European Structural Integrity Society

ESISNewsletter #43, May, 2007

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EDITORIAL BY THE ESIS PRESIDENT

Dear colleague,
I am most humbled and honored to have been elected President of ESIS, a prestigious organization involved in the structural integrity of engineering structures, components, systems and their associated materials. I would like to thank the members of the ESIS Council for the confidence they have shown in me. I would like to assure you that I will work with all my resources in order to further the progress made so far, and achieve new milestones for ESIS.
I am proud to succeed Professor Alberto Carpinteri, under whose presidency, and with his hard work, dedication and leadership ESIS has made enormous progress. I promise that I will continue on his footsteps so that ESIS fulfils its objectives in the best possible way. I trust that with the enthusiastic support of the Executive Committee, including the two newly elected vice-Presidents Professors Leslie Banks-Sills and Andrzej Neimitz, the Secretary and Treasurer Professor G. Ferro and the Editor of the Newsletter Professor S. Beretta, the ESIS Council and the ESIS members the progress made so far will be furthered and solidified, by achieving all of our goals.
ESIS will extend its realm to the new technological developments of our era, including biological materials, thin film/substrate systems, nanomaterials and nanostructures, while still maintaining a strong tradition in the conventional fracture mechanics analyses of engineering materials and structures. Fracture mechanics plays a protagonist role in the prediction of failure and safe design of materials and structures in the relatively new areas of technology mentioned above. The new developments were adequately addressed at the 16th European Conference of Fracture where six plenary lectures and 93 papers referring to fracture at the micro and nano scale levels were presented. I am sure that ECF17 to be held in Brno, Czech Republic, in 2008, will follow to extend ECF16's tremendous success in that respect, and devote a large number of papers in those areas.
Among our goals are:

1. To increase the ESIS membership and the countries affiliated with ESIS.
2. To extend the realm of ESIS into edge-cutting technologies, including nanotechnology and bioengineering.
3. To pay special emphasis in the educational and training objectives.
4. To play a key role in organizing and sponsoring fracture mechanics activities including conferences, tutorials, summer schools, in Europe and worldwide.

5. To cooperate closely with the International Congress on Fracture and other fracture mechanics organizations in Asia and the Americas in an effort to better serve the international fracture mechanics community.

We will achieve our goals by:

1. Communicating with individuals and fracture mechanics societies in Europe and showing them the need of ESIS membership.
2. Establishing technical committees in the nanotechnology and bioengineering areas which will coordinate the ESIS activities.
3. Introducing tutorials in traditional and new developments of fracture mechanics in conjunction with the biannual conference of fracture.
4. Sponsoring fracture mechanics conferences organized by European fracture mechanics societies.
5. Coordinating our activities with those of the International Congress on Fracture, the American Society for Testing and Materials and the Asian Group of Fracture.

I am looking forward to working closely with the executive committee, the council, the chairs of the technical committees and the members of ESIS for the achievement of our objectives. I am confident that through all of our hard work and dedication we will achieve our objectives, and ESIS will continue to serve the fracture mechanics community in Europe and around the world in the best possible way.

If you have any questions, suggestions or comments please do not hesitate to contact me. I would be most glad to hearing from you.

E.E. Gdoutos
ESIS President 2006-2010

WELCOME !

Dear colleague this is the fourth issue of the ESISNewsletter. You will find here the report of the ESIS activity in the year 2006: i) minutes of the Alexandroupolis ESIS council including the situation of TC activities; ii) a report of TC activities. Concerning the scientific content this issue contains the invited papers by Prof. Bank-Sills (p. 21) and Prof. Karihaloo (p. 30).

During 2006 it has been very difficult to collect the information about TC activities and to timely announce them. In order to overcome this situation and to offer a more updated service (it takes a long time for ESIS announcements to appear in journals) we have substituted the Calendar of ESIS events with an announcement of TC meetings and ESIS events in the website of the Elsevier journals affiliated with ESIS. I think that this solution better serves our needs.

We are sorry to announce that Dr. John Radon, who was very active with the European Group on Fracture which later became ESIS. has past away on last 4th May after a short illness. You find a memory of him on page 10.

Stefano Beretta

ESIS FINANCIAL SITUATION

First of all I would like to thank ESIS President, Emmanuel Gdoutos, and the vice-Presidents, Leslie Bank-Sills and Andrzej Neimitz, for the confidence they shown to me in confirming as ESIS Secretary and Treasurer. ESIS Members increased in the last five years from 105 in 2003, 313 in 2004, 354 in 2005 and 525 in 2006. This increment was due to the activity of the ESIS National Representative, to whom goes my gratitude. 14 Nations have set their National Group and helped the Central Office in collecting the fees.

The ESIS portfolio at the end of 2005 arrived close to 100000 euro. In order to support our colleagues from Eastern Europe, ESIS gave 25000 euros to contribute in increasing the participation from all parts of the Continent. The ESIS deposit in May 2007 is equal to 89223 Euro, including 12750 Euro that ESIS received for participating in the Pilot Project Proposal ILTOF – (Innovative Learning and Training On Fracture).

I hope to see you during the next conference in Brno (Czech Republic) which will be the most important event for ESIS.

Giuseppe Ferro

ESIS 2007 Membership

good reasons for renewing your ESIS membership:

- a free copy of an ESIS procedure;
- a paper copy of ESISNewsletter;
- access to TC documents and activities;
- your support to ESIS.

how to renew?
see page 35-36

ECF17 Conference

http://ecf17.fme.vutbr.cz/

Brno,
September 2-5 2008

ESIS Website

www.esisweb.org

Newsletter and Invited papers to be downloaded

ESIS COUNCIL MEETING
5th July 2006, 18.00 – 19.30

Egnatia Hotel
ALEXADROUPOLIS, GREECE

Agenda
1. Introduction and Communications
2. ESIS Membership
3. National Groups
4. Financial Report
5. Technical Committees
6. ECF17 (Czech Republic)
7. ECF18 (Organiser/Location to be decided)
8. ESIS Awards
9. Election of the two ESIS Vice-Presidents 2006-2010
10. Election of ESIS President 2006-2010

Attendees
Twenty-one Countries and ten ESIS Technical Committees were represented at Council, which was composed of 43 Members.
A full list of attendees is given at the end of these Minutes.

1. Introduction and Communications
This Council Meeting was held during the week of the 16th EUROPEAN CONFERENCE ON FRACTURE (ECF16), in Alexandroupolis.
The President of ESIS, Professor Alberto Carpinteri, chaired the meeting.
He informed that during the last two years the following activities have been organized or coorganized by ESIS:

- International Conference on Crack Paths CP 2006, September 14–16, 2006, Parma, Italy
- Conference on Multiaxial Fatigue and Fracture ICMFF8, June 10-14, 2007, Sheffield, UK
- 6th International Conference on Fracture Mechanics of Concrete and Concrete Structures & Post-Conference Workshops FraMCoS-6, June 17-22, 2007, Catania, Italy
- 13th International Conference on Experimental Mechanics, July 1-6, 2007, Alexandroupolis, Greece
- ICF12 Ottawa (Canada) 2009
- ICF13 Beijing (China) 2013.

The President postponed further communications to the following specific points.

2. Esis Membership
The Secretary, Professor Giuseppe Ferro, reported the figures of the ESIS Members who sent the membership form to the registered office during the last four years. ESIS registered 105 in 2003, 313 in 2004, 354 in 2005, while for 2006 the members are (up to June) more than 500.
The strong increment in the number of ESIS Members is an indicator of the validity of the Federal Model adopted recently.

3. National Groups
The Secretary informed the Council about the situation of the National Groups.11 Nations published material on ESIS web site: Bulgaria, Croatia, Czech Republic, France, Italy, Romania, Russia, Serbia, Slovak Republic, Sweden, Ukraine. 17 Nations (Austria, Bulgaria, Czech Republic, Croatia, France, Germany, Greece, Italy, Poland, Romania, Russia, Serbia, Spain,

Sweden, Switzerland, UK, Ukraine) have used 2/3 of ESIS Membership for national group organization.
From 2006 the membership will be connected with the ECF Conferences.

4. Financial Report
The Treasurer, Professor Giuseppe Ferro, informed the Council about the financial situation of theSociety.
The figures are the following (in Euro):

ESIS Deposit in March 2005	94635,59
EXPENSES FOR 2005-06	
Postal	1600,00
Secretariat (redaction of web site, collaborators, bank,etc.)	4000,00
Web site	1600,00
Newsletter	2400,00
Contribution to ECF 16	25000,00
TOTAL EXPENSES	34600,00
INCOMING	
ESIS Membership 2005 (350 members)	3500,00
Royalties Elsevier	10000,00
TOTAL INCOMING	13500,00
New ESIS Deposit in June 2006	73535,59

The new ESIS' Portfolio consists of 73535,59 €.
The Assembly approved the report unanimously.

5. Technical Committees
Prof. Stefano Beretta briefly reported to the Council about the "some news from TC's":
i) TC2 will be re-established under the chair of Prof. Pokluda;
ii) TC12 has just held a very successful meeting (in terms of participation and contributions) in London;
iii) there has been no interest in re-launching the activity of TC19 ('Structural Health Monitoring') that therefore will be definitely closed;
iv) TC24 has elected new chairmen, namely Prof. R. Smith (Imperial College, UK) and Prof. U. Zerbst (GKSS, Germany).
About TC7, Prof.Francois gratefully acknowledged the support of ESIS to attend ECF16 where he was having contacts with other TC Chairmen in order to update the ESIS Nomenclature (following the decision taken by the Council in Turin).
About TC9, Prof.Karihaloo illustrated the recent results of TC9 in terms of a compendium about Fracture of Concrete Structures that had been submitted to Elsevier for pubblication as an STP. Considering that the main goal of his chair has been achieved, Karihaloo expressed his intention to resign from TC9 Chair and that TC9 has already approved the new appointment to Prof. Jan van Mier. Carpinteri thanked Karihaloo for his effort in achieving such an important publication, that will be part of the ESIS editorial activity within the agreement with Elsevier.
About the Newsletter, Beretta briefly re-called the difficulties in obtaining TC reports for the Newsletter, whose production had been delayed up to the beginning of June. Such difficulties are also reflected by the fact that the Calendar of TC meetings is no longer appearing in Elsevier Journals.
About the website, the same situation (lack of information from TC Chairmen) has been affecting its content. The problem is also that only a few TCs maintain their own homepage.

6. ECF 17 (CZECH REPUBLIC)
Professor Pokluda presented the organization of ECF 17 to the Assembly.
The 17th EUROPEAN CONFERENCE ON FRACTURE (ECF17) with the title "Multilevel Approach toFracture of Materials, Components and Structures", will be held in Brno, Czech Republic on September 2 - 5, 2008.
The web site of the conference is: http://ecf17.fme.vutbr.cz/.
The General Chairmen are: Jaroslav Pokluda (Brno University of Technology) and Petr Lukas (Institute of Physics of Materials).
ECF17 will be held at the Faculty of Mechanical Engineering, Brno University of Technology, Technická 2, Brno, Czech Republic.
As for the preceding conferences, ECF17 will focus on all aspects of fracture of engineering materials, components and structures. A special emphasis will be given to a multiscale investigation of damage processes on atomistic, mesoscopic and macroscopic levels. Thus, the conference topics will focus on the following fields:
Different level of approaches to fracture analyses: fracture at atomistic and molecular scales, mesomechanics, micromechanics and macromechanisms of fracture, linear and nonlinear fracture mechanics etc. Physical aspects of fracture: brittle fracture, ductile fracture, fatigue, fretting fatigue, mixed mode fractures, creep, temperature and environmental effects, strain rate effects etc.
Advanced engineering materials in the service: metals, ceramics, polymers and their composites, smart materials and structures, biomaterials, nanostructured materials, etc.
Structure and component integrity topics: probabilistic approaches to fracture, reliability and life of components and structures, failure analysis and case studies, scaling and size effects, damage mechanics etc.
The conference will comprise invited lectures together with contributed oral and poster

presentations covering the above mentioned topics.
The Assembly approved the proposal unanimously.

7. ECF 18 (organiser/location to be decided)
The President informed that two Nations (UK and Germany) manifested the intention to organise ECF 18, to be held in 2010 and prepared the formal documented bids. It had been agreed that UK (London) would make the first presentation. The Delegates from Germany then left the Council Chamber and the Delegation from UK made a full presentation to Council followed by wide-ranging questions. The Delegation from UK then left the Council Chamber and the Delegates from Germany (Dresden) returned and made a full presentation to Council followed by wide-ranging questions. The Delegation from UK then returned to the Council Room and by agreement of Council the voting process was commenced.
The result was the following:
UK 10 Votes
Germany 20 Votes
The decision of the ESIS Council was thus announced formally: the EIGHNTEENTH EUROPEAN CONFERENCE ON FRACTURE-ECF18 will be held in Dresden, Germany, on September 2-6, 2010 under the Chairmanship of Professor Meinhard Kuna and of Professor Michael Schaper.
This was approved with appreciation to both candidatures.

8. ESIS AWARDS
Professor Emmanuel Gdoutos, Chairman of the Awards Committee, was pleased to announce that his tasks were satisfactorily completed following lengthy discussions with his committee members, and that Awards, Medals and Certificates would have been presented at the Banquet of ECF16 on Thursday.
The ESIS Medals and Awards for 2006 were as follows:
THE GRIFFITH MEDAL & CERTIFICATE
Professor Bhushan Karihaloo
THE WÖHLER MEDAL & CERTIFICATE
Professor Robert Ritchie
AWARD OF MERIT
Professor Andrzej Neimitz
HONORARY MEMBERSHIP
Professor Leslie Banks-Sills

9. ELECTION OF THE TWO ESIS VICE-PRESIDENTS 2006-2010
Professor Andrej Neimitz and Professor Leslie Banks-Sills were elected unanimously to the posts of Vice-President, after being nominated by Professor Alberto Carpinteri (Proposer) and Professor Bushan Karihaloo (Seconder).

10. ELECTION OF ESIS PRESIDENT 2006-2010
Professor Emmanuel Gdoutos, organizer of an excellent and outstanding ECF conference, was elected unanimously to the post of President, after being nominated by Professor Alberto Carpinteri (Proposer) and Professor Leslie Banks-Sills (Seconder).
The meeting was closed at 19.30 hours.

Attendees At Council Meeting

Austria	Loibngger (Voting member), Major
Bulgaria	Angelova (Voting member)
Canada	David Taplin
Croatia	Jalasha (Voting member)
Czech Republic	Pokluda (TC2 Voting member), Dlouhy (Voting member), Sandera
France	Petit (Voting member), Francois (TC7 Voting member)
Germany	Kuna (Voting member) Dieztel (TC10 Voting member)
Greece	Gdoutos (Voting member)
Hungary	Lenket (Voting member)
Ireland	David Taylor
Israel	Banks-Sills (Voting member)
Italy	Carpinteri, Ferro (Voting member), Beretta (TC20 Voting member), Spagnoli (TC3 Voting member)
Poland	Neimitz (Voting member)
Romania	Marsavina (Voting member)
Russia	Goldstein (Voting member)
Serbia	S.Sedmak (TC13 Voting member), A.Sedmak, Sumarac, Radovic, Ognjanovic, Ravik (Voting member), Milovic, Marskovic (TC 12 Voting member), Dogan (TC11 Voting member)
Slovakia	Cacko (Voting member)
Slovenia	Gubeliak (Voting member)
Spain	Meizoso (Voting member)
Switzerland	Brunner (Voting member), van Mier (TC9 Voting member)
UK	Flewitt, Barton, Truman, Karihaloo (Voting member), Williams (TC 4 Voting member)
Ukraina	Panasjuk (Voting member), Nyicyforchyn

OPENING CEREMONY OF ECF16

Distinguished Guests, Friends, Ladies and Gentlemen,
A few times before, I addressed you in English even though English is not my native language. Not being a polyglot, I would like to address you orthophonically in Greek, my native language. However, if I addressed you in Greek it would be Greek to all of you.

