Fracture of Nano and Engineering Materials and Structures

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

Edited by
E.E. Gdoutos

INCLUDES CD-ROM

Springer

Fracture of Nano and Engineering Materials and Structures

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

Edited by

E.E. Gdoutos

Started in 1976, the European Conference of Fracture (ECF), organized under the auspices of the European Structural Integrity Society (ESIS), takes place every two years in a European country. The 16th European Conference of Fracture (ECF16) was held in Alexandroupolis, Greece, July 3-7, 2006. ECF16 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). The technical program of ECF16 was the product of the hard work and devotion of more than 150 leading experts in the world.

This volume contains two-page abstracts of the 698 papers presented at ECF16. The accompanying CD attached to the back cover of the book contains the full length papers. The abstracts of the fifteen plenary lectures are included in the beginning of the book. The remaining 683 abstracts are arranged in 25 tracks and 35 special symposia/sessions with 303 and 380 abstracts, respectively. The papers of the tracks have been contributed from open call, while the papers of the symposia/sessions have been solicited by the respective organizers. Both tracks and symposia/sessions fall into two categories, namely, fracture of nano and engineering materials and structures with 88 and 595 papers, respectively.

The volume contains the latest research work of renowned experts in the area of failure of engineering materials and structures and is useful for the student, the engineer and the researcher who wants to get an integrated picture of the recent developments in the area of fracture mechanics and fatigue.

ISBN 1-4020-4971-4

9 781402 049712

springer.com

Fracture of Nano and Engineering Materials and Structures

E.E. Gdoutos (Ed.)

ORGANIZING COMMITTEES

Scientific Advisory Board

Emmanuel E. Gdoutos (Chairman)

Track 1 (Nanomaterials and Nanostructures)

Awaji, H. (Japan), Bahr, D., (USA), Ballarini, R., (USA), Batra, R. (USA), Belytschko, T. (USA), Berndt, C. (USA), Bhushan, B. (USA), Espinosa, H. (USA), Friedrich, K. (Germany), Karimi, A. (Switzerland), Kouris, D. (USA), Lagoudas, D. (USA), Meletis, E.I. (USA), Michel, B. (Germany), Moody, N. (USA), Plumbridge, W.J. (UK), Pluvinage, G. (France), Ruoff, R. (USA), Sih, G.C. (China), Zhang, Z. (Germany), Zhou, M. (USA).

Track 2 (Engineering Materials and Structures)

Akid, R. (UK), Aliabadi, M.H. (UK), Andrianopoulos, N. (Greece), Angelova, D. (Bulgaria), Aravas, N. (Greece), Atkins, A.G. (UK), Banks-Sills, L. (Israel), Bartolozzi, F. (Italy), Barton, J. (UK), Bartzokas, D. (Greece), Bathias, C., (France), Bazant, Z. (USA), Beaumont, P. (UK), Beretta, S. (Italy), Blackman, B. (UK), Brocks, W. (Germany), Bunch, J. (USA), Cacko, J. (Slovakia), Carpinteri, Alberto (Italy), Carpinteri, Andrea (Italy), Chona, R. (USA), Daniel, I.M. (USA), Danzer, R. (Austria), Dietzel, W. (Germany), Dover, B. (UK), Exadaktylos, G. (Greece), Fernando, U.S. (UK), Ferro, G. (Italy), Finnie, I. (USA), Fischer, F.D. (Austria), Fleck, N. (UK), Freitas, M.J.M. (Portugal), Gabetta, G. (Italy), Galiotis, C. (Greece), Georgiadis, H.G. (Greece), Goldstein, R. (Russia), Gosz, M. (USA), Gubeljack, N. (Slovenia), Hawong, J.S. (Korea), Hedrich, K. (Republic of Serbia), Hopkins, S. (USA), Ingraffea, A. (USA), Isogimi, K. (Japan), Jelaska, D. (Croatia), Jirasek, M. (USA), Johnson, E. (Sweden), Jones, R. (Australia), Kalluri, S. (USA), Kalthoff, J.F. (Germany), Karalekas, D. (Greece), Karihaloo, B. (UK), Kassner, M. (USA), Kermanidis, Th. (Greece), Kienzler, R. (Germany), Kocanda, D. (Poland), Konsta-Gdoutos, M. (Greece), Kostopoulos, V. (Greece), Kourkoulis, S. (Greece), Landes, J. (USA), Lee, B-L (USA), Lee. O.S. (Korea), Lee, S.B. (Korea), Liolios, A. (Greece), Liu, C.T. (USA), Luxmoore, A.R. (UK), MacGillivray, H. (UK), Mai, Y.W. (Australia), Maier, H.J. (Germany), Marioli-Riga, Z. (Greece), Markenskoff, X. (USA), Massabo, R. (Italy), Matczynski, M. (Poland), Matysiak, S. (Poland), Mayer, H.R. (Austria), McEvily, A. (USA), Michopoulos, J. (USA), Mines, R. (UK), Mitchell, M. (USA), Moscovic, R. (UK), Murakami, Y. (Japan), Needleman, A. (USA), Neimitz, A. (Poland), Neu, R. (USA), Nied, H. (USA), Nilsson, F. (Sweden), Nurse, A. (UK), Nykyforchyn, H. (Ukraine), Paipetis, S.A. (Greece), Panoskaltsis, V. (USA), Pantelakis, S. (Greece), Papadopoulos, G. (Greece), Papakaliatakis, G. (Greece), Pappalettere, C. (Italy), Patterson, E. (UK), Pavan, A. (Italy), Petit, J. (France), Pineau, A. (France), Pokluda, J. (Czech Republic),

