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Loadings in Thermal Barrier Coatings of Jet Engine Turbine Blades

An Experimental Research and Numerical Modeling

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Preface

The book discusses complex loadings of turbine blades and protective layer thermal barrier coating (TBC), under real working airplane jet conditions. They obey both multi-axial mechanical loading and sudden temperature variation during starting and landing of the airplanes. In particular, two types of blades are analyzed: *stationary* and *rotating*, which are widely applied in turbine engines produced by airplane factories.

The numerical modelling, consisting of computational fluid dynamics (CFD) and computational structural mechanics (CSM), requires some basic experimental research, necessary to correct formulation of the turbine blades thermo-mechanical analysis.

The experimental program of research based on the samples with TBC coating was designed for:

- uniaxial tensile tests (UTT),
- 3-point bending tests (3-PB),
- micro-hardness tests.

Before the strength tests, the samples were subjected to aging for different times at the temperature of 1000 °C. The UTT were performed using the ARAMIS optical displacement measurement system and acoustic emission in order to determine the load value at which the TBC cracking is initiated. In order to analyze the level of damage of the protective layer structure the scanning electron microscopy (SEM) observations were carried out. The thermally grown oxide (TGO) layer thickness was measured and the function describing its growth depending on the aging time was determined. The different types of damage which arise as a result of a combination of different aging times and different levels of mechanical stresses were also described. Energy dispersive spectroscopy (EDS) analysis was performed by specifying the content of chemical elements in each layer, which allowed to observe the phenomenon of diffusion due to aging. Micro-hardness test of each layer of the TBC coating became the basis for determining of the elastic properties used in the finite element method (FEM) simulations.

The numerical solution of the thermo-mechanical response of the stationary and rotating turbine blades requires CFD and CSM analyses:

- Thermal loads of *stationary blade* were determined on the basis of CFD simulation, taking into account both the exhaust gas and cooling air flow. The obtained non-uniform temperature fields constitute a basis for determining of the thermal stresses resulting from the difference in thermal expansion coefficients of the blade and ceramic layer materials.
- Numerical calculations were performed for the *rotating moving blade* subjected to a centrifugal and thermal loads force in order to determine the critical places of the blades from which the cracking process initiates.

The obtained results provided the basis for building a more advanced FEM model with application of the extended finite element method (X-FEM) technique. This advanced method allows for introduction of the material cracking to trace trajectory of the major crack in relation to rotational speed of the blade with a TBC layer. The exact analysis of the cracking process is possible by application of the *submodelling technique*, which allowed for separation from the global model a critical fragment of the blade with the highest stress concentration. Introduction of much more dense FEM mesh leads to more precise description of the failure blade process.

The formulated conclusions in this book can be useful for the application of this new methodology in airplane industry.

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Contents

1 Introduction 1

2 Protective Thermal Barrier Coatings 5
2.1 Structure of TBCs 6
2.2 Development and Application of New Coating Materials 7
2.3 Conclusions 10
References 10

3 Thermal Loads 13
3.1 Numerical Methods—Application of Finite Elements Method (FEM) 13
3.2 Deformation and Stress in Structural Elements, Caused by Thermal Loads 18
3.3 Numerical Analysis of Temperature Fields in Critical Elements of Turbo-Engines by CFD (Computational Fluid Dynamics) with Application of FLUENT Program. 20
3.4 Conclusions 24
References 24

4 Mechanical Loads 25
4.1 Preparation of Model for Simulation 25
4.2 Analysis of Results 29
4.3 Blade Vibrations Resonance 30
4.4 Conclusions 35
Reference. 35

5 Environmental Loads. 37
5.1 Corrosion 37
5.2 Erosion 39
5.3 Thermally Growth Oxide (TGO) Layer Growth. 40

5.4 Author's Own Tests of Moving Blade Surface, Including Chemical Analysis. 41
5.5 Conclusions 43
References 44

6 State of Arts in Experimental Testing of TBCs Systems—Literature Analysis 45
6.1 Review and Analysis of Currently Utilised Tests 45
6.2 Conclusions 63
References 63

7 Proposed Experimental Investigations of TBCs Systems 67
7.1 Sample Ageing 67
7.2 Uniaxial Stretching of Dumbbell Samples with TBC Layers—Author's Own Tests 68
7.2.1 First Batch of Samples Not Subjected to Ageing 68
7.2.2 Second Batch of Samples Subjected to Ageing 69
7.3 3-Point Bending of Beam Samples with TBC Layers—Author's Own Tests 78
7.4 Conclusions 89

8 Numerical Analysis of Cracks Propagation Process in Turbine Blades TBCs Systems Under Thermo-Mechanical Loading Based on Experimental Results 91
8.1 Formulation of FEM Approach and Brittle Damage of the TBCs System 91
8.1.1 Brittle Damage Model 93
8.1.2 Cohesive Degradation Model 94
8.1.3 Simulation Results 95
8.2 Application of Submodeling Technique and X-FEM Methods for Detailed Analysis of Cracking Process in Turbine Blades TBCs. 98
8.2.1 Submodeling 98
8.2.2 X-FEM Method Basics 99
8.2.3 Preparation of Model for Simulation 100
8.3 Analysis of Results 101
8.4 Conclusions 103
References 103

9 Summary 105