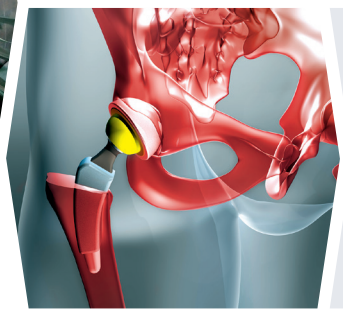
fatigue design2017

ABSTRACTS BOOK



7th edition

of the International conference
on fatigue design

29 & 30
November 2017
Senlis France

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Introduction Message

On behalf of the Fatigue Design 2017 International Scientific Committee and Organizing Committee, we would like to welcome you all to the 7th edition of Fatigue Design 2017 taking place at Cetim, Senlis, France on November 29 & 30 2017.

Since 2005, and every two years, the conference takes place at Senlis, the City of culture and history, located at 45km from Paris with more than 2000 years of history. The Notre-Dame Cathedral of 12th century, Saint-Pierre church, Medieval ramparts of 13th - 16th century, the château royal and 4 museums are among the most attractive places to be visited.

Organized by Cetim and his partners, the 7th Fatigue Design 2017 International Conference aims to present the most innovative approaches, scientific and technological progress in design methodologies, testing methods and tools to evaluate and extend the fatigue life time of the industrial equipment. The papers are mostly focusing on the industrial applications.

For the second time, the organizing committee has decided to dedicate the conference to the scientific community from a specific country.

Italy has been proposed as the "partner country" for Fatigue design 2017in respect to the italian advance research works in the area of fatigue and fracture mechanics in the last decade,. More than 20% of conference speakers are coming from Italy including 2 plenary key speakers.

This edition of the conference will cover the following scientific and technical topics:
– additive manufacturing,
– experimental and numerical design and validation methods,
– damage tolerance and fatigue life,
– reliability-based approaches and probabilistic methods,
– fatigue under severe conditions environment (corrosion, low temperature...),
– nonlinear behavior and cumulative damage,
– fatigue of assemblies (mechanical, welded, adhesive-bonding, multimaterial...),
– composite and elastomers,
– contact fatigue,
– vibration fatigue behavior,
– complex loadings,
– thermal and thermo-mechanical fatigue,
– taking into account manufacturing process in fatigue analysis (effect of microstructure, welding, stress relief techniques...).

The presentations will focus on the latest development and most recent experimental, numerical simulation techniques and the associated engineering tools applied to the large domain of the industrial applications.

The 7th edition of the Fatigue Design International conference is organized in close collaboration with Elsevier editor for the proceedings publication through Elsevier Procedia. The papers are published online on ScienceDirect, which makes available worldwide for a better dissemination and maximum exposure. In this respect the selection and peer review of the papers have been done in collaboration with the International Scientific and Organizing Committees.

"Fatigue Design" became the reference conference to address the concerns of industrials on fatigue design of structures and components. It is also considered as the trade crossroads between industry and academia: 86 oral presentations are performed with 50% by industry.
We hope that the speakers and the delegates would have a fruitful exchange and discussions on technical and scientific developments and issues during the conferences. The poster sessions and exhibition stands are the complementary opportunities to facilitate the exchanges between the Scientists, industry participants, PhD students and the solution providers.

We would like to thank members of the International Scientific and Organizing Committees for their valuable scientific support for the selection and paper review, the authors, delegates for their contributions, exhibitors and sponsors, and SF2M and the colleagues of Cetim for the organization and to make this conference successful one.

We wish you all a most pleasant stay in Senlis and hope that you will enjoy the conference.

Fabien Lefebvre
Chairman
Organizing Committee
Fatigue Design 2017

Pascal Souquet
Co-Chairman
Organizing Committee
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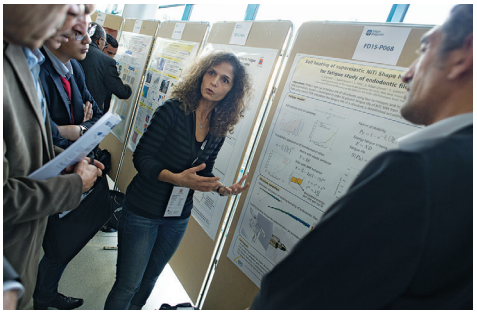

Poster Award 2017

The poster session of the 7th edition of the Fatigue Design conference includes more than 25 posters. This session will offer the opportunities for the technical exchanges between the scientists, industry participants, PhD students.

In order to acknowledge and promote outstanding research and to encourage the young researchers/scientists and PhD students, an award for the best poster has been set. The best poster will be chosen by the Poster Award Committee members with scientific and technical criteria. The Poster Award winner will receive a Certificate of Recognition and an I-Pad©.

During the 6th Fatigue Design 2015 conference, the Poster Award has been dedicated to Georg Schauer for his thesis work and poster on "Influence of Gaseous Hydrogen on Fatigue Behavior of Ferritic Stainless Steel – A Fatigue-Life Estimation".

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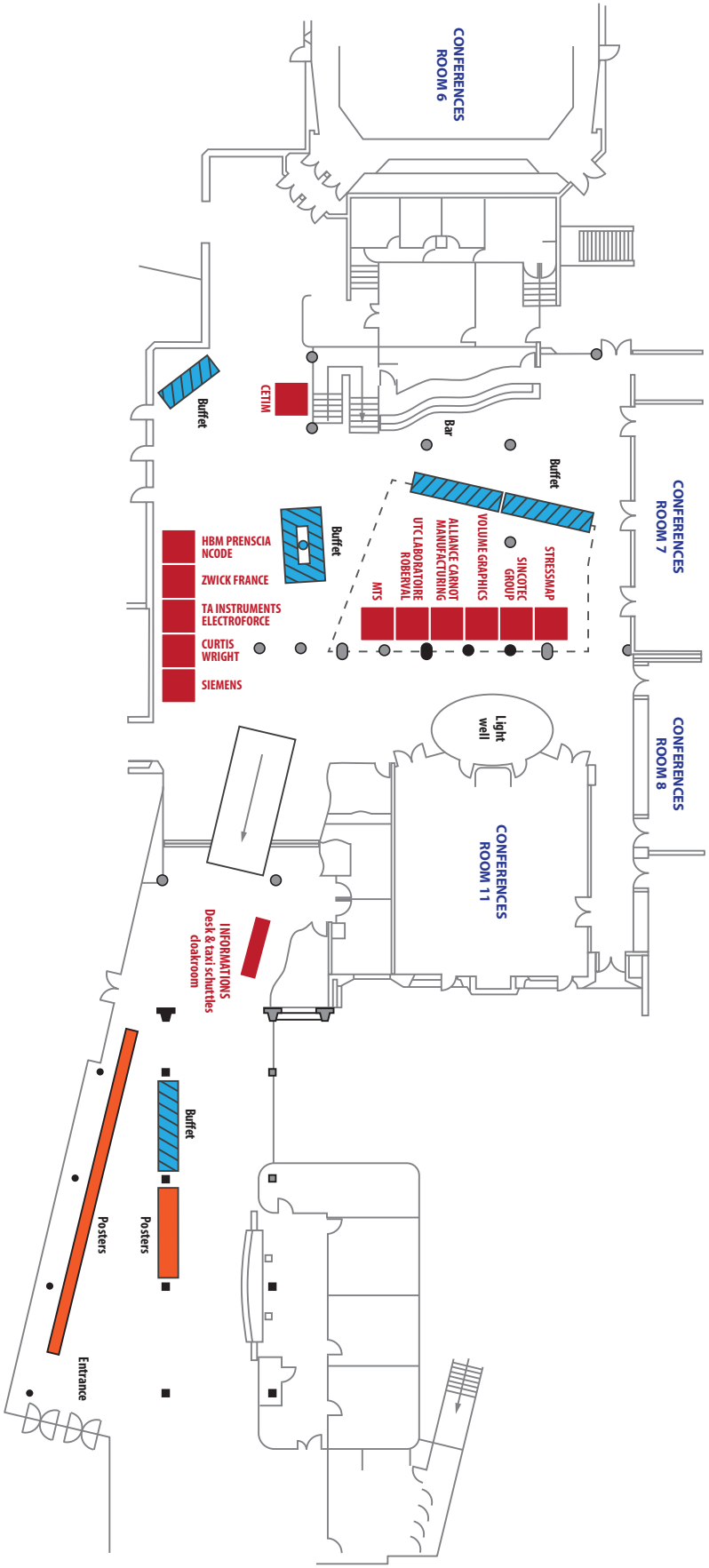
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Entrance

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SO2 - Bio-mechanical and orthopaedic implant

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S04 - Composites and elastomers

S05 - Contact fatigue

S06 - Damage tolerance and fatigue life

S07 - Experimental and numerical design and validation methods

S08 -Fatigue of assemblies

S09 - Fatigue under severe environnemental conditions (corrosion, low, temperature...)

S10 - Manufacturing processe effects in fatigue analysis

S11 - Reliability-based approaches and probabilistic methods

S12 - Thermal and thermo-mechanical fatigue

S13 - Vibration fatigue behavior

Poster Session

Plenary session

Chairmen:

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FD17-013

FATIGUE DESIGN WITH ADDITIVE MANUFACTURED METALS: ISSUES TO CONSIDER AND PERSPECTIVE FOR FUTURE RESEARCH

Ali Fatemi, Reza Molaei

University of Toledo, Toledo, Ohio, USA

Additive manufacturing (AM) is a state of the art technology enabling fabrication of complex geometries, in addition to providing other advantages as compared to the traditional subtractive manufacturing methods. However, a wide variety of factors significantly influence fatigue behaviour and structural performance of components made of AM metals. In addition to the fabrication process parameters, these include the effects of build direction, surface roughness, residual stresses, stress state, and heat treatment. At the microstructural level, defects such as pores and lack of fusion particles, as well as other microstructural features affect the behaviour. In this paper, first a brief review of the aforementioned factors and issues affecting the fatigue behaviour will be presented. Then experimental fatigue data for selective laser melting, which is a powder bed fusion metal AM process, of a common Ti alloy (Ti-6Al-4V) with applications in many industries will be presented and discussed. The effects of surface finish, heat treatment, and stress state will be evaluated, as well as failure mechanisms in different life regimes and the role of defects. Finally, some novel specimen geometries for fatigue testing will be presented which take advantage of the AM fabrication process. These geometries offer significant advantages over the currently used conventional fatigue test specimen geometries.

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FD-099

FATIGUE DAMAGE AND STIFFNESS EVOLUTION IN COMPOSITE LAMINATES: A DAMAGE-BASED FRAMEWORK

Paolo A. Carraro, Marino Quaresimin

University of Padova - Department of Management and Engineering, Vicenza, Italy

A damage-based design procedure has been developed by the authors to predict the damage evolution and the stiffness degradation in polymeric composite laminates under fatigue loading. For a safe and reliable design against fatigue degradation and failure, the initiation of the main damage mechanisms (off-axis cracks, delamination and fiber failure) as well as their evolution are considered and suitable models are proposed for the quantitative assessment of the lifetime associated to each mechanism. In parallel, the stiffness degradation deriving from the damage evolution over the fatigue life is properly described. After the illustration of the overall damage-based strategy, the paper discusses in details the analysis and modelling of the off-axis crack initiation and propagation. The initiation of cracks in the off axis plies has been proved to be the consequence of a damage process occurring at the microscopic scale since the early stages of fatigue. On this basis, crack initiation prediction is based on the use of local stress parameters: Local Hydrostatic Stress, LHS, and Local Maximum Principal Stress, LMPS, depending on the local degree of multiaxiality of the stress state and accounting for the statistical distribution of the local laminate strength. The propagation phase is then quantified by using a conventional fracture mechanics approach. The model has been implemented in a Matlab procedure for the quantitative evaluation of the crack density in each ply of a laminate during its entire fatigue life. The knowledge of the crack density trend allows the description of the laminate stiffness evolution taking advantage of another model recently developed by the authors, valid for a generic laminate configuration and accounting for the interaction between cracks in the neighbouring plies.

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FD17-081

EFFECT OF MEAN SHEAR STRESS ON THE FATIGUE STRENGTH OF NOTCHED COMPONENTS UNDER MULTIAXIAL STRESS STATE

Mohamed Bennebach[1], Thierry Palin-Luc[2], Alexandre Messager[2]

[1]Cetim, Senlis, France, [2]Arts et Métiers ParisTech, Bordeaux, France,
[3]Arts et Métiers ParisTech, Bordeaux, France

In power transmission machinery or crane industries, shafts are designed using specific standards like NF E 22-057 or DIN743; that may not correctly cover the large panel of materials and loadings involved in these sectors, making it necessary to use safety factors leading to over-conservative life predictions and non-optimized designs.

Shafts are key components, usually experiencing alternated normal stresses combined with static or fluctuating (intermittent) shear stresses. In high cycle multiaxial fatigue, it is admitted that mean shear stress has no significant effect on the fatigue strength of smooth specimens if the maximum shear stress does not exceed ~80% of the material yield limit. Under combined rotating bending and torsion the situation is unclear, especially in presence of notches.

In this paper, the effect of a static and intermittent shear stress on the fatigue strength of two quenched and tempered steel grades, 30NiCrMo8 and 42CrMo4, is studied on notched specimens with bending theoretical stress concentration factors Kt=2 and Kt=3. The chosen steel grades and stress concentration factors being representative of a majority of industrial components.

For both steel grades and notch geometries studied, the results of fatigue tests on about 150 specimens, in several multiaxial loading conditions, tend to confirm that the influence of a static torsion on the rotating bending strength is negligible even when the static torsion level is equivalent to the yield strength in torsion. This observation supports the fatigue criteria and methods that states independence of the fatigue limit upon a superimposed mean shear stress under constant amplitude cyclic loading. However, in intermittent service conditions where repeated cycles of torsion are introduced, it has been shown that these cycles can affect significantly the rotating bending endurance limit, depending on the notch acuity and torsion level applied. In this case, a maximum reduction of 30% was observed.

Results of several fatigue models are discussed with regard to the cyclic plastic strains at the notch tip calculated by Finite Element Modelling.

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FD17-014

MODELING AND SIMULATION OF WELD RESIDUAL STRESSES AND ULTRASONIC IMPACT TREATMENT OF WELDED JOINTS

Jing Zhenga, Ayhan Ince[a,b], Lanqing Tanga*

[a]Purdue Polytechnic Institute, Purdue University, West Lafayette, IN 47906, USA
[b]Department of Mechanical, Industrial & Aerospace Engineering, Concordia University, Montreal, Quebec H3G 1M8, Canada

Most structures are fabricated using welded joints because of its low cost, structural strength and geometric flexibility. Welding is considered a highly complex metallurgical process that results in irregular geometries, material imperfections/flaws and tensile residual stresses. High tensile residual stresses and stress concentrations resulting from the weld process have a significant impact on fatigue life of structures, and thus a topic of great concern in product design. Ultrasonic impact treatment (UIT) is considered as one of the most effective post welding treatment techniques to enhance the fatigue performance of welded structures. UIT aims to introduce fatigue-beneficial compressive stresses by plastically deforming the weld toe and reduce stress concentrations by modifying local weld geometries.

In this study, 3D modeling and simulation using finite element method has been performed to simulate welding process and numerical modeling of UIT process to predict weld residual stress distribution of butt and fillet weld joints. The predicted numerical results under as-welded and UIT treatment conditions were correlated with experimental data. UIT has potential applications on the fatigue design of welded structures, can lead to lighter structures and products, in which structures can be down-sized and optimized to reduce weights.

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FD17-071

AN APPROACH FOR COMPARING IN-SERVICE MULTI-INPUT LOADS APPLIED ON NON-STIFF COMPONENTS SUBMITTED TO VIBRATION FATIGUE

Gwenaelle Le Corre (Genet)

Volvo Group, Saint Priest, France

We focus on applications from the automotive industry, on mechanical components submitted to vibration loads. On one hand, the characterization of loading for dimensioning new structures in fatigue is enriched and updated by customers data analysis. In a second hand, the loads characterization also aims to provide robust specifications dedicated to the simulation or test rigs. We aim to provide vibration specifications that are adapted to a calculation time or physical test durations in accordance with the pace imposed by the projects timeframe. The vibration specifications also need to be robust by taking care of the diversity of vehicles and markets considered in the projects. In the trucks industry, the dynamic behaviour can vary significantly from one configuration to another. For non-stiff structures, the lifetime depends on the frequency content of the loads, as well as the interactions between load directions, loads input. The loads modelling in the frequency domain induces some issues and limitations. Some of them will be presented and illustrated by examples, mainly in simulation.

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FD17-037

EXPERIMENTAL TESTS AND MULTIAXIAL FATIGUE STRENGTH ASSESSMENT OF FILLET-WELDED VALVE ACTUATOR IN STEEL ACCORDING TO THE PEAK STRESS METHOD

Matteo Bergonzoni[1], Alberto Campagnolo[1], Davide Pellinghelli[2], Matteo Riboli[2], Andrea Spagnoli[3], Giovanni Meneghetti[1]

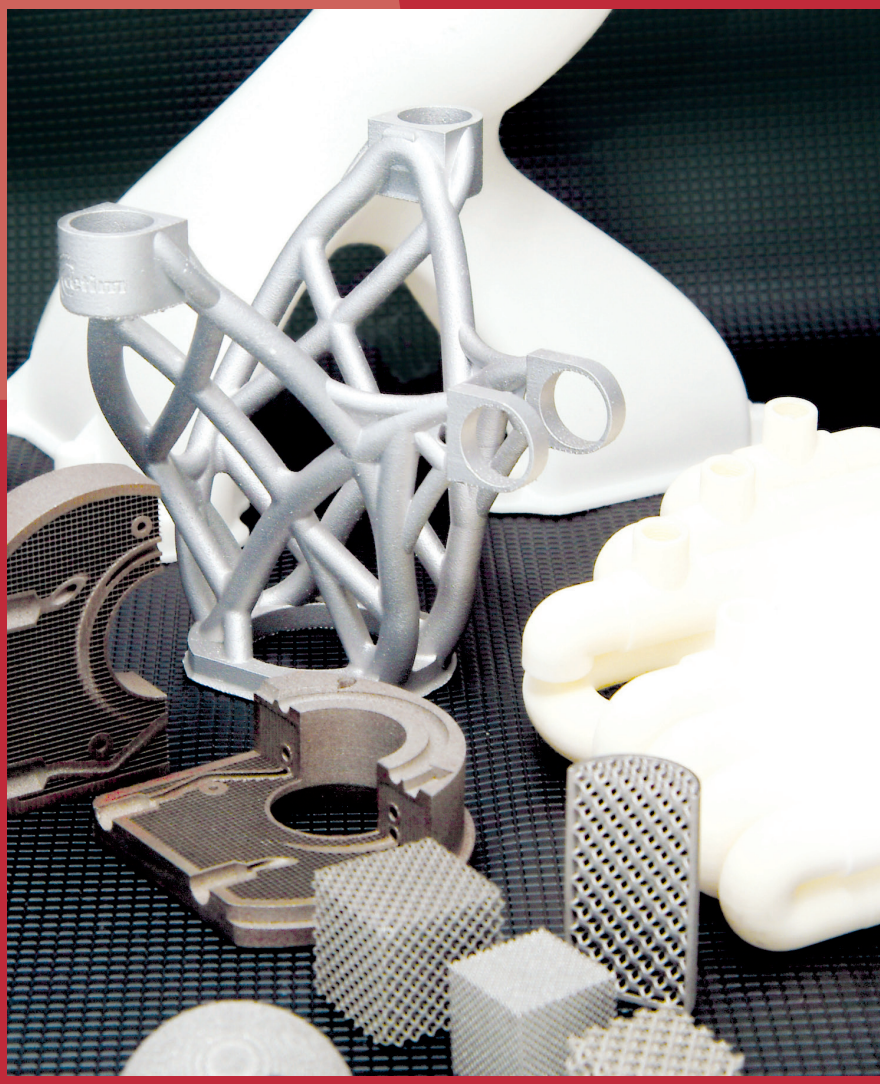
[1]University of Padua, Padua, Italy, [2]Limitorque Fluid Power System, Flowserve S.r.l., Piacenza, Italy, [3]University of Parma, Parma, Italy

Aim of this work is the fatigue assessment of one of the main component of a valve actuator used for oil & gas, power and chemical industries, in order to comply with its heavy-duty applications. Full-scale valve actuator assemblies have been tested under combined in-phase bending-torsion fatigue loadings. Due to the presence of fillet-welded joints, weld toe and weld root were the potential crack initiation points. All joints have been tested under stress-relieved conditions by adopting a nominal load ratio R=-1, taking into account the maximum load provisions given in EN 15714-3. First, the experimental fatigue test results have been compared with the theoretical estimations based on the nominal stress approach as proposed in International Standards and Recommendations. Then, the experimental data have been re-analysed by using the Peak Stress Method (PSM), which is a local approach based on linear elastic finite element analyses with coarse meshes feasible in an industrial context. The PSM is an engineering, FE-oriented application of the Notch Stress Intensity Factor (NSIF) approach to fatigue design of welded joints, which takes advantage of the singular linear elastic peak stresses calculated from FE analyses carried out by using a proper mesh pattern. The element type is kept constant, while the average element size can be chosen arbitrarily within a given range of applicability. The PSM allows to adopt rather coarse FE meshes if compared to those required for the NSIFs evaluation from the local stress fields. Thanks to the PSM and by using the averaged Strain Energy Density (SED) as a fatigue strength criterion, a design stress, the so-called equivalent peak stress, can be defined and adopted in conjunction with a reference design fatigue curve to assess multiaxial fatigue failures. The equivalent peak stress adopted in conjunction with the multiaxial fatigue design scatter band has shown to correlate with good approximation all experimental data.

S01
Additive manufacturing

Chairmen:

A. Fatemi & B. Verquin



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FD17-017

PREDICTING FAILURE IN ADDITIVELY MANUFACTURED PARTS USING COMPUTED TOMOGRAPHY AND SIMULATION

Johannes Fieres, Christof Reinhart

Volume Graphics GmbH, Heidelberg, Germany

In additive manufacturing, injection or molding processes, there are some typical issues that changes part's geometry and causes porosity/material gap. With the aid of computed tomography (CT), internal discontinuities and geometry deviation be acCurately detected and visualized. However, the question remains whether a given discontinuity affects the mechanical function of a part in a critical way, i.e., whether the part must be rejected or not. This study aims at bridging this gap. Using structural mechanics simulations based on CT images, we acCurately predict the relative failure load of tension rods. For a first proof of concept, 18 aluminum rods were built by additive manufacturing, artificially introducing different porosity patterns in a controlled way. The rods were tomographed in high resolution. Linear-elastic stress simulations were carried out with taking into account all individual pore structures as captured in the CT images. We use a mesh-free simulation code which calculates directly on the CT image data. The generation of a mesh model is not required. The same rods were also subjected to destructive physical tensile tests. The failure loads were predicted from the simulated stress distributions. We show that there is an excellent correlation between the predicted and measured failure loads. Finally, the same approach was applied to a real-life aeronautic construction part with complex geometry. Again, we find excellent correspondence between prediction and experiment.

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FD17-064

FATIGUE RESISTANCE OF SELECTIVELY LASER MELTED ALUMINUM ALLOY UNDER T6 HEAT TREATMENT

Julius N. Domfang Ngnekou[a,b], Gilbert Henaff[a], Yves Nadot[a], Julien Nicolai[a], Lionel Ridosz[b]

[a]Institut Pprime UPR CNRS 3346, Department of Physique and Mechanics of Materials, ENSMA-Université de Poitiers, 1 avenue Clément Ader, Téléport 2, 86960 Chasseneuil-Futuroscope, France
[b] Zodiac Aerospace, 61 rue Pierre Curie, 78370 Plaisir, France.

In the aeronautical context, Additive Manufacturing (AM) is considered as a promising technology. It Due to complex microstructure and defect inherited from this ALM process, it is necessary to assess the fatigue resistance of the material constitutive of manufactured parts prior to certification. This work is precisely tackling this issue with a special attention paid to the role of microstructural parameters and defects on fatigue life. Specimens were built with two configurations (0° and 90°) in order to evaluate the impact of the induced anisotropy of microstructure on fatigue properties. X-Ray 3D tomography was used to characterize defect population by their size. Microstructure is furthermore characterized by considering four characteristic scales [1-3]: melt-pools, crystallographic grains, dendritic structure and the precipitates. The fatigue properties are determined by establishing S-N curves for as-built and heat-treated samples for R= -1. The defect size responsible for the fatigue damage initiation is determined in each sample so as to establish a relation between the fatigue limit and the defect size by means of Kitagawa type diagrams. It is shown that the defect size is the first order parameter in terms of the fatigue resistance. Through the Kitagawa diagrams for as-built and heat treated samples, we quantify the improvement of the fatigue resistance due to the peak hardening treatment.

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FD17-121

SURFACE ROUGHNESS OF TI-6AL-4V PARTS OBTAINED BY SLM AND EBM: EFFECT ON THE HIGH CYCLE FATIGUE LIFE.

Bastien Vayssette[1], Nicolas Saintier[1], Charles Brugger[1], Mohamed Elmay[1], Etienne Pessard[2]

[1]Arts et Métiers Paristech I2M, Talence, France, [2]LAMPA, Angers, France

Selective Laser Melting (SLM) and Electron Beam Melting (EBM) are powder bed fusion processes which allow to build parts by successive addition of layers directly from 3D-CAD models. Among the advantages are the high degree of freedom of design and the small loss of material, which explain the increase of Ti-6Al-4V parts obtained by these processes.