ECF16 TRACKS

B: TRACKS

B1: Nanomaterials and Nanostructures

1T1. Fracture and Fatigue of Nanostuctured Materials

1T2. Failure Mechanisms

1T4. Fatigue and Fracture of MEMS and NEMS

1T7. Thin Films

1T9. Failure of Nanocomposites

B2: Engineering Materials and Structures

2T1. Physical Aspects of Fracture

2T2. Brittle Fracture

2T3. Ductile Fracture

2T4. Nonlinear Fracture Mechanics

2T5. Fatigue and Fracture

2T8. Polymers, Ceramics and Composites

2T11. Fracture Mechanics Analysis

2T13. Probabilistic Approaches to Fracture Mechanics

2T14. Computational Fracture Mechanics

2T15. Experimental Fracture Mechanics

2T16. Creep Fracture

2T17. Environment Assisted Fracture

2T18. Dynamic, High Strain Rate, or Impact Fracture

2T19. Damage Mechanics

2T21. Concrete and Rock

2T22. Sandwich Structures

2T23. Novel Testing and Evaluation Techniques

2T26. Structural Integrity

2T28. Mesofracture Mechanics

2T32. Micromechanisms in Fracture and Fatigue

ECF16 SPECIAL SYMPOSIA/SESSIONS

C: SPECIAL SYMPOSIA/SESSIONS

C1: Nanomaterials and Nanostructures

1. Fracture and Fatigue at the Micro and Nano Scales (Organized by H.D. Espinosa and I.M.Daniel)
3. Nanoscale Deformation and Failure (Organized by M. Zhou)
29. Reliability and Failure Analysis of Electronics and Mechanical Systems (O.S. Lee)
31. Multiscaling in Molecular and Continuum Mechanics – Scaling in Time and Size from Macro to Nano (Organized by G.C. Sih)
34. Cracks in Micro- and Nanoelectronics (Organized by B. Michel)
43. Interfacial Fracture in Composites and Electronic Packaging Materials (Organized by C.T. Sun and T. Ikeda)

C2: Engineering Materials and Structures

4. Fracture and Fatigue of Elastomers (Organized by C. Bathias and E. Bayraktar)
5. Integrity of Dynamical Systems (Organized by K. Hedrih)
8. Modelling of Material Property Data and Fracture Mechanisms (Organized by R. Moskovic)
9. Micromechanisms in Fracture and Fatigue (Organized by J. Pukluda and R. Pippan)
12. Interface Fracture and Behavior of Joints (Organized by L. Banks-Sills)
13. Computational Fracture Mechanics (Organized by T. Belytschko and A. Gravouil)
14. Cohesive Models of Fracture (Organized by W. Brocks)
16. Environment Assisted Fracture (Organized by G. Gabetta, W. Dietzel and H. Nykyforchyn)
17. SIM, Philosophy, Instrumentation and Analysis (Organized by W. D. Dover)
18. Fracture of Biomaterials (Organized by J. tong)
19. Structural Integrity Assessment in Theory and Practice (Organized by S. Vodenitsarov and S. Sedmak)
20. Critical Distance Theories of Fracture (Organized by D. Taylor)
22. New Investigations on Very High Cycle Fatigue of Materials (Organized by H. Mayer and S. Stanzl-Tschegg)
23. Deformation and Fracture of Engineering Materials (Organized by C.T. Liu)
24. Materials Damage Prognosis and Life Cycle Engineering (Organized by R. P. Wei, G. Harlow, A. Ingraffea and J. Larsen)
25. Mixed-Mode Fracture (Organized by M. Gosz)

Invited Lecture

MEASUREMENTS OF DYNAMICAL SYSTEM INTEGRITY AND FRACTURE MECHANICS

K. S. Hedrih
Faculty of Mechanical Engineering University of Nis, Institute of Mathematics SANU Belgarede
Yu-18000 Niš, ul. Vojvode Tankosia 2/22, Serbia and Montenegro
katica@masfak.ni.ac.yu, khedrih@eunet.yu

I. What is the Dynamical System ? Problems in dynamics have been fascinating physical scientists (and mankind in general) for thousands years. Modern dynamical system theory has relatively short history.

