fatigue design 2011

November 23 & 24 - Senlis

International conference on the respective input of the numerical simulation and the experimental approach in Fatigue design 2011

4th edition

ABSTRACTS BOOK

www.fatiguedesign.org

INSTITUT CARNOT Cetim · PICARDIE LA RÉGION · utc Université de Technologie Compiègne · SF2M · ECCS CECM EKS · cetim

fatigue design 2011

International conference on the respective input of the numerical simulation and the experimental approach in Fatigue Design 2011

4th edition

ABSTRACTS BOOK

Partnerships

1110-039

Introduction Message

On behalf of the Fatigue Design 2011 International Scientific Committee and Organizing Committee, we would like to welcome you all to the 4th edition of Fatigue Design 2011 taking place at Cetim, Senlis, France on November 23rd & 24th 2011.

Senlis, the Royal City, located at 45km from Paris, has more than 2000 years of history. 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.

The topics of this conference are covering not only the traditional one as fatigue analysis of the welded structures but also the new topics as composite and elastomers fatigue behaviour, fatigue of orthopaedic implant materials and vibration fatigue testing and analysis. As in the previous edition the numerical simulation, fatigue analysis techniques and experimental approach are the important issues in the industry and will be discussed during the conference. The development of new modeling and simulation techniques in the area of fatigue make available for the industries, the valuable tools for fatigue analysis and design of the components and structures.

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.

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

Mansour Afzali
Chairman
Organizing Committee
Fatigue Design 2011

Fabien Lefebvre
Co-Chaiman
Organizing Committee
Fatigue Design 2011

Committees

Organisational committee :

M. Afzali, I. Huther, F. Lefebvre (Cetim),
R. Alberny (SF2M),
V. Aubin (École Centrale de Lille),
A. Bignonnet (AB Consulting),
E. Charkaluk (Université de Mécanique de Lille),
L. Flacelière (Total),
A. Galtier (Acométal),
M. Huther (Bureau Veritas),
H.-P. Lieurade (AFM),
M. Lukic (CTICM),
F. Morel (Ensam),
L. Remy (ENSMP),
F. Rezaï-Aria (École des Mines d'Albi),
M. Risbet-Voitot (UTC),
J.L. Robert (IUT de Montluçon),
M.-C. Sonsino (Institut Fraunhofer LBF Darmstadt)

International scientific committee :

M. Bacher-hoechst (Germany),
M. Browne (United Kingdom),
W. Fricke (Germany),
P. Haagensen (Norway),
A. Hobbacher (Germany),
M. Kocak (Turkey),
M. Lemaire (France),
S.J. Maddox (United kingdom),
A. Magnée (Belgium),
H. Maitournam (France),
G. Marquis (Finland),
A. Nussbaumer (Switzerland),
E. Petitpas (France),
M. Prager (USA),
J. Samuelsson (Sweden),
T. Svensson (Sweden)

Content

ROOM 6 - Plenary session

ROOM 6 - Workshop 1
Welded components and structures

ROOM 6 - Workshop 7
Fatigue crack propagation assessment

ROOM 6 - Workshop 8
Welded components and structures – Improvement techniques

ROOM 7 - Workshop 2
Thermal and thermomechanical fatigue damage

ROOM 7 - Workshop 3
Composites and elastomers fatigue behaviour improvement techniques

ROOM 7 - Workshop 9
Fatigue of orthopaedic implant materials

ROOM 7 - Workshop 4
Fatigue damage mechanisms

ROOM 7 - Workshop 10
Fatigue design methodologies

ROOM 8 - Workshop 4
Fatigue damage mechanisms

ROOM 8 - Workshop 5
Fatigue testing

ROOM 8 - Workshop 6
Mechanical behaviour in contact fatigue

ROOM 8 - Workshop 11
Vibration fatigue behaviour

ROOM 8 - Workshop 12
Reliability approaches in fatigue design

POSTERS

APPRoFi project - Probabilistic methods for the reliability assessment of structures subjected to fatigue

N. Gayton[3], M. Afzali[1], A. Bignonnet[2], P-A. Boucard[4], G. Defaux[5], J-L. Dulong[6], B. Echard[3], A. Ghouali[7], F. Lefebvre[1], M. Masmoudi[9], A. Otsmane[8], A. Pyre[7]

Most of the industries use the deterministic methods to design industrial products. However in some industries as automotive, the engineering technique called "stress-strength" has been developed and applied with success. In recent years this technique has been used, in DEFFI project, for several other applications as aerospace, train and crane applications. Since this project, the industries expressed the needs of evaluation of the safety margin taking into account the variability of the material, process data and usage of the sensitive industrial products.

After having finalized the DEFFI (Démarche fiabiliste de conception en fatigue pour l'industrie) project and in the framework of French National Research Agency (ANR), Cetim and his partners have decided to launch the APPRoFi project (Approche mécano-probabiliste pour la conception robuste en fatigue) dealing with stochastic and reliability methods for fatigue design with aerospace applications.

To create the APPRoFi project members, three French research laboratories (IFMA-LAMI, ENS-LMT Cachan, UTC-Laboratoire Roberval) have been invited to join Cetim, Snecma, Phiméca, Modartt to create the most experienced team in the area of stochastic methods and their applications.

The research studies in this project cover the stochastic methods for modelling the material and loading input data, new techniques in Finite Element analysis for model reduction and / or for speed up the computations to evaluate the stress distribution and analysis, and the reliability methodology. The implemented strategy and stochastic tools have been applied to two aerospace applications.

This paper will present the objectives and the current results of APPRoFi project and will focus on methods and the implemented methodologies and tools. Two other papers will present the detail results of the project for two aerospace applications.

1. Cetim, 52 avenue Félix Louat. BP 80067. 60304 SENLIS CEDEX
2. AB Consulting, 3. Clermont Université, Institut Français de Mécanique Avancée, 63000 Clermont-Ferrand, 4. ENS Cachan/ LMT, 5. Phiméca, 6. Université de Technologie de Compiègne, 7. Snecma/ Vernon, 8. Snecma/ Villaroche, 9. Modartt

The influence of semi-active dampers on the loads of passenger cars

S. Schneider, D. Brechter, A. Janßen, H. Mauch
(Volkswagen AG, Wolfsburg, Germany)

The number of mechatronical components in modern car suspensions is continuously increasing in order to solve conflicts concerning design goals. Since the introduction of intelligent components can influence the loads of the vehicle and its components, resulting changes need to be determined in order to achieve load assumptions of acceptable quality.

Therefore, forces acting on the vehicle suspension as well as the body have been measured for a car with conventional dampers as well as semi-active shock absorbers. The latter are adjusted to changes of driving conditions by means of a controller unit within milliseconds. Hence, semi-active dampers assist to solve the goal conflict between optimum road holding as well as handling performance (obtained by reduction of dynamic tyre forces) and maximum comfort for the passengers (achieved by compensation of car body vibrations). The driver can choose from three different settings of the controlled dampers (comfortable, normal and sporty performance). However, this does not mean the selection of a characteristic curve, but the definition of the baseline level in a characteristic diagram.

By means of road tests on tracks representing customer behaviour and on specific test tracks the influence of different settings of semi-active dampers on the loads acting on suspension components and on the car body have been measured. The results are used in order to determine, whether the customer behaviour is appropriately represented on the test track. In addition, extrapolation coefficients which are applied in calculations of fatigue life are verified. Furthermore, a vehicle model for multi-body simulations is set up. In order to thoroughly model the loads of the passenger car, the semi-active dampers and their control unit need to be represented. By means of numerical calculations, the influence of mechatroncial components on the loads of a passenger car can be analysed at low cost.

The aim is to determine realistic loads of a car in an early state of the design process by application of numerical simulations. Hence, load assumptions, the design of components, fatigue analyses on test rigs as well as the following calculations of fatigue life can be improved.

Influence of frequency and stress concentration on fatigue behaviour of short glass-fibre reinforced polyamides

J. Hartmann[1], M. Monin[2], A. Marie Louise[2], D. Ayglon[3], P. Robichon[4], E. Limousin[4], F. Gerard[5], F. Naudin[5], D. Guyon[5], A. Launay[2], I. Raoult[2], A. Büter[1]

By now more and more, materials like short fibre reinforced polyamides are used in structural durability applications. Hence, application related material data are required for the dimensioning of components made of these materials. However, the procedures of the performance of fatigue testing are still discussed.

From there, this paper gives attention to experimental investigations regarding to the influence of test frequency on the fatigue life of short glass-fibre reinforced polyamides. Fatigue tests with constant amplitudes were carried out and simultaneously the data of hystereses and surface temperature were recorded and afterwards analyzed.

Beside the value of load level the influencing parameter stress concentration (notch factor), which reduces the highly stressed material volume, and the parameter mean stress (stress ratio) were considered for the assessment of the frequency influence on the fatigue life.

1. Fraunhofer Institute for Structural Durability and System Reliability LBF, Bartningstr. 47, 64289 Darmstadt
2. PSA Peugeot Citroën / 18, rue des Fauvelles, 92256 La Garenne-Colombes Cedex,France
3. Du Pont International Operations Sarl / Route du Nant d'Avril 146, CH-1217 Meyrin, Geneva, Switzerland
4. Mann + Hummel France, Z.A. autoroutière / Boulevard de la communication-CS 26161 Louverné, 53061 LAVAL Cedex 9, France
5. Mark IV Systèmes Moteurs S.A./ Zone d'activités Les Grands Prés N°6, 68370 Orbey, France

contact : julia.hartmann@lbf.fraunhofer.de

Fatigue of ceramics-tungsten electronic power substrates tridimensional multilayers

C. Robert[1-2], S. Pommier[1], S. Lefebvre[2]

Electronic power substrates use metal as electrical and thermal conductor. The electrical insulation is achieved by insertion of ceramics layers. This study is devoted to the analyses of damage mechanisms of tungsten-alumina co-fired 3D structures. The most innovative feature of these structures is the three dimensional nature of the electrics lines circuit. This circuit has to be small enough to connect a lot of compounds (few millimetres in width). Most important, it has to be designed to operate under large thermal loading amplitude.

The main problem encountered stems from the heterogeneity of the structure. As a matter of fact, alumina is a poor thermal conductor and has a low expansion coefficient, while tungsten lines have higher expansion coefficient and capability of thermal conduction. Since both materials are co-fired to form the 3D structure, thermal internal stresses arise because of ambient temperature variations and thermal dissipation in operating conditions due to the Joule effect. In addition, the complexity of the geometry is at the origin of stress and strain singularities, in particular at the material interfaces. Two types of fracture are hence observed in such substrates, a brittle fracture of the ceramics and an interfacial progressive delamination. Both of them require cyclic loading of the compound.

The first type of fracture is modeled by a Weibull law that has the advantage of accounting for gradient and scale effects. The failure probability of the ceramics layer is function of the stress distribution in the brittle material that evolves because of thermal loads and of the non-linear behavior of the metal lines.

Modeling requires identifying the mechanical behavior of each material as a function of the temperature at the suitable scale, i.e. a hundred microns scale. Some special sample have been made to characterize both alumina and tungsten.

1. LMT-Cachan, ENS Cachan/CNRS/UPMC/UniverSud Paris, 61 avenue du Président Wilson, 94235 Cachan, France
2. SATIE, ENS Cachan/CNRS/UPMC/UniverSud Paris, 61 avenue du Président Wilson, 94235 , 94235 Cachan, France

A Probabilistic Multiaxial Two-Scale Model for Cast Materials in High Cycle Fatigue Regime: application to marine propellers

S. Calloch, A. Ezanno, C. doudard (Laboratoire Brestois de Mécanique et des Systèmes ENSTA Bretagne, Brest), J.-L. Heuze (DGA), T. Millot (DCNS)

Cast process is widely used in industry because it allows producing even huge structures with complex shapes (e.g. marine propellers) in a few operations. However, cast materials contain initial defects such as shrinkage pores which appear during the solidification of the melt alloy. Industrial feedback shows clearly that these defects are harmful regarding fatigue resistance. Moreover, some authors have demonstrated that they are the cradle of microplasticity phenomena which lead to the initiation of a fatal fatigue crack.

In the framework proposed here, it is assumed that fatigue failure is due to microplasticity activity which induces a dissipative energy. To describe this phenomenon, we propose here a multiaxial and probabilistic two scale model which takes into account cast defects by indirect approach, i.e. without describing size and shape of pores. We consider ¿sites¿ where microplasticity takes place, randomly distributed in an elastic matrix. As cast materials contain initial porosity, their mechanical behavior depends on hydrostatic pressure. So, we propose that microplasticity activation criterion takes into consideration first stress invariant as it is described in Berg`s elasto-plastic model. As microplasticity appears gradually, we suggest that the activation sites scenario follows a Poisson Point Process.

