Japan Academy Prize to:

Toshimitsu YOKOBORI
Emeritus Professor, Tohoku University
Specially-appointed Professor, Teikyo University

for “The Research on the Fundamental Theories of Fatigue and Time-dependent Strength of Materials based on Meso-scale Dynamics and their Practical Applications”

Outline of the work:

Dr. Toshimitsu Yokobori established a unique mesoscale mechanics that links physical metallurgy with macroscale mechanics and derived original theories that quantitatively predict fatigue fracture and time-dependent fracture such as hydrogen embrittlement and creep. These theories are widely applied not only to metals and polymers but also for estimation of elasticity of blood-vessel wall and derived mechanical indicators on deterioration of strength and life prediction which concern the maintenance of structural safety for these materials. These theories exceed the frame of fracture mechanics and change the paradigm of each specialized field.

1. Research of Fatigue Crack Growth

Many comet aircraft disasters occurred in the 1950s. Due to these disasters, research on fatigue crack growth was promoted, and Paris law was proposed which experimentally characterizes fatigue crack growth rate. It is the basic law for designing fatigue crack growth life. Dr. Yokobori found out a similar law of dislocation groups flow. Using this law, Dr. Yokobori derived a dynamic theoretical law of fatigue crack growth that corresponds with experimental Paris law (Paper 3). This theory is an original theory distinguished from that based on fracture mechanics and has been quoted mostly as Yokobori’s theory in the literatures.

2. Quantitative Characterization of the Sensitivity of Hydrogen Embrittlement based on Analysis of Hydrogen Diffusion

Low-temperature brittle fracture of merchant and crystal carry ships occurring during sailing in winters (USA and Japan, 1969 and 1970) is considered to be caused by hydrogen embrittlement originated by corrosive chemical reaction. It has been prevented by the development of anticorrosive technology; however, concerning the technological development of hydrogen energy such as those for parts of fuel cell vehicle and infrastructure of hydrogen station, high-grade prevention measures for hydrogen embrittlement are needed, and the transportation analysis of hydrogen that flows into engineering structures under stress application is essential because of the difficulty in conducting experiments. For this, Dr. Yokobori has proposed a unique analysis method by introducing a factor that manifests hydrogen concentration into the term of differential equation of stress-induced hydrogen diffusion and of coupling finite difference method for diffusion with finite element analysis for stress analysis. He first derived the theoretical law of predicting the sensitivity of hydrogen embrittlement (Papers 10, 13). Previous literatures on analyses of hydrogen diffusion mainly comprised with those for materials science, and the analysis on the problem of hydrogen inflow into engineering structure conducted by Dr. Yokobori is distinguished from them as a practical research on the maintenance of safety for hydrogen energy infrastructure.

3. Research of High-temperature Fracture Mechanism for Materials

Dr. Yokobori has conducted a systematic research on high-temperature creep crack initiation and growth and proposed the original parameter Q*, which characterizes creep crack growth life. Dr. Yokobori has also conducted the research on "proposal of the testing method to predict creep fracture life and its standardization." In this research, the testing method of creep crack growth using a sharp notch specimen was adopted in ASTM E1457–07,15 including the definition of creep crack initiation. Q* parameter was also introduced in ASTM E1457–07,15 and ISO TTA 5; 2007, "Code of practice for creep/fatigue testing of cracked components," as one of the estimation methods. These findings contribute to the establishment of international standardization, and it has been valued as a practical application of strength of materials. Furthermore, Q* parameter has been accepted as an original theory of predicting creep crack growth life, and it has been introduced in many worldwide literatures. Furthermore, on the basis of systematic researches for various materials and dimensions of specimens, Dr. Yokobori has proposed original concepts such as "structural brittleness" and "time-dependent fracture based on multi-scale analysis."