I found out, however, that I could make a brief euphonic, orthological, orthoglossic and orthographic address in Greek which would still be English to everybody by using, with the exception of articles, prepositions and the auxiliary verbs "to be" and "to have," only words of Greek origin.

I would like to express my gratitude to my good friend Isaac Daniel for his kind advice during the preparation of this address, and to my wife Maria who provided me with many English words of Greek origin she has been collecting for years. I will be using many of these words in this address.

In the panegyric of this epicentral episode in the history of the European Symposia of Schisms (ECFs) in this halcyon, aesthetic, euphoric, and idyllic atmosphere, homologate me, according to the protocol, to eulogize synoptically from this bema, this pompous synod, even though, I am not a logologist, logomaniac, philologist, anthologist, etymologist, lexicologist, grammatologist, neologist, polylogist, macrologist, logolatrous, logophiliac, or logodeadalist, but only an autodidact.

On behalf of those who organized this symposium with hyperbolic enthusiasm and zeal, the eugenic, generous and theistic Hellenes and the sympathetic, eudaemonist, philoxenist, xenodochial, and xenophile Thracian autochthons, I emphasize my Eucharist to my homologues, the academics, neophiliacs, noetics, talented, epiphanous, dynamic, charismatic, and energetic protagonists of this periodic, pancosmic, technical, pedagogical, epistemic, orphic, gastronomic, terpsichorean, Bacchic, phantasmagoric, amphictyonic and Amphitryonic symposium.

The irenic, monastic, paradisial, Olympian, Arcadian and exotic atmosphere of this panoramic, georgic, bucolic, hyperborean Hellenic polis of Alexandroupolis with its tantalizing, sirenic, adonic, narcissistic, erotic, Aeolian, Polynesian Aegean archipelago, famous for its diaphanous, ethereal Uranus, aromatic atmosphere, chimerical, idyllic and polychromatic scenes, its archaeological character, mythological heroes, archaic myths, its Thracian autochthons and its paleontological history, is ideal for this academic symposium.

I emphasize my euphoria, euthymia and ecstasy for this pancosmic, plethoric, phantasmagoric, enthusiastic, antaean, cyclopean, poly-ethnic and dynamic synod in this amphitheater. I eulogize our patrons and the Hellenic and pancosmic organizations under the aegis of which this ecumenical symposium is organized.

Schisms are the genesis of catastrophes. The scope of this symposium is to analyze the genesis and exegesis of schisms, deleterious or not, and emphasize methodologies for the prognosis and prophylaxis from catastrophes, whose cost is astronomical, by authentic, systematic, logical, didactic, encyclopedic, Herculean, economical, ecological, and epistemic analyses. A paradigm of a schism is the seismic phenomenon.

For the diagnosis of schisms and prognosis of catastrophes a plethora of drastic criteria has been hypothesized. Some of them dichotomized the academia. Without being a prophet or a Cassandra, I emphasize that no criterion is a panacea for all problems.

Parenthetically, I had logomachies with other academics about the criteria, beyond my idiosyncrasy. I have emphatically, categorically, caustically, criticized, even stigmatized, with no empathy, the empiricism on which many criteria are based. Without being a utopian, I emphasize that a synergetic, and syllogistic harmonization, with no schism, or skepticism, between theory and praxis is basic.

Griffith, the patriarch of the mechanics of schisms, analyzed heuristically the oxymoronic, paradoxial and mysterious character of catastrophic phenomena by a methodology based on thermodynamics. The problem of the mechanics of schisms is synthetic and poly-parametric and is analyzed synergistically by the axioms of mechanics, kinematics, dynamics, mathematics, physics and chemistry.

Our epoch is characterized by cataclysmic and plethoric technological gnosis and the zeal and pathos to emphasize methodologies, without acrobatisms or hypocrisy, for the exegesis of the genesis of schisms at the macrocosm, microcosm and nanocosm or the categories of macro, micro and nano.

Schisms can be tele-diagnosed by non-catastrophic methodologies. Pragmatists have the dynamism to programme in manyparadigms therapeutic practices hierarchically, in

synergyand harmonization with economical ideas, for the prophylaxis from catastrophes.

This symposium is characterized by eurhythmy and eutaxy. Its spheroid and polymorphic program of a plethora of topics is categorized into 186 Procrustean, Spartan synods.

The scope of the organizers of ECF16 is, besides its technical program, to be a catalyst toward genesis of polymorphic, harmonized, even antagonistic ideas, hypotheses, theories and dogmas through esoteric, enthusiastic, didactic, harmonized, gnostic, dynamic, orthologic, polyphonic, analytic, democratic, non-egocentric, methodical and, even, logomachic dialogues and Socratic elenchus.

In my epilogue of this laconic atypical prolegomenon, I apologize for my eccentric, unorthodox Hellenic rhetoric and my lexical and etymological hyperboles. I emphasize my Eucharist for stomaching me, for having tyrannized you with my Hellenic phraseology. The scope of my rhetoric is not demagogic; it is to emphasize with didactic deontology, a paradigm of the dynamism of the Hellenic logos.

To epitomize, in my exodium, it would be my paraleipsis if I would not emphasize hierarchically my encomium to the stentorian, orthophonic, euphonic, charismatic, hieratic, and lyric rhetoricians of this synod and the anonymous heroes, behind the scenes of this symposium.

If you are nostalgic for Alexandroupolis, I hypothesize you will be here again in 2007 for the Pan-cosmic Symposium of Practical Mechanics (ICEM13). It is my thesis that ICEM13 will be as phantasmagoric, dynamic and colossal as this European Symposium of Schisms (ECF16).

E.E. Gdoutos
ESIS President 2006-2010

ESIS AWARDS 2006

In connection with the ECF-16 conference ESIS President conferred the ESIS Awards.

THE GRIFFITH MEDAL
Professor Bhushan Karihaloo
"For his outstanding research in the field of theoretical fracture mechanics and fracture of quasi-brittle materials, in particular of concrete, fibre-reinforced cementitious composites, and advanced tough ceramics"

Bhushan Lal Karihaloo received his BE degree with First Class Honours and Gold Medal from the University of Ranchi, MTech in Structural Engineering from the Indian Institute of Technology, Bombay, PhD from Moscow Civil Engineering University, and DEng from the University of Sydney. Prior to his present appointment, he has held chairs at the University of Newcastle, NSW, the University of Sydney, and Aalborg University, Denmark, besides visiting appointments at Northwestern University, Oxford University, Essen University, Germany, The Technical University of Denmark and The EC Center of Excellence on Advanced Materials,Warsaw.

He is the owner of a British patent on CARDIFRC, has authored two books on fracture mechanics of concrete and ceramics, co-edited 11 books on structural optimisation and integrity, and written nearly 400 technical papers in refereed journals and proceedings. He is the co-editor-in-chief of the 10-volume Comprehensive Structural Integrity, published by Elsevier in 2003 which received the Best Engineering Reference award from the American Society for Engineering Education in 2004.

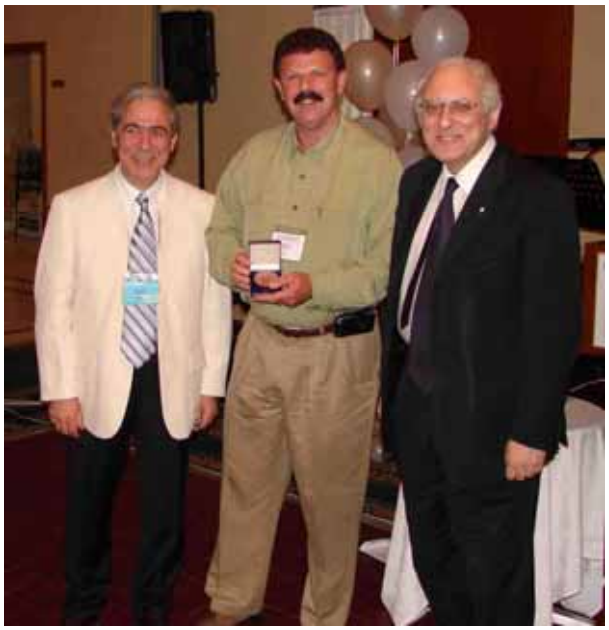
He is a member of the editorial boards of nine international journals, and an Associate Editor of the journal of Mechanics of Materials and of The International Journal of Fracture.

He is an Honorary Member of the Czech Society of Mechanics of the Czech Academy of Sciences since 1989, and an Honorary Fellow of the International Congress on Fracture since 2001.

He is Vice-President of the International

Congress on Fracture (ICF), chair of the Royal Society UK National Panel for Theoretical and Applied Mechanics, member of the Congress Committee of the International Union of Theoretical and Applied Mechanics (IUTAM), and Chairman of Technical Committee 9 on Fracture of Concrete of the European Structural Integrity Society (ESIS).

THE WÖHLER MEDAL
Professor Robert Ritchie
"For his outstanding research to the understanding of fatigue crack growth behavior"



Robert O. Ritchie is the H.T. & Jessie Chua Distinguished Professor of Engineering, and Chairman of the Department of Materials Science & Engineering at the University of California, Berkeley. He is also Senior Faculty Scientist and Head of Ceramic Materials in the Materials Sciences Division of the Lawrence Berkeley National Laboratory, and a member of the University of California San Francisco/University of California Berkeley Bioengineering group. He received a B.A. degree in physics and metallurgy in 1969, the M.A. and Ph.D. degrees in Materials Science in 1973, and the Doctor of Science (Sc.D.) degree in 1990, all from Cambridge University. Following periods as the Goldsmith's Research Fellow in Materials Science at Churchill College, Cambridge (1972-74) and as a Miller Research Fellow at the University of California in Berkeley (1974-76), he was an Assistant Professor and then the Class of 1922 Associate Professor in Mechanical Engineering at M.I.T. (1977-81). In 1981, he returned to Berkeley where he has been Professor of Materials Science since 1982; he was also Deputy Director of the Materials Sciences Division at the Lawrence Berkeley Laboratory (1990-94), and Director of the Center for Advanced Materials there from 1987 to 1995. Dr. Ritchie is well known for his research in the fields of materials science, fracture mechanics and particularly fatigue, having authored or co-authored over 550 papers and edited 17 books in the technical literature. He is a Member of the National Academy of Engineering in the U.S. and a Fellow of the Royal Academy of Engineering (FREng) in the UK. He was President of the International Congress on Fracture (ICF) from 1997-2001, and is a Fellow of ICF, TMS, the Institute of Materials, the Institute of Physics, and the American Society for Materials.
E-mail: roritchie@lbl.gov

AWARD OF MERIT
Professor Andrzej Neimitz
"For his outstanding contributions to the field of fracture and his work devoted to the advancement of the European Structural Integrity Society"

Prof. Andrzej Neimitz is the Professor of Kielce University of Technology (KUT) and the chairman of the Fundamentals of Machine Design Chair in the Mechatronics and Machine Design Faculty. He was the Rector of the KUT (1990-1996)and the Dean of the Mechanical Engineering Faculty (1987-1990). He received the MSc diploma (1971) from the Academy of Mining and Metalurgy, Cracow, PhD degree (1976) from KUT, DSc – habilitation degree (1986) from the Institute of Fundamental Research Problems of Polish Academy of Sciences and the Title of Professor (1995)-

national title. He published 125 papers in the field of Fracture Mechanics on the topics: fast crack growth, fracture in the creep conditions, hydrogen assisted cracking, subcritical crack growth, in- and out-of-plane constraint, structural integrity analysis. He received the IREX scholarship to visit the Northwestern University, Evanston, USA for seven months (1979-1980), spent twenty months at Michigan Technological University, Houghton, USA as a visiting professor (1984,1985), visited EMPA, Dubendorf for six weeks as an international research fellow (1989) and he spent six weeks at Imperial College, London receiving the Tempus scholarship. He has been a member of the Committee of Mechanics of the Polish Academy of Sciences since 1987, the President of Polish Group of Fracture since 1987. He is a member of Council and Vice-president of ESIS; in the past he was a member of Nomination Committee and Award Committee. He was a chairman of many Organizing and Scientific Committees of national and international scientific conferences; among them he was the Co-chairman of ECF 14. He is a member of Associate Editorial Board of Journal of Materials Science and Technology of Bulgarian Academy of Sciences as well as the member of Editorial Boards of: Physicochemical Mechanics of Materials - Journal of Ukrainian Academy of Sciences, International Journal of Pressure Vessels and Piping, Engineering Transaction - Journal of Polish Academy of Sciences- till 2003, The Archives of Mechanical Engineering - Journal of Polish Academy of Sciences, Przeglad Mechaniczny – Polish national journal for engineers and researchers.

HONORARY MEMBERSHIP
Professor Leslie Banks-Sills
"For her many valuable contributions to the field of fracture mechanics and for her good service to the international fracture mechanics community".

Leslie Banks-Sills is a Professor at Tel Aviv University in the Department of Solid Mechanics, Materials and Systems where she directs the Dreszer Fracture Mechanics Laboratory. She received an M.Sc. degree in applied mechanics from the University of Michigan in 1973 and a Ph.D. degree in engineering in 1977 from Harvard University. After post-doctoral work at Brown University, she joined the staff at Tel Aviv University in 1979.

Since 2001, she is an Adjunct Professor in the School of Civil and Environmental Engineering at Cornell University. She has consulted for many industries including NASA, the Israel Armed Forces, and Israel Aircraft Industries. For eight years, she served as the Chair of her department at Tel Aviv University. She serves on the Executive Committee of the International Congress of Fracture and was recently elected as one of the Vice Presidents of ESIS. She is an Honorary Fellow of the International Congress of Fracture, received the Hanin Prize from the Technion in 2006 for outstanding work in aeronautical engineering and is an Honorary Member of ESIS. She currently holds the Lise Meitner Chair at Lund University in Sweden. Her research interests include analytical, numerical, and experimental aspects of fracture mechanics focusing, particularly, on metals, composite and anisotropic materials, as well as interface fracture. She has guided 33 graduate and post-graduate students and published over 75 papers in international journals. You may view her web page at: http://www.eng.tau.ac.il/~leslie.

OBITUARY OF PROF. JOHN C. RADON

PROF. John C. Radon

Dr John C. Radon died in London on May 4th 2007 after a brief illness. John came to England from the then Czechoslovakia some years after World War II. He already held a first degree in engineering and joined the Mechanical Engineering Department, Imperial College, London, in the early 1960s to undertake research. He studied low cycle fatigue of cast irons at elevated temperature under Peter Benham (now deceased) and obtained his Ph.D. in 1966.

He then worked with Cedric Turner on many aspects on the then emerging subject of fracture mechanics, including instrumented impact testing, some early applications to low or medium strength steels and later, together with Turner and Webster, on creep crack growth in aluminium alloys, developing the British version of what became known from the U.S.A. as C* [asterisk]. In 1980, under the auspices of the then European Fracture Group (now European Structual Integrity Society) he conducted the Third Colloquium on 'Fracture & Fatigue, Elasto-plasticity, Thin Sheet and Micromechanisms Problems' at Imperial College and then edited the proceedings.

