VHCF-6

6th International Conference on Very High Cycle Fatigue

October 15-18 2014 · Chengdu, China

Conference Handbook

Organized by

Qingyuan WANG & Youshi HONG

Sponsored & supported by

Conference Venue

The conference take place in **Homeland Hotel** in Chengdu, as shown in the map. The Homeland hotel is a five-star hotel, locate just 6 minutes from Chengdu Shuangliu International Airport and 15 minutes from downtown. And the hotel offers extensive range of accommodations. Besides, free Internet access is provided.

On Wednesday 15th October, from 8:00 to 14:00, registration will take place in Homeland Hotel. The registration desk will be situated in the lobby of the hotel. The registration desk is also the help desk if you have any questions.

How to find us

At Chengdu Shuangliu International Airport, there are conference volunteers show you the way to the hotel. You can easily recognize them by their T-shirt with a logo of Sichuan University, as shown in below. Also, they will serve at the conference venue, if you have any questions about the conference or accommodation, you can ask them

Co-sponsors

Contents

VHCF-6
Chengdu

Foreword

On behalf of the **Organizing Committee**, we would like to welcome all participants to the sixth international conference on Very High Cycle fatigue (VHCF-6) event from Oct. 15-18, 2014, Chengdu, China.

Most of the experimental studies on fatigue of structure materials are usually limited to testing period between 10^7 to 10^8 cycles, and unexpected fatigue failures have been recorded for some structural components which were assumed to have a fatigue limit. It was concluded that the fatigue life of numerous aeronautic, locomotive, automotive and biomedical structures may go beyond 10^8 cycles. A growing interest in the investigation of extreme high cycle fatigue behavior is basically from the expectation of reduction in environmental impact and enhanced economic efficiency of the components which drives the new design to reach very high fatigue lives. Long life fatigue behavior determination, damage evaluation and understanding of fracture mechanisms become extremely important for better selection of materials and improvement of design the components and structures.

The VHCF conferences are international leading conference series on the ultra-long fatigue behavior of materials. It hosts scientists, engineers and engineering designers from all over the world and aims to provide a worldwide platform to exchange and present latest findings and ideas. VHCF-6 continues the trend of successful previous conferences started with VHCF-1 in 1998, organized by Prof. Claude Bathias in Paris, followed by VHCF-2 in 2001 organized by Prof. Stefanie Stanzle and Prof. Herwig Mayer in Vienna, VHCF-3 in 2004 organized by Prof. Sakai and Prof. Yasou Ochi in Kusatsu, VHCF-4 in 2007organized by Prof. J. Wayne in Ann Arbor, VHCF-5 in 2011 organized by Prof. Christina Berger and Prof. Hans-Jürgen Christ in Berlin.

On behalf of the Scientific Committee and Conferences Organizers, we would like to thank all the authors and session chairs for their important contributions to the conference. Prof. Claude Bathias should be appreciated here for his profound support to the conference and as a founder of this series of conferences. The previous chairmen of the conferences are acknowledged for their valuable suggestions. Appreciation should be given to those who have spent substantial time and energy on this handbook: Mr. Shaoxiong XIE ,Mr. Lang LI., Dr.Dongliang ZHANG, Mr. Fang HOU, Mr. Shaobo YANG. Mr. Shiming CUI, Ning ZHANG, Dr. Jackie Lee, Mr. Yu CHEN and Miss Renhui TIAN.

Conference chairmen

Professor Q.Y. Wang
Sichuan University, China
Chengdu University, China

Professor Y.S. Hong
Chinese Academy of Sciences, China

Local Information

"Once you come to Chengdu, you do not want to leave"

——Chengdu Images

Chengdu, the capital of Sichuan province, lies in the hinterland of the Chengdu Plain, in central Sichuan. As one of famous historical and cultural cites in China, Chengdu attracts a large amount of domestic and overseas visitors. Giant pandas, spicy Sichuan cuisine and the local leisurely and carefree lifestyle are some of Chengdu's major attractions, but the capital of southwestern Sichuan province is also justifiably proud of its appeal to foreign investors. Until now, Chengdu have attracted the presence of 212 Fortune 500 companies, including Intel, Texas Instruments and Dell, surpassing all other cities in China's central and western regions.

The provincial capital was chosen to host the 2013 Fortune Global Forum, making it the third city in the mainland to hold the major business event after Shanghai and Beijing. Chengdu's robust economic growth in recent years has attracted an increasing number of business travelers.

However, we will give you some basic information about transport, facilities around the meeting place and some sites you may need to know. Please remember that **taxi is the best way to go sightseeing in the center of Chengdu**, unless you are able to have a guide with you. If you lose the way back, do not be shy and ask enthusiastic people around you for help, or call our session volunteers.

It takes about only 10min from Airport to the hotel by taxi.

A: Homeland Hotel, the place holding our conference.

B: Chengdu Shuangliu International Airport, where special volunteers are offered to meet the participants.

Instructions for Presenters

All the conference rooms have been equipped as standard with the audio-visual equipment. Laptop is running Windows OS with PowerPoint and Adobe reader. Laser pointers will also be available in each conference room. If you intend to use animations in the presentation, please bring the movie files with you as well.

On the day of your presentation, you should report to the session chairman or support staff in the appointed conference room prior to the first report in the session. At that time, you can upload your presentation in a PDF or PPT file to the laptop of conference room, by using a memory stick or CD-Rom. You may wish to use your own laptop – if this is the case your are still required to attend in advance to check that the presentation will work. Please note, you should remember the time for your presentation and make sure that you will be present 5 minutes early in order to introduce yourself to conventioneers.

If you are absent at that time, the session chairman will proceed the session with skipping your presentation. If you come later, you can only begin your presentation after the ongoing one is over, according to the arrangement of the session chairman.

With the exception of the keynote and invited presentations, the time slot for each presentation is limited within 20 minutes. You should therefore aim to speak for 15 minutes, leaving the remaining 5 minutes available for questions.

Plenary Speakers

Prof. Claude Bathias
Paris X Nanterre University. France

Claude Bathias is currently Emeritus professor of Paris X Nanterre University since 2007. Prof. Claude Bathias served in SNIAS and "Service Technique des Constructions et Armes Navales" as engineer from 1972 to 1978 and 1978 to 1986 respectively and Aérospatiale as engineer consultant from 1978 to 1985. At the same time, He is the Head of the Materials Dept at DGRST Ministry for Research from 1978 to 1982, Advisor at Ministry for Defence from 1983 to 1986 and Advisor at AFNOR, CTIF, ANVAR, DGXII at Brussels from 1985 to 2000.

He was professor at University of Compiègne from 1974 to 1988. Subsequently from 1988 to 2007, he was Professor "Classe Exceptionnelle" at Conservatoire National des Arts et Métiers, School of Science & Technology for Engineering, Director of ITMA and head of the MS Education (Material Engineering). His research expertise is Very High Cycle Fatigue. He is Founder of several international conferences among them: International Conference on Fatigue of Composite and Very High Cycle Fatigue Conference.

He has published over 100 papers; contributed to 200 Publications and supervised 60 PhD students.
He was awarded Oppenheim Award from Engineer and Scientific of France in 1978, Recipient Chevalier of "Ordre National du Mérite" in 1983, Fellow of American Society for Metals in 1986, Award from National Research Institute for Metals of Tokyo in 1988 and Fellow of American Society for Mechanical Engineering in 2007.

Prof. Tatsuo SAKAI
Ritsumeikan University. Japan

Tatsuo SAKAI is currently a professor of Ritsumeikan University. He has long been working as the director of the Research Center for Advanced Materials Technology in Ritsumeikan University. He has been played the role of chairmen of many domestic and international committees such as organizing committee of the international conference of VHCF-3 and the Committee on Reliability Engineering in the Society of Materials Science in Japan. His current research interests are in fatigue properties of structural materials in the very high cycle regime, mechanisms of fatigue crack initiation and propagation, effects of microstructure and environments, databases of material properties and reliability engineering for the mechanical structures. He has long been working in the above wide range of the research areas as a member of the following societies; The Society of Materials Science, Japan, The Japan Society of Mechanical Engineers, The Japan Society for Design Engineering and The International Research Group for Statistical Aspects on Materials Strength and so on.
Prof. T. SAKAI has published over 200 papers in refereed journals and 50 papers in conference proceedings in the areas of fatigue, reliability engineering, fracture mechanics and mechanical design. Some of his papers were well cited in International Journals. Prof. T. SAKAI was awarded “Award of Annual Best Paper” from the Society of Materials Science in 1983 in Japan, “Award of Annual Best Paper”, from the Japan Society of Mechanical Engineers in 2003, “Award of Academic Achievements” from Japan Society for Design Engineering in 2005,” Award of Academic Achievements, Committee on Reliability Engineering” from the Society of Materials Science, in 2009, “Award of Annual Leading Technology” from the Society of Materials Science in 2009, “Award of Annual Leading Technology” from the Japan Society of Mechanical Engineers in 2014.

Plenary Speakers

Prof. Herwig Mayer
University of Natural Resources and Life Sciences, BOKU. Austria

Herwig Mayer is professor of applied physics at BOKU University in Vienna. He studied Technical Physics and completed his PhD at the Technical University of Vienna. He performed several research stays at international universities (University of Shizuoka, Japan; University of Pennsylvania, USA; University of Michigan, USA) and research institutions (Ford Research Laboratories, Dearborn, USA; GM Research and Development Centre, Warren, USA).

His main interest in the field of VHCF is the development of the ultrasonic fatigue testing method. His aims are to reach high precision and to extend the capabilities of the ultrasonic method. Recent developments of his group are variable amplitude testing with constant load ratio, cyclic torsion testing with mean load and early detection of fatigue damage using non-linear acoustics. Cyclic properties of a broad variety of materials are investigated mainly with the ultrasonic technique, including high strength steels, cast and wrought aluminium and magnesium alloys, titanium alloys, composites etc.

Prof. Hong Youshi
Institute of Mechanics , Chinese Academy of Sciences. China

Youshi Hong is a Professor of the Institute of Mechanics (IMECH), Chinese Academy of Sciences (CAS). He was the Director of IMECH-CAS between 1998 and 2006 and is the Chairman of Academic Degree Committee of the Institute. He is Editor-in-Chief for “Fatigue & Fracture of Engineering Materials & Structures”; and Associate Editor-in-Chief for “Science China - Physics, Mechanics & Astronomy”. He is Vice President for “Chinese Society of Theoretical and Applied Mechanics”.

His research fields are mechanical behavior of materials, fracture mechanics and structure mechanics. His main research achievements are related to: effects of second phase particles on deformation, fracture and stress corrosion cracking of steels; analyses of stress intensity factors and plastic zone sizes for notch-cracks and fatigue crack growth from a circular notch under biaxial stress; mechanism and modeling of collective damage evolution process of initiation and propagation for short fatigue cracks; mechanical behavior of submicron/nanometer crystalline metallic materials; and high-cycle and very-high-cycle fatigue behavior of metallic materials. He has published 260 papers in academic journals and conference proceedings, and has obtained 13 Chinese patents. He received a First Grade Award of Natural Science of CAS (1996), and a National Second Grade Award of Natural Science (2013).

Plenary Speakers

Prof. Martina Zimmermann
Technical University of Dresden. Germany

Martina Zimmermann is a full professor in the field of materials testing and characterization at the Technical University of Dresden since 2012 and at the same time the group leader of the group materials characterization at the Fraunhofer Institute of Materials and Beam Technology at Dresden.

Prof. Zimmermann studied mechanical engineering at the University of Siegen from 1990-1996 and received her PhD-degree in 2001 (Dr. -Ing.) in the field of engineering design at the University of Siegen. She continued working as group leader in the field of fatigue design of weldments till 2004, then changed to the materials science department and built up research activities and laboratory regarding VHCF as senior research group leader. She did research at the University of Michigan, USA as visiting research fellow from 2009 to 2010. Her research interests are fatigue, mechanical behavior of materials, weldments, composites and surface engineered structures, simulation of microstructural damage, failure analysis, experimental fracture analysis, fatigue of biomaterials. She was awarded the research fellowship of the German Research Foundation (GRF). She is the reviewer for the GRF and various international journals and sub-coordinator of the GRF priority program 'infinite life' on VHCF research, the member of the editorial board of the MSEA journal, alumna and tutor of the German renown foundation 'Studienstiftung'.

Prof. Wang Qingyuan
Sichuan University. China

Qingyuan Wang is a full Professor of Sichuan University since 2001, and currently the President of Chengdu University. His research activity is focused on Very High Cycle Fatigue, Mechanical Behavior of Structural Materials and Structures under Cyclic Loading, Composite Repairs of damaged Structures. He received his PhD in 1998 from Ecole Centrale Paris, France, followed by postdoctoral experience from 1999 to 2003 in Faculty of Engineering of Purdue University, and JSPS fellow at Kagoshima University, Japan. Prof. Wang has published over 150 technical papers in refereed journals and conference proceedings in the areas of Mechanics, Materials, and Structures. Dr. Wang was Enlisted Scientist for “100 Talents Program” of Chinese Academy of Sciences in 2003. He received the First class Natural Science Award of Research on VHCF in 2006 from National Ministry of Education (MOE), the special award of Chinese central government in 2008, and National Science Fund for Distinguished Young Scholars in 2009. He served as co-chief editor for Chinese Journal of Experimental Mechanics, editorial Committee member for Fatigue Fracture Eng Mater Structures, etc. He is co-chairman of organizing committee for VHCF6-2014.

Plenary Speakers

PhD candidate Jason Geathers
University of Michigan. USA

Jason Geathers is a 4th year PhD candidate in the Mechanical Engineering program at the University of Michigan working with Professor Samantha Daly in the Mechanical Engineering Department and Professor J. Wayne Jones in the Materials Science Engineering Department. Mr. Geathers earned a Bachelor of Science in applied physics from Morehouse College in Atlanta, GA, USA and Bachelor of Science in Engineering and Master of Science in Engineering degrees in mechanical engineering from the University of Michigan in Ann Arbor, MI, USA.

His current research focuses on the small-scale examination of deformation mechanisms active in structural materials during very high cycle fatigue (VHCF). More specifically, he is developing a combined ultrasonic fatigue and scanning electron microscopy system to study fatigue crack nucleation and early crack growth behavior in titanium alloys in the VHCF regime.

Mr. Geathers was awarded the Rackham Merit Fellowship and School of Engineering scholarship from the University of Michigan in recognition of his outstanding academic achievements. He was also awarded 1st Place honors in the 2014 Society of Experimental Mechanics International Student Paper and Presentation Competition.

Dr. Bernd SCHÖNBAUER
University of Natural Resources and Life Sciences, BOKU. Austria

Bernd Schönbauer is a research scientist and lecturer at the Institute of Physics and Material Sciences at the University of Natural Resources and Life Sciences (BOKU), Vienna. He studied Technical Physics and earned his PhD at the Vienna University of Technology. His research interests are fatigue and fracture mechanics of different materials with main expertise in corrosion fatigue, pit-to-crack transition and very high cycle fatigue using the ultrasonic testing technique. The research activities in VHCF resulted in numerous publications in international journals and oral presentations at scientific conferences.
He will undertake a research stay at the University of Fukuoka at the beginning of next year where he will investigate fatigue crack initiation at small defects.

Plenary Speakers

Prof. Andrey Shanyavskiy
State Centre for Civil Aviation Safety Flight. Russia

Andrey Shanyavskiy is a professor at both Moscow State University of Civil Aviation and Moscow State University of Aviation Technology. He entered State Centre for Civil Aviation Safety Flight since 1970 and currently is the Chief of Aviation Material Research Division and Vice-Head of Central Testing Laboratory Certified by Russian Gosstandard. Professor Andrey Shanyavskiy is a Member of DVM and ESIS, TC2 - "Mechanisms" - committee of ESIS. He is also a member of Advisory Board of Russian Journal "Dynamics of Complicated Systems". His area of Science interests are flight safety, failure analyses of structures (aircrafts, engines pipe-lines and est.), fracture surface analyses, quantitative fractography, physical approach for different damages investigation, mechanisms of metals cracking, physical and synergetics application for modelling (reproducing from fractography) metals manner of in-service cracking (corrosion, creeping, wearing, fatigue, and est.), multiaxial fatigue, variable amplitudes loading, simulation of fatigue cracking under irregular cyclic loads, very- (or ultra) high-cycle fatigue, fractal dimensions analyses.

Professor Andrey Shanyavskiy was awarded by ESIS because of best papers that were published in Journal "Fatigue and Fracture of Engineering Materials and Structures" in 1997-1998 , Merited Inventor of USSR in 1986 and Merited Science Worker of Russian Federation in 2001. He has published Science Works – more than 380, including 3 books.

Prof. Norio Kawagoishi
Daiichi Institute of Technology. Japan

Norio Kawagoishi is a professor at Daiichi Institute of Technology and a professor emeritus of Kagoshima University. He received the M.A. degree in Mechanical Engineering from Kagoshima University in1972 and Ph. D from Kyushu University in 1985. His research interests are Fatigue properties of metals in long life region, Fatigue fracture mechanism in various environments and Surface modification of metals.

He is a member of The Japan Society of Mechanical Engineers and The Society of Materials Science, Japan.

Prof. Norio Kawagoishi was awarded "Award for scientific papers of The Japan Society for Heat Treatment" in 2001, "JSMS Award for Technical Developments" and "Distinguished Prize for branch office" by the Society of Materials Science in 2009 and 2011 respectively.

Plenary Speakers

Prof. Thierry PALIN-LUC
Institute of Mechanics and Mechanical Engineering (I2M). FRANCE

Thierry PALIN-LUC is full professor at Institute of Mechanics and Mechanical Engineering (I2M) at Arts et Métiers ParisTech since 2008. Engineerin (I2M). He received his engineer diploma at ENSAM in 1991 and did master research in Mechanics of Bordeaux 1 University in 1992. In 1996, he completed his PhD at ENSAM on the subject : " Multiaxial fatigue of spheroidal graphite cast iron under combined loadings" in cooperation with RENAULT.

His research interests are very high cycle fatigue, multiaxial fatigue under constant and variable amplitude, interaction between the fatigue life of structures and manufacturing processes.

He was the head of the "Fatigue of Materials and Structures" activity of LAMEFIP from 2004 and deputy director of this laboratory from 2005 to 2010.Subsequently Since 2011 he is the head of the Department Durability of Materials, Assemblies and Structures of the Institute of Mechanics and Mechanical

Scientific Committee

Chairman

Q. Y. Wang — Sichuan University/Chengdu University — China
Y. S. Hong — Chinese Academy of Sciences — China

International Advisory Board

M. de Freitas — Instituto Superior Tecnico — Portugal
G. Dominguez Almaraz — Universidad Michoacana de San Nicolas de Hidalgo (UMSNH) — Mexico
M. N. James — University of Plymouth — UK
S. Beretta — Department of Mechanical Engineering — Italy
Y. Hong — Chinese Academy of Sciences — China
P. Liaw — The University of Tennessee, Knoxville — USA
D. G. Harlow — Lehigh University, 19 Memorial Drive West — USA
J. M. Larsen — Wright Patterson Air Force Base — USA
H. Mayer — BOKU — Austria
J. W. Jones — University of Michigan — United States
E. Macha — Opole University of Technology — Poland
Y. Murakami — Kyushu University — Japan
C. Berger —Techniseche Universitat Darmstadt — Germany
H. Mughrabi —University of Erlangen-Nurnberg — Germany
Y. Ochi —University of Electro-Communications — Japan
D. McDowell — School of Materials Science & Engineering Georgia Institute of Technology — USA
A. Navarro — Escuela Superior de Ingenieros, Universidad de Sevilla — Spain
J. Petit — LMPM, UMR CNRS 6617, ENSMA, 86961 Chasseneuil-Futuroscope — France
T. Nakamura — Hokkaido University — Japan
P. C. Paris — Washington University at Saint Louis — USA
K. Schulte — TU Hamburg-Harburg, Institut M-11 Polymer Composites — Germany
T. Palin-Luc — Arts et Metiers ParisTech, I2M, UMR CNRS, Esplanade des Artset Metiers — France
T. Sakai — Ritsumeikan University — Japan
S. Stanzl-Tschegg — University of Natural Resources and Life Sciences (BOKU) — Austria
R. O. Ritchie — University of California, Berkeley — USA
K. Shiozawa — College of Engineering, University of Toyama — Japan
H. W. Zoch — Stiftung Institut fur Werkstofftechnik (IWT) — Germany
A. Shanyavskiy — The State Center for Flights Safety of Civil Aviation — Russia
Q. Y. Wang — Sichuan University/Chengdu University — China
K. Tanaka — Meijo University — Japan
C. Bathias — LEEE/ITMA University Paris X at Ville d'Avray — France
E. H. Han — Institute of Metal Research, Chinese Academy of Sciences — China
Y. S. Pyun — Sun Moon University — Korea

C. M. SUH — Kyungpook National University — Korea
Kawagoishi N. — Kagoshima University — Japan
G. C. Chai — Sandvik Materials Technology — Sweden
H. J. Christ — Universitat Siegen — Germany

Local Scientific Committee

E. H. Han — Chinese Academy of Sciences — China
Y. S. Hong — Chinese Academy of Sciences — China
S. X. Li — Chinese Academy of Sciences — China
Z. F. Zhang — Chinese Academy of Sciences — China
G. P. Zhang — Chinese Academy of Sciences — China
P. Y. Huang — South China University of Technology — China
Q. Y. Wang — Sichuan University/Chengdu University — China
H. Q. Xue — Northwestern Polytechnical University — China
L. T. Lu — Southwest Jiaotong University — China
Z. G. Wang — Chinese Academy of Sciences — China
X. S. Wang — Tsinghua University — China
W. X. Yao — Nanjing University of Aeronautics and Astronautics — China
N. Yan — China Three Gorges University — China

Organizing Committee

Z. Y. Huang — Sichuan University — China
C. X. Huang — Sichuan University — China
Kashif — Sichuan University — China
Y. J. Liu — Sichuan University — China
H. D. Fan — Sichuan University — China
X. S. Shi — Sichuan University — China
C. Wang — Sichuan University — China
J. F. Dong — Sichuan University — China
J.K. Lee — Sichuan University — China

Conference Program

Wednesday, 15th Oct, 2014

8:00-14:00	**Registration**

14:00-14:20	**Opening Plenary** ➢ Qingyuan WANG

Honour Lecture (Chairman: **H.J.Christ)**	
14:20-15:00	● Fatigue limit of metals ➢ Claude Bathias ■ France
15:00-15:40	● Microscopic and Nanoscopic Observations of Metallographic Structures around Inclusions at Interior Crack Initiation Site in Very High Cycle Fatigue ➢ Tatsuo SAKAI, Noriyasu OGUMA, Akinari MORIKAWA, and Akira UENO ■ Japan

15:40-16:00	**Coffee break**

Invited Lecture (Chairman: **J.W.Jones)**	
16:00-16:30	● Ultrasonic torsion fatigue of VDSiCr spring steel at different load ratios and comparison to cyclic axial loading ➢ H. Mayer, R. Schuller, D. Irrasch, M.Fitzka, U.Karr, M.Hahn, M.Bacher-Höchst ■ Austria
16:30-17:00	● Characteristic Dimension and Related Mechanism of Crack Initiation and Early Growth for Very-High-Cycle Fatigue ➢ **Y.S. Hong** ■ China