This model has been implemented in a post-processing tool called “Cast”. Validation of the entire framework is based, on the one hand, on predictions of S-N curves and, on the other hand, by comparisons between experimental results and numerical predictions of life duration of a marine propeller.

This study is applied to the case of a cast copper-aluminium alloy often used for casting marine propellers.

Microplasticity and energy dissipation in Very High Cycle Fatigue

V. Favier, N.-L. Phung, N. Ranc, T. Bretheau, J. Groslafaige, G. Roger, W. Seiler, F. Vales[1], D. Wagner, C. Wang, C. Bathias, J. Cedelle, I. Ranc[2], A. Chrysochoos, A. Blanche, B. Wattrisse, G. Camp, A. Clary, Y. El Kaim, F. Jourdan[3], F. Grégori, B. Bacroix[4], A. Galtier, G. Thoquenne[5], H. Mughrabi[6]

The DISFAT project is an ongoing French project financially supported by the French National Agency ANR and its white program. It aims at a deeper understanding of mechanisms leading to crack initiation in metals and alloys in Very High Cycle Fatigue (VHCF).

The VHCF regime is associated with stress magnitudes lower than the conventional fatigue limit and as a result, numbers of cycles higher than 109. The present project is a fundamental research project. However, it is motivated by industrial problems. Some mechanical components, such as pistons, rotating axes, in the transportation and more generally engineering industry, have been designed previously using fatigue resistance data at lower numbers of cycles ($<10^7$ cycles ; the regime of High Cycle Fatigue, HCF) whereas they must endure oscillating loads for a number of cycles higher than $>10^9$ cycles and finally fail (Bathias C. and Paris P.C, 2004, Gigacycle fatigue in mechanical practice, editor: Marcel Dekker, ISBN 0-8247-2313-92004).

There is also growing demand for the development of robust life prediction and damage assessment methodologies that allow the safe extension of service lifetimes for transportation and power generation systems beyond their original design lifetimes. These requirements motivate the need to understand the fundamental mechanisms of fatigue in the VHCF regime, correspondingly, to explore novel methods for the characterization of fatigue behavior at these very long lifetimes. The main challenge of this project results from the fact that the manifestations of the mechanisms of interest give rise to very low and localized signal owing to the very low stress magnitudes involved. Our strategy is first to analyze the response of metals and alloys having "simple" microstructure and deformation mechanisms but also controlled initial states, with special attention paid to the surfaces.

From the existing knowledge of cyclic deformation mechanisms (High Cycle Fatigue range), we choose to study face-centered (fcc) and body centered (bcc) cubic metals and the role of two intrinsic properties of solid crystals: the tendency to wavy or planar slip and the lattice friction resistance.

Second, the VHCF range is reached using ultrasonic fatigue machines. The working frequency is 20 kHz. The use of higher loading frequencies than conventional frequencies (30 Hz) brings advantages (1) to provide fatigue limit and near threshold crack propagation data within a reasonable time and (2) to increase the dissipated power (energy per unit of time) and thus to generate temperature variations which can be detect with the current thermal measurement device. Thus, the aim is to correlate surface dissipation field, surface roughness and dislocation microstructure underneath the surface where irreversible changes of the surface profile appear.

1 Arts et Métiers ParisTech, PIMM UMR 8006, France, 2. Paris 10 University, LEME, France
3. Montpellier II University, LMGC UMR 5506, France, 4. Paris 13 University LSPM UPR 3407, France,
5. Cetim, Senlis, France, 6. Erlangen University, Germany

Improvements in the fatigue assessment of large welded structures using the nominal stress approach

G. Elbel[1], M. Karge[2]

By the fatigue assessment of large welded steel structures such as construction machines structures, the calculation engineer is confronted with a dilemma: the local stress approaches with fictitious rounding radii that are very accurate cannot be used on the global structure because of the current computer limitations. Only a nominal stress can be estimated on the whole structure. The accuracy of the current commercial code methods that are using the nominal stress approach is not satisfying for most of the cases. The major problems are the following:

- only one SN-Curve (FAT class) can be chosen for a weld,

- the stress used for the calculation is based on the critical plane concept, not taking into account the direction of the weld (anisotropy of notch effects) and the geometrical weld parameters (e.g. weld throat thickness and penetration),

- choice of the FAT-class when the structural detail is not available in the IIW guideline

The investigations that have been made in collaboration with the development of LMS Durability in the last two years have permitted us to elaborate a new nominal stress approach that improves the three issues above. The validation on some weld joints and geometries has shown that this new method allows making a big step forward in the accuracy without affecting the time required for the analysis.

1. Liebherr-France SAS, Colmar, France, 2. Liebherr Mining Equipment Co., Newport-News, USA

Fatigue analysis of a welded hub for a mid power wind turbine

P. Goes[1], F. Van den Abeele[1], X. Vanwijck[2], A. De Broe[2], H. Ahmed[1]

Keywords: fatigue analysis, welded hub, wind turbine, rainflow counting, hot spots

The hub of a mid-power wind turbine can be made directly from a mould (cast iron), or by welding the three blade connections onto the main body. From a structural point of view, a cast hub is more efficient to withstand fatigue loading, but from a manufacturing (and economic) point of view, a welded solution is preferred.

In this paper, a lifetime analysis is presented to predict the accumulated fatigue damage of a welded hub under different operating conditions. The fatigue analysis covers normal operation, start-up, normal shutdown and parked conditions. In addition, the effects of faults like overspeed, maximum yaw error and grid failure are taken into account in the lifetime estimation.

A finite element model is implemented, with load time histories for the forces $\{F_{x,}\ F_{y,}\ F_{z}\}$ and moments $\{M_{x,}\ M_{y,}\ M_{z}\}$. In the fatigue analysis, rainflow counting is performed to reduce the number of calculations, and hot spot detection is used to identify the most critical zone. The results of the fatigue analysis indicate the severity of the different load cases, and confine the design space for lifetime optimization.

1. OCAS N.V., Zelzate, Belgium
2. 3E, Brussels, Belgium

Fatigue Design of Welded Components and Structures: An Overview of Work Done within the International Institute of Welding

G. Marquis
(Aalto University, Finland)

Design decisions for welded structures are rarely made based solely on technical grounds. Safety requirements, cost restrictions, structural performance demands and, increasingly, environmental pressures, all contribute to the decision-making process. The importance of raw materials and energy efficiency is constantly growing and has motivated many industries to perform total lifecycle cost assessment and environmental footprint computations, both of which now integrally influence design and purchasing decisions. As materials and fabrication technologies for welded structures evolve and develop, new challenges and opportunities with respect to the Fatigue Design of Welded Components and Structures arise.

Advanced design solutions, incorporating weldable steel plate and strip products with yield strengths from 400 MPa to over 1100 MPa, provide considerable potential for raw materials and energy savings and for decreasing CO2 emissions over the lifetime of cars and trucks, heavy duty vehicles and other mechanical equipment and machinery. Increased performance characteristics, in terms of improved payload-to-weight ratio, amplified boom extension or enhanced vehicle manoeuvrability, are additional benefits when high-strength steels (HSS) or ultra-high strength steels (UHSS) are incorporated into lifting, hoisting or transport equipment.

This presentation attempts to provide a brief overview of select research topics and recent technological developments related to fatigue assessment for welded structures. Much of the work has been performed and reported within the scope of the International Institute of Welding (IIW), but other groups and individuals have also made important contributions. While many themes could have been selected, this paper provides brief discussions on several active research topics: the relationship between weld quality and fatigue performance for welded structures, advanced high strength steel for welded structures, high frequency mechanical impact treatment methods for fatigue improvement and developments in finite element-based fatigue assessment procedures.

Experimental and Numerical Investigation on the Fatigue Limit of Block Flanges used for Steel Penstocks in Hydro Power Plants

A. Lechner, R. Greiner
(Institute for Steel Structures and Shell Structures, Graz University of Technology, Austria)

In underground installations of hydro power plants nowadays large tunnels with diameters up to 5 – 8 m are being built. Considering such large diameters in connection with pressure heads up to 100 [bar] and more, pressure shafts are armoured by steel shielding of high strength steel grades in order to withstand the loading. Due to the increased operation in pumped storage mode – in comparison to the previous decades – and the use of high strength steel grades fatigue loading tends to be the governing load case for this type of steel shielding.

In a research programme owners, steel fabricators and research institutions investigated the fatigue resistance of existing steel penstocks of hydro power plants in Austria, both experimentally and by means of Finite-Element analysis, since specific FAT-classes could not be found in present design codes (Eurocode 3-1-9, FKM and IIW respectively). Special examples of block flanges used for the placement of grouting between concrete backfill and steel shielding were investigated and evaluated. The research work focused on the use of high strength steel grade S 690 Q for block flanges in the curved shielding. Three different types of welded and one detail of non-welded block flanges were investigated. In total 20*10^6 load cycles were applied in the laboratory for structural testing on large scale test specimens.

The test results were compared in accordance with different design concepts as nominal stress, structural hot-spot stress and effective notch stress approaches. The results found provide a sound basis for the assessment of the fatigue resistance of existing steel penstocks. Furthermore, improved details have been developed in a continuation of this research programme. Some achievements are presented.

Investigation of technological size effects of welding on the fatigue life of tubular K-joints made of structural steel S355

F. Zamiri, C. Acevedo, A. Nussbaumer
(EPFL, Lausanne, Switzerland)

The fabrication procedure changes when changing the size of the structural components. For the weldments, the change of the welding procedure leads to the change in residual stresses which consequently affects the fatigue life of the structure. The weld size and number of welding passes are important factors which have considerable impact on the values and distribution of the welding residual stresses. This technological size effect is investigated in this study by simulating the welding process for several tubular K-joints made of S355 structural steel with various wall thicknesses.

While rapidly developing, coupled thermo-mechanical analysis of welding is a powerful and versatile tool for the study of the development of thermal strains and stresses caused by welding process. In this study, both multi-pass and single-pass procedures with their corresponding simulation parameters are investigated. To verify the numerical procedure, the estimated residual stresses for one model are compared to the residual stresses in a tubular truss joint measured using neutron diffraction.

Keywords: Tubular joints, Welding simulation, Thermo-mechanical analysis, Welding residual stresses, Neutron diffraction, Size effect.

Fatigue behaviour of tubular K-joints with thickwalled chords

TU. Kuhlmann[1], Ö. Bucak[2], I. Mangerig[3], B. Kranz[4],
M. Euler[1], M. Hubmann[1], A. Fischl[2], R. Wagner[3], J. Herrmann[4], R. Zschech[4]

Thickwalled tubular trusses with welded uni- or multiplanar K-joints under fatigue loading are frequently used in many infrastructure facilities, Fig. 1a, b. Due to the stress concentration around the brace-to-chord intersection, the hotspot- stress method has to be used in order to verify such structures. As a consequence the fatigue evaluation has to be performed with structural instead of nominal stress ranges. However, this method can only be used efficiently for design purposes if appropriate fatigue strength values are available. Unfortunately, the existing design rules lack these values for the scope of thickwalled trusses with multiplanar K-joints ($4 \leq \gamma = d/t \leq 12$).

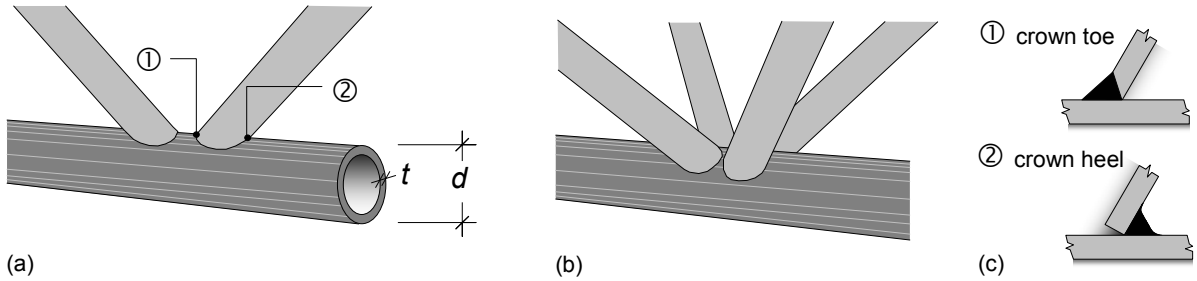


Fig. 1 Welded uniplanar K-joint (a) and multiplanar K-joint (b), weld configuration (c)

This paper is going to present the outcome of a still on-going, comprehensive research project where thickwalled K-joints are tested under different basic load cases such as chord axial loading, chord bending, brace axial loading, brace bending. As an innovation the investigation focuses on a particularly efficient weld configuration that consists of a full-penetration weld at the crown toe of the K-joint shifting into a fillet weld at the crown heel, Fig. 1c.