John had a very catholic interest in fracture at both micro- and macro- level, working with others on fracture and fatigue crack growth of several polymers, acoustic emissions during crack growth in steel, environmental effects on growth rate and test methods for, and effects of, biaxiality of loading.

For this last, working with Patrick Leevers, they collected a most unusal citation, leading to perhaps more lay readers becoming aware of fracture that from any other paper; it was a reference to their work on biaxiality in aircraft alloys in the bestselling novel 'Airframe' by Michael Crichton (he of Jurassic Park fame etc.). Leevers and Radon toyed with publishing 50,000 copies of their paper for avid readers to learn more of their topic but did not pursue the idea!

John worked with colleagues from many countries including Brazil, Canada, China, Hungary, Portugal and the then Yugoslavia. He became a friend of Dr. Ferenc Gillemot in Hungary and Professor Stojan Sedmak in Yugoslavia. Until the end he kept up his contacts with European colleagues, writing papers on various aspects of fatigue including four with Dr Z. Knesl in 2003/4, leading a seminar at Brno in 2004 and a last paper in 2006 for Professor Sedmak's conference on fatigue.

John was well known on the international fracture circuit, with his courteous and urbane manner a legacy of his central European upbringing. Together with his wife Joyce he gained a reputation as the 'fracture host of London' . He will be missed and remembered by his many colleagues and friends.

TC ACTIVITIES

TC2 - Micromechanisms
TC3 – Fatigue of Engineering Materials and Structures
TC4 – Polymers and Polymer Composites
TC5 – Fracture Dynamics
TC7 – Nomenclature
TC9 – Concrete
TC10 – Environmentally Assisted Cracking
TC11 – High temperature mechanical testing
TC12 – Probabilistic Interpretation of Mechanical Property Data
TC20 – Role of Defects and Inclusions
TC24 – Integrity of Railway Structures

ESIS TC2 "Micromechanisms"

MINUTES OF THE FIRST MEETING OF RECONSTRUCTED TC2, ALEXANDROUPOLIS, JULY 4, 2006

Present: Prof. Jaroslav Pokluda (CZ), Prof. Reinhard Pippan (A), Prof. A. Shaniavskiy (RU), Prof. Otmar Kolednik (A), Dr. Yannick Champion (F), Dr. Alexander Hartmaier (D), Dr. James Marrow (UK), Dr. Ivo Dlouhy (CZ).
Excused absence: Prof. Hans-Jürgen Christ (D).
Guest: Prof. Stefano Beretta (ESIS executive).

Agenda:
1) State of the Art of TC2 ESIS.
2) Reactivation and reconstruction of TC2.
3) Discussion concerning purpose, efficiency and outputs of TC2 meetings.
4) TC2 meetings in the future.
5) Conclusions.

Ad 1) + 2):
Prof. Stefano Beretta briefly outlined the long-term problem with the Technical Committee on Micromechanisms (TC2), ESIS. According to the decision of ESIS Officers the TC2 should be restored to become more active. Prof. Pokluda, as a designated chairman of TC2, was asked to start the process within the frame of the symposium on Micromechanisms during the ECF 16. Therefore, the chairmen of this symposium, Prof. Pokluda and Prof. Pippan, decided to address some European scientists to take a part in a short meeting concerning that matter. The ESIS council in Alexandroupolis (Wednesday, July 5) should confirm the re-establishment of TC2 following the results of the first TC2 meeting.
Prof. Pokluda presented some suggestions concerning the future work of TC2. The members should meat at least once in a year at seminars devoted to micromechanisms in Fracture and Fatigue. The meetings should be organized by TC2 members in various European countries. All future ECF conferences are to be considered to be natural venues of TC2 meetings. Special issues of Int. J. Fract., Engng. Fract. Mechanics and Engng. Fail. Analysis could appear as proceedings of individual meetings. The first meeting should be related to the MSMF 5 conference in Brno, June 27.-29, 2007.

Ad 3) + 4):
Prof. Kolednik emphasized that TC2 meetings should be devoted to limited special problems in the field of micromechanisms to achieve sufficiently rich and competent discussions. He expressed a willingness to organize the TC2 meeting in Leoben in spring 2008. Both suggestions were found to be very constructive and were accepted by all participants. According to Prof. Shaniavskiy, Moscow could host one of the next TC2 meetings as well (accepted with pleasure). Prof. Beretta confirmed the possibility to transfer as much as a half of financial resources coming from Elsewier (grants for production of special issues) to organizers of the TC2 meetings in order to support attendance of PhD students and young scientists.

Ad 5):
The participants unanimously agreed with the following conclusions of the first TC2 meeting:
(i) The TC2 was successfully re-established (chairman Prof. J. Pokluda).
(ii) The next meetings of TC2 will be held in Brno (June 2007), Leoben (spring 2008) and again in Brno (ECF 17, September 2008). The organizers will attempt to produce special issues of IJF, EFM or EFA devoted to TC2 meetings.

Additional note:
The re-establishment of TC2 was officially confirmed at the ESIS council meeting in Alexandroupolis, July 5, 2006.

ESIS TC3 "Fatigue Of Engineering Materials And Structures"

1. ACTIVITIES DURING 2006
(a) Professor Cetin Morris Sonsino (Darmstadt), Professor H. Zenner (Clausthal-Zellerfeld), Professor Andrea Carpinteri (Parma), Professor Les P. Pook (London): **Guest Editors of a Special Issue** of the **"International Journal of Fatigue (IJF)" (ESIS Special Technical Publication),** under the title "Multiaxial Fatigue and Fracture", with 26 papers selected from those presented at the 7th International Conference on Multiaxial Fatigue and Fracture (ICBMFF 7), held in Berlin in June 2004. Such a

Special Issue of IJF has been published as Issue Nos 5-6, Volume 28, 449-674, 2006.
(b) Professor Andrea Carpinteri (Parma) and Professor Les P. Pook (London): **Chairmen of the 2nd International Conference on "Crack Paths** (**CP 2006)"**, held in Parma, Italy, Thursday 14th to Saturday 16th September, 2006.

2. PRESENT AND FUTURE ACTIVITIES
(a) Professor Andrea Carpinteri (Parma), Professor Les P. Pook (London) and Professor Andrea Spagnoli (Parma) : **Guest Editors of a Special Issue** of the **International Journal "Engineering Fracture Mechanics",** under the title "Crack Paths", with papers selected from those presented at the International Conference on "Crack Paths (CP 2006)", held in Parma, Italy, Thursday 14th to Saturday 16th September, 2006.
(b) Dr Upul Fernando (Sheffield Hallam University, Sheffield), Professor Mike W. Brown (University of Sheffield, Sheffield), Dr Brian Tomkins (AEA Technology PLC): **Chairmen of the Eighth International Conference on Multiaxial Fatigue and Fracture (ICMFF 8, http://www.icmff8.org.uk),** to be held in Sheffield, 10th to 14th June, 2007, under the auspices of ESIS.
(c) Professor Andrea Carpinteri (Parma) and Professor Les P. Pook (London): **Chairmen of the 3rd International Conference on "Crack Paths (CP 2009)",** September 2009.

ESIS TC4 "Polymers And Polymer Composites"

1. ONGOING ACTIVITIES
TC4 met twice during 2006, continuing their work on many of the existing project areas. In addition, polymer cutting and scratch testing have been proposed as new work areas for the committee. Test protocols for these test methods are under development.
Ongoing work areas include mode I delamination at high test rates, quasi-static mode II delamination in composites and structural adhesive joints, the peel testing of structural adhesives using 90 degree peel, T-peel and the mandrel test, J-crack growth resistance testing of polymers, high rate testing of polymers at greater than 1m/s, the essential work of fracture method, impact testing of short fibre composites and delamination fatigue.

2. FUTURE MEETINGS
In 2007, the committee will meet on the following occasions:
23rd -25th May 2007 (Regular TC4 Committee meeting): Les Diablerets, Switzerland.
17th-19th October 2007 (Regular TC4 Committee meeting): Les Diablerets, Switzerland.
In 2008, the 5th International Conference on Fracture of Polymers, Composites and Adhesives will be held in Les Diablerets, Switzerland from 7th-11th September 2008. www.tc4pca.elsevier.com
(Deadline for the submission of abstracts is 2nd November 2007).

ESIS TC5 "Fracture Dynamics"

The activities of TC5 include the exchange of expertise in all aspects of impact fracture and high-strain rate material properties, and the development of agreed test methods in these fields, leading to ESIS or International standards. TC5 members work closely on standards issues with Dymat and with the relevant ASTM E08 and E28 committees. New committee members are always welcome.

TC5 has about forty active members. It normally meets for one or two days, twice per year at varied European locations, with around 15 members normally attending, although lately numbers have been reduced. The following meetings were held recently:-
October 2006 – Fraunhofer Institute IWM, Freiburg, Germany
April 2007 - Corus Steel, Rotherham, UK
The next meeting is planned for October/November 2007, with the venue to be finalised.

It has now been agreed that our test procedure on sub-size Charpy V will be added as an annex to the instrumented Charpy method ISO14556, also developed by TC5. The recently-finished pre-cracked Charpy test method has been accepted as work item ISO WD 26843 by ISO TC164 and is making satisfactory progress towards full standard status. TC5 member Enrico Lucon of SCK/CEN Belgium has been very helpful in monitoring progress at ISO committees.

The round-robin on high-rate tensile testing of sheet materials was completed some time ago, and the programme is continuing with comparisons of data analysis techniques. TC5 members were also closely involved in developing the new German standard SEP1230 high-rate test method for sheet steels for the automotive industry, and are following this through with the ISO committee that is currently working on this topic. Hopefully some aspects of our ESIS procedure on dynamic tensile testing P7-00 can also be included.

The work on impact compression is progressing well, with a successful round-robin on aluminium alloys in 2005/06; we are now starting a new round on armco iron.

A number of new work initiatives are planned and under discussion. Several TC5 members attended the successful Dymat conference in Dijon in September 2006, and the chairman continues to serve on the Dymat Governing Board.

The current officers of TC5 are:
- chairman - Hugh MacGillivray, Imperial College London, UK [h.macgill@imperial.ac.uk]
- vice-chairs - Gyongyver Lenkey, Bay Zoltan Institute, Miskolc, Hungary [lenkey@bzlogi.hu] and Uwe Mayer, MPA Stuttgart, Germany [Uwe.Mayer@mpa.uni-stuttgart.de]
- secretary – Celia Watson, RMCS [c.h.watson@cranfield.ac.uk].

ESIS TC7 "Nomenclature"

The activity of TC7 was re-launched at ESIS Council. TC Chairmen are invited to send a revision of nomenclature to Prof. Francois within 2007.

ESIS TC9 "Concrete"

The activity of TC9 devoted to the production of a Compendium of Concrete Design which has been submitted to Elsevier for pubblication. New TC Chairman is Prof. Van Mier, former secretary.

ESIS TC10 " Environmentally Assisted Cracking"

1.Activity

For the 16th European Conference of Fracture, **ECF16**, the TC and its SC jointly organized a **Special Symposium on Environment Assisted Fracture**. The aim of this symposium was to bring together researchers involved in experimental and theoretical investigations of this failure phenomenon and to present talks that would address the state-of-the-art in the current understanding of corrosion and corrosion assisted cracking. The symposium comprised a full day session involving 18 contributions, and successfully fostered discussions on all aspects of environmentally assisted damage, degradation, and rupture processes. More contributions related to environmentally assisted cracking (EAC) problems were presented in a separate Track and in some of the Special Sessions.

In December, Dr. Giovanna Gabetta, co-chair of ESIS TC 10, took part in the 25th Annual Conference "**Corrosion Problems in Industry**", the silver Jubilee of Egyptian Corrosion Society (ECS), in Palmera Hotel, El Soukhna, Egypt. The conference saw a significant number of presentations in the field of corrosion, including presentations dealing with EAC problems, like failure analysis, SCC testing, and integrity of pipelines. On the occasion of this conference, it was discussed to start a cooperation network between ESIS TC 10 and the Egyptian Corrosion Society, which could be a bridge toward the corrosion experts in the North African area. As a first step, an ad-hoc group was established (participants: Layla A.Al-Juhaiman, Rabab M.El-Sherif, Giovanna Gabetta) with the aim of collecting case histories for a data base.

2. Future actions

TC10 is now planning to organize a meeting on "Knowledge management for EAC problems" with potential emphasis on "Case histories and their management". For this meeting, which is likely to be held in Fall 2007 in Italy, participants from the Mediterranean area will be invited in addition to the TC 10 members, so that it is likely to become the first meeting of a future ESIS TC10 / Mediterranean Network on corrosion/EAC problems.

ESIS TC11 " High Temperature Mechanical Testing"

Minutes of 51st Meeting, held on Friday 26th April 2006 at QinetiQ, Farnborough, UK.

INTRODUCTION & WELCOME

The Chairman, Mr McCarthy opened the meeting and especially welcomed Mr Colin Austin, (*Serco Assurance*), & Dr Kamran Nikbin, (*Imperial College*), who were attending their first meeting. A welcome was also extended to a number of observers who had attended the Working Groups held earlier in the day.
The business cards of the twelve members present and observers together with a list of apologies received/attendance were recorded. The following were present: Messrs McCarthy (*Chairman*), Austin, Burt, Barnard, Dogan, Hurst, Klingelhöffer, Loveday *(Secretary),* Nikbin, O'Grady, Skelton & Wisbey.

MINUTES OF PREVIOUS MEETING

The Minutes of the 49th meeting held on Friday 29th April 2005 at ALSTOM, Rugby and the minutes of the 50th meeting held on Wednesday 21st September 2005 , Berlin. Both sets of minutes, having previously been distributed via E-mail, were accepted as a corrected record.

MATTERS ARISING

Mr Burt reported that appropriate requests had been submitted to the relevant service providers to prove links to the HTMTC web site: www.htmtc.com . Mr Burt offered to upload the minutes of the April meetings and the presentations from the TMAN Temperature Measurement meeting which were supplied on a CD by the Secretary.

Mr Phil Jones agreed to investigate the possibility of taking over the role of webmaster due to changes in Mr Burt's work responsibilities.

CORRESPONDENCE

The Secretary reported that correspondence had been received from Companies House and the Charity Commissioners. The annual return for the Charity Commission will be completed and returned now that details of the accounts are available.

The annual return to Companies House was registered 'on-line' for the fee of £15. Additional paperwork will be forwarded when the Chairman's report and the audited accounts are available.

CHAIRMAN'S REPORT

The Chairman presented his annual report of the activities of the committee during the last year in the form off a Power-Point presentation. In his report the Chairman, highlighted the following:

a) the technical meetings 1) '***Welds 2005'*** held at GKSS, Germany in September 2) **TMF Workshop** held at BAM, Berlin, also in September and 3) the **Temperature Measurement Awareness Network (TMAN)** Symposium held at NPL in March 2006.

b) the activities of the **Weldments** & **Temperature Measurement Working Groups.**

c) ESIS – Prof Dogan was thanked for representing the HTMTC at the ESIS Council Meeting

d) The HTMTC sponsored the visit of delegates attending the ISO TC 164 Meeting to the Kirkaldy Museum in October 2005.

e) Members provided technical input to the Modulus Measurement meeting held at NPL in February 2006.