17:00-17:55	**VHCF Commitee Meeting**

18:00-20:00	**Dinner**

Thursday, 16th Oct, 2014

Invited Lecture (Chairman: **C. Bathias)**	
08:00-08:30	● Characterization of Failure Relevant Defects in Aluminium Weldings under VHCF Loading Conditions ➢ M. Zimmermann ■ Germany
08:30-09:00	● A review: The Most Influential Articles in Very High Cycle Fatigue ➢ QingYuan Wang, Muhammad Kashif Khan ■ China
09:00-09:30	● Investigating Microstructural and Environmental Effects on VHCF Crack Formation in Ti-6242 ➢ **J. Geathers (Jones)** ■ USA
09:30-10:00	● Fracture Mechanical Characterization of Interior-Fatigue-Cracks ➢ **B.Schönbauer(S. Tschegg)** ■ Austria

10:00-10:20	**Coffee break & Photo**

Invited Lecture (Chairman: **T. Sakai)**	
10:20-10:50	● Transition from VHCF to HCF, Subsurface "FGA" Forming and Metals Cracking in VHCF Regime ➢ A.Shanyavskiy ■ Russia
10:50-11:20	● Growth Behavior of a Fatigue Crack of High Strength Al Alloys under Ultrasonic Loading ➢ Norio KAWAGOISHI, Qingyuan WANG, Xishu WANG and Kohji KARIYA, Qiang CHEN ■ Japan
11:20-11:50	● Influence of production process of Ti-6Al-4Mo titanium alloy on crack initiation mechanisms in Very High Cycle Fatigue regime ➢ Alexander Nikitin, Thierry Palin Luc, Andrey Shanyavskiy and Claude Bathias ■ France /Russia

11:50-12:50	**Lunch**

	Salle-B (Chairman: **A.Shanyavskiy)**	**Salle-C** (Chairman: **G.Chiandussi)**
13:30-13:55	● Construction of Electronic Database on Very High Cycle Fatigue Properties for Metallic Materials ➢ Tatsuo Sakai, Koushu Hanaki, Akiyoshi Sakaida, Kenji Okada,Yuki Nakamura, Kazutaka Mukoyama, Noriyasu Oguma,Takashi Matsumura, Yoshinobu Shimamura, and Akira Ueno ■ Japan	● Frequency effects in high cycle fatigue for polycrystalline pure copper ➢ MARTI Nicolas, SAINTIER Nicolas, RANC Nicolas, FAVIER Véronique ■ France

13:55-14:15	● Very high cycle fatigue behavior of riblet structured high strength Al alloy thin sheets ➢ Sebastian Stille, Tilmann Beck and Lorenz Singheiser ■ Germany	● Microstructural Features Controlling Very High Cycle Fatigue of Nitrided Maraging Steel ➢ An Verdiere, V. Bliznuk , L.A.I. Kestens and Roumen Petrov ■ Belgium
14:15-14:35	● Fatigue Characteristics of Aluminum Alloy (A7075-T651) treated by Shot Peening and UNSM under Ultrasonic and Rotary Bending Fatigue Tests ➢ Chang-Min SUH, Min-Soo SUH, Youngsik Pyun, and Seung-Hoon Nahm ■ Korea	● Development of a fatigue life prediction concept in the very high cycle fatigue range based on microstructural features ➢ Anton Kolyshkin, Edgar Kaufmann, Martina Zimmermann and Hans-Jürgen Christ ■ Germany
14:35-14:55	● Effect of hot isostatic pressing on very high cycle fatigue behavior of DZ4 directionally solidfied Ni-base supreralloy ➢ Baohua Nie, Zheng Zhang, Zihua Zhao and Qunpeng Zhong ■ China	● High temperature ultrasonic fatigue testing for Ti-17 ➢ J. K. Li, Y. J. Liu, Q. Y. Wang, F. Hou ■ China
14:55-15:15	● A new piezoelectric fatigue testing machine in pure torsion for gigacycle regime ➢ Alexander Nikitin ● France	● Effects of stress ratio on very-high-cycle fatigue property of a high-strength steel ➢ Xiaolong Liu, Chengqi Sun, Youshi Hong ■ China
15:15-15:35	● Effect of Ultrasonic Nanocrystal Surface Modification on Very High Cycle Fatigue Behavior of Steel and Titanium Alloys ➢ Muhammad Kashif Khan, Liu Yongji, Qing Yuan Wang, Young Shik Pyoun, Ravil Kamyrouv ■ China/ Pakistan	● Evaluation of multiple-flaw failure of bearing steel 52100 in the VHCF regime ➢ Klaus Burkart, Hubert Bomas, Brigitte Clausen, Hans-Werner Zoch ■ Germany

15:35-15:50	**Coffee break**

	Salle-B (Chairman: **M. Zimmermann)**	**Salle-C (**Chairman: **H.Mayer)**
15:50-16:15	● Duplex S-N fatigue curves: statistical estimation of model parameters ➢ D.S. Paolino, A. Tridello, G. Chiandussi, M. Rossetto ■ Italia	● A basic study on the formation of the fine grained area during very high cycle fatigue ➢ Guocai Chai, Tomas Forsman and Fredrik Gustavsson ■ Sweden
16:15-16:35	● High and Very High Cycle Fatigue Behaviour of an Austenitic-Ferritic Duplex Stainless Steel, Part 1: Experimental Investigation ➢ Marcus Söker, Anne Kathrin Hüsecken, Benjamin Dönges, Alexander Giertler, Ullrich Pietsch, Claus-Peter Fritzen, Hans-Jürgen Christ, Ulrich Krupp ■ Germany	● Analysis of Fatigue Crack Initiation and Size Effect on Fatigue Life of a Cast Aluminum Alloy in Very Long Life Cycles ➢ Hongqian Xue, Qian Tao, Weiwei Chen, Claude Bathias ■ China
16:35-16:55	● Influence of heat treatment temperature on VHCF strength of helical compression springs ➢ Isabell Brunner, Matthias Oechsner, Brita Pyttel, Desislava Veleva ■ Germany	● Stress Concentration in Fibre Reinforced Composite Plates ➢ Chensong Dong ■ Australia
16:55-17:15	● The fatigue mechanism to derermine the general relation between very high cycle fatigue strength and tensile strength ➢ Jianchao Pang ■ China	● Influence of stress ratio and environmental surface degradation on the VHCF behaviour of steam turbine blade steels ➢ Bernd M. Schönbauer, Andrea Perlega, Stefanie E. Stanzl-Tschegg ■ Vienna

17:15-17:35	● Investigation of the influence of test frequency and heat treatment on the fatigue life of EN AW-6060 in the VHCF-regime ➢ Christian Fischer, Enrico Bruder, Rainer Wagener, Clemens Müller,Tobias Melz ■ Germany	● Study on Very-High-Cycle-Fatigue Property of Aero-engine Blades Based on Subcomponent Specimen ➢ Shengbo Jiao, Li Cheng, Quantong Li, Ke Qu, JunYu Gao, Lulu Feng, Haitao Zhang ■ China
17:35-17:55	● Very high cycle fatigue behaviors of AA6061-T6 aluminum alloy friction stir butt welds with ultrasonic loading ➢ Chao HE, Yongjie LIU, Renhui TIAN, Jiukai LI, Qingyuan WANG ■ China	● VHCF damage behavior of metastable austenitic stainless steel: microstructure-sensitive modeling and simulation ➢ Philipp-Malte Hilgendorff, Andrei Grigorescu, Martina Zimmermann, Claus-Peter Fritzen, Hans-Jürgen Christ ■ Germany
17:55-18:15	● Method to determine early internal fatigue crack initiation in cast steel 42CrMo4 (QT) by in situ thermography measurements ➢ Dominik Krewerth, Anja Weidner, Horst Biermann ■ Freiberg	● Study on the Fatigue Properties of the TIG Weld Joint with the Stainless Steel Conduit in Aircraft ➢ Dongjie Li ■ China

18:00-20:00	**Dinner and Conference Evening**

Friday, 17th Oct, 2014

	Salle-B (Chairman: **V. Favier)**	**Salle-C** (Chairman: M.Bruchhausen**)**
08:00-08:25	● Ultrasonic Fatigue Performance of High Temperature Structural Material Inconel 718 Alloys at High Temperature after UNSM Treatment ➢ Young-Sik Pyun, Jun-Hyong Kim, Chang-Min Suh, In-Sik Cho, Joo-Yeon Oh, Qingyuan Wang, Muhammad Kashif Khan ■ South Korea	● Cyclic deformation and damage behavior of Ti6Al4V in the Very High Cycle Fatigue Regime ➢ Stefan Heinz, Guntram Wagner, Dietmar Eifler ■ Germany
08:25-08:45	● A Review of VHCF Behaviors of Non-inclusion Induced Crack Initiation of Bainite/Martensite Duplex-phase High Strength Steels ➢ Ping zhao ■ China	● Very high cycle fatigue behavior of titanium alloy at elevated temperatures ➢ Zhao Zihua, Ma Jing, Nie Baohua，Zhang Zheng ■ China
08:45-09:05	● A Study on Very High Cycle Fatigue Property of High Strength Steel (KNS-ES) for Particular Mechanical Use ➢ Tatsuo Sakai, Yasuo Ochi, Shoichi Kikuchi, Hiroshi Tanaka, Fumiharu Ikaiand Kazutaka Okumoto ■ Japan	● Fatigue initiation and strength of duplex stainless steel strip specimens in the very high cycle fatigue regime ➢ Muhammad Waqas Tofique, Jens Bergström, Nils Hallbäck, Christer Burman ■ Sweden
09:05-09:25	● Finite Element Dynamic Analysis of an Al6061 Specimen in Ultrasonic Fatigue test ➢ No-Jun Myeong, Hena Kown, Nak-Sam Choi ■ Republic of Korea	● Very High cycle fatigue property of austempered ductile iron ➢ Jiwang Zhang, Qingpeng Song , Ning Zhang, Liantao Lu , Dongfang Zeng , Mintang Zhang, Guodong Cui ■ **China**

09:25-09:45	● Review of study on the Fatigue in the Very high cycle fatigue regime ➢ Bolin He, Zongmin Lv ■ China	● Comparative study on the fatigue damage evolution of a stable and a metastable austenitic stainless steel in the VHCF regime ➢ Andrei Grigorescu, Philipp-Malte Hilgendorff, Martina Zimmermann, Claus-Peter Fritzen, Hans-Jürgen Christ ■ Germany
09:45-10:05	● Influence of hydrogen and deoxidation technique on the fatigue behaviour of steel SAE 52100 in the VHCF regime ➢ Torben Karsch, Brigitte Clausen, Hans-Werner Zoch ■ Germany	● Study on very high cycle fatigue test method of Titanium Alloy ➢ ZHANG Hai-tao, CHEN Wei, LI Quan-tong,Gao Xing-wei, Feng Lu-lu, Jiao Sheng-bo ■ China

10:05-10:20	**Coffee break**	
	Salle-B (Chairman: **N.Kawagoishi)**	**Salle-C (**Chairman: T.Palin-Luc**)**
10:20-10:45	● Effect of solute atoms content in carbon manganese steels on the self heating during gigacycle fatigue tests ➢ Zhiyong Huang, Nicolas Ranc, Danièle Wagner ■ France	● Dominant Factors for Very High Cycle Fatigue of High Strength Steels ➢ HisaoMatsunaga, Chengqi Sun, Youshi Hong, Yukitaka Murakami ■ Japan
10:45-11:05	● Dissipation in very high cycle fatigue for single phase ductile metals: comparison between b.c.c anf f.c.c structures ➢ Antoine Blanche, Chong Wang, Ngoc Lam Phung, Nicolas Ranc, Véronique Favier, Danièle Wagner, Claude Bathias, André Chrysochoos ■ France	● Very long life fatigue behavior of implant Ti-6Al-4V in air and simulated physiological environments ➢ Yong-jie LIU, Jiu-kai LI , Chao HE and Qing-yuan WANG ■ China

11:05-11:25	● A very high cycle fatigue thermal dissipation and dispersion investigation for titanium alloy TC17 ➢ Zhi Yong Huang, Qing Yuan Wang, Danièle Wagner, Claude Bathias ■ China	● In situ nonlinear ultrasonic for very high cycle fatigue damage characterization of a cast aluminum alloy ➢ Wenkai Li , Haitao Cui', Xuming Su, C.C. Engler-Pinto Jr, Weidong Wen ■ China
11:25-11:45	● Advances in ultrasonic tests for fatigue strength and crack growth on thin sheet steels ➢ Mohand Ouarabi, Ruben Perez Mora, Thierry Palin-Luc, Claude Bathias[b] ■ France	● High and Very High Cycle Fatigue Behaviour of the Austenitic-Ferritic Duplex Stainless Steel X2CrNiMoN22-5-3 Part 2: Mesoscopic Modeling ➢ Benjamin Dönges, Claus-Peter Fritzen, Hans-Jürgen Christ ■ Germany
11:45-12:05	● Very High Cycle Fatigue Resistance ($N>10^7$) of Middle- and High Strength Heat Treatment Conditions of 42CrMo4 ➢ M.Korn, T. Rohm, K.-H. Lang ■ Germany	● Research Progress of very high cycle fatigue for high strength steels ➢ Bolin He, Kang Wei ■ China
12:05-12:25	● Irreversible deformation of VHCF crack initiation mechanism on α-ferrite ➢ Chong WANG, Qingyuan WANG, Danièle WAGNER, Claude BATHIAS ■ China	● Failure mechanism in ultrasonically fatigued aluminum matrix composites ➢ Matthias Wolf, Guntram Wagner, Dietmar Eifler ■ Germany

12:30-13:10	**Lunch**

	Salle-B (Chairman: **D. Wagner)**	**Salle-C** (Chairman: **H. Matsunaga)**
14:00-14:25	● Very high cycle fatigue property of high-strength austempered ductile iron at 90 Hz and 20KHz loading ➢ Liantao Lu, Ning Zhang, Jiwang Zhang, Dongfang Zeng, Mintang Zhang ■ China	● Cyclic tension VHCF properties of nitrided 18Ni maraging steel sheets ➢ R.Schuller[1], H. Mayer, M. Fitzka, D. Tran, B. Pennings ■ Austria
14:25-14:45	● Impact of high-pressure hydrogen on the fatigue life of steel A-286 ➢ Matthias Bruchhausen, Burkhard Fischer, Ana Ruiz, Peter Hähner,Sebastian Soller ■ Netherlands	● Very high cycle fatigue of carbon fiber reinforced polyphenylensulfide by high power ultrasonics ➢ Daniel Backe, Frank Balle, Dietmar Eifler ■ Germany
14:45-15:05	● The Rotary Bending Fatigue and Ultrasonic Fatigue Performance of Ti-6Al-4V ELI and STA alloys after Ultrasonic Nanocrystal Surface Modification Treatment ➢ Young-Sik Pyun, Jun-Hyong Kim, Chang-Min Suh, In-Sik Cho, Joo-Yeon Oh, Qingyuan Wang, Muhammad Kashif Khan ■ South Korea	● Effects of Low Temperature Nitriding Process on the Very High Cycle Fatigue Properties of Ti-6Al-4V Alloy ➢ Shoichi Kikuchi, Stefan Heinz, Dietmar Eifler, Yuta Nakamura and Akira Ueno ■ Japan
15:05-15:25	● Study on the Model of Ultra-high Cycle Fatigue Destruction due to Curving Vibration after the Surface Strengthening ➢ FENG Lu-lu，LI Quan-tong，GAO Xing-wei，TONG Xu-dong，ZHANG Hai-tao，JIAO Sheng-bo ■ China	● Investigating the VHCF of composite materials using new testing methods and a new fatigue damage model ➢ Paul Lorsch, Till Julian Adam, Marcel Zeisberg, Michael Sinapius, Peter Horst, Raimund Rolfes, Peter Wierach and Heiko Krüger ■ Germany
15:25-15:45	● Influence of cyclic loading on damage behavior at twin and grain boundary in FCC materials during very high cycle fatigue ➢ Guocai Chai ■ Sweden	● A Monte Carlo simulation of specimen size effect on fatigue life ➢ Chengqi Sun, Xiaolong Liu, Youshi Hong ■ China

15:45-16:05	● Development and Several Additional Performances of Dual-Spindle Rotating Bending Fatigue Testing Machine GIGA QUAD ➢ TaizohYamamoto, Akio Kokubu,Tatsuo Sakai, Yuki Nakamura ■ Japan	● Interior-induced Fracture Mechanism of Valve Spring Steel (JIS SWOSC-V) with High Cleanliness in Very High Cycle Regime ➢ Taku MIURA, Takayuki SAKAKIBARA, Takanori KUNO, Akira UENO, Shoichi KIKUCHI and Tatsuo SAKAI ■ Japan

16:05-16:20	**Coffee break**

	Salle-B (Chairman: **Y.S. Pyun)**	**Salle-C** (Chairman: **Q.Chen)**
16:20-16:45	● Behavior of Fine Granular Area Formation of Bearing Steel in Rotating Bending Fatigue Process ➢ Noriyasu OGUMA, Naoya SEKISUGI, Yasuhiro ODAKE and Tatsuo SAKAI ■ Japan	● VHCF behavior of a ferritic-martensitic steel at high mean stresses ➢ Tilmann Beck, Stephan A. Kovacs ■ Germany
16:45-17:05	● Influence of High-Cycle Fatigue on Crater Wear Characteristics of Cemented Carbide Tool ➢ SONG Xiaoqi, Junnosuke SAIGAWA, Tohru IHARA ■ China	● Review and Prospects for Current Research about the Effect of Factors on the VHCF of Metallic Materials ➢ Yingxia Yu, Bolin He, Zongmin Lv, Kang Wei, Zhijun Zhang ■ China

17:05-17:25	● Ultrasonic fatigue of spray formed hypereutectic aluminum silicon alloy and vibration analysis by means of non-linear acoustics ➢ M. Fitzka, H. Mayer, R. Schuller, S.E. Stanzl-Tschegg, T. Przeorski, P. Krug ■ Austria	● Influence of ceramic particles on the very high-cycle fatigue behavior of Al-matrix-composites ➢ Alexandra Müller, Anja Weidner, Horst Biermann ■ Germany
17:25-17:45	● Effects of Cleanliness and Induction Hardening on Very High Cycle Fatigue Properties of Low Alloy Forged Steel ➢ Yiwen Yang, Nobuyuki Fujitsuna, Ryota Yakura, Mariko Matsuda Taku Miura, Akira Ueno, Shoichi Kikuchi, and Tatsuo Sakai ■ Japan	● Ultra-high cycle fatigue behavior of DZ125 superalloy used in turbine blades ➢ Yuli Gu, Chunhu Tao, Yuhuai He ■ China
17:45-18:05	● A Study on Very High Cycle Fatigue Properties of Bulk Amorphous Alloy in Rotating Bending ➢ Akiyoshi Sakaida, Yanbin Zhang, Shoichi Kikuchi Yoshihiko Yokoyama, Akira Ueno and Tatsuo Sakai ■ Japan	● Fatigue Analysis Based on The Non-Zero Point Force Moment Elasticity Theory ➢ Shuang-hua HUANG , Wen-ba HAN, Zhao-rong ZENG and Qiang LUO ■ China
18:05-18:25	● Effect of Inclusion Size on the Fatigue Life of High Carbon Chromium Bearing Steel ➢ Kwanho Kim and Chulmin Bae ■ Korea	● Fatigue failure mechanism of a 1900MPa grade maraging stainless steel ➢ Le Zhang, Yuhai Li,Zhenguo Yang, Yiyin Shan, Ke Yang and Wei Wang ■ China

18:30-18:50	**Closing Plenary** ➢ **Y.S. Hong**
18:50-19:30	**Dinner**

Saturday, 18th Oct, 2014

	Conference Tour
08:00-11:00	**Panda Park**
14:30-17:00	**Jinsha Site Museum**

Panda Park

Saturday Oct. 18th, 8:00 - 11:00

What you could not miss in Chengdu is the world famous ***Chengdu Research Base of Giant Panda Breeding*** which is located about 25km out of Chengdu City. This huge institution replicates the natural habitat of the giant panda and is dedicated to preserving and increasing their population so they will not become extinct. You are able to get real close-up to some pandas and photograph them as well as the so-called lesser red pandas which really look and act like raccoons.

One of the biggest attractions is the panda breeding center where you can watch the baby pandas through glass in their playpens. You are not allowed to photograph the baby pandas, as the flash can hurt their eyes. Another highlight is the video you watch about the reserve and panda reproduction and learn how a panda gives birth to a baby cub. The baby just slides out and at the first time mothers don't know what it is, so it is common for them to accidentally kill the baby as they swat it around if the researchers can not help out in time. In all, it is nice to see all in the panda breeding center.

It’s best to visit the base in the mornings as early as possible. You’ll see most action from the pandas between 8am and 11am – after that they’re likely to be sleeping. And, while you might not want to plan your whole trip around it, if you visit the base in September or October you’ll be able to see newborn pandas in the nursery.

Conference Tour

Jinsha Site Museum

Saturday Oct. 18th,14:30 - 17:00

Jinsha Site, located in Jinsha Village, Chengdu, Sichuan Province, it is the central site in Shang and Zhou Dynasties, including sacrifice places, large constructions, residential area, burial ground, etc. To well protect the Jinsha site and open it to the public, Jinsha Site Museum was built in 2007 in the same site where Jinsha Site was discovered . Jinsha Site was discovered in 2001, it represents the glorious culture of Ancient Shu Kingdom during Shang and Zhou Dynasty. It is called the most important archeological discovery in the Twenty-First Century and is the National Relic Protection Unit in Chinese. It is just 5 km.(about 3 miles) away from the downtown Chengdu, which is very convenient to visit.

The Culture Relics: The culture relics excavated from the Jinsha site mainly include Gold, Jade, Bronze, Stone, Ivory and Pottery items, etc. There are more than 5,000 relics unearthed at present. Among them, more than 1,200 pieces of bronze items were excavated, mainly with small items, the bronze statue, bronze dagger-axe, bronze ring, etc. The bronze statues are very similar to the unearthed Sanxingdui bronze portrait; More than 2,000 pieces of Jade, grand quantity and various shapes; More than 1,000 pieces of Stone, including stone statue, stone tiger, stone snake, stone tortoise, etc.

Abstracts

Keynote lectures

MIM01

Fatigue limit of metals

Claude Bathias; emeritus professor, U-Paris ouest, LEME

Abstract: It is well established that industrial alloys can failed in fatigue up to 10^{10} cycles, that is to say more than the fatigue life of many components. It means that all the service life of those components can fail in fatigue. This is explained by the stress concentration occurring around metallurgical defect, inclusions, pores, always existing in alloys. However, gigacycle fatigue also exists in pure metals such as cupper or iron where the defects are very small. According the recent experimental results got during the 2000s, it is obvious that Gigacycle fatigue is not in agreement with the asymptotique standard SN curve and the concept of infinite fatigue life is not correct, at least for practical applications. Several items are pointed out in this paper:

Assuming that the alloys can failed beyond 10^{10} cycles and that the most sophisticated mechanical components are designed for a fatigue life more or less in the order of the Gigacycle regime, the standard megacycle fatigue limit is not conservative. Thus, the interest of a Gigacycle curve is recommended. A new standard for the fatigue strength is mandatory.

