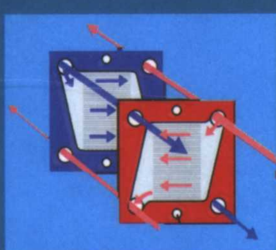
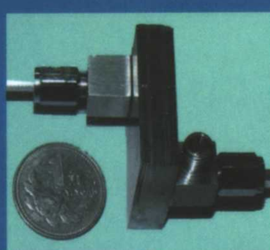
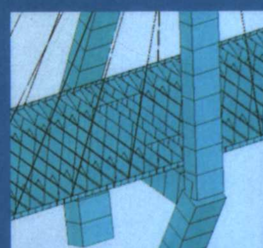
MULTISCALE DAMAGE RELATED TO ENVIRONMENT ASSISTED CRACKING

Fracture Mechanics and Applications

Editors: G.C. Sih, S.T.Tu and Z.D. Wang



EAST CHINA UNIVERSITY OF SCIENCE AND TECHNOLOGY PRESS

MULTISCALE DAMAGE RELATED TO ENVIRONMENT ASSISTED CRACKING

Fracture Mechanics 2005

EDITORS

George C. Sih

East China University of Science and Technology, China
Lehigh University, USA

Shan-Tung Tu

East China University of Science and Technology, China
Nanjing University of Technology, China

Zhengdong Wang

East China University of Science and Technology, China

East China University of Science and Technology Press

East China University of Science and Technology Press
Shanghai 200237, China

图书在版编目(CIP)数据

环境致裂的多尺度损伤/薛昌明,涂善东,王正东主编.
—上海:华东理工大学出版社,2005.10
ISBN 7-5628-1804-5

Ⅰ.环... Ⅱ.①薛...②涂...③王... Ⅲ.断裂力学
—国际学术会议—文集—英文 Ⅳ.0346.1-53

中国版本图书馆 CIP 数据核字(2005)第 122426 号

环境致裂的多尺度损伤
Maltiscale Damage Related to Environment Assisted cracking

主　　编/薛昌明　涂善东　王正东
责任编辑/徐知今
封面设计/李海燕
责任校对/张波　徐群
出版发行/华东理工大学出版社
地　址:上海市梅陇路 130 号,200237
电　话:(021)64250306(营销部)
传　真:(021)64252707
网　址:www.hdlgpress.com.cn
印　　刷/上海长阳印刷厂
开　　本/787×1092　1/16
印　　张/23
字　　数/739 千字
版　　次/2005 年 10 月第 1 版
印　　次/2005 年 10 月第 1 次
印　　数/1-1010 册
书　　号/ISBN 7-5628-1804-5/TB·6
定　　价/100.00 元

Preface

It is indeed a great honor for Zhengzhou University to host the third annual meeting of the Fracture Mechanics Group (FMG) during the period November 2-5, 2005. This series of conferences was initiated by a consortium of institutions that include East China University of Science and Technology in Shanghai, Nanjing University of Technology in Nanjing, Zhejiang University and Zhejiang University of Technology in Hangzhou and General Machinery Research Institute in Hefei under the general Chairmanship of Professor Tu Shan-Tung who had the foresight to realize that the East needs to take the initiative to disseminate scientific and technological information which for the most part has also been an endeavor of the West. It is only logical to aim for a balance in this joined collaborative effort. To this end, the International Advisory Committee of FMG has organized a US-China seminar of Multiscale Damage in Relation to Environment Assisted cracking, August 8-20, 2005.

The program was sponsored by NSF USA and China to visit the City University of New York, George Washington University of D. C., Lehigh University and Stanford University (See pictures in Figs. 1-4). The Chinese delegation was headed by Professor Dong Qiwu with Professor Tu Shan-Tung being the exofficio. One of the main objectives was for the Chinese academics to interact with the Americans in this era of rapidly changing science and technology related to research and education. In particular, the emphases placed on nanotechnology to miniaturize electronic devices and components for increasing the computational capacity and instrumental resolution have open doors to new challenges and responsibilities to all citizens at the global scale.