TREASURER'S REPORT

The treasurer, Mr Howard Burt, tabled copies of the annual accounts. The expenditure last year was £4,518 (*£1,212*) and the income was £9,582 (*£138*)—(*The figures for 2004 are shown in brackets*), resulting in a net gain for the year of £5,064 (-£1074). It was noted that the main income was provided by the TMF Workshop held in September 2005 together with the profit from the Data Generation meeting held in December 2004.The main expenditure was associated with the expenses of the TMF Workshop, travel expenses for Prof Carpinteri (*President of ESIS*), to attend the Welds 2005 meeting and Secretarial services. It was noted that further expenses from the TMF Workshop will be incurred when the Proceedings are published.

Adoption of the accounts, subject to approval by the independent examiner, was proposed by Prof R Hurst and seconded by Dr K Nikbin and accepted *nem con*. Four copies of the full accounts signed by the Examiner, Treasurer, Chairman & Vice Chairman will be forwarded to the Secretary for submission to Charities House as soon as possible.

It was reported that Barclays Bank had now insisted that the name of our account be changed from UKHTMTC to HTMTC to align with the registered name at Companies House; this had involved the Chairman & Treasurer in a considerable amount of administrative effort for a bureaucratic nicety.

ELECTION OF MEMBERS OF THE COUNCIL

In accordance with the Articles of Association of the High Temperature Mechanical Testing Committee and in accordance with the Minutes of the 15th Meeting of the Committee held on 18th October 1988, the following members of the Committee were due for re-election on a rolling three year cycle: B. Dogan; R. C. Hurst; H. Klingelhöffer & R. D. Lohr *[Prof Raymond Lohr has indicated that he will not seek re-election due to changes in work responsibilities, but wishes to remain a corresponding member.]*

In addition, Mr Phil Jones (ALSTOM) and Mr Ian McEnteggart (INSTRON Ltd)
were also nominated.

All of the above were proposed by Peter Skelton, seconded by Owen O'Grady and were elected *nem con*.

Other Changes in Membership

Following his retirement, Professor George Webster submitted his resignation from the committee in September 2005 and during the year Dr Kamran Nikbin was elected to represent Imperial College. In addition Ian Bretherton has moved to a new job with the NII, and Colin Austin was elected to represent Serco Assurance.

The Chairman agreed to write to Prof Webster to thank him for his valued contribution to the HTMTC since its inception in 1982.

ELECTION OF OFFICERS

The following officers were all elected *nem con*.

Chairman: Mr Paul McCarthy (Consultant)

Vice Chairman: Dr Hellmuth Klingelhoeffer (BAM, Berlin)

Treasurer: Peter Barnard (ALSTOM)

Secretary: Mr Malcolm S. Loveday

It was agreed that Peter Barnard would be appointed as a signature on the Bank Account, in addition to the Chairman and Secretary.

FUTURE HTMTC SEMINARS

Creep- Fatigue Interaction

The initial flier and call for papers for the IOM3 Meeting 'High Temperature Fatigue- Influences of Environment & Creep' had previously been circulated by E-mail by the Secretary. The meeting will be held on Tues / Wed 5th & 6th December 2006 at Carlton House Terrace, London. Although discussions had been held between the HTMTC Chairman and the representatives of the IOM3 Materials Committee [initially Mike Winstone (DTSL, Porton Down) and latterly Mike Henderson (ALSTOM)], it will not be a fully joint meeting since the HTMTC will not benefit by any profits or be responsible for any losses. It is unlikely that the registration fee will be kept low in line with other HTMTC Meetings since the IOM3 staff who are undertaking all the administrative organisation will need to cover their costs. Although the meeting will not specifically focus on testing techniques, nevertheless the meeting will probably be of interest to a number of HTMTC members. The Chairman agreed continue to liaise with Mike Henderson regarding possible speakers etc.

HT Materials Issues in Nuclear Fission and Fusion.

Prof. Roger Hurst confirmed that he and Dr. Peter Hähner, JRC-IE, Petten,
were willing to organise and host a seminar, possibly next spring/ autumn . The committee were endorsed for the suggestion and the organisers will be asked to map out a provisional programme, and forward it to the Chairman & Secretary for comment / circulation. Suitable dates need to be identified. There is a likely resurgence of interest in the nuclear option for power generation because of the minimal CO_2 emissions and their impact on global warming. This will introduce commensurate challenges for the improvement of testing techniques for the determination of reliable material property data for design of plant and life monitoring.

Other Future Meetings

The Secretary tabled a list of forthcoming meeting that may be of interest to HTMTC members. Attention was drawn to several meetings including a) **Small Specimen Testing- Methods & Analysis** to be held at the IMechE on 22nd May 2006, b) **ECF16 –16th European Congress on Fracture** to be held in Greece, 3rd – 7th July 2006,c) The **Malcolm McLean Symposium** to be held in London on 19th -20th April 2007 (***see Appendix 5***) , and d) **CREEP 2008** to be held in Bayreuth, Germany on 4th – 9th May 2008.

In addition it was noted that the following meetings were scheduled: a) the COST Material Conference at Liegè, on 18th – 20th September 2006, b) **ESIA8** on 24th – 25th October 2006 and c) **Fatigue 2007** was scheduled to take place at Cambridge on 26th – 28th March 2007.

DATES OF NEXT COMMITTEE MEETINGS

- **52nd Meeting –Thursday 19th October 2006 at NPL** Ad Hoc meeting to expedite urgent business. *To be held in conjunction with Temperature Measurement Working Group starting at 10.30am)*

53rd Meeting- AGM to be held on **Wednesday 18th April 2007** in London (at Imperial College or NPL), to be proceeded by Working Groups. *Note : The Malcolm McLean Memorial Symposium will be held*

ESIS TC12 "Probabilistic Interpretation Of Mechanical Property Data"

The ESIS Technical Committee TC12 is concerned with application of probability and statistical modelling to structural integrity assessments in general, and material property data in particular. To progress the TC12 activities a one day workshop was organised by TC12 in conjunction with the UK Forum for Engineering Structural Integrity (FESI) on 9th june 2006: the topic of the workshop was **"Using Probability Modelling in Structural Integrity Assessments"**.

The meeting was held in central London at the Royal Academy of Engineering. The workshop opened with a welcome to the 30 delegates pointing out that, in addition to the informed presentations and discussions, it was hoped to identify future topics for inclusion in the forward programme for TC12. A short introduction was given by Professor P E J Flewitt, chairman for the day, setting the background to this important area of probabilistic assessments for both the industrial and business communities across many sectors of transport, power generation, petrochemical, civil structures and aerospace.

A wide range of high quality presentations followed covering modelling of fracture toughness by different statistical techniques which include both the Master Curve approach and statistical analysis. In addition to these, presentations were given on modelling of creep crack growth, fatigue crack growth, evolution of pitting in stress corrosion cracking and use of partial safety factors in fracture mechanics. Each presentation was followed by a lively discussion highlighting the many challenges that remain to achieve broad acceptance and application of probabilistically based structural integrity assessments for structures and components. In the course of the concluding

discussion it was recognised that future topics to address would cover the use of computer simulations in modelling and application of probabilistic methods.

ESIS TC20 "Role of Defects and Inclusions"

A meeting of TC20 was held on 13th September '06 in Politecnico di Milano, Dipartimento di Meccanica (Milan, Italy) the participants of which were: Y. Murakami (Kyushu University), S. Beretta and F. Benzoni (Politecnico di Milano), J. Butler (Corus Group), D. Girodin (SNR Roulements), E. Henault (CREAS Ascometal)
F. Cirilli (CSM), E. Paravicini (Tenaris).

Round Robin #1 (Corus steel)
Murakami presents the results of measurements in his lab for the first round robin.
Beretta summarizes the results obtained in the first round robin by the different participants and the following discussion emphasizes the scatter of the results and the need of a confirmation by fatigue tests.
It is then agreed to write a journal paper presenting the results of this round-robin on a suitable journal in order to have the widest circulation of results. Some particpants (Cirilli, Henault) agree on carrying out a second series of measurements for estimating in-lab variability.

Round Robin #2 (Ascometal bearing steel)
Butler presents the results about automatical defect evaluation and the differences of CORUS measurements between 2005 and 2006 . **Girodin** then presents some results obtained on a bearing steel and **Henault** shows some interesting results obtained by simulations of measurements.

The following discussion pin-point that there is a big difference in image analysis results and classification of the different inclusion types. It is agreed to circulate a CD containing the images by the different participants in order to have a direct comparison of measurements.

Future events
Cirilli briefly describes the EVIR+ Project proposal presented at ECCS. It is agreed to prepare a joint paper about RR#1 for Spring 2007.

ESIS TC24 "Integrity of Railway Structures"

The annual meeting of TC24 was held in Brescia (Italy) on 29th November 06 with participants:
U. Zerbst – GKSS (Germany)
R.A. Smith – Imperial College (UK)
S. Beretta – Politecnico di Milano (Italy)
L. Drewitt – Corus Group (UK)
G. Donzella – Università di Brescia (Italy)
M. Guagliano – Politecnico di Milano (Italy)
F. Lombardo – Lucchini Sidermeccanica (Italy)
A. Mazzu – Università di Brescia (Italy)

1. Future plans
- **Zerbst** proposes to hold next Workshop/TC24 Meeting in Paris on spring 2007, in concomitance with the conclusion of a French-German jointed research project on rails
- **Beretta** proposes a Workshop/TC24 meeting in Spring 2008 in Milan, focussed on axles, summarizing the results of Widem and Deufrako Projects;
- **Smith** proposes a future Workshop/TC24 meeting in London entitled "Load and infracstructure in railway application", including several topics, like fatigue and fracture of rails, crashworthiness, structures (bridges), multiaxial fatigue of wheels, load spectra, climate changes, lightweighting, non-destructive controls.

2. Proposals for reports from the Committee
It has been discussed about the best way to present the activities of the TC24 members, wich at the moment seems to be the special issues of Elsevier journals. The space reserved by Elsevier for ESIS could be used to announce these special issues and future TC24 meetings.

3. Membership of the Committee
In the past, the requirement for TC24 membership was the ESIS membership, i.e. the participation to the correspondent national ESIS-related groups. Anyway, a better definition of TC24 permanent membership is worthwhile. It would be usefull a revision of the TC24 mailing list, including people interested in the Committee activities and people attending past meetings.

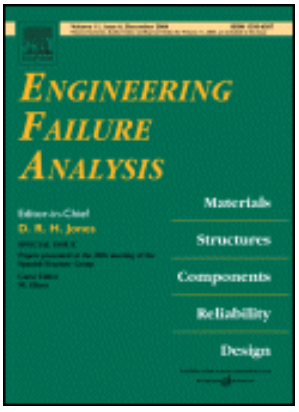
Workshop
On the following day a Workshop entitled "Structural Integrity of Railway Wheels and Wheel/Rail Interface" was held at the University of Brescia with an attendance of approx. 60 delegates. The following presentations were done:
- "Railway Wheels: The Background"
  R.Smith, Imperial College
- "Influence of the contact pressure distribution on the behavior of internally cracked railway wheels"
  M.Guagliano, L.Vergani , Politecnico di Milano
- "A numerical 3D model to study plastic ratchetting damage of a tramcar line"

S.Beretta, G.Bucca, S.Foletti, Politecnico di Milano

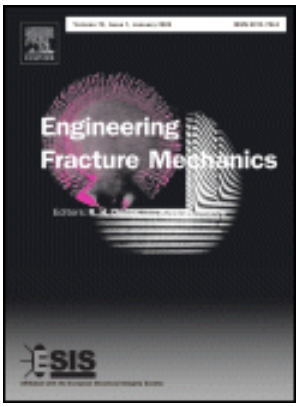
- "RCF-wear competition in railway wheel-rail interface"
  G.Donzella, M.Faccoli, A.Mazzù, C.Petrogalli, R.Roberti, Università di Brescia
- "Ultrasonic analysis of wheel-rail contact"
  B.Leban, M.Pau, Università di Cagliari
- "A simple approach to indirect control of railway vehicles rolling surfaces"
  R.Ciuffi, F.Piccioli, Università di Firenze
- "Investigations on railway components - some progress",
  U.Zerbst, *GKSS, Geesthacht*
- "Innovative bainitic steel grade for solid wheels tested in artic heavy haul operations"
  A.Ghidini*, A.Gianni*, A.Ekberg**, Lucchini Sidermeccanica and Chalmers University
- "Photoelastic analysis of railway wheels in presence of cracks"
  C.Colombo, M.Guagliano, M. Sangirardi, L.Vergani, *Politecnico di Milano*

TC24 members attendinding the workshop in Brescia (from right): Zerbst (chairman), Drewitt, Smith (chairman), Guagliano, Donzella and Beretta.

3 Elsevier journals are affiliated with ESIS



ENGINEERING FAILURE ANALYSIS



ENGINEERING FRACTURE MECHANICS

INTERNATIONAL JOURNAL OF FATIGUE

CALENDAR OF CONFERENCES

ICMFF8-2007 8th International Conference on Multiaxial Fatigue and Fracture 10th - 14th June 2007 Sheffield Hallam University, Sheffield, UK	Further details from: ICMFF8-2007 Conference Secretariat, Sheffield Hallam University, City Campus, Room 5503, Surrey Building, Sheffield S1 1WB, UK. Tel.: +44 114 225 5338; fax: +44 114 225 5337; E-mail: conference21@shu.ac.uk Web: http://www.icmff8.org.uk/	**FraMCoS6-2007** 6th International Conference on Fracture Mechanics of Concreteand Concrete Structures 17-22 June 2007 Catania, ITALY	Further details from: Web: http://www.icmff8.org.uk
ICEM 13 International Conference on Experimental Mechanics: Experimental Analysis of Nano and Engineering Materials and Structures 1–6 July 2007 Alexandroupolis, Greece	Further details from: Professor E.E. Gdoutos, School of Engineering, Democritus University of Thrace, Greece. E-mail: egdoutos@civil.duth.gr Web: http://www.icem13.gr	**IMPLAST 2007** Symposium on Plasticity and Impact Mechanics 21–24 August 2007 Bochum, Germany	Further details from: Professor Dr. Otto T. Bruhns, Lehrstuhl fu¨ r Technische Mechanik, Fakulta¨t fu¨ r Bauingenieurwesen, Ruhr-Universita¨ t Bochum, D-44780 Bochum, Germany. Tel.: +49 234 32 23080; fax: +49 234 32 14229; E-mail: implast07@tm.bi.rub.de
COMPLAS 2007 9th International Conference on Computational Plasticity 5–7 September 2007 Barcelona, Spain	Further details from: Web: http://congress.cimne.upc.es/complas07	**SEMC 2007** The Third International Conference on Structural Engineering, Mechanics and Computation 10–12 September 2007 Cape Town, South Africa	Further details from: Professor A. Zingoni, Department of Civil Engineering, University of Cape Town, Rondebosch 7701, Cape Town, South Africa. E-mail: azingon@ebe.uct.ac.za Web: http://www.semc2007.uct.ac.za
DTAS 2007 International Conference on Damage Tolerance of Aircraft Structures () 25–28 September 2007 Delft, The Netherlands	Further details from: Conference secretariat, D&G Partners, Ms. Dineke Heersma, Ms. Gemma van der Windt Tel: +31(0)6 27227520; fax: +31(0)10 5112119; E-mail: info@dtas2007.nl http://www.dtas2007.nl	**ICFC4** Fourth International Conference on Fatigue of Composites 26–28 September 2007 Kaiserslautern, Germany	Further details from: Conference Secretariat, c/o Dr N. Himmel, Institut fuer Verbundwerkstoffe GmbH. Fax: +49-631-2017-199; E-mail: icfc4@ivw.uni-kl.de www.ivw.uni-kl.de/icfc4
ICMOBT2 Second International Conference on Mechanics of Biomaterials and Tissues 9–13 December 2007 Lihue, Kaua'i, Hawaii, USA	Further details from: Nina Woods ICMOBT Conference Secretariat, Elsevier, The Boulevard, Langford Lane, Kidlington, Oxford, OX5 1GB, U.K. Tel.: +44 (0) 1865 843297 Fax: +44 (0) 1865 843958 E-mail: n.woods@elsevier.com Web: http://www.icmobt.elsevier.com/	**DFE2008** International Conference on Design, Fabrication and Economy of Welded Structures 24–26 April, 2008 Miskolc, Hungary	Further details from: Professor K. Jarmai, University of Miskolc, Miskolc, Hungary. E-mail: dfe2008@uni-miskolc.hu Website: http://www.alt.uni-miskolc.hu/dfe2008

