EDITORIAL BY THE ESIS PRESIDENT

The last meeting of the ESIS Executive Committee (ExCo) took place on December 4, 2015 in Catania, Italy. Recall that the Committee consists of myself as President, Francesco Iacoviello and Aleksandar Sedmak, the two Vice Presidents, Bamber Blackman, Secretary, Giuseppe Ferro, Treasurer, Valery Shlyannikov, Publications Manager, Zhiliang Zhang, Liaison to other organizations, and Per Ståhle, Blogger. An excellent meeting took place.

At this meeting, we discussed the ESIS contract with Elsevier which we signed for an additional two years. We added another journal to the affiliated journals; our journals include: Engineering Failure Analysis, Engineering Fracture Mechanics, International Journal of Fatigue and Theoretical and Applied Fracture Mechanics. We encourage you to publish your articles in these journals. The ExCo discussed the financial support which ESIS will be giving
for young and/or needy scientists to attend ECF21 in Catania. The support of 20,000 € has been earmarked for this purpose in the form of a waiver of the conference registration fees.

The statutes were discussed once again with three changes recommended. First, we are returning to the issue of ‘one person, one vote’. At Council meetings, it is suggested that any particular member have only one vote. If a member of Council has two positions which would entitle him/her to vote twice, one of the votes will be given to another person to represent a National Group or a TC. Second, it is suggested to do away with proxy votes. Both of these steps have been suggested to make the Council more democratic. Finally, an additional type of ESIS membership class will be suggested: university membership class. The ExCo approved all of these changes and they will be brought to the ESIS Council at ECF21 in Catania for a vote.

ESIS is requested to support many conferences, most of which are part of TC or National Group activities. In order to coordinate the dates so as to avoid conflicts, the ExCo has suggested to TC and National Group Chairs to coordinate their meetings with Aleksandar Sedmak.

Since our last Newsletter, our blogger, Per Ståhle, has posted a review of an additional paper:


This is an interesting paper which I recommend to you. In addition to the review by Per, there is a response by the first author. We welcome your comments which may be posted in the blog: http://imechanica.org/node/9794

As you may recall, ESIS has made an additional contract with Elsevier. This year, Elsevier will begin publishing Procedia Structural Integrity which will contain proceedings resulting from ECF meetings, TC meetings and National Group meetings. The first issue will be published by the Portuguese National Group. In order to encourage TCs and National Groups to take advantage of this option, ESIS will support part of the publication costs.

Please note: the next ECF conference will take place in Catania, Sicily, from June 20 to June 24, 2016. The ExCo supported Francesco Iacoviello’s proposal to video record the plenary sessions at ECF21. These videos will be put on youtube. To date, 700 abstracts have been submitted. Recall that ESIS presents awards at each ECF conference. The awards include: the Griffith medal, the Wöhler medal, the Award of Merit, Honorary Membership and ESIS-Elsevier Young Scientist Award (first and second prize). The Awards Committee is chaired by Francesco Iacoviello; its members are: Donka Angelova, Nenad Gubeljak, Antonio Martin-Meizoso, Nikita Morozov, Hrihory Nykyforchin, Reinhard Pippan, Aleksandar Sedmak, Gordon Williams and Zhiliang Zhang. The Fellows Committee is chaired by myself; the members are Francesco Iacoviello, Aleksandar Sedmak and Zhiliang Zhang. There will be a summer school before the meeting taught by Sylvie Pommier, Donato Firrao, Mimoun Elboujdaini, Daniele Dini and Timon Rabczuk. Recall that ESIS members receive a 50€ discount on the registration fee. The website is: http://www.ecf21.eu. So mark your calendars. I look forward to seeing you in Catania.

Leslie Banks-Sills
4 Elsevier journals are affiliated with ESIS

| ![Engineering Failure Analysis](image1) | ![International Journal of Fatigue](image2) |
| ![Engineering Fracture Mechanics](image3) | ![Theoretical and Applied Fracture Mechanics](image4) |
## Special Issues 2014-16

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National Committees

Portugal

The International Conference on Structural Integrity is the first of a series of biennial regular conferences on this scientific topic, of such relevance to all engineers concerned with structural integrity. The 2015 conference was organized by INEGI, with the support of ESIS Portuguese National Committee and the Fracture Division of the Portuguese Society of Materials at Madeira, in one of the most emblematic hotels in the Island which is also a living tribute to one of the greatest architects of all times: Oscar Niemeyer. As announced at the closing session, the biennial ICSI conference will remain resident in Funchal, Madeira.