However Ti-6Al-4V parts produced by SLM and EBM contain defects (surface roughness, porosity, residual stresses) which decrease significantly the High Cycle Fatigue (HCF) life. In order to minimize the porosity and the residual stresses, post-processing like Hot Isostatic Pressing (HIP) and Stress Relieving are often conducted. The modification of the surface roughness by machining is very costly and not always possible, especially for parts with complex design. The aim of this work is to evaluate the effect of the surface roughness and microstructure of Ti-6Al-4V parts produced by SLM and EBM on the HCF life.

5 sets of specimens were tested in tension-compression (R=-1 ; f=120Hz): Hot-Rolled (reference) ; SLM HIP machined ; SLM HIP « As-Built » ; EBM HIP machined ; EBM HIP « As-Built ». For every condition, microstructures characterization, observations of the fracture surface of the specimens and surface analysis were carried out respectively by Optical Microscope (OM), Scanning Electron Microscope (SEM) and 3D optical profilometer. The results of the fatigue testing show a significant decrease of the HCF life due to the surface roughness.

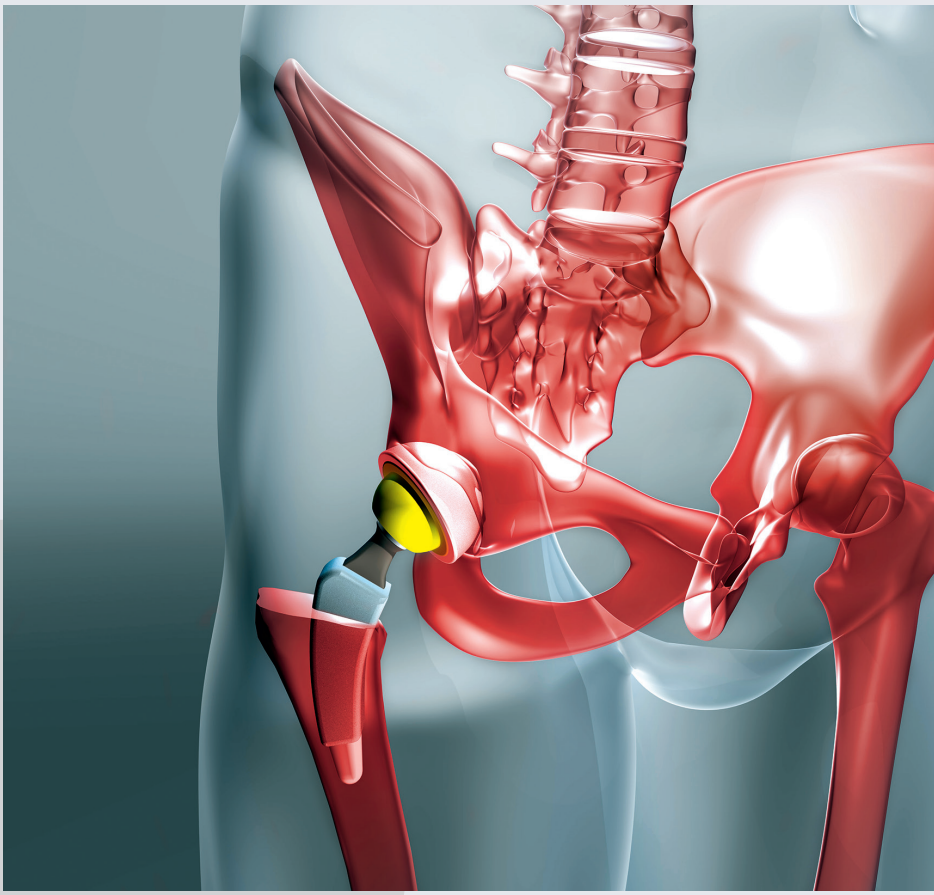
Along with experimental testing, numerical simulations using FEM were conducted from surface scans obtained by profilometry. Based on extreme values statistics, a methodology is proposed in order to take into account the effect of the surface roughness on the HCF life.

Keywords: HCF; SLM; EBM; Surface Roughness; Ti-6Al-4V; FEM.

S02
Bio-mechanical and orthopaedic implant

Chairmen:

R. Casimiro & Y. Suchier



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7th International Conference on Fatigue Design,
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FD17-116

THE ROLE OF MICROCONSTITUENTS ON THE FATIGUE FAILURE OF BONE CEMENT

Martin Brown

Southampton University, Southampton, UK

Implant fixation via the use of acrylic bone cement is now a well-established practice in orthopaedics. Excellent long-term clinical results are evidenced in national joint registers based on over 5 decades of clinical experience. Increased life expectancies, patient BMI, together with the need to remain active in later life, are expected to put greater demands on the materials used in load bearing joint arthroplasty. Failure of bone cement and its interfaces with the implant and bone often leads to loosening, requiring revision surgery. This is a particularly invasive procedure, for which the long-term success rate is low. To reduce the incidence of bone cement failure, it is necessary to understand the origins of failure in vivo. In the past, bulk failure of bone cement has often been attributed to damage accumulation originating at pores. Advances in imaging technology now mean that we are able to identify crack-initiating defects more precisely as we attempt to understand origins of failure. In this talk, the role of radiopacifier particles, a microconstiuent of bone cement rarely implicated in bone cement failure, is examined. A case study highlighting correlations between in vitro and in vivo failure patterns is presented, and potential means of improving the robustness of bone cement are discussed.

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FD17-119

FATIGUE RELIABILITY ASSESSMENT ON RANGE OF FEMORAL IMPLANTS

Maximilien Chollet, Yanneck Suchier

Cetim, Saint Etienne, France

Fatigue reliability is an important point to manage for prosthesis manufacturers. This task could however be hard to manage, as the engineer has to make sure that this reliability is ensured in all conditions:

- Configuration of the prosthesis: different size are available for the stem, that can be assembled with different heads
- Loading: depending on the patient, solicitation could vary

When the engineer meets an issue during production, he must have tools and method to decide quickly if parts are safe enough to be implanted.

A method is proposed with the following steps:
- Selection of parts to take into account
- FEA on the considered parts
- Analysis and assessment of a model
- Fatigue tests in order to validate the model
- Evaluation of the mission profile
- Operating reliability evaluation

This method will be illustrated with the implementation on a range of femoral prosthesis.

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FD17-120

DESIGN OF MODULAR PROSTHESES

Maximillien Chollet, Yanneck Suchier

Cetim, Saint Etienne, France

Hip modular implants provide real advantages to patients and surgeons: the opportunity to restore the natural anatomy, to correct discrepancy is positioning, etc…
Nevertheless, recent publication showed the weakness of these prostheses. A review of the literature on this phenomenon is carried out, and shows that fretting fatigue and fretting wear is often pointed out to explain these issues.

There are few solutions available to overcome these fretting problems. Titanium on titanium (TA6V) contacts seem to limit the production of wear particles but increase the risk of fatigue failure, unlike cobalt-chromium alloys, which lead to release harmful particles.

The aim of this study is to develop surface solutions (heat treatment, coating, texturing…) to optimize the fretting resistance of materials used in modular stem.

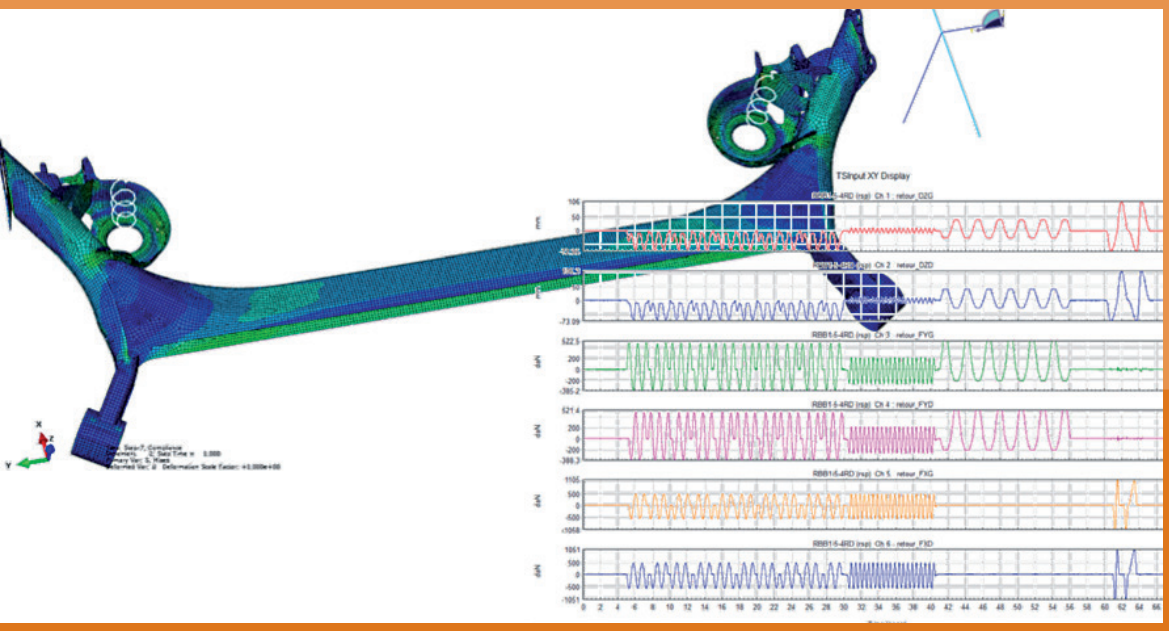
First, advanced simulations have been carried out with criterion that allow to compare the behavior regarding fretting in the modularity with consideration of different parameters like geometric, material (CoCr, TA6V), roughness and impaction load. Fatigue tests are also carried out in ISO 7206-6 conditions with post-mortem failure analysis in order to comparison to simulation.

Then, using the simulation results to define the contact stresses of modular junctions, some preliminary tests on tribometer have been carried out to study the fretting performance of alternate solution.

S03
Complex loading

Chairmen:

M. Bennebach & H. Maitournam



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FD17-048

FATIGUE DAMAGE OF MATERIALS AND STRUCTURES ASSESSED BY WÖHLER AND GASSNER FRAMEWORKS: RECENT INSIGHTS ABOUT LOAD SPECTRA FOR THE AUTOMOTIVE

Matteo Facchinetti

PSA Groupe, Belchamp, France

High cycle fatigue behaviour of materials and structures is widely assessed with respect to constant amplitude loading, because of extreme simplification of experimental procedures and numerical computations. Nevertheless, fatigue strength is usually supposed to guarantee in-service integrity face to variable amplitude loading. As the fatigue response may be very sensitive to the load time history, the gap between the former two points of view results in a long-lasting debate among the fatigue community, implying the use of a damage model and the choice of a framework. The pioneering Wöhler model is the natural reference when dealing with constant amplitude loading, whereas standard load spectra are widely applied since the seminal work of Gassner.

This paper takes advantage from fruitful discussions between German & French automotive researchers. It presents an appreciation of the Gassner model, usually applied by German engineers since at least 50 years, with the point of view of French engineers, more used to the Wöhler model.

Neglecting any sequence effect of the load time history, thus accepting the Palmgren-Miner's rule as a fact, we focus on the dual representation of high cycle fatigue behaviour expressed by Wöhler & Gassner, respectively. This necessary calls for the use of load spectra (in terms of amplitude, not frequency), which are discussed with particular attention to the automotive field.

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FD17-038

FULL-MODEL MULTIAXIAL FATIGUE LIFE CALCULATIONS WITH DIFFERENT CRITERIA

D. Pellinghelli[a], M. Riboli[a,b], A. Spagnoli[b]

[a]FLOWSERVE - Limitorque, Via P. Belizzi 40/42, 29100 Piacenza, ITALY
[b]University of Parma, Department of Engineering and Architecture, Parco Area delle Scienze 181/A, 43124 Parma, ITALY

Fatigue design of structural components under multiaxial loading often relies on full-model fatigue life calculations based on a post-processing of the full-field elastic stress/strain maps obtained from finite element analysis. In the present article, a post-processing tool, named LIFING (www.lifing-fdt.com), is adopted to compute the fatigue life of the component under study, and multiaxial fatigue assessment is carried out by considering different high-cycle fatigue criteria such as that of Carpinteri-Spagnoli, that of Dang Van and other critical plane-based criteria.

The present article focuses on the fatigue assessment of the main component of a quarter-turn heavy-duty valve actuator, called scotch yoke. This kind of machines is commonly used in many industrial sectors (such as oil & gas, power and chemical industries) and has many different applications. Among the most challenging scenarios, there are the high-cycle applications, which impose high frequency of operation often at relatively high operating speed. For plant and process efficiency, enhanced fatigue performances of the component under study and design tool reliability have to be achieved in order to reduce current maintenance intervals and process downtime.

The fatigue assessment of the component is carried out by employing a full-model finite element analysis, considering fillet-welded joints exposed to in-phase constant amplitude cyclic bending-torsion fatigue load with load ratio R=-1, with applied maximum load according to EN 15714-3, which is the Standard in the valve actuator sector. The elastic stress/strain field extracted from the finite element model is used to perform the fatigue assessment of the fillet-welded joints, where the local stress/strain values at the potential fatigue crack initiation points (weld toe and weld root) are deduced by modelling the weld notches adopting an effective radius. The theoretical results are critically compared and validated against some experimental results determined through tests on full-scale components.

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FD17-098

METHOD FOR CALCULATING A GLOBAL DYNAMIC FACTOR KAV IN GEARS SUBJECTED TO VARIABLE VELOCITY AND LOADING CONDITIONS

Francesca Curà

Dipartimento di Ingegneria Meccanica e Aerospaziale, Politecnico di Torino, Torino, Italy

Conventional design procedures to predict the load capacity of spur and helical gear drives compare the gear teeth strength with a calculated stress value, in both bending and pitting cases. The most common approach used in classical standards (ISO Standard 6336 and in AGMA Standard 2001-D04) involves the use of influence factors, derived from results of research and field service.

Influence factors related to the dynamic effects are the application factor KA, that adjusts the nominal load in order to compensate for incremental gear loads from external sources, and the internal dynamic factor KV, that takes into account the gear tooth acCuracy grade as related to speed and load.

The present paper aims to propose a method, in ISO Standard environment, in order to calculate a single global dynamic factor KAV, replacing both KA and KV, in the case of gears subjected to variable velocity and loading conditions.

This procedure, based on the Miner damage rule, allows to process a given load spectrum and to calculate a value of the equivalent tangential force that includes all dynamic effects; this force value is useful for bending and pitting calculation of the service life.

In this work a practical case is presented, based on a recorded flight mission, referring to a gear box for aerospace applications. Obtained results in terms of equivalent forces and global dynamic factor values have been compared to those calculated by means of the classical ISO Standard formula, based on the corresponding experimental data.

S04
Composites and elastomers

Chairmen:

M. Afzali & N. Leray

M. Quaresimin & C. Peyrac

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FD17-0122

NEW METHOD FOR FATIGUE STRENGTH RELIABILITY APPROACH OF ELASTOMER MEMBRANE

P. Bruno[1], P. Bonnet[2], J. Noel[1], C. Chiv[1], A. Houssais[1]

[1]Parker Hannifin Manufacturing, Colombes, France, [2]Cetim, Senlis, France

The development of bladder accumulators must now respond to two major major challenges:

- A use in service more and more severe, with hardest thermal working conditions, and also dynamic solicitation conditions, opening the way to new modes of failure,
- Regulatory requirements imposing experimental verification of the reliability and system dependability of the accumulator function, in a strong context of globalized competition.
  Within the accumulator function, the elastomer bladder is a real key component, for which gas permeability and endurance performance are "factor one" for the reliability of the assembly.

For this reason, to answer this stake, and noticing the absence of an experimental response in the current normative fields, Parker has chosen to have an endurance experimental validation process (fig.1), by developing its owned customized and accelerated endurance test benches, and adopting a methodological approach of testing and analyzing results based on the Weibull method.

In the end the gains become:

- a robust and fast test method to ensure the durability,
- a new approach to defining and guaranteeing the lower limit of membrane operating temperature for a "low temperature application" market,
- A mastery of the choice of material and the appropriate design to cold start.

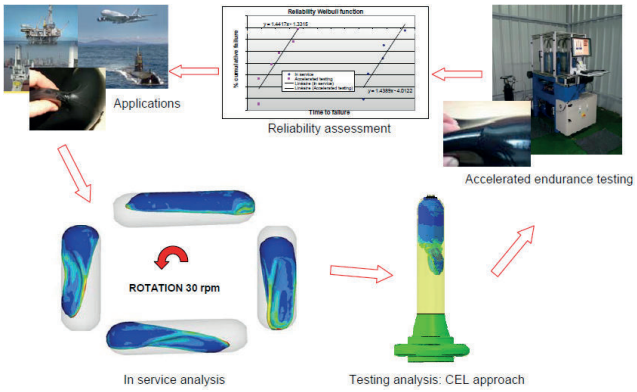

Fig.1 : Endurance experimental validation process of bladder accumulators

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FD17-106

FATIGUE CRACK GROWTH BEHAVIOR OF NBR, HNBR, HNBR ZSC COMPOUNDS

A.-S. Béranger[a], J. Qin[a], P. Heuillet[a], H.Baurier[b]

[a]LRCCP, 60 rue Auber, 94400 Vitry-sur-Seine, France
[b]Metravib (ACOEM group), 200 chemin des Orneaux, 69578 Limonest, France

Due to the insufficiency of reliable data, fatigue life calculations taking the crack propagation phenomena into account, remain scarce. Therefore, this work focuses on the characterization of fatigue crack growth behavior for materials NBR, HNBR and HNBR ZSC in different thermal ageing states at different temperatures. The experimental data base was analyzed using Fracture Mechanics principles, namely crack growth rate in relation with the tearing energy. The tests of the notched pure-shear specimen were performed on a Metravib DMA+300 fatigue testing machine. It is found that the crack growth rate is approximately proportional to the tearing energy in the steady propagation range. Furthermore, the test temperature and thermal ageing were observed to be able to weaken the shearing strength.

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FD17-097

FATIGUE OF HNBR BLENDS AND THE EFFECTS OF THERMAL AGEING

Kubat Narynbek Ulu[a,b], Bertrand Huneau[a], Erwan Verron[a], Patrick Heuillet[b], Anne-Sophie Béranger[b]

[a] Institut de Recherche en Génie Civil et Mécanique (GeM), UMR CNRS 6183, Ecole Centrale de Nantes, BP 92101, 44321 Nantes cedex 3, France
[b] LRCCP, 60 Rue Auber, 94400 Vitry-sur-Seine, France

HNBR (Hydrogenated Nitrile Butadiene Rubber) is a synthetic rubber with good resistance to heat and oil products; due its properties, HNBR is utilized in high-demanding applications in oil exploration, aerospace, and automotive and other industries [1]. However, compared to other industrial rubbers, there are only few published studies on the fatigue behavior of HNBR [2-4]. It is also important to understand how fatigue resistance is affected by the formulation of HNBR, specifically, the content of acrylonitrile monomers and percent hydrogenation (number of saturated bonds).

A total of 6 HNBR blends are tested with varying contents of acrylonitrile (24%, 36%, 44%, and a composite of 24% and 44% for an average of 36%) and with varying percent hydrogenation (91%, 95%, and 99.9%). The scope of fatigue analysis includes: fatigue life testing, fatigue crack propagation experiments, and damage mechanism analysis.

First, fatigue testing is carried out for unaged samples at 120oC, which is the median operating temperature for these HNBR blends. Afterwards, testing is carried out on sampled pre-aged at 150oC for durations up to 21 days. For fatigue life experiments, a Wohler curve is built with experiments carried out with a novel experimental approach of true stress control at 5 loading levels and loading ratio of R=0. Classical fatigue crack propagation experiments are also carried out 120oC for aged and un-aged samples. Finally, the damage mechanisms of crack initiation and propagation are analyzed with scanning electron microscopy (SEM).

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A STUDY OF VARIOUS INDICATORS TO DETERMINE THE FATIGUE LIMIT FOR WOVEN CARBON/EPOXY COMPOSITES UNDER SELF HEATING METHODOLOGY

Laurent Gornet [2], Deepika Sudevan [1,2], Patrick Rozycki[2]*

[1] Machine Design Section, Department of Mechnical Engineering,
Indian Institute of Technology Madras, Chennai - 600036, India.
[2] Institut de Recherche en Génie Civil et Mécanique (GeM),
Ecole Centrale de Nantes, Nantes - 44321, France.
e-mails : Laurent.Gornet@ec-nantes.fr
deepika.Sudevan@gmail.com and Patrick.Rozycki@ec-nantes.fr
** Corresponding authors*

The main objective of this paper is to presents three indicators to determine the limit of fatigue of woven carbon-fiber epoxy-matrix laminates from Self-Heating test method. The self-heating methodology comprises of applying a fatigue block loading sequence, with an increase in mean stress after each block. The approach adopted in the self-heating methodology is plotting the heat transfer indicator values against the maximum stress values. This plot is called the self-heating curve and from the profile of the self-heating curve, one can identify the fatigue limit. During the self-heating experiments, the temperature of the specimen increases with the number of applied cycles and then stabilizes after a certain number of cycles. In this study a novel "peak-temperature point" approach was identified as the most suitable methodology to determine the fatigue limit for a class of composite materials whose average surface temperature failed to stabilize in the loading blocks of higher stress levels. The paper also sheds some light on how a suitable approach can be chosen to uphold the economic aspect of the self-heating methodology.

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FD17-093

TOWARD COMPOSITE WIND TURBINE BLADE FATIGUE LIFE ASSESSMENT USING PLY SCALE DAMAGE MODEL

Damien Caous[1,3], Christophe Bois[2], Jean-Christophe Wahl[2], Thierry Palin-Luc[3], Julien Valette[1,2]

[1]TENSYL, Périgny, France, [2]Université de Bordeaux, I2M, CNRS, Gradignan, France, [3]Arts et Métiers ParisTech, Talence, France

During the last two decades, wind turbine diameter has increased from 50 to 180 meters and offshore wind turbine market objectives show that dimension race is not over. Nowadays, wind turbine blade market is confronted with the double issue to still increase offshore wind turbine blade length, and to make on-shore ones ever lighter in order to reach less windy areas. One of the keys identified to overcome this double issue is the acCuracy of wind turbine blade fatigue life assessment.

A lot of approaches are available to assess the fatigue life of composite laminates: fatigue life approaches based on SN-curves and damage cumulative rules (Miner rule being the widest used in industry in spite of its shortcomings), phenomenological approaches based on the residual stiffness and strength description, and fatigue damage models describing the damage state into the material.

Regarding the limitations of the first two families, a model of the last one - based on the works of C. Hochard et al. at LMA-Marseille [1] - is proposed for wind turbine blade materials (composite laminate with glass non crimp fabric – epoxy processed by vacuum assisted infusion). This model allows to describe residual strength, residual stiffness, residual strain and fatigue life of any laminate sequence under multiaxial loadings using a few specific and conventional fatigue tests on [0°], [±45°] and [±65°] laminates. The internal damage state variables used to describe matrix damage are the residual strain and the residual transverse and shear stiffness (d2 and d12). They are defined at the unidirectional ply scale, and evolve either under quasi-static or cyclic loading. A specific procedure has been developed in this study to identify the residual strength of the ply in the fibre direction as a function of matrix damage parameters d2 or d12.

Advantages and drawbacks of the proposed model are discussed regarding the classical fatigue life assessment approach based on both SN-curve, Goodman mean stress correction and Miner rule.

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FD17-023

EXPERIMENTAL MONITORING OF THE SELF-HEATING PROPERTIES OF THERMOPLASTIC COMPOSITE MATERIALS

Laura Muller[1], Jean-Michel Roche[1], Antoine Hurmane[1], Catherine Peyrac[2], Laurent Gornet[3]

[1]Onera, Châtillon, France, [2]Cetim, Senlis, France, [3]Centrale, Nantes, France

The full estimation of the fatigue lifetime of a given material is needed for the industrial structures sizing. However, it requires time-consuming, expensive fatigue testing campaigns and a huge number of samples. An alternative experimental procedure is based on the monitoring of the "self-heating" properties. The aim here is to correlate the fatigue limit with a change of thermal behavior. The main advantage of such tests is that they only require few samples and are constituted of a limited number of mechanical cycles. Thus, self-heating tests lead to an accelerated estimation of the endurance limit. The purpose of the present paper is to validate this approach for carbon/thermoplastic composite materials.

The first step of this work consisted in applying low-level, non-damaging cyclic loadings to the samples with a DMA (Dynamic Mechanical Analysis) experimental setup. The aims are to highlight the different self-heating sources of the composite and to discriminate the contributions due to viscosity on one hand and to diffuse damage on the other hand. The different parameters that affect the self-heating, such as the frequency of the loading, are to be thoroughly studied. The second step is to carry out standard tests on a hydraulic mechanical machine, and to monitor the variation of self-heating for increasing mean stress values. The drop of elastic properties and the evolution of the acoustic energy are also estimated, in order to obtain additional indicators of fatigue damage. The results are then successfully compared with data resulting from conventional fatigue tests (of several millions of cycles).