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CALENDAR OF CONFERENCES

ICHMM–2008 Second International Conference on Heterogeneous Materials Mechanics 3–8 June 2008 Huangshan, China	Further details from: Web: http://ichmm-2008.ustc.edu.cn/ichmm2008/	**PCF 2008** 11th Portuguese Conference on Fracture 13 - 15 February 2008 Lisbon, Portugal	Further details from: Rui Fernando Martins Departamento de Engenharia Mecânica e Industrial Faculdade de Ciências e Tecnologia Universidade Nova de Lisboa Campus de Caparica 2829-516 Monte de Caparica PORTUGAL E-mail: rfspm@fct.unl.pt Web: http://eventos.fct.unl.pt/pcf2008

CALENDAR OF TC MEETINGS

TC4	17 – 19 October 2007	Regular Committee meeting	Les Diablerets, Switzerland	Dr. B. Blackman: b.blackman@imperial.ac.uk
TC10	10-14 June 2007	10th Polish-Ukrainian-German Summer School on Fracture Mechanics	Wroclaw, Poland	Professor W. Kasprzak Waclaw.Kasprzak@pwr.wroc.pl Professor J. Kaleta jerzy.kaleta@pwr.wroc.pl

ECF 17
17th European Conference on Fracture

MULTILEVEL APPROACH TO FRACTURE OF MATERIALS, COMPONENTS AND STRUCTURES

September 2 – 5, 2008, Brno, Czech Republic

General Chairmen

Jaroslav Pokluda **Petr Lukáš**

Chairmen of Organising Committee

Pavel Šandera
Faculty of Mechanical Engineering
Brno University of Technology

Ivo Dlouhý
Institute of Physics of Materials
Academy of Sciences of Czech Republic

Scope

This conference will be already the seventeenth in a series of conferences held every two years on the subject of fracture. As the preceding meetings, the ECF17 will focus on all aspects of fracture of engineering materials, components and structures.

A special emphasize will be given to a multiscale investigation of damage processes on atomistic, mesoscopic and macroscopic levels. The conference scope will also embrace more traditional topics as:

- Different level of approaches to fracture analyses;
- Physical aspects of fracture;
- Advanced engineering materials in the service;
- Structure and component integrity.

Venue

ECF17 will be held in the second largest city of the **Czech Republic,** in the city of Brno. The city is situated in a picturesque countryside (190 - 425 m above sea level), surrounded on three sides by wooded hills and opened to the Southern Moravian lowlands. Geographically, Brno is part of the Danube Basin and has many historical ties to the Austrian capital Vienna, which lies a mere 110 km to the south. Brno enjoys a very pleasant, moderate climate, ideal for recreation and everyday living. After the foundation of Czechoslovakia in 1918 Brno became a cultural and educational centre of Moravia. Rich tradition in mechanical engineering was behind the idea of organizing international engineering exhibitions. All international fairs and exhibitions, largest in the Central Europe, take place at Brno Fair Grounds, established in 1928 for the then purpose of the Exhibition of Contemporary Culture.

The ECF17 scientific program will take place in the University campus of the Brno University of Technology, Technická 2, **Brno**.

Topics

- Multilevel approaches to fracture:
  fracture at atomistic and molecular scales, micromechanics and micromechanisms of fracture, mesomechanics, linear and nonlinear fracture mechanics.
- Physical aspects of fracture:
  brittle fracture, ductile fracture, fatigue fracture, creep fracture, mixed mode fracture, temperature and environmental effects.
- Advanced engineering materials:
  metals, ceramics and their composites, polymers and their composites, biomaterials and wood, concrete and rock, smart materials, nanostructured materials, thin films, functional gradient materials.
- Structure and component integrity topics:
  probability approaches to fracture, reliability and life of components, structural integrity, failure analysis and case studies, scaling and size effects, damage mechanics, MEMS and NEMS, sandwich structures.

Abstracts

A short abstract in a plain text containing 200-250 words should be submitted together with the Pre-registration form by those who want to present their papers. Authors will be notified of the acceptance in December 2007.

Deadlines

Pre-registration	September 30, 2007
Submission of short abstracts	September 30, 2007
Notification of acceptance	December 15, 2007
Early bird registration	April 30, 2008
Submission of extended abstracts	May 31, 2008
Submission of full papers	May 31, 2008

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Newsletter #43- 2007

ON THE ACCURACY OF INTENSITY FACTORS IN CRACKED PIEZOELECTRIC MATERIALS COMPUTED BY THE FINITE ELEMENT METHOD

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Abstract Piezoceramic elements can be manufactured easily in large quantities and in specific shapes. This makes them ideally suited for adaptive structural applications in the form of actuators, sensors, controllers and transducers. When employed in this way, piezoelectric ceramics are subjected to complex behavior associated with interactions between their mechanical and electrical fields. Since these ceramics are rather brittle and may crack during use, reliability and failure behavior of piezoelectric materials are important. This leads to the necessity to develop techniques for predicting crack growth under monotonic and fatigue loading (both mechanical and electric). To this end, accurate methods are required for calculating stress and energy flux density intensity factors in these materials. The solution is affected by the mechanical and electrical coupling, as well as material anisotropy in its poled state. In this study, the accuracy of the M-integral in calculating intensity factors is demonstrated with some example problems. In addition, some results are obtained with the displacement/potential extrapolation method.

1. Introduction

As a result of their wide use in the form of sensors and actuators, much interest has been focused on the reliability and failure behavior of piezoelectric materials. This leads to the necessity to develop techniques for predicting crack growth under monotonic and fatigue loading (both mechanical and electric). To this end, accurate methods are required for calculating stress and energy flux density intensity factors in these materials. The solution is affected by the mechanical and electrical coupling, as well as material anisotropy in its poled state.

Methods for calculating stress intensity factors from numerical calculations, such as the finite element method, for mechanically loaded cracked bodies have been presented in many studies (see for example [1]). The area M-integral and displacement/potential extrapolation method for impermeable crack face boundary conditions were presented and employed to obtain intensity factors for cracks in piezoelectric materials in [2]. In this study, the accuracy of these methods is examined.

One form of the constitutive equations is given by

$$\begin{aligned} \sigma_{ij} &= C^E_{ijkl}\varepsilon_{kl} + e_{sij}E_s \\ D_i &= e_{ikl}\varepsilon_{kl} + \kappa^{\varepsilon}_{is}E_s \end{aligned} \qquad (1)$$

where i,j,k,l,s = 1,2,3. The stress and strain components are denoted by σ_{ij} and ε_{ij}, respectively; the electric flux density and the electric field components are given by D_i and E_i, respectively. The material properties are the stiffness tensor C^E_{ijkl} where the superscript E denotes that $\boldsymbol{C}$ is measured with the electric field held constant, the piezoelectric coupling coefficient e_{ikl} and the permittivity $\kappa^{\varepsilon}_{is}$ where the superscript $\boldsymbol{\varepsilon}$ indicates that $\boldsymbol{\kappa}$ is measured with the strain held constant. Coupling between the mechanical and electric behavior of the material may be observed in eqs. (1).

The M-integral is given by [2]

$$M^{(1,2\alpha)} = \int_A \left[\hat{C}_1^{(1,2\alpha)} - \hat{C}_2^{(1,2\alpha)} + \hat{h}^{(1,2\alpha)}\delta_{1\beta}\right]\frac{\partial q_1}{\partial \hat{x}_\beta}\,d\hat{A} \qquad (2)$$

where the superscript (1) represents the sought after solution and the superscript (2α) represents auxiliary solutions with $\alpha = a,b,c,d$. In eq. (2),

$$\hat{C}_1^{(1,2\alpha)} = \hat{T}_\beta^{(1)}\hat{u}_{\beta,1}^{(2\alpha)} + \hat{T}_\beta^{(2\alpha)}\hat{u}_{\beta,1}^{(1)} \qquad (3)$$

$$\hat{T}_\beta = \hat{\sigma}_{\beta 1}n_1 + \hat{\sigma}_{\beta 2}n_2 \qquad (4)$$

$\beta = 1,2$, **n** is the outward normal to the area A in which the integral in eq. (2) is carried out. The hat above a quantity indicates that it is normalized (see [2] for a full explanation). The normalized stress components are $\hat{\sigma}_{\beta\gamma}$ ($\gamma = 1,2$), $\hat{u}_\beta$ represents the normalized displacement components and a comma represents differentiation. In eq. (2),

$$\hat{C}_2^{(1,2\alpha)} = c_3\left[\hat{D}_\beta^{(1)} n_\beta \hat{E}_1^{(2\alpha)} + \hat{D}_\beta^{(2\alpha)} n_\beta \hat{E}_1^{(1)}\right] \qquad (5)$$

where $\hat{D}_\beta$ and $\hat{E}_1$ are the normalized electric flux density components and electric field component in the x-direction, respectively. Equations (2) through (5) are written in the crack tip coordinates shown in Fig. 1. In eq. (5),

$$c_3 = \frac{e_{26}^2}{\kappa_{22} E_A} \qquad (6)$$

where e_{26} is a component of the piezoelastic coupling contracted tensor, κ_{22} is a component of the permittivity tensor and E_A is the Young's modulus in the axial material direction. In eq. (2),

$$\hat{h}^{(1,2\alpha)} = \hat{\sigma}_{\beta\gamma}^{(1)} \hat{\varepsilon}_{\beta\gamma}^{(2\alpha)} - c_3 \hat{D}_\beta^{(1)} \hat{E}_\beta^{(2\alpha)} \qquad (7)$$

is the normalized electric enthalpy density, δ is the Kronecker delta, q_1 is the normalized virtual crack extension, and $\hat{A} = A / L^2$ with L a characteristic length.

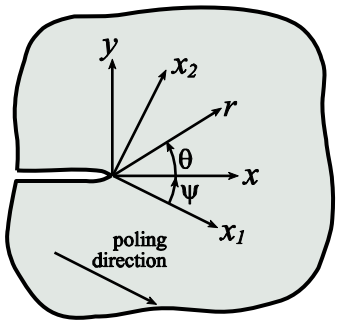

Fig. 1 – Crack tip and material coordinates.

Calculation of the M-integral is carried out in a ring of elements surrounding the crack tip as shown in Fig. 2.

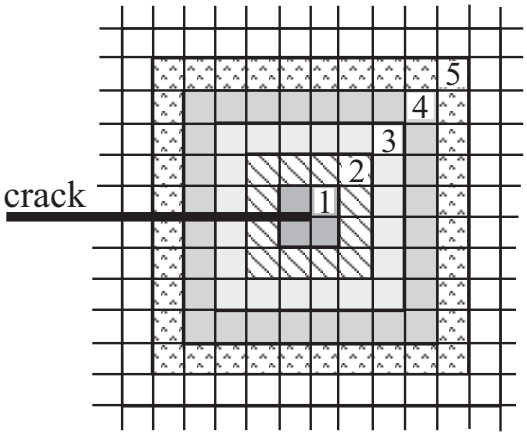

Fig. 2 - Mesh and integration regions about the crack tip.

On the other hand, it was shown in [2] that

$$M^{(1,2\alpha)} = \frac{1}{2}\left[\left(\hat{\mathbf{k}}^{(1)}\right)^T \hat{\mathbf{L}}^{-1} \hat{\mathbf{k}}^{(2\alpha)} + \left(\hat{\mathbf{k}}^{(2\alpha)}\right)^T \hat{\mathbf{L}}^{-1} \hat{\mathbf{k}}^{(1)}\right] \qquad (8)$$

where $\hat{\mathbf{k}}$ is the normalized intensity factor vector

$$\hat{\mathbf{k}}^T = \left[\hat{K}_{II}\ \hat{K}_I\ \hat{K}_{III}\ \hat{K}_{IV}\right] \qquad (9a)$$

with

$$\hat{K}_{I/II} = \frac{K_{I/II}}{E_A\sqrt{L}},\ \hat{K}_{III} = \frac{K_{III}}{G_A\sqrt{L}},\ \hat{K}_{IV} = \frac{K_{IV}}{e_{26}\sqrt{L}} \qquad (9b)$$

the superscript T represents the transpose of the vector, $\hat{\mathbf{L}}$ is one of the 4×4 normalized Barnett-Lotte tensors and is a function of material properties, and G_A is the shear modulus in the axial material direction. Normalization is carried out so that the diagonal and off-diagonal elements of $\mathbf{L}$ are of the same order of magnitude (see [2] for details).

To obtain the intensity factors $K_I^{(1)}$, $K_{II}^{(1)}$, $K_{III}^{(1)}$ and $K_{IV}^{(1)}$, four auxiliary solutions are chosen, namely $2a$, $2b$, $2c$ and $2d$. The first term of the asymptotic solution is used with the intensity factors given in Table 1.

Table 1 – Intensity factor values for the auxiliary solutions 2α.

	K_I	K_{II}	K_{III}	K_{IV}
$2a$	1	0	0	0
$2b$	0	1	0	0
$2c$	0	0	1	0
$2d$	0	0	0	1

Equating eqs. (2) and (8) allows determination of the desired intensity factors.

2. Numerical Results

In this section, both the extrapolation and M-integral methods are employed to calculate intensity factors for impermeable cracks in piezoelectric material. For these applications, the finite element program ANSYS [3] is used to obtain the displacement field and the electric potential. The elements exploited here are isoparametric, containing eight nodal points for the in-plane problems and twenty nodes for the mode III problems. Singular, quarter-point square and cubic elements are used at the crack tip and front, respectively.

For the in-plane problems, both extrapolation and the M-integral are utilized. Since a three-dimensional version of the M-integral is required for analysis of the mode III problems, only the former method is employed. The M-integral is evaluated in rings surrounding the crack tip. The five rings used in this study are shown in Fig. 2. The numbers designate the rings.

In the calculations, it was observed that the results in path 1 produced less accurate results. In addition, sometimes there were small differences in path 2. The results shown in the sequel are an average of paths 3 through 5. Some details will be shown in Section 2.2 for the two-dimensional problems.

For the extrapolation method, a 'best' straight line is passed through successive groups of points in the vicinity of the crack tip. The result is chosen for which the correlation coefficient is closest to unity.

The material used in this study to illustrate the methods is PZT-5H from Morgan Electro Ceramics [4] with the properties presented in Table 2. The poling direction is along the x_1-axis.

