperature oxidation and hot-corrosion behaviors of TBCs are described in Chapter 10. The emphasis is focused on failure mechanisms of TBCs associated with cracking of TGO grown on the metallic bond coat and comparison of several kinds of metallic bond coating materials which are practical use in engineering design. In Chapter 11, the behaviors of TBCs under thermal-mechanical coupled loads are presented, and a failure mechanism is also put forward. Recently, non-destructive evaluation (NDE) methods have been used for the premature failure detection of TBC systems. Chapter 12 reviews the fundamentals and application of different NDE methods with particular emphasis on the latest results in the promising area of emission spectroscopy NDE used for in situ TBCs failure inspection. The inter-diffusion between the bond coat and the underlying substrate under high temperatures has significant influence on the mechanical properties of superalloy, oxidation resistance and durability of TBCs. This is clearly stated in Chapter 13.

Chapter 14 deals with life prediction of TBCs. The ability to foresee, theoretically, the lifetime of TBCs is fundamental in improving the safety of TBC components in industrial applications. In this chapter, three visco-plastic constitutive models are developed for TBC systems. Failure mechanisms of TBCs are discussed and a fatigue life model is set up for life prediction of TBC vanes.

In the final chapter, new TBC materials and processing technologies are reviewed and some possible directions for the development of TBCs in the future are suggested.

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Huibin Xu
Beihang University, China

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