4. Application in Non-invasive Diagnosis of Blood-vessel Diseases

Dr. Yokobori has conducted pioneering and systematic research on the strength deterioration of vascular grafts and blood vessel that are polymeric materials. Furthermore, as an application of technology on the nondestructive inspection, Dr. Yokobori has established an algorithm for diagnosing blood-vessel diseases from the original viewpoint of noninvasively detecting the acceleration response of blood-vessel wall under pulsatile conditions and estimating viscoelasticity of blood-vessel wall by proposing I* parameter that quantifies its progressive degree of viscoelasticity. This method and theory obtained the pharmaceutical approval by Ministry of Health, Labour and Welfare in September 2004. In addition, the method and theory were effective in predicting coronary artery disease by the clinical research conducted by Division of Vascular Surgery, The University of Tokyo Hospital in 2015 (Paper 17). Furthermore, Dr. Yokobori has proposed the non-invasive diagnostic method of the existence of aneurysm based on Chaos theory in 2006 (Paper 15).

Research achievements by Dr. Yokobori are valued as an original application research of quantitatively predicting life of fatigue and time-dependent fracture and deterioration of strength of materials; in addition, they have been awarded by eminent domestic and international societies specialized in academic.

List of Main Publications

Papers

1. T. Yokobori, A. T. Yokobori, Jr. and A. Kamei, "Computer Simulation of Dislocation Emission from a Stressed Source", Philosophical Magazine, 30, (1974), pp.367–378.
2. A. T. Yokobori, Jr., T. Yokobori and A. Kamei, "Generalization of Computer Simulation of Dislocation Emission under Constant Rate of Stress Application", Journal of Applied Physics, 46, (1975), pp.3720–3724.
3. T. Yokobori, S. Konosu and A. T. Yokobori, Jr., "Micro and Macro Fracture Mechanics Approach to Brittle Fracture and Fatigue Crack Growth", Proceedings of the 4th International Conference on Fracture, 1977, Canada, 1, (1977), pp.665–682.
4. A. T. Yokobori, Jr., T. Yokobori, H. Ohuchi and H. Sasaki, "The Experimental Simulation of Elastic Model of Artery System (Some Behavior of Vascular Substitute Under Repeated Internal Stress)", Fracture Mechanics and Technology, Sijthoff & Noordhoff Int. Pub., The Netherlands, Proceedings of an Interna-

tional Conference on Fracture Mechanics and Technology, eds. G. C. Sih and C. L. Chow, 1, (1977), pp.623–638.