Using fracture mechanics as the central theme, failure anticipation and prevention in connection with fatigue and/or corrosion assisted cracking have been selected for discussion. Environmental effects such as high temperature and aggressive agents were addressed for both long and short term considerations. Multi-disciplinary interaction was the obvious undertaking where physics, chemistry and mechanics would converge simultaneously on seeking solutions to technical and societal problems. Demand of larger computational power is always needed to reach for simulation of physical reality while the drive to find the commonality of matters has been more evident than ever before. Multiscaling has become an often used topic in seminars, lectures and conferences. This was brought to light vividly by the presentation of the Director of Mechanics and Materials, Dr. Chong Ken P. of the National Science Foundation of USA. Dr. Chong emphasized that the engineering research and education is changing rapidly. A new infrastructure is developing in the direction of high performance computation, training people, instrumentation, broadband network connectivity and large database digital library. These changes are already in progress. It is the responsibility of the scientists, educators and administrators to understand from the grass root level how these changes can be implemented into the existing systems. Training people apply to the newcomers as well as the old-timers, especially to those in the position of influencing others. There is no doubt that the US-China seminar has at least accomplished some of the goals mentioned above. The presentations published in the proceedings contained in this volume will further testify to what has been said.

The symposium is co-organized by Zhengzhou University, East China University of Science and Technology, National Technical Research Center on Safety Engineering of Pressure Vessel and Pipelines, Nanjing University of Technology, Zhejiang University of Technology, and Zhejiang University, and co-sponsored by China Pressure Vessel Institution, NSF China and USA, Boiler & Pressure Vessel Safety Supervision Bureau of China and Henan Department of Science and Technology. I would like to take this opportunity to thank the above organizations and the members of International Advisory Committee for making this annual meeting possible. I also wish to show special appreciation and respect to Professor George C Sih who made the symposium series and US-China seminar possible and successful.

On behalf of the organizing committee of FM 2005, I also wish to take this opportunity to express special gratitude to Prof. Wang Zhengdong, Prof. Liu Minshan and Prof. Wei Xinli, not only for their support and time to organize this meeting but also for their personal interest that has given the participants a warming feeling. I also wish to emphasize the leadership and encouragement of Prof. Li Peining and his technical expertise that have planted the seed to the FMG activities. The members of the local organizing committees are to be complemented for taking care of the participants.

Zhengzhou, Henan
November 2005

Q. W. Dong
Executive Chairman

Fig. 1. Seminar attendees at City University of New York.

Fig. 2. Banquet hosted by Dean Timothy Tong of GWU.

Fig. 3. Speakers at Lehigh in front of Sinclair auditorium.

Fig. 4. Group picture after visiting University Stanford.

From the Editors

The third annual meeting of FM 2005 was hosted by the Thermal Energy Engineering, Research Center, Institute of Technology, Zhengzhou University, Zhengzhou, Henan, November 3-4, 2005. Collaboration with the US-China Seminar of "Multiscale Damage in Relation to Environment Assisted Cracking", August 8-20, 2005 was an effort made to interact with scientists, researchers and engineers from the US that otherwise would not have been possible. To this end, four universities were selected. They consist of the City University of New York, George Washington University, D. C., Lehigh University and Stanford University. Sponsorship of the National Science Foundation of US and China are gratefully acknowledged. These activities have opened a new chapter to the series of FM annual meetings in that the dissemination of research results have been broadened to audience at an international level. Keep in mind that the FM series was initiated as a national event although the importance of globalization in science and engineering has been long recognized. This effort can be evidenced not only from the contents of the proceedings and the email interviews, but also from the emphases placed on the multidisciplinary of the fields covered. A case in point is the subject of stress corrosion where physics, chemistry and mechanics interact via scaling in size and time. Historically, each field has been separated by the size and time scales that they are engaged in research. Note that particle physics is starting to break the length scale barrier of 10^{-16} cm so that strings would not look like particles. Chemistry has been traditionally involved at scales of 10^{-8} cm for the atoms and molecules while continuum mechanics on the whole has been delving with the microscopic and macroscopic scale range of 10^{-4} to 10^{0} cm. Hence, the connection of physics, chemistry and mechanics would involve multiscaling if the hope to establish a common ground of communication for these disciplines is to be kept alive. Needless to say, the aim is to relate events at the macroscopic to the microscopic, atomic, subatomic and even smaller. For now, the behavior of the electrons stands out as the basis for explaining many of the seemingly unrelated phenomena at the larger scales. Among them is the subject of stress corrosion that has been chosen for the development of mutliscaling models in this meeting.