It is found that a coupling exists between thermal dissipation, plasticity and damage in the Gigacycle fatigue regime. Thermal dissipation helps to characterize propagation, initiation and PSB formation.

However ,for a fundamental point of view, it is difficult to conclude, because it seems that a threshold for the PSB formation would exist. The accuracy of the microscopic observation and of the thermal measurement does not allow concluding.

Thermal dissipation and fracture mechanics approach demonstrate that initiation of a crack is the crucial mechanism in Gigacycle fatigue.

MIM02

Microscopic and Nanoscopic Observations of Metallographic Structures around Inclusions at Interior Crack Initiation Sitein Very High Cycle Fatigue

Tatsuo SAKAI[1, a], Noriyasu OGUMA[2, b], Akinari MORIKAWA [3, c],and Akira UENO[1, d]
[1]College of Science and Engineering, Ritsumeikan University,
1-1-1 Noji-higashi, Kusatsu, Shiga, 525-8577 Japan
[2]Faculty of Engineering, University of Toyama,3190 Gofuku, Toyama, 930-8555 Japan
[3]Hitachi High-Technologies Corporation,11-1 Ishikawa-cho, Hitachinaka, Ibaraki, 312-0057 Japan
[a]sakai@se.ritsumei.ac.jp, [b]oguma@eng.u-toyama.ac.jp,
[c]morikawa-akinari@naka.hitachi-hitech.com,[d]ueno01@fc.ritsumei.ac.jp

Abstract: In some high strength steels, a fatigue crack tends to occur at the interior inclusion after a long term sequence of the cyclic loadings, although the crack takes place at the surface in the usual life region at high stress levels. Thus, we have the duplex S-N curves consisting of the respective S-N curves for usual life region and very high cycle regime. It is well known that a significant fracture surface having the fine granular morphology is formed around the interior inclusion at the crack initiation site. This surface area is sometimes called as “Fine Granular Area(FGA)”. In this work, metallographic structures around the interior inclusion at the fatigue crack initiation site were carefully observed by combining several special techniques such as focused ion beam technique and high resolution scanning electronic microscopes. Based on current observation results, it was found that the microstructure around the interior inclusion was changed into the penny-shape fine granular layer from the usual martensitic structure along with the long term cyclic loadings. Then, debondings along with the boundaries of the matrix and the fine granular layer produced the small cracks inside the metallic material and this crack caused the final fatigue fracture after definite loading cycles of crack propagation.

Keywords: Very high cycle fatigue, Bearing steel, Interior crack initiation, Fine granular area(FGA), Rotating bending

AAI01

Ultrasonic torsion fatigue of VDSiCr spring steel at different load ratios and comparison to cyclic axial loading

H.Mayer[1*], R.Schuller[1], D.Irrasch[1], M.Fitzka[1], U.Karr[1], M.Hahn[2], M.Bacher-Höchst[2]
[1] University of Natural Resources and Life Sciences, Vienna, Institute of Physics and Materials Science,1190 Vienna, Austria
[2] Robert Bosch GmbH, Corporate Sector Research and Advance Engineering, Materials and Process Engineering Metals, P.O. 300240, 70442 Stuttgart, Germany
* Corresponding author: herwig.mayer@boku.ac.at

Abstract: Ultrasonic torsion fatigue tests with torsion mean loads are performed with VDSiCr spring steel with shot peened surface. This serves to reproduce loading of coil springs, where the testing material is used. Cyclic torsion tests at load ratios R of 0.1, 0.35 and 0.5 are compared to cyclic axial loading tests at load ratios between -1 and 0.5. Experiments are performed up to limiting lifetimes of 5×10^9 cycles (cyclic torsion) or 10^{10} cycles (cyclic tension).
A strong influence of load ratio on the HCF and VHCF strength is found for cyclic torsion as well as cyclic tension loading. Increasing mean load reduces the cyclic stress amplitude the material can withstand without failure for both loading conditions. Fatigue cracks are always initiated at the surface, if lifetimes are below 10^7 cycles. In the VHCF regime, fatigue cracks produced by cyclic torsion are preferentially initiated internally in the matrix. Matrix cracks start adjacent to the surface layer where beneficial compression residual stresses due to shot-peening are present. The fracture surfaces are inclined 45 ° to the specimens' lengths perpendicular to the maximum tensile stress, i.e. fatigue cracks produced by cyclic torsion grow in mode I. Internal inclusions are preferential crack initiation sites in specimens that failed in the VHCF regime under cyclic tension loading. Considering mean lifetimes in the VHCF regime, the stress amplitudes for cyclic torsion and cyclic tension loading are comparable for load ratio R = 0.1. For load ratios R = -1 and R = 0.5, the shear stress amplitudes must be about 86 % or 94 % of the tensile stress amplitude, respectively, to obtain comparable VHCF lifetimes.

Keywords: Ultrasonic fatigue, Cyclic torsion, Cyclic tension, Load ratio, VDSiCr spring steel, Residual stresses

MIM29

Characteristic Dimension and Related Mechanism of Crack Initiation and Early Growth for Very-High-Cycle Fatigue

Youshi Hong
LNM, Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China

Abstract: For Very-High-Cycle Fatigue (VHCF) of high strength steels, the process of crack initiation and early growth is responsible for the majority part of fatigue life. The origin of fatigue crack for VHCF commonly locates at the interior of material or specimen with the morphology of "fish-eye" and "fine granular area (FGA)". This paper focuses on the characteristic dimension of FGA and the mechanism of crack initiation for VHCF of high strength steels. By taking advantage of the methods of Cross Section Polishing (CSP) and Focused Ion Beam (FIB), the specimens of crack initiation and early growth region were prepared then observed via scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The observations show the microscopic morphology of FGA and fish-eye with the layer of fine grains containing nano-meter size grains, revealing the mechanism of crack initiation and early growth. The results also show the variation of threshold value and fatigue life with the characteristic dimension of FGA size. Therefore a model has been developed to correlate the fatigue life with FGA size. Another model is also proposed to estimate the fatigue strength for high-cycle fatigue and VHCF, which takes into account the effect of stress ratio.

MIM17

The Most Influential Articles in Very High Cycle Fatigue

QingYuan Wang[1,*], Muhammad Kashif Khan[1, 2]
[1] Department of Mechanics and Engineering Science, Sichuan University, Chengdu, 610065, China
[2] Department of Mechanical Engineering, DHA Suffa University, Karachi, 75500, Pakistan
* Corresponding author: wangqy@scu.edu.cn

Abstract: The most influential articles in Very high cycle fatigue (VHCF) during last 20 years have been indentified from web of science data. It has been found that VHCF field in the fatigue domain has produced the highest impact in the field. The number of articles and their citations is continuously dominating the overall published papers in the field of fatigue. In VHCF field, it was found that VHCF1-5 conference nationals are the main contributors in all the VHCF papers and in its top 100 influential papers. The fatigue crack initiation in the VHCF domain is considered the most important area in the field. In VHCF, it is now known which papers have been the most influential on this specialty to date , it may prove helpful to trainees mastering the most influential literature of the field as well as more established professionals searching for starting points for new investigations.

Keywords: Fatigue, VHCF, Citation, Fatigue crack initiation, Fatigue Journals

IET17

Investigating Microstructural and Environmental Effects on VHCF Crack Formation in Ti-6242

Jason Geathers[1,a], Christopher J. Torbet[2,b], J. Wayne Jones[3,c], and Samantha Daly[1,d]
[1]University of Michigan, Department of Mechanical Engineering, 2350 Hayward St., Ann Arbor, MI 48109, USA
[2]University of California-Santa Barbara, Materials Department,Santa Barbara, CA 93106, USA
[3]University of Michigan, Department of Materials Science & Engineering, 2300 Hayward St., Ann Arbor, MI 48109, USA
[a]jgeather@umich.edu, [b]ctorbet@engineering.ucsb.edu, [c]jonesjwa@umich.edu, [d]samdaly@umich.edu

Abstract: The effects of microstructural variability and environment on cyclic strain localization and damage accumulation in the very high cycle fatigue regime (VHCF) were studied in a near alpha titanium alloy (Ti-6242). An experimental methodology that combines scanning electron microscopy (SEM) and ultrasonic fatigue instrumentation was used to investigate mechanisms of fatigue crack initiation and growth in low vacuum saturated water vapor environments of 67 Pa and 133 Pa. In-situ observations of short crack growth behavior from focused ion beam (FIB) machined micro-notches located at critical microstructural sites were examined for the first time using ultrasonic fatigue (20 kHz) in a SEM. Crack initiation and propagation as a function of microstructural neighborhoods was also correlated with the evolution of small-scale strain fields as measured by advanced in-situ SEM digital image correlation (DIC) techniques, termed SEM-DIC. A significant decrease in fatigue crack growth rates was observed in the low vacuum water vapor environments compared to laboratory air tests. SEM-DIC strain field maps of the crack-tip and surrounding microstructural neighborhood also indicated a decrease in plasticity with increasing water vapor pressures. The role of microstructure and environment on strain localization, crack initiation, and short crack growth in the VHCF regime will be discussed.

Keywords: titanium, ultrasonic fatigue, corrosion fatigue, fatigue crack growth, digital image correlation

MIM03

Fracture Mechanical Characterization of Interior-Fatigue-Cracks

Stefanie E Stanzl-Tschegg[1], Takeshi Ogawa[2] and Bernd M Schönbauer[3]

[1, 3] University of Natural Resources and Life Sciences, BOKU Vienna, Vienna, Austria

[1] stefanie.tschegg@boku.ac.at;[3]bernd.schoenbauer@boku.ac.at

[2]Aoyama Gakuin University, Japan. ogawa@me.aoyama.ac.jp

Abstract: Formation and growth of interior cracks is an issue of extensive investigations during the last two decades owing to the high practical importance related to predictions on fatigue lives of structures and machine parts in the VHCF regime. Of special help is the ultrasonic fatigue method which allows generating cyclic loads up to 10^{10} cycles within days. The problem of crack growth and failure below a beforehand assumed fatigue limit at approximately 10^6-10^7 cycles especially applies to high strength steels. In this study, tests on a high carbon chromium bearing steel, SUJ2, and a precipitation hardened chromium-nickel-copper steel, 17-4PH, were carried out at constant amplitudes and a frequency of 20 kHz. Additional fatigue tests were conducted on the SU2J steel under repeated two-step amplitude stressing. Inclusions were observed at the initiation site of the fractures in all cases and optically dark areas (ODAs) and fish-eyes were observed around the inclusions. The sizes of the ODAs and fish-eyes depended on the stress intensity factor range which was derived from two-step amplitude stressing tests. The interior fatigue crack growth rates were lower than the long-crack growth rates obtained in a standardized test with a CT specimen in air. For this result, the vacuum prevailing in the specimen interior is made responsible. Therefore, additional fatigue crack growth measurements were performed in vacuum on 17-4PH steel at very low constant amplitudes, and the growth rates of the ODAs and adjacent fish-eye areas were estimated by comparing the resulting fracture morphology with that of the ODA and fish-eye features. Calculations accounted for cumulative damage processes in repeated two-step loading tests on SUJ2 steel. The characteristics of interior fatigue crack growth were determined by observations of beach marks and the ODA sizes on the fracture surface. Based on the results and the reports of other researchers, a formation mechanism of ODAs is proposed.

Transition from VHCF to HCF, Subsurface "FGA" Forming and Metals Cracking in VHCF Regime

Andrey Shanyavskiy[1,*]
[1] State Centre for Flights Safety, Airport Sheremetievo-1, PO Box 54, Moscow region, Chimkinskiy State, 141426, Russia
* Corresponding author: shananta@mailfrom.ru

Abstract: This research concerns the metals behavior as varying, with increasing cyclic stress level, in the transition range between the very-high-cycle (VHCF) and high cycle (HCF) fatigue regimes. Having analyzed the synergetics of surface crack initiation, the authors propose to identify the VHCF-to-HCF transition with a certain stress level corrected, with the respective dimensionless functions, for the effect of the environmental attacks, temperature, surface roughness of the test piece, etc. on the crack initiation behavior. Subsurface initiation of a fatigue crack occurs in the test-material susceptible of a deformation-induced transition to superplasticity state, which favors formation of the nanocrystalline zone bordered by a fine-granular area. Another case of subsurface cracking is in that a local even area forms owing to the vortex-like deformation combined with the diffusion of the retained gases toward and into the discontinuity. A proposed equation is plainly descriptive of the subsurface growth of fatigue-cracks and allowing to acquire the crack growth duration from the fractography data.

Keywords: very-high-cycle-fatigue, synergetics, cracks initiation, superplasticity, cracks growth

MIM05

Growth Behavior of a Fatigue Crack of Age-hardened Al Alloys under Ultrasonic Loading

Norio KAWAGOISHI[1], Qingyuan WANG[2], Xishu WANG[3]and Kohji KARIYA[1],Qiang CHEN[4]
[1]Department of Mechanical System Engineering, Daiichi Institute of Technology, Kirishima 899-4395, Japan
[2]Department of Civil Engineering & Mechanics, Sichuan University, Chengdu 610065, China
[3]Department of Engineering Mechanics, Tsinghua University, Beijing 100084, China
[4]Center for Globalization, Kumamoto University, Kumamoto 860-8555, Japan
Corresponding author qchen@kumamoto-u.ac.jp

Abstract: Growth behavior of a fatigue crack and the effect of humidity on crack behavior in high strength Al alloys were investigated under ultrasonic loading frequency. Crack growth was markedly accelerated at the early stage of fatigue in high humidity, while little influence of high humidity was recognized on the growth of a larger crack. In case of low humidity, however, fracture surface featured a typical sequence of fracture processslip planes at the crack initiation or stage I cracking, followed by striations in stable crack growth region and dimples in final fracture. In addition, many slip planes were observed beyond stage of striations, whereas the feature of these slip planes are different a little from the stage I slip planes. On the other hand, in high humidity, most of fracture surface was covered with slip planes and striations were hardly observed. It is concluded that a crack that propagated macroscopically in a tensile mode tends to grow in a shear mode in low humidity, though the crack propagates only in a shear mode in high humidity. The changes in growth mode and in growth rate of a crack by high humidity were explained from view point of effects of environment around crack tips.

Keywords: Fatigue, ultrasonic loading, high strength Al alloy, humidity, crack growth mechanism

AM02

Influence of production process of Ti-6Al-4Mo titanium alloy on crack initiation mechanisms in Very High Cycle Fatigue regime

Alexander Nikitin[1,a], Thierry Palin Luc[2,b], Andrey Shanyavskiy[3,c] and Claude Bathias[1,d]
[1] LEME, Paris University OUEST Nanterre La Defense, 50, rue de Sevres, Ville-d'Avray, 92410, France
[2] SCCAFS, Air.Sheremetevo-1, PO Box 54, Moscow reg., Chimkinskiy State, 141426, Russia
[3] Arts et Métiers ParisTech, I2M, UMR CNRS 5295, Université Bordeaux 1, Esplanade des Arts et Métiers, Talence, 33405, France.
[a] Nikitin_alex@bk.ru, [b] Thierry.palin-luc@ensam.eu, [c] Shananta@mailfrom.ru, [d] Claude@bathias.com

Abstract: Because its high resistance to fatigue, titanium alpha-beta alloys are widely used in aeronautical industry for producing turbo-jet engine elements that are subjected to cyclic loading. Depending on components all the fatigue regimes (LCF, HCF and VHCF) have to be considered for designing safe aeronautical structures. Low Cycle Fatigue and High Cycle Fatigue regimes are typical for hub and rim parts of compressor disks respectively. Very High Cycle Fatigue regime is the regime of turbine blades because of the high frequency vibrations due to air flow. According to recent researches, fatigue resistance of titanium alloys in VHCF is strongly related to microstructural features, such as size and morphology of alpha-plates, volume fraction of phases for instance. Most of these experimental results are obtained on materials prepared for tests in laboratories, i.e. without information about real technological process for turbine elements. However, general conclusions and recommendation about material behaviour are made for engineering. The objective of the present paper is to investigate the VHCF strength and crack initiation mechanisms of two types of specimens made from VT3-1 (Ti6Al4V) alpha-beta titanium: (i) manufactured from real forged turbo-jet engine disk and (ii) manufactured from extruded bars. Crack initiation mechanisms were investigated by using SEM observation on fracture surfaces. It has been shown, that variability in crack initiation mechanisms is much higher for forged titanium alloy in VHCF, which leads to significant scatter (up to three orders of magnitude) in fatigue life. Investigation on fracture patterns has shown that technological process is also strongly affects on features of crack propagation process.

Keywords: Gigacycle fatigue, Titanium alloy Ti-6Al-4Mo, Crack initiation, Production process

Advancements in VHCF Instrumentations

AAI02

Very high cycle fatigue of carbon fiber reinforced polyphenylensulfide by high power ultrasonics

Daniel Backe[*,1], Frank Balle[1], Dietmar Eifler[1]
[1] Institute of Materials Science and Engineering (WKK), University of Kaiserslautern,
P.O. Box 3049, 67653 Kaiserslautern, Germany
* Corresponding author: backe@mv.uni-kl.de

Abstract: Carbon fiber reinforced polymers (CFRP) are getting more and more important for structural components for automotive and aerospace applications. These components are subjected to 10^{11} and more loading cycles during their time in service. Therefore the VHCF behavior and the corresponding failure mechanisms have to be well understood. To obtain a comprehensive knowledge about the fatigue behavior and failure mechanisms of CFRP in the VHCF regime, a new Ultrasonic Testing Facility (UTF) for cyclic 3-point bending at 20 kHz has been developed at WKK. The high-frequency system enables VHCF experiments up to 10^9 cycles in twelve days without unacceptable heating up to the glass transition temperature of the polymer. The chosen material in this research project is the commercially available and aircraft qualified carbon fiber fabric reinforced polyphenylensulfide (CF-PPS). To determine the fatigue characteristics of CF-PPS load increase tests and based on these results constant amplitude tests up to 10^9 cycles have been carried out. Light optical and SEM microscopy have been performed in defined fatigue states or finally after reaching 10^9 cycles with stress amplitudes of at least 44% of the monotonic ultimate shear strength. The induced fatigue damage of CF-PPS in the VHCF regime was studied in detail.

Keywords:CFRP, cyclic 3-point bending, ultrasonic fatigue, CF-PPS, failure mechanisms of CF-PPS

AAI03

Method to determine early internal fatigue crack initiation in cast steel 42CrMo4 (QT) by *in situ* thermography measurements

Dominik Krewerth*, Anja Weidner, Horst Biermann
Institute of Materials Engineering, TU Bergakademie Freiberg, 09599, Freiberg
* Corresponding author: dominik.krewerth@ww.tu-freiberg.de

Abstract : The present paper illustrates the application of infrared thermal measurements during fatigue testing and internal fatigue crack initiation in cast steel 42CrMo4 (QT). An advanced raster-evaluation method of the infrared thermal measurements was developed enabling the exact detection of local temperature hot spots. Moreover, the fracture surfaces were correlated to the local thermography measurements. The presented results demonstrate well that the combination of fractography and thermography measurements can shed some light on the time and the location of the crack initiation point.

Keywords : Internal fatigue crack initiation, *In situ* thermography, Nonmetallic inclusions, 42CrMo4 (QT)

AAI04

Cyclic tension VHCF properties of nitrided 18Ni maraging steel sheets

R.Schuller[1], H. Mayer[1,*], M. Fitzka[1], D. Tran[2], B. Pennings[2]
[1] University of Natural Resources and Life Sciences, Vienna, Institute of Physics and Materials Science, 1190 Vienna, Austria
[2] Bosch Transmission Technology, Advanced Engineering, Dr. Hub van Doorneweg 120, P.O. Box 500, 5000 AM Tilburg, The Netherlands
* Corresponding author: herwig.mayer@boku.ac.at

Abstract: Nitrided thin sheets (thickness 0.35 mm) made of 18Ni maraging steel are tested under cyclic tension loading (load ratio R = 0.1) in the HCF and VHCF regime. The ultrasonic fatigue testing method with a cycling frequency of about 20 kHz has been further developed for these experiments. Sheet specimens are mounted onto a carrier specimen, pre-stressed and are forced to vibrate jointly. Fatigue cracks in the VHCF regime are exclusively initiated at interior inclusions with a strong influence of inclusion size on lifetime. This influence is considered using a crack propagation model and by adapting the Murakami area$^{1/2}$ model. Under the investigated loading conditions, VHCF strength of maraging steel was found comparable to other high strength steels.

Keywords : Ultrasonic fatigue, Maraging steel, Nitrided surface, Cyclic tension, Inclusions

Investigating the VHCF of composite materials using new testing methods and a new fatigue damage model

Paul Lorsch[1,*], Till Julian Adam[2], Marcel Zeisberg[3], Michael Sinapius[1], Peter Horst[2], Raimund Rolfes[3], Peter Wierach[4] and Heiko Krüger[3*]
[1] TU Braunschweig (IAF), Langer Kamp 6, 38106 Braunschweig, Germany
[2] TU Braunschweig (IFL), Hermann-Blenk-Str. 35, 38108 Braunschweig, Germany
[3] Leibniz Universität Hannover (ISD), Appelstr. 9A, 30167 Hannover, Germany (*formerly)
[4] German Aerospace Center e.V. (DLR), Lilienthalplatz 7, 38108 Braunschweig, Germany
* Corresponding author: p.lorsch@tu-braunschweig.de

Abstract Composite materials are used in several fatigue-relevant applications nowadays and characteristic fatigue data is needed. However, composites have to be told apart from metals and so have to be the fatigue behaviors. Unfortunately, the established testing and simulation methods are not suitable for composites. However, two new experimental approaches providing accelerated VHCF testing are presented. A resonant and a non-resonant setup are used. For the first setup the resonant behavior of specimen and test stand are used to load GFRP tubes at roughly 600Hz and a load ratio of R=-1. The second approach utilizes a specifically designed four-point bending test running at 50-80 Hz. Fatigue data including stiffness degradation, evaluation of crack density and delamination are gained up to 10^8 cycles. Both methods reach testing frequencies beyond classic testing methods and thus allow time efficient VHCF testing. First results for fatigue testing with glass-fiber-reinforced plastics are presented.
Furthermore, a new layer-based fatigue damage model (FDM) is presented, which is physically motivated by using an approach that relates energy dissipated under quasi-static and the energy dissipated under cyclic loading. The Puck failure criterion is used and has been extended with degradation factors for analyzing discontinuous damage. Load interactions as well as nonlinear damage accumulation are taken into account. Degradation of stiffness and strength can be calculated for every single layer over the simulated lifetime.