Basically, the test program is grouped into five test series. In the first two series the fatigue resistances of K-joints with different ratios of brace-to-chord thicknesses are investigated and compared with the fatigue behaviour of thinwalled K-joints that had been tested at MPA Stuttgart/Stuttgart University in the 1970s. By comparing the thickwalled and thinwalled K-joints it is possible to appraise the scale effect. The goal of the third test series is to identify the benefit of a post-weld treatment (high-frequency hammering). Within the fourth test series the influence of a spatial K-joint configuration is studied. The fifth series is dealing with the gain on fatigue life due to repair welding. Aside of the determination of fatigue strength values also recommendations for the fabrication will be developed.

In addition to the K-joint tests the fatigue strength of a truss girder with a span of about 10 m will be determined to adapt the actual stressing of the tubular joints in a large scale construction.

1. Stuttgart University, Germany, 2. Munich University of Applied Sciences, Germany, 3. Universität der Bundeswehr, Munich, Germany, 4. Schweißtechnische Lehr- und Versuchsanstalt Halle, Germany

High-strength steels: Low-cycle fatigue behavior of longitudinal stiffeners

J. Hrabowski, S. Herion, T. Ummenhofer
(KIT Steel & Lightweight Structures, Karlsruhe, Germany)

The growing demand for high load capacity in steel construction together with the need of decreasing total construction weight can be met by the use of high strength steels. Thereby, material cost and carbon footprint as well as weld volume can be reduced. Structures, for which high strength steel is preferentially used, are often exposed to very high alternating loads. Due to the cyclic load behaviour fatigue becomes the decisive factor for design. Lowcycle fatigue, that usually leads to failure at load cycles numbers below 40.000, is barely investigated and especially for high-strength steels there is nearly no information available up to now.

First step to close this lack of knowledge is made. The extensive database of fatigue tests on longitudinal fillet welds, which have been carried out at the Research Centre for Steel, Timber and Masonry at the Karlsruhe Institute of Technology in the last years, is now extended by low-cycle fatigue tests.

Fatigue tests on plates with longitudinal stiffeners made of S690QL and S960QL were carried out. Three different base plate thicknesses have been investigated: 8 mm, 16 mm and 30 mm.

The results of the low-cycle fatigue tests are analyzed and compared to the previous test results for high-cycle fatigue. A shared evaluation of all tests is made, too. The influence of yield strength on the low-cycle fatigue behavior will be further considered. These results are discussed referring to the classification into the detail categories of EN 1993-1-9 (2010) as well as the new IIW guideline (Hobbacher, 2008).

Specimen with longitudinal stiffener L = 200 mm
(t = 8 mm, S960QL, $\Delta\sigma$ = 495 MPa, N_f = 14.580)

Seam weld fatigue design for automotive chassis parts: recent numerical computation improvements

L. Armani[1], M. L. Facchinetti[1], M. Duchet[2], B. Weber[2]

Automotive chassis parts are usually made from steel sheet blanks undergoing a forming process (e.g. simple folding, stamping or hydro-forming) and thus assembled by several welded joints (e.g. standard arc-, spot- and laser-weld). Fatigue strength assessment naturally focuses on weld assemblies, which may be the weakest portion of the overall part and are usually affected by the largest mechanical properties scatter.

Fatigue numerical computations of weld assemblies use of the finite element method (FEM): in past decades, more and more detailed concepts have been proposed [Hobbacher (2009)], starting from the coarser nominal stress approach, then developing the so-called "hot-spot" stress method, the notch-stress approach down to the details of fracture mechanics techniques. The more detailed the modelling, the more sensitive and effective the method is supposed to be. Anyway, the FEM technique is supposed to be consistent with modelling hypothesis usually applied to steel chassis parts. These are usually modelled under plane stress assumption by 2D shell mesh, whose characteristic size is of some mm, the sheet thickness being from 1 mm up to 4 mm.

In this framework, since the early 90s PSA Group has been using the "hot-spot" stress method in order to assess fatigue design of arc-weld assemblies [Fayard & al. (1996)]. Despite an overall effectiveness, some particular cases still need a deeper stress analysis in order to achieve successfully the fatigue design. In this paper, we analyze the stress-state at the "hot-spot" by considering the stress gradient within the steel sheet, i.e. under the weld toe, as an essential parameter driving the seam-weld fatigue strength. Analytical and numerical computations are supported by experimental fatigue tests which allow us to recover former results of the so-called "VOLVO method" [Fermér & al. (1998)].

References

Hobbacher A.F. – The new IIW recommendations for fatigue assessment of welded joints and components – A comprehensive code recently updated – International Journal of Fatigue (2009), vol. 31, pp. 50-58

Fayard J.L., Bignonnet A., DangVan K. – Fatigue design criterion for welded structures – Fatigue & Fracture of Engineering Materials & Structures (1996), vol. 15, pp. 723-729

Fermér M., Andreasson M., Frodin B. – Fatigue life prediction of MAG-welded thin-sheet structures – SAE technical paper 982311 in Proceedings of the IBEC 1998, vol.2

1. *PSA Peugeot Citroën, INOVEL parc sud, 78140 Vélizy-Villacoublay, France*
2. *ArcelorMittal, voie Romaine, 57283 Maizières-les-Metz, France*

New FEA shell element model for seam weld static and fatigue structural assessment

D. Turlier, P. Klein, L. De Noni, (LOHR Industrie, Duppigheim, France)
D. Lawrjaniec (Institut de Soudure, Yutz, France)

LOHR Industrie is a large vehicle manufacturer who strives to provide integrated manufacturing process cost analysis in the product design phase. Assembly joints are mainly fillet welds. In order to deal with seam weld-design optimization, the only issue is to accurately model the weld connection for the structural analysis. The innovative approach consists of a new seam weld FEA representation using a shell element. This special weld element enables to assess the weld throat strength for static load and fatigue load. In order to provide the correct assembly stiffness, LOHR weld model has the same cross-section area as the physical weld seam. The shell seam mesh is connected to the metal idealized sheets or to the metal massive parts using glue connectors.

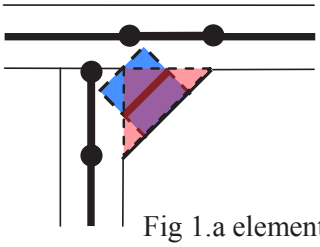


Fig 1.a element cross-section

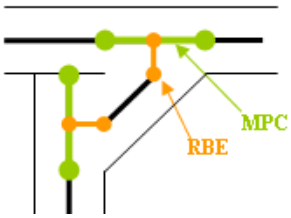


Fig.1.b weld element connexion

For static analysis, the Eurocode 3 equivalent stress may be displayed at each weld element along the seam length. For fatigue, the structural stress approach uses linearized stress distribution over the throat thickness in the crack continuation plane, as described by Pr Fricke. The verification and the validation of the innovative model have been performed in a collaborative LOHR and IS project and they are discussed in IIW fatigue stress analysis working group. An extension of the Pr Fricke structural stress method is proposed in case of shear dominant stress in the weld leg section. In this case, all sections are investigated using a throat scanning formula in order to determine the maximum structural stress plane. The validation is based on Pr. Maddox test results with longitudinal UIT fillet welded stiffeners. The model is also convenient for the fatigue local nominal stress analysis based either on the resultant stress through the weld throat or on the stress including the secondary bending effect. Loads are extracted from the weld element nodes.

LOHR uses NX from SIEMENS Industry Software as CAD and CAE pre/post solutions. In order to reduce 60% of time during the tedious model preparation process, automation toolboxes have been developed with NXOpen API. Seam weld idealization is based on a CAD solid representation of the weld. Toolboxes first make the scar imprint of the solid seam over the welded plates. If the geometry is idealized to mid-surfaces, the imprints are transferred to the mid-surfaces. The last LOHR toolbox performs the weld FEA connections on the sheet plate meshes. This seam to simulation approach is very powerful when used in a "what if" variation context because the FEM model is updated when CAD modification is performed.

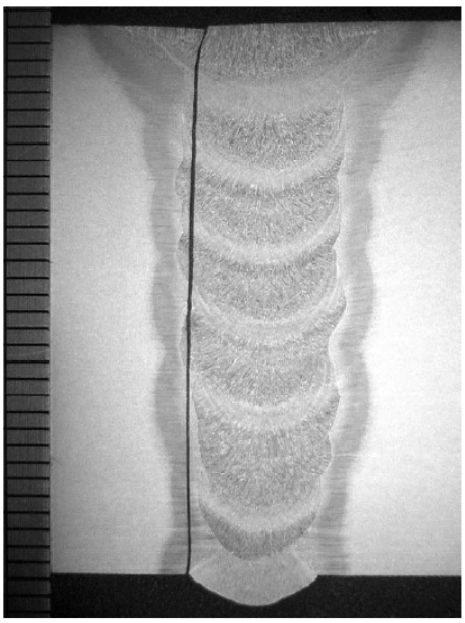
For industrial application demonstration, static and fatigue (root and toe) local results are displayed over large FEA models.

A Review of S-N Data for Fatigue Design of Pipeline and Riser Girth Welds

K.A. Macdonald (Subsea 7, Stavanger, Norway),
J.L. Legras, J. Wang (Subsea 7, Paris, France)

This paper presents a study of the fatigue design of girth welds in offshore pipelines, flowlines and risers. The study concentrates on reviewing available experimental fatigue test data, with a focus on supporting or improving the established design classifications for such welds. The offshore industry repeatedly commits resources to establishing the fatigue performance of girth welds in risers and pipelines, often on a project-specific basis. This is dictated in the main by client requirements and is a recurring cost ultimately borne by the industry in general.

The objective of this study was to collate, review and analyse both published and in-house fatigue test data in order to establish trends and a new S-N based design guideline. The aim being to reduce the amount of unnecessary testing performed in the future and to established robust design guidance. The data set has been analysed to extract trends and to define design S-N curves suitable for design purposes. Factors driving trends that are suspected as being important are related to: material; weld process; pipe size; wall thickness; environment; stress ratio; failure site (root/cap); and presence of weld flaws. Trends in the data are compared with the wider published data and current Standards and Codes. The existing design framework is challenged where better than assumed fatigue behaviour is apparent. Clear differentiation is made between weld types where, on the one hand sufficient data exist to support a robust design basis and on the other weld types where continued generation of project-specific fatigue test data remains appropriate.



Girth weld made from one side, showing failure
from theroot (flush ground weld cap)

Fatigue assessment of welded bicycle frames

A. Callens (Decathlon, Mknix Engineering Center, Lille-France),
A. Bignonnet (Andre Bignonnet Consulting, Beaulieu-France)

This paper presents the methodology developed by Decathlon to assess the fatigue behaviour of welded aluminium-alloy bike frame. The objective is to predict the reliability of the bicycle frame faced to the complex fatigue loading and therefore to optimize the design before the standardized testing. Fatigue failures always occur at the weld toes and classical fatigue analysis do not allow predicting correctly the fatigue strength of the structure. The main difficulties are:

- Bicycle frame are made of thin wall tubes
- Actual loading and standardized tests lead to multi-axial stress at critical points
- Welds are handmade, and there are a variety of weld size
- Geometries of welded areas are quite complex.

It has been decided to apply the method developed by [Fayard and Bignonnet] which has the advantage to use a unique S-N design curve whatever the geometry of the welded structure and the loading mode. The knowledge of the design stress S and the use of a unique S-N curve allow to predict the fatigue strength of any bicycle frame.

The Design Stress S is determined by the geometric stress at hot spots with a linear elastic finite element analysis using thin shell modelling. To define this Design Stress, the Dang-Van criterion has been implemented in our finite element analysis software, Ansys Workbench. It is a combination of the maximum shear amplitude and the hydrostatic pressure at the hot spot. A specific meshing rule is defined to ensure that the Design Stress is calculated precisely for every welded joint and that it takes in account the weld size.

The unique S-N curve was defined using fatigue tests on an elementary welded tubular joint. The specimens were welded in a real production way to be representative of the bicycle frame. Fatigue tests with two loading conditions (pure bending, pure torsion) have been done to establish the Dang Van criterion.