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FD17-040

RAPID DETERMINATION OF THE FATIGUE LIMIT BY THE SIMULATION OF SELF-HEATING TEST BY THE COLLABORATIVE MODEL BASED ON THE FRACTIONAL DERIVATIVE APPROACH

Alina Krasnobrizha, Laurent Gornet, Patrick Rozyckia, Pascal Cosson

[a]Ecole Centrale de Nantes, Institut de Recherche en Génie Civil et Mécanique (GeM), 1 rue de la Noë, Nantes 44321, France

This paper proposes a method for on the fast fatigue limit estimation for composite materials using a simulation of a self-heating test. The experimental method based on the material self-heating was successfully applied for composite materials and allows to determine a material's endurance limit in a few hours. In order to increase the potential of this experience, the thermomechanical modelling is proposed with the precise description of the intrinsic energy dissipation. The rise of material's temperature is linked with development of plastic strains, material damage, viscoelastic proprieties of polymer matrix and intro-crack friction. Therefore, the collaborative behaviour model including the hysteresis loops is used to represent the visco-elastoplastic damage composite behaviour. The collaborative model consists of two sub-models. The first one describes an envelope of the loading curves and insures the computation of elastic and the in-elastic strains as well as the in-ply damage. The second part deals with modelling of hysteresis loops during unloading path using a fractional derivative approach. Just a few parameters are required to represent the hysteresis loops. Using a proposed modelling, the dissipation due to the in-ply damage propagation, the material hardening and the viscoelastic effects can be precisely calculated. The fatigue limit is determined by using thermodynamic simulation the quasi-static cyclic test with the dissipation measurements as an equivalent to self-heating test. The method is validated for composite materials with thermosetting and thermoplastic matrixes.

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FD17-117

FATIGUE SIMULATION OF A SHORT FIBER RE-ENFORCED OIL-FILTER UNDER HIGH TEMPERATURE AND PRESSURE LOADS

Michael Hack[1], Wolfgang Korte[2], Stefan Sträßer[1], Matthias Teschner[3]

[1] Siemens PLM Software, Kaiserslautern (GE)
[2] PART Engineering GmbH, Bergisch Gladbach (GE)
[3] MANN &HUMMEL GmbH, Ludwigsburg(GE)

Keyword: Fatigue, Short fiber re-enforced composites, Master SN-curve high temperatures

Short-fiber reinforced parts show a distinct anisotropic behavior, caused by the alignment of the fibers during the injection molding process. The injection molding simulation provides the local probability distribution of the fibers (orientation tensor). By applying multi-scale material models it is possible to estimate the local anisotropic stiffness. This leads to considerable more acCurate results in a subsequent FEA as with isotropic approaches. This is true even if higher temperatures lead to local plasticity. Tools that enable this integrative simulation approach have been established in the last years. To account for the anisotropic fatigue behavior an interpolation of fatigue strength at a discrete fiber orientation distribution is often used by estimating the anisotropic stiffnesses in direction of the orientation tensor principal directions. This is in most cases not appropriate. In the paper an approach is described that uses a so-called Master SN curve concept which estimates SN curves for varying local fiber orientation distributions. For the application case of high temperatures and local plasticity several enhancements were implemented and tested. The methodology is verified on an oil-filter under pressure at elevated temperature.

S05
Contact fatigue

Chairmen:

P. Amuzuga & Y. Chen

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FD17-009

A CONTRIBUTION TO STUDY THE TOOTH FLANK FRACTURE (TFF) IN CYLINDRICAL GEARS

Dhafer Ghribi[1], Michel Octrue[1], Philippe Sainsot[2]

[1]Technical Center for Mechanical Engineering Industries, Cetim, Senlis, France,
[2]LaMCoS, INSA Lyon-Université de Lyon, Villeurbanne, France

The Tooth Flank Fracture, TFF, is a failure mode observed in the surface-hardened gears. There is a fatigue phenomenon which initiates from a subsurface crack that occurs in the transition zone between the hardened layer and the core structure of the tooth. It is substantially initiated close to the mid-height of the tooth in the single pair of contact area from a crack that progresses in a direction normal to the active surface flanks and also spreads in the thickness of the tooth up to the breakage of the non-active flank, slightly above the root fillet.

The two main modes of fatigue damages for gears are: (i) contact fatigue and (ii) tooth bending root fatigue, are well established and addressed in the international standards such as ISO 6336 part 2 and 3. However, up to now, there is no detailed calculation method used to determine the load capacity related to the Tooth Flank Fracture, TFF.

The main objective of this work is to develop an efficient and a standardized methodology to identify the occurrence risk of the Tooth Flank Fracture (TFF) in cylindrical gears. Then, to estimate the risk of appearance of TFF, we have studied two fatigue criteria which are introduced in a developed numerical model. The developed approach, which is based on the Hertz theory with the half-space approach, has been validated by finite elements simulations, revealing a good compliance of the "simplified" criteria proposed by Dang Van to characterize this failure mode. Good agreement of this criterion is also observed after a comparative study relative to some experimental tests carried out in literature. An advanced parametric study is carried out to properly identify the real impact of the case hardening depth on this damage mode.

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FD17-127

INTERNAL VOIDS AS A STRESS RELIEVER AND PALLIATIVE IN FRETTING FATIGUE

Diego Erena, Jesús Vázquez, Carlos Navarro, Jaime Domínguez

University of Seville, Camino de los Descubrimientos, Seville 41092, Spain

Currently, additive manufacturing with metals is an increasingly popular technique that allows the manufacturing of pieces of difficult shapes, nearly impossible to make with other techniques. Usually, these shapes try to optimize the solid to have the same strength with a lower weight. The fatigue behavior of the material of the components manufactured with this technique is a field in development. On the other hand, fretting fatigue is a common type of fatigue where a "stress concentration" appears due to the contact between two components. There are some procedures used to increase fatigue life in this situation (shot peening, surface knurling, etc.). This paper tries to analyze the possible beneficial effect on fatigue life of introducing voids inside the material in components under fretting, which is feasible now thanks to additive manufacturing. The problem under study is, for now, a 2D simplification where a cylinder is in contact with a half plane and a normal constant load and a variable tangential load are applied. This geometry has been numerically simulated, introducing a circular hole below the surface. The effect of this hole is to make the contact more elastic, which decreases the stresses near the surface. This work analyses and compares the stress and strain fields and Smith-Watson-Topper multiaxial fatigue parameter in the areas sensitives to fretting with respect to a case with homogeneous material (no internal voids). Various configurations changing different parameters like size and position of the hole, friction coefficient and the size of the slip zone have been considered. The problem analyzed in this paper is two-dimensional, therefore there would be no need to use additive manufacturing in a real situation. However, the results obtained in this paper indicate that it could also work in 3D. Actually, it is in a real three-dimensional problem where the additive manufacturing would be necessary for the introduction of voids inside the material to improve fatigue life.

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FD17-0108

PREDICTION OF FRETTING FATIGUE ENDURANCE : A COMBINED CRACK NUCLEATION CRACK ARREST APPROACH

Siegfried Fouvry[1], Simon Garcin[1], Bruno Berthel[1], Camille Gandiolle[2]

[1]Ecole Centrale de Lyon, Univ. of Lyon, Ecully, France,
[2]CentraleSupelec, Univ. Paris Saclay, Saclay, France

Cracking process induced by fretting fatigue loadings are particularly complex to formalize. The stress state induced by fretting (normal loading combined with cyclic oscillating tangential shear) is multiaxial and characterized by very severe stress gradients [1-3]. Crack nucleation prediction implies a microstructural descriptions from stage I (≈ 10 µm grain size) to stage II (≈ 100 µm multigrain size) crack length. Modelling of propagation and possible crack arrest configurations require to consider the compressive and varying stress ratio state imposed below the fretted interface but also to address a short crack arrest description. Taking in account all these considerations a global approach is described. First FEM simulation are considered to establish the elastic shakedown stress state which transposed in non local multiaxial fatigue stress analysis allows to predict the crack nucleation endurance as a function of the considered crack length. Then the crack propagation stage is formalized considering a short crack description and using a mixed mode propagation description. The obtained predictions regarding finite and infinite fretting fatigue endurances are compared versus experiments given for different materials. The stability of this "incremental" cracking approach is discussed regarding the elasto-plastic description of the interface and comparing different cumulated damage formalisms. This methodology which was developed using a reference cylinder/plane fretting fatigue interface is compared investigating more representative industrial interfaces like connecting rod or pressed fitted assemblies.

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S06
Damage tolerance and fatigue life

Chairmen:

E. Pessard & M. Risbet

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FD17-094

FATIGUE DAMAGE MECHANISMS AT ROOM TEMPERATURE OF THIN BRAZED ALUMINIUM ALLOY USED IN AUTOMOTIVE HEAT EXCHANGERS: EFFECT OF THE RESIDUAL CLAD LAYER

Josselin Paturaud[1,3], Damien Fabregue[1], Armelle Danielou[2], Anne Gaelle Noumet-Villemiane[3], Jean-Yves Buffiere[1]

[1]INSA Lyon, Villeurbanne, France, [2]Constellium Technology Center, Voreppe, France, [3]Valeo, La Verriere, France

Nowadays, most of the automotive heat exchangers are made of brazed aluminium sheets. Due to economic and environmental issues, the thickness of heat exchanger components have been reduced. Concomitantly, the stress undergone by the heat exchanger increased which raised the risk of fatigue failure, and particularly on tube for radiators.

In this work, a detailed characterization of the cyclic damage mechanisms in car heat exchangers has been carried out. The standard material used to make radiator is a very thin (<0.27mm) aluminium sheet composed by 3 layers (4XXX /3XXX/ 4XXX). To assess the effect of the structure of this "sandwich" on the damage mechanisms, a material composed of a single layer (3XXX) has also been studied. Both materials have been brazed in similar industrial conditions in order to obtain representative metallurgical and surface conditions. At the end of the brazing process a fully recrystallized structure composed of about 5 to 6 grains through the thickness is obtained. Fatigue properties and damage mechanisms of such microstructures have not been widely studied and this constitutes a real challenge.

To characterize the cyclic resistance of the studied materials, fatigue tests at constant stress amplitude have been performed at room temperature. Crack initiation and propagation have been observed by 2D and 3D monitoring techniques. These techniques, in addition to a detailed microstructure characterization of the materials, allowed to clarify the damage mechanisms leading to fracture in fatigue of these thin sheets and, in particular, to point out the key role of the residual clad (left by the 4XXX melting) on the damage mechanisms.

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FD17-010

PARAMETRIC CALCULATIONS OF FATIGUE LIFE OF CRITICAL PART OF TROLLEYBUS REAR AXLE

Miloslav Kepka, Miloslav Kepka Jr.

Regional Technological Institute, research center of Faculty of Mechanical Engineering, University of West Bohemia in Pilsen, Pilsen, Czech Republic

Strain gauge measurements and fatigue life assessment of heavily-stressed structural details and parts of trolleybuses are carried out at various stages throughout the development process. The testing locations include several hundred critical locations on the vehicle, tested either during service load simulations on an electrohydraulic test stand or during prototype vehicle rides on actual routes. In the present case, the measurement was conducted at a later stage because the part in question (rear axle) had not been expected to pose any problems. Sufficiently representative stress-time histories for the critical point on this part were obtained by measurement carried out during rides with empty as well as fully-loaded vehicles. Estimates of relevant fatigue characteristics had to be developed using information on material composition, design, and the manufacturing route of this part. The data gathered in actual service included information about the part's service life to failure. By comparing the information from service and the computational prediction of fatigue life, one could find whether the measurement and fatigue calculations would have been a sufficient basis for identifying the part as a critical one if it had been subject to scrutiny early on. The summary of this basic stage of research is that well-conceived parametric calculations of fatigue life can provide predictions of reliability in service of parts operated under dynamic loads, enable the main adverse factors to be eliminated, and allow the optimization of the part's shape and quality, as well as its workmanship in terms of technological processes.

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FD17-054

FATIGUE CRACK GROWTH IN WELDS BASED ON A V-NOTCH MODEL FOR THE SHORT CRACK PROPAGATION AT THE TOE

Naman Recho[1,2], Tom Lassen[3]

[1]ERMESS, EPF – Graduate School of Engineering, 3 bis rue Lakanal, 92330, Sceaux, France, [2]Institut Pascal, Blaise Pascal University, 63000, Clermont-Ferrand, France, [3]University of Agder, Lilltunsvei 9 N-4879 Grimstad, Norway

The paper presents a new fatigue crack growth prediction model for non-load-carrying fillet welded steel joints. For this joint configuration the fatigue cracks will emanate from the weld toe region. Due to the presence of a V-notch in this region the crack initiation point becomes a point of singularity for the stress field. This may in many cases make it difficult to determine the Stress Intensity Factor Range (SIFR) for small cracks by conventional methods based on Linear Elastic Fracture Mechanics (LEFM). The present approach solves this problem by using the Energy Release Rate (ERR) to determine the SIFR in the small crack growth regime. The model is fitted to crack growth curves from tests with cruciform steel welded joint subjected to constant stress ranges in both axial and bending loading mode. The Paris crack propagation law is adopted and the calculation of SIFR for larger cracks outside the material volume influenced by the V-notch singularity is carried out by the conventional approach. The model gives results in agreement with experimental facts and has also the potential of being extended to variable amplitude loading. The model is also well suited for taking into account the crack initiation phase that is significant for high quality welded joints.

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FD17-062

A STUDY ON LIFETIME OF A RAILWAY AXLE SUBJECTED TO GRINDING

Xavier Lorang[1], Yann Cheynet[2], Philippe Feraud[2], Yves Nadot[3]

[1]SNCF, I&R, PARIS, France, [2]SNCF, AEF, Vitry Sur Seine, France,
[3]Institut Pprime CNRS ENSMA, Futuroscope France

For security requirements, no fatigue failure of axles is admitted in railway industry. Design process of axles must ensure that there is no crack initiation during its life. Maintenance inspections are realized and guarantee that no critical propagation of fatigue cracks can occur.

For the suppression of surface defects, wheel grinding is commonly realized during maintenance task.

This present paper treats of a lifetime comparative study of an axle with and without grinding operation. The goal is to investigate the influence of the grinding parameters on the lifetime of axle.

In the first part of the paper, the context of maintenance of railway axle is briefly described and the grinding process is presented. The grinding process modify the roughness, the microstructure of the surface and induces residual stresses: some experimental results are shown.

In the second part, the case of a ground axle is considered without defect in the ground zone. A study of the effect of the grinding process on the lifetime of fatigue samples is presented.

In the third part, the case of a ground axle is considered with defects in the ground zone.
In this case, a study of the effect of the grinding process on the lifetime is presented for different types of defects. Fatigue tests results on specimens are presented. Numerical simulations results for lifetime evaluation are also presented.

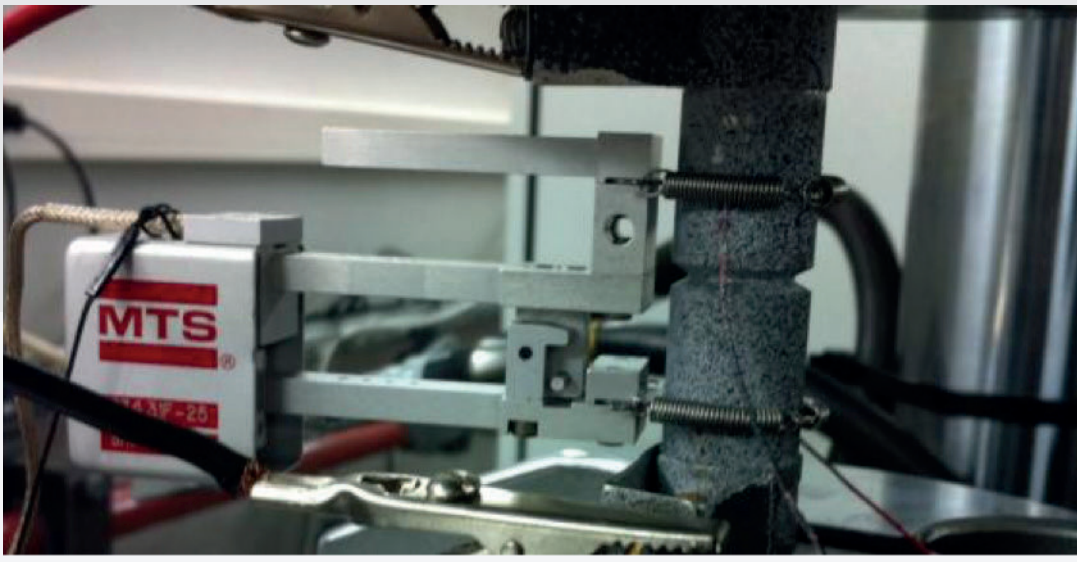
S07
Experimental and numerical design and validation methods

Chairmen:

F. Laurin & H. Rognon

J. Favergeon & T. Palin-Luc

F. Curà & B. Depale



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FD17-015

FATIGUE TEST RESULTS OF SURFACE HARDENED COMPONENTS TO EVALUATE A TWO LAYER APPROACH FOR STRENGTH ASSESSMENT

D'enes Dobberke[a], Jens Wiebesiek[a], Jürgen Fröschl[a], Martin Leitner[b]

[a]BMW Group, Research, New Technologies, Innovations, Parkring 17-19, Garching 85748, Germany
[b]Montanuniversit¨at Leoben, Chair of Mechanical Engineering, Franz-Josef-Straße 18, 8700 Leoben, Austria

In the automotive industry, forged steels are commonly used for powertrain components like gears, axles, crankshafts etc. In order to minimize wear and increase fatigue strength, these components are usually surface-hardened. The surface heat treatment leads to a significant change of the local material properties in the heat effected zone of the surface area. This paper addresses an effective two-layer model for evaluating fatigue behavior of surface hardened components based on local stresses. Hence, one layer represents the induction-hardened surface and the second characterizes the base material. The aim of this elaborated method is a more reliable computational estimation of fatigue life among other assessments based on technology factors for components designed for the high cycle fatigue (HCF) regime by taking into account local material properties, defects and residual stresses.

In order to verify the presented method and to determine the fatigue strength, specimens are extracted from highly stressed component areas considering forged grain structure. The sample notch shape is approximated to component notch (e.g. crankshaft fillet) regarding form factor, stress gradient and highly stressed volume. The idea behind the fatigue tests is to study low residual stress manufactured material samples in hardened and unhardened condition to separate the cause variables (residual stresses, strength of base material and martensitic phase etc.) on fatigue strength. Compared to the unhardened base material, the fatigue tests at different stress ratios revealed (as expected) higher fatigue strength within low and high cycle fatigue of the martensitic material. A final application study of the presented method on a highly stressed crankshaft fillet shows the engineering feasibility and validates the numerical analysis with experimental results. Accompanying X-ray residual stress and hardness measurements at the component indicate a compressive residual stress state and, compared to the core material, a significantly increased hardness condition in the surface layer. Considering these input data in combination with the fatigue strength of each material section, the layer approach enables a more reliable local fatigue assessment in relation to fatigue evaluation methods including technology factors.

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FD17-019

INFLUENCE OF THE MODAL DAMPING ON THE ESTIMATED FATIGUE LIFE

Fred Kihm[a], Arnaud Langelier[b],Kurt Munson[c]

[a]HBM Prenscia, 95700 Roissy-en-France, France
[b]Donaldson Filtration, 50420 Domjean, France
[c]HBM Prenscia, Southfield MI 48076, USA

The durability assessment of a component or structure is often assessed using Finite Element Analysis (FEA)-based structural simulations. Fatigue is a progressive failure mode that is related to the stress cycle's range in a power law such that the fatigue damage increases exponentially as the stress range increases.

When the frequency content of the loading gets closer to the natural frequencies of the structure, resonance effects are activated. In this case, the dynamic properties of the structure must be included in the analysis in order to better account for the increased stress response. A dynamic FEA produces therefore more realistic results compared to a static analysis, but requires knowledge of additional characteristics such as mass and damping. In a dynamic FEA, whether transient or steady state frequency response, the damping property governs indeed the magnitude of the dynamic stress response and hence the durability of the component.

Unfortunately a default damping value is sometimes erroneously assumed for all modes leading to errors in the stress response, which in turn leads to significant errors in the fatigue life estimates. The modal parameters – including damping ratios - for the structure's modes of vibration can be extracted using experimental modal analysis techniques.

The purpose of this article is first, to explain the critical role that damping plays in fatigue damage; and second, to recommend best practices for determining modal damping experimentally.

A simple example of an automotive component will be used to illustrate the importance of using experimental modal analysis to adjust the properties of a FE-based dynamic structural analysis. An experimental modal test followed by a modal analysis will be described. The mode shapes obtained experimentally and analytically will be compared to validate the mass, stiffness and boundary conditions used in the modelling. Then, it will be shown that using realistic values for the damping ratios will help to obtain stress results that correlate with the measured stress. Finally, this example will illustrate the very high sensitivity of the fatigue life estimate to the damping ratios.

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FD17-046

NEW STANDARD XP X50-144 RELATED TO MECHANICAL ENVIRONMENT STRENGTH PROOF. IMPLEMENTATION AND FIRST FEEDBACK

Jean-Yves Disson[a], Bruno Colin[b]

[a]Metravib ACOEM Group, 200 ch des Ormeaux, Limonest 69578, France
[b]Nexter Systems, 11 allees des Marronniers Versailles Cedex 78022, France

The paper presents a new fatigue crack growth prediction model for non-load-carrying fillet welded steel joints. For this joint configuration the fatigue cracks will emanate from the weld toe region. Due to the presence of a V-notch in this region the crack initiation point becomes a point of singularity for the stress field. This may in many cases make it difficult to determine the Stress Intensity Factor Range (SIFR) for small cracks by conventional methods based on Linear Elastic Fracture Mechanics (LEFM). The present approach solves this problem by using the Energy Release Rate (ERR) to determine the SIFR in the small crack growth regime. The model is fitted to crack growth curves from tests with cruciform steel welded joint subjected to constant stress ranges in both axial and bending loading mode. The Paris crack propagation law is adopted and the calculation of SIFR for larger cracks outside the material volume influenced by the V-notch singularity is carried out by the conventional approach. The model gives results in agreement with experimental facts and has also the potential of being extended to variable amplitude loading. The model is also well suited for taking into account the crack initiation phase that is significant for high quality welded joints.

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FD17-044

THROUGH PROCESS MODELLING APPLIED TO THE FATIGUE RESISTANCE OF CAST ALUMINUM

Yves Nadot[1], Mohamed Iben Houria[1,2], Raouf Fathallah[3], Daan Maijer[4]

[1]P' - ENSMA, Futuroscope, France, [2]ETS, Montreal, Canada,
[3]ENISO, Sousse, Tunisia, [4]UBC, Vancouver, Canada

The aim of this study is to evaluate a full integrated modelling strategy to evaluate the influence of casting defects on the fatigue life directly from process simulation. We have shown that defects characterized by their size and the microstructure characterized by the SDAS, are the main parameters that control the fatigue limit. A fatigue criterion was modified to introduce the effect of SDAS. This improved criterion has been employed to predict the Kitagawa diagram for multiaxial loading for different loading cases. The simulation of the modified criterion showed that the reduction of the fatigue limit with the defect size and SDAS is well described. In the last part a numerical model was developed to perform a simulation of the fatigue limit starting from the casting process. Using this numerical model, we simulated the defect size and SDAS depending on the solidification time, the fatigue limit is simulated using the improved criterion. We proposed in this part a mold which let to obtain samples with two different microstructures. In this study, a second fatigue tests was carried out on these samples to validate the numerical simulation on the proposed mold. It turns out that the numerical model provides reasonably well the obtained experimental results.

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FD17-004

CORRELATION OF SIMULATION, TEST BENCH AND ROUGH ROAD TESTING IN TERMS OF STRENGTH AND FATIGUE LIFE OF A LEAF SPRING

Mehmet Bakir, Caner Donertas, Murat Siktas, Basaran Ozmen

Mercedes-Benz Turk A.S., Istanbul, Turkey

There are three major methods to verify the durability characteristics of a new designed leaf spring. These are simulation, test bench and rough road testing.

Simulation is a rapid approach to find out the very first results for the assessment of the design. Test bench uses a pre-defined load program to estimate the lifetime of the leaf spring. It takes more time than simulation and is more costly. Rough road testing covers a complete endurance run for the whole heavy duty truck structure which is very costly and takes a very long time to accomplish.

The aim of this paper is to reduce the time and the cost of the development procedure of a new designed leaf spring. The most efficient way to reach this goal is to correlate the results of the testing and simulation, so that, it would be possible to release new designs mostly depending on the simulation which is the fastest and the reasonable way to reach a final evaluation.

A new designed leaf spring, with two leaves, is simulated in finite element analysis with the loads from multi body simulations in order to reach a fatigue life assessment; is tested in the test bench with the pre-defined loads from the rough road; is mounted to a complete truck structure to run a full rough road truck program to reach the final evaluation.

In this paper, these three durability assessment techniques are compared and correlated with each other as a main scope. Additionally, the simulation methodology, the structure of the test bench and the procedure of the rough road testing are given in details.