It began with Poincaré (1880, 1890, 1899), who revolutionized the study of nonlinear differential equations by introducing the qualitative techniques of geometry and topology rather than strict analytic methods to discus the global properties of solutions of these systems.

Robert Devaney in his book [1] wrote: "The simple examples of dynamical systems show how dynamical systems occur in the "real world" and how some very simple phenomena from nature yield rather complicated dynamical systems".

The answer is quite simple: take a scientific calculator and input any number whatsoever. Than, start striking one of the function keys over and over again. This iterative procedure is an example of a discrete dynamical system: $x_0,\ f(x_0),\ f(f(x_0)),\ f(f(f(x_0))),\dots,\ \ f(f(\dots f(f(x_0))))$.

The basic goal of the theory of Dynamical Systems is to understand the eventual or asymptotic behavior of an iterative process. If the process is a discrete process such as iteration of a function, then the theory hopes to understand the eventual behavior of the points $x,\ f(x),\ f^2(x),\ f^3(x),\dots,\ f^k(x),\dots,\ f^n(x)$. Functions which determine dynamical systems are also called mappings, or maps, for short. Mathematical phenomenology and analogy [2] is very useful in the investigation of kinetic properties and processes in the dynamical systems with disparate nature.

A very important notation in the study of dynamical systems is the behavior or persistence of the system under *small changes or perturbations*. This is the *concept of structural stability*.

The notion of structural stability is extremely ***important for practical application.***

***II. Characterization of a dynamical system*:**

Material model with material structures (construction with structural elements);

Mathematical description of material structure dynamics (geometry and material of construction, constitutive stress-strain relation depending of material properties [3], time rate changes in the system structures, material coefficients, coefficients of inertia tensor, coefficients of stiffness……and other material properties; coupled tensor fields properties of material…);

Stress and strain states of dynamical system structure on the boundary surfaces (defined by boundary conditions for free and for loaded system, external surface contour excitations, contour displacements);

Stress and strain states [4] of dynamical system structure at initial time moment or with all history before initial moment on the observation in all material structures and on the boundary surfaces (by initial condition satisfying the boundary conditions for free and for loaded system);

States of dynamical processes in dynamical system;

State of stress and strain in the material, and also state of displacements of structure points and also states of other coupled fields depending on the type of material structure.

III. Types of dynamical system integrity [5,6]

Ideal integrity of dynamical system is when properties of the material structure system and its own kinetic parameters do not change under external excitations;

Partial integrity of dynamical system is when properties of the material structure system or its own kinetic parameters do not change under external excitations.

Modified integrity of dynamical system is when properties of the material structure system or its own kinetic parameters change under external excitations in the proposed intervals.

Rheonomic integrity of dynamical system is when properties of the material structure system and its own kinetic parameters are functions of time and do not change under the external excitations.

Integrity of subprocesses in dynamical systems (In the linear oscillatory system own modes are mutual independent processes and single frequency processes with one own frequency each).

Integrity of the real structure material in dynamical system (Measurements of integrity of the real structure material are defined by development of material sciences and the fracture mechanics theory [7] and [8]. Papers written by the British scientist A. A. Griffith (1920, 1924) are of permanent importance for the early formative period of fracture mechanics. He was the first to consider the energy balance approach to the crack problem, the important aspects of which have been reviewed by Panasyuk (1993) [9].

IV. *Chaotic Clock Models: A paradigm for vibrations and noise in machines and integrity of machines.* For examining natural clocks [10] of reductors (power transmission), as well as sources of nonlinear vibrations and noise in its dynamics, it is necessary to investigate properties of nonlinear dynamics, and phase portraits, as well as structures of homoclinic orbits, layering and sensitivity of this layering of homoclinic orbits and bifurcation of homoclinic points. The natural clocks of nonlinear dynamics of coupled rotors are studied, as well as integrity of machines with respect to the fatigue of the material structure of power transitions [11].

Key words: Homoclinic orbits and points, separatrice layering, trigger, coupled singularities, bifurcation, vector method, mass moment vectors, phase plane and portrait, couple triggers, the form of number eight or it multiplicand, Chaotic Clock Models, integrity, machines.