Table 2 – Material properties for PZT-5H from [4].

property	C_{11}^E (GPa)	C_{22}^E (GPa)	C_{55}^E (GPa)
value	117	126	23.0
property	C_{12}^E (GPa)	C_{23}^E (GPa)	
value	84.1	79.5	
property	e_{11} (C/m^2)	e_{12} (C/m^2)	e_{26} (C/m^2)
value	23.3	-6.55	17.0
property	$\kappa_{11}^{\varepsilon}$ (F/m)	$\kappa_{22}^{\varepsilon}$ (F/m)	
value	1.3×10^{-8}	1.5×10^{-8}	

In Section 2.1, a benchmark problem is presented for the case in which the poling direction is parallel to the crack front. The first term of the asymptotic solution for the displacement field and electric potential is used as a boundary condition on the outer boundary of a disk. Intensity factors are prescribed which should be obtained as the solution to the calculations. This is a check on the fields and numerical calculations, as well as the mesh density. Next in Section 2.2, several in-plane problems are solved with poling taken at an angle to the the crack faces as shown in Fig. 1. Two problems are solved: the benchmark problem and a finite crack in an infinite body. For all cases, traction and normal energy flux density free boundary conditions are imposed on the crack faces. This implies impermeable crack conditions.

2.1 Poling direction parallel to the crack front

In this section, the poling direction is taken to be along the x_3-axis. The material properties in Table 2 are rotated appropriately. The crack front direction is along the z-axis; these axes coincide. For this problem, the out-of-plane deformation and the in-plane electric field are coupled. Hence, modes III and IV are studied in this section.

In the first problem considered, the first term in the asymptotic expansion for the displacement field and electric potential are applied to the outer boundary of a disk containing an edge crack (see Fig. 3). Various combinations of intensity factors are imposed; the solution should duplicate these enforced intensity

factors. This is defined as the benchmark problem. In Fig. 3, the normalized crack length $a/R=1$ and the normalized thickness $B/R=0.03$.

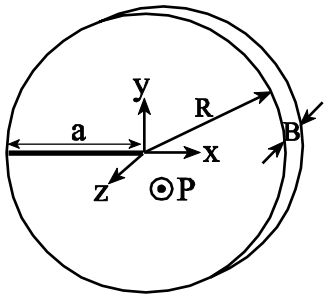

Fig. 3 - Benchmark problem of a disk containing an edge crack.

Two finite element meshes were constructed as shown in Fig. 4; these are the in-plane meshes. The quarter-point elements along the crack front are cubic. This leads to the best simulation of the square-root singularity for a brick element. The elements along the crack front for the fine mesh have a height, width, thickness ratio of 1:1:10. For the coarse mesh, the ratio is 1:1:5.

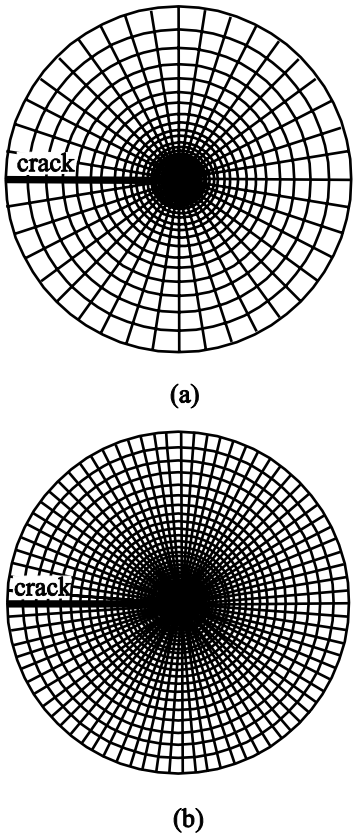

Fig. 4 - In-plane meshes for the disk in Fig. 3.

(a) Coarse mesh containing 3,900 brick elements and 20,112 nodal points. (b) Fine mesh containing 12,000 brick elements and 61,052 nodal points.

For each mesh there are three elements through the thickness. Details of the meshes near the crack tip are exhibited in Fig. 5. For the coarse mesh in Fig. 5a, the ratio of an element side in the plane to the crack length is $\ell/a=2\cdot10^{-3}$. For the fine mesh in Fig. 5b, this ratio is half of that of the coarse mesh.

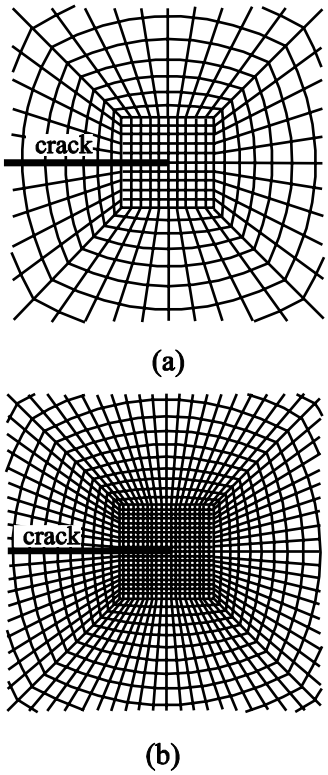

Fig. 5 - Meshes in the neighborhood of the crack tip. (a) Coarse mesh; crack tip element size is $\ell/a=2\cdot10^{-3}$. *(b) Fine mesh; crack tip element size is* $\ell/a=1\cdot10^{-3}$.

The first term of the asymptotic expansions for the displacement $\hat{u}_3$ and the electric potential $\hat{u}_4$ is imposed on the outer boundary of the disk with

$$\hat{K}_{III}=1 \qquad \hat{K}_{IV}=0. \tag{10}$$

The intensity factors are calculated by means of the extrapolation method along one of the rays of the middle element along the crack front. The jump in the displacement and electric potential along the crack faces, normal to the crack front, are obtained from the finite element

results and used to obtain local intensity factors [2]. In the graph obtained by this method for mode III, the first five points closest to the crack front for both the fine and coarse meshes differ greatly from the straight line fit in the neighborhood of the crack tip; for mode IV, the first three points show large differences from the remainder of the points. Neglecting these points, the results are extrapolated to zero and presented in Table 3. The results for both meshes for $\hat{K}_{III}$ are excellent. For $\hat{K}_{IV}$ the results are small. This is the level of zero that is obtained with these meshes. It may be observed that the coarse mesh yields sufficiently accurate results. In fact, a coarser mesh could have been used. Such a mesh will be considered for the analogous in-plane problem in Section 2.2.1.

Table 3 – Calculated intensity factors for the problem in Fig. 3 with the boundary conditions employing eq. (10).

	$\hat{K}_{III}$	$\hat{K}_{IV}$
coarse mesh	0.9998	1.8×10^{-5}
fine mesh	0.9999	9.7×10^{-6}

Next, the intensity factors

$$\hat{K}_{III}=0 \qquad \hat{K}_{IV}=1 \tag{11}$$

are imposed through the boundary conditions on the outer surface of the disk in Fig. 3. The same meshes shown in Fig. 4 were used to calculate the displacement field and electric potential. The intensity factors were calculated by means of extrapolation and are presented in Table 4. The results for both intensity factors deteriorate slightly as compared to those in Table 3. However, those for $\hat{K}_{IV}$ are excellent.

Table 4 – Calculated intensity factors for the problem in Fig. 3 with the boundary conditions employing eq. (11).

	$\hat{K}_{III}$	$\hat{K}_{IV}$
coarse mesh	1.1×10^{-4}	0.9996
fine mesh	-4.9×10^{-5}	0.9995

The problem studied with the two sets of boundary conditions demonstrates that with a refined mesh, intensity factors may be obtained accurately by the extrapolation method and quarter-point elements.

2.2 Poling direction at an angle to the crack faces within the crack plane

In this section, poling is within the xy-plane and at an angle to the crack faces as shown in Fig. 1. Several problems are considered in this section. First, the equivalent disk problem solved in Section 2.1 is reconsidered for this poling direction. Next, intensity factors for a finite length crack in an infinite body subjected to various boundary conditions at infinity are determined. The results are compared to analytic solutions. These problems are chosen to examine the accuracy of the solutions, mesh refinement required, and the differences between the two methods presented.

2.2.1 Benchmark problem

The disk containing an edge crack and shown in Fig. 6 is studied. Poling is chosen such that $\psi=-30^{\circ}$ and the non-dimensional crack length $a/R=1$. The crack faces are traction and energy flux density free. On the outer boundary of the disk, the first term of the asymptotic displacement field and electric potential are enforced with different values for the normalized intensity factors. The three problems considered are $2a$, $2b$, and $2d$ shown in Table 1.

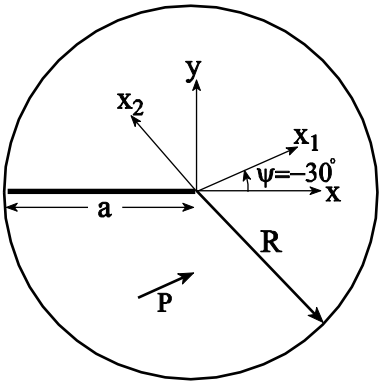

Fig. 6 - In-plane benchmark problem of a disk containing an edge crack.

The coarse and fine meshes are illustrated in Fig. 7. The coarse mesh contains 180 eight noded isoparametric elements and 595 nodal points, whereas the fine mesh contains 900 eight noded isoparametric elements and 2,791 nodal points. The ratio of the crack tip element

length to crack length is $\ell / a = 0.1$ for the coarse mesh and $2 \cdot 10^{-3}$ for the fine mesh. The fine mesh used here is the in-plane mesh that was used as the coarse mesh in Section 2.1 for the three-dimensional problem. Thus, the detail in Fig 5a is appropriate for the mesh in Fig. 7b.

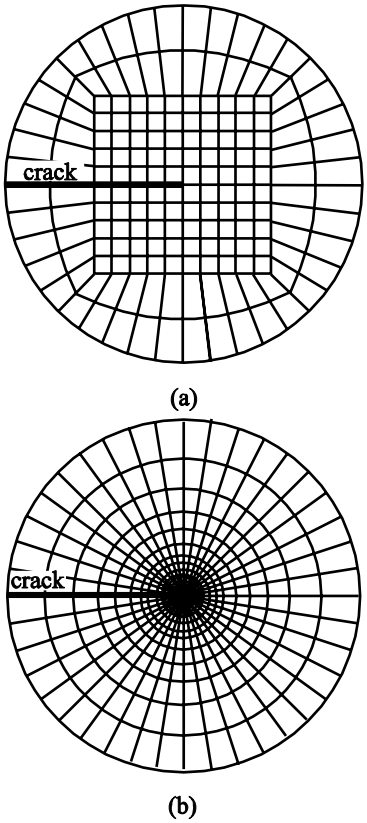

Fig. 7 - Meshes for the disk in Fig. 6. (a) The coarse mesh contains 180 eight noded isoparametric elements and 595 nodal points. (b) The fine mesh contains 900 eight noded isoparametric elements and 2,791 nodal points.

Results are presented in Table 5 for problem $2a$ in Table 1. For the M-integral, the average of results obtained in the three outer paths (3, 4 and 5) in Fig. 2 are given. It is observed that the values of $\hat{K}_I$ for both the coarse and fine meshes are excellent (the value should be unity). There is some deterioration for $\hat{K}_{IV}$ with the coarse mesh. It was seen that even results in paths 1 and 2 are excellent. It may be observed, further, that values obtained by means of the extrapolation method are also in excellent agreement with the prescribed values. The largest discrepancy of $\hat{K}_I$ from unity is 0.3% for extrapolation and the coarse mesh.

Problems $2b$ and $2d$ in Table 1 were also solved. The results are similar to those found for the mode I case (problem $2a$). The largest error of 1.6% for $\hat{K}_{II}$ (problem $2b$) was found with extrapolation and the coarse mesh. It may be noted that in all cases, near the crack tip, the values of displacement and electric potential deviate substantially from unity.

Table 5 - Calculated intensity factors for the problem in Fig. 6 with the boundary conditions for problem $2a$ in Table 1

	$\hat{K}_I$	$\hat{K}_{II}$	$\hat{K}_{IV}$
M-integral			
coarse mesh	1.0004	$O(10^{-5})$	$O(10^{-4})$
fine mesh	1.00002	$O(10^{-6})$	$O(10^{-6})$
extrapolation			
coarse mesh	0.997	$O(10^{-4})$	$O(10^{-3})$
fine mesh	0.999	$O(10^{-4})$	$O(10^{-4})$

.

With the fine mesh in Fig. 7b, poling was taken both parallel ($\psi = 0^\circ$) and perpendicular ($\psi = -90^\circ$) to the crack faces. The same excellent results were obtained for each of the intensity factors which were taken to be unity for both the M-integral and extrapolation methods. In general, the intensity factor that should be zero was found to be between $O(10^{-6})$ and $O(10^{-11})$. An exception occurred when poling was perpendicular to the crack faces and $\hat{K}_I = 1$; $\hat{K}_{IV}$ was found to be $O(10^{-5})$ with the M-integral and $O(10^{-3})$ with extrapolation. Several other results with extrapolation also deteriorated. It is noted that the results for the zero intensity factors for angles different from 0° and -90° (namely, $\psi = -30^\circ$) are for the most part smaller than $O(10^{-8})$.

Although these problems demonstrate the accuracy of the analytically obtained asymptotic fields, as well as the post-processors, they do not demonstrate the strength of the M-integral. To this end, the problem of a Griffith's crack in an infinite body is examined next.

2.2.2 Griffith crack

In this section, a finite length crack in an infinite body illustrated in Fig. 8 is studied. To model an infinite body, the normalized height and crack length are taken, respectively, as $h/W=1$ and $a/W=0.05$. For $a/W=0.1$, the body is not sufficiently infinite. The applied far field boundary conditions include $\sigma_{yy}=\sigma_{\infty}=1\,\text{MPa}$, $\sigma_{xy}=\tau_{\infty}=1\,\text{MPa}$ and $D_y=D_{\infty}=0.01\,\text{C/m}^2$. These boundary conditions are applied in turn. Poling is taken such that $\psi=-30^{\circ}$ (see Fig. 1). The solution to the infinite body problem is [5]

$$K_I=\sigma_{\infty}\sqrt{\pi a},\ K_{II}=\tau_{\infty}\sqrt{\pi a},\ K_{IV}=D_{\infty}\sqrt{\pi a} \tag{12}$$

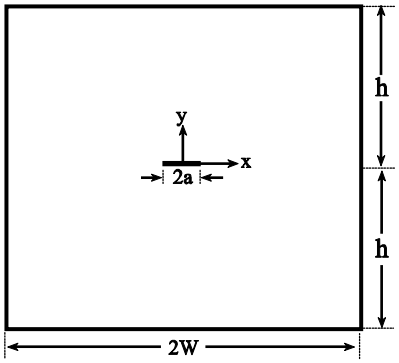

Fig. 8 – Central crack in an infinite body.

As with the previous problems, two meshes were employed. The coarse and fine meshes are illustrated in Figs. 9a and 9b, respectively, with details surrounding the crack tips shown in Fig. 10.

With the M-integral and extrapolation, the intensity factors normalized as in eq. 9b are computed. These are normalized again to yield

$$\tilde{K}_I=\frac{K_I}{\sigma_{\infty}\sqrt{\pi a}},\ \tilde{K}_{II}=\frac{K_{II}}{\tau_{\infty}\sqrt{\pi a}},\ \tilde{K}_{IV}=\frac{K_{IV}}{D_{\infty}\sqrt{\pi a}}. \tag{13}$$

To examine path independence of the M-integral, the mode II problem in which σ_{xy} is applied to the infinite body is considered in detail. It may be observed in Table 6 that the normalized stress intensity factor $\tilde{K}_{II}$ is path independent to five significant figures along paths 2 through 5 (see Fig. 2) for the coarse mesh and paths 3 through 5 for the fine mesh. With σ_{yy} applied, path independence to five significant figures occurred in paths 2 through 5 for the coarse mesh and 3 through 5 for the fine mesh. When D_y was applied there was five significant figure agreement on paths 2 through 5. This occurred for both meshes.