Hot topics in the realm of Structural Integrity addressed at ICSI2015 included: Fracture and Fatigue; Stress Analysis; Damage Tolerance; Crack Closure; Nanoscale Damage; Material Ageing; Friction Stir Welding and associated problems; Other welding related problems; Health Monitoring; Image Processing for SHM; New Materials; Structural Integrity in Biomechanics.

A total of 156 abstracts were submitted, 113 of which were accepted. Six plenary lectures were presented by extraordinary people, well-known in their own fields. All accepted manuscripts were published on Procedia Engineering Volume 114, pages 1-876 (2015), and a special issue of the Elsevier journal Engineering Failure Analysis is under preparation.

The ICSI board acknowledges the support of the Regional Government and the sponsorship of INEGI, ESIS, SPM, EURASEM, MRA, and Quality Park Aviation Centre.

Pedro Moreira
Paulo Tavares

Sweden

The Swedish fatigue network – UTMIS arranged a course on 22-23 of October at Sandvik Materials Technology in Sandviken, Sweden. The course with the title “Very high cycle fatigue and the fatigue limit: significance of microstructurally short fatigue cracks” was given by Prof. Ulrich Krupp, University of Applied Sciences Osnabrück in Germany. 81 participants joined the event.

Jörgen Larsson

Switzerland

The Swiss ESIS Group is planning their next annual one day meeting on April 6, 2016 (jointly with the Structural Integrity Group of SVMT) at the RMS Foundation in Bettlach, Switzerland. The meeting language will be German. The invitation with the call for contributions will be mailed in Spring 2016. People interested in participating (but not on the mailing list of SVMT) or desiring further information are kindly asked to contact the Swiss National Representative, Andreas J. Brunner (andreas.brunner@empa.ch, www.empa.ch).

Andreas J. Brunner

TECHNICAL COMMITTEES

TC 3: Fatigue Of Engineering Materials And Structures

ACTIVITIES in the years 2015-2016

(a) Professor Andrea Carpinteri (Parma, Italy), Professor Les Pook (Sevenoaks, UK), Professor Luca Susmel (Sheffield, UK) and Professor Roberto Tovo (Ferrara, Italy): Chairmen of the 5th International Conference on Crack Paths (CP 2015), held in Ferrara, Italy, 16th to 18th September, 2015.

(b) Professor Andrea Carpinteri (Parma, Italy), Professor Ali Fatemi (Toledo, USA) and Professor Carlos Navarro (Seville, Spain): Chairmen of the 11th International Conference on Multiaxial Fatigue and Fracture (ICMFF11), to be held in Seville, Spain, 1st to 3rd June, 2016.

(c) Professor Roberto Brighenti (Parma, Italy), Professor Andrea Carpinteri (Parma, Italy), Professor Ali Fatemi (Toledo, USA) and Professor Luca Susmel (Sheffield, UK): Guest Editors of a Special Issue of Engineering Fracture Mechanics entitled “Crack Paths 2015”, with papers selected from those presented at the 5th International Conference on
Crack Paths (CP 2015), held in Ferrara, Italy, 16th to 18th September, 2015.

(d) Professor Filippo Berto (Padua, Italy), Professor Andrea Carpinteri (Parma, Italy), Professor Sabrina Vantadori (Parma, Italy) and Professor Michael Vormwald (Darmstadt, Germany): Guest Editors of a Special Issue of International Journal of Fatigue entitled “Fatigue Crack Paths 2015”, with papers selected from those presented at the 5th International Conference on Crack Paths (CP 2015), held in Ferrara, Italy, 16th to 18th September, 2015.

The 5th International Conference on Crack Paths (CP 2015)
Ferrara, Italy, 16-18 September, 2015

Professor Andrea Carpinteri (Parma, Italy), Professor Les Pook (Sevenoaks, UK), Professor Luca Susmel (Sheffield, UK) and Professor Roberto Tovo (Ferrara, Italy) have organised the 5th International Conference on Crack Paths (CP 2015), held in Ferrara (Italy) from 16th to 18th September, 2015 (Website: www.CP2015.unipr.it), under the auspices of ESIS (European Structural Integrity Society).

The Este castle in Ferrara

CP 2015 has followed the Crack Paths Conferences in Parma (2003 and 2006), Vicenza (2009), and Gaeta (2012). Special issues of international journals have been devoted to the research studies presented at the first four Crack Paths Conferences. Special Issues of two International Journals (that is, Engineering Fracture Mechanics and International Journal of Fatigue) with extended versions of selected papers presented at CP 2015 are being edited.