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FD17-059

THE DISSIPATED HEAT ENERGY AS A FATIGUE DAMAGE INDEX FOR EXPERIMENTAL FATIGUE LIFE ESTIMATIONS

Giovanni Meneghetti, Mauro Ricotta

University of Padova, Department of Industrial Engineering, via Venezia, 1, Padova, Italy

Fatigue of metallic materials is a dissipative phenomenon involving plastic deformations that require a certain amount of mechanical energy in a unit volume of material, W. Only part of this energy is accumulated in the form of internal energy, which is responsible for fatigue damage accumulation and final fracture. The remaining part is dissipated as heat (Ellyin, 1997), thus translating into some temperature increase during fatigue testing. The thermal energy dissipated in a unit volume of material per cycle (the Q parameter) has been adopted as a fatigue damage indicator during fatigue tests of stainless steel specimens and a relatively simple experimental technique has also been proposed to estimate Q from in-situ measurements of the temperature at the surface of a specimen or a component (Meneghetti, 2007). Similar to W, Q is thought of as a material property, i.e. it is independent, within certain limits, of the thermal, mechanical and geometrical boundary conditions of the laboratory fatigue tests. Then, the specific heat loss per cycle Q at a given point of a component (similar to the plastic hysteresis energy) depends only on the applied load cycle, defined by amplitude, mean value and stress state.

Originally, the Q parameter was adopted to rationalize in a single scatter band approximately 150 experimental results generated from constant amplitude, completely reversed, stress- or strain-controlled fatigue tests on plain or notched hot rolled stainless steel specimens. Afterwards, the heat-energy based approach was extended to include the mean stress effect, by using a thermodynamic fatigue damage variable that combines two parameters, i.e. Q and the thermoelastic temperature achieved by the material at the maximum stress of the load cycle. Finally, Q was used to rationalise two-stress level fatigue test results, by using the Q-based fatigue curve combined with Miner's rule.
In this paper, the Q-based approach is discussed, focusing mainly on its use including the mean stress as well as the two-stress level effects in fatigue of stainless steel specimens.

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FD17-114

FATIGUE PHENOMENA ON TRUNNIONS OF LARGE SPHERICAL VALVES

David Graveleine

EDF, Le bourget du lac, France

Hydroelectric power plants consist of water supply circuits on which are installed flow cut-off devices. In some cases, those equipments may be subjected to loading cycles causing disorders: cracking due to fatigue.

EDF Hydro Division proposes to share its recent experience on an analysis conducted on a spherical valve of diameter 1300 mm operating at a working pressure about 100 bars.

In 2016 EDF Hydro Division has launched the diagnoses of spherical main inlet valves on a pomp-turbine plant after more than 30 years of service with about 2 starts & stops per day. These diagnoses where decided because cracks were discovered in the fillet of 2 trunnions shafts after their removal. Finally, the expertise of all the trunnions revealed that all of these parts had cracks, without exception. A generic disorder has been found. Therefore, it was necessary:

- to understand the origin of these cracks,
- to estimate the size of the cracks in the short term (next 3 years) due to possible fatigue propagation,
- to assess the cracks with regard to British Standard fracture mechanics requirements.

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FD17-070

STRATEGIES FOR MATERIAL MODELLING REGARDING FATIGUE DESIGN UNDER VARIABLE AMPLITUDE LOADING WITH STRAIN-BASED FATIGUE DESIGN APPROACHES

Matthias Hell[2], Rainer Wagener[2], Heinz Kaufmann[2], Tobias Melz[1,2]

[1]Resarch Group of System Reliablity, Adaptive Systems, and Machine Acoustics, Technische Universität Darmstadt, Darmstadt, Germany, [2]Fraunhofer Institute for Structural Durability and System Reliability LBF, Darmstadt, Germany

Strain-based fatigue design approaches allow a reliable assessment for arbitrarily shaped components on the basis of the cyclic material behaviour which may be determined by strain controlled testing on smooth specimen. It is assumed, that the stress-strain state of the homogeneously loaded specimen is equivalent to an infinitesimal small material volume. The cyclic material behaviour consists of a stress-strain relation, which is used to assess the local stress-strain state of the component, and a strain-life relation, which relates the numbers of cycles to fatigue to the maximum local strain. The stress-strain relation, the strain-life relation and also the experimental determination of the cyclic material behaviour depend on the selected material model and the required parameters. Different elasto-plastic material models are available in order to implement the specific material behaviour into the assessment of the stress-strain state and the fatigue life. Depending on the load magnitude, load ratio and the boundary conditions of the deformation, the cyclic stress-strain behaviour may exhibit cyclic hardening, cyclic softening, mean stress relaxation or ratchetting. For many engineering applications in the High Cycle Fatigue (HCF) regime, a cyclic stabilization of the material behaviour is assumed and transient effects are neglected. Regarding fatigue design under variable amplitude loading, this assumption may not be valid. The stabilization of the stress-strain behaviour is influenced by the load magnitude, the load sequence and the slip character of the material. For variable amplitude loading, load time functions are usually given for the external loads. In order to assess the fatigue strength with strain-based approaches, the load time function has to be transferred to the local stress-strain system on the basis of the cyclic stress-strain behaviour and the component geometry. The quality of the fatigue assessment will therefore to a huge extent depend on the assumptions regarding the stress-strain behaviour under inhomogeneous stress-strain states. The presented work compares the influence of different models for the cyclic stress-strain behaviour and the strategies to derive the parameters from the test data on the fatigue assessment under constant and variable amplitude loading.

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FD17-091

MODELLING FATIGUE BEHAVIOR OF SLEWING RINGS IN CRANE STRUCTURES. IDENTIFICATION OF INFLUENCING PARAMETERS ON LOCAL STRESSES AND FATIGUE DAMAGE CALCULATIONS

Romain Duval[1], Mohamed Bennebach[1], Aymen Guelbi[2], Jeremy Blasiak[2]

[1]Cetim, SENLIS, France, [2]Manitowoc, Dardilly, France

In a technological environment in constant evolution, highly competitive, with increasingly high requirements of security, performance, and economic issues associated, designers and users must pay special attention to reliability and durability of structures.

In the case of Crane industry, slewing rings are important parts of equipment and manufacturers need to guarantee their mechanical strength and durability.

Since more than ten years, on demand of industrial groups, CETIM is working on slewing rings in the fields of tests, design and calculations. For the last couple of years, extensive work has been done to develop a calculation methodology giving access to forces in balls of rings. Thanks to these forces and to non-linear finite element analysis, local models including precise contact definition allow stress state calculations in the tracks of rings. From the stress distributions at the surface and in depth, fatigue analysis is conducted based on appropriate criteria taking into account the complex multiaxial stress state and the gradient of material properties due to the surface treatment of the tracks (induction hardened parts). Parametric calculations have been made in order to estimate the influence of some parameters such as contact angle of the balls, geometric conformity, mechanical clearance and depth of treated material. Results allow identifying most important parameters and show how these parameters influence the damage location on the slewing rings, with good correlation with physical observations on damaged components. A synthesis of this long term work is presented in this paper.

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FD17-058

FATIGUE PERFORMANCE OF OVERHEAD CONDUCTORS TESTED UNDER THE SAME VALUE OF H/W PARAMETER

Remy Badibanga Kalombo, Mielle Silva Pestana, Thiago Barbosa de Miranda, Cosme Roberto Moreira da Silva, Jorge Luiz de Almeida Ferreira, José Alexander Araújo

Universidade de Brasília, Brasília - DF, Brazil

The objective of this work is to conduct an experimental campaign to evaluate the effects of the catenary parameter (H/w) on the fatigue life of overhead conductors. A battery of twenty seven fatigue tests was carried out on three types of conductors, namely a 900 MCM All Aluminium Alloy Conductor (AAAC 900 MCM), an All Aluminium Conductor (AAC Orchid) and an Aluminium Conductor Steel Reinforced (ACSR Tern). The H/w parameter is defined as the ratio between the initial horizontal tensile load, H, and the conductor weight per unit length, w. For this study, all tests have been carried out using the value of H/w equal 2144 m. Fatigue damage is one of the major problems affecting power line conductors around the world. It is caused by Aeolian vibration, which is characterised by high frequency and low amplitude movements. Based on field observations, a same H/w limit value has recently been proposed as a fatigue design criterion for different families of cables (AAC, AAAC, ACSR). However, there are few experimental data available in literature to corroborate this hypothesis. Comparison between the generated S-N curves proved that the ACSR Tern conductor could sustain a significantly higher number of cycles before fatigue failure than the AAAC 900 MCM for this level of H/w. Meanwhile, the AAC Orchid presents a fatigue life in between the AAAC 900MCM and the ACSR Tern conductors. Failure analysis of the broken samples revealed not only that cracks initiated in the fretted areas of the aluminium wires but also that their morphology presented some clear evidences of fatigue failure, such as beach marks and secondary cracks. Additionally, a failure map has been raised to determine the layer and the position from the clamp mouth where the wires broke. Data obtained in this study could be used in a non-linear finite-element analysis in order to estimate a proper local to conduct a more refined stress/fatigue evaluation to estimate life, rather than using the classical nominal stress approach. Furthermore, the provided information could be helpful for planning the maintenance of power lines.

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FD17-113

FATIGUE CRACKING OF ROTOR POLE FASTENERS OF PUMP-TURBINES USED IN HYDROELECTRIC POWER PLANT

P. Bryla et H. Colombié

EDF - CIH, Le Bourget du Lac, France

Recently, as a result of a dramatic damage to a hydroelectric generating machine in a foreign plant, a new eye was taken by the profession on the consequences of the numerous start-up cycles undergone by electricity generating machinery in hydroelectric power plant.

Thus the impact of cycling was analyzed on the stator coils (thermal cycling) and (especially) on the rotors (mechanical cycling).

The calculations carried out by the manufacturers and the experience recently acquired by EDF have shown that the rotors are indeed subject to fatigue in the zones undergoing alternating stresses of traction (cycles 0-500g). The clamping keys of the poles are particularly concerned.

The presentation presents the analysis made by the profession at this stage of knowledge, and the means used to try to remedy it.

S08
Fatigue of assemblies

Chairmen:

G. Meneghetti & I. Huther

Z. Barsoum & HP. Lieurade

P. Klein & I. Huther

D. Osage & M. Marzin

J. Baumgartner & M. Marzin

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FD17-043

A NUMERICAL METHOD FOR DETERMINING THE FATIGUE STRENGTH OF WELDED JOINTS WITH A SIGNIFICANT IMPROVEMENT IN ACCURACY

Gerhard Lener, Robert Lang

University of Innsbruck, Innsbruck, Austria

There exist numerous concepts for calculation of fatigue strength in steel and mechanical engineering. However, in many cases, the acCuracy in the computational determination of the fatigue strength and possible number of stress cycles to failure is very imprecise and often also in the non-conservative range.

If an increase in the acCuracy is desired, an evaluation of the actual geometry of the welded connection is unavoidable. The difficulties of stochastically distributed geometric shapes do not lie only in the calculation of the effective notch stresses themselves but, above all, in the evaluation of the notch sensitivity.

This paper presents a new approach to the determination of the fatigue strength of welded joints. With this approach, nearly fully automated calculations of the fatigue strength can be achieved independently of fatigue details tables and with minimal user interaction. In the approach presented, the actual geometry with respect to notch shape and size effect is taken into consideration. The results show significantly increased predictability with respect to the location of the starting points of cracks and endurance life.

The method was used for the comparison of different welding processes and welding positions. The presentation includes examples which intend to demonstrate the feasibility of the assessment of existing steel structures with regard to fatigue strength.

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FD17-061

FATIGUE STRENGTH AND WEIGHT OPTIMIZATION OF THREADED CONNECTIONS IN TIE-RODS FOR AIRCRAFT STRUCTURES

Markus Schaberger[1], Peter Heftberger[2], Martin Schagerl[1]

[1]Institute of Constructional Lightweight Design, Johannes Kepler University, Linz, Austria,
[2]RO-RA Aviation Systems, Schoerfling, Austria

Tie-rods are commonly used connecting elements in an aircraft and attach e.g. galleys, lavatories or storage bins to the fuselage structure. They basically consist of a straight tube and two adapter ends, which are screwed into the tube in order to adjust the length of the complete assembly. Such tie-rods are subjected to tension and compression loads with variable amplitude and must meet the high requirements of the aeronautic industry. Structural components in aircrafts in general have to be designed for a certain service life and therefore a detailed knowledge of their fatigue behavior is of great importance [1]. The complex load and contact distribution within the threaded connection between tube and adapter end make a secure and efficient fatigue design challenging. Moreover, the connection is realized with a thread insert to assure smooth adjustability of the adapter ends, which further increases the complexity of a fatigue strength assessment.
Thus, cyclic fatigue tests with a load ratio of R=0.01 are performed to investigate the influences of thread insert length and position on the fatigue life of three different configurations. These experimental results then are explained using a detailed finite element model of the threaded connection. Finally fractographic examinations as well as the finite element analysis are utilized to further optimize the threaded connection in terms of reduced weight and high fatigue strength.

[1] C.-C. Rossow, K. Wolf und P. Horst, Handbuch der Luftfahrzeugtechnik, Carl Hanser Verlag München, 2014.

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FD17-065

EXPERIMENTAL STUDY OF WELD FATIGUE STRENGTH REDUCTION FOR A STAINLESS STEEL PIPING COMPONENT

Dave Hannes[1], Thomas Svensson[2], Magnus Dahlberg[1], Andreas Anderson[3]

[1]Inspecta Technology AB, Stockholm, Sweden, [2]TS Ingenjörsstatistik, Borås, Sweden,
[3]SP Technical Research Institute of Sweden, Borås, Sweden

An experimental design fatigue curve corresponding to 95% survival probability was derived from realistic fatigue experiments on a water pressurized piping component with primarily focus on high cycle fatigue. The components were subjected to a synthetic variable amplitude bending deformation. Comparison with the design fatigue curve obtained for a similar piping component with a circumferential butt weld allowed the determination of an experimental fatigue strength reduction factor. Comparison with the fatigue procedure and design curve in ASME BPVC Section III allowed to quantify its conservatism with regards to accounting for the presence of a weldment and more generally transferability.

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THE PEAK STRESS METHOD TO ASSESS THE FATIGUE STRENGTH OF WELDED JOINTS USING LINEAR ELASTIC FINITE ELEMENT ANALYSES

Giovanni Meneghetti, Alberto Campagnolo

University of Padova - Department of Mechanical Engineering, Padova, Italy

In fatigue design of welded joints, the local approach based on the notch stress intensity factor (NSIF) assumes that the weld toe profile is a sharp V-notch having a tip radius equal to zero, while the root side is a pre-crack in the structure. The Peak Stress Method (PSM) is an engineering, FE-oriented application of the NSIF approach to fatigue design of welded joints, which takes advantage of the singular linear elastic peak stresses from FE analyses carried out by using a given mesh pattern in Ansys software, where the element type is kept constant and the average element size can be chosen arbitrarily within a given range. The meshes required for the PSM application are rather coarse if compared to those necessary to evaluate the NSIFs from the local stress distributions. Two-dimensional as well as three dimensional FE analyses can be adopted to apply the method. By using the averaged Strain Energy Density (SED, which can be expressed as a function of the relevant NSIFs) as a fatigue strength criterion, a so-called equivalent peak stress is defined to assess either weld toe and weld root fatigue failures in conjunction with a properly calibrated design curve.

Originally, the PSM was validated for pure axial or bending loadings and pure torsion loadings; afterwards, the PSM has been extended to deal also with in-phase as well as out-of-phase multiaxial fatigue loadings. After presenting the theoretical background of the PSM, the paper presents several applicative example relevant to both aluminium and steel welded joints. Because of the relatively coarse FE analyses required and simplicity of post-processing the calculated peak stresses, the PSM might be useful in the everyday design practice.

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FD17-072

SEVERAL 1D/2D SEAM WELD FINITE ELEMENT IDEALIZATIONS CHALLENGED IN FATIGUE WITHIN A FRENCH INDUSTRIAL COLLABORATIVE WORKGROUP

Patrice Klein[1], Mohamed Bennebach[2], Emmanuel Kirchner[3]

[1]Kuhn, Saverne, France, [2]Cetim, Senlis, France, [3]Manitowoc, Dardilly, France

In industry with fatigue strengthening concern, it is possible to find as many ways to make an FE seam weld idealization as factories involved in these types of simulations. Tens of ways to model a seam weld are available as soon as it is necessary to get out of direct connection assumption and if it is needed to take into account local weld stiffness and secondary bending effect of the fillet weld. Then it becomes mandatory to be able to discriminate such idealization processes (sample methods are: PSA-Fayard, Lohr, Volvo, Hot Spot Stress, Glinka…) while evaluating associated life prediction acCuracy and industrial idealization efficiency (automation). This concern leads the idea to create a French industrial workgroup including CETIM and about 20 industrial companies, members of the "Mobile machinery program committee". The main goal of this collaborative project being to challenge well documented and most promising seam weld idealization models (with associated methods) to converge at the end towards the most capacitive ones (with better results on given fatigue metrics).

As a first part of the multi-partner project work, a complete and precise technical review was achieved, giving a state of the art of these idealization models and methods available. Then the workgroup did extensive comparisons between well documented fatigue tests on seam welded components and associated FEA for some retained models and methods (Fayard, Lohr, IIW Hot Spot Stress, Notch Stress). Seven components were considered, with more than 100 fatigue test results. A round robin was also done between some "in house" methodologies used by several industrial companies.

Results of this work help choosing the right methodology, depending of the seam weld configuration and the in service loadings. This can be complemented by a partnership with FE software editors to include most efficient methodologies in an automated way, making less tedious the job consisting of seam weld modelling on huge chassis frames. Small and medium factories should then reach an efficiency gain and improved acCuracy level when building their virtual seam welded frames with new automated scripts integrated in their own FEA solutions.

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FATIGUE ASSESSMENT OF EMPT-WELDED JOINTS USING THE REFERENCE RADIUS CONCEPT

Jörg Baumgartner[1], Kai Schnabel[1], Frank Huberth[2]

[1]Fraunhofer Institute for structural durability and system reliability, Darmstadt, Germany,
[2]Fraunhofer Institute for Mechanics of Materials IWM, Freiburg, Germany

The electromagnetic pulse technology (EMPT) is a joining process similar to the explosion welding. In the process, a flyer-sheet is accelerated towards a target-sheet using electromagnetic fields. During impact high normal and lateral contact forces are generated which join the sheets on an atomic level. This process can be automated for joining thin sheets and is therefore especially suited for mass production, e.g. in the automotive industry.

The resulting joints are not comparable to ones made by common MIG/MAG or laser welding processes since no heat is induced. This leads to the question if the standard approaches to assess the weld in terms of their fatigue behaviour can be used also and if a reliable fatigue assessment can be achieved.

In the paper, the fatigue strength of EMPT-welded connections under constant amplitude loading is presented. Common assessment approaches like the notch stress approach are applied to assess the fatigue life. A comparison between numerically derived fatigue life and experimental tests shows a good agreement and proves the applicability of established approaches.

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EVALUATION REGARDING FATIGUE FOR VARIOUS TYPE OF HANGERS USED FOR TIED ARCH BRIDGES

Jacques Berthellemy

CEREMA, Paris, France

The roads represent an important heritage owned by the French Ministry of Transports. Even more than corrosion, the fatigue is the principal aging process that affects the durability of steel bridges. Several examples illustrate in the article the importance of affecting a right consideration to the fatigue design of bridges.

Details that may appear as accessory to most of the usual bridge designers may be in fact of a crucial importance. It is in particular the case of the welded joints. The fillet joints are much more sensible to the fatigue stresses and should be avoided when there is a doubt, because their evaluation is very complicated. If the designer of a bridge uses such attachment, he has to verify the relevance regarding fatigue before calling for tender because the time for such studies is generally not available during the execution studies.

Calculation FEM techniques are used to evaluate the stress concentration factor that has to be taken into account for the fatigue design. For bridges, many fatigue details are classified in the Eurocode 3 (part 9) from tests. But some details that cannot be found in the Eurocode, and can however be studied and evaluated by computation. Several examples of tied arch bridges are presented. The article presents also an example where the fatigue class of the detail regarding longitudinal stresses is evaluated thanks to a FE-modelization according to the 2008 IIW Fatigue Recommendations at the location of the attachment of a hanger.

Crack in a similar fillet weld of the attachment of the stiffener of a box girder bridge is presented to illustrate that fatigue may really cause severe trouble.

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A COMPARATIVE STUDY OF VARIOUS JOINING TECHNIQUES FATIGUE BEHAVIOUR FOCUSING ON STIFFNESS DEGRADATION

Peter Rösch, Thomas Bruder

BMW Group, Munich, Germany

The design of parts and structures in the vehicle development process is highly influenced by stiffness and strength requirements. Under cyclic loading a change in the stiffness of local connection points can be observed which motivates analysis in order to tackle stiffness changes in structures. The fatigue and stiffness behaviour has been obtained for several joining techniques and material combinations: spot and seam welds, resistance element welds, remote laser welds or high velocity bolting using steel and/or aluminium combinations. Shear, peal and hat profiles have been tested under cyclic constant amplitude loading. Quasi-static tests and materialographic evaluations have been conducted in order to determine material parameters and the setup of FE-model. Online stiffness measurement during fatigue life has been performed.

In this paper a first approach to describe degradation in specimens representing a joint detail is presented. The stiffness degradation curves for the various joining techniques are compared and a degradation law for further simulations is derived. The concept of simulating stiffness changes in conventional joining techniques is introduced. First numerical analysis of simulating stiffness changes in spot welded specimens are shown. Several sensitivity analysis, e.g. with regard to various R-ratios or loading amplitude, are performed in order to check the numerical stability of the implemented method.

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ON THE APPLICATION OF A CRITICAL PLANE APPROACH TO THE LIFE ASSESSMENT OF WELDED JOINTS

Giuseppe Marulo[1], Francesco Frendo[1], Leonardo Bertini[1], Ali Fatemi[2]

[1]University of Pisa, Pisa, Italy, [2]The University of Toledo, Toledo, Ohio, USA

The fatigue life assessment of welded joints is a still open research field and a relevant topic in terms of industrial applications. When multi-axial loads are taken into account, a vast number of assessment procedures can be found in design codes and technical literature. However the application of critical plane approaches in this field is still limited.

In the present work the Fatemi-Socie approach is adopted, since it has achieved good results in the nucleation life prediction of plain and notched components.

Some issues related to the practical implementation to this application are discussed such as the effects of material properties, weld seam geometry and residual stresses caused by the welding process.
An assessment procedure based on the Fatemi-Socie approach is presented and applied to a collections of experimental tests performed in the laboratories of The University of Pisa.

The tested specimens reproduces a plate-to-pipe fillet welded joint, with the pipe having an external diameter of 64 mm and a thickness of 10 mm. The plate, instead, had a thickness of 25 mm.

In this work the results of tests carried out under prevalent bending and torsion loads, with load ratio R=0 and R=-1, are analyzed, Then, those data are compared with results obtained with combined in-phase and out-of-phase bending and torsion loads, also in this case load ratios of R=0 and R=-1 were investigated. A total of circa 80 experimental tests are taken into account.

The results of this investigation allows to assess the proposed fatigue life assessment procedure proposed produces an acCurate fatigue endurance estimation under multi-axial loads.

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FD17-034

ON THE NOTCHED FATIGUE BEHAVIOR OF STRUCTURAL ADHESIVES WITH CONSIDERATIONS OF MECHANICAL PROPERTIES AND STRESS CONCENTRATION EFFECTS

Vinicius Carrillo Beber[1,2], Bernhard Schneider[1], Markus Brede[1]

[1]Fraunhofer IFAM, Bremen, Bremen, Germany, [2]Universität Bremen, Bremen, Bremen, Germany

In present work, three types of structural modified epoxy adhesives were used to investigate the effect of stress concentrations on the fatigue behavior of notched bulk specimens. SN curves of un-notched and notched specimens were measured at constant amplitude and R=0.1 in the range between Nf = 103 (LCF) and Nf = 106 (HCF). The following key conclusions were made: (i) fatigue strength was reduced due to the presence of notches, especially at the HCF, (ii) adhesives showed different values of notch sensitivity according to their mechanical properties, with values for the adhesives lower than typical value of metals, (iii) for un-notched samples, fatigue strength was between 62 and 78% of tensile strength for Nf = 103 and around 50% for Nf = 106, (iv) for notched samples, fatigue strength was between 67 and 78% of the tensile strength for Nf = 103 and around 40% for Nf = 106, (v) fractography evidenced void cavitation and shear yielding around the notches, (vi) unnotched samples showed the same fracture behavior for both LCF and HCF, with crack formation at the external surface. For notched samples, there was a significant distinction between LCF and HCF, with cracks forming at the notch root.

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FD17-001

FATIGUE PROPERTIES OF CUT AND WELDED HIGH STRENGTH STEELS QUALITY ASPECTS IN DESIGN AND PRODUCTION

Zuheir Barsoum[1], Thomas Stenberg[2,1], Eric Lindgren[3]

[1]KTH Royal Institute of Technology, Stockholm, Sweden,
[2]Scania CV, Södertälje, Sweden, [3]HIAB Cargotec, Hudiksvall, Sweden

In this study several aspects regarding effect of quality on the fatigue strength in welded cut HSS have been investigated. A novel numerical algorithm has been developed which assesses the welded surface and calculates and quantifies weld quality parameters and the presence of defects which are critical in fatigue applications. The algorithm is designed for implementation in serial production. It will provide robust and reliable feedback on the quality being produced, which is essential if high strength steels are utilized and high quality welds are necessary for the structural integrity of the welded component. Two welding procedures which can increase the weld quality in as welded conditions have been assessed. It was found that by using these methods, the fatigue strength can be increased with 20% compared to normal weld quality. Furthermore, two fatigue assessment methods ability to account for increased weld quality in low cycle and high cycle fatigue applications has been studied. One of these methods showed sufficient acCuracy in predicting the fatigue strength with small scatter and also account for increased weld quality. The influence of surface quality on cut edges was studied and the fatigue strength was estimated using international standards and a fatigue strength model for cut edges. It was found that the fatigue strength in testing was 15-70% higher compared to the estimation, thus proving a weak link between the international standard and fatigue strength.