Keywords VHCF, Composites, GFRP, resonant, testing

AAI05

Resonant testing method for the VHCF of composite materials

Paul Lorsch[1, a], Michael Sinapius[1,b] and Peter Wierach[2,c]
[1]TU Braunschweig, Langer Kamp 6, 38106 Braunschweig, Germany
[2]German Aerospace Center e.V. (DLR), Lilienthalplatz 7, 38108 Braunschweig, Germany
[a]p.lorsch@tu-braunschweig.de, [b]m.sinapius@tu-braunschweig.de, [c]peter.wierach@dlr.de

Abstract: Composite materials are being used in several fatigue-relevant applications nowadays. Therefore, characteristic fatigue data is needed. As composites have to be told apart from metals, conventional testing machines are not suitable. An innovative concept for testing composites in the Very-high-cycle-fatigue regime was developed and will be presented in this paper. The resonant behavior of the specimen and the test stand are used to load the specimen with a dynamic load at the load ratio of R=-1. The validation of the testing concept is done in comparison to the associated finite-element simulation. For the actual VHCF testing a slightly altered test stand for tubular specimen is presented along with the special requirements for the specimen. First results for fatigue testing with glass-fiber-reinforced plastics are presented. A specific final damage state is defined as the tubular specimens do not undergo a fatal rupture at the end of the fatigue life. Summarizing the results, a concept for controlling the test stand is proposed for future works. It contains two different control circuits as the resonant frequency of the system and the load amplitude have to be controlled independently, though both are mechanically linked.

Keywords: VHCF, Composites, GFRP, resonant, testing

AAI06

Development and Several Additional Performances of Dual-Spindle Rotating Bending Fatigue Testing Machine GIGA QUAD

Taizoh Yamamoto1*, Akio Kokubu1, Tatsuo Sakai2, Yuki Nakamura3
1 Yamamoto Metal Technos Co. Ltd., 4-7 Setoguchi 2-chome, Hirano-ku, Osaka, 547-0034 Japan
2 Ritsumeikan University, 1-1-1 Nojihigashi, Kusatsu, Shiga, 525-8577 Japan
3 Toyota National College of Technology, 2-1 Eiseicho, Toyota, Aichi, 471-8525 Japan
* Corresponding author: yamakin@mx1.alpha-web.ne.jp

Abstract: In order to investigate the fatigue characteristics of metallic materials experimentally, a long period of time is required to get sufficient number of S-N data. In recent years, in order to overcome this difficulty, multi-type rotating bending fatigue testing machine whose name is GIGA QUAD has been developed by Yamamoto Metal Technos Co., Ltd., in which four specimens can be tested simultaneously. In this time, some additional new functions have been developed as follows; (1) 'high and low temperature environmental testing unit' whose target temperature is in a range of 600 deg.C and -150deg.C, (2) 'constant temperature/humid environmental testing unit' combined with the conventional corrosive cell, (3) ‘fracture alarm unit’, and (4) ‘2-step variable loading unit’.By combining these new functions with the machine of GIGA QUAD, one can perform the fatigue tests efficiently corresponding to the respective requirements for researchers in both of academic and industrial sectors.

Keywords: High temperature environmental testing unit, Low temperature environmental testing unit,Constant temperature/humid environmental testing unit, Fracture alarm unit, 2-step variable loading unit

AAI07

Ultrasonic fatigue of spray formed hypereutectic aluminum silicon alloy and vibration analysis by means of non-linear acoustics

M. Fitzka[1,*], H. Mayer[1], R. Schuller[1], S.E. Stanzl-Tschegg[1],T. Przeorski[2], P. Krug[3]
[1] University of Natural Resources and Life Sciences, Vienna, Institute of Physics and Materials Science,1190 Vienna, Austria
[2] PEAK Werkstoff GmbH, 42553 Velbert, Germany
[3] Cologne University of Applied Sciences, Institute of Automotive Engineering, 50679 Cologne, Germany
* Corresponding author: michael.fitzka@boku.ac.at

Abstract: Spray formed hypereutectic aluminum silicon alloys offer great advantages for applications in technical components where excellent mechanical properties and low weight are required. Fatigue tests at ultrasonic frequency with constant amplitude (CA) and variable amplitude (VA) are performed up to the very high cycle fatigue (VHCF) regime with DISPAL® S323-T6x. Cracks in this material are initiated at voids, at inclusions or in areas with distributed inhomogeneities (small voids, oxides), which may be located at the surface or in the interior. The predominant type and location of crack initiation vary with fatigue lifetime. Vibration properties are derived in situ through advanced signal analysis by means of non-linear acoustics and high-resolution monitoring of resonance frequency. They indicate microstructural changes in the VHCF regime. It is found that cracks start growing early in fatigue life, even when failure does not occur until the VHCF regime. Lifetime predictions are performed using a crack propagation model considering voids or inclusions as initial cracks. Fatigue lifetime under CA and VA loading conditions is strongly influenced by the size of a possible material inhomogeneity at the crack initiation location, which is successfully covered with the crack propagation model.

Keywords: Ultrasonic fatigue, Non-linear acoustics, Spray formed PM aluminum alloy, Lifetime prediction

AAI08

Study on very high cycle fatigue test method of Titanium Alloy

ZHANG Hai-tao[1], CHEN Wei[2], LI Quan-tong[3],Gao Xing-wei[4], Feng Lu-lu[5], Jiao Sheng-bo[6]

[1,2,3,4,5,6] Aeronautics and Astronautics Engineering College, Air Force Engineering University, Xi'an 710038, China

Zhang Hai-tao : mao.mao360@163.com

Abstract: Very high cycle fatigue (VHCF) destruction is one of the main approaches to blades failure in aero-engine. Ultra-phonic fatigue test is a main method in studying very high cycle fatigue properties of metal material. Aiming at VHCF problems in aero-engine blades testing specimen, a developed curving VHCF test system was discussed, the tests for material fatigue characteristics of titanium alloys and the results of theoretical analysis in recent years were introduced, offering referenced basis to blades very high cycle researches.

Keywords:titanium alloys ; ultra high cycle fatigue ; bending vibration ; crack initiation

Advanced Materials

AM01

Microstructural Features Controlling Very High Cycle Fatigue of Nitrided Maraging Steel

An Verdiere[1,*], V. Bliznuk[1] , L.A.I. Kestens[1,2] and Roumen Petrov[1,2]

[1] Department of Materials Science and Engineering, Ghent University, Ghent 9052, Belgium
[2] Department of Materials Science and Engineering, Delft University of Technology, Delft 2628 CD, The Netherlands
* Corresponding author: an.verdiere@ugent.be

Abstract: Maraging steels belong to the group of ultra-high strength materials and are often used in critical aerospace, automotive and tooling components. By applying a surface treatment such as nitriding, the fatigue and wear resistance can be improved. The microstructural features that influence the (very) high cycle fatigue response of nitrided maraging steels are studied in this work. Although the used steel has practically no inclusions, it was found that small surface imperfections, introduced during processing, may form potential fatigue initiation points. The samples are nitrided during aging in order to form nitrided layers with various thicknesses, microstructures and hardness profiles without formation of a continuous (compound) iron nitride layer. Data from microhardness tests, scanning electron microscopy, electron backscatter diffraction, x-ray diffraction and transmission electron microscopy were used to characterize the microstructure of the layers. Bending fatigue tests were employed to evaluate the fatigue response of the steel. It was found that the best fatigue behavior is obtained in samples with a thin diffusion zone with a narrow constant hardness region. In this zone, coherent disc-shaped nitride precipitates are detected with TEM.

Keywords: Maraging steel, very high cycle fatigue, nitriding, microstructure

AM02

Failure mechanism in ultrasonically fatigued aluminum matrix composites

Matthias Wolf[1,*], Guntram Wagner[2], Dietmar Eifler[1]
[1] Institute of Materials Science and Engineering, University of Kaiserslautern, 67663, Germany
[2] Institute of Materials Science and Engineering, Chemnitz University of Technology, 09125, Germany
* Corresponding author: wolf@mv.uni-kl.de

Abstract Ultrasonic fatigue experiments were carried out to investigate the cyclic deformation behavior of aluminum matrix composites (AMC) and the corresponding matrix alloy in the very high cycle fatigue (VHCF) regime. The AMC were reinforced with different SiC particles to investigate their influence on the fatigue behavior at low stress amplitudes. During cyclic loading the courses of relevant process parameters such as dissipated energy, temperature development and change in the electric resistivity of the specimens were recorded as appropriate indicators to characterize the cyclic deformation behavior and to detect specimen failure at an early stage. The fracture surfaces were characterized via SEM, EDS and CT. The analyses have shown that crack initiation of the composites occurs subsurface at reinforcing particle clusters in some cases but considerably more often at aluminum-copper-iron-rich inclusions. However, the matrix alloy fails in all cases at the surface. In CT scans of the specimens a small number of additional inclusions were also detected for the matrix alloy, but due to their small size they do not lead to crack initiation.

Keywords Aluminum Matrix Composites, Ultrasonic Fatigue, Failure Mechanisms, AA2124.

AM03

Very high cycle fatigue behaviors of AA6061-T6 aluminum alloy friction stir butt welds with ultrasonic loading

Chao HE, Yongjie LIU, Renhui TIAN, Jiukai LI, Qingyuan WANG*
(Key Laboratory of Energy Engineering Safety and Disaster Mechanics, Ministry of Education, Sichuan University, Chengdu 610065, PR China)

Abstract: In order to clarify the very high cycle fatigue behaviors of friction stir welds, the ultrasonic fatigue tests were carried out for AA6061-T6 aluminum alloy in the range of 10^5-10^9 cycles. The fatigue strength of the friction stir weld was lower than that of base material with a percentage of 60% at 10^9 cycles. Surface observation revealed that fatigue crack initiation significantly was influenced by microplasticity (slip bands) in the thermo-mechanically affected zone. Finally, the effects of microstructure and microplasticity on fatigue crack initiation and propagation were taken into consideration to analysis the failure mechanisms in very high cycle fatigue range.

Keywords: Very high cycle fatigue; Friction stir weld; Fatigue crack initiation; Fatigue crack propagation; Microplasticity.

AM07

Influence of ceramic particles on the very high-cycle fatigue behavior of Al-matrix-composites

Alexandra Müller*, Anja Weidner, Horst Biermann
TU Bergakademie Freiberg, Institute of Materials Engineering, 09599 Freiberg, Germany
* Corresponding author: Alexandra.mueller@iwt.tu-freiberg.de

Abstract: During technical operation, high performance materials are very often exposed to cyclic loading conditions leading to damage accumulation until the final fracture. Simultaneously, quite high requirements with regard to high number of cycles without any damage are claimed for major parts of components. The fatigue behavior of Al-matrix composites (Al-MMCs) reinforced by alumina particles or short fibers was already intensively studied in the LCF and HCF range. The present investigations are focused on Al-MMCs with 15 vol.% of alumina particles in comparison to the unreinforced material tested by ultrasonic fatigue under symmetric push-pull loading (R=-1) at stress amplitudes up to 140 MPa to reach fatigue life of about 10^{10} cycles. These fatigue tests were complemented by *in situ* thermography measurements and correlated investigations on the fracture surfaces by scanning electron microscopy. Moreover, the resonant frequency as well as the nonlinearity parameter were evaluated in order to determine the beginning of damage in the Al-MMCs during very high cycle fatigue. The combination of these methods should contribute to a better understanding of kinetics of damage processes and damage accumulation.

Keywords :metal-matrix composites, particle reinforced aluminum AA6061, ultrasonic fatigue, thermography

AM08

Study on Very-High-Cycle-Fatigue Property of Aero-engine Blades Based on Subcomponent Specimen

Shengbo Jiao[1, a], Li Cheng[2, b], Quantong Li[3, c], Ke Qu[4], JunYu Gao[5], Lulu Feng[6], Haitao Zhang[7]
[1.2.3.4.5.6.7]Aeronautics and Astronautics Engineering College, Airforce Engineering University, Xian, China
[2] Co-Innovation Center for Advanced Aero-Engine, Beijing, China
a. jsbkgd@163.com b. cheng_qiaochu@yahoo.com.cn c.lebalqt@sina.com

Abstract: The cyclic load number of aero-engine blade during its service life is very likely beyond 10^7, which is regarded as the conventional fatigue limit. Moreover, surface strengthening is very often used in the manufacturing process of blade. The conventional testing method in the VHCF regime cannot exactly reflect the stress state of the blade, including the mechanism of crack initiation. To study the fatigue behavior and effects of laser shock peening, a kind of bending fatigue subcomponent specimen was designed and the laser shock peening model was established. Experiment about TC17 was accomplished by the Ulra-High Cycle bending fatigue system. It is found that the fatigue damage occurs beneath the surface and the S-N curve is continuously rather than multi-step declining in the VHCF regime. Process of surface strengthening has a significant effect on fatigue performance of TC17 titanium alloy.

Keywords: VHCF, Surface strengthening, Blade, Subcomponent Specimen

AM10

Stress Concentration in Fibre Reinforced Composite Plates

Chensong Dong[1,*]
[1] Department of Mechanical Engineering, Curtin University, Perth WA 6845, Australia
* Corresponding author: c.dong@curtin.edu.au

Abstract :A study on the stress concentration of composite plates with a central circular hole subject to axial and bending loads is presented in this paper. The stress concentration of composite plates with a central circular hole subject to axial and bending loading was studied with the aid of finite element analysis. It is shown that geometry has a significant effect on stress concentration, while fibre volume fraction has little effect. The stress concentration factor decreases with increasing hole diameter to plate width ratio. Further analysis shows stress concentration is strongly dependent on anisotropy and the stress concentration factor increases with the longitudinal-transverse moduli ratio.

Keywords : Composites; stress concentration; axial; bending; fibre volume fraction

AM11

Dominant Factors for Very High Cycle Fatigue of High Strength Steels

Hisao Matsunaga[1, 2, 3*], Chengqi Sun[4], Youshi Hong[4], Yukitaka Murakami[5]
[1]Department of Mechanical Engineering, Kyushu University, Fukuoka 819-0395, Japan
[2]Research Center for Hydrogen Industrial Use and Storage (HYDROGENIUS), Fukuoka 819-0395, Japan
[3]International Institute for Carbon -Neutral Energy Research (I2CNER), Kyushu University, Fukuoka 819-0395, Japan
[4]Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China
[5]Professor Emeritus, Kyushu University, Fukuoka 819-0395, Japan
*Corresponding authors matsunaga.hisao.964@m.kyushu-u.ac.jp, hongys@imech.ac.cn

Abstract: Dominant factors affecting fatigue failure from non-metallic inclusion in very high cycle fatigue (VHCF) regime are reviewed and the mechanism of the disappearance of the conventional fatigue limit is discussed. Particularly, this paper focuses on the followings: (i) Crucial role of internal hydrogen trapped by non-metallic inclusions for the growth of ODA (Optically Dark Area around the non-metallic inclusion at fracture origin),(ii) Behavior of the crack grown from non-metallic inclusion as a small crack, and (iii) Statistical aspects of the VHCF strength in consideration of the maximum inclusion size by statistics of extremes.

Keywords: Very high cycle fatigue, Non-metallic inclusion, Bearing steel, Small crack, The $\sqrt{\text{area}}$ parameter model

AM13

Advances in ultrasonic tests for fatigue strength and crack growth on thin sheet steels

Mohand Ouarabi[1, a], Ruben Perez Mora[1], Thierry Palin-Luc[2], Claude Bathias[1,b]
[1]Université Paris Ouest Nanterre La Defense, LEME, 50 rue de Sèvres, Ville d'Avray, France
[2]Arts et Metiers ParisTech, I2M, Esplanade d'Arts et Métiers, Talence, France
[a]mohand.ouarabi@yahoo.fr, [b]claude@bathias.com,

Abstract: Ultrasonic fatigue tests represent a hard work when setting up the testing system working at high frequency (20–30 kHz). The challenge increases when the raw material to test is not such suitable for manufacturing usual cylindrical specimens to carrying out such tests. In this work, thin flat sheets, with 1.2 mm thickness of a dual phase ferrite-martensitic steels were considered for carrying out fatigue tests at high frequency (20 kHz) up to the gigacycle regime ($>10^9$ cycles). Both crack initiation and propagation tests were carried out in air, at room temperature under stress ratio R=-1. To do that, special designs of specimens were made and computed using FEM for defining the stress amplitude for endurance tests. Special attachments for specimens to the ultrasonic system's horn were enhanced. A particular FEM computing of the stress intensity range on crack growth specimens was carried out for determining the specimen dimensions and an equation that defines the stress intensity range as a function of the harmonic displacement amplitude, dynamic Young's modulus, material density and crack length. Detailed procedures and fatigue results are presented in this paper.

Keywords: Ultrasonic fatigue, Plate steel fatigue, Fatigue resistance, Fatigue crack growth.

AM14

Formation of Slip Bands in Nano-polycrystalline Copper under High-Cycle Fatigue of Si/Ti/Cu/SiN Nanoscale Material

Takashi SUMIGAWA [1], Hui FANG [1]*, Takayuki KITAMURA [1]
[1] Department of Mechanical Engineering and Science, Kyoto University,
Kyoto-daigaku-katsura, Nishikyo-ku, Kyoto 615-8246, Japan

Abstract: The purpose of this study is to investigate the effects of a nano-scale stress field on fatigue damage in a nano-polycrystalline material under fully-reversed and high-cycle loading. A resonant fatigue experiment is carried out for a nano-cantilever specimen that has a nano-polycrystalline Cu thin layer sandwiched by Si, Ti and SiN. Crystallographic slip bands associated with extrusion/intrusion of about 30 nm width are formed on the Cu surface owing to the high-cycle fatigue loading. The slip bands appear only in particular grain though others possess slip systems with a higher Schmid factor. Detailed stress analysis, taking into account the Cu grains and dissimilar surrounding materials (Si, Ti, SiN), indicates that the grain where the slip bands are formed possesses a slip system with the highest resolved shear stress. Slip band formation during fatigue of a polycrystalline material in a nanoscale component is governed by the stress field in the grain. The stress, defined on the basis of continuum mechanics, is available as the governing quantity for slip band formation in fatigue of nanoscale materials with an understructure.

Keywords: Nano-polycrystalline material; high-cycle fatigue; Slip band; Stress field; Resolved shear stress; Copper

AM16

Ultra-high cycle fatigue behavior of DZ125 superalloy used in turbine blades

Yuli Gu, Chunhu Tao, Yuhuai He
AVIC Beijing Institute of Aeronautical Materials, Beijing Key Laboratory of Aeronautical Materials, Testing and Evaluation, AVIC Testing Innovation Corporation, Beijing 100095, China
bluebee4646@163.com

Abstract The high temperature ultra-high cycle fatigue(UHCF) behaviors at 20kHz of DZ125superalloy used in aero-engine turbine blades were systematically studied. The results show that fatigue fracture still occurs above 10^8 at the conditions of 20kHz, R=-1 and 700℃. There is negligible frequency effect for DZ125 superalloy, therefore, it is proposed that the ultrasonic fatigue testing can be expected as an accelerated fatigue testing method. Fatigue cracks originate from the subsurface of the specimens, no metallurgy defects or "fish eye" character there.The crystal orientation change of the alloy is very little after fatigue.The maximum change value of the elastic modulus of the alloy is about 30GPa after fatigue compared with that before fatigue.

Keywords: Directionally solidified superalloy, Ultra-high cycle fatigue, Frequency, Crystal orientation, Elastic modulus

Influence of Environment and Temperature

IET01

Influence of stress ratio and environmental surface degradation on the VHCF behaviour of steam turbine blade steels

Bernd M. Schönbauer[1,*], Andrea Perlega[1], Stefanie E. Stanzl-Tschegg[1]
[1] Institute of Physics and Materials Science, University of Natural Resources and Life Sciences (BOKU), Vienna, Peter-Jordan-Str. 82, 1190 Vienna, Austria
* Corresponding author: bernd.schoenbauer@boku.ac.at

Abstract: The fatigue life of standard materials for turbine blades in the low pressure part of steam turbine blades was investigated in the very high cycle fatigue (VHCF) regime. Fatigue tests were performed at different stress ratios using the ultrasonic fatigue testing technique. Failure was observed up to 10^{10} cycles. Smooth specimens and specimens with artificially generated corrosion pits were tested. For smooth specimens, crack initiation was found mainly from non-metallic inclusions at the surface or the interior. At high stress ratios, failure due to cyclic creep was observed. The influence of defect size on the endurable stress was investigated using the $\sqrt{area}$-parameter model of Murakami and Endo and the small-crack model of El-Haddad *et al.*.

Keywords: Very high cycle fatigue, Steam turbine blade steel, Corrosion fatigue, Ultrasonic fatigue

IET02

Influence of heat treatment temperature on VHCF strength of helical compression springs

Isabell Brunner[1,*], Matthias Oechsner[1], Brita Pyttel[2], Desislava Veleva[1]
1State Materials Institute Darmstadt, Chair and Institute for Materials Technology, Technische Universität Darmstadt, 64283 Darmstadt, Germany
2Hochschule Darmstadt, University of Applied Sciences, 64295, Germany
* Corresponding author: brunner@mpa-ifw.tu-darmstadt.de

Abstract: Previous fatigue tests show that heat treatment temperature has a significant influence on high cycle fatigue behaviour of helical compression springs. In order to investigate the impact of the heat treatment temperature on the fracture behaviour and the cyclic life, fatigue tests in the very high cycle range (VHCF) were conducted. The tested springs were manufactured from oil hardened and tempered SiCr-alloyed valve spring steel wire with a diameter of d = 1.6 mm. After winding and grinding of the spring endings, the springs were heat treated at either 360 ℃ or 400 ℃. Subsequently, they were shot peened and afterwards heat treated at 240 ℃. Time at temperature was for every heat treatment step 30 minutes. Fatigue tests were conducted at 40 Hz using a special spring fatigue device. Up to 900 springs were tested simultaneously at different stress levels to $5 \cdot 10^8$ or 10^9 cycles. Fractured springs were investigated with a stereomicroscope as well as a scanning electron microscope to analyse the fracture behaviour and failure mechanisms. The vast majority of the springs show crack initiation at the surface at the inner side of the coil. Less frequently, crack initiation occurs at subsurface sites. As a conclusion, heat treatment at a temperature of 360 ℃ leads to four times more subsurface cracks than a temperature of 400 ℃ but to a lower fatigue life as well.

Keywords： Helical compression springs, spring steel, very high cycle fatigue test, heat treatment

IET03

Investigation of the influence of test frequency and heat treatment on the fatigue life of EN AW-6060 in the VHCF-regime

Christian Fischer[1,*], Enrico Bruder[2], Rainer Wagener[3], Clemens Müller[2], Tobias Melz[1,3]
[1] TU Darmstadt, System Reliability and Machine Acoustics SzM, Magdalenenstr.4, 64289 Darmstadt, Germany
[2] TU Darmstadt, Physical Metallurgy PhM, Alarich-Weiss-Straße 2, 64287 Darmstadt, Germany
[3] Fraunhofer Institute for Structual Durability and System Reliability, Bartningstr. 47, 64289 Darmstadt, Germany
* Corresponding author: cfischer@szm.tu-darmstadt.de

Abstract : Research of the Very High Cycle Fatigue regime in an acceptable time span is only possible with an increased test frequency. For many materials it was shown that the test frequency has no influence on the fatigue life if time depending effects like corrosion and warming are avoided. Fatigue life investigations of aluminum alloys show that there could be a significant influence of the test frequency. The mechanism of this effect is still not clarified.
In this paper the influence of the test frequency on the fatigue life will be discussed for the age-hardenable aluminum alloy EN-AW6060 in an under aged (T4), peak aged (T6) and over aged (T7) condition. To ensure a comparable surface roughness all specimens were polished with pulsed electrolytic polishing.
Three different test frequencies are compared. The test frequencies were generated using a resonance pulser with 140 Hz, a new piezo-based testing system with 700 Hz and an ultrasonic fatigue testing system which enables a test frequency of 20 kHz. It will be shown that the degree of test frequency influence on the resulting fatigue strength in the VHCF-regime is depending on the test frequency itself as well as on the ageing conditions of the aluminum alloy. These results are substantiated by metallurgical investigations.