The CP 2015 Conference has been sponsored by ESIS (the European Structural Integrity Society) together with various Organisations and Institutions: the University of Ferrara, the University of Parma, the University of Sheffield, the German Association for Materials, Research and Testing, the French Society for Metallurgy and Materials, the American Society of Testing and Materials, the Italian Group of Fracture, and the RUMUL Resonant Fatigue Testing Machines.

Two esteemed members of the Conference Scientific Committee have been honored during the Conference: Professor Ewald Macha, who worked at Opole University in Poland and was Chairman of the ESIS Committee on Multiaxial Fatigue for many years (he died in July 2014); Professor Paolo Lazzarin from the University of Padua in Italy, who was Editor of the Int. J. Fatigue and Fracture of Engineering Materials and Structures for 3 years (he died in September 2014).

Andrea Carpinteri
Les P. Pook
**TC 5: Dynamics of fracture and structural transformations**

TC5 meeting was organized during ICM12 in Karlsruhe, Germany. The meeting was attended by several ESIS/TC5 members.

The main topic of discussion was reinvigoration of TC5 activities.

The following actions were suggested:

- to use the platform of ECF (European Conference on Fracture) - starting with the next meeting in 2016 in Catania, Italy - for consolidation of the dynamic-fracture activities by organizing dedicated sessions;
- to consider organizing special events (e.g. EUROMECH Colloquia) in years without ECF meetings;
- to put emphasis on participation of early-stage researchers in these events;
- to invite industrial partners to these events;
- to approach ESIS regarding the possibility of sending out information about the TC5's "new start" and invitation to the ECF Special Session in Dynamic Fracture to all ESIS members;
- to support self-organization of interest groups of TC5 members, creating, if needed, respective subcommittees.

As a result, Minisymposium “Dynamic Fracture” (chaired by Y. Petrov and V. Silberschmidt) was included in the ECF21 program (see [http://www.ecf21.eu/](http://www.ecf21.eu/)).

Six topics were chosen as points of special interest of TC5 within its scope:

1) Dynamics of fracture in brittle long-range ordered materials (brittle crystals): study of energy-speed relationship for a single crack (theoretical, experimental and numerical); fracture mechanisms along a crack front; the effect of a reflected stress wave.

2) Dynamics of fracture via atomistic simulations to understand the atomistic scale of dynamic fracture.

3) Metamaterials with special performances in dynamics and dynamic testing protocols for specially engineered materials, which might require non-standard measurements.

4) Application of the incubation-time approach to quasi-brittle materials.

5) Development of new engineering standards and recommendations for testing the strength of materials undergoing high-rate dynamic deformation. The development of a standard testing procedure providing a set of material properties should be accompanied by elaboration and dissemination of simple (easily applicable in engineering practice) criteria capable of reliable prediction, based on the measured material properties and strength of material/structure undergoing dynamic deformation.

6) Dynamic fracture of composites.

Prof. Vadim Silberschmidt (Loughborough University, UK) was elected to serve as TC5 vice-chairman and Dr Vladimir Bratov (St. Petersburg State University, Russia) was elected to serve as TC5 secretary.

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**TC 11: High Temperature Mechanical Testing**

The ESIS TC 11 committee activities:

- The already announced 3rd TMF-Workshop 2016 was extended to 2,5 days. Thus the date changed to 27-29th April, 2016. At the workshop there is some space for some more posters. The deadline is January 31th, 2016.

- The 69th HTMTC-meeting will take place in conjunction with the 3rd TMF-Workshop on Friday 29th April 2016 at BAM, Berlin, Germany. The meeting will start in the afternoon. The time will be determined.

- A seminar on Low Rupture Ductility of Materials (Metallurgical considerations, modeling, testing) will be held on June 2-3, 2016, at Burleigh Court, University of Loughborough, UK. The seminar is jointly organized by IOM3 and HTMTC.
At the last meeting of TC24, held on 1-2 October 2014 at Politecnico di Milano, excellent talks presented results obtained within different research projects, including EURAXLES - EBFW3 and SUSTRAIL.

A selection of those contributions may be found in a special issue of Int. J. Fatigue that is to be published in the next Volume 86. I have had the pleasure of being the Guest Editor of this Special Issue entitled "Railway axles: design & maintenance" with ten papers that draw from state-of-the-art results in research about new fatigue design concepts and on durability and maintenance of railway axles.

This issue consists of two topics: four papers concerning the improvement of fatigue design of axles and six contributions on new results about the inspection period and NDT control. These two fields of interests move from the current standards EN131303 and EN13104, which on the one hand prescribe a simple fatigue assessment based on beam theory calculations. On the other hand, the many threats that may occur during a 30-year service are left to a ‘protection and maintenance policy applied to the axle that ensures the efficiency of the protection against impact and corrosion throughout the life of the axle and ensures that the original surface condition of the axle material is maintained’ (quote from EN13103-13104).