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FD17-002

FATIGUE STRENGTH OF A PINION-MOTOR SHAFT CONNECTION: COMPUTATIONAL AND EXPERIMENTAL ASSESSMENT

Samuel Kœchlin

Leroy Somer, Angoulême, France

Load capacity of keyway couplings is usually calculated according to standards (e.g. DIN6892, DIN743) based on nominal stress and simplifying assumptions dating back to several decades. Detailed modeling of keyway couplings is still a research topic, because of the complex mechanical behaviour involved. Moreover, the current standards apply only to usual geometries the designer sometimes needs to depart from, especially for the sake of compacity.

In order to connect the electric motor to the gearbox in its gearmotors, Leroy Somer has developped a compact design, where the input pinion is directly fixed on the motor shaft.
In the case of small pinions, the pinion shaft is inserted in a hollow motor shaft end, with a special key transmitting the torque. This design is substantially different from usual shaft-hub connections, with a combination of several notch effects and a very peculiar stress distribution.

The paper explains the detailed investigations made on such a connection: after a literature review on classical keyway connections, different possible failure modes are identified. Traditional analytical strength evaluations are first performed. Then one describes the setup of a complex Finite Element Model, as well as the assessment methodology based on local stresses. Despite its inherent limitations, the model still gives valuable insight into the behaviour of the connection : especially the strong influence of the interference fit, and the progressive stress stabilization after a few revolutions, due to the combination of friction and relative deformations.
A simplified dimensioning strategy is also discussed, which is more suited to practical application in the design office.

Based on the model behaviour, a dedicated test bench was built, in order to replicate acCurately the complex loading on the connection, confirm the predicted failure mode and compare the experimental endurance limit to the theoretical one.

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FD17-082

FATIGUE ASSESSMENT OF WELDED JOINTS IN API 579-1/ASME FFS-1 2016 EXISTING METHODS AND NEW DEVELOPMENTS

David Osage[1], Pingsha Dong[2]

[1]E²G | The Equity Engineering Group, Inc., Shaker Heights, USA,
[2]Michigan Engineering - University of Michigany, Ann Arbor, USA

The 3rd Edition of API 579-1/ASME FFS-1 2016 Fitness-For-Service includes a new Part 14 dedicated to fatigue assessment. An important category in this part covers the fatigue assessment of welded joints. The classical fatigue method used in the ASME B&PV Code is based on smooth bar fatigue curves in conjunction with a fatigue strength reduction factor. In addition, the mesh insensitive structural stress method is provided using an equivalent stress parameter based on fracture mechanics considerations in conjunction with a master S-N curve based on the analysis of over a 2000 high and low cycle S-N test data. The resulting master S-N curve approach is applicable to high cycle fatigue and low cycle fatigue if a Neuber correction is introduced. In this paper, an overview of the existing methods as well as a new structural strain method is presented to extend the early structural stress based master S-N curve method to low cycle fatigue regime in which plastic deformation can be significant while an elastic core is still present. With this new method, some of the inconsistencies of the pseudo-elastic structural stress procedure in can now be eliminated, such as its use of Neuber's rule in approximating structural strain beyond yield. More importantly, both low cycle and high cycle fatigue behaviors can now be treated in a unified manner. The earlier mesh-insensitive structural stress based master S-N curve method can now be viewed as an application of the structural strain method in high cycle regime, in which structural strains are linearly related to traction-based structural stresses according to Hooke's law. In low-cycle regime, the structural strain method characterizes fatigue damage directly in terms of structural strains that satisfy linear through-thickness deformation gradient assumption, material nonlinear behavior, and equilibrium conditions. A PVRC Joint Industry project is currently sponsoring work on the structural strain approach that will lead to incorporation of the method in the next edition of API 579-1/ASME FFS-1.

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FD17-005

ENHANCED FATIGUE STRUCTURAL STRESS ANALYSIS OF A HEAVY VEHICLE SEAM WELDED STEEL CHASSIS FRAME: FEA MODEL PREPARATION, WELD MODEL DESCRIPTION, FATIGUE STRESS CALCULATION AND CORRELATION WITH 10 YEAR OPERATING EXPERIENCE

Jean Abry, Christophe Mittelhaeuser, Didier Turlier, Sébastien Wolf

LOHR Industrie, Hangenbieten, France

A FE seam weld model has been built for advanced fatigue structural stress analysis. The shell element model allows both weld toe and weld root fatigue assessment. In order to validate the model, this project deals with the complete analysis of a last decade manufactured vehicle for which experience feedback is possible. The vehicle structure is mainly built with steel sheets and the assembly is performed by seam welding.

Shell element model is appropriate for FEA. The entire FEM preparation is presented and each step is detailed: 3D CAD weld building, mid-surface idealization, weld leg imprint creation, weld mesh connection and load application.

Fatigue analysis is performed based on a fatigue limit approach and IIW FAT data. For every structure location a Haigh diagram is built. Different diagrams are presented for plain metal, cut edge, weld toe and weld root.

The FEA results are post processed and each appropriate tensor component is taken into account. For plain metal, stress variation along the worst principal stress orientation is calculated. In welds, for both toe and root locations, the structural stress computation based on grid point forces extraction is described. Longitudinal shear stress in weld and at weld toe as well as weld longitudinal normal stress calculations are detailed. Fatigue results are displayed for each location over the whole chassis model.

Finally, vehicles built during last decade are inspected back from the customers experience field. Observed crack types and locations are compared to fatigue analysis predictions.

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FD17-104

ALUMINIUM WELD FATIGUE: FROM CHARACTERISATION TO DESIGN RULES

Zidane Tahir, Raymond Aso, Tom Yates, M. Bell, Alan Muse

Gestamp Chassis, Skerne road, DL5 6EP, UK

In suspension design, subframes and links are traditionally welded structures, with one of the main design criteria being fatigue. Better understanding, correlation and correct design rules are vital to ensure safety and avoid over design that can lead to reducing Gestamp's competitiveness.

Traditionally, a known mesh modelling T-joint SN method is used to design the welds and mainly driven from standards used for thicker panels seen in the construction and ship industry.

To consider the thin sheet designs largely seen in automotive, Volvo & nCode have developed a new method based on structural stress and is known to be mesh insensitive. However, new difficulties emerged due to the clear separation between the membrane and bending behaviour needed for stress recovery. Specific tests need to be defined to ensure correct characterisation.

Gestamp have generated a new standard of design rules to ensure correlation in Weld-Ends & Mid-Weld cracks and correct toe position definition to ensure acCurate stress recovery and give more beneficial input to process by better defining the weld torch position. New test specimens have been developed and intensive testing carried out to fully characterise the bending and tension behaviour and reduce the gap in predictions between Lap Weld and Fillet Weld. This methodology has been successfully used in suspension designs with high confidence and correlation.

These design rules have been used in conjunction with studying the effect of weld process and sequence on fatigue performance. Controlled distortion subframes, against high distortion subframes, have been tested to capture the benefit by reducing the fit-up gaps and residual stresses.

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FD17-018

FATIGUE BEHAVIOUR OF ALUMINIUM TUBE CRIMP CONNECTIONS APPLYING THE ELECTROMAGNETIC PULSE TECHNOLOGY

Klaus Lipp[1], Ralph Schaefer[2], Dieter Horwatitsch[3]

[1]Fraunhofer Institute for Structural Durability and System Reliability LBF, Darmstadt, Germany,
[2]PSTproducts GmbH, Alzenau, Germany, [3]AIT Austrian Institute of Technology, Wien, Austria

During a still running European Project the feasibility of vehicle light weighting technologies for the manufacturing of light urban electric vehicles with new standards of mechanical performance will be demonstrated. One of the innovative technologies of the project, the Electromagnetic Pulse Technology (EMPT), which is a high speed crimping method, will be applied for joining of particular structural parts of the BiW, especially to join different lightweight materials such as Al- or Mg-tubes and Al- and Mg-cast or forged nodes.

Current heat-intensive joining processes are faced with a number of drawbacks and "cold" classical adhesive techniques require cost-intensive preparation methods plus long curing times and show design uncertainties in terms of mechanical strength. Hence, joining of dissimilar materials is presently not widely used.

The Electromagnetic Pulse Technology (EMPT) will be innovative for joining particular structural parts, especially to join different lightweight materials, e.g. such as Al-tubes, Mg-tubes and Al- and Mg-cast or forged nodes by a fast process without a heat-intensive joining. Therefore, this technology is characterized by being a high efficiency joining process as well as from the quality and the energetic standpoint, with virtually no loss of energy in form of heat.

Presently, no design relevant characteristic values of such joints are available neither endurable stress amplitudes (fatigue) nor stiffness behaviour of the connection during cyclic loading. Therefore, the reliability of such EMPT joints has to be validated with regard to fatigue, stiffness behaviour in order to guarantee a durable connection under typical service loading conditions.

This paper will present first fatigue testing results for aluminium tube joints of EN AW-6082-T6 having a diameter of 40mm. Within this investigation the endurable strength and stiffness behaviour of EMPT-joints will be considered in order to validate the performance of the Electromagnetic Pulse Technology for reliable applications under cyclic loading for e. g. urban electric vehicles.

S09
Fatigue under severe environmental conditions (corrosion, low temperature...)

Chairmen:

JF. Flavenot & R. Juergen

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FD17-012

PWR EFFECT ON CRACK INITIATION UNDER EQUI-BIAXIAL LOADING: DEVELOPMENT OF THE EXPERIMENT

Hager Dhahri[a-b], Cédric Gourdin[a-b], Grégory Perez[a], Stéphan Courtin[c], Jean-Christophe Le Roux[d], Habibou Maitournam[b]

[a] DEN-Services d'Etudes Mécaniques et Thermiques (SEMT), CEA, UNIVERSITY OF PARIS-SACLAY, F-91191 GIF-SUR-YVETTES, FRANCE
[b] IMSIA, UMR 9219, CNRS, CEA, EDF, UNIVERSITY OF PARIS-SACLAY, 91762, Palaiseau, Cedex France
[c] AREVA NP SAS, Tour AREVA F-92084 Paris La Défense, France
[d] EDF, R&D, Site des Renardières, F-77818 Moret sur Loing Cedex, France

The lifetime extension of the nuclear power stations is considered as an energy challenge worldwide. That is why, the risk analysis and the study of various effects of different factors that could potentially represent a hazard to a safe long term operation are necessary. These structures, often of great dimensions, are subjected during their life to complex loading combining varying mechanical loads, multiaxial, with non-zero mean values associated with temperature fluctuations and also PWR environment.

The methodology for fatigue dimensions of the Pressurized Water Reactor components (PWR) (ASME, RCC-M, KTA, …) is based on the use of design curves established from test carried out in air at 20°C on smooth specimens by integrating safety coefficient that covers the dispersion of tests associated with the effects of structures.

In the framework of fatigue design rules upgrading (RCC-M, RCC-MRx), the uniaxial reference fatigue curve was altered by taking into account effects like: Multiaxiality, Mean stress or strain, Surface roughness (polished or ground), Scale effect, Loading History. In addition to this effect, Environmentally Assisted Fatigue is also receiving nowadays an increased level of attention.
In order to take into account the effects of these aggravating factors, two experimental device are developed at LISN with same specimen geometry:

The first device (FABIME2) is to determinate the effect of equi-biaxiality and mean strain/ stress on the fatigue behavior of 316L and 304L-CLI austenitic stainless steel. A second and a new device (FABIME2E) based on FABIME2 is developed to study the impact of the environmental effect in the biaxial fatigue.

The first results obtained with this new test stand FABIME2E of biaxial fatigue in the PWR environment will be presented. Their numerical interpretations using the engineering methods, provide answers to the different aggravating effects of fatigue in the components of nuclear reactors.

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FD17-047

THE EFFECT OF MEAN STRESS ON CORROSION FATIGUE LIFE

Marta Morgantini[1], Donald MacKenzie[1], Tugrul Comlekci[1], Ralph Van Rijswick[2]

[1]University of Strathclyde, Glasgow, UK, [2]WEIR Mineral, Venlo, The Netherlands

The effect of mean stress on the corrosion fatigue life is a problem that affects many areas of industrial applications. Understanding the dependence between the fatigue strength of a metallic material under the influence of an aggressive environment and mean stress is quite difficult as different mechanisms occur and interact during the corrosion fatigue life. Nowadays, most of critical components are designed for a lifetime close to 109 number of cycles. The experimental testing of components or material samples up to this number of cycles is very long and expensive. Only few experimental data are available for corrosion fatigue under non-zero mean stress. All this makes investigation of the influence of mean stress on corrosion fatigue a very challenging problem.

In the current investigation, circular standard specimens of low carbon steel material are tested in air and tap water environment under different conditions and levels of mean stress that cause failure of the sample in the range between 10^5 and 10^7 numbers of cycles. The stress ratio R is varied in the experimental programme and, for each stress ratio, different magnitudes of alternating stress are applied. Comparison of the results in two different environments shows significant reduction of the fatigue lifetime in tap water. The character of the mean stress influence in the two environments is also different. In addition to the experimental program, theoretical investigation of the corrosion fatigue lifetime is performed. The aim is to adapt existing fatigue assessment techniques to the case of corrosion fatigue under the influence of mean stress.

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FATIGUE CRACK GROWTH ANALYSIS IN AL/TI LAYERED MATERIAL IN AMBIENT AND CRYOGENIC CONDITIONS

Dariusz Boronski, Robert Soltysiak, Maciej Kotyk, Pawel Mackowiak

UTP University of Science and Technology, Bydgoszcz, Poland

Results of the fatigue crack growth rate of the layered material made by explosive welding method will be presented in the paper. Testing of mechanical properties of inhomogeneous materials very often presents a lot of difficulties connected with the experimental procedures as well as with the interpretation of study results. It is also in the case of the layered Al/Ti material, for which cracking history has different nature for both layers: aluminium and titanium alloy. However, from the viewpoint of practical application, the knowledge of 'global' material properties is important. Analysed material consist of two main layers: AA2519 aluminium alloy and Ti6Al4V titanium alloy. For improving quality of welding process additional thin layer of AA1050 aluminium alloy was used.

Crack growth measurement was realised in two different conditions: for ambient temperature (293K) and in cryogenic conditions (77K). 'Cryogenic' test were realised with the use of original chamber, which enabled loading of specimens immersed in liquid nitrogen.

Standard specimens of CT (compact tension) type with dimensions as required by ASTM E 399 norm have been used in the crack resistance tests. Due to the fact that thickness of sheets used for specimens was merely 10 mm, characteristic dimension W, equal to 4 times the thickness of the specimen, was used.

For ambient temperature conditions, due to the significant differences of mechanical properties of aluminium and titanium alloys used in the tested material a simultaneous measurement of crack length in both materials was applied. The measurement method involves applying the digital image correlation (DIC) for a displacement distribution analysis on both specimen surfaces. Gradients of crack displacements in the direction of the force loading the specimen was used to make an analysis of the actual location of the crack tip.

For cryogenic conditions hybrid crack length measurement method based on the finite element method (FEM) and the crack opening displacement (COD) analysis was used.

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EFFECT OF MECHANICAL (MONOTONIC AND CYCLIC) STRESS ON THE CORROSION RESISTANCE OF CHROMIUM-PLATED STEEL RODS

Matthieu Dhondt[1], Varvara Shubina[2], Rémi Homette[1], Shabnam Arbab Chirani[2], Sylvain Calloch[1]

[1]ENSTA Bretagne, FRE CNRS 3744, IRDL, Brest, France, [2]ENI Brest, FRE CNRS 3744, IRDL, Brest, France

Providing high hardness, low friction coefficient, as well as, relatively good corrosion resistance, chromium-plated coatings (~20 µm), are widely used for steel cylinder rods in marine environment. However, the standardized corrosion test method (ISO 9227, NSS) used to evaluate the effectiveness of this type of coating do not take into account the mechanical loadings during the service-life of cylinder rods. Nevertheless, a uniform network of microcracks in chromium coating is evolving under mechanical loadings. The propagation of these microcracks is in the origin of the premature corrosion of the steel substrate.

The aim of the study was to evaluate the relationship between mechanical stresses (monotonic or cyclic), the evolution of the microcracks network and the corrosion resistance of chromium coatings.

After monotonic tests, it was demonstrated by microscopic observations that the microcracks propagation began only for stress levels higher than the yield strength of the substrat (520 MPa). Some of microcracks become effective ones, ie. they have passed instantly through the whole thickness of the coating and reached the steel substrate. The density of microcracks increases with the level of total strain until stabilizing at about 5 % (inter-crack distance of about 70 µm). For the specimens subjected to cyclic loading, no microcracks propagation was observed.

Electrochemical measurements have shown that the higher the level of plastic strain applied during the mechanical loading, the more the corrosion potential of the sample decreases until reaching that of the steel substrate of approximately -0.55 V/ECS after 2 hours of immersion. The polarization curves also evidenced an increase in the corrosion current density with the strain level. Moreover, we note the absence of the characteristic passive region of the reference samples that have not undergone any loading.

The study of the samples after ISO 9227 NSS test showed that in the case of many "effective microcracks", but homogeneously distributed in the chromium-coating, we observed rather uniform corrosion phenomenon. On the contrary, the samples after the mechanical cyclic testing were demonstrated an advanced localized corrosion zones.

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Manufacturing process effects in fatigue analys

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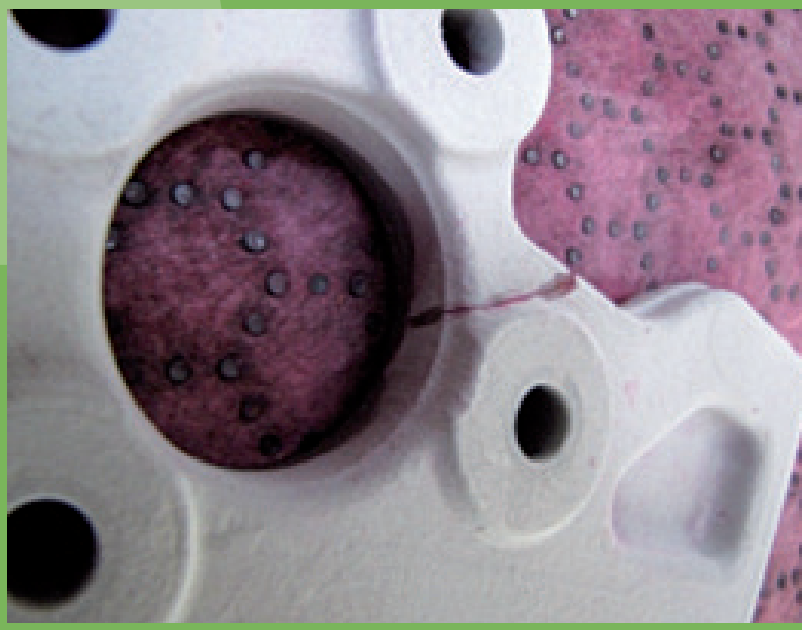

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FATIGUE ANALYSIS OF DIAPHRAGM SPRING IN DOUBLE DRY CLUTCH INCLUDING MANUFACTURING PROCESS

Karthik Krishnasamy, Olivier Simon, Francois Masse

Valeo Transmissions, Amiens, France

In the automotive light-duty passenger vehicles, double dry clutch provides high comfort and fuel efficiency to passengers with automated gear box. Its functional performance and quality depends on its pressurizing component-diaphragm spring. Fatigue analysis on this component and correlation is quite complex because of several manufacturing processes involved like stamping, heat stabilization and shot-peening. The procedure to predict the diaphragm fatigue strength is described in the paper, also it integrates the new simulation softwares capabilities to handle the process effects for evaluation of Diaphragm.

This paper outlines the different simulation stages involved to access the fatigue assessment on diaphragm spring, also it is done at various life situations of vehicle: normal, parking, overloading conditions. A great attention is paid for correlation and it is fitted through curve fitting in simulation.
Between each manufacturing process simulation, the deformed shape and its residual stress-strain data are mapped using customized scripts in Ansys. After the process simulations, fatigue actuation on diaphragm is done for new, semi-worn and worn positions of clutch. Miner's damage and its summation are done at each critical point in diaphragm to determine its total life under nominal design. Finally the reliability of diaphragm spring is defined using Weibull distribution (β and η) for robust design with manufacturing process.

Keywords: Fatigue with manufacturing processes, Dual dry clutch, Diaphragm spring.

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THE INFLUENCE OF MACHINED TOPOGRAPHY ON THE HCF BEHAVIOUR OF THE AL7050 ALLOY

Foued Abroug, Etienne Pessard, Franck Morel, Guenael Germain, Etienne Chove

[1]LAMPA-Arts et Métiers ParisTech, Angers, France, [2]Europe Technologies, Carquefou, France

This study is dedicated to the effect of machined topography on the fatigue strength of the Al7050 alloy. During the High Speed Machining (HSM) of aircraft components, geometrical defects, such as mismatches or chatter, can be created. In order to obtain good surface quality, an expensive manual grinding operation is typically done to remove these defects. The aim of this study is to identify the impact of HSM defects on the fatigue behaviour of the Al7050 aluminium alloy.

A vast experimental campaign under fully reversed plane bending loads containing different surface states has been undertaken to characterize the effect of the surface topography on the fatigue behaviour. The results show that the fatigue strength decreases only when the surface roughness is significantly degraded. It is also pointed out that manual grinding eliminates the effect of the machining defects on the fatigue behavior

In order to predict the influence of the surface condition on the fatigue behaviour, a numerical approach based on the real surface topology has been developed. It is shown that the numerically identified crack initiation sites are in agreement with the experimental results. A probabilistic approach based on the weakest link concept, associated with the definition of a stress based crack initiation threshold has been integrated in a FE model. This approach leads naturally to a probabilistic Kitagawa type diagram, which in this case explains the relationship between the size defect and the scale effect on the fatigue strength.

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INFLUENCE OF RESIDUAL STRESS PROFILE AND SURFACE MICROSTRUCTURE ON FATIGUE LIFE OF A 15-5PH

F. Valiorgue[a], V. Zmelty[a], M. Dumas[a], V. Chomienne[a,b], C. Verdu[b], F. Lefebvre[c], J. Rech[a]

[a] LTDS, UMR CNRS 5513,Ecole Nationale d'Ingénieurs de Saint Etienne rue Jean Parot, Saint-Etienne 42023, France
[b] Université de Lyon, INSA-Lyon, MATEIS CNRS UMR 5510, 69621 Villeurbanne, France
[c] Cetim

This works aims at identifying the influence of surface integrity parameters on fatigue life of a 15-5PH. The effect of residual stress profile, surface roughness and microstructure are investigated. Various cutting and superfinishing processes (turning, ball burnishing and belt finishing) are used so as to reach various engineered surface integrities and as a consequence to highlight the influence of each surface integrity parameter. Rotary-bending tests have been carried out on samples to determine the average fatigue strength at 2 millions cycles. It is shown that the influence of a deep compressive sublayer is by far more important than the ones of surface roughness or microstructure. The so-called 'white-layer' brings also a slight improvement of the fatigue resistance.

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EFFECT OF POROSITY ON THE FATIGUE STRENGTH OF CAST ALUMINIUM ALLOYS : FROM THE SPECIMEN TO THE STRUCTURE

Viet Duc Le[1], Pierre Osmond[2], Franck Morel[1], Daniel Bellett[1], Nicolas Saintier[3]

[1]Arts et Métiers ParisTech - Laboratoire LAMPA, Angers, France, [2]PSA Peugeot Citroën, La Garenne-Colombes, France, [3]Arts et Métiers ParisTech - Laboratoire I2M, Talence, France

The fatigue strength of cast aluminium alloys is known to be greatly affected by different types of defect due to the manufacturing process, particularly the microshrinkage pores occurring during the solidification phase. Even if some procedures of classification are given in the standard ASTM E155-15 [1], the presence of defects is not readily related to the capacity of a component or a structure to meet the requirements of the mechanical technical specifications.

The present study aims at establishing a clear link between some microstructure features and a mean fatigue strength level. This is possible by looking for the average size of the critical defects and using a relevant statistical analysis. More exactly, the Murakami's approach based on the statistics of extremes is employed.

The main originality of this work lies on the application of this approach to the case of a real structure submitted to high cycle fatigue damage: the engine cylinder heads, used in the automotive industry. Indeed, both fatigue tests and microstructural characterizations are carried out on cylindrical specimens and real structures.

The specimens are subjected to uniaxial and multiaxial loading conditions [2]. Original fatigue tests, specially developed by PSA to load in service critical regions, are carried out on cylinder heads. Systematic analyses of fracture surface are conducted to get the statistics of critical defects at the origin of the failures of specimen and structure.