Keywords : Aluminum, age-hardenable, test frequency, piezo-based testing facility

IET04

Effect of Ultrasonic Nanocrystal Surface Modification on Very High Cycle Fatigue Behavior of Steel and Titanium Alloys

Muhammad Kashif Khan[1,3*], Liu Yongji[1], Qing Yuan Wang[1], Young Shik Pyoun[2], Ravil Kamyrouv[2]
[1] Department of Mechanics and Engineering Science, Sichuan University, Chengdu, 610065, China
[2] Department of Mechanical Engineering, Sun Moon University, Asan-si, 336-708, Chungnam, South Korea.
[3] Department of Mechanical Engineering, DHA Suffa University, Karachi, 75500, Pakistan.
Email*: kashooo@engineer.com

Abstract : Effects of Ultrasonic Nanocrystal Surface Modification (UNSM) on the very high cycle fatigue of Ti6Al4V and AISI 310 stainless steel have been investigated. It was found that UNSM treatment increased the fatigue life of the alloys significantly. The effect of UNSM on fatigue life was higher up to 10^6 cycles. The subsurface crack initiation depth, at lower stress levels, increased substantially in both alloys. The hardness of the materials was found 15% higher after the treatment.

Keywords : Ultrasonic Nanocrystal Surface Modification, Very High Cycle Fatigue, Crack Initiation, Surface Hardness

IET05

Impact of high-pressure hydrogen on the fatigue life of steel A-286

Matthias Bruchhausen[1]*, Burkhard Fischer[1], Ana Ruiz[1], Peter Hähner[1], Sebastian Soller[2]
[1]European Commission, Joint Research Centre (JRC), Institute for Energy and Transport (IET), Westerduinweg 3, 1755 LE Petten, The Netherlands
[2]Airbus Defence And Space, Launcher Propulsion - Advanced Programs & Systems Technologies, 81663 Munich, Germany
*Corresponding author matthias.bruchhausen@ec.europa.eu

Abstract: Ultrasonic techniques are an established means for carrying out fatigue tests at very high numbers of cycles. These techniques are based on the formation of a standing ultrasonic wave in the specimen and usually use frequencies around 20 kHz. Although such systems allow testing to a very high number of cycles in a relatively short time, the use of a standing wave for creating the strains restricts them to symmetric push-pull mode. This limitation can be overcome by coupling an ultrasonic test device to a universal test rig. In this work a different approach is presented that is particularly well suited for studying environmental effects. The load train with the specimen is enclosed in a pressure vessel. An acoustic horn divides this pressure vessel into two separate chambers. Applying a pressure difference between the two chambers then leads to a static stress in the specimen on which the oscillating stress from ultrasonic excitation is superposed. The addition of both stresses allows testing at varying Rratio. The deteriorating effect of high-pressure gaseous hydrogen on the steel A-286 is presented as function of oscillating and static stresses at room temperature. SEM analysis of the fracture surface is presented.

Keywords:asymmetric push-pull mode, hydrogen, A-286, environmental effects

IET06

Ultrasonic Fatigue Performance of High Temperature Structural Material Inconel 718 Alloys at High Temperature after UNSM Treatment

Young-Sik Pyun[1,*], Jun-Hyong Kim[1], Chang-Min Suh[2], In-Sik Cho[3], Joo-Yeon Oh[3], Qingyuan Wang[4], Muhammad Kashif Khan[5]

[1] Department of Mechanical Engineering, Sun Moon University, 336-708, South Korea
[2] School of Mechanical Engineering, Kyungpook National University, 702-701, South Korea
[3] Mbrosia, 336-708, South Korea
[4] Department of Civil Engineering and Mechanics, Sichuan University, 610065, China
[5] Department of Mechanics and Engineering Science, Sichuan University, 610065, China
* Corresponding author: pyoun@sunmoon.ac.kr, cmsuh@knu.ac.kr

Abstract: This study investigates the influence of ultrasonic nanocrystal surface modification (UNSM), a novel surface treatment technology, on the mechanical characteristics and fatigue performance of two types of alloys. Annealed Inconel 718 alloy and aged Inconel 718 alloys were chosen as high temperature structural materials. The mechanical properties are acquired and compared for UNSM-treated and untreated specimens. Ultrasonic fatigue test (UFT) was conducted at various temperatures for both types of materials. Rotary bending fatigue test (RFT) data is acquired and compared for UNSM-treated and untreated specimens. Fracture analysis is performed. The improvement in the fatigue performance is attributed mainly to the UNSM-induced compressive residual stress, micro-hardness, and nanograin in the subsurface of the material.

Keywords: Annealed and aged Inconel 718 alloy, UNSM(Ultrasonic Nanocrystal Surface Modification) treatment, UFT(Ultrasonic Fatigue Test), High temperature fatigue test, Compressive residual stress

IET07

Dissipation in very high cycle fatigue for single-phase ductile metals:comparison between b.c.c and f.c.c structures

BLANCHE Antoine[1,a], WANG Chong[2,b], PHUNG Ngoc Lam[3,c], RANC Nicolas[3,d], FAVIER Véronique[3,e], WAGNER Danièle[2,f], BATHIAS Claude[2,g], CHRYSOCHOOS André[1,h]
[1]Laboratoire de Mécanique et Génie Civil (LMGC), , CNRS, Place Eugène Bataillon, 34090 Montpellier, France
[2]Paris Ouest Nanterre University,LEME EA 4416,50 rue de Sèvres 92410 Ville d'Avray, France
[3]Arts et Metiers ParisTech, CNRS PIMM, 151 Boulevard de l'Hôpital, 75013 Paris, France
[a]antoine.blanche@univ-montp2.fr,[b]wangchongscu@163.com,
[c]ngoclam250@yahoo.com,[d]nicolas.ranc@ensam.eu,
[e]veronique.favier@ensam.eu,[f]daniele.wagner@u-paris10.fr,
[g]claude.bathias@u-paris10.fr,[h]andre.chrysochoos@univ-montp2.fr,

Abstract: This paper aims at a deeper understanding of microplastic mechanisms leading to crack initiation in ductile metals in Very High Cycle Fatigue (VHCF). Fatigue tests were conducted using an ultrasonic technique at loading frequency of 20 kHz. The microplastic mechanisms are revealed via observations of slip markings at the specimen surface and self-heating measurements due to intrinsic dissipation. Pure copper and Armco iron (which contains a very low amount of carbon) were investigated. Both are single-phase ductile materials but the crystallographic structure of copper is face-centered cubic while it is body centered cubic for Armco iron. A good correlation was found between slip markings initiation and dissipation for both materials. However, at very small stress amplitudes, no slip markings appeared up to 10^8 cycles but the materials were found to dissipate energy. The dissipation for both materials is on the same order of magnitude but the location and the morphology of slip markings were found different.

Keywords: very high cycle fatigue, slip bands, dissipation, microstructure, polycrystals.

IET08

Very long life fatigue behavior of implant Ti-6Al-4V in air and simulated physiological environments

Yong-jie LIU, Jiu-kai LI , Chao HE and Qing-yuan WANG
Department of Mechanics and Engineering Science, Sichuan University, Chengdu 610065, China

Abstract: By use of the self-regulating ultrasonic vibration corrosive fatigue test system, the very long life fatigue behaviors of Ti-6Al-4V alloy in ambient air and simulated physiological environments (simulated body fluid and physiological saline) were experimentally investigated. The effects of surface condition (ground, polish) and presoaking in physiological environment on the fatigue behaviors of Ti-6Al-4V alloy were studied. The results showed that, in ambient air, the Ti-6Al-4V alloy is insensitive to cyclic frequency, therefore, the ultrasonic vibration test method could be effectively used in the study of its VHCF behaviors. The improvement of fatigue strength was pronounced for surface improved samples below 10^6 cycles in ambient air due to fatigue cracks initiated from surfaces of specimens at high stress amplitudes, while surface conditions had no effect on fatigue behaviors of the material because the defects located within the sample became favorable sites for crack initiation. The presoaking in physiological environment has no effect on the fatigue property of Ti-6Al-4V alloy. The endurance limit at 10^7 cycles of Ti-6Al-4V samples decreased by 11.4% if it was cycled in simulated body fluid, while the deceased rates were 8.8 % and 20% respectively in nature and acid physiological salines. Fracture surface investigations showed all fatigue failure initiated from surfaces in physiological environments.

Keywords: Ti-6Al-4V alloy; High cycle fatigue; surface condition; simulated physiological environments ; S-N curve; fatigue crack initiation.

IET09

Formation of Multiple Fish-Eyes in Very High Cycle Fatigue Region at Elevated Temperature for a Low-Alloy Steel

Yukio Takahashi[1,a] , Kenji Kanazawa[1,b] and Tohru Ihara[1,c]
[1]Chuo University, Faculty of Science and Engineering,
1-13-27 Kasuga, Bunkyo-ku, Tokyo, 112-8551, Japan
[a]takahashi@mech.chuo-u.ac.jp,[b]kanazawa@mech.chuo-u.ac.jp,[c]ihara18@mech.chuo-u.ac.jp

Abstract: Stepwise S-N curves were obtained under fatigue tests at elevated temperatures for a low-alloy steel,where internal fracture occurred in high cycle region. In general, a single fish-eye was observed on fracture surfaces, but occasionally many fish-eyes could be observed on a fracture surface. In this study, fracture surfaces accompanying with many fish-eyes were examined and mechanisms of formation of multiple fish-eyes were discussed.The material used was an 1Cr-0.5Mo steel and rotating bending fatigue tests were carried out at 673K.Fracture surfaces with a single fish-eye were formed on specimens fatigued below 10^8 cycles and fracture surfaces with multiple fish-eyes were formed on specimens fatigued in very high cycle region such as 10^9 cycles.For the latter case about twenty fish-eyes could be observed on the fracture surface. Many of them reached the specimen surface and the surfaces of the fish-eyes were covered with thick oxides. They could not grow as surface cracks because of oxide induced crack closure. After reaching the specimen surface a fish-eye grew gradually as a surface crack and brought final fracture. Whether a fish-eye becomes a propagating crack as a surface crack or not depends on the size of fish-eye and stress condition.

Keywords: Very High cycle fatigue, Elevated temperature, Low alloy steel, Internal fracture, Fish-eye, Oxide-induced crack closure

IET10

VHCF behavior of a ferritic-martensitic steel at high mean stresses

Tilmann Beck[1,*], Stephan A. Kovacs[2]
[1] Institute of Materials Science and Engineering, Universität Kaiserslautern, 67663 Kaiserslautern, Germany
[2] Institute of Energy and Climate Research – IEK 2, Forschungszentrum Jülich, 52425 Jülich, Germany
* Corresponding author: beck@mv.uni-kl.de

Abstract : Low-pressure steam turbine blades undergo VHCF-loadings induced by inhomogenous flow behind the vanes resulting in excitation frequencies of ≈3 kHz for rotational speeds of 50Hz and a typical number of stator vanes of ≈60. The VHCF loading is superimposed by considerable mean stresses caused by centrifugal forces. In the present study, the VHCF-behavior of the ferritic-martensitic turbine blade steel X10CrNiMoV12-2-2 is investigated using an ultrasonic fatigue testing system up to cycle numbers of $5x10^9$ at stress ratios from R=-1 up to 0.7, i.e. up to very high mean stresses.
Generally, crack initiation changes from the surface to internal inclusions at fatigue lives around $5x10^7$. The transition between fatigue failure and run-outs is shifted to higher lifetime with increasing R, and fine grained areas (FGAs) at the crack initiation sites only occur at R<-0.1. However, the fracture mechanics approach proposed by Murakami consistently describes the lifetime behavior for all load ratios over 4 decades of lifetime. At R up from 0.5 considerable cyclic creep occurs, even for lifetimes above 10^8 cycles, resulting in cyclic hardening which was proved by microhardness measurements at longitudinal sections. This effect at least partially explains the high maximum stresses close to the tensile strength of the material occurring in the VHCF regime at load ratios ≥ 0.5.

Keywords : VHCF, ferritic-martensitic steel, mean stress, cyclic creep, ODA formation, cyclic hardening

IET11

High temperature ultrasonic fatigue testing for Ti-17

J. K. Li, Y. J. Liu, Q. Y. Wang[1], F. Hou
College of Architecture and Environment, Sichuan University, Chengdu 610065, China
Corresponding author： Q. Y. Wang , wangqy@scu.edu.cn (Q.Y. Wang).

Abstract:A high-temperature ultrasonic fatigue testing system was developed to evaluate the gigacycle fatigue properties of Ti-17. Ultrasonic (20 kHz) fatigue tests were performed at room temperature, 200℃ and 350℃, respectively. The dynamic Young's modulus and fatigue endurance limit decrease with increasing temperature linearly. Rotating bending (50 Hz) tests were performed to evaluate the influence of loading frequency at different temperature. There is an obviously loading frequency effect at elevated temperature, although no loading frequency effect at room temperature.

Keywords: Ultrasonic fatigue, High-temperature, Titanium alloy, Frequency effect

IET12

Very High cycle fatigue property of austempered ductile iron

Jiwang Zhang [a*], Qingpeng Song [a], Ning Zhang [a], Liantao Lu [a], Dongfang Zeng [a], Mintang Zhang [b], Guodong Cui [c]

[a] State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, China.

[b] Henan Aoudi Co.,Ltd, Hebi 456750, China

[c] School of material science and engineering, Southwest Jiaotong University, Chengdu 610031, China

*Corresponding author. E-mail address: zhangjiwang@swjtu.cn

Abstract: Austempered ductile iron (ADI) has been widely applied to mechanical structures as a new kind of engineering material, while in order to ensure the reliability and durability of the ADI structures during service, the fatigue property needs to be studied in detail. In this study, ADIs with different strength grades were produced and the very high cycle fatigue tests were conducted. The results show that the S-N curves give a step-wise shape and there is no fatigue limit in the very high cycle fatigue regime. According to the SEM observations, the fatigue fracture can be divided into two modes: one is the fatigue fracture from defects at specimen surface, which occurs at short fatigue life region; the other is the fatigue fracture from defects at specimen subsurface, which occurs at long fatigue region. Most of the fatigue failures initiate from large casting shrinkages and some of them initiate from graphite nodules. On the fracture surfaces of some specimens, the 'granular-bright-facet' (GBF) granular area was observed in the vicinity of the defect. The threshold stress intensity factor ranges for subsurface crack growth was obtained.

Keywords: Austempered ductile iron; Very high cycle fatigue; S-N curve; Fatigue defect

IET13

Very high cycle fatigue behavior of titanium alloy at elevated temperatures

Zhao Zihua[1,*],Ma Jing[1], Nie Baohua[1]， Zhang Zheng[1]
School of Materials Science and Engineering, Beihang University, Beijing, 100191, China
* Corresponding author: zhzh@buaa.edu.cn

Abstract: The high-temperature fatigue behavior of a titanium alloy used in whole compressor disk of aircraft engine in the very high cycle regime was investigated. A high-temperature ultrasonic fatigue testing system was set up to evaluate the very high cycle fatigue properties. Tests at 15℃, 400℃ and 600℃ were performed operating at 20kHz. SEM and EDS were used to determine the initiation sites and the fatigue mechanism. Results indicated that increasing test temperature led to a significant decrease in endurance limit by about 25% from 15 to 400 ℃, while slighter decrease in endurance limit by only 2% from 400 to 600 ℃. Fatigue crack initiated on the surface in the short life regime, but the subsurface crack initiation occurred in the long life regime. The mechanism of subsurface initiation in very high cycle fatigue was discussed based on the fracture surface analysis at different temperatures.

Keywords: titanium alloy; high temperature; very high cycle fatigue

IET14

Effects of Microstructure, Surface Fish and Environment on Surface-Initiated Fatigue of Hardened Steels

Junbiao Lai[1, a], Hanzheng Huang[2,b] and Wijbe Buising[3,c]
[1]SKF Engineering and Research Centre, Nieuwegein, Netherlands
[2]SKF Engineering and Research Centre, Nieuwegein, Netherlands
[3]SKF Engineering and Research Centre, Nieuwegein, Netherlands
[a]Junbiao.Lai@skf.com, [b]Hanzheng.Huang@skf.com, [c]Wijbe.Buising@skf.com

Abstract: Hardened steels are sensitive to defects which, depending on their type and size, can reduce the fatigue strength significantly. The present study focuses on a special type of defects, namely, surface roughness resulting from surface finishing of hardened components. Rotating bending fatigue (RBF) tests are conducted on a high-strength steel, heat-treated with two different microstructures, i.e. martensite tempered at 160 ℃ and bainite. The testing samples are surface-finished with three conditions: polished surface, ground surface with roughness Ra ~ 0.3 - 0.4 m and ground surface with Ra ~ 0.7 - 0.8 m. The RBF tests are conducted in dry-air condition, as well as in oiled environment in which an oil film covering the specimen surface is realized by droplets of oil onto the specimen surface using a special oil pump set-up. The experimental results indicate that specimens with rough surface (Ra ~ 0.7 - 0.8 m) fail predominantly by surface crack initiation, whereas the fatigue fracture of the specimens with smooth surface is primarily due to subsurface crack initiation from inclusions. It is also found that the fatigue strength of the marensitic specimen is lower than that of the bainitic specimen in the stress cycle range corresponding to the surface initiated fatigue fracture, whereas this difference diminishes in the HCF or VHCF regime where subsurface initiated fatigue prevails. Furthermore, the oiled environment seems to have an effect on the fatigue strength of the RBF samples too. The fatigue strength of the RBF specimens with different surface finishes is modeled in terms of the micro and macro notch effects, based on the description of the threshold and speed of small crack propagation in different environments.

Keywords: defect, surface finish, hardened steels, defect sensitivity, environmental effect.

Review and Prospects for Current Research about the Effect of Factors on the VHCF of Metallic Materials

Yingxia Yu*, Bolin He, Zongmin Lv, Kang Wei, Zhijun Zhang
Key Laboratory of Ministry of Education for Conveyance and Equipment, East China Jiaotong University, Nanchang 330013, China
* Corresponding author:hebolin@163.com

Abstract : In recent years, very high cycle fatigue has become a major concern in design and durability of engineering components and structures such as railway wheels, rails, offshore structures, bridges, load bearings, etc. There are some factors which have been assumed to influence the fatigue behavior for metallic materials in VHCF regime. But most factors influencing the VHCF behavior have not been studied thoroughly. In order to deeply understand the essence of material fatigue, the experimental and theoretical aspects of the factors influencing on very high cycle fatigue for metallic materials should be studied further more. This paper deals with an overview on the effect of factors on the property in very high cycle fatigue regime. Research trends and some conclusions in this field are briefly discussed and obtained.

Keywords :VHCF, Metallic materials, Frequency, Environment, Inclusion

INS01

Fatigue Characteristics of Aluminum Alloy (A7075-T651) treated by Shot Peening and UNSM under Ultrasonic and Rotary Bending Fatigue Tests

Chang-Min SUH[1, a], Min-Soo SUH[2, b], Youngsik Pyun[3, c], and Seung-Hoon Nahm[4, d]
[1]School of Mechanical Engineering, Kyungpook National University, Daegu 702-701, Korea
[2]Korea Institute of Energy Research, Daejeon 305-343, Korea
[3]Department of Mechanical Engineering, Sun Moon University, Asan 336-708, Korea
[4]Korea Research Institute of Standards and Science, Daejon 305-600, Korea
[a]cmsuh@knu.ac.kr, [b]mssuh@kier.re.kr, [c]pyoun@sunmoon.ac.kr, [d] shnahm@kriss.re.kr

Abstract: The fatigue characteristics of JIS A7075-T651 aluminum materials were studied and compared with various surface treatments of shot peening (SP) and UNSM (Ultrasonic Nano-Crystal Surface Modification) technology. Fatigue characteristics of those are unearthed by using various fatigue testing machines of followings; the ultrasonic fatigue testing machine (20 KHz), and the rotary bending fatigue testing machines (53 Hz) with a single-spindle (simple beam type) and a multi-spindles (cantilever type).

The improvement of fatigue life were confirmed for both rotary bending fatigue testing machines (53Hz) with the specimens treated under SP and UNSM. However, the effects of surface modification as fatigue life improvement was not appeared for ultrasonic fatigue testing machine (20 KHz). The fatigue life under both of rotary bending fatigue tests (53 Hz) show similar properties.

The subsurface microstructures of about 70 – 180 μm depth from the surface becomes nanocrystallized after the surface treatments. The mechanical characteristics including hardness and fatigue strength drastically improved by the surface modification of microstructures.

Keywords: UNSM (ultrasonic nanocrystalline surface modification), aluminum alloy (A7075-T651), fatigue crack initiation, ultrasonic fatigue test, multi-spindle (cantilever type) rotary bending fatigue test, shot peening, S-N property.

INS02

Cyclic deformation and damage behavior of Ti6Al4V in the Very High Cycle Fatigue Regime

Stefan Heinz[1], Guntram Wagner[1], Dietmar Eifler[*,1]
Institute of Materials Science and Engineering (WKK), University of Kaiserslautern, P.O. Box 3049, 67653 Kaiserslautern, Germany
* Corresponding author: eifler@mv.uni-kl.de

Abstract: High frequency fatigue tests with Ti6Al4V were carried out using a 20 kHz ultrasonic testing facility to investigate the cyclic deformation behavior in the Very High Cycle Fatigue (VHCF) regime in detail. The S,N_f-curve at the stress ratio R = -1 shows a significant decrease of the stress amplitude and a change from surface to subsurface failures in the VHCF regime for more than 10^7 cycles. Microscopic investigations of the distribution of the α- and β-phase of Ti6Al4V indicate that inhomogeneities in the phase distribution are reasons for the internal crack initiation. Scanning electron as well as light microscopy were used to investigate the internal crack initiation phenomenon in the VHCF-regime in detail. Beside the primary crack additional defects like micro cracks and crack clusters were observed in the fatigued specimens. SEM-investigation of specimens which were loaded up to 10^{10} cycles without failure are showing irreversible microstructural changes inside of the specimens. Two step tests were performed to evaluate the degree of damage of internal defects which occur in specimens which did not fail within 10^{10} cycles.