With a bit of pride, I can say that – as the papers collected in this issue prove – the railway axles went from the problem at the origin of our discipline, into a European excellence of industry-driven research and products. As a matter of fact most of the high speed trains and wheelsets are designed and produced by European companies.

The next meeting of TC24 will be organized in Leoben (Austria) by H.P. Ganser (Materials Center Leoben) and Prof. R. Pippan (Eric Schmid Institute of Material Science) 8-9 November 2016 at the Materials Center Leoben. The meeting will be devoted to advances in crack propagation modelling and damage tolerance of railway components. Further information about the meeting will be posted on the ESIS and TC24 websites.

Stefano Beretta
Volodymyr PANASYUK
On the 90th Birthday

Volodymyr Panasyuk is a well-known Ukrainian scholar in the field of mechanics and physics of materials and structural integrity, Academician of the National Academy of Sciences of Ukraine (since 1978), Doctor of Sciences (Eng.) (since 1967) and Professor (since 1968).

Prof. Panasyuk was born on February 27, 1926 in the village of Krasne (now the Lublin region, Poland). In 1951 he graduated from the Lviv State University (Faculty of Physics and Mathematics) and since that time he has been working at the Physico-Mechanical Institute of the National Academy of Sciences of Ukraine in Lviv. From 1971 to 2014 he held the position of Director of the Institute.

Prof. Panasyuk has made a significant contribution to the formation of the basis of the theory of brittle fracture and strength of materials and founded Lviv School of Mechanics in this branch of science. He has conducted original research on the stress-strain state and limiting equilibrium of elastoplastic bodies with cracks, contact problems in the theory of elasticity, problems of the physicochemical mechanics of materials. He is also the author of the well-known δc-model which is widely used in fracture mechanics. A great part of his studies is devoted to the development of new methods for assessment of strength and durability of engineering materials and critical structures.

Prof. Panasyuk authored more than 600 papers, including 17 monographs. Among them there is the first book in Eastern Europe on the problems of fracture (Panasyuk V. V. Limiting Equilibrium of Brittle Solids with Cracks – Kyiv: Naukova Dumka, 1968, in Russian; – Detroit; Michigan: Manag. Inform. Ser., 1971, in English). His monograph "Strength and Fracture of Solids with Cracks" (2002), published under auspices of ESIS, also received wide recognition. He has personally supervised 47 PhD and 18 dissertations for the degree "Doctor of Sciences" which were prepared and successfully defended. Since 1978 he is Editor-in-Chief of the International Journal “Physicochemical Mechanics of Materials” (Ukraine) and the

English version of this journal published by “Springer” under title “Materials Science”.

Prof. Panasyuk has always given significant attention to strengthening international scientific collaboration and organisation of international conferences, symposia and workshops on different aspects of fracture mechanics and structural integrity. He was the Chairman of the ICF 8 Organizing Committee, which was held in Kiev (1993). There he presented the ICF8 Honour Lecture and he was awarded the Diploma of the International Congress on Fracture Mechanics. He was also elected the ICF Vice-President (1993–1997).

Prof. Panasyuk is the winner of the State Prize of Ukraine in Science and Engineering (1995). He was awarded the prizes of the National Academy of Sciences of Ukraine named after outstanding scientists of Ukraine (1974, 1994 and 2002). He has the honorary title “Doctor Honoris Causa” of Wroclaw University of Technology (Poland, 1998) and several Ukrainian National Universities.

Since 1992 Prof. Panasyuk is the Head of the Ukrainian National Group of ESIS. He is co-founder of the Polish-Ukrainian-German Summer Schools on fracture mechanics and structural integrity, which in 2002 received the status of ESIS Summer Schools on fracture mechanics in Central and Eastern Europe. His outstanding contribution in the development of fracture mechanics of materials and strength of engineering structures was marked by the Griffith Medal of the European Structural Integrity Society (2000).

The ESIS community heartily congratulates Prof. Panasyuk with his jubilee and wishes him the best of health and further success in his remarkable activity in the area of fracture mechanics and structural integrity.