The increase in world population has exerted relentless pressure on the use of energy. It needs no great foresight to realize that greater power generation with higher efficiency will depend on superior integrity of the material. The explosive character of electrons needed to generate energy must be counteracted by the appropriate atomic or subatomic structures of the containment material to maintain a reasonable balance. A minute unbalance at the atomic scale could translate into large mismatch in the design of the material to resist against, say stress corrosion. More critically speaking, this balance may have to be matched atom for atom, if not electron for electron. A better understanding of the fundamental nature of how the time behaviors of electrons are affected by temperature and their positions in the prevailing energy field can be informative. The state-of-the-art in quantum physics, however, seems to be satisfied with knowing only the behavior of the electrons averaged over the atom. While particle physics should reach upward in scale, continuum mechanics must also reach down in scale. Hopefully, a meso region can be identified to direct both views into a common channel. More specifically, Intergranular Stress Corrosion Cracking (IGSCC) requires an understanding how physics, chemistry and mechanics can work together and come to grip with the degradation of materials aggravated by environments. The problems associated with IGSCC can be found .in the PWR and BWR nuclear power plant components, bridge cables and related structural members, and aging aircrafts, just to mention a few. Trend of current research in science and technology certainly indicates that the empirical approaches adopted in macro-fracture mechanics for controlling IGSCC will be short lived in view of its decline in effectiveness and high cost. Even more disturbing is the fact that the traditional approaches are not in line with the progress of modern science and technology. This is not to say that particle physics and large scale computer simulations will be the answer. However, it has been long overdue to explore new avenues for possible approaches. Certainly, the search for the basic mechanism of IGSCC must not be discouraged. At least, science and technology have advanced to the stage of recognizing that "ignorance is no longer bliss".

Once again, the FM 2005 meeting has encouraged the submission of research works in the areas of:

- Aging of metals and polymers.
- Effects of high temperatures and moistures.
- Environment assisted cracking and failure.
- Multiscale modeling of physical systems.
- Nanoscale behavior of matter and device.
- Chemical instability.
- Atomistic simulation models and applications.
- Interatomic potentials for two or more interacting atoms.
- Monitoring and defect detecting methodologies.
- Structure failure in contrast to malfunction of micron size device.
- Safety issues associated with engineering materials and products.
- New laws for small scale matters and those used by tradition.

Other topics at both the macroscopic and nanoscopic scale also deserve attention, particularly in showing that the material behavior is scale dependant. There is no doubt that beneficial effects have been achieved through the interaction of the FM group with the Mesomechanics meetings sponsored by the International Society of Mesomechanics. Such activities will be further encouraged at the 16th European Conference of Fracture in 2006 that will be forthcoming. The event is sponsored by the European Structural Integrity Society. The gathering of active minds certainly has had far reaching consequences. The best example is that of the 1959 lecture of Richard Feynman sponsored by the American Physical Society and held at the California Institute of Technology. The wisdom of a single individual was able to alter the direction of national, if not international research trends. It provided the main trust for the development of nanotechnology. More than four decades have since been elapsed. The message was that many of the answers of current technical and societal problems may be found by reaching down the scale. Perhaps, there is benefit to step up on the shoulder of Feynman to obtain a better foresight of the future.

The editors wish to take this opportunity to express their gratitude to the representatives of the organizing institutions. Their collaborative efforts and ideas have contributed to the success of this conference. Thanks are also due to Wang Zhenbang, Li Yuexia, Shen Shufang, Chen Qingqi, Wang Yongqing, Xing Zhanya, Zhang Bo, Liu Xiao, Li Shuxin, Chen Jianjun and Zhou Guoyan who assisted in typing, examining and editing manuscripts.