Keywords: VHCF, Ti6Al4V, cyclic deformation behavior, failure mechanisms

INS03

Influence of hydrogen and deoxidation technique on the fatigue behaviour of steel SAE 52100 in the VHCF regime

Torben Karsch*, Brigitte Clausen, Hans-Werner Zoch
IWT, Stiftung Institut für Werkstofftechnik, 28359 Bremen, Germany
Corresponding author: karsch@iwt-bremen.de

Abstract: The fatigue life of the bearing steel SAE 52100 (DIN 100Cr6), deoxidised by silicon, in martensitic and bainitic heat treatment state was investigated up to 2 x 10^9 load cycles. Prior to testing half of the specimens were electro-chemically charged with hydrogen. Fatigue tests under uniaxial cyclic stresses (load ratio R=-1 and R=0.1) were performed on a piezo-electric resonant system with a load frequency of 20 kHz. The increased content of diffusible atomic hydrogen reduces the fatigue life nearly to the half in comparison to the uncharged conditions. At the same time hydrogen increased the harmfulness of weakly bonded inclusions like MnS or globular oxidic slag agglomerations. For a better understanding further investigations were carried out with hydrogen charged specimens from ultra clean 100Cr6 steel, in this case deoxidised by aluminium. Here cracks initiate solely at titanium nitrides and the fatigue life is nearly the same as the silicon deoxidised variant. In both cases numerous SEM micrographs of the fractured surfaces show an inclusion in the centre of a fisheye, surrounded by a fine grain area (FGA) if the specimen failed at high number of cycles. Using the stereomicroscope additionally an optically bright zone (OBZ) surrounding the fisheye was detected. All three phenomena can be explained with specific stress intensity factors.

Keywords: Very High Cycle Fatigue (VHCF), ultrasonic fatigue, hydrogen, SAE 52100, fine granular area (FGA).

INS04

Fatigue strength evaluation for high pressure loaded diesel injection components considering Very High Cycle Fatigue

Mike Köder[1,a], Andreas Scheffold[1], Christoph Marquardt[1], Hans-Jürgen Christ[2,b] and Martina Zimmermann[3,c]

[1]Robert Bosch GmbH, PO 30 02 20, 70442 Stuttgart, Diesel Systems, Germany

[2]Universität Siegen, Institut für Werkstofftechnik, Paul-Bonatz-Str. 9-11, 57076 Siegen, Germany

[3]TU Dresden, Institut für Werkstoffwissenschaft, Helmholtzstr. 7, 01069 Dresden, Germany

[a]Mike.Koeder@de.bosch.com, [b] Hans-Juergen.Christ@uni-siegen.de,

[c]Martina.Zimmermann@iws.fraunhofer.de

Abstract: The steady increase of injection pressure necessitates an increased use of high strength steels (such as 100Cr6) for highly stressed common rail injection components. As the load collectives of these parts can have accumulated load cycles above the commonly used ultimate number of cycles, the SN curve beyond 1E+07 cycles is of great importance for the fatigue strength evaluation. The fatigue life in this area can only be economically investigated using very high frequency ultrasonic testing systems. This type of testing is limited to small specimens only, thus testing of actual diesel injection parts is not possible. Accordingly, the prediction of the SN curve of complex parts considering different failure mechanisms must be accomplished using fatigue data of specimens. An approach to fatigue strength verification for high strength steels in common rail systems is presented in this article. It is based on experimental results of notched 100Cr6 specimens which were tested on an ultrasonic testing machine up to an ultimate number of cycles of 1E+09 cycles. This allows an estimation of the components' fatigue life considering the relevant failure mechanisms in the HCF and VHCF regimes.

Keywords: Very high cycle fatigue, fatigue strength evaluation, ultrasonic testing, 100Cr6, failure mechanism, variable amplitude

INS05

Study on the Model of Ultra-high Cycle Fatigue Destruction due to Curving Vibration after the Surface Strengthening

FENG Lu-lu[1,a], LI Quan-tong[2,b], GAO Xing-wei[3,c], TONG Xu-dong[4,d], ZHANG Hai-tao[5,e], JIAO Sheng-bo[6,f]

[1]Aeronautics and Astronautics Engineering College，Air force Engineering University，Xi'an 710038，China

[a]shaanxifenglu@163.com

Abstract：The paper based on the surface hardening analysis and the influences of stress distribution processing, a dynamic model of ultra-high cycle fatigue destruction due to curving vibration of aero-engine rotor testing specimen was established. The mechanism of fatigue destruction was analyzed and striding size model method for ultra-high cycle fatigue was proposed. The ultra-high cycle fatigue test was carried out for the use of titanium alloy specimens by laser shock processing treatment technology with untreated specimens. Comparing and analyzing of test results, to verify the method of this paper. Providing a reference basis for further study of ultra-high cycle fatigue destruction due to curving vibration of rotor.

Keywords：surface strengthening；curving vibration；striding size model；titanium alloy

INS06

Effects of Cleanliness and Induction Hardening on Very High Cycle Fatigue Properties of Low Alloy Forged Steel

Yiwen Yang[1], Nobuyuki Fujitsuna[2], Ryota Yakura[2], Mariko Matsuda[2]
Taku Miura[1], Akira Ueno[3*], Shoichi Kikuchi[4], and Tatsuo Sakai[3]
[1] Graduate School of Science and Engineering, Ritsumeikan University, Kusatsu, Shiga, 525-8577, Japan
[2] Research & Development Section, Technical Development Department, Steel Casting & Forging Division, Kobe Steel, Ltd., Takasago, Hyogo, 676-8670, Japan
[3]College of Science and Engineering, Ritsumeikan University, Kusatsu, Shiga, 525-8577 Japan
[4]Graduate School of Engineering, Kobe University, Kobe Hyogo, 657-8501, Japan
* Corresponding author: ueno01@fc.ritsumei.ac.jp

Abstract: In order to investigate the effects of cleanliness and induction hardening on fatigue properties of low alloy forged steel, rotating bending fatigue tests were performed with specimens of different cleanliness (super clean steel and conventional steel) and different heat treatment (no heat treatment and induction-hardening). For induction hardened steel, 2 kinds of hardened layer's thickness (0.4mm or 0.2mm) were formed. Surface modified layer was characterized by the Micro-Vickers hardness and the residual stress was measured at a transverse section of the tested section. After fatigue tests, fracture surfaces were observed using a scanning electron microscope (SEM) to evaluate the fracture mechanism. Super clean steel had higher fatigue limit than conventional steel, because fatigue fracture from non-metallic inclusion was suppressed. Induction-hardening had a positive effect to increase the fatigue life of both the super clean and conventional steels in finite life region; however, induction-hardened steels provided lower fatigue limit in comparison with non-induction-hardened steels. This was because all induction-hardened steels failed beneath the hardened layer due to the generation of tensile residual stress inside the material. The reason for the phenomena above mentioned was discussed by introducing a schematic illustration showing the concept of “local fatigue strength”.

Keywords: Very high cycle fatigue, Low alloy steel, Cleanliness, Induction hardening, Fractography

INS07

Influence of different stress amplitudes on duplex steel in the VHCF regime

Anne K. Hüsecken[1a], Nadja Pashniak[1b], Marcus Söker[2c], Konstantin Istomin[1d], Benjamin Dönges[1e], Hans-Jürgen. Christ[1f], Ulrich Krupp[2g] and Ullrich Pietsch[1h]

[1]Naturwissenschaftlich-Technische Fakultät der Universität Siegen, D- 57078 Siegen, Germany

[2]Fakultät für Ingenieurwissenschaften und Informatik, Hochschule Osnabrück, D-49009 Osnabrück,Germany

[a]anne-huesecken@tu-dortmund.de, [b]pashniak@physik.uni-siegen.de, [c]m.soeker@hs-osnabrueck.de, [b]istomin@physik.uni-siegen.de, [e]doenges@ifwt.mb.uni-siegen.de, [f]christ@ifwt.mb.uni-siegen.de,[g]u.krupp@hs-osnabrueck.de, [h]pietsch@physik.uni-siegen.de

Abstract: Effects of very high cycle fatigue (VHCF) damage in an austenitic-ferritic duplex stainless steel have been investigated by in-situ X-ray diffraction technique applying up to 10^9 cycles and a nominal load amplitude of 360MPa. Due to the coarse grain structure of specimens distinct Bragg peaks appear allowing single grain analysis of ferritic and austenitic grains. We investigated the evolution of peak widths and angular positions of these individual Bragg spots as a function of fatigue cycles and stress amplitude, i.e. the distance from the minimum cross section of the hourglass-type specimens. During in-situ observation an increasing splitting of Bragg peaks of austenite reflections was monitored as function of load cycles which can be taken as an indication for the VHCF damage whereas ferrite reflection remain nearly unchanged. In addition we observed a rapid strain release resulting from internal stress relaxation for both types of reflections for low number of cycles, while internal strain increases again at very high number of cycles. Using X-ray nanobeam inspection we could interpret these findings as the formation of stress-induced planar dislocation arrangements and dislocation pile-ups in austenite grains acting as nuclei for crack formation in adjacent ferrite grains.

Keywords: austenitic-ferritic duplex steel, VHCF damage, in-situ X-ray diffraction, dislocation pile-up, crack initiation.

INS08

Review of study on the Fatigue in the Very high cycle fatigue regime

Bolin He*, Zongmin Lv
School of Mechanical & Electronic Engineering, East China Jiaotong University, Nanchang 330013, China
* Corresponding author: hebolin@163.com

Abstract : With the development of industry level and the strength increase of materials，research on ultra-high cycle fatigue has become a new topic for engineering components failure. In this paper, the state of the art in this field is summarized. High-strength steels behavior in fatigue is represented by a stepwise shape in the S-N curve. There are two competing failure modes consisting of surface induced failure at higher stress level and subsurface induced failure at lower stress level. The inclusion inside fish-eye surrounded by fine granular morphology can be observed on fracture surface via SEM. Most of the fatigue life was consumed at the crack initiation and FGA forming stage.

Keywords :VHCF, S-N curve, crack initiation, crack propagation, fine granular area (FGA)

Microstructure and Initiation Mechanism

MIM04

A basic study on the formation of the fine grained area during very high cycle fatigue

Guocai Chai[1, 2*], Tomas Forsman[1] and Fredrik Gustavsson[1]
[1]R&D center, Sandvik Materials Technology, 811 81 Sandviken, Sweden
[2]Engneering Materials, Linköping University, 581 83 Linköping, Sweden
* Corresponding author: guocai.chai@sandvik.com

Abstract:"Fish eye" is a typical phenomenon of fatigue crack initiation at a subsurface defect such as inclusion during very high cycle fatigue. The formation of a fine grained area and micro-debonding is believed to cause fatigue crack initiation. This paper provides a basic study on the formation of the fine grained area in a martensitic stainless steel during very high cycle fatigue using scanning electron microscopy, SEM, focused ion beam technique, FIB, electron backscatter diffraction, EBSD, and electron channeling contrast imaging, ECCI. The results show that the formation of a fine grained zone is a local behavior. The fine grained zone is very near the fatigue crack initiation origin. In the transversal direction (cross section), the depth of the fine grained zone is only few micrometers. In the longitudinal direction (crack propagation direction), the depth of the fine grain zone is about one micrometer. ECCI analysis shows that in the fine grained area with high retained strain, high plastic deformation can be found. Dislocation slip bands can be observed. They interact with grain boundaries and cause the formation of damage due to impingement cracking. The results indicate that occurrence of plastic deformation in metallic material during very high cycle fatigue is very localized, mainly near the front of the crack tip or a defect.

Keywords: Fine grain area, FGA, Very high cycle fatigue, Dislocation, cyclic deformation

MIM06

High and Very High Cycle Fatigue Behaviour of an Austenitic-Ferritic Duplex Stainless Steel,Part 1: Experimental Investigations

Marcus Söker[1,a], Benjamin Dönges[2,3,b], Alexander Giertler[1,c],
Claus-Peter Fritzen[3,d], Hans-Jürgen Christ[2,e] and Ulrich Krupp[1,f]
[1]Fakultät für Ingenieurwissenschaften und Informatik, Hochschule Osnabrück, D-49009 Osnabrück,Germany
[2]Institut für Werkstofftechnik, Universität Siegen, D-57068 Siegen, Germany
[3]Institut für Mechanik und Regelungstechnik – Mechatronik, Universität Siegen, D-57068 Siegen, Germany
[a]m.soeker@hs-osnabrueck.de, [b]doenges@ifwt.mb.uni-siegen.de, [c]a.giertler@hs-osnabrueck.de,
[d]fritzen@imr.mb.uni-siegen.de, [e]christ@ifwt.mb.uni-siegen.de, [f]u.krupp@hs-osnabrueck.de,

Abstract: In order to develop a sound experimental mechanism and data basis for the development of a physically oriented modeling approach towards crack initiation and propagation in the VHCF regime, detailed mechanistic experiments were carried out in the present investigation. The focus of the study was on the systematic analysis of local microstructure influences on the crack initiation and short crack propagation behavior in a low-carbon 22wt% Cr, 5wt%Ni, 3% Mo duplex steel (German designation: 1.4462) in the VHCF regime. For this purpose, electrolytically polished shallow-notched hourglass-type specimens were fatigued in an ultrasonic fatigue testing machine at a stress ratio of R = -1, and the surface was simultaneously observed in-situ by an optical far-field microscope. The investigations show that fatigue cracks initiate in those areas in which the highest local stress strain concentrations are present. These concentrations can be attributed to the elastic anisotropy of the microstructure and grain patches that are oriented for easy slip. After initiation, the propagation of microstructural short fatigue cracks is hindered by the first phase or grain boundary. Such cracks that pass through the boundaries exhibit a strong acceleration in the crack propagation rate and may lead to failure, eventually. The quantitative correlation of the da/dN data with local microstructural features, such as the crystallographic orientation (measured by automated electron back-scatter diffraction EBSD) or residual stresses, allow the identification and quantitative determination of important material parameters and later the verification of a numerical simulation approach, being subject of part 2 of the present paper.

Keywords: Crack initiation, short crack propagation, fatigue limit, modeling

MIM07

Effect of microstructure on very high cycle fatigue behavior of TC21 titanium alloy

Nie Baohua, Zhang Zheng, Zhao Zihua*, Zheng Zhiteng, Zhong Qunpeng
School of Materials Science and Engineering, Beihang University, Beijing, 100191, China
* Corresponding author: zhzh@buaa.edu.cn

Abstract: The effect of microstructure on very high cycle fatigue behavior of TC21 titanium alloy was investigated in this paper. Very high cycle fatigue properties of the alloy with basket-weave size of 60um and 40um were investigated by ultrasonic fatigue tests at 20 KHz. The results showed that the both alloys illustrated duplex S–N characteristics over the wide range of 10^5 to 10^9 cycle regime, and fatigue fracture in both alloys occurred beyond the conventional fatigue limit of 10^7 cycles. Subsurface crack initiation occurred in both types of specimens at low stress amplitude. A fine granular area (FGA) and micro-voids were observed along α lamellar at subsurface crack initiation. The stress intensity factor range at the front of the FGA was regarded as the threshold value that controls the internal crack propagation. Furthermore, the effect of basket-weave size on very high cycle fatigue limit of TC21 titanium alloy was discussed based on the microstructure features at crack initiation site.

Keywords: very high cycle fatigue; subsurface crack; TC21 titanium alloy; crack initiation

MIM07

Effect of hot isostatic pressing on very high cycle fatigue behavior of DZ4 directionally solidfied Ni-base supreralloy

Baohua Nie[a], Zheng Zhang[b], Zihua Zhao[c] and Qunpeng Zhong[d]
School of Materials Science and Engineering, Beihang University, Beijing, 100191, China
[a]niebaohua@mse.buaa.edu.cn, [b]zhangzh@buaa.edu.cn, [c]zhzh@buaa.edu.cn, [d]zhongqp@buaa.edu.cn

Abstract: DZ4 directionally solidified nickel-based superalloy is used for high performance gas-turbine blades due to excellent fatigue and creep resistant. This study is concerned with the effect of hot isostatic pressing (HIP) on very high cycle fatigue behavior of DZ4 alloy. Very high cycle fatigue properties of DZ4 alloy in casting state and after HIP were obtained by ultrasonic fatigue tests at room temperature. The results showed that fatigue fracture of DZ4 alloy in both states occurred beyond 10^7 cycles, and the alloy had no the conventional fatigue limit. HIP enhanced fatigue strength of DZ4 alloy in very high cycle regime because of the significant reduction in the size of pores after HIP. The fractographic observation indicated that crystallographic Stage I and non-crystallographic Stage II propagation were present in both states. In the casting specimens, fatigue crack initiated from large casting pores where the stress concentration promoted crystallographic Stage I propagation, thereby leading to the decrease in fatigue life. However, the small pores in the HIP specimens had insignificant effect on fatigue crack initiation. Fatigue strength of DZ4 alloy in very higy cycle regime was dicussed based on Murakami model.

Keywords: Very high cycle fatigue; DZ4 alloy; Hot isostatic pressing; Casting pores

MIM08

Very high cycle fatigue property of high-strength austempered ductile iron at 90 Hz and 20KHz loading

Liantao Lu [a*], Ning Zhang [a], Jiwang Zhang [a], Dongfang Zeng [a], Mintang Zhang [b]
[a] State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, China.
[b] Henan Aoudi Co.,Ltd, Hebi 456750, China
*Corresponding author. E-mail address: luliantao@swjtu.cn

Abstract: In this study, the very high cycle fatigue tests were conducted on high-strength austempered ductile iron (ADI) at 90Hz and 20KHz. The S-N curves decrease continuously and there is no fatigue limit in the very high cycle fatigue regime. The fatigue strengths of the 90Hz and 20KHz tests show a good agreement and the specimens show similar fracture behaviors. The specimens fracture from defects at specimen surface at short fatigue life region, while they fracture from internal defect with fish-eye area at long fatigue life region. Meanwhile, on the fracture surfaces of some specimens, the 'granular-bright-facet' (GBF) area is observed in the vicinity of the defect. The threshold stress intensity factor ranges for internal crack growth is obtained and the fatigue limit is evaluated based on the defect size.

Keywords: Austempered ductile iron; Very high cycle fatigue; Loading frequency; Fracture behavior ; Defect size

MIM09

Interior-induced Fracture Mechanism of Valve Spring Steel (JIS SWOSC-V) with High Cleanliness in Very High Cycle Regime

Taku MIURA[1, a], Takayuki SAKAKIBARA[2, b], Takanori KUNO[2, c], Akira UENO[3, d], Shoichi KIKUCHI[3, e] and Tatsuo SAKAI[3, f]

[1]Graduate School of Science and Engineering, Ritsumeikan University, 1-1-1 Noji-higashi, Kusatsu, Shiga, 5258577, Japan

[2]Research & Development Division, Chuo Spring Co., Ltd., 43-1 Miyashita Fukuta-cho, Miyoshi, Aichi, 4700225 Japan

[3]College of Science and Engineering, Ritsumeikan University, 1-1-1 Noji-higashi, Kusatsu, Shiga, 5258577 Japan

[a]rm009077@ed.ritsumei.ac.jp, [b]Takayuki_Sakakibara@chkk.co.jp, [c]Takanori_Kuno@chkk.co.jp, [d]ueno01@fc.ritsumei.ac.jp, [e]kiku-sho@fc.ritsumei.ac.jp, [f]sakai@se.ritsumei.ac.jp

Abstract: In order to investigate the interior-induced fatigue crack propagation behavior of high cleanliness valve spring steel (JIS SWOSC-V), rotating bending fatigue tests were performed for various kinds of specimens with different hardness (tempered at 395 degree C and 363 degree C) or surface finishing (polished, electrochemical polished, shot-peened and electrochemical polished pre-treated with shot peening). The harder specimen with higher compressive residual stress showed longer fatigue life. The electrochemical polished specimen pre-treated with shot peening showed almost same fatigue life as the shot-peened specimen despite of different surface roughness. After fatigue tests, fracture surfaces were observed using a scanning electron microscope (SEM) to evaluate the fatigue fracture mechanism. Most specimens did not fail in interior-induced fracture mode due to high cleanliness; however, some specimens failed in interior-induced fracture mode in very high cycle regime. Non-metallic inclusions were not observed at interior fatigue crack initiation sites, but 2 types of significant microstructures (with smooth surface or granular surface) were observed. EBSD analysis, profile analysis and computational simulation using a fracture surface topographic analysis (FRASTA) method were performed to investigate the mechanism of fatigue fracture induced by the microstructures at non-inclusion fatigue crack origins.

Keywords: Very high cycle fatigue, Spring steel, Interior-induced fracture, Fractography

MIM10

Construction of Electronic Database on Very High Cycle Fatigue Properties for Metallic Materials

Tatsuo Sakai[1]*, Koushu Hanaki[2], Akiyoshi Sakaida[3], Kenji Okada[4],Yuki Nakamura[5], Kazutaka Mukoyama[6], Noriyasu Oguma[7],Takashi Matsumura[8], Yoshinobu Shimamura[9], and Akira Ueno[1]

[1]College of Science and Engineering, Ritsumeikan University, 1-1-1 Noji-higashi, Kusatsu, Shiga, 525-8577 Japan

[2]Kyoto Materials Co. Ltd., 1-39 Goryoohara, Nishikyo-ku, Kyoto, 615-8245 Japan

[3]Akashi National College of Technology, 679-3 Nishioka, Uozumi, Akashi, Hyogo, 674-8501 Japan

[4]Kagawa National College of Technology, 355 Chokushi-cho, Takamatsu, Kagawa, 761-8058 Japan

[5]Toyota National College of Technology, 2-1 Eisei-cho, Toyota, Aichi, 471-8525 Japan

[6]Graduate School of Engineering, Osaka University , 2-1 Yamadaoka, Suita, Osaka, 565-0871 Japan

[7]Faculty of Engineering, University of Toyama, 3190 Gofuku, Toyama, 930-8555 Japan

[8]The University of Electro-Communications, 1-5-1 Chofugaoka, Chofu, Tokyo, 182-8585 Japan

[9]Shizuoka University, 3-5-1 Johoku, Naka-ku, Hamamatsu, Shizuoka, 432-8561 Japan

*Corresponding author sakai@se.ritsumei.ac.jp

Abstract: As a joint project of Committees on Fatigue and Reliability Engineering in the Society of Materials Science, Japan(JSMS), an electronic database on fatigue strength of metallic materials fabricated in Japan had been constructed and published in 1996. Book style of the same data compilation had been published at the same time by the JSMS and Elsevier. About twenty years have passed since the above publications of database and databook. Thus, a lot of new fatigue test data have been obtained during such a long period including many data on the very high cycle fatigue such as gigacycle regime. Based on such a circumstance, the JSMS has organized a new project to construct an electronic database on very high cycle fatigue. A lot of numerical data obtained by fatigue tests were compiled together with many photographs of fracture surfaces. At the present conference of VHCF-6, fundamental view of the database and the proto-type database constructed from domestic data in Japan are briefly introduced.

Keywords: Very high cycle fatigue, Metallic materials, Fracture surface, S-N data, Electronic database

MIM12

Models of Subsurface "FGA" Forming and Metals Cracking in Very-High-Cycle-Fatigue Regime

Andrey Shanyavskiy
State Centre for Flights Safety, Airport Sheremetievo-1, PO Box 54, Moscow region, Chimkinskiy State, 141426, Russia
shananta@mailfrom.ru

Abstract: The presented paper discussed FGA formation process in VHCF regime based on the next criteria: (1) non-elastic local deformation; (2) whirls formation under hydrostatic stress-state; (3) self-organized introducing in area of cracked metals own vapor or liquid because free surface can be creates only in environment conditions with some pressure. The FGA being the typical feature of fracture subsurface originates in two sequential stages.At stage one, the test body stores energy through quasi-viscous deformation controlled by the motion of the nanodipoles of partial disclinations in the fields of vortex-like flows. In a compression half-cycle transition to a superplastic flow occurs, involving rotation of nanoscopic volumes where variously shaped nanoscopic particles form.At stage two, tensile and compression stresses become inhomogeneously distributed at the interface between the matrix and nanocrystalline region of the material. Plastic deformation occurs and helps opening of the nanocrystalline zone, i.e., makes faster creation of the discontinuity combined with the rotation of the structural elements.After FGA forms, metals cracking perform in unknown subsurface environment conditions when fist crack increment takes place on the value being "quant of cracking" not less than $a_q=2b$, where b is Burgers vector. Following the relation Paris-Bathias for subsurface crack growth description it was simplified description of subsurface crack propagation to the form: $da/dN=a_q(a_i/a_o)^2$, where a_i is a critical length of subsurface propagated crack, a_o is radius of FGA.