Hryhorii M. Nykyforchyn
### CALENDAR OF TC MEETINGS & ACTIVITIES

| TC24 | October 2016 | TC24 meeting | Leoben, Austria | stefano.beretta@polimi.it |

### CALENDAR OF CONFERENCES & WORKSHOPS

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<td>Fourteenth International Conference on Fracture (ICF14)</td>
<td>Rhodes, Greece</td>
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<td>June 27-29, 2017</td>
<td>Eighth International Conference on Low Cycle Fatigue (LCF8)</td>
<td>Dresden, Germany</td>
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<tr>
<td>July 3-5, 2017</td>
<td>Seventh International Conference on Very High Cycle Fatigue (VHCF7)</td>
<td>Dresden, Germany</td>
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<tr>
<td>August 26-31, 2018</td>
<td>22nd European Conference of Fracture (ECF22)</td>
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**ESIS Summer School**  
**Understanding and modelling fracture and fatigue of materials and structures**  
**18-19 June 2016, Catania, Italy**  

Fracture mechanics and fatigue are broad disciplines dealing with the structural integrity of materials. Their importance in the design of traditional engineering materials and structures is well established, but their applications to new areas are constantly emerging. Nowadays, despite the wealth of literature and textbooks in the field, there is a need for schools which can convey the fundamental knowledge of fracture mechanics and fatigue to younger generations in order to fully exploit the potential of the disciplines in understanding and modelling the mechanical behaviour of materials and structures, and in assessing their integrity.

Following the first edition in Trondheim, an ECF summer school will be organized in Catania, with four leading scientists presenting different issues in the field of fracture mechanics and fatigue. The summer school is mainly aimed at PhD students, young researchers and engineers, but is naturally open to everybody. Participants will become acquainted with fundamental aspects, modelling and practical applications of fracture mechanics and fatigue. The program will contain lectures on topics related to fracture mechanics methods for the modelling of fatigue crack growth, to the role of fractography in the assessment of fatigue crack growth, and to hydrogen-induced and environmental cracking in steel. Moreover, a lecture on fatigue behaviour and assessment in contact mechanics problems will be offered. The summer school will terminate with a comprehensive overview of the state-of-the-art on computational methods for fracture.

**Summer School Secretariat and Registration**  
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Fatigue Thresholds for Engineering Applications

Reinhard Pippan

Erich Schmid Institute of Materials Science, Austrian Academy of Sciences and Department of Material Physics, Montanuniversität Leoben, Jahnstr.12, A-8700 Leoben, Austria

Most engineering structures contain flaws or crack like imperfections ab initio. The design methodology that takes this into account is the damage tolerant approach. In the case of fatigue loading it ensures that the inherent cracks will not propagate to failure either within the design life or between inspection periods. The concepts are based on a fracture mechanics description of fatigue crack growth and they depend on the applications. The lifetime prediction and determination of inspection periods by the damage tolerant concept are widespread in engineering design in the aerospace and transport industries, offshore exploration, the nuclear industry, pressure vessel design, etc.

The materials database of this approach comprises the fatigue crack growth curves: (i) in terms of parameters $C$ and $m$ of the Paris relation

$$\frac{da}{dN} = C\Delta K^m$$

where $da/dN$ is the crack growth rate, $\Delta K$ is the stress intensity range and $C$ and $m$ are material constants; (ii) the real fatigue crack growth curves; or (iii) approximations of these curves.

The consequent application of this methodology to determine the non-propagation condition of inherent cracks should allow the prediction of the endurance limit of components. The material parameter for such an approach is the threshold stress intensity range, $\Delta K_{th}$. Despite the vast amount of research work in the field of threshold stress intensity range, the application of $\Delta K_{th}$ for infinite life design with fracture mechanics methods is limited. Furthermore, it should be noted that the application of $\Delta K_{th}$ in standard damage tolerant design concepts in the case of finite life design under variable amplitude loading, with a significant amount of load cycles in the near threshold regime, is also underdeveloped. Nevertheless, there are a large number of engineering components that need to be designed for infinite life and in the case of standard damage tolerant design very often a relatively large number of load cycles corresponds to stress intensity ranges, $\Delta K$, in the near threshold regime.

The reasons for this limited application of $\Delta K_{th}$ are:

- many applications fall into the short-crack regime, where cracks can propagate below the standard measured $\Delta K_{th}$ (see Suresh 1998);
- there exists no standard procedure to determine the length where a long-crack threshold can be used;
- there is a lack of nondestructive techniques to detect sufficiently small flaws with high accuracy;
- and the knowledge of load interaction effects in the near threshold regime is unsatisfactory.

This article will focus on the application of the threshold concept for the “extrinsically” short-crack regime and the transition to the long-crack behavior. It is appropriate first to define the terms extrinsic and intrinsic crack growth resistance, short and long cracks, and the $R$-curve for fatigue threshold. The present paper is an extended version of short review about the engineering application of the fatigue threshold by Pippan 2001 in Encyclopedia of Materials: Science and Technology.