Shanghai, China
September, 2005

G. C. Sih
S. T. Tu
Z. D. Wang

Communication Forum

The editors have decided to publish the Communication Forum as a supplement to the Proceedings of the annual meetings since FM2004. In line with one of the objectives of Fracture Mechanics Symposium Series, the forum will contain communications from the public to the editors and vice versa. One of the mechanisms is to include email interviews from authorities in fracture mechanics and related fields of scientific, philosophical, technological, social matters and others. In this way, up-to-date knowledge and information can be disseminated to the public on a personal basis concerning the inside tracks of international organizations that may include research institutions, societies, universities and government agencies that would otherwise not be available. On the agenda the communication was centered on the International Congress of Fracture ICF, an organization that has devoted more than four decades to serve the technical community world wide in the application of fracture mechanics for enhancing the well being of structures and materials. To this end, the Founder President of ICF Professor Takeo Yokobori and the current President of ICF Professor Mai Yiu-Wing accepted the email interviews extended to them from the editors which were published in the FM2004 proceedings. The communication has been continued since then to interview with other three famous scientists. Those are **Dr. Cheng Kai-Jia**, Director and Deputy Commander of the Chinese Nuclear Testing Laboratory, **Professor Emmanuel E. Gdoutos**, Chairman of the European Association of Experimental Mechanics and Director of the Laboratory of Applied Mechanics at the Democritus University of Thrace, Xanthi, Greece, and **Professor Alberto Carpinteri**, President of European Structural Integrity Society and Chairman of International Conference on Fracture ICF-11 held in Turin, Italy, March 20-25, 2005.

Comments to the editors are most welcome.

I. Interview with Dr. Kai-Jia Cheng

Director and Deputy Commander of the Nuclear Test Laboratory, China

In 1960, Dr. Cheng joined the Chinese nuclear weapon research activities. He had served as the Deputy Director of the Chinese Nuclear Weapon Research Institute. He was the first who computed the detonation temperature and pressure of the atomic bomb. He also overcame many of the difficult problems associated with the atomic bomb blast.

When the atomic bomb project was near success in 1962, Dr. Cheng was assigned to the newly establish Nuclear bomb testing site in the West-Northern part of China，pronounced as “ge bi tan”. There, he stayed for nearly 20 years and held the positions of Deputy Director, Director and Deputy Commander of the Nuclear Test Laboratory. Dr. Cheng was engaged in a variety of projects that led to the successful testing of the atomic and hydrogen bombs and other nuclear weapons.

In 1999, he received the “ATMS achievement award” from President Jiang Ze-Min together with 23 other scientists who are responsible for the development and testing of the atomic/hydrogen bombs, missiles and satellites in China, analogous to the scientists who worked on the Manhattan project in the USA during the Second World War.

In recent times, his daughter Cheng Shu-Yu has been studying under the guidance of Dr. Cheng in the area of material science to develop and fabricate new materials using nanotechnology. Some of the works of Dr. Cheng and Shu-Yu are reflected in:

- M. Born and K. J. Cheng, Theory of superconductivity, Nature 162 (1948) 1017
- Cheng Kaijia，Study On Mechanism of Superconductivity , New Times Press , Beijing ,1991
- Cheng Kai-Jia, Theoretical foundation of condensed material, Progress in Nature Science, 6(1) (1996) 12
- Cheng Kaijia and Cheng Shuyu，Boundary Conditions of Electrons at Interfaces:

Part I- Mixture of nanometer crystals and amorphous silicon and Part II-Internal stresses in thin films, Theoretical and Applied Fracture Mechanics, 37(1)(2001)11.

Questionaire

The interview consisted of the following ten questions to which Dr. Cheng was asked. The corresponding answers are:

Q1. If you had the choice to restart your career, would you have specialized in some other fields of science instead of physics or a multidisciplinary field? In view of your interest in material science, do you believe that by making things smaller will help us to understand better and faster?

A1. I have never repented of the choice what I made. I have done my best to complete the missions beneficial to people and motherland. If I can restart my career, I will do the same.

Bulk material with sizes ranging from macro to nano exhibits a sharp transition in macroscopic behavior. Electrons obey partly classical mechanics in kinetic energy, yet Pauli Exclusion Principle and Fermi statistics still hold. This causes a new behavior when two pieces are brought in contact. They result in new properties for composite materials, boundary conditions will play important role in composite materials.

This creates a new field in material sciences. Hence, research carrying on from micro to nano will be important in this century.

Q2. As a doctorate candidate under Prof. Max Born at Edinburgh, did you engage in research work related indirectly or directly to the Nobel Prize awarded years later to your adviser in 1954? In retrospect, what was some of the most memorable research activities you were involved at Edinburgh?

A2. Professor Max Born was awarded the Nobel Prize for his interpretation of the probability of wave functions in quantum mechanics. When I was in Edinburgh, I knew that Born was corresponding constantly with Einstein on the topic of chance and causality, to which Einstein insisted on a deterministic approach by using quantum mechanics. I attended several invited lectures delivered by Professor Born at Oxford University. They were on chance and causality.