Keywords: Fine granular area, mechanism, model, crack growth.

MIM13

Analysis of Fatigue Crack Initiation and Size Effect on Fatigue Life of a Cast Aluminum Alloy in Very Long Life Cycles

Hongqian Xue[1,*] Qian Tao[1], Weiwei Chen[1], Claude Bathias[2]
[1] Northwestern Polytechnical University, 127, West Youyi Road, 710072 Xi'an, China
[2] Université ParisOuest Nanterre La Défense, 50, Rue de Sèvres, 92410 Ville d'Avray, France

Abstract The fatigue behavior and crack initiation of Al–Si-Cu casting alloys under the influence of microstructural heterogeneities were investigated for lifetimes as long as 10^{10} cycles. Constant amplitude axial fatigue tests were performed at room temperature at R =-1 by using ultrasonic fatigue test machine operating at 20 kHz and conventional fatigue test machine at 35Hz respectively, so as to understand the frequency effect. In order to determine the fatigue limit up to 10^{10} cycles and evaluate the size effect, fatigue tests were carried out on two sets of specimens with different dimensions, according to the staircase schedules. The results show that the fatigue strength of the alloy decreases with increasing component size. The fracture surfaces of the specimens tested were examined using a scanning electron microscope (SEM) to determine the fatigue crack initiation sites, most fatigue cracks initiate from microstructural defects located at or very near to the specimen surface, the porosity is responsible for decreasing the fatigue life of the castings. Statistical analysis of fatigue data was done to estimate fatigue behavior of the Al-Si-Cu alloy in the gigacycle regime.

Keywords: Ai-Si-Cu alloy, Size effect, fatigue limit, porosity

MIM14

Influence of cyclic loading on damage behavior at twin and grain boundary in FCC materials during very high cycle fatigue

Guocai Chai[1, 2*]
[1] Strategy Research, Sandvik Materials Technology, 811 81 Sandviken, Sweden
[2] Engneering Materials, Linköping University, 581 83 Linköping, Sweden
* Corresponding author: guocai.chai@sandvik.com

Abstract: In very high cycle fatigue regime, fatigue crack initiation can occur either at subsurface defect or non-defect origin in the matrix. This paper provides a study on the influence of cyclic loading on the mechanical behavior at the grain and twin boundaries in one nickel base alloy, Alloy 690 and one austenitic ferritic stainless steel, SAF 2507 with the purposes to increase the understanding on the damage mechanisms of the material in the very high cycle fatigue regime. The fatigue damages were investigated using electron backscatter diffraction and electron channeling contrast imaging. The results show that the strains in these materials were highly localized. High strain localization causes dislocation accumulation of very small strain during each cyclic loading and can also lead to the formation of local "fine grain area" consisting of numbers of micro twins. The results also show that the annealing twins and fatigue induced twins will have interactions with slip bands, which can cause the fatigue damage or impingement cracking. The results in this paper indicate that the role of a twin or grain boundary to block dislocation slip transmission depends on crystal orientation, Schmid factor and twin boundary orientations.

Keywords: Very high cycle fatigue, Twin, Local plasticity exhaustion, Fatigue crack initiation, Nickel base alloy

MIM16

Irreversible deformation of VHCF crack initiation mechanism on α-ferrite

Chong WANG[1]*, Qingyuan WANG[1], Danièle WAGNER[2], Claude BATHIAS[2]

[1]Department of Mechanics and Engineering Science, Sichuan University, Chengdu 610065, China
[2]University Paris Ouest Nanterre La Défense – LEME Laboratory – 92410 VILLE D'AVRAY – France
* Corresponding author: wangchongscu@163.com

Abstract: Paris's law of fatigue crack propagation rate is well applied in the defect-tolerance fatigue approach. When carry out same approach on the very high cycle fatigue, the understanding of mechanism about fatigue crack initiation is obviously important. In the present work here, the fatigue crack initiation of a surface crack in iron loaded in the VHCF regime was investigated by a new approach which combines the fracture surface analysis and fatigue crack thermal dissipation. The experiments were carried out on a sheet specimen under a 20 KHz ultrasonic frequency with images registration thermal or optical. A Micron Abreast Pipes model is established to introduce how the irreversible deformation cumulates the damage and finally conducts the fatigue crack. Three stages of fatigue crack were identified with different mechanism. Together with thermal image, it is found that the transition between initiation and short crack propagation corresponds to the intrinsic threshold of fatigue crack. It takes more than 99% of the gigacycle fatigue life to achieve this transition size.

Keywords: Irreversible deformation, Fatigue crack initiation, Threshold of fatigue crack, Very high cycle fatigue, Thermal dissipation.

Effect of solute atoms content in carbon manganese steels on the self heating during gigacycle fatigue tests

Zhiyong Huang[1], Nicolas Ranc[2], Danièle Wagner[3,*]
[1]Sichuan University, School of Aeronautics and Astronautics, No.29 Jiuyanqiao Wangjiang Road, Chengdu, 610064, China
[2]Arts et Métiers ParisTech, PIMM UMR 8006, 75013 Paris, France,
[3] University Paris Ouest Nanterre, Laboratoire LEME, 50 rue de Sèvres, 92410 VILLE D'AVRAY, France
* Corresponding author: daniele.wagner@u-paris10.fr

Abstract: Tests were performed on two Carbon-Manganese steels (A42 and A48 steels, French standard) in the gigacycle fatigue domain thanks to a piezoelectric fatigue machine working at 20000Hz. During the tests, the temperature recordings were achieved by an infrared camera for various stress amplitudes. The main difference between the two steels compositions was the aluminum content (0.045% for the A42 steel and 0.004% for the A48 steel), and the carbon content (0.140% for the A 42 steel and 0.198% for the A48 steel). In the A48 steel, the few aluminum content induces a higher free content of solute nitrogen in the lattice. Mechanical spectroscopy tests were performed and gave qualitative results on the solute contents repartition in the lattice. The temperatre increases recorded during the fatigue tests for the two steels are different at the beginning of the tests. The differences can be explained by the different repartition of the solute atoms which induces a different dislocation gliding between the two materials. At the end of the tests, the thermal recordings are similar and attributed to the evolution of the dislocation structure.

Keywords: Carbon- manganese steels, gigacycle fatigue tests, infrared camera, self heating, solute content

Very high cycle fatigue behavior of riblet structured high strength Al alloy thin sheets

Sebastian Stille[1,a], Tilmann Beck[1,b] and Lorenz Singheiser[1,c]
[1]Institute of Energy and Climate Research (IEK-2), Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany
[a]s.stille@fz-juelich.de, [b]t.beck@fz-juelich.de, [c]l.singheiser@fz-juelich.de

Abstract: The VHCF behavior of age hardened (T351) 2024 aluminum sheets (thickness: 1.6 and
2 mm) has been studied. The experiments were performed at frequencies of ≈ 20 kHz with fully reversed axial loading (R=-1). Special focus was put on the influence of Al 99.5 claddings and riblet-like surface structures, which are used in aerospace applications to reduce the aerodynamic drag. The fatigue life and fatigue limit of the Al 2024 bare material is -compared to the non-structured case- significantly reduced by the stress concentrations induced by the riblet structure. However, the fatigue behavior of the clad material is nearly insensitive to the surface structure. In this case, we obtained a sharp transition from HCF failure up to $5x10^6$ cycles to run-outs at ≥ $2x10^9$ cycles. This threshold value for failure differs with cladding thickness as well as with riblet geometry. We attribute this to the modified stress distribution near the interface (cladding/substrate) as well as to a locally reduced thickness of the cladding in the riblet valleys. Fatigue cracks are -even in the case of run-outs- always initiated at the surface of the clad layer and grow easily to the substrate. Samples only fail, if the threshold for further crack growth into the substrate is exceeded. The fatigue limit of both, the flat and riblet structured clad material can be described by a fracture mechanics approach using the Kitagawa-Takahashi diagram.

Keywords: Al 2024, Al-cladding, riblet structure, fracture mechanics

A Study on Very High Cycle Fatigue Property of High Strength Steel (KNS-ES) for Particular Mechanical Use

Tatsuo Sakai[1,*], Yasuo Ochi[2], Shoichi Kikuchi[3], Hiroshi Tanaka[4], Fumiharu Ikai[4]and Kazutaka Okumoto[4]

[1]College of Science and Engineering, Ritsumeikan University, 1-1-1 Noji-higashi, Kusatsu, Shiga, 525-8577 Japan

[2]The University of Electro-Communications, 1-5-1 Chofugaoka, Chofu, Tokyo, 182-8585

[3]Graduate School of Engineering, Kobe University, Rokkoudai, Nada-ku, Kobe, Hyogo, 657-8501 Japan

[4] Kikusui Seisakusho Ltd., 104 Minamikamiai-cho, Nishinokyo, Nakagyo-ku, Kyoto, 604-8483 Japan

[*] Corresponding author: sakai@se.ritsumei.ac.jp

Abstract: In the fabrication process of medicine tablets, working speed of the tablet compressing is an important factor to realize the high fabricating efficiency together with the low cost. In such a circumstance, a number of loadings would be applied with high frequency to tips of a couple of compressing punches. Sometimes, the tablet compressing speed exceeds 150 tablets per second. Thus, the very high cycle loadings are applied to the tips of the compressing punches making medicine tablets. The high strength steel of KNS-ES was specially designed and fabricated for the particular use as the compressing punches. In this work, very high cycle fatigue tests were performed in the loading type of rotating bending in order to obtain the fundamental S-N property of this steel. Based on current experimental results, the S-N property in giga-cycle regime was discussed including the effect of the residual stress on the S-N properties. Thus, the duplex S-N curves were clearly found, but the surface-induced fractures were often found in the fatigue data belonging to the second S-N curve in the longer life region.

Keywords: Very high cycle fatigue, Low alloy steel, Residual stress, Tablet compressing punches,
Rotating bending

Frequency effects in high cycle fatigue for polycrystalline pure copper

MARTI Nicolas[1,2,a], SAINTIER Nicolas[2,b], RANC Nicolas[1,c], FAVIER Véronique[1,d]
[1]Arts et Metiers ParisTech, CNRS PIMM, 151 Boulevard de l'Hôpital, 75013 Paris, France
[2]Arts et Metiers ParisTech, CNRS I2M, Esplanade des Arts et Métiers,33405 Talence, France
[a]nicolas.marti@ensam.eu, [b]nicolas.saintier@ensam.eu, [c]nicolas.ranc@ensam.eu,
[d]veronique.favier@ensam.eu

Abstract: This paper aims at a deeper understanding of frequency effects in the fatigue response.
Commercially pure polycrystalline copper was investigated. Fatigue tests were conducted at 20 kHz using an ultrasonic technique and at 100 Hz using an electromagnetic fatigue device. The specimens were designed to get the same stress amplitude gradient along the specimen axis during both types of tests. Quasi-isothermal conditions were considered. The amount of slip markings at the specimen surface was estimated by the surface area covered by slip markings. The number of cycles to failure was found much higher at 20 kHz than at 100 Hz while the amount of slip markings (for the same stress amplitude and number of cycles) was much lower. The slip markings amount increases with the number of cycles the specimen surface. This increase is much lower at high than low frequencies. The reasons for these differences are discussed.

Keywords: very high cycle fatigue, slip bands, microstructure, strain localization, frequency effects.

Fatigue initiation and strength of duplex stainless steel strip specimens in the very high cycle fatigue regime

Muhammad Waqas Tofique[1, a], Jens Bergström[2, b], Nils Hallbäck[3, c] and Christer Burman[4, d]
[1,2,3,4] Department of engineering and physics, Karlstad University, SE-651 88 Karlstad, Sweden
[a]muhammad-waqas.tofique@kau.se, [b]jens.bergstom@kau.se, [c]nils.hallback@kau.se,
[d]christer.burman@kau.se

Abstract: Fatigue studies of cold-rolled duplex stainless strip steel were performed in the very high cycle fatigue life region. The duplex austenitic-ferritic microstructure gives this grade a combination of high mechanical strength and high corrosion resistance. Fatigue properties of thin steel strips are particular due to cold rolling introducing a very fine microstructure. Crack initiation and fatigue strength are controlled by steel microstructure and alloying. The initiation and growth of the very short initial fatigue crack in very high cycle fatigue are unclear and subject to different descriptions. Fatigue test data of thin strip specimens at very high fatigue lives are scarce due to testing difficulties. For practical reasons testing must be performed at ultrasound test frequencies which involves fixturing problems. A test setup including the load chain ultrasonic horn, fixture and specimen was designed for resonance with a horse-shoe design of a screw fixture. The design of the horse-shoe fixture and the specimens along with FEM calculation of stresses are presented. Fatigue testing was performed at 20 kHz in R=-1 conditions up to fatigue life of 10^7 to $5*10^9$ cycles. Fatigue strength was evaluated and crack initiation was studied on the fracture surface using FEG-SEM at the initiation site.

Keywords: Very high cycle fatigue, initiation, ultrasonic fatigue testing, strip specimen.

MIM27

High and Very High Cycle Fatigue Behaviour of the Austenitic-Ferritic Duplex Stainless Steel X2CrNiMoN22-5-3

Part 2: Mesoscopic Modeling

Benjamin Dönges[1,2*], Claus-Peter Fritzen[2], Hans-Jürgen Christ[1]
[1] Institut für Werkstofftechnik, Universität Siegen, D-57068 Siegen, Germany
[2] Institut für Mechanik und Regelungstechnik - Mechatronik, Universität Siegen, D-57068 Siegen, Germany
* Corresponding author: benjamin.doenges@uni-siegen.de

Abstract : High frequency push-pull fatigue experiments on the austenitic-ferritic duplex stainless steel X2CrNiMoN22-5-3 (318LN) revealed that crack nucleation and crack propagation through the first grain determine significantly the lifetime of the material. Only in very few cases it was observed that fatigue samples which endured one billion load cycles without failure (run-out samples) contain microcracks which reached or overcame the first microstructural barrier (phase or grain boundary). This leads to the conclusion that in most cases the highest macroscopic stress or strain amplitude which does not lead to fatigue crack propagation through the entire first grain can be considered as the fatigue limit of the material. The present study documents that the experimentally identified fatigue mechanisms can be represented in mesoscopic finite element simulations by taking into account the effects of anisotropic elasticity, crystal plasticity, macro and micro residual stresses, plastic strain concentration in form of slip bands, crack nucleation and short crack propagation through the first grain. The current investigation shows that such simulations enable the determination of the fatigue limit of both real and synthetic microstructures. By means of real microstructures, containing slip traces and microcracks, the calculations can be verified and the required microstructural parameters can be determined.

Keywords : Crack nucleation, short crack propagation, fatigue limit, mesoscopic modeling

Behavior of Fine Granular Area Formation of Bearing Steel in Rotating Bending Fatigue Process

Noriyasu OGUMA [1, a], Naoya SEKISUGI [2], Yasuhiro ODAKE [3, b] and Tatsuo SAKAI [4, c]
[1]Faculty of Engineering, University of Toyama, 3190 Gofuku, Toyama, 930-8555 Japan
[2]Graduate School of Science and Engineering, University of Toyama,3190 Gofuku, Toyama, 930-8555 Japan
[3]Product Development Division, NACHI-FUJIKOSHI Corporation,1-1-1 Fujikoshi honmachi, Toyama, 930-8511 Japan
[4] College of Science and Engineering, Ritsumeikan University, 1-1-1 Nojihigashi, Kusatsu, Shiga, 525-8577 Japan
[a]oguma@eng.u-toyama.ac.jp, [b]y-odake@nachi-fujikoshi.co.jp, [c]sakai@se.ritsumei.ac.jp

Abstract: It has been reported that an interior inclusion induced fatigue life to accomplish fine granular area (FGA) occupies more than 90% of the total fatigue life for high strength steel specimen. In order to examine the behavior of FGA formation in the vicinity around the interior inclusion, crack propagation rate was accelerated due to hydrogen charging into a rotating bending fatigue process for the specimen of bearing steel. After the charge, the rotating bending tests were continuously carried out. From a view point of fracture mechanics, the stress intensity factor range of FGA areas, ΔK_{FGA}, were calculated by √area model. The ΔK_{FGA} values increase with the increase of stress cycles before hydrogen charge. And ΔK_{FGA} values in this study were smaller than 5 MPa√m which was obtained from usual fatigue testing. Furthermore, the rate of the smallest number of stress cycles in which the FGA was formed was 5% of the estimated life. Therefore, it is considered that FGA starts formation and grows gradually from the early stage of fatigue.

Keywords: Very high cycle fatigue, Fine granular area, Rotating bending, Bearing steel

MIM29

The research and application of ultrasonic fatigue testing technology

Wenjie Peng*, Huan Xue, Yue Wang and Jia He
Research and Development center of Wuhan Iron and Steel group Corporation, 430080, Wuhan, China
*Corresponding author: ppengwenjie@gmail.com.

Abstract: In the present paper, the characteristic and the application of ultrasonic fatigue testing technology is illuminated. The main problems i.e. the size effect, the thermal effect and frequency effect due to the high frequency are discussed. The results show that: 1. As there is a size effect, the specimen size should be noted along with the fatigue test results; 2.the heat generation attributes mainly to the low yield strength and the high applied stress, as a result, ultrasonic fatigue testing technology can be mainly applied to the ultra-high cycle fatigue test of high-strength steel; 3.the frequency effect is related to the crystal structure of metallic materials, however, ultrasonic fatigue testing technology can be applied to conduct the comparison of the fatigue properties of the same steel grade before and after the smelting process.

Keywords: Ultrasonic fatigue testing, size effect, thermal effect, frequency effect

MIM30

Fatigue failure mechanism of a 1900MPa grade maraging stainless steel

Le Zhang[1, a], Yuhai Li[1, b],Zhenguo Yang[2], Yiyin Shan[2], Ke Yang[2] and Wei Wang[2, c]
[1]Shenyang Ligong University, China
[2]Institute of metal research, Chinese academy of science, China
Corresponding author: Dr. Wang, wangw@imr.ac.cn

Abstract: The VHCF behaviors of a 1900MPa grade maraging stainless steel are investigated in this paper. The crack initiation sites of the fractured samples were observed by scanning electron microscopy(*SEM*) and laser scanning confocal microscope(*LSCM)*. The results showed that fatigue crack initiation performs two different mechanisms: the surface crack initiation mechanism and the internal crack initiation mechanism. The fracture mechanism and a new crack initiation and propagation model were discussed and proposed, after the calculation of crack initial size parameter and observation on the microstructure of the samples by *SEM*, transmission electron microscopy(*TEM*) and atom probe tomography(*APT*).

Keywords: Maraging stainless steel; Very high cycle fatigue (VHCF); Fish-eye shape feature; Crack initiation mechanism.

Life Prediction, Statistical Analysis and Modeling in Fatigue

PSM01

Development of a fatigue life prediction concept in the very high cycle fatigue range based on microstructural features

Anton Kolyshkin[1*], Edgar Kaufmann[2], Martina Zimmermann[3] and Hans Jürgen Christ[1]
[1]Institut für Werkstofftechnik, Universität Siegen, 57068, Germany
[2] Department Mathematik, Universität Siegen, 57068, Germany
[3] Institut für Werkstoffwissenschaft, TU Dresden, 01062, Germany
* Anton Kolyshkin: anton.kolyshkin@uni-siegen.de

Abstract: The fatigue life of metallic materials in the Very High Cycle Fatigue (VHCF) regime is characterized by a large scatter of experimental results. The aim of the present work is to investigate the reasons of the scattering as well as to model their impact statistically. For this purpose crack initiation in the Ni-base superalloy Nimonic 80A was investigated as a function of the number of cycles to failure at different stress amplitudes both in the HCF and the transitional HCF-VHCF regime. According to the experimental observations the fatigue crack initiation depends on the stress amplitude and occurs at twin boundaries and grain boundaries with a large misorientation angle. The misorientation factor developed by C. Blochwitz et al., which depends on the misorientation angle between two adjacent grains as well as on the orientation of their boundary with respect to the external load, was used to estimate the stress concentration at the grain boundaries in the VHCF regime. It was revealed, that the cracks initiate at the grain boundary of maximum misorientation factor calculated for each specimen. Furthermore, the calculated maximum misorientation factors show a direct relation to the number of cycles to failure and can be used as an additional microstructural information for statistically based fatigue life prediction models.

Keywords: VHCF regime, Nimonic 80A, crack initiation, elastic anisotropy, probabilistic prediction

PSM02

Duplex S-N fatigue curves: statistical estimation of model parameters

D.S. Paolino[1,a], A. Tridello[1,b], G. Chiandussi[1,c], M. Rossetto[1,d]
[1]Politecnico di Torino, Department of Mechanical and Aerospace Engineering, Corso Duca degli Abruzzi 24, 10129 Torino
[a]davide.paolino@polito.it, [b]andrea.tridello@polito.it, [c]giorgio.chiandussi@polito.it, [d]massimo.rossetto@polito.it

Abstract: In recent years, experimental tests exploring properties of materials in gigacycle regime have suggested modifications to well-known statistical fatigue life models. Classical fatigue life models, characterized by failures due to a single failure mode and by the presence of the fatigue limit, have been integrated by models that can take into account the occurrence of two failure modes (duplex S-N models). Duplex S-N models involve a number of unknown parameters that must be statistically estimated from experimental data.
The present paper proposes a simplified and automated procedure for statistical parameters estimation. The procedure is applied to experimental datasets taken from the literature: duplex S-N models with and without fatigue limit are taken into consideration. Parameter estimation is carried out by applying the Maximum Likelihood Principle and by taking into account the possible presence of right-censored specimens (runouts) with unequal number of cycles. The application of the procedure allows to estimate different key material parameters (e.g., the characteristic parameters of transition stress and fatigue limit), as well as to statistically predict the failure mode of each failed specimen.

PSM03

Influence of High-Cycle Fatigue on Crater Wear Characteristics of Cemented Carbide Tool

SONG Xiaoqi[1,*], Junnosuke SAIGAWA[1], Tohru IHARA[1]
[1] Department of Precision Mechanics, Chuo University, 112-8551, Tokyo
* Corresponding author: kevinsong1127@gmail.com

Abstract: Recently, in order to make positively use of the effect of adhesive layer, which works as Build-up edge or Belag on the tool surface during machining operation, there have many investigations on the technique to reduce the wear of cutting tool. However, the mechanism of wear on the rake face is unknown and the reason why the adhesive layer can resist the abrasion is also unclear.
This study aims to propose a new crater high-cycle fatigue wear model depending on the tool adhesion model established by the surface cluster on the interface between the tool-workpiece. By using this model we can elucidate the mechanism of adhesive layer. When the chip flows on the rake face, the commensurate phase occurs in the surface cluster on the interface, and the surface cluster slides in the similar form of dislocation. At the same time, the strong chemical bonding among the surface clusters becomes the repeat force which can result in the fatigue failure on the tool, and the tool crater wear happens. The energy dissipation process associates with the vibration of cluster, which increases the tool temperature rapidly. Therefore, the crater wear is a damage process on the tool with the high-temperature and high-cycle fatigue.
In this study, the mechanism of crater wear when the cemented carbide cut the carbon steel was investigated using the adhesion cluster model, and the crater wear model was proposed to estimate the properties of the adhesive layer.