General Remarks

Extrinsic and Intrinsic Threshold

Microstructure and environment significantly affect the threshold and near threshold behavior. A vast number of mechanisms are responsible for this effect. The different mechanisms which lead to different contributions to the threshold can be divided into two groups (Ritchie 1988), the most important are schematically depicted in Fig. 1(a). The first group is that of the intrinsic mechanisms, which determine the inherent resistance of a material to fatigue crack propagation at a certain crack driving force. In metals the intrinsic threshold seems to be determined by the onset of the cyclic plastic deformation at the crack tip (Pippan 1991). The second group is that of the extrinsic mechanisms, which cause a local reduction or local increase in the crack driving force at the crack tip, and are therefore often called shielding mechanisms or anti-shielding mechanism, respectively. The most discussed extrinsic mechanisms in metals that influence the fatigue crack propagation near the threshold are crack deflection and branching, different crack closure.
mechanisms (plasticity, roughness, and corrosion-debris-induced crack closure), and crack bridging (see Suresh 1998).

Figure 1. Schematic representation of the contributions of the different mechanisms to the threshold of stress intensity range (a) and its change as a function of the crack extension (b) where ∆Kcs th is the contribution of contact shielding at the threshold

Short and Long Cracks

For long cracks there exists a unique relation between the stress intensity factor, ∆K, and the crack growth rate da/dN for a given stress ratio, R=K_{min}/K_{max}. In the case of short cracks this similitude breaks down. The problem for engineering applications is that short cracks (usually) propagate faster than long cracks and they can propagate below the threshold of long cracks measured in standard experiments (ASTM Standard E647 1993). In order to classify the observed behavior and identify the applicability of concepts it is helpful to divide the different types of short cracks into groups (Suresh 1998); microstructurally, mechanically, chemically, and extrinsically small cracks. Microstructurally short cracks are smaller than the characteristic length scale of the microstructure, macro continuum mechanics is inappropriate to describe the crack driving force in this case. With mechanically short cracks the plastic zone is no longer within the K dominated stress field, i.e., the plastic zone size is not small in relation to the crack length. Therefore, the linear elastic fracture mechanics (small-scale yielding) relation between ∆K and the cyclic plastic deformation at the crack tip - which controls the fatigue crack propagation in metals - breaks down. Most extrinsic mechanisms (crack closure mechanism) act in the wake of the crack tip. Cracks smaller than a certain critical value cannot build up the full shielding, and are called extrinsically small cracks (often designated as physically small cracks). A typical example of such extrinsic short crack behavior measure on deep sharp notches with constant stress intensity range in pure Fe is shown in Figure 2. It is interesting to note that for very short cracks the crack growth rate is independent of the stress ratio R, which indicate that the R-ratio effect in ductile metals is solely induced by crack closure. Finally, cracks can also be small compared to the characteristic length scales involved in chemical transport at the crack tip; in this case they are classified as chemically small cracks.

Figure 2. Fatigue crack propagation rate, da/dN, as a function of crack extension, ∆a, determined on deep sharp notches in ARMCO iron, (a) shows the typical result for ∆K values below and above the long crack threshold (Pippan, Berger et al. 1987), (b) shows the results at different R ration in log scale for ∆a
**R-curve**

The R-curve is defined as the plot of the resistance to fracture versus crack extension. For monotonic loading—for which the R-curve concept had been developed originally—the critical energy release rate, the fracture toughness $K_c$, or the critical crack tip opening displacement are used as resistance parameter. In the case of fatigue the R-curve can be defined as resistance of a material to fatigue crack propagation (in the case for non-propagation condition this is characterized by $\Delta K_{th}$) versus crack extension. The application of the standard fracture mechanics R-curve procedure allows the prediction of the propagation/non-propagation condition for materials and loading conditions where a length-dependent threshold has to be taken into account (Pippan and Stüwe 1987, Tanaka and Akinawa 1988, Tabernig et al. 1999).