The methodology has been validated on bicycle frames and the fatigue strength prediction is excellent with regards to the standardized tests. The methodology is now included in the reliability assessment procedure at Decathlon.

Furthermore the methodology provides a powerful control tool to pilot and to follow the suppliers' production process, therefore to guarantee the quality of the final product.

Stress intensity factors for planar cracks of arbitrary shapes

P. Lindroth, G. Marquis (Aalto University, Finland),
G. Glinka (Aalto University, Finland ; University of Waterloo,Canada)

Engineering materials and mechanical components contain occasional defects created during the manufacturing processes or introduced in service by fatigue, impact damage or corrosion. In most cases they appear as material discontinuities which can be modelled as planar cracks. It is known that the size and geometry of an initial crack have profound effect on the subsequent durability of machine structures and components subjected to cyclic loading. Estimation of safe fatigue lives of mechanical components containing small flaws requires using fracture mechanics methods to assess crack growth. The basic parameter used in such analyses is the stress intensity factor (SIF),K. Therefore, accurate calculation of SIFs for fatigue planar cracks is essential for a reasonably accurate simulation of the fatigue crack growth and the estimation of the fatigue life of such components.

There are various methods of obtaining SIFs and numerous solutions can be found in handbooks. However, most of available literature solutions have been obtained for idealized geometrical configurations such as edge, circular, elliptical and other standard crack geometries. Natural cracks are seldom circular or elliptical and therefore an efficient method of calculating stress intensity factors for planar cracks of arbitrary shapes is needed. Available analytical or numerical methods are labour intensive and time consuming when applied for the analysis of fatigue cracks. In this study, an approximate weight function method based on certain properties of SIFs for planar cracks has been developed and validated.

The new method is suitable for irregular planar cracks subjected to uniform stress distribution. The approach consists of three steps: 1) first, the crack geometry and the applied stress distribution are used to determine the average stress intensity factor around the perimeter of an arbitrary crack, 2) secondly, the relative stress intensity factor distribution around the crack contour is computed and in step 3) the results from steps 1 and 2 are combined resulting in the determination of the actual stress intensity factor distribution along the crack perimeter. Stress intensity factor data obtained from this approach for a variety of different crack geometries were compared with available literature solutions. The method was found to have good accuracy for a variety of reference crack shapes.

Combined fatigue crack growth and modal analyses

E. Wyart, H. Minnebo

(Multiscale Modeling of Material and Structures Cenaero - 29, rue des frères Wright - 6041 Gosselies, Belgique)

The eXtended Finite Element Method coupled with the Level Set Method (XFEM/LS method) has proved to be an efficient method to handle three-dimensional crack growth within damage tolerant approaches. During the service life, engine components are subjected to complex load cycles that can lead to crack propagation under superimposed Low Cycle Fatigue and High Cycle Fatigue (LCF/HCF) loading.

A first approach consists in computing the eigenmodes on the uncracked finite element model and selecting the most critical mode. The selected mode is taken as loading for the HCF crack propagation. When the crack length influences the mode frequencies and/or the mode shapes, the authors propose to compute the eigenmodes after each combined LCF/HCF cycle.

The crack propagation under combined LCF/HCF cycles is performed using the XFEM/LS method with Morfeo/Crack while the eigenmodes computation is performed with Samcef using a mesh conforming to the crack faces. The conformed mesh is obtained by refining and splitting the mesh thanks to the level sets at the end of each propagation step. The frequencies and the mode shapes obtained for the cracked model are compared with the uncraked model.

Two cases are considered:

- If the mode shape is modified and the mode frequency not (or within a certain tolerance), the HCF loading is reactualised

- If the mode frequency is modified, only the LCF loading subsists in the fatigue life analysis This strategy will be applied on a stator blade of an aero-engine.

Some recent advances in remeshing techniques for complex 3D crack growth industrial applications

V. Chiaruttini
(Onera - The French Aerospace Lab, DMSM/MNU, BP72 - 29 avenue de la Division Leclerc FR-92322 Chatillon Cedex)

Robust and efficient strategies for simulation of cracked structures are of great interest for a wide range of industrial applications.

However, the usual finite element method, which is one of most popular tool for computational mechanics is suffering many limitations that prevent its use to robustly and accurately predict critical damage tolerance analysis of 3D structures.

To tackle those difficulties, the computational mechanics community has developed various methods in order to deliver strategies able to simulate crack growth on complex industrial structures. Thus, alternative techniques, such as meshless methods, boundary element methods, or partition of unity derived methods have been highly investigated.

Concerning the standard finite element approach, recent improvements of meshing and remeshing techniques allow the generation of complex 3D meshes that could be refined in local areas of interest where a crack could propagate. Thus, inserting the discontinuity surface in those refined uncracked meshes became one of the last drawback of those methods. Traditional approaches, usually based on a cracked CSG model, or mesh generation with boolean operations, generally lack of robustness which makes it difficult to deal with complex geometries.

In order to fundamentally push the lines of remeshing based techniques, a new algorithm as been developed. Our approach is mostly based on a fast and efficient crack insertion algorithm. The robustness and quickness of this method is obtained by the way the output cracked mesh is represented (linked to element mesh size near the surface of discontinuity). In fact, each volume element of the input mesh that crosses the crack surface is cut. An important assumption is that the generated surface can be approximate by the polygonal elements built on the input element edges intersection points. Some special treatments are also performed on element faces to carry out the crack front intersection and some topological difficulties that could arise for highly curved cracks. This obtained mesh is finally rebuilt using an adaptive remeshing strategy in order to eliminate bad quality elements and provide a suitable discretization for accurate finite element solution and stress identity factors computation.

This approach has been implemented in the Z-set finite element software co-developed by Onera. This technique has already been successfully applied to some complex 3D cracked structures mesh generation and used to treat very efficiently various 3D crack growth simulations in the context LEFM for industrial structures (with even multiple coalescing cracks), adaptive cohesive zone modeling and damage to fracture transition.

Model prediction of fatigue crack propagation in base and corroded metal

D. Marhabi, A. Iost, M. Smati, M. Nasri, J.M. Nianga
(Département Conception Mécanique, Hautes Études d'Ingénieur
13 Rue de Toul - 59046 LILLE CEDEX, France)

This study was inspired by an experiment with injection pumps sea water for the operation of an oil production platform. In these machines, fatigue is a major cause of deterioration of mechanical parts. A fatigue failure usually originates at a point of stress concentration such as a sharp, a notch, a metallurgical inclusion or micro-crack. Once a crack is present in a material, it will tend to grow under the influence of cyclic loading. The crack may be initiated by fatigue or may be caused by an impact, or similar event; once the crack is released it will grow to a critical length and product the fracture of the concerned component.

To investigate the cause of damage, the fatigue test machine was used in the laboratory. The tests were performed on steel 17-4 PH in the following two conditions: base material, corroded material.

The present study is aimed at comparison between simulation and experimental investigating both on the fatigue crack growth behavior in ambient environment for a stainless steel 17-4 PH and the same metal with corroded effect produced by sea water.

Comparison between simulations and experimental results is done. Thus helping to reduce costs and optimize the number of experimental tests needed for alloy characterizations.

Influence of weld-seams on fluid-structure-interactions in pipe flows

M. Kuschewski, D. Klören, R. Kulenovic, E. Laurien
(University Stuttgart, Germany)

The joint research project ‘Thermal Fatigue - Basics of the system-, outflowand material-characteristics of piping under thermal fatigue“ funded by the Federal Ministry of Education and Research is an ongoing German research project. The introduced part of one sub-project aims at the fluid-mechanical modelling for coupled fluid-structure-simulations. This paper presents the large scale test facility of the project and a second setup for demonstrating of optical measurement techniques. The experimental results of a weld-seams influence on the fluid-structure-interaction (FSI) are compared to coupled large-eddy simulations.

Unsteady non-isothermal fluid flows, known for instance from power plants, cause temperature fluctuations in pipes. Crack initiation must be expected for specific components after some hundreds of hours. In general, the common problems link to plug-type transients, steady state stratification effects and the associated Low Cycle Fatigue (LCF) are acceptably understood and can be controlled by plant instrumentation systems. In history engineers faced problems regarding turbulent non-isothermal fluid mixing, for instance in piping systems with bows and t-junctions. By today the external surface thermocouples can not monitor the highly transient temperature fields and therefore provide no information regarding the High Cycle Fatigue (HCF).

According to generic data provided by Électricité de France SA (EDF) weld seams are of special interest. In the case of non-isothermal fluid mixing cracks are often observed in circumferential welds or close to them in the smooth base material. Due to this reason the paper concentrates on the interactions between welds and the fluid flow.

According to recent developments in international ageing management activities, the proactive approach to avoid and minimize premature ageing is promoted. For this task knowledge about the transients and FSI must be available in the modelling / design stage. The FSI is not yet understood and needs further investigations for advanced computational models. In this context experiments are needed for the validation of new multiphysical models which take into account the heat transfer from fluid to wall and vice versa. For this purpose a new large scale test facility is built at the University Stuttgart. A T-junction made of austenitic steel complying the german nuclear standards connects a ID 71.8 mm hot main line and a 38.9 mm branch line. The system is operating at 75 bar, and working fluid water in the branch line is 20 °C resp. in the main line at maximum temperature 280°C. Thermocouples utilise temperature measurements near the inner pipe wall while optical modules installed in the flow path provide an optical access to the fluid. The second cold t-junction setup operates at ambient pressure and temperature. It is used to demonstrate the application of optical measurement system and to compare experimental with numerical results.

3D experimental and numerical fatigue crack analysis

M.-C Baietto[1], A.Combescure[1], A. Gravouil[1], J. Réthoré[1], J.-Y Buffière[2], S. Roux[3], F. Hild[3]

Fatigue cracks are three dimensional objects in essence, but the lack of 3D data about crack propagation in optically opaque materials has made necessary the development of simplified 2D fatigue models. Efforts have been made in the last 20 years to develop both experimental and numerical techniques for investigating and predicting the behaviour of fatigue cracks within the bulk of opaque materials. A combined experimental and numerical research program has been planned to improve the understanding of 3D crack behaviour and growth.

This presentation will be devoted to the presentation of the main results of the Propavanfis research program. This research was devoted to the study of full 3D fatigue crack propagation in metals. The idea was to perform 3D fatigue crack propagation experiments using tomography which allow to follow crack propagation within a specimen without destroying the specimen and to compare with 3D X-FEM simulation. A nodular graphite cast iron was used. The following tools were used:

- X-ray microtomography to visualize various states of a fatigue crack within a volume made of cast iron,

- eXtended Digital Volume Correlation (X-DVC) to measure in situ displacement fields in the bulk in the presence of a crack, and identify stress intensity factors along the crack front,

- eXtended 3D Finite Element Method to analyze stress intensity factors by considering the experimentally determined crack geometry.

This work was funded by the Cetim Foundation grant entitled PROPAVANFIS: ''Advanced methods for the experimental and numerical analyses of crack propagations under complex loadings.'' This work was also made possible by an ESRF grant for the experiment MA-501 on beamline ID19

1. Université de Lyon, INSA Lyon, CNRS LaMCoS, France, 2. Université de Lyon, INSA Lyon, CNRS MATEIS, France, 3. LMT-Cachan ENS Cachan/UPMC/CNRS/PRES UniverSud Paris, France

Improvement of the welding joints and components by shot peening

I. Huther (Cetim, Senlis),
E. Daniel (Metal Improvement Company)

The commission XIII of the International Institute of Welding published in 2007 a document called "recommendations for fatigue design of welded joints and components". It presents various processes to improve fatigue life after welding.

Shot peening is well known to improve fatigue life of metallic components, including welded joints and components, but it has never been properly qualified for the IIW recommendation.

In order to include the benefits of shot peening in this paper, METAL IMPROVEMENT COMPANY together with CETIM Senlis, started the procedure to qualify it.

The samples are longitudinal non-load-carrying fillet welds, done in DOMEX 700, a hot rolled high strength steel from SSAB Tunnplat, 8 millimeters thick. 12 samples have been peened by METAL IMPROVEMENT COMPANY and 3 not. Then they have been fatigue tested at CETIM SENLIS with 3 load levels up to 2 000 000 cycles at R=-1 and R=0.1 in order to quantify the benefits of shot peening.

Shot peening is introducing compressive residual stress and also improving the geometry of the weld toe. It is the projection of hard shots made in steel, stainless steel, ceramic or glass of various sizes (diameters from 50 µm to 3 mm). There is also the control of the intensity and of the coverage rate (minimum 100%) of the treatment in order to get an uniform compressed layer. It can be apply manually till fully automatic controlled machines. It is used for more than 60 years to treat fatigue, fretting, pitting (contact fatigue), stress corrosion cracking, intergranular corrosion or thermal fatigue. It is applied for single as well as serial parts in all industrial fields: aerospace, automotive, energy, power generation, medical or general industry.