Professor Born proposed a theory of "Reciprocity", and insisted a conjugate pair (P, Q) for natural laws that can be changed in order as the laws of motion. I proposed a transformation P to Q and Q to P, referred to as reciprocity conjugation. This work was published in the Proceeding of Royal Society of Edinburgh.

In 1949, Niels Bohr attended a conference in Edinburgh University. He and Max Born discussed the future particle development of quantum mechanics, Bohr proposed a five dimension universe (x, y, z, t, $\lambda = \hbar / mc$), involving a Compton wave length $\hbar / mc$ as a fifth dimension. Prof. Born proposed Reciprocity. They argued vehemently before us. I was very interested at this problem, because Prof. Wang Gan Chang and I had published the research result related to the five dimensions: Cheng Kai Chia and Wang Gan Chang, A Five Dimensional Field Theory.

My doctorate thesis was titled "Theory of Superconductivity". It was mainly concerned with the "Broken Symmetry" of electron currents by lattice and electron exchange energies. Up to this date, superconductivity still threads a paradoxical course in theoretical physics.

Q3. You wrote an article in 1988 to commemorate the 90^{th} Anniversary of the late Premier Zhou En-Lai. Can you tell us some of the contents of that article in relation to the on-going project at that time? Was the late Premier Zhou an initiator, if not the originator, of the nuclear weapon development program in China?

A3. Premier Zhou Enlai was a real leader for research, particularly in manufacturing and testing of nuclear weapon at the embryo stage of development in China. He was a super leader in the committee for the atom bomb, missile and satellite. Premier Zhou was responsible for making decision, giving commands and supporting the projects. He was always clear to the point of key issues concerning the execution of every mission. This shows that he is a great man with vision and a leader of our country and party.

Q4. As the Director and Deputy Director of the Nuclear weapon test facilities in the West-Northern part of China, you had to supervise a team of scientists and technicians to carry out one of the most important missions of China. What was the secret of your success in terms of discipline, encouragement, leadership, etc.? Will the same ingredients in managing technical personnel apply today? If not, why?

A4. The success of our career was based on the professional scientific attitude, the seriousness of carrying out orders, the thoroughness of planning and the disciplined working habit, not to mention the spirit of cooperation and the spirit of mutual respect. These are the principles that I have adhered to all my life.

Q5. Were you and your team confident to achieve success in the test of the first Chinese atomic bomb hydrogen bomb blast? Did you make efforts to provide contingency plans if the tests had failed? Do you believe that the balance of power achieved by China via the atomic and hydrogen bombs has contributed to the economical success of China in recent years?

A5. From the very beginning of the mission, I was confident in myself that there was no reason for failing the test of the first atom bomb. We had been preparing with meticulous care without possible flaws for the first bomb blasting.

Of course, for China to be in the lime light of all countries around the world with and without nuclear bombs, it is very important to be successful as the reputation of the country is on the line. In retrospect, the nuclear bomb development policy has added prestige to China's military and economic capability that lead to social well being. There is no doubt that the achievements of to-day's China could not have been made possible without the success of the nuclear weapon program of the past.

Q6. It is now open information that nuclear weapons shall be tested by computer simulation instead of underground explosion. The reliability of the stockpile of nuclear weapons is also of great concern. Do you think computer simulation techniques can achieve the same effectiveness and reliability as underground testing?

A6. I believe the word said by Deng Xiaoping: "The unique standard used to examine the truth is the practice." This is the watchword to be obeyed by everything. No one is capable of ensuring complete success in computer simulation.

Q7. You have been the champion of the Thomas-Fermi-Dirac (TFD) theory for analyzing abrupt changes in the properties of the electrons. Much of this work has been co-authored with Cheng Shu-Yu. First, can you tell us what the TFD approach can do that the other theories are not able to do? You have pointed out in your past works that non-uniform densities in the electrons in fact act as interfaces and they are important to the behavior of nano-materials. Can you tell us why this is so and how can we use this information to fabricate more superior materials for resisting higher temperature or other hostile environments?