V. *Single and multifrequency vibration regimes in the sandwich system with discontinuity.* By using two examples of free and forced vibrations of the elastically connected multi body systems and corresponding system with a discontinuity in an elastic connection, we show some basic properties and measurements of the integrity of basic dynamical system. The integrity of dynamical subprocesses in the behavior of the whole system and its subsystems or in component processes and as response of the whole system to corresponding system with discontinuity have been studied by using methods of Bernoulli's particular integral and Lagrange's method of constants variation. It is shown that one- and two frequency subprocess regimes change into multi-frequency regimes induced by discontinuity in the system, which represents the loss of integrity of the system structure and marks the appearance of the loss of integrity of basic subprocesses [6]. The presence of multifrequency regimes in one of the modes of vibrations is an indicator of discontinuity in dynamical system and of loss of previous integrity.

VI. Concluding remarks. For the measures of dynamical system integrity it is possible to take one of the sets of kinetic parameters, the changes of which in the critical values range are sources of bifurcation processes or of the appearance of nonprogrammed processes in dynamical system with possible appearance of structure discontinuity.

Acknowledgment

Parts of this research were supported by the Ministry of Sciences, Technologies and Development of Republic Serbia trough Mathematical Institute SANU Belgrade Grants No. 1616 Real Problems on Mechanics and Faculty of Mechanical Engineering University of Niš Grant No. 1828 Dynamics and Control of Active Structures.

References

1. Devaney R., (1989), An Introduction to Chaotic Dynamical Systems, Addison-Wesley Publishing Company, Inc. p. 336.
2. Petrovi Mihailo, *Fenomenološko preslikavanje*, Srpska kraljevska akademija, Štamparija Planeta, Beograd, 1933.
3. Goroško O.A. and Hedrih (Stevanovi), K., Analitika dinamika (mehanika) diskretnih naslednih sistema, (Analytical Dynamics (Mechanics) of Discrete Hereditary Systems), University of Niš, 2001, Monograph, p. 426. (in Serbian).
4. Raškovi, D., (1985), *Teorija elastinosti (Theory of Elasticity)*, Nauna knjiga, 1985, 414.
5. Rega G. and. Lenci S., (2004), Identifying, Evaluating, and Controlling Dynamical Integrity Measures in Nonlinear Mechanical Oscillators, Booklet of Abstracts, WCNA Orlando 2004, pp.13-14.
6. Hedrih (Stevanovi), K., *Integrity of dynamical systems, Booklet of Abstracts, WCNA Orlando* 2004, pp. 25-32.
7. Gdoutos E. E., *Fracture Mechanics, An Introduc***tion**, Kluwer Academic Publishers, Dordrecht, 1993.
8. Hedrih (Stevanovi) K., Jovanovi D. B., (2003), *Mehanika loma i ošteenja (Damage and fracture mechanics) – matematika teorija – renik pojmova i prilozi*, Mašinski fakultet u Nišu, str. 208.
9. Ukrainian Siciety on Fracture Mechanics 1992-2002, Spolom, Lviv 2002, p. 273.
10. Moon F,C.: Chaotic Clock Models: A Paradigm for Noise in Machines, Booklet of Abstaracts, IUTAM Symposium on Chaotic Dynamics and Control of Systems and Processes in Mechanics, *Università di Roma "La Sapienza", Roma, Italy, 2003, pp. 41-44.*
11. Hedrih (Stevanovi) K., (2004), Homoclinic orbits layering in the coupled rotor nonlinear dynamics and chaotic clock models: A paradigm for vibrations and noise in machines, Proceedings ICTAM04 Abstracts Book and CD-ROM Proceedings, pp. 320, SM17S-10624.

Fracture of Nano and Engineering Materials and Structures

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

Edited by
E.E. Gdoutos

Started in 1976, the European Conference of Fracture (ECF), organized under the auspices of the European Structural Integrity Society (ESIS), takes place every two years in a European country. The 16th European Conference of Fracture (ECF16) was held in Alexandroupolis, Greece, July 3-7, 2006. ECF16 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). The technical program of ECF16 was the product of the hard work and devotion of more than 150 leading experts in the world.

This volume contains two-page abstracts of the 698 papers presented at ECF16. The accompanying CD attached to the back cover of the book contains the full length papers. The abstracts of the fifteen plenary lectures are included in the beginning of the book. The remaining 683 abstracts are arranged in 25 tracks and 35 special symposia/sessions with 303 and 380 abstracts, respectively. The papers of the tracks have been contributed from open call, while the papers of the symposia/sessions have been solicited by the respective organizers. Both tracks and symposia/sessions fall into two categories, namely, fracture of nano and engineering materials and structures with 88 and 595 papers, respectively.

The volume contains the latest research work of renowned experts in the area of failure of engineering materials and structures and is useful for the student, the engineer and the researcher who wants to get an integrated picture of the recent developments in the area of fracture mechanics and fatigue.

ISBN 1-4020-4971-4
9 781402 049712

springer.com

Fracture of Nano and Engineering Materials and Structures

E.E. Gdoutos (Ed.)