Fatigue test have been done with 3 loads levels up to 2 000 000 cycles at R=0.1 and R=-1 in order to quantify the effect of compressive load on the fatigue life.

The results are good. At 2 X 10^6 cycles, the average stress level is 126 MPa for the aswelded samples and 221 MPa for the shot peened samples. It is an improvement of 75% of the fatigue life. The residual stress level has also been measured at the surface of the part close to the welded area and give also good results of -500 to -650 MPa.

Taking into account of execution quality, steel grade and post-welding treatment in Eurocode 3 Part 1-9

M. Lukić (CTICM, Saint-Aubin, France)

Fatigue behaviour and thus the probability of failure of a structural detail subject to fatigue is mainly dependant on five parameters: stress range, geometry of the detail, initial imperfection size, material characteristics and environmental conditions. Eurocode 3 Part 1-9 (EN 1993-1-9) defines the resistance to cyclic loading in terms of the detail category $\Delta\sigma C$ which is the numerical designation given to a particular detail for a given direction of stress fluctuation, in order to indicate which fatigue strength curve is applicable for the fatigue assessment.

Since fatigue behaviour is mainly influenced by stress range, and assuming imperfections are within tolerances, the probability of developing a fatigue crack with time is function of the fatigue utilisation grade (not explicit in EN 1993-1-9), which can be expressed as : $U = E_d/R_d = \gamma_{Ff}\, \Delta\sigma_{E,2} / (\Delta\sigma_C / \gamma_{Mf})$. For the same U, all details can be said to be equal in terms of failure probability and thus fabrication quality and controls should be a function of U. Nevertheless, in structural details where fatigue is preeminent, higher levels of fabrication quality and controls might be necessary to guarantee the design fatigue resistance of these details. Failure probability / consequences, and thus fabrication quality and controls, should also depend on the detail category.

Regarding the choice of not only execution quality (Execution Class in EN 1090-2), but also the influence of steel grade (existing detail categories in the standard, valid up to S460, are extended to S690 in EN 1993-1-12) and of post-welding treatment, nothing is explicitly recommended in EN 1993-1-9. An attempt to associate particular detail categories $\Delta\sigma C$ to Execution and Consequence Classes recently failed to get the approval of all the national standardisation bodies within CEN.

Nevertheless, since 2009 there has been a working group within ECCS TC6 "Fatigue", narrowly associated with the CEN evolution group on EN 1993-1-9, with a task of extending the fatigue approach to take into account execution quality, different steel grades and post-welding treatment and including it in the next revision of the standard. The final stage in this process would be to define the actual fitness-for-purpose (ffp) criteria for particular details.

Fatigue of Laser-Arc Hybrid Steel Welded Joints and Comparison with Conventional Arc Welding

D. Lawrjaniec[1], P. Gressel[1], S. Deckert[2], D. Turlier[2], K. Chouf[3], A. Miclot[4], R. Fabbro[5], E. Le Guen[5], A. Hazotte[6]

The laser-arc hybrid welding process, which combines laser and arc welding, is gradually coming out of laboratories, but is still not widely used in the industry, in particular in France.

However, the use of hybrid welding in mechanized welding allows productivity improvements such as rising welding speed, reducing pre or post welding operations, reducing the number of welding passes and brings the advantages of laser welding, such as penetration depth.

The ANR HYPROSOUD project proposes a global approach of this process to convince industry of all its potential. A compact equipment adapted to a production environment and fitted on a robot was developed early in the project and was used to set the welding procedure specifications. At the same time, modelling and numerical simulation were performed and over 200 fatigue tests were carried out at the Institut de Soudure in order to compare the fatigue resistance of laser-arc hybrid joints with conventional arc welded joints.

T-joints, butt joint and L-joint from S355 and S700MC grade steels and thickness between 5 and 12 mm were tested under different loading modes. Especially, specimens were subjected to bending or transversal load leading to root cracking.

Both arc welding and laser-arc hybrid welding processes were used to weld the specimens, all of them with single-sided joint in order to meet the welding conditions of the industrial partners. Laser-arc hybrid welding process needs 1 pass when conventional arc welding can need up to 4 passes depending of plate thickness and preparation. Therefore it can be seen some differences in weld geometry. The tests confirm that resistance of assemblies is closely linked to geometry parameters like weld toe radius, and to the depth of penetration in case of load leading to root cracking.

All tests were conducted until 2.10^6 cycles in order to draw S-N curves of laser-arc hybrid welding process, and compare the resistance of this new promising process with IIW recommendations as well as with conventional arc welding.

Laser-arc hybrid welding process brings many advantages for welding assemblies. In addition, its mechanical behaviour is at least very close to conventional arc welding or even better due to its high penetration ratio.

1. Institut de Soudure, Yutz, France, 2. Lohr Industrie, Duppigheim, France,
3. Air Liquide - CTAS, Saint Ouen l'Aumône, France, 4. Caterpillar, Grenoble, France,
5. CNRS/PIMM, Paris, France, 6. CNRS/LEM3, Metz, France

Fatigue behaviour of arc welded assemblies: paths of improvement

M. Duchet[1], M.Amblard[2], L. Cretteur[2], S. Michaut[1], J. Goudemez[3], B. Weber[1], O. Brière[4], V. Desfontaine[4]

Regarding stiffness and monotonic behaviour, internal studies of steels solutions led by ArcelorMittal for chassis and suspension parts have shown that weight reduction of the components is reachable by using Advanced High Strength Steels (AHSS) with Ultimate Tensile Strength (UTS) around 800MPa in place of current High Strength Low Alloyed (HSLA) or Ferrite-Bainite (FB) steel grades (400 < UTS < 600 MPa). The potential of mass saving is assessed to more or less 20%.

Indeed if the use of AHSS allows saving weight by thickness reduction, it leads also to much higher stress loading for the same in-service usage. For a static loading, the stress increase is balanced by a higher Yield Stress (YS) and the thickness reduction will depend on the ratio between the yield stresses of both HSLA/FB and AHSS grades. For a dynamic loading (fatigue), if the fatigue strength increases with higher mechanical properties, as in static case, for the base material, the fatigue of Gas Metal Arc Welded (GMAW) assemblies becomes a problem because there is no difference between steel grades in term of fatigue strength. The stress concentration induced by the geometry of the weld (notch effect) explains this well-known behaviour.

Therefore solutions to improve the fatigue strength of arc-welded assemblies have to be investigated in order to assist and support the introduction of AHSS grades, especially in chassis part, i.e. to reach the mass saving target. For that two main objectives have been defined:

1. Test of solutions to improve the fatigue behaviour of GMAW lap specimens.

2. Then, validate the solutions on proto-types manufactured in industrial conditions.

The investigations done on welding processes, design, mechanical and remelting post-treatments, thermal treatments… have shown that the best fatigue behaviour of single assemblies were obtained after ultrasonic impact treatment (by Sonats) and TIG remelting. Then the welding of prototypes and both post-treatments were achieved in industrial conditions by using robots. The fatigue tests performed on a bench have shown that both post-treatments have improved the fatigue life of prototypes versus the as-welded reference. These results confirmed the ones obtained on specimens and validate the interest to apply such post-treatments.

1. ArcelorMittal, Maizières-Lès-Metz, France, 2. ArcelorMittal, Montataire, France, 3. ArcelorMittal, Grande Synthe, France, 4. Sonats, Carquefou, France

Experimental and numerical study of crack propagation and non-propagation conditions in a 304L austenitic stainless steel pipe under thermal fatigue

P. Bouin (DEN/SEMT/LISN - CEA Saclay, Gif sur Yvette , France)

The incident of the Civaux I power plant as some works in thermal fatigue have disproved current methodologies and usual criteria to predict propagation when components are submitted to thermal fatigue. Improvements in analytical methodologies and new experimental data are required to get better assessments of crack propagation and arrest under thermal fatigue.

As part of this work, a new thermal fatigue test, Fat3D, has been developed to study the problem of closure effect and fatigue crack growth under thermal fatigue conditions on AISI 304L quasi-structure specimens. The importance of the initiation and the propagation phases on a notched specimen and the evolution of the stress intensity factor according to the propagation were also investigated. Moreover, a bulk tension (BT) specimen, adapted from a standard compact tension (CT) specimen, has been designed to assess the existence or non-existence of a propagation threshold for high loading ratio. These experimental campaigns have also been completed by a characterisation campaign on the AISI 304L material and by a benchmark of different non destructive techniques to detect and follow crack propagation.

In parallel, numerical analyses have been developed using the French finite element code of the CEA, Cast3M. This combined experimental and numerical study enables to evaluate the proposed improvements in analytical methods to accurately predict crack growth under thermal loadings and to understand the influence of the main parameters concerning crack propagation in such components.

Thermo-mechanical fatigue characterisation of a new ferritic stainless steel for very high temperature exhaust parts

L. Faivre, P.-O. Santacreu, A. Acher (Aperam Stainless France, Isbergues)

The increase of service temperature of the engine is a challenge that car manufacturers have to face when it comes to comply with more and more severe depollution standards. The requirements in terms of exhaust gas temperature could soon reach and overtake the limits of stainless steel grades commonly used for hot end of exhaust line. Although stainless steel solutions allow higher service temperatures than cast iron ones, most of the common grades used for manifold and turbocharger applications (1.4509, 1.4541, 1.4828, etc.) can not be used over 950°C.

This paper aims at presenting the characterization procedure and results of a new ferritic stainless steel grade – named K44X – which has been developed to withstand service temperature up to 1000°C. With 19% of chromium content, 2% of molybdenum and niobium additions, this grade complies respectively with EN 1.4521 and AISI 444 classifications. Thanks to this chemical composition, K44X shows higher strength, better fatigue resistance and better creep resistance than common ferritic grades while presenting also lower thermal expansion and higher cyclic oxidation resistance than austenitic grades.

A wide range of high temperature properties have been investigated in the range 750-1000°C including tensile, creep, cyclic oxidation, HCF and thermal fatigue. K44X results were then compared to other stainless steel grades dedicated to high temperature applications.

In the development of an industrial exhaust part, motor bench tests are essential but long and expensive. To assess the thermal fatigue behaviour of a material, independently of the part design, a simplified test has therefore been used. The aim is to reproduce exhaust manifold service conditions in terms of thermal and mechanical constraints on a simple V-shaped sample.

As lifetime prediction tools turn out to be crucial in the design of an exhaust part to reduce the need for motor bench tests, various models are also proposed for K44X in this paper: a Chaboche elasto-viscoplastic behaviour model identified on LCF data, a strain-based thermal fatigue damage model and a creep criterion. Moreover, both damage criteria are integrated into an Abaqus post-processor called Xhaust-life which allows lifetime calculations for various stainless steel grades thanks to its material library included.

Design of a fatigue rig for testing turbine blades under cyclic loading at ambient and elevated temperature

M. Leroy, A. Köster, D. Ryckelynck, L. Rémy
(Centre de matériaux, Mines de Paris, Paristech, CNRS UMR 7633, BP 87, 91003 Evry Cedex, France)

Various foundry defects can occur during manufacturing of single crystal turbine blade. In service, the presence of a defect could lead to blade failure under severe thermomechanical solicitations such as creep, fatigue, temperature gradients and localization of stress due to the complex geometry of the blade. It is important to evaluate properly the influence of foundry defects on the blade lifetime. This paper focuses on bicristalline blade, one of the possible foundry defects consisting in two single grains of single crystal nickel-based superalloy, AM1. The disorientation of each grain and between grains are obtained for each blade with the Laüe method. The position of the grain boundary in the turbine blade is a parameter taken into account for the choice of the tested blade.

In order to study the influence of the grain boundary (geometry, position, …), tests on real turbine blade are achieved. An assembly (figure 1), adaptable on a fatigue machine, has been designed in order to maintain in various positions the blade. The assembly allows the translation (lateral and horizontal) and the rotation of the turbine blade in such way to adapt the loading to the geometry of the grain boundary. The tests at elevated temperature are taken account into the design of test rig. The turbine blade has been modified by electro discharge machining to increase the fatigue damage in the area of interest, the grain boundary in our case.

Tests are prepared with numerical simulation using the non-linear finite element code ZeBuLoN in order to determine if the localization of damage occurs in the wanted area and to define the loading given the elastic return of the blade.