**The Length Dependence of $\Delta K_{th}$**

As mentioned, mechanically short cracks cannot be described by linear elastic fracture mechanics (LEFM) and in microstructurally short cracks many local microstructural parameters (which usually cannot be considered in an engineering application) have to be taken into account and very often the standard LEFM breaks down. Therefore, $\Delta K_{th}$ can only be used for the prediction of long cracks and extrinsically short cracks. For typical structural materials this means that an application of $\Delta K_{th}$ is only possible down to flaw sizes of a few ten micrometers for high strength materials and few hundred micrometers for low strength materials. Many research studies (e.g., Romaniv et al. 1981, Pineau 1986, Pippan et al. 1987, Tanaka and Akinawa 1988) show that the threshold of stress intensity increases with increasing crack length and reaches a constant value after a certain crack extension which can be interpreted as the R-curve for the threshold of stress intensity range. The reason for this increase of threshold is mainly induced by an increase of crack tip shielding due to crack closure as indicated in Fig. 1(b), because each extrinsic contribution to $\Delta K_{th}$, which originated in the wake of the crack tip, needs a certain crack extension to build up its shielding capacity.

A typical example is depicted in Figure 2. From such data a fatigue resistance curve, $\Delta K$ versus $\Delta a$, for different crack growth rates, $da/dN$, can be deduced as illustrated in Figure 3a. Figures 3b, c and d show the used sample for a short crack growth experiment, the experimental observed extension of the crack at different constant load amplitudes, and the resulting $da/dN$ vs $\Delta K$ data for short and long crack experiment, respectively. The crack driving forces for the three constant load experiments are also indicated in Figure 3a.

![Figure 3. Illustration of the application of an R-curve concept to short fatigue cracks. From short crack data as shown in Figure 2 a R-curve for fatigue crack propagation can determined (a) (Pippan et al. 1987), (b), (c) and (d) show the investigated short crack sample and the observed crack growth behavior. The crack driving forces for three constant load amplitude experiments are also indicated in (a). The comparison of the experimentally observed crack propagation rates (d) and R-curve prediction (a) are in very good agreement (Pippan and Stüwe 1987)](image-url)
A comparison of the growth rate in Figure 3a and 3d shows the good agreement of the R-curve prediction and the experimental short crack data. The $\Delta K$ versus $\Delta a$ curve for $da/dN=10^{-9}$ mm/cycle can be interpreted as the R-curve for the threshold of stress intensity range.

Till now no standard procedure to measure such R-curves for the threshold exists. A possible method is to measure directly the change of the extrinsic contribution of the threshold with the crack extension (Tanaka and Akinawa 1988). In metals it is usually sufficient to measure the change of the stress intensity factor where the crack closes. Unfortunately, this measurement is associated with a relatively large amount of uncertainty. A simple method is the measurement of the change of crack extension, a reduction of crack growth rate, and maybe a stopping of the crack, should occur. This can then be used to determine the contribution of crack tip shielding and the R-curve for $\Delta K_{th}$ (Pippan et al. 1987, Tabernig et al. 2000).

An experimental procedure based on this idea is depicted in Figure 4. Standard fracture mechanics specimens can be used. The specimen is pre-cracked in cyclic compression. The crack originates from the notch, similar to the crack initiation in cyclic tension, but then decreases progressively until the crack stops propagating completely. The advantage of pre-cracking specimens in cyclic compression is that the pre-crack is usually open when unloaded, i.e., no crack closure takes place at the beginning of the real crack growth test. Since the pre-crack is not perfectly plane, a certain amount of crack tip shielding, induced by crack deflection or crack branching, cannot be avoided. In order to minimize this deflection shielding, a possible shielding due to crack bridging, and to reduce the effect of pre-deformation in front of the pre-crack, the use of very short pre-cracks on very sharp notches is helpful. Extremely sharp notches, with a root radius smaller than 10 µm, can be machined, for example, by razor blade polishing. The load amplitude to initiate a pre-crack in such a case corresponds to $\Delta K$ values in the order of the threshold (Tabernig et al. 2000). The threshold test for a constant load ratio is then performed by increasing the load amplitude in steps until the threshold value of the long crack is reached. If the load amplitude corresponds to a $\Delta K$ which is smaller than a certain critical value, the crack will not grow. The first propagation is observed when $\Delta K$ is larger than this critical value. If crack closure is the dominant shielding mechanism, this critical value is equal to the effective threshold $\Delta K_{eff \, th}$, the threshold of a crack without shielding induced by crack closure or bridging. Therefore, this technique usually allows determination of an upper and lower bound for $\Delta K_{eff \, th}$.