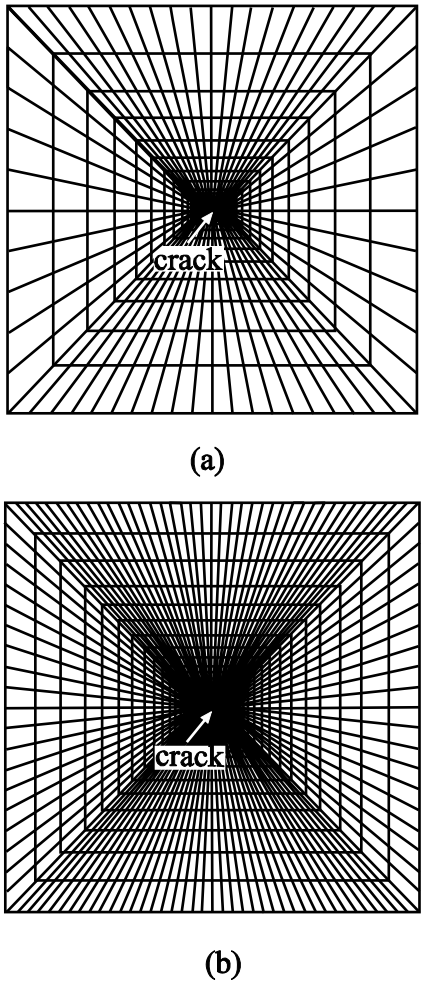

Fig. 9 - Meshes for the plate in Fig. 8. (a) The coarse mesh contains 800 eight noded isoparametric elements and 2,480 nodal points. (b) The fine mesh contains 2,600 eight noded isoparametric elements and 7,960 nodal points.

Table 6 - The stress intensity factor $\tilde{K}_{II}$ along various paths for the problem in Fig. 8 with σ_{xy} applied.

path	coarse mesh	fine mesh
1	1.0016	1.0018
2	1.0005	1.0009
3	1.0005	1.0007
4	1.0005	1.0007
5	1.0005	1.0007

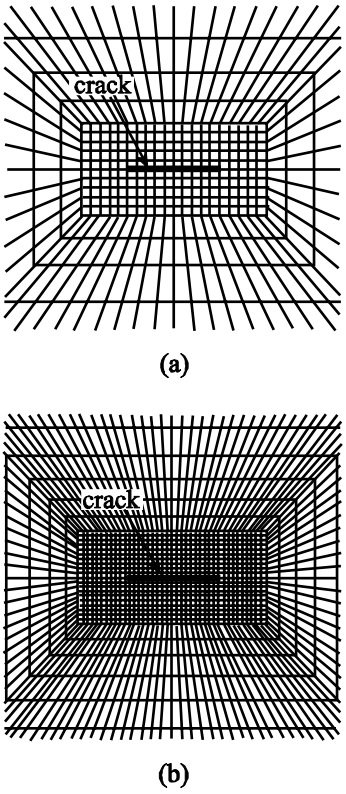

Fig. 10 - Meshes in the neighborhood of the crack tip for the infinite plate. (a) Coarse mesh; crack tip element size is $\ell / a = 0.2$. *(b) Fine mesh; crack tip element size is* $\ell / a = 0.1$.

In Table 7, normalized intensity factors are presented for each of the boundary conditions. It should be noted that both $\tilde{K}$ and $\hat{K}$ defined in eqs. (13) and (9b), respectively, are given for different cases. Values calculated by means of the M-integral are averaged from paths 3 through 5. For mode I deformation, $\tilde{K}_I$ is seen to be the same for the coarse and fine meshes and to differ from the analytic value of unity by 0.4% when calculated by means of the conservative integral. With extrapolation, an error of 1% occurs for the coarse mesh and 0.7% for the fine mesh. When σ_{xy} is applied, $\tilde{K}_{II}$ differs with the expected solution by 0.05% and 0.07%, for the coarse and fine meshes, respectively. Note that the value deteriorates to 1.6% when obtained by extrapolation and the coarse mesh. There is improvement with the fine mesh. Similar results are found when the electric flux density D_y is applied far from the crack. With this example, the superiority of the conservative integral is seen. The values for the intensity factors obtained with the M-integral are observed to be more accurate than those found by means of the extrapolation method. It may be noted, that the coarse mesh is sufficient to obtain extremely accurate results when the M-integral is used in the calculations. In addition, the intensity factors which should be obtained as zero are also presented. When K_I and K_{II} are the dominant stress intensity factors respectively, $\tilde{K}_{II}$ and $\tilde{K}_I$, respectively, are obtained by normalizing with σ_∞ and τ_∞. This is the opposite from that in eq. (13). These values are seen to range between $O(10^{-2})$ and $O(10^{-5})$. If the $\hat{K}_{I/II}$ values are considered instead, they decrease to $O(10^{-7})$ and $O(10^{-9})$. This gives the reader a handle on the level of zero which may be obtained with these methods. Moreover, since $D_\infty = 0$ in these two cases, only $\hat{K}_{IV}$ can be calculated. It is seen to range from $O(10^{-7})$ and $O(10^{-8})$.

Table 7 - Calculated intensity factors for the Griffith crack (see Fig. 8) with various boundary conditions

applied tensile stress	$\tilde{K}_I$	$\tilde{K}_{II}$	$\hat{K}_{IV}$
M-integral			
coarse mesh	1.004	$O(10^{-5})$	$O(10^{-8})$
fine mesh	1.004	$O(10^{-5})$	$O(10^{-8})$
extrapolation			
coarse mesh	1.010	$O(10^{-3})$	$O(10^{-7})$
fine mesh	1.007	$O(10^{-3})$	$O(10^{-8})$
applied shear stress	$\tilde{K}_I$	$\tilde{K}_{II}$	$\hat{K}_{IV}$
M-integral			
coarse mesh	$O(10^{-2})$	1.0005	$O(10^{-7})$
fine mesh	$O(10^{-2})$	1.0007	$O(10^{-7})$
extrapolation			
coarse mesh	$O(10^{-2})$	1.016	$O(10^{-7})$
fine mesh	$O(10^{-2})$	1.007	$O(10^{-7})$
applied electric flux density	$\hat{K}_I$	$\hat{K}_{II}$	$\tilde{K}_{IV}$
M-integral			
coarse mesh	$O(10^{-6})$	$O(10^{-7})$	1.0007
fine mesh	$O(10^{-6})$	$O(10^{-7})$	1.0009
extrapolation			
coarse mesh	$O(10^{-5})$	$O(10^{-5})$	1.016
fine mesh	$O(10^{-6})$	$O(10^{-6})$	1.007

3. Conclusions

The accuracy of a conservative M-integral has been examined for calculating intensity factors of impermeable cracks in piezoelectric materials. Comparisons were made to the extrapolation method. Two geometries were examined: (1) a benchmark problem and (2) a Griffith crack. It was seen that excellent results may be obtained with the M-integral. There was some deterioration with extrapolation.

In the future, the M-integral will be extended and results presented for more realistic crack face boundary conditions.

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ASYMPTOTIC FIELDS AT COHESIVE CRACK TIPS

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The stress and displacement fields at the front of propagating fracture which depend on the actual loading on the structure and its boundary conditions are needed to study its growth. In this paper we shall review these fields for cohesive cracks by which are meant a traction-free fracture front with a large process zone ahead of it in which the material experiences progressive softening (Fig. 1). Over the process (or cohesive) zone the material is able to transfer some traction across the crack faces depending upon how much the faces have separated or slid relative to each other (Karihaloo, 1995) which are prescribed by cohesion-separation relationships. The cohesive cracks under consideration are therefore different from both Barenblatt (1959), Dugdale (1960) and BCS (1963) simplified models.

The lack of any work on the asymptotic fields at the tips of cohesive cracks belies the widespread use of cohesive crack models. The solution of asymptotic fields at cohesive crack tips was obtained very recently by Xiao & Karihaloo (2006). They considered only normal cohesion-separation relationships, but allowed for the effect of Coulomb friction on the cohesive crack faces. The special case of a pure mode I cohesive crack was fully investigated. Their solution is valid for any cohesion-separation law that can be expressed in a special polynomial form. They showed that many commonly used separation laws, e.g. rectangular, linear, bilinear, exponential, etc can be easily expressed in this form. They used these asymptotic fields as enrichment functions in the extended/generalized finite element method at the tip of long cohesive cracks, as well as short branches/kinks. These asymptotic crack tip fields parallel those of Williams (1957) for brittle materials.

Asymptotic Fields at Frictionless and Frictional Cohesive Crack Tips

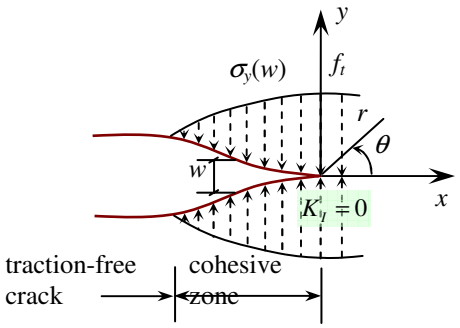

Fig 1. A real traction-free crack terminating in a fracture process (cohesive) zone (FPZ) with residual stress transfer capacity $\sigma_y(w)$ whose faces close smoothly near its tip ($K_I = 0$). The material outside the FPZ is linear elastic, but within the FPZ is softening.

In order to simplify the derivation of the cohesive crack tip asymptotic fields, we will represent cohesion-separation law by the following general polynomial

$$\frac{\sigma}{f_t} = 1 + \sum_{i=1}^{5} \alpha_i \left(\frac{w}{w_c}\right)^{\frac{2}{3}i} - \left(1 + \sum_{i=1}^{5} \alpha_i\right)\left(\frac{w}{w_c}\right)^4 \qquad (1)$$

where α_i, $i = 1 \sim 5$, are fitting parameters. Xiao & Karihaloo (2006) showed that the commonly used exponential (2), linear (3), bilinear (4) and rectangular (5) cohesion-separation laws given below can be faithfully expressed in the general form (1).

$$\frac{\sigma}{f_t} = f\left(\frac{w}{w_c}\right) - \frac{w}{w_c} f(1); \qquad f\left(\frac{w}{w_c}\right) = \left[1 + \left(C_1 \frac{w}{w_c}\right)^3\right] e^{-C_2 \frac{w}{w_c}} \tag{2}$$

$$\hat{\sigma} = 1 - \hat{w} \tag{3}$$

$$\hat{\sigma} = \begin{cases} 1 - \left(1 - \hat{f}_1\right)\dfrac{\hat{w}}{\hat{w}_1}, & 0 \le \hat{\sigma} \le \hat{f}_1 \\ \dfrac{\hat{f}_1}{1 - \hat{w}_1}(1 - \hat{w}), & \hat{f}_1 < \hat{\sigma} \le 1 \end{cases} \tag{4}$$

$$\hat{\sigma}^m + \hat{w}^{2m} = 1 \quad \text{or} \quad \hat{\sigma} = 1 - \hat{w}^{2n} \tag{5}$$

In (2)-(5), C_1, C_2, m, n are material constants, $\hat{\sigma} = \sigma / f_t$, $\hat{w} = w / w_c$, $\hat{f}_1 = f_1 / f_t$, and $\hat{w}_1 = w_1 / w_c$, where w_1 and f_1 are the co-ordinates of the knee of the bilinear law. Xiao & Karihaloo (2006) used the eigenfunction expansion method of Williams (1957) and combined it with the complex function formalism of Muskhelishvili (1953) in the spirit of Sih and Liebowitz (1968) to solve the fields. The cohesive and frictional laws on the crack faces were imposed through appropriate boundary conditions. For a general plane mixed mode I + II problem, the complex functions $\phi(z)$ and $\chi(z)$ were chosen as series of complex eigenvalue Goursat functions

$$\phi(z) = \sum_{n=0}^{\infty} \left(a_n^1 + i a_n^2\right) z^{\lambda_n}, \qquad \chi(z) = \sum_{n=0}^{\infty} \left(b_n^1 + i b_n^2\right) z^{\lambda_n + 1}$$

Below we will use the designations $a_{1n} = a_n^1$, $a_{2n} = a_n^2$, $b_{1n} = b_n^1$ and $b_{2n} = b_n^2$.

To complete the asymptotic analysis of the crack tip fields, solutions need to satisfy the proper symmetry conditions along the line of extension of the cohesive crack, and boundary conditions on the cohesive crack faces.

If normal cohesive separation applies to the crack faces, relationship (1) needs to be satisfied over the cohesive zone. The stresses at the cohesive crack tip are non-singular (because the SIF K_I = 0). Moreover, the following conditions need to be satisfied:

(a) if the cohesive crack faces are frictionless

$$\sigma_y\big|_{\theta=\pi} = \sigma_y\big|_{\theta=-\pi} \neq 0, \quad \tau_{xy}\big|_{\theta=\pi} = \tau_{xy}\big|_{\theta=-\pi} = 0 \tag{6}$$

(b) if the Coulomb friction is considered

$$\sigma_y\big|_{\theta=\pi} = \sigma_y\big|_{\theta=-\pi} \neq 0, \quad \tau_{xy}\big|_{\theta=\pi} = \tau_{xy}\big|_{\theta=-\pi} = -\mu_f \sigma_y\big|_{\theta=\pm\pi} \neq 0 \tag{7}$$

where μ_f equals the positive or negative value of the coefficient of kinetic friction, which is assumed to be constant, depending on the relative sliding direction of the two crack faces. Specifically, $\mu_f > 0$ when $\delta > 0$ and $\mu_f < 0$ when $\delta < 0$.

(c) if the cohesive crack faces are in pure mode I condition

$$\sigma_y\big|_{\theta=\pi} = \sigma_y\big|_{\theta=-\pi} \neq 0, \quad \tau_{xy}\big|_{\theta=\pi} = \tau_{xy}\big|_{\theta=-\pi} = 0, \quad \tau_{xy}\big|_{\theta=0} = 0, \text{ and } v\big|_{\theta=0} = 0 \tag{8}$$

In all three situations, the length of the process (cohesive) zone is either prescribed (i.e. an initial cohesive zone exists before the loading is applied, and does not propagate under the present loading) or is determined by the condition $w = w_c$ in the normal cohesion-separation relation (1) at the instant of growth of the pre-existing traction-free crack.

Frictionless Cohesive Crack with Normal Cohesive Separation

The relationship (1) between cohesion and normal separation will be discussed below. After considering conditions (6) on the crack faces, the solutions are composed of two parts. The first part corresponds to integer eigenvalues

$$\text{(a) } \lambda_n = n + 1, \quad b_{2n} = -\frac{n}{n+2} a_{2n}, \quad n = 0, 1, 2, \cdots, \tag{9}$$

giving

$$\hat{\sigma}_y = \frac{\sigma_y\big|_{\theta=\pm\pi}}{f_t} = \sum_{n=0} c_n r^n = 1 + \sum_{n=1} c_n r^n \tag{10}$$

where

$$c_n = \frac{(n+2)(n+1)(a_{1n}+b_{1n})\cos n\pi}{f_t},\ \ c_0 = \frac{2(a_{10}+b_{10})}{f_t} = 1 \tag{11}$$

since $\sigma_y\big|_{\theta=\pm\pi} = f_t$ when $r \to 0$.