In a first time, fatigue tests have been performed under cyclic loading at ambient temperature. In a second time, tests will be performing at elevated temperature. Displacements of the turbine blade are measured during the fatigue test with digital image correlation and linear variable differential transformer (LVDT) and the failure is observed through images taken with each cycle. Numerical simulations are compared to the experimental observations of tested turbine blades.

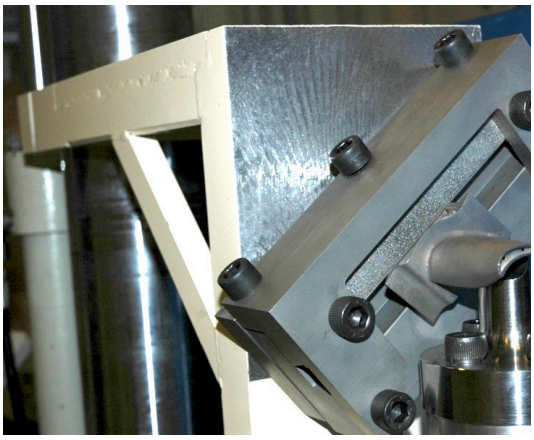


Figure 1 : Assembly

Improving of hot forging tool life hardfaced by Stellite-6

W. Fekih Ahmed[1], H. Bonnefoy[1], P. Revel[2], A. Lodini[1]

Hot forging tools are subjected to high cyclic thermo-mechanical stress resulting in their premature failure. Forging materials such as stainless steels and titanium alloys accelerates the degradation of these tools. The aim of this study is to improve lifetime of hot forging tool using thick hardfacing. The retained solution is a cobalt base (Stellite-6) hardfacing deposited by PTA (Plasma Transferred Arc) process.

Cobalt base alloys are attractive owing to an excellent corrosion resistance and a good resistance to thermal fatigue over a wide temperature range. PTA deposition allows to obtain very interesting characteristics of coating such as a strong metallurgical bond to the substrate, a low dilution and homogeneous refined microstructure of coating. Isothermal low cycle fatigue tests were performed on cylindrical specimens machined in substrate and coating in the temperature range of tool service (20-700°C). Determination of coating mechanical behaviour and comparison of isothermal fatigue behaviour with tool steel were presented. Microstructural analyses were performed in order to highlight failure mode of cobalt base coating.

A viscoplastic kinematic and isotropic hardening model was chosen in order to determine and simulate thermo-mechanical stresses in hardfaced forging tools. A hardfaced punch submitted to thermal cycling was tested in industrial condition. The results show that the use of Stelite-6 coating allows increasing by three the life time compared to a non hardfaced tool.

1. Laboratoire d'Analyse des Contraintes Mécaniques et de Dynamique des Transferts aux Interfaces LACMDTI, Université de Reims UFR science, Moulin de la housse 5100 Reims, France
2. Laboratoire Roberval, UMR 6253, UTC/CNRS, Centre de Recherches de Royallieu, BP 20529, 60205 Compiègne, France

Thermomechanical fatigue test of cast iron GGG SiMo 4.05 and its numerical evaluation

C. Novotny, M. Spaniel, M. Dvorak
(CTU in Prague, Faculty of Mechanical Engineering, Czech Republic)

Cyclic heating and cooling is typical for some structures. External constraint of free thermal expansion and contraction is the cause of cyclic tensile and compressive straining. If forces generated in material due to constrains are high enough, plastic strain occurs. Alternating tensile and compressive plastic macrodeformation leads to initialization and propagation of fatigue cracks. This phenomenon is called thermomechanical fatigue and belongs to the category of low cycle fatigue. Fatigue life of structures is possible to describe by experimentally determined dependence mechanical strain range – cycles to failure.

A typical thermomechanical fatigue test with external constrains is performed on Coffin apparatus. The rod specimen is fixed in the apparatus and cyclically heated by direct passage of electric current and cooled until the rupture. The relative movement of specimen's ends is measured during experiment. Mechanical strain range of specimen is calculated from known stiffness of testing device. In this way, the dependence mechanical strain range – cycles to failure is obtained.

This is classical evaluation approach of thermal fatigue test performed on Coffin apparatus. When applying results it is necessary to be taken into account that temperature along the specimen is not constant in the same time. This leads to the fact that the evaluated strain of the specimen is "average". The general usage of such thermomechanical fatigue tests for real structure will be problematical if the temperature field distribution or stiffness doesn't correspond to test conditions. It was proposed methodology that generalizes the results of such thermomechanical fatigue tests. The principle of this methodology is finite element simulation of real fatigue test. Local strain range is determined in the middle of the specimen. This is the typical location of the rupture. Computed local mechanical strain range is assigned to experimentally obtained cycles to failure. Localized lifetime curve is obtained.

Credible numerical simulation of fatigue test is based on knowledge of material properties and conditions during the test. It is necessary to know (i) cyclic plastic behaviour of material including temperature dependence, (ii) real temperature distribution along specimen in time and (iii) temperature dependence of thermal expansion coefficient. This methodology was applied to cast iron GGG SiMo 4.05. Two types of specimens with different size of cross-section were tested. The lowest temperature was set at 100 oC, peak temperature was selected from 510 oC to 800 oC.

In this project there were not available cyclic stress-strain curves. Instead of them, there were used calibrated static stress-strain curves. As the best calibration was chosen one that provide the best match of the numerical simulation with measured strain of the specimen. The proposed methodology allows the evaluation of thermomechanical fatigue test on Coffin apparatus for more general application.

Lifetime of a welded structure subjected to thermal-mechanical loadings: application to exhaust manifolds

A. Benoit[1-2-3], L. Remy[2], A. Koster[2], H. Maitournam[3] And F. Oger[1]

Exhaust manifolds are usually designed in cast-iron. However, when increasing the engine performance, the output gas reaches higher temperature, and other types of material like welded steel plates are considered to design exhaust manifolds. These components are subjected to complex thermomechanical loadings which must be taken into account in fatigue design. To limit the computational costs, only a few loading cycles are simulated and a fatigue criterion is used to estimate the lifetime of the structure. This study proposes a junction model combined to a fatigue criterion to assess the lifetime of a welded structure. The model is simple enough to be integrated into a computation on a complete structure and the fatigue criterion is available for thermal-mechanical loadings.

To build this model, butt welded joints in ferritic stainless steel plates were characterized. Tension tests were made at ambient temperature on butt welded specimens and on butt welded specimens after smoothing out the weld bead. A speckle was applied on the surface of the specimens, in order to monitor the evolution of the strain fields by image correlation. For welded specimen, the geometry has a significant influence on strain localization since it modifies the deflected shape of the specimen. When the bead is smoothed out, the influence of the microstructure is observed: the strains seem to localize in the thermally affected zone. The junction model uses a unique elasto-visco-plastic law for plate and weld. The stiffness of the weld is modelled thanks to additional shell elements calibrated to reproduce the deflected shapes of the welded specimens.

Then isothermal low cycle fatigue tests were completed up to specimen crack initiation. Fatigue lifetime of welded specimens is compared with data on base material using local strain analysis. Damage mechanisms are studied and used to propose a fatigue criterion. Finally thermal-mechanical fatigue tests were completed on welded specimens to reproduce the typical loading seen by welds on exhaust manifolds. The fatigue criterion is extended to cover non isothermal loadings in a large range of temperatures. This criterion and the junction model are used then to predict the lifetime of welds subjected to thermal-mechanical loadings.

1. PSA Peugeot Citroën, France, 2. CdM CNRS UMR 7633, École des Mines Paristech, France, 3. LMS CNRS UMR 7649, École Polytechnique Paristech, France

Contact: aurelie.benoit@mat.ensmp.fr

Low cycle fatigue behavior of a type 304L austenitic stainless steel in various environmental and temperature conditions (air, vacuum at 20°C or 300°C)

L. de Baglion[1-2], J. Mendez[2], J.A. Le Duff[1]

(1. Areva, La Défense, France, 2. Institut P' (LMPM_Ensma), Poitiers, France)

Primary piping of Pressurized Water Reactors "PWR" is made of 304L-type austenitic stainless steel and is used to convey water at elevated temperature under high pressure. Because of temperature gradients during start-ups, shutdowns or operating transients, this component is subjected to cyclic thermal stresses leading to high strain amplitudes at low frequency. Consequently, the low cycle fatigue (LCF) behavior of this steel has to be considered for the fatigue design and life analysis of piping systems or other reactor components.

In this context, a preliminary work has been performed by conducting reference LCF tests in vacuum or in air instead of in PWR water coolant environment, the main goal being the identification of key parameters intrinsic influence on the LCF behavior and damage evolution of this steel.

Those tests were performed on 304L cylindrical specimens at 20 or 300°C under total axial strain control using a triangular waveform at strain amplitudes of ±0.3 or ±0.6% and at strain rates of 4×10^{-3}, 1×10^{-4} or 1×10^{-5} s^{-1}.

It was found that whatever the environment, the cyclic stress response as well as the deformation or damage modes are very similar. In vacuum, a beneficial influence of the temperature of 300°C was observed on the LCF life but was almost totally hidden in air because of a deleterious environmental effect. At 300°C, a decrease in strain rate led to a decrease in LCF life, not explained by a stronger air environment effect.

In conclusion, because of several couplings existing between parameters effects, these results should be taken into account in the analysis of the PWR water coolant environment detrimental effect.

Multiaxial fatigue characteristics of vulcanized natural rubber

Yan-ping Wang

(Mongolia Polytechnic University, School of Chemical Engineering, Inner Mongolia Polytechnic University, China)

Abstract: Rubbers are extensively used in many applications because of their large reversible elastic deformation, excellent damping and energy absorption characteristics. Typical applications include engine mounts and tires for automobiles, vibration isolators, seals, hoses, belts, structural bearings, etc. Since these applications impose large static and time varying strains, durability, mechanical properties are often the primary consideration. It is important to investigate the fatigue characteristics and mechanism of rubber, and to further investigate the relation between fatigue failure mechanism of rubber and its macroscopic mechanical characteristics is crucially important to anti-fatigue design and fatigue life predicted model. Hainsworth [1] investigated fatigue crack initiation and propagation in silicone rubber and carbon-black-filled rubber with an environmental scanning electron microscopy, and found that the crack growth processes was non-linear and cracks were particularly found to initiate at edges and flaws in the sample. Le Cam [2] observed microscopic phenomena involved in the growth of the crack with SEM. It revealed that the cavitations induced by decohesion between zinc oxides and rubber matrix was major fatigue damage. Beurrot et al. [3] proposed the peculiar morphology of the crack tip and mechanisms of crack propagation in NR were due to strain-induced crystallization. However, only Mars and Fatemi [4] observed the surface morphology of fatigue failure specimen under multiaxial cyclic loading. Until now there are few studies on microscopic mechanism of multiaxial fatigue of rubber.

In this paper, to investigate the multiaxial fatigue properties of vulcanized natural rubber, a series of tests including both proportional and non-proportional loading paths based on on two kinds of vulcanized natural rubber with different formulas were performed. Fatigue tests were conducted at room temperature on a tension-torsion home made machine. The failure section of vulcanized natural rubber was cut down from specimen. XL30E SEM was employed to take photograph for the failure section. The results reveal that the stress amplitude rapidly decreases at the beginning and reaches to a stable period with constant stress decreasing rate until final breakage. With the same equivalent strain amplitude, the fatigue life of the rubber under non-proportional loading is much shorter than that under uniaxial loading. The fatigue life of rubber A is much longer than that of rubber B. Through the observation of Scanning Electronic Microscope, it is found that most of fatigue failure is due to decohesion and cavitation of inclusion. The adhesiveness of fillers and matrix in A is better and fatigue life is longer. Compared to uniaxial loading, the rubbers have larger agglomerates under multiaxial loading. More cavitations and shorter fatigue life under multiaxial loading were observed.

Keyword: Vulcanized natural rubber; Multiaxial fatigue; Microscopic mechanism;

References:

[1] S.V. Hainsworth: Polym. Test., 2007, 26, 60-70.
[2] J.B. Le Cam, B. Huneau, E. Verron: Macromol., 2004,37, 5011-5017.
[3] S. Beurrot, B.Huneau, E. Verron: J. Appl. Polym. Sci, 2010,117, 1260-1269.
[4] W.V. Mars, A. Fatemi: J. Mater. Sci., 2006, 41, 7324-7332.

Elastomers characterization in fatigue and crack propagation

L. Perier, (01dB-Metravib, Limonest, France)
F. Rouillard, (Lrccp, Vitry, France)

A better understanding of elastomers crack growth or material resistance to crack phenomenon would be an important step for improving the products.