At the load steps where the amplitudes correspond to a $\Delta K$ which is larger than $\Delta K_{eff \, th}$ and smaller than the long-crack threshold, the crack starts to propagate and stops at a certain extension. The reduction of the growth rate until arrest is caused by the increase of crack closure or other shielding mechanisms. Finally, there is a step where the crack does not stop. At this load amplitude the increase of the stress intensity range by crack extension is larger than the increase of the effect of crack tip shielding. From then on the test can be continued to measure the conventional $da/dN$ vs. $\Delta K$ diagram. The stress intensity factor ranges, $\Delta K$ where the crack stops for the last time, and the $\Delta K$ where the crack does not stop growing, provide an upper and a lower bound for the long-crack threshold of stress intensity range. A plot of the extension of the crack where it stops growing versus the corresponding $\Delta K$, gives the R-curve for the threshold. Typical R-curves measured with this technique for different R-ratios are depicted in Figure 5.

As already mentioned it is important to perform such R-curve measurements on pre-cracks which are open and without residual stresses (or as small as possible). By generation of such pre-cracks in cyclic compression it is essential to apply the smallest possible load amplitude with a large number of load cycles, because the pre-crack should propagate through...
the main part of the compression affected zone and this zone should be as small as possible. By reducing the notch root radius too few microns and using pre-crack lengths in the same order of magnitude the effect of pre-cracking on the resulting R-curve for the threshold of stress intensity is negligible (Tabernig et al. 2002).

Figure 5. R-curve of the fatigue crack growth threshold of a 20% SiC particle reinforced 359T6 aluminum alloy at the load ratio R = -1.0, 0.1, and 0.6 (Tabernig et al. 2000).

(a)

Fatigue Limit as a Function of Defect Size: Application of the R-curve Concept

According to the R-curve procedure for monotonic loading the resistance curve is drawn into the crack driving force diagram ($\Delta K$ vs. $a$, see Figure 6(a) or Figure 3(a)). The difference between the origin of the R-curve and the origin of the driving force diagram is set equal to the equivalent defect size. Assuming a through surface defect and further assuming that the component width is much larger than the defect size, the crack driving force is given by $\Delta K = 1.12 \Delta \sigma (\pi a)^{1/2}$, where $\Delta \sigma$ is the stress amplitude and $a$ is the total crack length. The crack driving forces for different constant stress amplitudes are also plotted in Figure 6:

At smaller stress amplitudes the crack may propagate at first but it should arrest after a certain extension which is determined by the intersection of the two curves. At larger load amplitudes the driving force is always larger than the resistance (threshold of stress intensity range). Hence, such a component should fail. The $\Delta K$ versus crack length curve which is tangential to the R-curve gives the fatigue limit for the given defect size.

Suppose that the shape of the R-curve is independent of the initial crack length, a shift of the R-curve in the driving force diagram to different defect sizes permits the simulation of the influence of defect size on the fatigue limit. A plot of the fatigue limit vs. defect size is designated in the Kitagawa diagram. Figure 6(b) shows an example of such a diagram. The dotted line represents the estimated fatigue limit obtained by the R-curve of Fig. 5. The regime below this line should be safe and no failure should occur. The material was a 20% SiC particle-reinforced 359T6 cast aluminum alloy, containing relatively large defects. The standard fatigue experiments on smooth specimens exhibited a large scatter, which could be attributed to the scatter in the defect size (Tabernig et al. 2000). The determined equivalent defect size of the tests performed near the fatigue limit are also plotted in Fig. 6(b) (open symbols for run-out and solid symbols for failed specimens, respectively). It is evident that the experimental results are in good agreement with the predicted boundary curve separating the safe and the fatigue failure regime. Maierhofer et al. 2013 and 2015 have extended this concept to describe the fatigue limit and the fatigue crack growth behavior for extrinsically short cracks in a more general term.

Figure 6. Representation of R-curve of the 20% SiC particle reinforced 359T6 aluminum alloy for R = -1.0 and the crack driving force, $\Delta K$, for different stress amplitudes, $\Delta \sigma$, to predict the fatigue limit.

(a) The Kitagawa diagram resulting from an assumed initial defect size of 1 mm (fatigue limit vs. equivalent defect size). (b) The defect size of a smooth specimen tested near the fatigue limit (after Tabernig et al. 2000).
different approaches are suggested to estimate the fatigue limit or the fatigue life in cases with a significant number of cycles in the near threshold region with standard long-crack threshold values, e.g., with lower limit values obtained at large R-ratios (e.g., Brook 1984).

**Concluding Remarks**

The technique as described here permits the prediction of the behavior of extrinsically short cracks and, in addition, it indicates where the long-crack threshold can be applied. It is based on a resistance curve (R-curve) for the threshold of stress intensity range. Such R-curves can be measured easily by a stepwise increase of the load amplitude on standard fracture mechanics specimens containing pre-cracks with a minimum extrinsic shielding of the crack tip (e.g., produced by cyclic compression).

**Bibliography**


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