In parallel, critical regions and associated local loading mode in the structure are characterized by an appropriate high cycle fatigue analysis [3].

The latter, combined with the fatigue test data and the identified statistics of critical defects, allows a discussion about the size effect (necessary to correctly predict the structure fatigue response from the specimen strength) and an approach is proposed to be used as a relevant fatigue design procedure.

1] ASTM E155-15, Standard Reference Radiographs for Inspection of Aluminum and Magnesium Castings, ASTM International, West Conshohocken, PA, 2015, www.astm.org

[2] Le, V. D., Morel, F., Bellett, D., Saintier, N., & Osmond, P. (2016). Multiaxial high cycle fatigue damage mechanisms associated with the different microstructural heterogeneities of cast aluminium alloys. Materials Science and Engineering: A, 649, 426-440.

[3] Le, V. D., Morel, F., Bellett, D., Saintier, N., & Osmond, P. (2016). Simulation of the Kitagawa-Takahashi diagram using a probabilistic approach for cast Al-Si alloys under different multiaxial loads. International Journal of Fatigue, 93, 109-121.

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USING SHOT PEENING TO AVOID MICROPITTING IN GEARS APPLICATIONS

Catherine Peyrac[1], Dhafer Ghribi[1], Joan Samuel[2], Fabien Lefebvre[1]

[1]Cetim, Senlis, France, [2]Winoa, Grenoble, France

It is well known that in the field of gears, bearings or wind turbines the micropitting mechanism is responsible for fracture/failure by contact fatigue, and there is a lot of information in literature describing its morphology, apparition….

However, if it is clear that surface roughness has a predominant impact on micropitting apparition, there is no quantitative information concerning the relationship between roughness and micropitting.

The main objective of this study is to find the best shot peening conditions, leading to surface topography optimization as well as roughness parameters optimization, in order to eliminate or at least postpone micropitting apparition.

The performed works have shown that it is possible to reduce the micropitting phenomenon using shot peening. By an adequate image analysis it has been found that for one specific solution, named G2, after the same fatigue test duration, the surface rate affected by micropitting can be about twice lower compared with the reference without shot peening.

Using some surface (Rku or Rsk) and functional (l and sliding ratios) parameters, the relationship between surface topography and micropitting is well established.

To validate the adopted solution on structure, tests on gears device have been performed.

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SHOT PEENING AND CASE PROCESS, A COMBINATION TO PREVENT FATIGUE

Frédéric Savrot

MIC, Amilly, France, France

Controlled Shot Peening is a well-known and mastered technic to increase fatigue life of metallic material parts by delaying crack initiation and crack propagation and to preserve from pitting, fretting and stress corrosion cracking, this process can be more efficient when it is completed with a surface finishing process. It is well known that contact fatigue is mainly due to damages initiated at the surface and subsurface by defects caused by machining operations, by the surface finishing process or the solid pollution of the lubricant.

The C.A.S.E. Process (Chemically Assisted Surface Enhancement) consists of an isotropic surface finishing drastically decreases the roughness up to 0,02 µm Ra.

These two operations combined allowed to preserve fatigue life improvement.

This work presents briefly the shot peening, principles and applications and mainly the super finishing treatment (CASE) process, positive effects and examples of industrial applications.

Shot peening introduces compressive residual stress layer and drastically increases yield stress from 15 to 30% for steel parts such as transmission components, bearings, cam shafts, cam followers and seal faces.

C.A.S.E. Process removes Shot Peening peaks and allows distribution of contacts over a larger area. That improves fatigue strength by an additional 15 to 20% gain onto shot peening performances. Some example shows a life time multiplied by five on case hardened steel gears. For instance the combination of shot peening and CASE increases the pitting resistance of gears by 21%.
This surface treatment improves the surface roughness close to mirror-like finishes and is particularly suitable to steel parts like gears under heavy roots bending load and tooth flank contact load.
CASE Process can be also performed without shot peening when only roughness improvement is expected.

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LOCAL FATIGUE STRENGTH ASSESSMENT OF INDUCTION HARDENED COMPONENTS BASED ON NUMERICAL MANUFACTURING PROCESS SIMULATION

Martin Leitner[1], Roman Aigner[1], Dénes Dobberke[2]

[1]Montanuniversität Leoben, Leoben, Austria, [2]BMW Group, München, Germany

Induction hardening as common heat treatment process for highly-stressed automotive components significantly affects the surface layer properties leading to a compressive residual stress condition and a local hardening of the material. The beneficial effect of the post-treatment is generally well investigated and already implemented in industrial applicable guidelines by considering nominal fatigue strength enhancement factors. However, as the fatigue strength improvement essentially depends on the applied manufacturing process parameters, the resulting local material properties and the local load stress distribution, an elaborated numerical fatigue assessment procedure based on a manufacturing process simulation is presented in this paper.

At first, focus is laid on the numerical analysis of the induction hardening process investigating a notched round specimen. Comprehensive X-ray residual stress measurements and hardness mappings experimentally characterize the influence of induction hardening on the local properties in the notch area. The numerical simulation routine is divided into two stages; firstly, an electro-magnetical part to evaluate the local time-depended heat input, and secondly, a thermo-metallurgical-mechanical analysis simulating the quenching process and the resulting local phase-depended material properties, is set-up. It is shown that both compressive residual stress and hardness condition at the surface region of the notch area are in good agreement with the measurements approving the applicability of the numerical process simulation chain.

At second, a local stress-based numerical fatigue strength assessment of the examined specimen is executed. Herein, the simulated residual stress condition of the induction hardening process is primarily considered as mean stress state and further fatigue-related technological influences, such as notch support effect and surface finish, are additionally incorporated. The final fatigue life results reveal that the presented numerical methodology is well suitable and enables a basic procedure to effectively optimize induction hardening process parameters in regard to fatigue.

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DETERMINATION OF RESIDUAL WELD STRESSES WITH THE INCREMENTAL HOLE-DRILLING METHOD IN TUBULAR STEEL BRIDGE JOINTS

Evy Van Puymbroeck, Wim Nagy, Heng Fang, Hans De Backer

Ghent University, Ghent, Belgium

Tubular arch bridges are susceptible to fatigue problems due to stress concentrations, welding imperfections and tensile residual weld stresses. These bridges are composed of circular hollow section profiles welded together in tubular joints. This paper describes the determination of residual weld stresses in T-joints with the incremental hole-drilling method. The residual stress distribution can be used to determine fatigue crack behaviour and fatigue lifetime more precisely.

The incremental hole-drilling method is used to measure residual welding stresses on two similar T-joints. Experimental residual stress measurements were performed with the aid of the RS-200 milling guide. Strain gauge rosettes are attached to the test surface and with the milling guide, a small hole is drilled through the centre of the strain gauge rosette. Strains at incremental depths are measured and the residual stresses are calculated according to ASTM E837-13a.

A comparison is made between theoretical residual stress distributions and the experimental measurements. Theoretical distributions show tensile yield stresses close to the weld while the experimental measurements indicate tensile yield stresses only in the axial direction of the primary tube. In all other cases, the residual stresses are tensile within 50% of yield stress or even compressional.

The experiments show that more research with more measurements on similar test specimens is necessary for a reliable residual stress distribution. In future research, these residual stresses can be used to study the influence of residual weld stresses on the fatigue lifetime and improve the design of steel tubular joints in arch bridges.

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LOCAL STRESS GRADIENT APPROACH FOR MULTIAXIAL FATIGUE ASSESSMENT OF HIGH STRENGTH STEELS IN OCCURRENCE OF DEFECTS

Fabienne Pennec[1], Wichian Niamchaona[1], Kevin Tihay[2], Michel Duchet[2], Bastien Weber[2], Jean-Louis Robert[1]

[1]Université Clermont Auvergne, Institut Pascal, BP 10448, F-63000 Clermont-Ferrand, France,
[2]ArcelorMittal Maizières Research, 57283 Maizieres-Les-Metz CEDEX, France

As surface defects in high strength steels have been shown to be at the origin of the failure under cyclic loading, understanding the fatigue process and assessing its effects in engineering components or structures are of great importance for mechanical design.

This study is dedicated to the effect of surface defects on the fatigue behaviour of high strength steels. For that purpose, cracks were introduced by Electro-Discharge Machining (EDM) on the edge and on the front side of sheet metal test samples. Different depths are tested on seven high strength steel grades. Experimental results obtained with the 0.1 load ratio in tension are analyzed with a Kitagawa diagram which plots the endurance limit as a function of the defect size, using the Murakami parameter.

A stress-based multiaxial fatigue life prediction method is then developed to assess the fatigue life and to predict the critical material plane where crack initiation will occur. Input data are cyclic stress tensor histories which are calculated by a FEM analysis using Femap/Nastran software. In fact elastic–plastic numerical simulations were performed for each defect geometry to determine stress distribution around the notch for any spatial direction.

New classes of fatigue criteria extended from classical formulations to new ones with stress gradient terms introduced in the normal stress component are formulated. Particular attention is paid to the integral approach criteria as the Fogue's criterion which is proved to give pertinent prevision under rotating principal stress directions multiaxial loading. For any physical plane P which unit normal vector is denoted h the local stress gradient in that h-direction is calculated by parabolic interpolation and integrated in the normal stress component of the multiaxial fatigue criterion. Note that for all the defects loaded in tension, the critical point is located at the notch tip. To reflect the beneficial influence of the stress gradient on the fatigue strength, a new material parameter is introduced in the fatigue criteria. This coefficient is then identified using one of the experimental results obtained for a component with an artificial defect. For each investigated multiaxial criterion, acCurating for stress gradient effect is assessed from the overall experimental campaign results on the materials in occurence of defects.

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CORROSION FATIGUE OF LOW CARBON STEEL UNDE COMPRESSIVE RESIDUAL STRESS FIELD

Volodymyr Okorokov[a], Marta Morgantini[a], Yevgen Gorash[a], Tugrul Comlekci[b], Donald Mackenzie[a], Ralph van Rijswick[c]

[a]University of Strathclyde, 99 George St, Glasgow, G1 1RD, UK
[b] University of the West of Scotland, High Street, Paisley, PA1 2BE, UK
[c]Weir Minerals, Venlo, 5928 PH, NL

This paper presents experimental investigation and numerical modeling of the effect of compressive residual stress on the corrosion fatigue life of a low carbon steel. A fatigue life test methodology based on double notched tensile test specimens is proposed. A new plasticity model is proposed for acCurate simulation of compressive residual stress and calibrated to experimental stress-strain curves obtained for low carbon steel. The proposed model is implemented as a user-material in the ANSYS Workbench Finite Element Analysis program and utilized in plastic analysis and fatigue assessment. Corrosion fatigue test results are discussed and compared to numerical predictions.

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COVERAGE AND PEENING ANGLE EFFECTS IN SHOT PEENING ON HCF PERFORMANCE OF TI-6AL-4V

Jochen Fuhr[1], Manfred Wollmann[2], Lothar Wagner[2], Mahmoud Basha[2]

[1]Curtiss-Wright Surface Technologies, Wickede, Germany, [2]TU Clausthal, Clausthal, Germany

Shot peening of titanium alloys is known to enhance the HCF performance by inducing in near-surface regions residual compressive stresses which can drastically retard the growth rates of surface cracks. In addition, the induced high dislocation densities may increase the resistance to fatigue crack nucleation while the typically accompanied high surface roughness has the opposite effect.

The present work aimed at studying the effect of coverage and peening angle effects in shot peening on fatigue crack nucleation and micro-crack growth on Ti-6Al-4V.

The coverage was varied to a wide extent ranging from 20% to 1200% and the peening angle from 90 to 30 degrees. Residual stresses were evaluated by the incremental hole drilling method. Fatigue performance of shot peened rotating bending hour-glass shaped and flat bending fatigue specimens was studied and compared to an electrolytically polished.
The results indicate that low (20%) coverage peening leads to a loss in HCF strength presumably, caused by insufficient residual compressive stress fields which cannot compensate the early crack nucleation caused by the high roughness. In contrast, full (100%) up to a high (1200%) coverage was found to result in a marked increase in HCF strength.

The variation of peening angles resulted in a significant beneficial effect on the fatigue performance of the flat bending fatigue samples in direction to increasingly flat angles and high coverages (1200%) at constant Almen intensities of 0,20mmA. Beside the deeper compressive stress layer at flat impact angles especially the increased dislocation density and the creation of a material texture with an orientation 90degrees to the cracking direction seems to be responsible for the increased fatigue performance.

These results are even more interesting as those peened surfaces resulted in the highest roughness values and a topography with a starting waviness on the surface.

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7th International Conference on Fatigue Design,
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FD17-063

HIGH CYCLE FATIGUE STRENGTH ASSESSMENT METHODOLOGY CONSIDERING PUNCHING EFFECTS

Dehmani Helmi[1], Brugger Charles[2], Palin-Luc Thierry[2], Mareau Charles[3], Koechlin Samuel[1]

[1]Leroy Somer, Angoulême, France, [2]Arts et Métiers ParisTech, Bordeaux, France, [3]Arts et Métiers ParisTech, Angers, France

Rotors of electrical machines are built from stacks of thin steel sheets. The fabrication process of these components usually involves punching operations that generate defects on the steel sheet edges. Since a degradation of the fatigue strength may result from these alterations, this study proposes a methodology for designing such punched parts against high cycle fatigue crack initiation. To reach this goal, high cycle fatigue tests are performed on different specimens with either punched or polished edges. Results show a significant decrease of the fatigue strength for punched specimens [1]. Investigations are carried out to understand the origin of fatigue failure in this case. SEM observations of the fracture surfaces, reveal that crack initiation occurs always on the edge, especially on a punch defect. Additional investigations are combined to characterize how the edges are altered by the punching operations. Residual stresses on the punched edges are analyzed by X-Ray diffraction techniques. Results show that punching induces a high tensile residual stress level along the loading direction [1, 2]. X-Ray diffraction reveals also a strong hardening of the surface layer due to punching. This is confirmed by micro-hardness measurements: a strong hardness gradient is present from the surface to the core of the thin sheet. In conjunction with the stress concentration caused by the punching defects, all these promote crack initiation and fast crack propagation. For a better understanding of crack initiation, the edge geometries have been scanned with 3D optical microscopy, allowing us to identify the most critical defect (and its real geometry) by comparing the edges before and after fatigue failure. A non-local high cycle multiaxial fatigue strength criterion, proposed by El May et al. [3] and derived from Gadouini et al. [4], has been used as post-processing of FEA to consider the effect of defects and the strong stress-strain gradients around them. To do that a finite element model has been developed to account for the influence of the punched edge and the defects on the HCF strength of punched components. Residual stresses have been introduced in the model together with the gradient of material properties (yield stress) to take in account the effect of the punching process.

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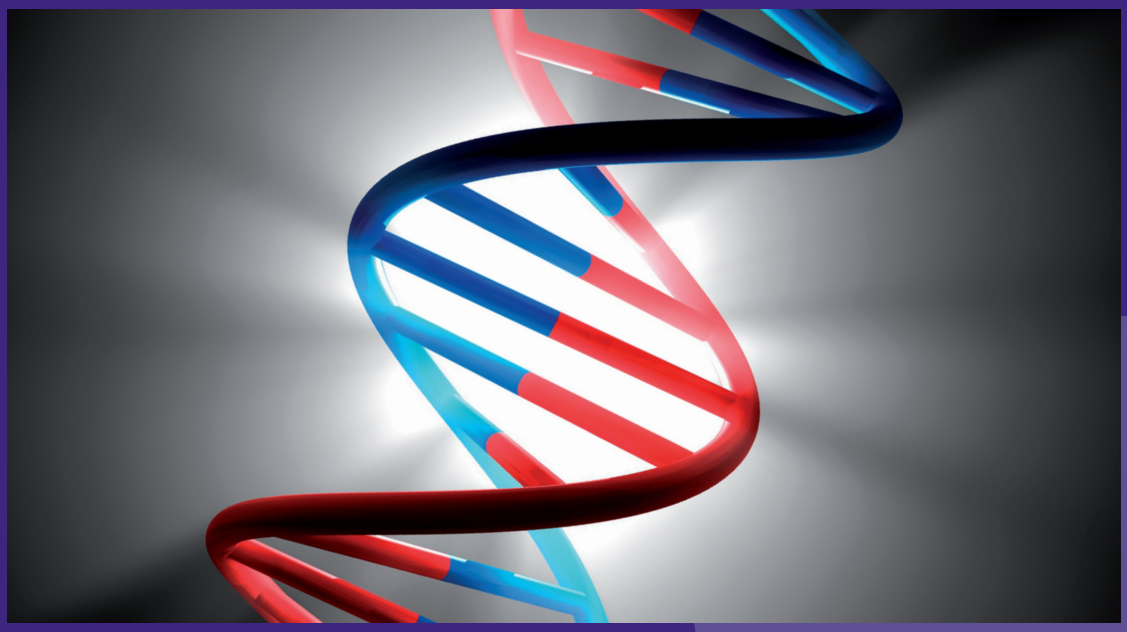
S11
Reliability-based approaches and probabilistic methods

Chairmen:

A. Bignonnet & M. Chollet



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FD17-007

SINTERED STEEL ENDURANCE LIMIT APPLIED TO MAIN BEARING CAPS: AN INNOVATIVE PROBABILISTIC APPROACH

Jean-Michel Fiard, Didier Miazga

Renault sas, Guyancourt, France

Nowadays, 3D numerical analysis and fatigue analysis have become common for designing parts in the automotive industry.

A small investment in numerical simulation often enables to save a lot of time and avoid onerous validation tests.

Nevertheless, the major challenge now is to obtain more predictive models. To do so, we need to develop tailored material modelling using probabilistic approaches in order to take into account the scatter of physical properties occurring in the manufacturing process or inherent to fatigue mechanisms.

We illustrate here this theme in the context of introducing a new sintered steel material for main bearing caps of recent 3 cylinder gasoline engines.

We have developed an innovative experimental and numerical methodology along with a probabilistic approach to determine endurance limit.

A four point bending test has been developed and specimen machined from parts have been used to be as close as possible of actual material properties and loadings.

A virtual numerical model of the test bed, tightly correlated with strain measures allowed to calibrate fatigue campaigns and also gave access to mechanical variables of high cycle fatigue tests

Finally probabilistic S-N models have been identified with the "likelihood maximization method" at two stress ratio higher than +0.1.

Thus, a resultant fatigue domain related to the part's reliability objective has been defined for the design department.

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UNCERTAINTY PROPAGATION WITHIN FATIGUE OF OFFSHORE FLEXIBLE PIPE RISERS DESIGN

Duy Hung Mac[2], Paul Sicsic[1]

[1]Technip - Innovation and Technology Center, Rueil Malmaison, France,
[2]Technip - FlexiFrance, Le-Trait, France

Flexible riser system offer operators a robust method of producing oil and gas fields in harsh environments. Systems are currently designed using a mixture of local and international standards such that they can withstand conditions with a sufficient margin of safety. Flexible pipes have been installed for water depth up to 3000m.

The application of reliability methods to determine the design of offshore systems such as jackets and ship hulls is well developed and has a long and successful track record. Flexible risers are subjected to the same random environmental loads. While probabilistic methods have been explored, they have yet to be applied in any meaningful manner to the fatigue limit state.

How to account in the most robust manner for uncertainties within the loading has become critical for deriving cost effective and robust design rules for flexible risers. Especially the layer of the flexible riser bearing the tensile load, named tensile armours, is critical in the design in many of the deep-water developments.

In this paper multiple structures designed for west of Africa and the North Sea are investigated through a reliability method. Uncertainties within the global riser motions, the local stress computations and in the S-N curve resistance are accounted for. Demonstration is made that for the same uncertainties the variables influencing the reliability of the structure differ. Finally, the comparison with actual international design rules is made through the value of the safety factor applied on the design life.

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FD17-056

PROBABILISTIC ASSESSMENT OF WIND-INDUCED FATIGUE OF STRUCTURES

Maria Pia Repetto, Michela Damele

[1]Curtiss-Wright Surface Technologies, Wickede, Germany, [2]TU Clausthal, Clausthal, Germany

Wind-induced fatigue is a key issue in design of many slender structures, such as wind turbines, cranes, poles and towers. Despite this reality, suitable engineering and standards procedures are almost completely lacking, this being a major shortcoming in the structural and wind engineering sectors.

Working in this field, the author of this paper has carried out a wide research project aimed at formulating and calibrating a general procedure for determining the wind-induced fatigue damage, based on the joint probability distribution of the mean wind velocity, of the wind direction and of the Monin-Obukhov length, taking into account the simultaneous alongwind, crosswind and torsional aerodynamic actions and structural responses.

Later, the complete probabilistic method has been progressively simplified, introducing a hierarchy of hypotheses, in order to develop a closed form solution of the alongwind-induced fatigue, suitable for engineering calculations and code provisions, aimed at evaluating the alongwind-induced fatigue damage and the fatigue life of structures and structural elements. A parallel research is in progress to derive an analogous method for the crosswind-induced fatigue.

The present paper describes the complete closed form solution, discussing the main analytical features and the simplifying hypotheses adopted. The method is applied to a real structure and compared with a benchmark solution, obtained with the numerical simulation of the whole 50-year time series of the wind-induced stress at the base of the structure. These contain both macro- and micro-meteorological fluctuations, coherent with the parent distribution and the power spectrum of the wind-induced loads. The comparison between the benchmark numerical analysis and the simplified closed form solution shows a surprisingly good agreement, putting in evidence that probabilistic approach can have the potentiality of catching the main features of the wind-induced fatigue phenomenon, giving rise to good results with simplified procedures engineering design oriented.

S12
Thermal and thermo-mechanical fatigue

Chairmen:

C. Peyrac & L. Remy

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FD17-022

A NEW FATIGUE MODEL INCLUDING THERMAL AGEING FOR LOW COPPER ALUMINUM-SILICON ALLOYS

M. Beranger[a], JM. Fiard[a], K. Ammar[b], G. Cailletaud[b]

[a] Renault SAS, Direction de la Mécanique, Guyancourt, France
[b] Mines ParisTech, PSL Research University, Centre des matériaux, CNRS UMR7633, 91003 Evry, France

Numerical simulation is more and more used in automotive industry to reduce design time and cost. Moreover, for high performance engines, the development of cylinder heads requires well known and adapted materials to ensure their reliability.
The estimation of adapted fatigue criteria based on few experiments is thus an important challenge: to obtain more predictive model on more complex mechanical phenomena.
This paper describes the methodology adopted by Renault to estimate fatigue life of a new aluminum-silicon alloy.
A low copper aluminum-silicon alloy has been developed for a new generation of cylinder heads. Those kinds of alloys provide a good compromise between the two main failure modes encountered for cylinder heads: high cycle fatigue of water jacket and low cycle fatigue of fire deck.
However, those materials are subjected to thermal ageing that can affect behavior, such as yield stress and hardening, but also fatigue mechanism at high temperature.
This article presents first the selected constitutive equations that introduce thermal ageing effect in a cyclic elasto-viscoplastic model. The low cycle fatigue criterion is then calibrated on the relevant database, which includes isothermal and non-isothermal tests.
The fatigue criterion is a specific version of a classical model previously developed at Onera. The critical variables for the fatigue part are the stress amplitude and the mean stress, both of them being normalized by an ultimate stress which depends on temperature and ageing state.
Finally, the constitutive and damage models have been applied on 3D cylinder head numerical analysis. The paper proposes a brief comparison of those results with more classical simulations made on cylinder heads and highlights the perspectives offered by this new aluminum-silicon alloy.

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FATIGUE LIFE PREDICTION OF AL319-T7 SUBJECTED TO THERMO-MECHANICAL LOADING CONDITIONS

Hong-Tae Kang[1], Ranjith Nayaki[1], Jim Chen[2], Yung-Li Lee[2], Xiao Wu[1]

[1]The University of Michigan-Dearborn, Dearborn, MI, USA, [2]FCA US LLC., Auborn Hills, MI, USA

This study investigated a fatigue life prediction method based on extensive experiment results of cast aluminium alloy Al319-T7 subjected to repeated thermal and mechanical loading. Cyclic tests and fully reversed fatigue test results of the material were obtained from the specimens subjected to three different strain rates (5x10-5, 5x10-4 and 5x10-3) and various temperature conditions. At each strain rate the specimens were subjected to room temperature (25oC), 150oC, 200oC, 250oC and 300oC. Thermo-mechanical fatigue tests were also conducted for in-phase and out-of-phase conditions of the temperature and mechanical loading. During the thermo-mechanical fatigue tests, the effect of loading phases and dwell time on fatigue life of the specimens was also observed.

This study modified Taira's fatigue damage model for thermo-mechanical loading condition to include the strain rate effect on the fatigue damage. Taira assumed that fatigue damage per reversal is proportional to the damage factor, l(T), and plastic strain range powered by n, (Dep)n. The relationship between the plastic strain range (Dep) and the number of cycle to failure (Nf) is presented as l(T)•(Dep)n•Nf = C. Where C is a temperature independent material constant. The temperature effect is included in the damage factor, l(T) that can be determined from the ratio of l(T)/l(To) for law cycle fatigue test results at various isothermal conditions. To is the reference temperature and can be determined by experiment. This study used stress range applied instead of plastic strain range in the original equation. Furthermore, the modified equation includes the effect of strain rate, phase, and dwell time. The new fatigue damage equation was well correlated with the experiment results.

