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KEY=THE - PRATT CARNEY

Influence of High Cycle Thermal Loads on Thermal Fatigue Behavior of Thick Thermal Barrier Coatings

Thick thermal barrier coating systems in a diesel engine experience severe thermal low cycle fatigue (LCF) and high cycle fatigue (HCF) during engine operation. In the present study, the mechanisms of fatigue crack initiation and propagation, as well as of coating failure, under thermal loads which simulate engine conditions, are investigated using a high power CO2 laser. In general, surface vertical cracks initiate early and grow continuously under LCF and HCF cyclic stresses. It is found that in the absence of interfacial oxidation, the failure associated with LCF is closely related to coating sintering and creep at high temperatures, which induce tensile stresses in the coating after cooling. Experiments show that the HCF cycles are very damaging to the coating systems. The combined LCF and HCF tests produced more severe coating surface cracking, microspallation and accelerated crack growth, as compared to the pure LCF test. It is suggested that the HCF component cannot only accelerate the surface crack initiation, but also interact with the LCF by contributing to the crack growth at high temperatures. The increased LCF stress intensity at the crack tip due to the HCF component enhances the subsequent LCF crack growth. Conversely, since a faster HCF crack growth rate will be expected with lower effective compressive stresses in the coating, the LCF cycles also facilitate the HCF crack growth at high temperatures by stress relaxation process. A surface wedging model has been proposed to account for the HCF crack growth in the coating system. This mechanism predicts that HCF damage effect increases with increasing temperature swing, the thermal expansion coefficient and the elastic modulus of the ceramic coating, as well as the HCF interacting depth. A good agreement has been found between the analysis and experimental evidence.

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Createspace Independent Publishing Platform Thick thermal barrier coating systems in a diesel engine experience severe thermal Low Cycle Fatigue (LCF) and High Cycle Fatigue (HCF) during engine operation. In the present study, the mechanisms of fatigue crack initiation and propagation, as well as of coating failure, under thermal loads which simulate engine conditions, are investigated using a high power CO2 laser. In general, surface vertical cracks initiate early and grow continuously under LCF and HCF cyclic stresses. It is found that in the absence of interfacial oxidation, the failure associated with LCF is closely related to coating sintering and creep at high temperatures, which induce tensile stresses in the coating after cooling. Experiments show that the HCF cycles are very damaging to the coating systems. The combined LCF and HCF tests produced more severe coating surface cracking, microspallation and accelerated crack growth, as compared to the pure LCF test. It is suggested that the HCF component cannot only accelerate the surface crack initiation, but also interact with the LCF by contributing to the crack growth at high temperatures. The increased LCF stress intensity at the crack tip due to the HCF component enhances the subsequent LCF crack growth. Conversely, since a faster HCF crack growth rate will be expected with lower effective compressive stresses in the coating, the LCF cycles also facilitate the HCF crack growth at high temperatures by stress relaxation process. A surface wedging model has been proposed to account for the HCF crack growth in the coating system. This mechanism predicts that HCF damage effect increases with increasing temperature swing, the thermal expansion coefficient and the elastic modulus of the ceramic coating, as well as the HCF

interacting depth. A good agreement has been found between the analysis and experimental evidence. Zhu, Dongming and Miller, Robert A. Glenn Research Center...

Effect of Grain Orientation and Coating on Thermal Fatigue Resistance of a Directionally Solidified Superalloy (MAR-M 247)

Thermal Fatigue Testing of ZrO2-Y2O3 Thermal Barrier Coating Systems Using a High Power CO2 Laser

In the present study, the mechanisms of fatigue crack initiation and propagation, and of coating failure, under thermal loads that simulate diesel engine conditions, are investigated. The surface cracks initiate early and grow continuously under thermal low cycle fatigue (LCF) and high cycle fatigue (HCF) stresses. It is found that, in the absence of interfacial oxidation, the failure associated with LCF is closely related to coating sintering and creep at high temperatures. Significant LCF and HCF interactions have been observed in the thermal fatigue tests. The fatigue crack growth rate in the ceramic coating strongly depends on the characteristic HCF cycle number, N̂ sub HCF, which is defined as the number of HCF cycles per LCF cycle. The crack growth rate is increased from 0.36 micrometer/LCF cycle for a pure LCF test to 2.8 micrometers/LCF cycle for a combined LCF and HCF test at NĤ sub HCF about 20,000. A surface wedging model has been proposed to account for the HCF crack growth in the coating systems. This mechanism predicts that HCF damage effect increases with increasing surface temperature swing, the thermal expansion coefficient and the elastic modulus of the ceramic coating, as well as with the HCF interacting depth. A good agreement has been found between the analysis and experimental evidence.