A7. The TFD theory describes statistical behavior of electrons motion. It is successful in application to equation of states, the distribution of electrons in atom or solid. But it has not been applied to the development of the physical behavior of condensed material. I propose to include boundary conditions in the motion of electrons across boundaries of crystalline with the stipulation that wave density should be continuous, i.e., electron density should be continuous and chemical potential should be equal for electrons at both sides. The new proposition provides added features to the solution for the behavior of composite materials and to the understanding of their properties. It leads to the development of new materials with new mechanical, electrical, and many other properties, namely high strength and high electrical capacitance.

Q8. Do you think that the capability of future weapon systems will be limited by the integrity of materials? In your opinion, what kind and type of new materials are needed? Is the current development of nanotechnology heading in the right direction?

A8. The development of various weapons is restricted by the material. The material with light, tenacity, small dimension and special electricity, light and magnetic property are necessary for making weapons with new technology. Among them are nano-materials with many special characteristics. This is key for the development of future weapon systems.

Q9. What advice can you give to the young scientists and researchers today to achieve excellence in research? Monetary reward seems to be the carrot that is being dangled in front of the younger generation. Do you think this is sufficient? Are there other elements that could be more effective?

A9. From our previous conversations, you had a lot of good ideas of how to encourage the young scientists to do good research. Your comments will be most helpful!

Q10. Science has always thrived during war time. Do you think that this trend may be changing owing to the process of globalization that has encouraged all nations to share scientific and technological knowledge and know-how? Is this one of the reasons that made you to change from nuclear physicist to a material scientist?

A10. I don't think so. In my opinion, material science has not done well to solve theoretical problems and to explain the underlying physics. Mankind has to do it's best to the exploration of unknowns that will always be part of our life. Only peace will enhance progress and endure the well being of mankind.

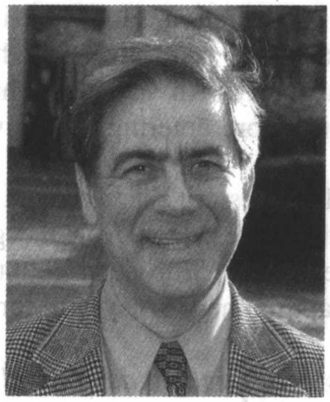
While I must be responsible for the testing of nuclear weapons, I am also deeply concerned with the well being of the society in general. To that end, I have been devoting my present time to research in material science in the hope that science would march in the direction of peace rather than conflict by war.

Kaijia Cheng
程开甲

Dr. Cheng Kaijia
November 15, 2004

II. Interview with Professor Emmanuel E. Gdoutos

Chairman of the European Association of Experimental Mechanics
Professor and Director of the Laboratory of Applied Mechanics at the Democritus University of Thrace, Xanthi, Greece



Professor Emmanuel E. Gdoutos holds the position of Professor and Director of the Laboratory of Applied Mechanics at the Democritus University of Thrace, Xanthi, Greece since 1980. He joined the Department of Civil Engineering of the university in 1977. From 1974 until 1977 he was an instructor at the National Technical University of Athens. He is a member of the European Academy of Sciences and Arts, Fellow of the American Society of Mechanical Engineers, Fellow of the New York Academy of Sciences, Fellow of the USA Society for Experimental Mechanics and Honorary Member of the Italian Group of Fracture. He is the Chairman of the European Association of Experimental Mechanics for the period 2004-2007 and will chair the 13th International Conference on Experimental Mechanics to be held in Greece in 2007.

Professor Gdoutos has been active in research associated with experimental mechanics, advanced composite materials, fracture mechanics, sandwich construction and nanotechnology. He published more than two hundred technical papers and published and edited several books dealing with mechanics of solids and fracture mechanics. In addition to his academic interests, he has been active in organizing national and international conferences. He is President of the Greek Group of Fracture which is a chapter of ESIS. He will chair the16th European Conference of Fracture (ECF16) to be held in Greece, July 3-7, 2006.

Questionaire

The following ten questions have been prepared and approved by the Executive Committee members of FMG for the email interview of Prof. Gdoutos:

Q1. In your experience as a teacher and researcher in Europe and United Sates, what can you say about the major differences between the educational systems, qualification of the faculty members, levels of the undergraduate and graduate students, availability of research funds from the industry and government?