In the context of the partnership with 01dB-Metravib, the LRCCP has purchased the new crack growth testing machine developed by 01dB-Metravib. This machine, called DMA+300, is a dynamic testing machine dedicated to materials fatigue analysis.

This testing instrument allows the measurement of cracks propagation rate of cracks initiated on pure shear specimen under controlled temperature, frequency and tearing energy, for various periodic loads.

The tests realized with elastomeric materials are basically divided into four stages: material accommodation, characterization of specimen without crack, cracks initialization and growth follow-up.

An application to the characterization of natural and synthetic rubbers (EPDM) will be presented, along with a repeatability study of this measure.

Innovative methodology for fatigue cracking assessment of gas loaded accumulator's separator using accelerated endurance testing

K. Nesnas[1], A. Houssais[1], Régis Borek[2], P. Bonnet[2]

An innovative methodology for fatigue cracking assessment of gas loaded accumulator's separator used in severe environment is considered. The accelerated endurance testing on accumulator bladder component (separator), made with rubber material, has proven that it is possible to produce in reasonable testing time the experienced fatigue cracking in service. Based on that and new complex simulation techniques, a methodology has been built in order to predict the reliability of bladder accumulator in the case of either both a new bladder material and design or new solicitation conditions. This work has permitted to develop a new modelling of the accelerated endurance test bench using mult-physic approach. This approach using the Coupled Eulerian Lagrangian (CEL) technique available in Abaqus FE code has been conducted to simulate both the fluid domain and structure domain as well as their interaction, allowing to take into account the real loading produced by the fluid solid interaction.

The numerical results have shown clearly the predictive capability of this modelling for the representation of the real behaviour of the test bench. The model has permitted also to give a degree of severity between the testing and in service conditions through the MTBF estimation.

References:

1. GAM EG 13. annex 5 to 9.
2. La fiabilité en mécanique. J.CL. Ligeron, CL.Marcovici. PIC Edition technique et documentation.
3. La pratique des essais de fatigue. HPLieurade. PYC édition. Mars 1982.
4. Sûreté de fonctionnement des systèmes industriels. Alain Villemeur. Collection de la DER d'EDF. Ed Eyrolles – 1988.
5. Reliability of the structures of industrial installations. Theory and application of probability mechanics. H.Procaccia, P.Morilhat: DEREF Collection – Eyrolles – Paris - 1996
6. Des solutions industrielles pour des objectifs de fiabilité - P.Bonnet, JFFlavenot, HPLieurade - CETIM ,SF2M - 23ème journée - Méthodes fiabilistes en fatigue pour conception et essais - Mai 2004
7. Fiabilité des structures – Maurice Lemaire. Edition Lavoisier, 2005.
8. "A data bank to size validation tests in the automotive for the fatigue failure mode" A.Poncet, P.Schimmerling, C.Dumas - Congrès Fatigue Design – novembre 2005
9. Standard EN 14359:2006: Gas-loaded accumulators for fluid power applications
10. Gas-loaded accumulators – A guide to applying the guarantee factor method to standard EN 14359 - J.Lallementa ,A.Guillardb ,A.Houssaisc, P.Bonnetd - Fatigue-Design 2007, CETIM Senlis.
11. Tenue en service d'un composant à partir du retour d'expérience et suivi en série". Georges Perroud - PSA PEUGEOT CITROEN. Colloque ASTELAB 18 Novembre 2007

1. OLAER Industries, 16 Rue de Seine - BP 7 – 92704, Combes cedex France,
2. I-comète, 15 avenue de Norvège - 91978 Courtaboeuf Cedex France

Fatigue behaviour of laser welded thermoplastic composites

P. Boutet, C. Peyrac, A. Galtier
(Cetim, 52 avenue Félix-Louat, BP 80067, 60304 Senlis Cedex)

Since the end of the twentieth century, composite materials are of ever growing interest for companies in many sectors of industry. Among these, transport industry (particularly ground transport) is a real great actor of this change because of the competition in the performance raising and in the decreasing of polluting emissions that involves a drastic reduction of masses and inertias in movement. In addition, European instructions concerning recycling force companies to replace the use of thermosetting matrixes, which cannot be smelted, with the use of thermoplastic ones. Mastering appropriate assembly techniques allowing matching well the companies Safety Quality Delivery Costs (SQDC) requirements is thus necessary for this kind of materials.

Among all existing assembly techniques, transmission laser welding offers great perspectives. While it is well known and mastered when used on polymer materials, few studies have been performed on laser transmission welding applied to continuous fibers reinforced polymers, which are mainly used on structural parts. Taking into account the specificities of composite materials compared to classical polymers, the present work deals with the fatigue behaviour of such assemblies. The studied base material is a stratified polyamide 6.6 reinforced with 40% continuous glass fibers.

Some pure tensile fatigue tests (R = 0,1) have been carried out, and the influence of different parameters (width of the seam, number of passes, feedback of the laser beam, …) has been studied. Some sections and fractures observations have also been performed in the welded zones in order to understand the mechanisms involved in the damage process. The obtained testing results have been grouped in some Wöhler curves and discussed. The specificities of the welding process due to the composite materials heterogeneities are also approached and their influences on the weld quality are highlighted. In conclusion, some perspectives in research continuation are thus proposed.

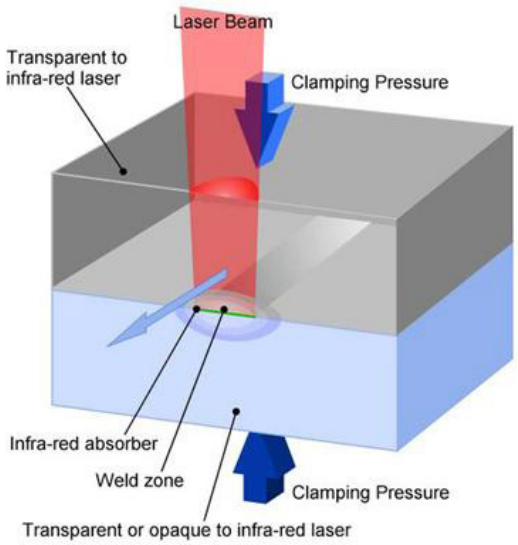


Illustration of the laser transmission welding process
[LEAPFROG Integrated Project]

Development of Pre-Clinical Verification Programmes for Novel Hip Replacement Designs

A.S. Dickinson[1-2], A.C. Taylor[2], A.C. Roques[2], J.R.T. Jeffers[3],, M. Browne[1]

Orthopaedic implants such as joint replacements can experience impact and cyclic loads several times the weight of the body. There is an incentive to preserve bone by minimising the wall thickness of prostheses. This is enabled by novel biomaterials with improved strength, including transformation toughened ceramic composites. In pre-clinical testing there is a particular focus on tribology and wear performance, but the strength of thin walled prostheses must also be verified before clinical use. The large safety factors of thicker, over-engineered devices can no longer be relied upon, so thorough fatigue-life analysis and testing must be conducted. Standard test methods exist for traditional implant designs, but a challenge to the bioengineer is the development of clinically representative in-vitro tests for novel designs. The present study involved the development of pre-clinical analyses and tests for two case study designs: a monolithic ceramic femoral resurfacing head, and a large bore modular acetabular cup, comprising a transformation toughened ceramic bearing insert and a titanium alloy outer shell.

Two approaches were used in the pre-clinical verification: computational analysis and physical testing. Initially, the in-vivo stress distribution in both designs was predicted with Finite Element (FE) analysis, using supporting bone models derived from clinical CT scans. Clinical variability was incorporated by modelling a range of loads and implant positions. There is abundant mechanical test data for the Ti-6Al-4V medical titanium alloy material, so it was possible to analyse the shell's fatigue failure risk using the FE stress predictions. For the ceramic components, published fatigue strength data for the material was sparse. Therefore, in-vitro tests were developed, to reproduce the predicted in-vivo stress patterns, under extreme magnitude fatigue and static loading and worst-case surgical positioning.

For the acetabular cup, under assembly loads the peak stress in the titanium shell was 274.5MPa. With superimposed jogging loading (peak 5kN), the peak stress was 303MPa, giving a mean fatigue stress of 288.8MPa and a stress amplitude of 14.3MPa. As such, the thin wall section of this design for improved bone conservation led to a high steady-state stress with a smaller magnitude dynamic stress. Therefore, to assess the predicted performance of the ductile titanium shell under the combined loading, resulting stresses were analysed using the conservative Soderberg relationship. Taking lower bound literature data for the yield strength and endurance limit of plasma sprayed Ti-6Al-4V material, a reserve factor of 2.40 was predicted in comparison to the Soderberg limit. In the event of a surface scratch in the shell creating additional stress concentration, a minimum reserve factor of 2.04 was predicted. For the ceramic bearing insert, a peak residual assembly stress of 31.0MPa was predicted, increasing to approximately 166MPa under 5kN loading. Compared to a worst-case reported material strength value, this was predicted to give a safety factor of approximately 6.9. In physical testing, no insert or shell failures occurred after 10 million cycles. No cups failed under 100kN static loading post-fatigue, representing over 100xbody weight.

In the monolithic head there was no residual assembly stress, but three main stress concentrations resulting from in-vivo loads were identified. A worst-case fatigue test was conducted with 10 million cycles of 5kN jogging loading, and no implant failures occurred. The post-fatigue mean static strength was 39kN, which represents over 39xbody weight.

This study employed a combination of computational modelling and physical testing to verify the strength of two case study joint prosthesis concepts, under worst case static and fatigue loading conditions. The test programme development represents an improvement in the state of the art where international test standards refer largely to conventional prostheses, and similar methods could be applied to a wide range of novel prosthesis designs.

1. University of Southampton, United Kingdom, 2. Aurora Medical Ltd., Chilworth, United Kingdom, 3. Imperial College London, United Kingdom

Assessing the fatigue performance of commercial bone cements

M. Browne[1], N. Shearwood-Porter[1-2], I. Sinclair[2]

Acrylic bone cement is considered to be the 'gold standard' in fixation of load-bearing orthopaedic implants, and has produced excellent long term clinical results. However, increasing patient body mass indexes, activity levels and longer life expectancies are placing ever greater demands on joint replacements. Aseptic loosening is a process by which the prosthesis loosens in the absence of infection; mechanical factors are thought to be responsible for this phenomenon, which on average accounts for failure of 10% of hip and knee replacements after 5 years. Given the increased demands being placed on these orthopaedic implants, there is a need to improve the mechanical performance of the cement either through microstructural optimisation or changes in cement formulation. Damage accumulation in the cement mantle due to initiation and coalescence of fatigue cracks has been implicated as playing a role in the loosening process. While the effect of porosity on crack initiation processes has been widely reported, relatively little is known about the influence of different radiopacifying agents.

Barium sulphate radiopacifier particles have been reported to form large agglomerates within the cement, and have been linked to initiation of fatigue cracks in vitro. However, there is limited understanding of the micromechanical aspects of cement failure due to barium sulphate agglomeration.

The present study utilised microfocus computed tomography (μCT) and field emission gun scanning electron microscopy (FEG-SEM), together with mechanical testing, to provide a systematic assessment of the relative effect of barium sulphate agglomeration on crack initiation processes in conventional acrylic bone cement. Three-dimensional characterisation of defect populations was performed and agglomerates of barium sulphate particles were found to be large (up to 0.3 mm equivalent spherical diameter), numerous (~6/mm3) and evenly distributed through the cement. Fatigue cracks consistently initiated at the largest agglomerates; furthermore, fatigue life was found to scale consistently with defect size. As such, the tendency of barium sulphate particles to agglomerate is clearly evidenced to be detrimental to fatigue performance. Optimisation of mixing techniques and/or cement formulations containing barium sulphate may therefore be advantageous to reduce the formation of agglomerates and their potential effects in vivo.

1. Bioengineering Group, Faculty of Engineering and the Environment, University of Southampton, UK
2. Materials Group, Faculty of Engineering and the Environment, University of Southampton, UK

Reliability Approach in Implant Fatigue Design

Y. Suchier, M. Chollet, I. Huther
(Cetim,52 avenue Félix-Louat, 60300 Senlis, France)

Today, the hip prosthesis is validated following Standards. For the stemmed femoral components, the Standard ISO 7206-4 requires to test 6 components at 230daN during 5×10^6 cycles without crack. For the neck region of stemmed femoral components, the Standard ISO/FDIS 7206-6 (draft) requires 6 tests at 534daN during 10×10^6 cycles without crack.