The Effect of Mold Coating and Mold Matrix on the Thermal Fatigue and Mechanical Fracture of Continuously Cast Gray Iron Permanent Mold Inserts

Measurement of Thermal Conductivity of Permanent Mold Ceramic Coatings

High Temperature Coatings

Butterworth-Heinemann High Temperature Coatings, Second Edition, demonstrates how to counteract the thermal effects of rapid corrosion and degradation of exposed materials and equipment that can occur under high operating temperatures. This is the first true practical guide on the use of thermally protective coatings for high-temperature applications, including the latest developments in materials used for protective coatings. It covers the make-up and behavior of such materials under thermal stress and the methods used for applying them to specific types of substrates, as well as invaluable advice on inspection and repair of existing thermal coatings. With his long experience in the aerospace gas turbine industry, the author has compiled the very latest in coating materials and coating technologies, as well as hard-to-find guidance on maintaining and repairing thermal coatings, including appropriate inspection protocols. The book is supplemented with the latest reference information and additional support to help readers find more application- and industry-type coatings specifications and uses. Offers an overview of the underlying fundamental concepts of thermally-protective coatings, including thermodynamics, energy kinetics, crystallography and equilibrium phases Covers essential chemistry and physics of underlying substrates, including steels, nickel-iron alloys, nickel-cobalt alloys and titanium alloys Provides detailed guidance on a wide variety of coating types, including those used against high temperature corrosion and oxidative degradation and thermal barrier coatings

Coated Metal

Structure and Properties of Metal-Coating Compositions

Springer Science & Business Media This book can be viewed as a scientific investigation combined with methodological studies. For practical reasons each of the methods is described in the following general manner including: the uses and the scientific investigation tasks; methods of sampling; testing equipment; test preparation; tests; data processing; controversial issues and conclusions. Each of the 37 methods contains a range of 1 to 8 variants. As far as we know, the book is the first publication in the field.

Fracture of Nano and Engineering Materials and Structures

Proceedings of the 16th European Conference of Fracture, Alexandroupolis, Greece, July 3-7, 2006

Springer Science & Business Media The 16th European Conference of Fracture (ECF16) was held in Greece, July, 2006. It focused on all aspects of structural integrity with the objective of improving the safety and performance of engineering structures, components, systems and their associated materials. Emphasis was given to the failure of nanostructured materials and nanostructures including micro- and nano-electromechanical systems (MEMS and NEMS).

Investigation of Thermal High Cycle and Low Cycle Fatigue Mechanisms of Thick Thermal Barrier Coatings

Handbook of Thermal Spray Technology

ASM International This reference covers principles, processes, types of coatings, applications, performance, and testing and analysis of thermal spray technology. It will serve as an introduction and guide for those new to thermal spray, and as a reference for specifiers and users of thermal spray coatings and thermal spray experts. Coverage encompasses basics of th

Effect of Several Metallurgical Variables on the Thermal Fatigue Behavior of Superalloys

The effect of several metallurgical variables on the thermal fatigue behavior of high-temperature materials systems was studied using a highly characterized high-velocity hot gas stream to produce a well-defined strain/temperature/time cycle. Metallurgical factors considered were: alloy compositions in both cast cobalt- and nickel-base superalloys, degree of microstructural refinement, grain orientation, effect of presence and morphology of carbides, surface/environmental interaction (surface stability), and protective coatings. The nickel-base alloys studied were superior or equivalent to the cobalt-base alloys when compared on uncoated and coated bases. Within a given alloy class the effect of alloy chemistry as it affects oxidation behavior was shown to be significant. On polycrystalline substrates, an inward type of diffusion aluminide coating improved fatigue performance, whereas an outward type was detrimental. "Overlay" coatings show a great deal of potential in providing an optimum in mechanical/protective response. Columnar-grained alloys when strained along the growth direction gave fatigue resistance superior to their polycrystalline counterparts. The importance of recognizing the

unique compositional/microstructural/mechanical nature of a coating in achieving optimum thermal fatigue resistance for high-temperature materials systems is emphasized.