Keywords: Adhesive layer, High-cycle fatigue, Commensurate, Surface cluster, Crater wear

PSM04

Effects of Low Temperature Nitriding Process on the Very High Cycle Fatigue Properties of Ti-6Al-4V Alloy

Shoichi Kikuchi[1,*], Stefan Heinz[2], Dietmar Eifler[2],
Yuta Nakamura[3] and Akira Ueno[4]
[1] Department of Mechanical Engineering, Kobe University, Hyogo 6578501, Japan
[2] Institute of Materials Science and Engineering (WKK), University of Kaiserslautern, Kaiserslautern 67663, Germany
[3] Graduate School of Science and Engineering, Ritsumeikan University, Shiga 5258577, Japan
[4] Department of Mechanical Engineering, Ritsumeikan University, Shiga 5258577, Japan
* Corresponding author: kikuchi@mech.kobe-u.ac.jp

Abstract: Accelerated fatigue tests were carried out at the stress ratio R = -1 using a 20 kHz ultrasonic testing facility to investigate the effects of low temperature nitriding process on the fatigue properties of Ti-6Al-4V alloy in the very high cycle fatigue (VHCF) regime in detail. The oscillation and fatigue behavior of the nitrided Ti-alloy were characterized by measuring parameters like the ultrasonic generator power, the displacement of the specimen and dissipated energy under ultrasonic cyclic load. Moreover, the surface microstructure of the nitrided Ti-alloy was characterized using a micro-Vickers hardness tester, an optical microscope, scanning electron microscopy (SEM), X-ray diffraction (XRD) and electron backscatter diffraction technique (EBSD) to clarify the fatigue fracture mechanism. The Ti-alloy nitrided at the temperature of 873 K showed duplex *S-N* properties consisting of the respective fracture modes of the surface fracture and the subsurface fracture. The low temperature nitriding process reduced the surface fatigue life of Ti-alloy in comparison to the un-nitrided one due to the formation of a brittle titanium nitride (Ti_2N), whereas the subsurface fatigue life in the VHCF regime was increased by the low temperature nitriding. In addition, the fatigue fracture mechanism of the low temperature nitrided Ti-alloy was discussed from viewpoints of fractography.

Keywords:VHCF, Ultrasonic fatigue, Nitriding, Titanium alloy, Fractography

PSM05

VHCF damage behavior of metastable austenitic stainless steel: microstructure-sensitive modeling and simulation

Philipp-Malte Hilgendorff[1,a*], Andrei Grigorescu[2,b*], Martina Zimmermann[3,c], Claus-Peter Fritzen[1,d], Hans-Jürgen Christ[2,e]

[1] Institut für Mechanik und Regelungstechnik - Mechatronik, Universität Siegen, 57068 Siegen, Germany

[2] Institut für Werkstofftechnik, Universität Siegen, 57068 Siegen, Germany

[3] Institut für Werkstoffwissenschaft, Technische Universität Dresden, 01062 Dresden, Germany

[a]philipp.hilgendorff@uni-siegen.de, [b]andrei.grigorescu@uni-siegen.de,

[c]martina.zimmermann@tu-dresden.de, [d]claus-peter.fritzen@uni-siegen.de,

[e]hans-juergen.christ@uni-siegen.de.

Abstract: In the present study the damage mechanisms of a metastable austenitic stainless steel (AISI304) are modeled and investigated starting from an initially pure austenitic condition. Microscopic examinations of the damage behavior of AISI304 tested at the real VHCF limit indicate that plastic deformation is localized in shear bands and is accompanied by deformation-induced martensite formation starting mostly at grain boundaries and intersecting shear bands. Based on these observations and well-known model approaches from the literature a microstructure-sensitive model is proposed that accounts for the damage mechanisms in shear bands (allowing irreversible plastic sliding deformation) and considers nucleation and growth of martensite at grain boundaries and intersecting shear bands. The model is numerically solved using the two-dimensional (2-D) boundary element method. By using this method, real simulated 2-D microstructures can be reproduced and fatigue damage evolution can be investigated within different microstructure morphologies. Results show that simulation of slip bands is in good agreement with experimental observations and prediction of sites of deformation-induced martensite formation is possible in many cases. The present work contributes to a better understanding of the microstructural damage mechanisms of AISI304 and their interaction in the VHCF regime.

Keywords: metastable stainless steel, modeling, slip band, martensite, boundary element method.

PSM06

The Rotary Bending Fatigue and Ultrasonic Fatigue Performance of Ti-6Al-4V ELI and STA alloys after Ultrasonic Nanocrystal Surface Modification Treatment

Young-Sik Pyun[1,*], Jun-Hyong Kim[1], Chang-Min Suh[2], In-Sik Cho[3], Joo-Yeon Oh[3], Qingyuan Wang[4], Muhammad Kashif Khan[5]
[1] Department of Mechanical Engineering, Sun Moon University, 336-708, South Korea
[2] School of Mechanical Engineering, Kyungpook National University, 702-701, South Korea
[3] Mbrosia, 336-708, South Korea
[4] Department of Civil Engineering and Mechanics, Sichuan University, 610065, China
[5] Department of Mechanics and Engineering Science, Sichuan University, 610065, China
* Corresponding author: pyoun@sunmoon.ac.kr, cmsuh@knu.ac.kr

Abstract: This study investigates the influence of ultrasonic nanocrystal surface modification (UNSM), a novel surface treatment technology, on the mechanical characteristics of the rotary bending fatigue (RFT) and the ultrasonic fatigue tests (UFT) of solution-treated and annealed (STA) Ti-6Al-4V and extra low interstitial (ELI) Ti-6Al-4V alloys. Fatigue data is acquired and compared for UNSM-treated and untreated specimens of Ti-6Al-4V ELI and STA alloys. Fracture analysis is performed to find the mechanical characteristics. The improvement in the fatigue characteristics is attributed mainly to the UNSM-induced compressive residual stress, micro-hardness, and nanograin in the subsurface of the material.

Keywords: Ti-6Al-4V ELI and STA alloys, UNSM(Ultrasonic Nanocrystal Surface Modification) treatment, RFT(Rotary Bending Fatigue Test), UFT(Ultrasonic Fatigue Test), Compressive residual stress

PSM07

A Monte Carlo simulation of specimen size effect on fatigue life

Chengqi Sun, Xiaolong Liu, Youshi Hong*
State Key Laboratory of Nonlinear Mechanics, Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China

Abstract: The size effect of specimen on fatigue behavior of materials is a very important topic in engineering applications. A large number of evidences have revealed that the decrease in fatigue strength of large specimens is generally due to the high existence possibility of large defects or inhomogeneities, which increases the probability of occurrence of eventual damage and failure. In this paper, a method is proposed to investigate the size effect of specimen on fatigue life by the use of Monte Carlo simulation. First, the distribution form of fatigue life under an arbitrary stress level is determined for a smaller specimen, and the ratio n (integer) of risk volume (where fatigue failure may occur) for a larger specimen to that for a smaller specimen is calculated. Then, the fatigue life for the larger specimen under a certain stress level is obtained by taking the minimum fatigue life among n times simulations by Monte Carlo simulation on the smaller specimen under the same stress level. The simulation results are compared with a series of experimental data in high cycle and very-high-cycle fatigue regimes from literature, and the comparison shows a good agreement. The method is of help for a quantitative estimation of the fatigue life of large specimens with the experimental data tested by small specimens.

Keywords: Monte Carlo simulation; Size effect; Fatigue life

PSM08

A very high cycle fatigue thermal dissipation and dispersion investigation for titanium alloy TC17

Zhi Yong Huang[1)], Qing Yuan Wang[1)], Danièle Wagner [2)], Claude Bathias[2)]
1)Sichuan University, School of Aeronautics and Astronautics, No.29 Jiuyanqiao Wangjiang Road, Chengdu, 610064, China
2)Université ParisOuest Nanterre La Défense, France

Abstract: Titanium alloy TC17 is widely used in aeronautics engineering high compressor blades applications and undertakes high frequency fatigue load. In the article tests are performed to investigate the fatigue behavior of the alloy in Very High Cycle Fatigue (VHCF) through ultrasonic fatigue machine in the article at r = 0.1. Thermal dissipation of VHCF for the alloy in 20kHz frequency is also studied and a model is proposed to describe the temperature increment of VHCF in the framework of thermodynamics by estimation of the inelastic thermal dissipation at active sites in the reference element volume. Failure probability prediction method is used to evaluate the VHCF dispersion based on the two scale model and fatigue thermal dissipation analysis.

Keywords : Titanium alloy ; VHCF, Inelastic deformation ; Thermal dissipation; Fatigue dispersion

PSM09

Effects of stress ratio on very-high-cycle fatigue property of a high-strength steel

Xiaolong Liu, Chengqi Sun, Youshi Hong
State Key Laboratory of Nonlinear Mechanics, Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China
* Corresponding author. Tel.: +86 10 82543966; fax: +86 10 62561284.
Email address: hongys@imech.ac.cn (Youshi Hong).

Abstract: The effects of stress ratio (R) on very-high-cycle fatigue (VHCF) property of a high-strength steel were investigated. Fatigue tests were performed at stress ratios of -1, -0.5, 0.1 and 0.3 by using an ultrasonic fatigue testing machine. The experimental results indicate that the stress ratio has a substantial effect on the fatigue strength, which decreases with the increase of stress ratio. However, the tendency of the S-N curves from low cycle fatigue to VHCF is similar for the different stress ratios. SEM observations of the fracture surface indicate that fatigue crack initiates from the surface of specimen in low cycle fatigue regime and initiates mostly from the inclusion in the interior of specimen in high cycle and VHCF regimes, which is irrespective of the stress ratio. The stress intensity factor ranges at the periphery of FGA are within a small range and irrespective of the stress ratio and fatigue life. In addition, both the effects of stress ratio and inclusion size on fatigue life are investigated. It is shown that the effect of stress ratio and inclusion size on fatigue strength is well described by our recently proposed relation of $\sigma_a \propto a_0^m[(1-R)/2]^\alpha$, where m and α are material parameters.

Keywords: High-strength steel; Very-high-cycle fatigue; S-N curve; Stress ratio; Inclusion size

PSM10

Comparative study on the fatigue damage evolution of a stable and a metastable austenitic stainless steel in the VHCF regime

Andrei Grigorescu[1,*], Philipp-Malte Hilgendorff[2], Martina Zimmermann[3], Claus-Peter Fritzen[2], Hans-Jürgen Christ[1]
[1] Institut für Werkstofftechnik, Universität Siegen, D-57068 Siegen, Germany
[2] Institut für Mechanik und Regelungstechnik - Mechatronik, Universität Siegen, D-57068 Siegen, Germany
[3] Institut für Werkstoffwissenschaft, TU Dresden, D-01069 Dresden, Germany
* Corresponding author: andrei.grigorescu@uni-siegen.de

Abstract :A stable (AISI316L) and a metastable (AISI304) austenitic stainless steel were investigated with respect to their VHCF behavior. The 304L steel is characterized by a pronounced cyclic softening during its initial stage of cyclic deformation. During the following loading cycles a phase transformation (γ-austenite → α'-martensite), accompanied by volume expansion, reduces the global plastic strain amplitude and induces compressive stresses in the near surface layer. As a consequence the material shows no failure up to 10^9 cycles at 240 MPa. For the more stable type 316L steel with its higher stacking fault energy the microstructure remains fully austenitic during cyclic deformation. In this case, initiation of microcracks was observed in the VHCF regime and samples failed even beyond 10^7 cycles. This study presents a comparative investigation of the damage evolution - including dislocation morphology - during cyclic loading for both materials. For the more stable steel 316L very localized plastic shear occurred and the slip band topography determined by means of serial sectioning using FIB-technique revealed the formation of pronounced intrusions. Short cracks initiated from these intrusions whereas no such intrusions were found in the metastable type 304L.

Keywords :stainless steel, martensite, intrusion, crack initiation

PSM11

Evaluation of multiple-flaw failure of bearing steel 52100 in the VHCF regime

Klaus Burkart[1,*], Hubert Bomas[2], Brigitte Clausen[1], Hans-Werner Zoch[1]
[1] Stiftung Institut für Werkstofftechnik (IWT), Badgasteiner Str. 3, 28359 Bremen, Germany
[2] Bergstr. 41, 28865 Lilienthal, Germany
* Corresponding author: burkart@iwt-bremen.de

Abstract : Caused by different factors, the interest in extended fatigue life of components is increasing. Therefore, the demand for additional knowledge about the fatigue behavior in the VHCF regime grows. In the case of high strength steels, fatigue tests mostly reveal that multiple failure mechanisms occur. However, the common statistical analysis of constant amplitude tests generates summarized multiple-flaw S-N curves which neglect the differentiation between the type of failure origin, e.g. oxides or sulfides as non-metallic inclusions. To improve the fatigue life of materials it is essential to determine single-flaw S-N curves for the assessment of the harmfulness of each failure type. It has also to be taken into account that some mechanisms occur more seldom because they are covered by others. Furthermore, it has to be considered that the probability of the occurrence of different failure types depends not only on the stress amplitude but also on the applied mean stress. In this investigation specimens made of different heats of the bearing steel 52100 were tested uniaxially at two stress ratios up to $2x10^9$ load cycles. The tests exhibited crack initiation at different types of inclusions and at the surface. A mathematical approach to calculate single-flaw S-N curves from these results is presented.

Keywords :bearing steel 52100, very high cycle fatigue, single-flaw failure, competing failure

PSM14

A Study on Very High Cycle Fatigue Properties of Bulk Amorphous Alloy in Rotating Bending

Akiyoshi Sakaida[1, a], Yanbin Zhang[2], Shoichi Kikuchi[3, b]
Yoshihiko Yokoyama[4, c], Akira Ueno[3, d] and Tatsuo Sakai[3, e]
[1]Department of Mechanical Engineering, Akashi National College of Technology.
679 Nishioka, Uozumi, Akashi, Hyogo, 674-8501 Japan
[2]State Key Laboratory of Traction Power, Southwest Jiaotong University. Chengdu, 610031 China
[3]Faculty of Science and Engineering, Ritsumeikan University.
1-1-1 Nojihigashi, Kusatsu, Shiga, 525-8577 Japan
[4]Institute for Materials Research, Tohoku University.
2-1-1 Katahira, Aoba, Sendai, Miyagi, 980-8577 Japan
[a]sakaida@akashi.ac.jp, [b]kiku-sho@fc.ritsumei.ac.jp, [c]yy@imr.tohoku.ac.jp
[d]ueno01@fc.ritsumei.ac.jp, [e]sakai@se.ritsumei.ac.jp

Abstract: In order to investigate very high cycle fatigue properties of $Zr_{55}Al_{10}Ni_5Cu_{30}$ bulk amorphous alloy, rotating bending fatigue tests were conducted at room temperature by using 5 different $Zr_{55}Al_{10}Ni_5Cu_{30}$ materials. The differences of materials processing conditions are manufacturer, product year, material size and minimum diameter of specimen. Although all specimens fractured at surface, duplex *S-N* characteristics were observed for each material. Time strength distributions at 10^3 for short life region and at 10^7 for long life region were well approximated by normal distribution. Pooled *S-N* property obtained by normalizing stress amplitude by time strength at 10^3 or 10^7 has shown more clearly duplex *S-N* characteristics. *P-S-N* properties were estimated by using standard deviation of time strength distribution at 10^3 or 10^7. Based on the observation of fracture surface by scanning electron microscope (SEM), it is confirmed that every fracture surface was consisting of typical three regions such as multi-facet region, stable crack growth region and instantaneous fracture region.

Keywords: Bulk amorphous alloy, *S-N* property, very high cycle fatigue, rotating bending, fracture surface.

PSM16

Effect of Inclusion Size on the Fatigue Life of High Carbon Chromium Bearing Steel

Kwanho Kim and Chulmin Bae
Technical Research Laboratories, POSCO, 1, Goedong-dong Nam-gu, Pohang, Gyeongbuk 790-785, Republic of Korea
rockite@posco.com, chmbae@posco.com

Abstract: The effect of inclusion size on the fatigue life of high carbon chromium bearing steel was investigated by ultrasonic fatigue tests at the frequency of 20kHz. At first, it was confirmed that the best rating methods for inclusions to reveal their effects on the fatigue life of the steel was the extreme value analysis by statistics. In addition, the inclusion size had a stronger relationship with fatigue life of the steel than the number of inclusions. The fatigue life of the steel has increased remarkably with the decrease of inclusion size, especially giga-cycle fatigue life with inclusions smaller than 23 ㎛ in diameter. Although the frequency of fatigue fracture was found to be much higher by Ti inclusions than alumina, the fatigue life by the former was longer than the latter, which is supposed to result from the difference in inclusion size. Most Ti inclusions were smaller than 15 ㎛ in diameter, while alumina larger than 20 ㎛. Consequently, it is inferred that the most important characteristics of inclusions which affect the fatigue life of high carbon chromium bearing steel is the inclusion size, resulting in the longer fatigue life with the smaller inclusion size.

Keywords: Inclusion size; Fatigue life; Ultrasonic fatigue test; Extreme value analysis; Bearing steel

PSM17

Finite Element Dynamic Analysis of an Al6061 Specimen in Ultrasonic Fatigue Test

No-Jun Myeong[1, a], Nak-Sam Choi[2,b]

[1]Department of Mechanical Engineering, Graduate School, Hanyang University, 17 Haengdang-dong, Seongdong-gu, Seoul 133-791, Republic of Korea

[2]Department of Mechanical Engineering, Hanyang University, 1271 Sa3-dong, Sangrok-gu, Ansan-si, Gyeonggi-do 426-791, Republic of Korea

[a]mnj-2000@hanmail.net, [b]nschoi@hanyang.ac.kr

Abstract: The accelerated ultrasonic fatigue test (UFT) was used for analyzing very high cycle fatigue (VHCF, $N_f > 10^7$) behaviors of an Al6061 specimen. UFT applies cyclic stress to the specimen at resonance frequency of around 20 kHz. The specimen geometry depends on test materials and wavelengths. Local stresses at the gage portion of the specimen are calculated with the stress equation following the gage portion profile. Finite element analysis (FEA) showed characteristic behaviors of stresses and resonance mode of a specimen in UFT. The stress equation of UFT assumed that the shape of gage portion profile was a hyperbolic cosine. However, the used specimen in the test was a circular arc profile. So, FEA is used to study local stresses in two cases of the gage portion profile. As a result, the profile of circular arc experimentally used caused higher stresses. The stress increase might affect a decrease in fatigue life in the VHCF range. The FEA stress distribution of the specimen could be visualized for the comparison with real test results.

Keywords: Ultrasonic fatigue test, Resonance, Finite element analysis

PSM18

Research Progress of very high cycle fatigue for high strength steels

Bolin He *, Kang Wei
Key Laboratory of Ministry of Education for Conveyance and Equipment, East China Jiaotong University, Nanchang 330013, China
* Corresponding author:hebolin@163.com

Abstract: High cycle fatigue is the most reasons for failure of high strength steel components. Most of the fatigue tests were performed which concentrated in the low and high cycle regime. However, railways, automobiles (car engine), aircrafts, etc., are required to endure fatigue loads up to 10^{10} cycles without failure. Very high cycle fatigue (VHCF) is the study of fatigue failure behaviors of materials and structures at and beyond 10^{8} cycles. Due to the fact that VHCF behaviors of high strength steels occur below traditional fatigue limit which is different from the conventional ones, hence the VHCF investigations of high strength steels help to further understand the fatigue essence and mechanism. This paper summarizes works of VHCF researches for high strength steels in recent years, such as the characteristics of S-N curve, the observations on fish-eye, which is one of the typical characteristics of fracture surface, crack initiation, crack propagation, etc. The present work also analyzes the fatigue mechanisms and briefly discusses several factors that affect VHCF properties, such as hydrogen effect, inclusion effect, frequency effect and loading mode. Some possible and prospective aspects of future researches are also proposed.

Keywords: Very high cycle fatigue, S-N curve, Fatigue limit, Fatigue mechanism, Crack initiations

Fatigue Analysis Based on the Non-Zero Point Force Moment Elasticity Theory

Shuang-hua HUANG[1, a] , Wen-ba HAN[2, b*], Zhao-rong ZENG[3, c] and Qiang LUO[4,d]

[1] School of Civil Engineering and Architecture,Panzhihua University, Panzhihua, China

[2] School of Civil Engineering and Architecture,Panzhihua University, Panzhihua, China

[3] School of Civil Engineering and Architecture,Panzhihua University, Panzhihua, China

[4] School of Civil Engineering and Architecture,Panzhihua University, Panzhihua, China

[a] 1960392501@qq.com, [b*] 770771174@qq.com, [c]zengzhaorongtmgc@126.com,[d]16086147@qq.com

Abstract: The current theory of elasticity persisted in the standpoint that normal stress exists in pure bending and shearing stress exists in pure torsion, which has been negated by the non-zero point force moment elasticity theory .The mentioned new theory proved that bending point moment exists in pure bending and torsional point moment exists in pure torsion, which debunk the current theory of elasticity that the limit moment acting on the unit area is zero. As a consequence, the causation of fatigue should be revised as point moment instead of stress. By using theory of stress and the new theory to analyze fatigue of non-slender rod, safety factor worked out by the former one is much bigger, which suggests that theory of stress cannot ensure safety. Undoubtedly, that is the fundamental causation of frequent occurrence of fatigue rupture. Thus, the new theory is of great significance in the prevention of unexpected fatigue rupture in the field of aerospace, navigation, transportation and mechanical engineering, etc.

Keywords: Fatigue, Cyclic, Stress, Point force moment.

Current Understanding and Key Issues in Very High Cycle Fatigue

QingYuan Wang
Dept of Civil Eng & Mechanics, Sichuan University, 610065 China

Abstract: The fatigue life of numerous aerospace, locomotive, automotive and biomedical structures may go beyond 10^8 cycles. Determination of very high cycle fatigue (VHCF) behavior becomes extremely important for better understanding and design of components and structures. Initially, before the invention of ultrasonic fatigue testing, most of the engineering materials were supposed to exhibit fatigue life up to 10^7 cycles or less. This paper reviews our current understanding of some fundamental aspects on the development of accelerated fatigue testing method and its application in VHCF, crack initiation and growth mechanisms of internal fracture, S-N diagram, fatigue limit and life prediction, etc. Furthermore, Research fronts and pioneering papers in VHCF have been identified by examining highly cited research papers from 1994 through 2013 based on journal article publication counts and citation data from Web of Science databases. A list of the most influential papers in VHCF has been topped and provided for different cases.

Keywords Very high Cycle Fatigue, Ultrasonic fatigue testing, Inclusions; Fatigue failure, Fatigue Limit