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EXPERIMENTAL CHARACTERIZATION OF A CUAG ALLO FOR THERMO-MECHANICAL APPLICATIONS: NON-LINEAR PLASTICITY MODELS AND LOW-CYCLE FATIGUE CURVES

Luciano Moro[1], Jelena Srnec Novak[1], Denis Benasciutti[2], Francesco De Bona[1]

[1]Università degli Studi di Udine, Udine, Italy, [2]Università degli Studi di Ferrara, Ferrara, Italy

This works aims to present the results of an experimental characterisation of the mechanical response of a commercially-available CuAg alloy for thermo-mechanical applications. Owing to its high thermal conductivity and strength, this alloy is widely used for components of steel-making plants (e.g. moulds for continuous casting, electrodes for electric arc furnaces, etc.) in direct contact with the molten steel.

In the experiments, the cyclic response and the low-cycle fatigue strength are investigated by isothermal strain-controlled fatigue tests at three temperature levels (room temperature, 250 °C, 300 °C) and different strain ranges (0.25 ÷ 2.5%).

The cyclic and stabilised stress-strain responses are used for identifying the material parameters of non-linear kinematic (Armstrong-Frederick, Chaboche) and isotropic models separately, according to a non-linear regression procedure.

In order to assess the acCuracy of the calibrated models, numerical simulations of the cyclic response is compared with experimental records, showing that monotonic hardening and cyclic softening phenomena are correctly predicted.

Strain-based experimental fatigue data are finally used to estimate, by linear regression, the Manson-Coffin strain-life curves at different temperatures. A comparison with the estimations given by the well-known Universal Slopes Equations method is also proposed.

In order to estimate the design fatigue curves for prescribed probability and confidence levels, a statistical approach based on three simple approximated methods based on analytical equations (tolerance interval, EPI and deterministic approach) is proposed.

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ELASTO-PLASTIC APPROXIMATION PROCEDURE FOR NOTCHED BODIES SUBJECTED TO THERMAL TRANSIENT LOADINGS

Alexander Bosch[1], Michael Vormwald[1], Jürgen Rudolph[2]

[1]Technical University of Darmstadt, Darmstadt, Germany, [2]Areva GmbH, Erlangen, Germany

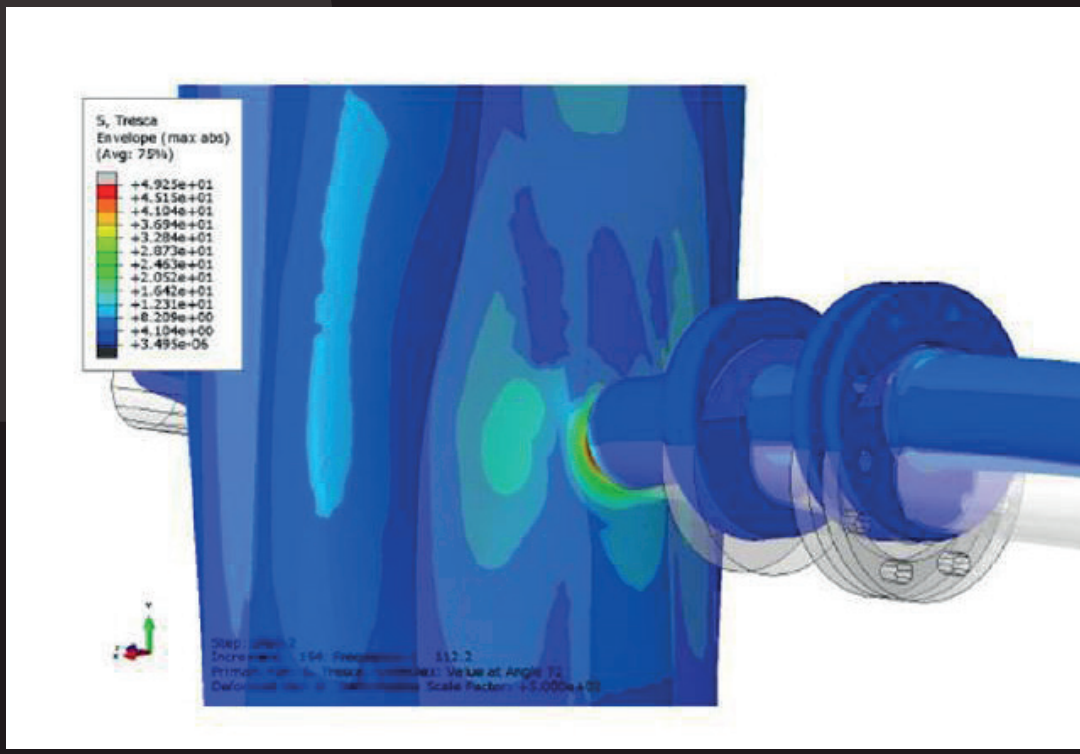
Components of power plants are often subjected to thermo-mechanical loading conditions. Thermal loadings alone are strain controlled loadings, inducing locally high mechanical strains and stresses, which may result in low cycle fatigue issues. Furthermore, these cycles are mixed with numerous cycles of lower stress and strain ranges. Regarding applicable design codes such as ASME, French RCC-M or German KTA, fatigue evaluation of such components can be based on elasto-plastic finite element analysis or on the simplified elastic plastic fatigue analysis. The latter constitutes the standard approach. With regard to processing of long load-time histories (e.g. within an online or offline fatigue monitoring approach), elasto-plastic finite element analyses are too time-consuming and not really feasible. In contrast, the simplified elastic plastic fatigue analysis is a comparatively fast method, but may yield overly conservative results. This may lead to unsatisfactory results by neglecting important influences (cyclic plastic deformation behavior, load sequence and mean stress). In order to consider effects of load sequence and mean stress in fatigue evaluation, it is necessary to calculate the local stress-strain paths over the entire load-time history, using the elastic plastic deformation behavior of the material. The application of commonly used notch approximation procedures (e.g. Neuber's rule, equivalent strain energy density method) fail under thermos-mechanical loading conditions by overestimating the local stresses and strains.

As a general application e.g. for the purpose of long-term fatigue monitoring, measured or calculated temperature-time sequences have to be transferred to fatigue relevant stress and strain time sequences at critical locations. In order to support this task, a fast approximation procedure was developed. The acCuracy is checked by comparing with finite element results. Finally, the resulting fatigue lives are assessed.
As an example, based on the investigations the local stresses and strains for the inner surface of a notched pipe (dimensions and material relevant in power plant applications) are calculated by application of a new advanced approximation procedure and compared to elasto-plastic finite element analyses. The component is loaded under thermal transients causing local cyclic in-phase elastic-plastic strains.

S13
Vibration fatigue behavior

Chairmen:

B. Colin & Y. Goth



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EXPERIMENTAL PROCEDURE AND ANALYTICAL MODEL FOR THE INVESTIGATION OF THE RANDOM FATIGUE ELASTIC BEHAVIOR OF A LIGHT ALLOY BY MEANS OF VIBRATIONAL PARAMETERS MONITORING

Cristiana Delprete[1], Roger Serra[2], Raffaella Sesana[1]

[1]Politecnico, Torino, Italy, [2]INSA Centre Val de Loire, Blois, France

Introduction

In the present paper, the experimental procedure to investigate random fatigue damage evolution in elastic loading is investigated by means of the monitoring of vibration parameters at ambient temperature.

The investigated material is an aluminum alloy used in a large range of applications, in particular in aeronautic and automobile industries. Nevertheless, the fatigue behaviour of these materials, especially of the aluminium alloy studied here, is often underestimated. The strong influence of chemical composition and fatigue behaviour in aluminium alloys has been reported in [1] as an example.

Experimental modal analysis has been already used as non-destructive technique to study damage and fatigue life of metallic materials [2-4] and these studies show the evolution of natural frequencies and damping coefficient as good damage estimators for steels and alloys [5,6].

Scope and themes

The aim of this experimental work is to characterize the fatigue damage of the aluminum alloy, analysing its dynamic behaviour using modal analysis investigation at ambient temperature. The evolution of the dynamic parameters (such as natural frequencies and damping) and the number of fatigue cycles before failure is investigated as well as the strategy used.

>

Materials and methods

The material is a commercial aluminum alloy and the specimens have been obtained from commercial components.

Specimen geometry is extracted from the literature and reported in Figure 1.

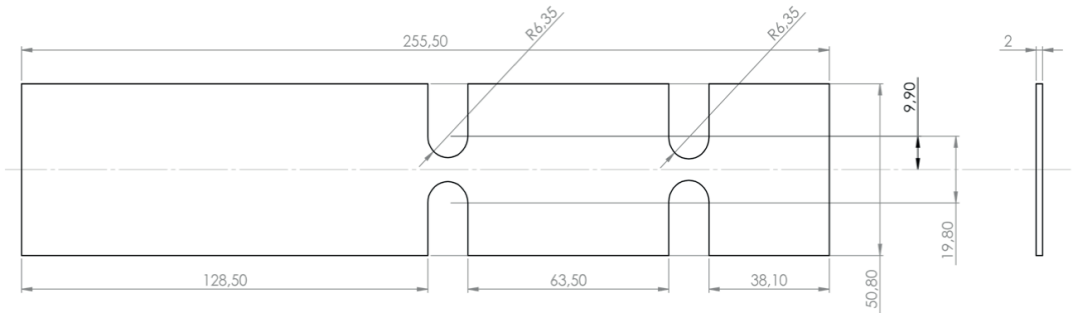

Figure 1: specimen geometry – dimensions in mm

Additional parameters, with respect to the mentioned papers, are monitored during testing, i.e. strains and specimen stiffness to correlate and cross check the damage evolution.

Experimental test are run for different strategy, in particular variable levels of vibration maximum amplitudes.

A FE analysis is performed to validate experimental strain results and to set up vibration input parameters.

Results

Results show a relation between damage evolution using the cumulative Miner model and vibrational parameters. In Figure 2, as an example, the evolution of the second modal frequency is reported.

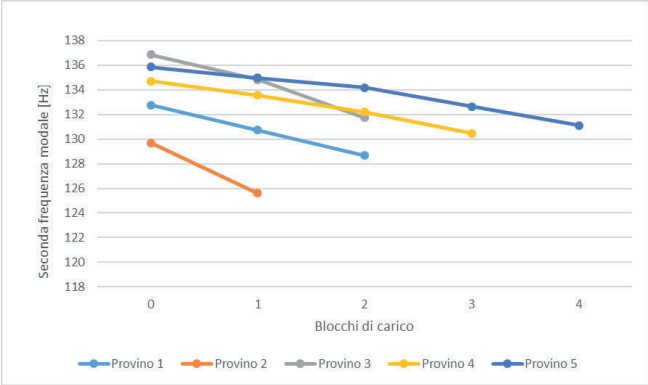

Figure 2: modal frequency evolution with loading blocks application

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INNOVATIVE NUMERICAL FATIGUE METHODOLOGY FOR PIPING SYSTEMS: QUALIFYING ACOUSTIC INDUCED VIBRATION IN THE OIL&GAS INDUSTRY

Anne Coulon, Rémi Salanon, Loic Ancian

Vibratec, Ecully, France

Acoustic Induced Vibration (AIV) refers to the high acoustic energy generated by pressure-reducing devices that excite pipe shell vibration modes, producing excessive dynamic stress. Analysis of this risk is an important part of Asset Integrity Management systems as AIV can cause catastrophic piping failure. Existing guidelines address this risk through an analytical assessment. However, these methodologies are not fully known and input parameters are limited. Some limits to the guidelines are pointed out with recommendations to improve them.

The approach presented for identifying AIV damage is based on a dynamic stress evaluation at pipe discontinuities (welded connections and supports). This evaluation is performed through a fluid-structure coupling Finite Element Analysis. Pressure fluctuations inside the pipe are predicted and coupled with a pipe structural analysis. This methodology is provided with its validation through measurement on an actual AIV field case, corresponding to a crack initiation due to AIV on an FPSO flare network tail pipe.

To conclude the paper, the method is then applied to quantitatively assess the mitigation actions' efficiency on an actual case. Different solutions have been individually tested to end up with a final solution that reduces the damage to acceptable levels in the most cost-effective manner.

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FD17-088

STUDY OF FATIGUE ON A HYDRAULIC INSTALLATION SUBJECTED TO THE VIBRATIONS OF A SAFETY VALVE

Hervé Rognon, Thomas Jung

Cetim, Senlis, France

In order to study methodologies robustness associated with vibratory fatigue in respect to industrial problems, CETIM is working on fatigue characterization of a hydraulic installation subjected to vibratory instabilities on safety valves.

These safety devices are dimensioned according to calculation codes that do not take into account dynamic phenomena and fluid / structural coupling.

In this context, a hydraulic loop combining a safety valve, pipes and a mounting bracket has been dimensioned in order to promote the phenomena occurrence of valve instabilities.

A first part of the study has been consisted in characterizing experimentally and numerically the vibratory responses of the hydraulic loop and in determining the operating hydraulic parameters which defines the life cycle.

The second part of the study have been aimed to correlate the fatigue test on the loop with the fatigue calculating via the set of gauges measurements and accelerometers placed throughout the loop during the fatigue test.

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FD17-021

FATIGUE LIFETIME MODELING OF OXIDE/OXIDE COMPOSITES

Orianne Sally[1,3], Cédric Julien[2], Frédéric Laurin[2], Rodrigue Desmorat[3], Franck Dupe[1]

[1]Safran Ceramics, Le Haillan, France, [2]Onera, Chatillon, France, [3]LMT Cachan, Cachan, France

As of 2020, the regulations, defined by the Advisory Council for Aeronautics Research in Europe (ACARE), impose on the airline industry to reduce the energy consumption, as well as the ecological and acoustical footprints of all aircrafts. One of the strategies used to comply with these recommendations consists in introducing innovative composite materials, including in the engine hot parts. The Ceramic Matrix Composites (CMCs), thanks to their excellent mechanical properties at high temperatures and low density, are potential candidates for these applications.

In order to efficiently use these materials, it seems necessary to develop efficient calculation strategies for the design of composite parts submitted to static and fatigue loadings.

The aim of this study is to propose a strategy to forecast composite structure fatigue lifetime.

This strategy will be applied on Oxide/Oxide CMCs, which are expected to be used for the manufacturing of some engines components subjected to thermo-mechanical loading (between 800°C and 1000°C), because of their interesting trade-off between mechanical properties and costs.

Two complementary continuum damage models are proposed, which are based on previous approaches already developed for 3D woven composites with polymeric matrix, capable of predicting failure and fatigue life under complex loadings. The link between a constant-cycle cumulated damage model on one hand and an incremental model on the other hand, has been established. The predictions, in terms of evolution of the effective rigidity and fatigue lifetime, are finally compared to the available experimental data on this material and structures.

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MULTIAXIAL FATIGUE LIFE ASSESSMENT OF WELDED CONNECTIONS IN RAILWAY STEEL BRIDGE USING CRITICAL PLANE APPROACH

K. R. Praveen[1], S. S. Mishra[1], Prasad Babu[2], Andrea Spagnoli[3], Andrea Carpinteri[3]

[1]National Institute of Technology, Patna, India, [2]Deutsche Bahn Engineering and Consulting, Bengaluru, India, [3]University of Parma, Parma, Italy

Fatigue is one of the primary causes of structural deterioration in steel structures. About 80-90% of failures in steel structures are due to fracture and fatigue. Fatigue limits the service life of railway steel bridges and is, therefore, considered a crucial factor in design of steel bridges. The fatigue evaluation of bridge connections is generally based on notion of uniaxial S-N curves provided in the codes of practice. However, local stresses developed at critical locations in welded connections under normal railway traffic loading are always multiaxial. In addition, directions of principal stresses change due to stochastically varying stress components defining the variable amplitude non-proportional stress histories. Prediction of fatigue damage under multiaxial loading conditions can be done with the help of several models such as stress, strain, energy based or fracture mechanics models. However, there is still no consensus on a method which can correctly account for non-proportional loading. Fatigue life prediction based on the concept of critical plane approach is generally accepted to be more acCurate for multiaxial non-proportional loading. Among different critical plane fatigue criteria, the modified Carpinteri-Spagnoli (C-S) criterion is rather a simple approach in which the critical plane orientation can be determined a priori.

The aim of this paper is to investigate the applicability and reliability of critical plane approach based C-S criterion that can be employed to calculate the fatigue life of bridge connections under railway traffic loading. A typical half through railway steel bridge subjected to standard railway traffic load is analyzed using Finite Element Modelling in ANSYS. The averaged principal stress directions determined through appropriate weight functions are used to predict the critical plane orientation. Then, the multiaxial fatigue life is assessed through an equivalent stress expressed by a nonlinear combination of the normal stress and the shear stress components acting on the critical plane. The applicability of C-S criterion is investigated by estimating the fatigue life of critical welded connection and is compared with the fatigue life calculated according to Eurocode EN1993-1-9 and International Institute of Welding (IIW) recommendations.

Keywords: Multiaxial high cycle fatigue, Carpinteri-Spagnoli criterion, Railway bridge.

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P92 AND 15CH2NMFA STEELS – A COMPARISON OF FATIGUE CHARACTERISTICS OBTAINED ON STANDARD AND MINIATURE TEST SPECIMENS

Josef Volak, Zbynek Bunda, Vaclav Mentl

University West Bohemia, Plzen, Czech Republic

In this paper, the results of the fatigue tests of the P92 and 15CH2NMFA steels are presented and discussed. The fatigue S – N curves were obtained by means of both standard and miniature test specimens. The Small Fatigue Test (SFT) specimens were manufactured partially by machining and also by waterjet cutting.

The fatigue tests were performed on Amsler 10 HFP 5100 ZWICK//Roell high-frequency pulsator at room temperature and R = 0,1 and R = -1 cycle asymmetries. The results obtained on standard and SFT specimens are compared and in case of P92 steel are also compared the two methods of SFT specimens manufacturing.

In case of 15CH2NMFA steel, the results of standard and SFT specimens are in a very good agreement both within the time limit fatigue range and the fatigue limit. After taking the stress concentration of SFT specimens into consideration, the results of traditional fatigue test samples and SFT samples are similar.

In case of P92 steel, the leaning branch of S-N curves is much steeper for SFT specimens and the fatigue limits lower than it could be expected after the stress concentration is taken into account. The fatigue limits for equal cycle asymmetry show the same ratio of standard to SFT fatigue limits, for R = 0,1 it is 1,31, for R = 1 it is 1,32. This very good agreement can be used for the evaluation of fatigue behaviour of P92 steel by means of SFT specimens.

The comparison of the two ways of SFT samples manufacturing revealed a scatter of fatigue test results, nevertheless the fatigue limits differ by 5 MPa only, so that even the influence of the manufacturing seems to be negligible.

Keywords: Fatigue; Miniature test specimens, Standard test specimens; Stress concentration; P92 and 15CH2NMFA steels

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EXPERIMENTAL FATIGUE ANALYSIS OF HIGH STRENGTH STEEL WELDED DETAILS

Balázs József Mecséri, Balázs Kövesdi

Budapest University of Technology and Economics, Budapest, Budapest, Hungary

Nowadays the barrier of applying HSS (High Strength Steel) material in bridge structures is their considered low fatigue strength related to the yield strength. To the economical application of the HSS material in bridge structures, it is necessary to find improvement methods to increase the considered fatigue strength. There are numerous improvement techniques, which can increase the fatigue strength of the fatigue details, but the fatigue life time calculation methods are mainly based on experimental results. To collect more information about the mechanical behaviour of typical structural details used for bridges, experimental research programs are necessary. However comparative fatigue tests investigating NSS and HSS structural details having the same manufacturing process and structural details are unique in the international literature. The current paper focuses on the fatigue behaviour of two important structural details comparing the fatigue life time of the same specimens made from S235 and S420 steel material. Applying the data from experiments, the number of load cycles, where the fatigue crack initiates is calculated and analysed. The crack propagation related to the number of load cycles is also determined and evaluated.

The experimental research program is carried out at the Budapest University of Technology and Economics Department of Structural Engineering to investigate the fatigue behaviour of a cruciform joint and a gusset plate connection, which are frequently used for bridges in Hungary. The main aim of the test program is to investigate the differences in the fatigue behaviour of as-welded and post-weld treated details. Large advantage of HSS structures is that the plate thickness can be reduced having the same resistance. Thus the size effect can have also beneficial effect on the fatigue strength, specimens with similar tensile strength but reduced thickness are also tested and the results are compared to the reference test results. A total of 60 fatigue tests are executed within this research program, which results are introduced in the current paper.

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FATIGUE LIFETIME ESTIMATION OF BEARING PIN OF CONSOLE MANIPULATOR LOADED WITH MULTIAXIAL RANDOM LOADING

Matus Margetin, Miroslav Sulko

Institute of applied mechanics and mechatronics, Slovak university of technology
Faculty of mechanical engineering, Bratislava, Slovakia

Fatigue lifetime estimation of load bearing parts of construction is a key factor in a design of technique used for long term operation. Complex loading in combination with complex geometry of the most loaded parts represents only one of many problems that engineers have to deal with. One of the most commonly used approaches how to deal with this problem is to use the technical standards. This approach, despite its indisputable advantages (clear and comprehensible steps of calculation), has several significant shortcomings (non-economical oversized design). In this paper we propose procedure of how to estimate fatigue lifetime of construction parts that are loaded with random operational loading. The result of proposed procedure is distribution function of fatigue lifetime which takes into account the complex geometry of the designed part and random character of the complex loading (multiaxial stress state) in a hotspot. This approach is then demonstrated on fatigue lifetime estimation of bearing pin of a console manipulator loaded by random operational loading. Loading process was obtained using set of strain gages. The measured loading process was then transformed into stress histories in critical hotspot using FEM. Method of processing the stress loading histories in critical hotspot into a form usable in combination with hypotheses for fatigue damage calculation under multiaxial stress states is presented.

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THERMAL AGEING EFFECT ON CYLINDER HEADS' RELIABILITY

Mathieu Beranger, Florent Daubercies, Guillaume Morin

Renault SAS, Direction de la Mécanique, Guyancourt, France

Reliability of systems is a relevant challenge for the automotive industry not only in terms of image but also to optimize the development's costs and duration.

Actually by taking into consideration the variability of customer usages and the variability in parts production, reliability methods allow to estimate the failure rate demonstrated by engines' test or to fit an optimized duration of those tests regarding the durability's target.

The subject is particularly sensitive for cylinder heads due to validation tests' costs and the complexity of failure mechanism.

This article describes stress-strength interference method applied by Renault to estimate the in-use reliability of cylinder heads.

As cylinder heads are subject to low cycle fatigue on fire deck, a 1D thermomechanical model has been developed. That analytical model can be run on numerous random profiles in an acceptable elapsed time while remaining sophisticated enough to represent the main order of the physical phenomena.

To ensure that, a great attention is given to the acCuracy on thermal loading and on material modelling.

The method is illustrated on a low copper aluminium-silicon alloy from which material properties and fatigue criterion depend on the thermal ageing. Those dependencies do not affect in the same level random customer usages and severe validation test. It is so necessary to take into account ageing phenomena in order to increase the acCuracy of our reliability estimation.

Finally, the article gives thermomechanical potential overview of two aluminum-silicon alloys using this stress-strength approach.

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OPTIMUM DESIGN OF FATIGUE-RESISTANT CARBON/EPOXY COMPOSITE LAMINATES

Hamza Arda Deveci, H. Seçil Artem

Izmir Institute of Technology, Izmir, Turkey

Laminated composite structures especially used in the applications such as airplanes and wind turbine rotor blades are subjected to significant cyclic fatigue loads throughout their service life, which may lead to catastrophic failure. Accordingly, fatigue is an important parameter that must be considered in design processes. Fatigue life, thus structural performance of laminated composites can considerably be increased through design optimization. In this study, a fatigue life prediction model termed as Failure Tensor Polynomial in Fatigue (FTPF) is applied to the optimum stacking sequence design of carbon/epoxy composite laminates under various in-plane cyclic loadings to obtain maximum fatigue life. A hybrid algorithm is used as search algorithm in the optimization. Before starting the optimization, first, the FTPF model is verified by an experimental correlation using the data available in the literature. The results of correlation study indicate the applicability of the fatigue life prediction model on design optimization. Then, the proposed hybrid algorithm is tested by solving problems selected from the literature. The hybrid algorithm shows superior or at least comparable performance than the results given in the literature. After assuring the reliability of the model and performance of the hybrid algorithm, a number of problems including different design cases are solved, and the multidirectional laminate designs with maximum fatigue life are determined. In order to verify the proposed fatigue design methodology, some selected optimum designs obtained for uniaxial loading cases are produced and fatigue tests are conducted to obtain their multidirectional fatigue behaviour. Finally, the fatigue strengths of the related laminates experimentally found are compared to the estimated fatigue strengths.

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SFRC CHARACTERIZATION AND FATIGUE BEHAVIOR, DISCUSSION AND METHODOLOGIES

Nacira Saoudi[1], Nacera Rezgui[1], Kamel Meddahi[1], Boudjemaa Bezzazi[2], Hayet Cherfa[3]

[1]UAMOB, BOUIRA, Algeria, [2]URMPE, BOUMERDESS, Algeria, [3]USTHB, USTHB, Algeria

Results of an investigation conducted to study the behavior of steel fiber reinforced conventional concrete (SFRC) containing different volume fraction of fiber are presented. Approximately 200 specimens of size 70x70 x 280 mm were tested under several tests in order to obtain the improvements brought by fibers at different environments conservation specimens. The specimens incorporated 0,5% 1% ,1.5 and 2.0% volume fraction of hooked end steel fibers. Each volume fraction incorporated fibers is investigated using two different methodology, by an experimental program consisted, of firstly Superplasticizers is constant for all fractions, secondly it is various in order to gives approximately the same slump test.