A1. There are substantial differences in the educational system between Europe and the United States. Generally speaking, in Europe the various subjects are studied in more depth than in the States. The philosophy of the educational system in the States is to provide the average student with the basics of education. However, in the States the system is more flexible and allows talented students to take advanced (honor) classes, classes at higher grades, even classes at the university. An advanced high school graduate may have completed a university year even before entering the university. This does not happen in Europe.

European higher educational studies are characterized by a more in-depth education of the various disciplines than in the States. However, the graduate studies in the USA are more systematic than in Europe. Lately, European countries follow the USA model for undergraduate studies and are adapting the USA system for PhD studies.

Q2. What are the mechanisms used by the industry and government in Europe and USA to determine the relevancy of research topics? In what ways are the educational systems connected with national interest? For Europe, please qualify your answer with reference to national interest in contrast to that of the European Community.

A2. In both Europe and USA the funding priorities are set by relevant government-industry organizations. Expert committees are also appointed by the government for this purpose. Industry plays a major role in defining the research directions. Organizations like the USA Academy of Engineering, the American Society of Mechanical Engineers (ASME) may also be asked to express their opinion.

In Europe the educational system is connected to the interests of the various countries. For example, after the Second World War research in Europe was oriented towards civil engineering applications. The damaged infrastructure and housing during the war needed to be rebuilt. The years following the war, civil engineers held the most wanted profession. This situation came to a plateau in the 1970s. It had an immediate impact on the priorities of the students in choosing their school of study. It shifted from civil engineering to medicine. The advent of computers in the 1990s led to an increase in the popularity of electrical engineering and computer science schools which were included among the first priorities of the students.

Q3. In your opinion, what are similarities and dissimilarities of the research programs in fracture mechanics and material science that are sponsored by the governments in Europe and USA? Please also comment on the connection with reference to commercial products. Airbus and Boeing are needles to say the two major end products that reflect the European and USA technological capability.

A3. There is no doubt that fracture mechanics that started in the 1950s came to maturity in the 1980s. By that time the basic principles of fracture mechanics have been developed and have been applied to the design of engineering components and structures. Nuclear reactors, pipelines, aircrafts have been among the most popular applications of fracture mechanics. Since the late 1980s applications of fracture mechanics have shifted from brittle and ductile metals to new materials including composites, cementitious materials, concrete, rock, geomaterials, among others. Lately, fracture mechanics is applied to thin films, micro- and nano- electromechanical systems (MEMS and NEMS) with the objective of improving their performance and reliability and extending their lifetime. Research work in fracture mechanics of thin films has mainly started in the USA in the late 1980s.

Q4. Based on the pros and cons of the European and US systems, do you see a third force such as China or another Asiatic country that will enter the world arena of scientific and technological competition in the near future? What would be your assessment in the order of scientific and technical education, research topic relevancy, industrial application and product competition in the world market?

A4. China, with its huge population and old tradition in culture and education, is entering dynamically the word arena in science and technology. This is evident from the vast number of articles published in technical journals by Chinese scientists and engineers. Today, the basic journals of fracture mechanics including the "International Journal of Fracture," the journal of "Theoretical and Applied Mechanics" and the "Engineering Fracture Mechanics" are overwhelmed by Chinese authors. On the other hand, the universities of USA are full of Chinese students. There is definitely a technology transfer from USA and Europe to China. I think that in the near future China will advance in science and technology and will play a key role in the technological developments.

Q5. Since the post World War II period, aircraft manufacturers and computer producers are now aware that the public places structural and material integrity at the top of the list. Codes and standards of the 1960s will no longer be adequate, do you think that the technical societies concerned with the well being of structures and materials in Europe and USA are aware of the seriousness of this problem? What are the precautions and plans they have made to uphold the possible down-fall of the world economy once the public looses confidence in high technology?

A5. Technical societies in Europe and USA such as the European Structural Integrity Society (ESIS) or the American Society for Testing and Materials (ASTM) are non profit organizations with limited funding that comes mainly from membership and publications. Technical committees of the societies or individual members may be aware of the problem that old standards and codes are not adequate in our times. However, they do not have particular power and capabilities to cope with the problem. The best they can do is to make recommendations to the appropriate decision-taking bodies in Europe and USA. Usually, the role of these societies is restricted to organize conferences, to publish technical journals and publications, to coordinate the activities of their technical committees. The role of the technical societies should increase in the future. They should advise and interact with