The opening and sliding displacements of the cohesive crack faces vanish for integer eigenvalues

$$w = 0, \quad \delta = 0 \tag{12}$$

The second part of the asymptotic solutions corresponds to non-integer eigenvalues

$$\text{(b)}\ \ \lambda_n = \frac{2n+3}{2},\ b_{1n} = -\frac{2n+1}{2n+5}a_{1n},\ b_{2n} = -a_{2n},\ n = 0, 1, 2, \cdots, \tag{13}$$

giving

$$\sigma_y\big|_{\theta=\pm\pi} = 0 \tag{14}$$

$$\hat{w} = \frac{w}{w_c} = \sum_{n=0} \bar{d}_n r^{\frac{2n+3}{2}},\ \ \bar{d}_n = \frac{\left[\left(\kappa + \frac{2n+3}{2}\right)a_{1n} + \frac{2n+5}{2}b_{1n}\right]\sin\frac{2n+3}{2}\pi}{\mu w_c} \tag{15}$$

$$\delta = \sum_{n=0} \frac{r^{\frac{2n+3}{2}}}{\mu}\left[\left(\frac{2n+3}{2} - \kappa\right)a_{2n} + \frac{2n+5}{2}b_{2n}\right]\sin\frac{2n+3}{2}\pi \tag{16}$$

Consider the truncated $N+1$ terms of $\hat{w}$ (15), and denote $d_0 = \bar{d}_0$, $d_n = \bar{d}_n / d_0$ $(n > 1)$

$$\hat{w} = d_0 r^{\frac{3}{2}}\left(1 + \sum_{n=1}^{N} d_n r^n\right) \tag{17}$$

The expansion of $\hat{w}$ raised to the power $2i/3$ is also truncated to $N+1$ terms, since these terms include only the truncated $N+1$ terms of $\hat{w}$. Hence

$$\hat{w}^{\frac{2}{3}i} = d_0^{\frac{2}{3}i} r^i \left(1 + \sum_{n=1}^{N} \beta_{in} r^n\right) \tag{18}$$

where

$$\beta_{in} = \frac{f_i^{(n)}(0)}{n!},\ \ f_i(r) = \left(1 + \sum_{n=1}^{N} d_n r^n\right)^{\frac{2}{3}i}, \tag{19}$$

where $f_i^{(n)}(0)$ denotes the nth derivative at $r = 0$.

The derivatives of function $f_i(r)$ (19) are given in Xiao & Karihaloo (2006) and the corresponding first five coefficients β_{in} are

$$\begin{aligned}
\beta_{i1} &= \frac{2}{3}id_1 \\
\beta_{i2} &= \frac{1}{3}i\left(\frac{2}{3}i-1\right)d_1^2 + \frac{2}{3}id_2 \\
\beta_{i3} &= \frac{1}{9}i\left(\frac{2}{3}i-1\right)\left(\frac{2}{3}i-2\right)d_1^3 + \frac{2}{3}i\left(\frac{2}{3}i-1\right)d_1d_2 + \frac{2}{3}id_3 \\
\beta_{i4} &= \frac{1}{36}i\left(\frac{2}{3}i-1\right)\left(\frac{2}{3}i-2\right)\left(\frac{2}{3}i-3\right)d_1^4 + \frac{1}{3}i\left(\frac{2}{3}i-1\right)\left(\frac{2}{3}i-2\right)d_1^2d_2 + \frac{1}{3}i\left(\frac{2}{3}i-1\right)d_2^2 + \frac{2}{3}i\left(\frac{2}{3}i-1\right)d_1d_3 + \frac{2}{3}id_4 \\
\beta_{i5} &= \frac{1}{180}i\left(\frac{2}{3}i-1\right)\left(\frac{2}{3}i-2\right)\left(\frac{2}{3}i-3\right)\left(\frac{2}{3}i-4\right)d_1^5 + \frac{1}{9}i\left(\frac{2}{3}i-1\right)\left(\frac{2}{3}i-2\right)\left(\frac{2}{3}i-3\right)d_1^3d_2 + \frac{1}{3}i\left(\frac{2}{3}i-1\right)\left(\frac{2}{3}i-2\right)d_1d_2^2
\end{aligned} \tag{20}$$

$$+\frac{1}{3}i\left(\frac{2}{3}i-1\right)\left(\frac{2}{3}i-2\right)d_1^2d_3+\frac{2}{3}i\left(\frac{2}{3}i-1\right)d_2d_3+\frac{2}{3}i\left(\frac{2}{3}i-1\right)d_1d_4+\frac{2}{3}id_5$$

With the use of (18), if we choose $N = 5$, then after satisfying the cohesive relationship (1) we can obtain the following expressions for coefficients c_n appearing in (10) (see Xiao & Karihaloo, 2006):

$$\begin{aligned}
c_1 &= \alpha_1 d_0^{\frac{2}{3}} \\
c_2 &= \alpha_2 d_0^{\frac{4}{3}} + \alpha_1 d_0^{\frac{2}{3}}\beta_{11} \\
c_3 &= \alpha_3 d_0^{2} + \alpha_1 d_0^{\frac{2}{3}}\beta_{12} + \alpha_2 d_0^{\frac{4}{3}}\beta_{21} \\
c_4 &= \alpha_4 d_0^{\frac{8}{3}} + \alpha_1 d_0^{\frac{2}{3}}\beta_{13} + \alpha_2 d_0^{\frac{4}{3}}\beta_{22} + \alpha_3 d_0^{2}\beta_{31} \\
c_5 &= \alpha_5 d_0^{\frac{10}{3}} + \alpha_1 d_0^{\frac{2}{3}}\beta_{14} + \alpha_2 d_0^{\frac{4}{3}}\beta_{23} + \alpha_3 d_0^{2}\beta_{32} + \alpha_4 d_0^{\frac{8}{3}}\beta_{41} \\
c_6 &= \alpha_1 d_0^{\frac{2}{3}}\beta_{15} + \alpha_2 d_0^{\frac{4}{3}}\beta_{24} + \alpha_3 d_0^{2}\beta_{33} + \alpha_4 d_0^{\frac{8}{3}}\beta_{42} + \alpha_5 d_0^{\frac{10}{3}}\beta_{51} - \left(1+\sum_{i=1}^{5}\alpha_i\right)d_0^4 \\
c_7 &= \alpha_2 d_0^{\frac{4}{3}}\beta_{25} + \alpha_3 d_0^{2}\beta_{34} + \alpha_4 d_0^{\frac{8}{3}}\beta_{43} + \alpha_5 d_0^{\frac{10}{3}}\beta_{52} - \left(1+\sum_{i=1}^{5}\alpha_i\right)d_0^4\beta_{61} \\
c_8 &= \alpha_3 d_0^{2}\beta_{35} + \alpha_4 d_0^{\frac{8}{3}}\beta_{44} + \alpha_5 d_0^{\frac{10}{3}}\beta_{53} - \left(1+\sum_{i=1}^{5}\alpha_i\right)d_0^4\beta_{62} \\
c_9 &= \alpha_4 d_0^{\frac{8}{3}}\beta_{45} + \alpha_5 d_0^{\frac{10}{3}}\beta_{54} - \left(1+\sum_{i=1}^{5}\alpha_i\right)d_0^4\beta_{63} \\
c_{10} &= \alpha_5 d_0^{\frac{10}{3}}\beta_{55} - \left(1+\sum_{i=1}^{5}\alpha_i\right)d_0^4\beta_{64} \\
c_{11} &= -\left(1+\sum_{i=1}^{5}\alpha_i\right)d_0^4\beta_{65}
\end{aligned} \qquad (21)$$

Note that the above asymptotic solution is not for pure mode I cohesive crack tip (cf. (6) and (8)), since along the line of extension of the crack, $\theta = 0$, the shear stress does not vanish ($\tau_{xy} \neq 0$).

For non-integer eigenvalues (13), the coefficients a_{1n} and a_{2n} may be regarded as independent, so that coefficients b_{1n} are linearly dependent on a_{1n} and b_{2n} on a_{2n}. For integer eigenvalues (9), coefficients a_{1n} and a_{2n} may also be regarded as independent, so that coefficients b_{2n} now depend linearly on a_{2n}. However, the coefficients b_{1n} for integer eigenvalues will depend both linearly on a_{1n} for integer eigenvalues and nonlinearly on a_{1n} for non-integer eigenvalues via (15), (16), (20), and (21). The inherent nonlinear nature of the problem is reflected in these nonlinear relationships between the coefficients of the asymptotic fields.

The displacements corresponding to $\lambda_1 = 0$, or $n = -1$ in (9) are rigid body translations at the crack tip

$$2\mu u_{-1} = \kappa a_{1,-1} - b_{1,-1}, \quad 2\mu v_{-1} = \kappa a_{2,-1} + b_{2,-1} \qquad (22)$$

The displacements corresponding to a_{20} ($n = 0$, $\lambda_0 = 1$ and $b_{20} = 0$ from (9)) represents rigid body rotation with respect to the crack tip

$$2\mu\hat{u}_0 = -r(\kappa+1)a_{20}\sin\theta, \quad 2\mu\hat{v}_0 = r(\kappa+1)a_{20}\cos\theta \qquad (23)$$

Coulomb Frictional Cohesive Crack with Normal Cohesive Separation

In principle, a cohesive relationship can also be considered in the tangential direction. However, this is a contentious issue, since it is difficult to separate the cohesive-sliding relation from the frictional force between the rough cohesive crack faces. Hence we will only consider the Coulomb friction between the crack faces instead of a tangential cohesive relationship. The corresponding boundary conditions are (7).

The complete asymptotic solutions are again composed of two parts. The first part corresponding to integer eigenvalues is similar to that above but with different constraints on the coefficients

$$\lambda_n = n+1, \; na_{2n} + (n+2)b_{2n} = -\mu_f(n+2)(a_{1n}+b_{1n}), \; n = 0, 1, 2, \cdots \qquad (24)$$

From (24), we have

$$b_{2n} = -\frac{n}{n+2}a_{2n} - \mu_f(a_{1n}+b_{1n})$$

When $\mu_f = 0$, the cohesive crack faces are frictionless, and (24) reduces to (9). These solutions have non-zero σ_y and τ_{xy} along the cohesive crack faces, but zero crack opening w and sliding δ. The second part of the asymptotic solutions corresponding to non-integer eigenvalues satisfies

$$b_{1n} = -\frac{\lambda_n - 1}{\lambda_n + 1} a_{1n},\ b_{2n} = -a_{2n},\ \left(\mu_f a_{1n} - a_{2n}\right)\cos(\lambda_n - 1)\pi = 0 \tag{25}$$

Assuming that

$$\mu_f a_{1n} - a_{2n} \neq 0 \tag{26}$$

the third equation in (25) gives

$$\cos(\lambda_n - 1)\pi = 0 \tag{27}$$

so that the second part of asymptotic solutions is identical to (14) – (16).

The remaining solution procedure and final asymptotic solutions as well as the dependence of the coefficients are similar to those for frictionless cohesive cracks. Equations (22) and (23) again represent the rigid body modes for the present case.

Finally, we give without detail the leading term in the asymptotic displacement field of a pure mode I cohesive crack (with the boundary conditions (8)). This term is given by the lowest non-integer eigenvalue

$$u = \frac{r^{3/2}}{2\mu} a_{11}\left[\left(\kappa + \frac{1}{2}\right)\cos\frac{3}{2}\theta - \frac{3}{2}\cos\frac{1}{2}\theta\right],\ v = \frac{r^{3/2}}{2\mu} a_{11}\left[\left(\kappa - \frac{1}{2}\right)\sin\frac{3}{2}\theta - \frac{3}{2}\sin\frac{1}{2}\theta\right] \tag{28}$$

where the coefficient a_{11} depends on the geometry and loading of the structure and on the cohesion-separation law.

Implementation of the Asymptotic Fields in XFEM/GFEM

In the implementation of the cohesive crack asymptotic fields as enrichment functions in the XFEM/GFEM, if not only the first term but also the higher order terms are used as in Liu et al. (2004), the linear dependence of the coefficients can be enforced in advance, while the nonlinear dependence of the coefficients can be enforced as constraints in the solution process. It is more convenient to use only the leading term of the displacement asymptotic field at the tip of a cohesive crack (which ensures a displacement discontinuity normal to the cohesive crack face) as the enrichment function, as in most implementations of the XFEM in the literature. The complete implementation with several examples can be found in Xiao et al. (2007).

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ESIS Procedures and Documents

Two kinds of documents are produced by ESIS Technical Committees with the following designatory system: ESIS P2-92 or ESIS P4-92D, where:

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P1-92
ESIS RECOMMENDATIONS FOR DETERMINING THE FRACTURE RESISTANCE OF DUCTILE MATERIALS.
Responsible body: TC1 Subcommittee on Fracture Mechanics Testing Standards.

P2-92
ESIS PROCEDURE FOR DETERMINING THE FRACTURE BEHAVIOUR OF MATERIALS.
Responsible body: TC1 Subcommittee on Fracture Mechanics Testing Standards.

P3-03D
DRAFT UNIFIED PROCEDURE FOR DETERMINING THE FRACTURE BEHAVIOUR OF MATERIAL.
Responsible body: TC1 Subcommittee on Fracture Mechanics Testing Standards (UNDER PREPARATION NOT AVAILABLE).

P4-92D
ESIS RECOMMENDATIONS FOR STRESS CORROSION TESTING USING PRE-CRACKED SPECIMENS.
Responsible body: TC10 Committee on Environmental-Assisted Cracking.

P5-00/VAMAS
PROCEDURE FOR DETERMINING THE OF FRACTURE TOUGHNESS OF CERAMICS USING THE SEVNB METHOD .
Responsible body: TC6 Committee on Ceramics.

P6-98
ESIS PROCEDURE TO MEASURE AND CALCULATE MATERIAL PARAMETERS FOR THE LOCAL APPROACH TO FRACTURE USING NOTCHED TENSILE SPECIMENS.
Responsible body: TC8 Committee on Numerical Methods.

P7-00
ESIS PROCEDURE FOR DYNAMIC TENSILE TESTS
Responsible body: TC5 Subcommittee on Dynamic Testing at Intermediate Strain rates.

P8-99D
ESIS DRAFT CODE OF PRACTICE FOR THE DETERMINATION AND INTERPRETATION OF CYCLIC STRESS-STRAIN DATA.
Responsible body: TC11 Committee on High Temperature Mechanical Testing.

P9-02D
GUIDANCE ON LOCAL APPROACH OF RUPTURE OF METALLIC MATERIALS.
(UNDER PREPARATION NOT AVAILABLE).

P10-02
A CODE OF PRACTICE FOR CONDUCTING NOTCHED BAR CREEP RUPTURE TESTS AND INTERPRETING THE DATA.
Responsible body: TC11 High Temperature Mechanical Testing Committee.

P11-02
TECHNICAL RECOMMANDATIONS FOR THE EXTREME VALUE ANALYSIS OF DATA ON LARGE NONMETALLIC INCLUSIONS
Responsible body: TC20 Committee on Inclusions.

D1-92
FRACTURE CONTROL GUIDELINES FOR STRESS CORROSION CRACKING OF HIGH STRENGTH ALLOYS.
Responsible body: TC10 Committee on Environmental Assisted Cracking.

D2-99
FRACTURE TOUGHNESS OF CERAMICS USING THE SEVNB METHOD; ROUND ROBIN, TEST PROGRAMME.
The ESIS TC6 and VAMAS TWA3 developed a test method and conducted a round robin for its validation. D2-99 presents a detailed documentation of this activity. The final form of the test method has appeared as P5-00.
Responsible body: TC6 Committee on Ceramics.

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