Fatigue under Thermal and Mechanical Loading: Mechanisms, Mechanics and Modelling

Springer Science & Business Media The International Symposium "Fatigue under Thermal and Mechanical Loading", held at Petten (The Netherlands) on May 22-24, 1995, was jointly organized by the Institute for Advanced Materials of The Joint Research Centre, E. C. , and by the Societe Fran~se de Metallurgie et de Materiaux. The fast heating and cooling cycles experienced by many high temperature components cause thermally induced stresses, which often operate in combination with mechanical loads. The resulting thermal / mechanical fatigue cycle leads to material degradation mechanisms and failure modes typical of service cycles. The growing awareness that the synergism between the combined thermal and mechanical loads can not be reproduced by means of isothermal tests, has resulted in an increasing interest in thermal and thermo-mechanical fatigue testing. This trend has been reinforced by the constant pull by industry for more performant, yet safer high temperature systems, pushing the materials to the limit of their properties. Dedicated ASTM meetings in particular have set the scene for this area of research. The proceedings of the symposium organized by D. A. Spera and D. F. Mowbray in 1975 provided a reference book on thermal fatigue which reflects the knowledge and experimental capabilities of the mid-seventies.

Oxidation and Thermal Fatigue of Coated and Uncoated NX-188 Nickel-base Alloy in a High-velocity Gas Stream

A cast nickel-base superalloy, NX-188, coated and uncoated, was tested in a high-velocity gas stream for resistance to oxidation and thermal fatigue by cycling between room temperature and 980, 1040, and 1090 C. Contrary to the behavior of more conventional nickel-base alloys, uncoated NX-188 exhibited the greatest weight loss at the lowest test temperature. In general, on the basis of weight change and metallographic observations a coating consisting of vapor-deposited Fe-Cr-Al-Y over a chromized substrate exhibited the best overall performance in resistance to oxidation and thermal fatigue.

High temperature alloys for gas turbines and other applications, 1986 : proceedings of a conference held in Liege, Belgium, 6-9 October 1986

Springer Science & Business Media

Proceedings of the 2014 Energy Materials Conference Xi'an, Shaanxi Province, China, November 4 - 6, 2014

John Wiley & Sons This DVD contains a collection of papers presented at Energy Materials 2014, a conference organized jointly by The Chinese Society for Metals (CSM) and The Minerals, Metals & Materials Society (TMS), and held November 4-6, 2014, in Xi’an, Shaanxi Province, China. With the rapid growth of the world’s energy production and consumption, the important role of energy materials has achieved worldwide acknowledgement. Material producers and consumers constantly seek the possibility of increasing strength, improving fabrication and service performance, simplifying processes, and reducing costs. Energy Materials 2014 has provided a forum for academics, researchers, and engineers around the world to exchange state-of-the-art development and information on issues related to energy materials. The papers on the DVD are organized around the following topics: Materials for Coal-Based Systems Materials for Gas Turbine Systems Materials for Nuclear Systems Materials for Oil and Gas Materials for Pressure Vessels

Thermal Fracture and Fatigue of Anodized Aluminum Coatings for Space Applications

A concern for the use of anodized aluminum as Space Station thermal control surfaces is the potential degradation of critical optical properties due to oxide coating cracking. This cracking may be induced by differential thermal expansion during hot adhesive bonding of the radiator assembly or during 30 years of exposure to sunlight/darkness cycles in low earth orbit (LEO). This paper summarizes investigations into the effects of temperature and humidity on coating stresses and cracking. Experimentally measured coating residual stresses after anodizing and sealing are shown to be strongly dependent on humidity. Two sets of tests are used to study cracking directly: one determines the temperature (Tc at which cracks first appear during a single heating cycle, while the other involves rapid thermal cycling (RTC) between maximum and minimum temperatures. The effects of several test parameters on cracking are reviewed, with special attention to temperature, coating thickness, and humidity. Fatigue models are developed to describe the observed cracking and to serve as the basis for predictions of LEO cracking. The physical characteristics of cracks and related substrate plastic deformation in both Tc and RTC tests are discussed briefly.

High Temperature Alloys for Gas Turbines 1982

Proceedings of a Conference held in Liège, Belgium, 4–6 October 1982

Springer Science & Business Media The European Collaborative Programme on Materials for Gas Turbines known as COST-50 was initiated in 1971 and has been supported since then by the Commission of European Communities. The achievements made during the first phase of COST-50 were reviewed at the Conference held in Liege, September 25-27, 1978 and published by Applied Science Publishers Ltd. Nine European Countries : Austria, Belgium, the Federal Republic of Germany, France, Italy, The Netherlands, Sweden, Switzerland, the United Kingdom, and the Joint Research Center of the Community, agreed to continue their participation in COST-50 and the results of the second phase were presented at the Conference held in Liege, October 4-6, 1982 under the following headings : - Corrosion and Coatings - Fatigue, Creep and Structural Stability - Processing The technical sessions consisted of invited papers reviewing recent progress in the development of high temperature alloys with particular emphasis on the results of the European Collaborative Programme. Furthermore, some areas were reviewed by eminent speakers from the United States of America, due to their expertise in their respective fields. In this context and as a tradition introduced in 1978, the keynote lecture "Superalloys technology : today and tomorrow" was del ivered by Dr. F. L. Versnyder. The Conference was completed with a significant Poster Session comprising about fifty contributions from Europe and elsewhere. This book comprises a total of fifty four contributions representing almost all of the papers delivered at the technical sessions and a large part of the presentations made at the Poster Session.