Steel fibers are more extensively used in construction compared with other types of fibers. But the data base to determine the relationship among stress and enhancements is it correct, to conclude, and prove the improvements, and reflects the really effect of incorporation steel fiber and reasonable comparison at different additions, as in the case of a superlasticizers telling the formulation results of difference plasticity concrete type, according to fiber content, so the comparison between firm and plastic concrete is very complicated.

A database of experiments on conventional reinforced concrete tested in flexural fatigue, compressive, flexural three points, at different environment, is developed, classified and compared on the basis of two formulations.

Keywords: Steel fiber, Fatigue, compressive, methodology formulation

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FD17-067

IN-SITU CRACK PROPAGATION MEASUREMENT OF HIGH-STRENGTH STEELS INCLUDING OVERLOAD EFFECTS

David Simunek, Martin Leitner, Florian Grün

University of Leoben, Chair of Mechanical Engineering, Leoben, Styria, Austria

In general, the requirements of endurable light-weight structures are challenging tasks for engineers. High-strength steels provide a major potential by replacing commonly applied mild steels. However, higher notch sensitivity and increased crack propagation rates may decrease the benefit of high-strength steels and their practicability of application. Therefore, reliable assessment methods are demanded to assess fatigue life and crack propagation of welded and un-welded structures. For this purpose, an optical measurement system consisting of an industrial camera, telecentric lenses, and special LED components is set-up to analyze crack initiation and propagation of high-strength steels compared to common mild steels. Furthermore, an image processing program is set-up to investigate the crack length during testing automatically. Additionally, indirect potential drop method with crack gauge and optical-light microscopical investigations are used to calibrate this elaborated measurement system. Constant amplitude tests including overload effects are performed for different high-strength steel grades and specimen geometries, such as plates and round bars, to specify the material behavior under in-service load-conditions. Based on the researched data, material parameters are determined and an estimation of residual lifetime facilitating analytical and numerical linear-elastic fracture mechanical methods is finally carried out.

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ON THE APPLICATION OF A CRITICAL PLANE APPROACH TO THE LIFE ASSESSMENT OF WELDED JOINTS

Giuseppe Marulo[1], Francesco Frendo[1], Leonardo Bertini[1], Ali Fatemi[2]

[1]University of Pisa, Pisa, Italy, [2]The University of Toledo, Toledo, Ohio, USA

The fatigue life assessment of welded joints is a still open research field and a relevant topic in terms of industrial applications. When multi-axial loads are taken into account, a vast number of assessment procedures can be found in design codes and technical literature. However the application of critical plane approaches in this field is still limited.

In the present work the Fatemi-Socie approach is adopted, since it has achieved good results in the nucleation life prediction of plain and notched components.

Some issues related to the practical implementation to this application are discussed such as the effects of material properties, weld seam geometry and residual stresses caused by the welding process.

An assessment procedure based on the Fatemi-Socie approach is presented and applied to a collections of experimental tests performed in the laboratories of The University of Pisa.

The tested specimens reproduces a plate-to-pipe fillet welded joint, with the pipe having an external diameter of 64 mm and a thickness of 10 mm. The plate, instead, had a thickness of 25 mm.
I
n this work the results of tests carried out under prevalent bending and torsion loads, with load ratio R=0 and R=-1, are analyzed, Then, those data are compared with results obtained with combined in-phase and out-of-phase bending and torsion loads, also in this case load ratios of R=0 and R=-1 were investigated. A total of circa 80 experimental tests are taken into account.

The results of this investigation allows to assess the proposed fatigue life assessment procedure proposed produces an acCurate fatigue endurance estimation under multi-axial loads.

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STRUCTURAL RETROFIT FOR FATIGUE AND REFURBISHMENT OF THE CORROSION PROTECTION AT THE DANCOURT MOTORWAY BRIDGES

Jacques Berthellemy

CEREMA, Paris, France

The roads represent an important heritage owned by the French Ministry for Ecology and Sustainable Development and Energy. Even more than corrosion, the fatigue is the principal aging processes that affects their durability.

Important works of very innovative character were brought to a successful conclusion to improve the durability of the two independant bridges decks of a French motorway carrying heavy high heavy traffic since 40 years.

Each of these decks built in 1971/1972 is carried by 5 steel beams insuring the structure an important intrinsic redundancy. The three spans are of 37m - 66m - 37m. The slabs of both bridge decks are very fine : steel-concrete composite slabs associating a 8 mm steel plate and a 100 mm concrete layer according to an original design of Charles Brignon.

The structure of the bridges was recently strengthened to extend their fatigue resistance :

- Addition of a continuous welded steel plate inclined outside of the edge girders to increase the safety at the ULS and the robustness in fatigue of the lower steel flanges. The inclined additional plate is supported by the webs and the free bottom flanges.
- Metal improvement with TIG (tungsten inert gas) refusion of the welded cross-beams connection gussets were performed,
- Sticking of carbon fibers on lower steel flanges of the main beams at the extremities of the welded existing coverplates. These fibers need a high elastic modulus of 400 000 MPa.

In addition, an innovative option of mixed complete-partial sandblasting methods was proved more economic than the usual complete sandblasting cleaning method, and performed.

The initial conception with two independent decks carrying the highway showed itself particularly relevant for the implementation of heavy repairs. The trafic deviation on the other deck allowed to work on each deck without stopping the traffic. The works were realized during each of two successive summer periods.

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EFFECT OF TEMPERATURE AND STRAIN RATE ON MATERIAL CHARACTERISTICS OF AL319-T7

Hong-Tae Kang[1], Ranjith Nayaki[1], Jim Chen[2], Yung-Li Lee[2], Xiao Wu[1]

[1]The University of Michigan-Dearborn, Dearborn, MI, USA, [2]FCA US LLC., Auborn Hills, USA

Currently more engine components are designed with cast aluminium alloys replacing heavy cast irons. This change is resulted from efforts to increase fuel economy of vehicles by reducing its weight. Furthermore, the operating temperature range of engine components drastically increased to improve engine efficiency. Thus, some engine components such as cylinder heads experience peak temperature of 300oC. Those components subjected to high cyclic thermal and service loads may be prone to fatigue failure. Thus, understanding of fatigue characteristics for engine components becomes a very important part during vehicle designs.

This study investigated the material characteristics of cast aluminium alloy Al319-T7 subjected to repeated thermal and mechanical loading. Monotonic tensile strength tests, fully reversed cyclic tests, and fully reversed fatigue tests of the cast aluminium were conducted with isothermal conditions at room temperature (25oC), 150oC, 200oC, 250oC and 300oC. At each isothermal temperature, three strain rates (5x10-5, 5x10-4 and 5x10-3) were applied for those tests. Finally, thermo-mechanical fatigue tests were conducted for in-phase and out-of-phase conditions of the temperature and mechanical loading. The thermo-mechanical fatigue tests were performed with and without dwell time at peak and valley of the temperature and mechanical loading.

As temperature increases, the monotonic and cyclic strength decrease, and as the strain rate increases, the monotonic and cyclic strength also increase. For the same strain amplitude and strain rate conditions, fatigue life of the specimen subjected to higher temperature was shorter than that subjected to lower temperature. As strain rate increases, fatigue life increases when the specimen subjected to the same temperature except room temperature. The thermo-mechanical test results showed that the out-of-phase is more critical than in-phase condition due to larger mechanical strain amplitude. Fatigue life of specimen with dwell time is longer than that without dwell time due to stress relaxation happened during dwell time.

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NOTCH EFFECT IN THIN ELASTIC SHEETS WITH SKEWED HOLES UNDER UNIAXIAL LOADING

Raffaella Sesana, Francesca Cura

Politecnico di Torino, Torino, Italy

This research activity is focused on the analysis of the notch effect in case of inclined holes in thin sheets, as in postcombustor liners for aeronautical applications.

The liner is a component, which operates at elevated temperatures, close to the resistance limit of the material. It undergoes elevated temperature gradients along the component and elevated thermal cycles, up to 90% melting temperature.

Aim of this paper is to determine the notch intensity factor in case of very thin shells and inclined axis small diameter holes, employing the concepts of linear elastic isotropic fracture mechanics.

Firstly an analytical approach has been used to calculate the stress concentration factor Kt
Analytical results have been compared with notch intensity factor values obtained by means of experimental testing and FEM analysis.

Then an experimental testing activity has been carried out to obtain the stress intensity factor Kf.
In particular, tube specimens with hole configurations, typical of advanced cooled turbine airfoil designs, has been tested under various fatigue conditions.

The test program referred to one material, a nickel-base superalloy, and two hole drilling methods (laser drilling on the fly and trepanning).

The correlation between the predicted and test results was good in all cases.

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FATIGUE BEHAVIOUR OF LAMINATED GLASS FIBRE REINFORCED POLYAMIDE

Mehdi Nikforooz[1,2], Mohammad Golzar[1], Mahmood Mehrdad Shokrieh[3], John Montesano[2]

[1]Department of Mechanical Engineering, Tarbiat Modares University, Tehran, Iran, [2]Mechanical & Mechatronics Engineering Department, University of Waterloo, Waterloo, Ontario, Canada, [3]Composites Research Laboratory, Center of Excellence in Experimental Solid Mechanics and Dynamics, School of Mechanical Engineering, Iran University of Science and Technology, Tehran, Iran

Fiber-reinforced thermoplastic composite materials are gaining more interest due to their excellent mechanical properties, including high toughness and ductility. Thermoplastic composite parts can also be recycled at the end of their life and the raw materials have an extended shelf life, which is a big advantage in comparison to thermosetting composites. Nevertheless, the application of these materials in industry is limited due to a lack of knowledge about their mechanical behavior, particularly under fatigue loading.

The fatigue performance of a laminated glass fiber reinforced polyamide was investigated in this study. Fatigue tests were conducted on unidirectional as well as transverse specimens at room temperature conditions. The generated S-N curves were then used as building blocks to study the fatigue behavior of [02/902]s cross-ply specimens. The S-N diagram of longitudinal specimens followed a bilinear curve, which is consistent with results for unidirectional glass-epoxy composites from other studies. However, the cross-ply specimens had a linear S-N diagram, and is more typical for a cross-ply laminate.

During the fatigue tests, an infrared (IR) camera was also used to monitor the temperature rise resulting from mechanical cyclic loading, and to capture the temperature profile associated with the failure area in the specimens. The final temperature in some of the cross-ply specimens reached to 50 °C, which was near the glass transition temperature of polyamide matrix, causing thermal degradation in addition to mechanical fatigue. It should be noted that as soon as the specimen temperature approached the glass transition temperature of the matrix, both the modulus and strength of the laminate decreased significantly. Additionally, scanning electron microscopy was used to investigate different modes of damage that were propagated in the specimens. For the unidirectional specimens matrix splitting and fiber fracture were observed, for transverse specimens the dominant mode was debonding, and for cross ply specimens debonding in transverse layers, fiber breakage and matrix splitting in longitudinal layers, and delamination between longitudinal and transverse layers were observed

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DAMAGING OF PA6.6 GF30 PRODUCTS UNDER COMBINED STRESSES (VIBRATIONS AND TEMPERATURE)

Jérémy Tomczak, Richard Coquet, Anil Abdoulhoussen

Cetim-Cermat, Mulhouse, France

Accelerated testing is useful to validate a manufactured product for a given lifespan, being the most representative to its life conditions, in terms of environmental and mechanical stresses.
By increasing the test severity, it is possible to create in a much reduced time an equivalent damage compared to the one created during the whole life of the product.

Today's methods to design accelerated test profiles are robust but don't work when more than one solicitation is involved. It can be an issue when both thermal and mechanical stresses have a combined impact on the behavior of a product during its life, especially on materials such as plastics or composite materials with glass reinforcement. These kinds of materials are more and more used in industry but there are few data concerning their durability and reliability.

CETIM-CERMAT is currently studying the impact of combined stresses (thermal and mechanical random vibrations) on the lifespan of components in PA6.6 GF30. We performed an experimental approach by leading tests at different levels of temperature and Power Spectral Density of random vibrations. The results showed that the test temperature, combined with the severity of the vibrations, have a significant impact on lifespan. We verified that the current method used to create vibration test profiles cannot be used for components sensitive to temperature, i.e. when their Young modulus depends on the temperature.

The next step is to propose a method based on the existing one, to create an accelerated test specification which takes into account both contributions of the vibrations and the temperature to the lifespan of a product.

Key-words: accelerated testing, fatigue, random vibrations, temperature, damage, plastic

Objectives: creation of a method to design test profiles for plastic products under mechanical stresses and temperature

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FATIGUE CALCULATION METHODOLOGY FOR PARTS HARDENED BY INDUCTION

Michel Marzin, Isabel Huther, Guimin Shi, Fabien Lefebvre

Cetim, Senlis, France

In order to calculate hardened shaft, Cetim is working to define a methodology for FEA and fatigue calculations to have a good accuracy regarding to the field correlation.
The aim is to define a simple way to calculate hardened parts with less data as possible and to have a correlated result.

This methodology is developing through ABAQUS software and a fatigue post-treatment under nCode. In this context, these calculations need data from material behavior, hardened thickness, roughness, etc…

A first part is dedicated to experimental characterization of samples to obtain: Wöhler curve on hardened material and rough material, hardness, tensile strengths, residual stress field. Some characterizations will be used to entry data to the calculations and other those will allow validating the calculations.

A second part presents the calculation methodology, using FEA model, to estimate the fatigue strength of hardened shafts. The necessary data will be defined.

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PARAMETER IDENTIFICATION OF DELAMINATION ONSET IN MODE I (UD AND ANGLED-PLY INTERFACE) FOR STATIC AND FATIGUE SIMULATION OF CFRP

D. Carrella-Payan[1], B. Magneville[1], T. Naito[2], R. Aoki[3], T. Yokozeki[3], K. Allaer[4], W. Van Paepegem[4], A. Matveeva[1], M. Hack[1]

[1] Siemens PLM Software, Leuven (BE) , [2] Honda R&D Co Ltd, Tochigi (JP) ,
[3] Department of Aeronautics and Astronautics, University of Tokyo (JP),
[4] Department of Materials Science and engineering, Ghent University (BE)

The composite research community has been investigating for decades the mechanisms of delamination to provide to the industry acCurate and efficient numerical models for design optimization [1–7]. Although each models has pros and cons, the main acCuracy of a simulation relies on the acCuracy of the parameter identification for the material. In this work we are presenting the challenges and the characterization of interlaminar static and fatigue properties for a standard CFRP composite for both interlaminar configurations 0//0 and +45//-45. Influence of the pre-cracking method applied on tested coupons and correlation between FEA and experimental results using Simcenter™ commercial software have been investigated. In order to reduce the number of experimental data, Simcenter™ VMC ToolKit was used to obtain the homogenized elastic material properties by running random packing models at the micro-scale level [8]. All interlaminar cohesive element parameters were derived from a set of testing data (energy release rate, G and out-of-plane ultimate strength). The influence of the raw data variability has been investigated and FEA has been used to determine acCurately the cohesive material parameters. The G-N curves for the angled-ply interfaces showed a higher variability due to crack migration in the case of the +45//-45 interfaces. Also, residual static tests after fatigue loading were performed prior to re-onset of the delamination and no evidence of residual stresses was observed on the G measurements.

Keyword: Angled-ply, mode I, static, fatigue, residual stresses, parameter identification, virtual material characterization

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NUMERICAL AND EXPERIMENTAL APPROACH FOR IMPROVING QUASI-STATIC AND FATIGUE TESTING OF A UNIDIRECTIONAL CFRP COMPOSITE LAMINATE

Fabrizio Pagano[1,2], Pascal Paulmier[1], Myriam Kaminski[1], Alain Thionnet[2]

[1]Onera, Châtillon, France, [2]Ecole Nationale Supérieure des Mines de Paris, Paris, France

Mechanical response of CFRP unidirectional prepreg was investigated under tensile quasi-static and fatigue loading. Firstly, the findings of an initial investigation on the effects of the end tabs and gripping condition are presented. A dialogue between numerical simulations and experimental tests led to avoid premature splitting failures in the clamps. Proper tensile failure is assessed in the gage length, at enhanced strength levels for the material considered. Consequently, the unidirectional material was successfully tested under tension-tension fatigue, at high load levels. Fatigue damage mechanisms arise at high stress amplitude, revealing that also a UD laminate can suffer from fatigue degradation along the fibres direction.

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FD17-135

SN CURVE TRANSITION FROM "CRACK-LIKE" TO "BLUNT NOTCH" BEHAVIOUR

M.Ciavarella, P.D' Antuono, G.P Demelio, Politecnico di Bari, Italy

We generalize the concept of "crack-like" notches to finite life according to the well established Critical Distance Method (originally proposed by Neuber and Peterson) where we assume the critical distance to depend as a power law of life. Under these assumptions, SN curves of all notches are very close to SN curves for cracked specimen, up to a certain number of cycles N•, above which they tend to the SN curve of the uncracked/unnotched (plain) specimen, reduced by the stress concentration factor Kt. This results in a form of SN curves which becomes as a special case the SN curve suggested by Fuchs to estimate the notch effect in finite life. The difference infact is that Fuchs does not attribute any role to the size effect in the notch, simply assuming no notch effect at a given low number of cycles, and drawing a power law curve to the infinite life point, estimated by means of a notch factor Kf , rather than the stress concentration factor Kt. We validate these results with some SAE keyhole tests from the 1970's, although more data would be useful to establish the notch size effect.

Keywords: Fatigue, SN curves, notches, Medium-Cycle fatigue, critical distance approach, random loading

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THE EFFECT OF THE DIRECT SELF CURLING POLYMERIZATION ON THE RHEOLOGICAL AND STRUCTURAL OF THE POLYANILINE

N. Naar , M. Satouh, A. M. Zerrouk, A. Benaboura

[a]Macromolecular Laboratory Of Synthesis And Macromolucular Thio-Organics,
University of Science and Technology Houari Boumediene ;
Faculty of Chemistry BP 32 El Alia Bab- Ezzouar 16111 Algiers, Algeria, tel : 00213540025654
**email ; naar.nacira@gmail.com; Corresponding Author.*

Abstract

The polyaniline is known by these bad mechanical properties. It's a conducting load used in the thermoplastic polymers used for the absorption the loads electrostatic. In this work, we propose a synthesis in order to improve the rheological, electrical and structural properties of this charge using a self curling process polymerization in one step. In the case considered, two doping agents containing the combined and unsaturated functioned carboxylic acids (cinnamic acid and crotonic acid) were used and these doping agents were not cited in the other work in the literature. Several methods of analysis were used to characterize the samples obtained (FTIR, DSC, DRX, cand electric conductivity).

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FD17-142

EFFECT OF MACHINING, HEAT AND SURFACE TREATMENT PROCESS ON GEAR FATIGUE PERFORMANCE (BENDING AND PITTING)

O. Cuevas Melo[a,b], H. Orkhis[a], M. Risbet[b], J. Marteau[b], JP. Canivet[a], J. Favergeon[b], M. Octrue[c], H. Rognon[c], F. Lefebvre[c],

[a]GIMA: Groupement International de Machinisme Agricole, Beauvais, 60000, FRANCE
[b]Sorbonne universités, Université de technologie de Compiègne, CNRS, UMR 7337 Roberval, Centre de recherche Royallieu -CS 60319 -60203 Compiègne cedex - France
[c]Cetim, Senlis, France

Abstract

Gear manufacturing is, sometimes, mainly driven by optimizing cost and lead-time, nevertheless a modification in the process may change dramatically the results in the performance of gears. This paper concentrates on the impact of the manufacturing process in the gear performances for bending and contact fatigue.

1. Introduction

In agricultural transmissions, gears are the most common components used to transmit power. The gear meshing induces a complex multiaxial load on the gear tooth, those loads generates bending stresses on the gear root fillets and contact stresses on the active flank. The tooth breakage coming from bending fatigue and gear pitting after contact fatigue are some of the identified failures on agricultural tractors transmissions, the mechanisms leading to those failures are the object of this project.

2. Bending fatigue

Mechanical strength on gears, regarding bending fatigue performance, depends among other parameters, on material, heat treatment and machining process. Surface treatments can also be applied on gears to enhance the bending performances. Each process produces different results in terms of mechanical, geometrical and metallurgical characteristics. This study will mainly be focused on the residual stresses, roughness, internal oxidation and retained austenite produced by each process to discover its influence on the gear bending fatigue.

Moreover, the microstructure on the surface layer need to be look into detail metallurgically speaking to understand the mechanism leading to the increase or decrease of the bending performances on the gear root.

A pulsator type machine will be used for the fatigue endurance tests, different process will be applied separately on tested samples to compare them and to study its impact. In a second time, it would be of particular interest to produce samples with compatible combinations of process in order to know how the microstructure on the near surface layer reacts to the interaction of process and to know what is the response in terms of bending fatigue of those interactions.

This paper presents a comparison between different machining, surface and heat treatment process regarding the gear bending fatigue performance. The aim of the study is to identify the interaction of the fabrication process and their effect into the treated layer on gears.

3. Future works

Once that the results on bending fatigue will be obtained, the most performant configurations will be chosen to be tested on a back to back test machine to know the influence of the gear manufacturing process on the contact fatigue performance.

Authors

FD17-142 FAVERGEON Jerome
FD17-106 FAVIER A.
FD17-062 FERAUD Philippe
FD17-058 FERREIRA Jorge
FD17-007 FIARD Jean-Michel
FD17-022 FIARD Jean-Michel
FD17-017 FIERES Johannes
FD17-038 FORTESE G.
FD17-108 FOUVRY Siegfried
FD17-078 FRENDO Francesco
FD17-015 FROSCHL Jürgen
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FD17-085 GERMAIN Guenael
FD17-009 GHRIBI Dhafer
FD17-115 GHRIBI Dhafer
FD17-109 GILLES Philippe
FD17-101 GOLZAR Mohammad
FD17-045 GORASH Yevgen
FD17-023 GORNET Laurent
FD17-040 GORNET Laurent
FD17-144 GORNET L.
FD17-012 GOURDIN Cédric
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FD17-091 GUELBI Aymen
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FD17-118 HACK M.
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FD17-106 HEUILLET Patrick
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FD17-014 INCE Ayhan
FD17-021 JULIEN Cédric
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FD17-058 KALOMBO Remy
FD17-125 KAMINSKI Myriam
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FD17-087 KANG Hong-Tae
FD17-070 KAUFMANN Heinz
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FD17-010 KEPKA Jr.
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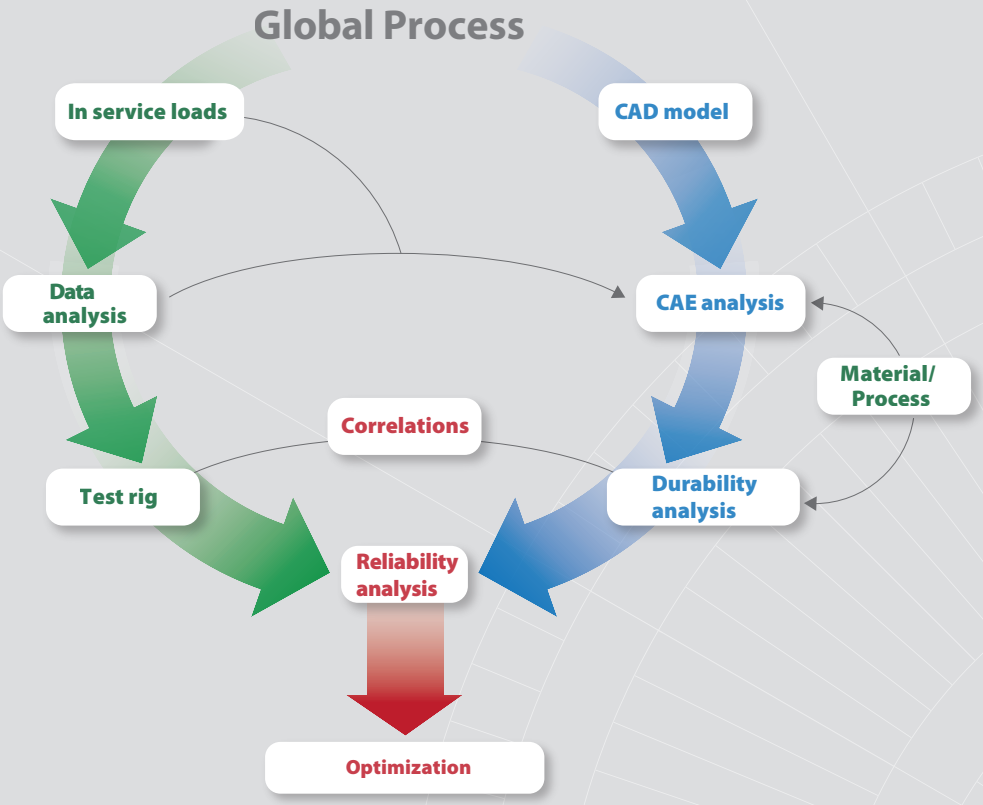

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