5. A. T. Yokobori, Jr., T. Maeyama, T. Ohkuma, T. Yokobori, H. Ohuchi, S. Nara, H. Sasaki and M. Kasai, "Bio-Medico-Mechanical Behavior of Natural Artery Blood Vessel Under Constant and Variable Internal Pulsatile Pressure Flow Test In Vitro", Transaction of the ASME Journal of Biomechanical Engineering, 108, (1986), pp.295–300.
6. A. T. Yokobori, Jr. and T. Yokobori, "New Concept to Crack Growth at High Temperature Creep and Creep-Fatigue", Advances in Fracture Research, Proceedings of the 7th International Conference on Fracture (ICF7), eds. K. Salma, K. Ravi-chandar, D. M. R. Taplin and P. Rama Rao, Pergamon Press, Oxford, (1989), pp.1723–1735.
7. A. T. Yokobori, Jr. and T. Yokobori, "The Mechanical Test Method of Cardiovascular and Related Biomaterials", Bio-Medical Materials and Engineering, 1, (1991), pp.25–43.
8. A. T. Yokobori, Jr., T. Isogai and T. Yokobori, "A Model Emitting Dislocation Group from Crack Tip with Stress Singularity and its Application to Brittle—Ductile Transition", Acta Metallurgica et Materialia, 41, (1993), pp.1405–1411.
9. A. T. Yokobori, Jr., T. Ohkuma, S. Sasaki, H. Yoshinari, T. Yokobori, H. Ohuchi and S. Mori, "Algorithm of the Noninvasive Diagnosis Method on the Atherosclerosis by Ultrasonic Doppler Effect", Bio-Medical Materials and Engineering, 4, (1994), pp.87–96.
10. A. T. Yokobori, Jr., T. Nemoto, K. Satoh and T. Yamada, "Numerical Analysis on Hydrogen Diffusion and Concentration in Solid with Emission around the Crack Tip", Engineering Fracture Mechanics, 55, (1996), pp.47–60.
11. A. T. Yokobori, Jr., M. Shibata, M. Tabuchi and A. Fuji, "Comparative Study of the Estimation of Creep Crack Growth Behaviour of TiAl by Using a Precrack and a Notch CT Specimens", Materials at High Temperatures, 15, (1998), pp.57–62.
12. A. T. Yokobori, Jr., T. Uesugi, T. Yokobori, A. Fuji, M. Kitagawa, I. Yamaya, M. Tabuchi and K.Yagi, "Estimation of Creep Crack Growth Rate in IN-100 Based on the Q* Parameter Concept", Journal of Materials Science, 33, (1998), pp.1555–1562.
13. A. T. Yokobori, Jr., Y. Chinda, T. Nemoto, K. Satoh and T. Yamada, "The Characteristics of Hydrogen Diffusion and Concentration around a Crack Tip Concerned with Hydrogen Embrittlement", Corrosion Science, 44, (2002), pp.407–424.
14. A. T. Yokobori, Jr., R. Sugiura, M. Tabuchi, A. Fuji, T. Adachi and T. Yokobori, "The Effect of Multi-axial Stress Component on Creep Crack Growth Rate concerning Structural Brittleness", Proceedings of the 11th International Conference on Fracture (ICF11), (2005), CD-ROM.
15. A. T. Yokobori, Jr., M. Owa, M. Ichiki, T. Satoh, Y. Ohtomo, Y. Satoh, S. Ohgoshi, Y. Kinoshita and S. Karino, "The Analysis and Diagnosis of Unstable Behavior of the Blood Vessel Wall with an Aneurysm Based on Noise Science", Journal of Atherosclerosis and Thrombosis, 13, (2006), pp.163–174.
16. A. T. Yokobori, Jr., R. Sugiura , T. Ohmi and R. A. Ainsworth, "A Review of Time-dependent Fracture Life Law (or Model) Based on a Proposed Multi-scale Analysis" Strength, Fracture and Complexity, 8, (2014), pp.205–218.
17. R. Taniguchi, A. Hosaka, T. Miyahara, K. Hoshina, H. Okamoto, K. Shigematsu, T. Miyata, R. Sugiura, A. T. Yokobori, Jr. and T. Watanabe, "Viscoelastic Deterioration of the Carotid Artery Vascular Wall is a Possible Predictor of Coronary Artery Disease" Journal of Atherosclerosis and Thrombosis, 22, (2015), pp.415–423.

Other 349 papers

Books

1. Biomaterials' Mechanical Properties, ASTM Special Technical Publication, 1137, Edited by H. E. Kambic and A. T. Yokobori, Jr., (1994).
2. The Strength of Materials and Fractology –Creative Development and Application–, (1999). [Published by Sasaki Pub. (The charged parts of writing) Sections 14 and 15 of Chapter 6, Sections 2–6 of Chapter 7, and Sections 2–4 of Chapter 8]
3. Handbook of Materials Behavior Models, (2001). [The charged parts of writing] Section 9 Creep Crack Growth Behavior in Creep-Ductile and Creep-Brittle Materials, pp.597–609, Academic Press.
4. Innovative Testing and Estimation Methods of Hydrogen Embrittlement Under Sustained, Rising and Cyclic Loadings, pp.37–72, (2013). [Published by Japan Society for the Promotion of Science 129th Committee on Strength and Fracture of Advanced Materials Standard, Edited by A. T. Yokobori, Jr., T. Iwadate and R. Sugiura]

Other 19 books