Fusion Energy Update

Energy Materials 2014

Conference Proceedings

Springer

Low-cycle Thermal Fatigue

Impact Fatigue Failure Investigation of HVOF Coatings

Dynamic impact-wear and coating fatigue at cyclic loading conditions demonstrates a very demanding failure mode, which occurs in a number of mechanical applications and it becomes very critical when the application concerns aggressive working environments. The coating impact testing is a novel experimental technique developed to investigate the fatigue behavior of coating-substrate compounds, which was not possible with the common testing methods previously available. The objective of this study is to investigate the influence of the impact load on the fatigue strength of thermal spray high velocity oxy-fuel (HVOF) coatings. Furthermore, the overall aim of the current research is to prove the reliability of the impact testing method to assess the coating lifetime against fatigue, to interpret the coating failure modes, and thereby to explore its capability, whether this nonstandard test can be used in industrial scale as a reliable technique in the development and optimization of fatigue resistant coatings. Based on the above method the current research provides experimental results concerning the coating fracture in terms of cohesive and adhesive failure modes. The fatigue strength of the tested coatings is determined in terms of fatigue-like diagrams by means of scanning electron and white light interference microscopy, as well as by electron dispersive x-ray analysis (EDX) at discrete loads and number of loading cycles. From the conducted experiments, it was shown that the optimum HVOF coating against fatigue is the WC-CoCr.

Scientific and Technical Aerospace Reports

Ceramic Coatings

Applications in Engineering

BoD – Books on Demand The main target of this book is to state the latest advancement in ceramic coatings technology in various industrial fields. The book includes topics related to the applications of ceramic coating covers in enginnering, including fabrication route (electrophoretic deposition and physical deposition) and applications in turbine parts, internal combustion engine, pigment, foundry, etc.

Thermal Spray 2004

Advances in Technology and Application : Proceedings of the International Thermal Spray Conference, 10-12 May, 2004, Osaka, Japan

ASM International This proceedings volume representing the second International Thermal Spray Conference (May 2004, Osaka, Japan) contains 232 papers and 93 poster presentations. Arrangement is in sections on applications, characterization methods for coating properties, coating technologies for vehicle engines, cold spray, consumables for thermal spraying, corrosion protection, economics and quality, HVOF processes and materials, innovative equipment and process technology, modeling and simulation, nanostructured materials, photocatalytic materials, process diagnostics, protective coatings against wear and erosion, and thermal barrier coatings. No index is provided, but the included CD- ROM presumably contains the contents in a searchable format. Annotation :2004 Book News, Inc., Portland, OR (booknews.com).

Advances in Ceramic Coatings and Ceramic-Metal Systems

A Collection of Papers Presented at the 29th International Conference on Advanced Ceramics and Composites, Jan 23-28, 2005, Cocoa Beach, FL

John Wiley & Sons This volume includes 46 contributed articles from the Advanced Ceramic Coatings for Structural, Environmental and Functional Applications and the International Symposium on Advances in Ceramic-Metal Systems symposia. Topics include processing and microstructure design, mechanical and thermal properties, advanced testing and non-destructive evaluation, wear, erosion and corrosion behavior, functional properties and modeling. A significant portion of the contributed articles focus on current state-of-the-art industrial applications of ceramic coatings and ceramic-metal composites.

Thin Films and Coatings

Toughening and Toughness Characterization

CRC Press Thin Films and Coatings: Toughening and Toughness Characterization captures the latest developments in the toughening of hard coatings and in the measurement of the toughness of thin films and coatings. Featuring chapters contributed by experts from Australia, China, Czech Republic, Poland, Singapore, Spain, and the United Kingdom, this first-of-its-kind book: Presents the current status of hard-yet-tough ceramic coatings Reviews various toughness evaluation methods for films and hard coatings Explores the toughness and toughening mechanisms of porous thin films and laser-treated surfaces Examines adhesions of the film/substrate interface and the characterization of coating adhesion strength Discusses nanoindentation determination of fracture toughness, resistance to cracking, and sliding contact fracture phenomena Toughening and toughness measurement (of films and coatings) are two related, yet separate, fields of great importance in today’s nanotechnology world. Thin Films and Coatings: Toughening and Toughness Characterization is a timely reference written in such a way that novices will find it a stepping stone to the field and veterans will find it a rich source of information for their research.

Functional Ceramic Coatings

MDPI Ceramic materials in the form of coatings can significantly improve the functionality and applications of other engineering materials. Due to a wide range of controllable features and various deposition methods, it is possible to create tailored substrate–coating systems that meet the requirements of modern technologies. Therefore, it is crucial to understand the relationships between the structures, morphology and the properties of ceramic coatings and expand the base of scientific knowledge about them. This book contains a series of fourteen articles which present research on the production and properties of ceramic coatings designed to improve functionality for advanced applications.

Thermal Spray 2007: Global Coating Solutions: Proceedings of the 2007 International Thermal Spray Conference

ASM International

Research & Technology 1997

DIANE Publishing

Monthly Catalog of United States Government Publications

Superalloys 2012

John Wiley & Sons A superalloy, or high-performance alloy, is an alloy that exhibits excellent mechanical strength at high temperatures. Superalloy development has been driven primarily by the aerospace and power industries. This compilation of papers from the Twelfth International Symposium on Superalloys, held from September 9-13, 2012, offers the most recent technical information on this class of materials.

Determination of the Fatigue Resistance of HVOF Thermal Spray WC-CoCr Coatings by Means of Impact Testing

Impact testing is an efficient experimental procedure that enables the determination of the fatigue resistance of mono- and multi-layer coatings deposited on various substrates, which was not possible with the common testing methods previously available. In this paper an advanced impact tester, able to assess the fatigue failure resistance of coatings working under cyclic loading conditions, is presented. The fatigue failure of the tested coatings was determined by means of scanning electron, optical microscopy, and EDX analysis. The test results are recorded in diagrams containing the impact load versus the number of successive impacts that the examined coatings can withstand. From the experimental results it was concluded that a hard, wear resistant HVOF thermal spray WC-CoCr coating deposited on P91 steel substrate presents a high fatigue resistance.

Aerospace Materials Handbook

CRC Press Whether an airplane or a space shuttle, a flying machine requires advanced materials to provide a strong, lightweight body and a powerful engine that functions at high temperature. The Aerospace Materials Handbook examines these materials, covering traditional superalloys as well as more recently developed light alloys. Capturing state-of-the-art d

Influence of Material and Testing Parameters on the Lifetime of TBC Systems with MCrAlY and NiPtAl Bondcoats

Forschungszentrum Jülich

Coating Microstructure-Property-Performance Issues

Results of studies on the relationships between spray parameters and performance of thermally-sprayed intermetallic coatings for high-temperature oxidation and corrosion resistance are presented. Coating performance is being assessed by corrosion testing of free-standing coatings, thermal cycling of coating substrates, and coating ductility measurement. Coating corrosion resistance was measured in a simulated coal combustion gas environment (N2-CO-CO2-H2O-H2S) at temperatures from 500 to 800°C using thermo-gravimetric analysis (TGA). TGA testing was also performed on a typical ferritic-martensitic steel, austenitic stainless steel, and a wrought Fe3Al-based alloy for direct comparison to coating behavior. FeAl and Fe3Al coatings showed corrosion rates slightly greater than that of wrought Fe3Al, but markedly lower than the steels at all temperatures. The corrosion rates of the coatings were relatively independent of temperature. Thermal cycling was performed on coated 316SS and nickel alloy 600 substrates from room temperature to 800°C to assess the relative effects of coating microstructure, residual stress, and thermal expansion mismatch on coating cracking by thermal fatigue. Measurement of coating ductility was made by acoustic emission monitoring of coated 316SS tensile specimens during loading.

Machine Design

Handbook of Residual Stress and Deformation of Steel

ASM International Annotation Examines the factors that contribute to overall steel deformation problems. The 27 articles address the effect of materials and processing, the measurement and prediction of residual stress and distortion, and residual stress formation in the shaping of materials, during hardening processes, and during manufacturing processes. Some of the topics are the stability and relaxation behavior of macro and micro residual stresses, stress determination in coatings, the effects of process equipment design, the application of metallo- thermo-mechanic to quenching, inducing compressive stresses through controlled shot peening, and the origin and assessment of residual stresses during welding and brazing. Annotation c. Book News, Inc., Portland, OR (booknews.com)

Metallurgical Coatings 1980

Proceedings of the International Conference, San Diego, California, U.S.A., April 21-25, 1980

Monthly Catalog of United States Government Publications, Cumulative Index

Index to the Monthly Issues