On one hand the implantation of hip prosthesis advances because more and more people are implanted and people of all ages. The implanted people have tendency to load more and more the prosthesis because they want to be able to continue a "normal" life: then there is a modification of the use of prosthesis in comparison with some years ago. On the other hand, there is the risk-benefit ratio.

The objective of this study is to establish a statistical distribution of the uses of hip prosthesis in order to define at best a minimum value of strength required for a good fatigue design. To define this strength, the Stress-Strength approach will be applied. This approach will allow defining the validation proceedings of hip prosthesis for the new Standards in progress.
After to establish the distribution of the uses for a hip prosthesis, for a given risk level, the required strength can be defined, knowing the dispersion of this strength.

The strategy to have the distribution of the uses is :
- to obtain the loads for each activities divided by the dynamic coefficient and the weight of the person,
- to know the breakdown of the activity time and the activity type of implanted population by age group, sex, profession group, weight on a number of years,
- to search a relation between the dynamic coefficient (ratio between maximum load and the weight) and weight.

After to verify the validity of the combination of the data, the distribution of the uses could be established to particular population group, for examples:
- young people (lower than a certain age),
- old people (above a certain age),
- the people with a certain weight, etc

High-cycle Fatigue Modeling at Heat Treatment of Nickel Superalloy ChS70VI for Gas-turbine Blades

Y. E.L. Sanchugov[1], V. V.P. Valuev[2]

In the present work we studied the relation between the high-cycle fatigue strength and heat treatment regimes of high-temperature nickel alloy ChS70VI for gas-turbine blades. Alloys for the study were obtained by induction melting in VIAM-24, UPPF-1, UPPF-2M furnaces at a pressure of 5,3-1,4 Pa in crucibles with basis lining. The molten alloys were cast under vacuum into heated ceramic molds. The temperature and time regimes of melting and casting were chosen depending on the aims of the study and the shape number of performs for specimens and pars. We used the methods of standard mechanical tests.

The optimization parameters were the high-cycle fatigue strength at $N = 2*10^7$ cycles (T = 20 °C) The independent variables were the heat treatment by the various regimes:
a) 1160 °C - 3h, 1160 <->1140 °C (termo- cycles) -1h, 1050 °C - 4h, 850 °C - 16h;
b) 1160 °C - 4h, 1050 °C - 4h, 850 °C - 16h; Analyzing the results of the study we plotted the high-cycle fatigue strength curves in coordinates: strength - cycle for the various heat treatment regimes.

The high-cycle fatigue strength of high-temperature nickel alloy ChS70VI after a)-regime of the heat treatment is 280Mpa ($N = 2*10^7$ cycles, T = 20 °C). The high-cycle fatigue strength of high-temperature nickel alloy ChS70VI after b)-regime of the heat treatment is 240Mpa.

The plotted curves are used to predict the relation between the high-cycle fatigue strength with the various cycle-bases and the heat treatment by the various regimes of high-temperature nickel alloy ChS70VI for gas-turbine blades.

1. Section Institute of Mechanic Dynamic, German Society for Material Science,
FUN University Hanover, Germany,
2. Chair of physical metallurgy, Institute of Machine-Building LMZ-VTUZ at Leningrad, Russian Federation

Fatigue design of A356T6 under multiaxial loading

Y. Nadot[1], M. Roy[2], D.M. Maijer[2], M. Iben Houria[3], R. Fathallah[3]

A356T6 is a widely employed casting alloy in the automotive industry. This material is comprised of a dendritic microstructure with Silicon particles, intermetallic needles, pores and oxide films that dictate the fatigue behaviour. While this behaviour is relatively well characterised under tension loading, there are very few results are available under torsion loading or with the effect of a mean stress. The purpose of this study is to demonstrate experimental results on A356T6 under multiaxial loading with the effect of mean stress.

Experimental Kitagawa diagrams are produced for cast A356 T6 containing natural and artificial defects. Results are obtained for three different loadings: tension, torsion and combined tension-torsion, for load ratio R = -1 and R = 0. The experimental critical defect size determined is 400 +/- 100 µm in A356 T6 under multiaxial loading. Below this value, the microstructure governs the fatigue limit mainly through the SDAS. We compared four theoretical approaches to simulate Kitagawa diagram: Murakami's equation, a defect is equivalent to a crack using Linear Elastic Fracture Mechanics, the Critical Distance Method (CDM) proposed by Susmel and Taylor and the gradient approach proposed by Nadot. It is shown that CDM and gradient methods give very good results but need three fatigue data for the identification.

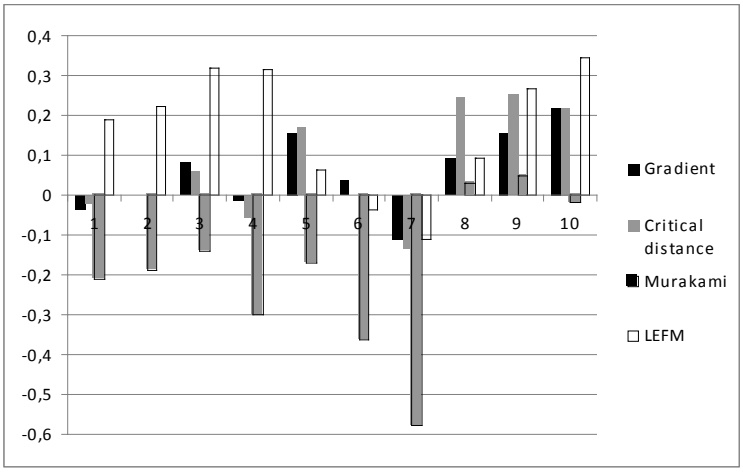


Figure 1: Quantitative comparison between simulations and experimental results for the four approaches tested.

1. Institut PPrime - CNRS - Université de Poitiers - Ensma - UPR 3346 - Département Mécanique des Matériaux - Téléport 2 - 1 Avenue Clément Ader - BP 4019 - 86961 Futuroscope Chasseneuil Cedex – France
2. Dept. of Materials Engineering, The University of British Columbia, Vancouver, BC, Canada V6T 1Z4
3. LGM, Ecole nationale d'Ingénieurs de Sousse, Avenue 18 janvier 1952 4000 Sousse, Tunisia

Fatigue properties prediction of forged components: influence of the process

M. Puget, C. Doudard, S. Calloch, F. Boucher
(Laboratoire Brestois de Mécanique et des Systèmes :
Ensta Bretagne, 2 rue François Verny 29200 Brest, France)

Fatigue life prediction of structures remains a difficult task. This is particularly true for hot-forged components. During the forging operation, the material is significantly hot-strained which induces changes of mechanical properties (e.g., yield stress, fatigue limit,), microstructure, generation of residual stresses and cumulated plastic strains. An efficient fatigue life prediction requires the determination of the influence of these parameters on fatigue properties. Nevertheless the study of each parameter (evolution of the microstructure, cumulated plastic strain,) by traditional fatigue tests campaigns is cost- and time- prohibitive.

In order to reduce the time necessary for fatigue life characterization, we are using a method which we developed the last few years. The efficiency and the reliability have already been shown by several research teams. The proposed method, so-called self-heating, allows to determine with a single test specimen the fatigue properties of the studied materials. The process influence on the fatigue behavior is accounted for by testing samples with a non standard initial state and is representative of the manufacturing process. Various non standard states are being studied with different deformation ratio (80% and 20%), different grain sizes (G=9 and G=5) as well as standard materials specimen with shot-peened or polished surface treatments. Finally we are proposing a two-scale probabilistic model for high cycle fatigue that accounts for the influence of the materials initial state on fatigue properties.

This model is coupled with a finite element analysis to determine the strain/stress state after the forging process of the component and will be used to predict the fatigue life of a hip prosthesis.

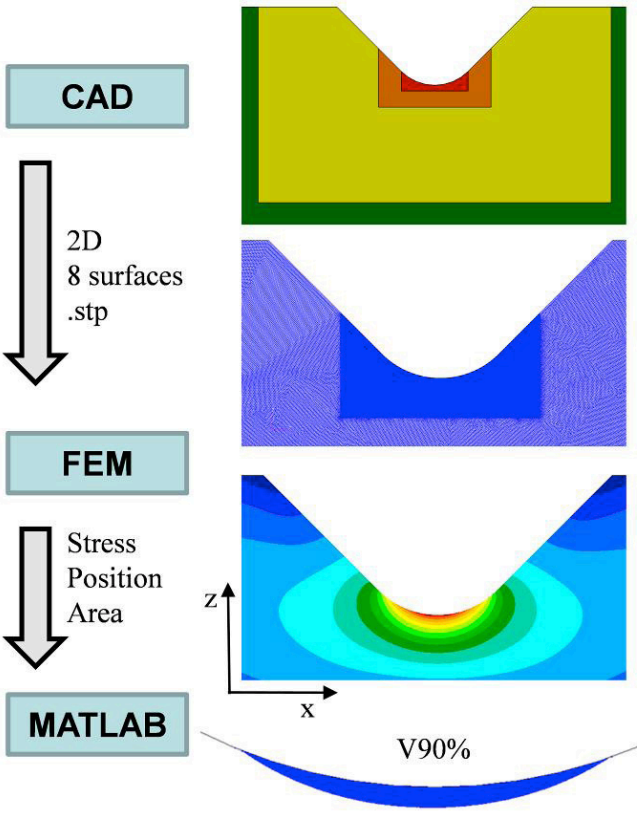
Evaluation of the highly stressed volume as design parameter for fatigue strength of notched aluminium specimens

B. Van Hooreweder, R. Boonen, D. Moens, P. Sas
(Department of Mechanical Engineering (PMA), K.U.Leuven, Belgium)

Stress concentrations are always present in real-life mechanical components, often in the form of grooves, fillets, keyways or holes. Although a variety of methods are available to analyze the influence of these stress raisers on the fatigue life of materials, it is still very difficult to account for this effect.

This paper covers the fatigue analysis of notched aluminium components loaded in reversed bending using the highly stressed volume method. Specimens with different notch geometries are tested at high frequency by means of a straightforward test rig. The highly stressed volume is precisely calculated using finite element software in combination with Matlab for post-processing. The endurance limit is determined using a minimum amount of samples and the application of the staircase method.

The results indicate that the highly stressed volume is a relevant and efficient design parameter to account for notch-effects in aluminium specimens.



Multiaxial Fatigue Limit Evaluation by Criteria Based on von Mises Stress

J. Papuga, M. Hronek, M. Vargas
(Czech Technical University in Prague, Prague, Czech Republic)

The paper focuses on the computational evaluation of the set of experiments gathered in the FatLim database (www.pragtic.com/fatlim.php). The experimental results correspond to fatigue limits obtained under multiaxial loading, where the loads on individual load channels are either constant or harmonic. The experiments are related to smooth unnotched specimens. The final set of carefully selected 407 experiments is used as an input for analyses of validity of various criteria based on Mises stress.

The trend today tends to more complex multiaxial fatigue analyses and there are numerous criteria proposed for such a solution. These criteria are often based on an evaluation of the stress state on a set of separate planes. Logically, in comparison to common uniaxial calculation procedures, the solution is more complicated and costs more computational effort. On the other hand, criteria based on Mises stress are very simple and efficient for any immediate use. In comparison to multiaxial methods, the computational procedure is so simple, that the engineers are able to implement them by themselves for an automated evaluation of FEA-results. Therefore, in addition to our previous work on multiaxial criteria, our team focuses now on these simple analytical tools. We have collected different methods based on Mises stress and analysed their preditictive capability on the aforementioned experimental set. In addition to their mutual comparison under various load conditions (in-phase, out-of-phase, with/without mean stresses,…) they were compared also with the most prominent multiaxial criteria.

The results are very interesting. Overall, if the complete test set is evaluated, the best of these simple methods are comparable with the worse half of multiaxial methods, which could be expected. Nevertheless, it can be found that the group of sets realized on brittle materials substantially worsens the prediction results of the methods based on Mises stress. If only ductile materials (352 experiments) are accepted to the comparison, the results of some of the Mises stress based criteria can be compared with many multiaxial models and if classified, could be evaluated as an average as regards the quality of the prediction. The detailed overview of results can save a lot of the effort invested into programming some multiaxial model, which are today used even in commercial fatigue solvers. On the other hand, there are multiaxial criteria, which provide prediction results with two times smaller range of relative error in the fatigue limit estimation, namely the Papuga PCr method.

A computational fatigue approach to threaded connections

D. Bellett1, F. Morel1, H. Mejia
(LAMPA, Arts et métiers ParisTech, Centre d'Angers, France)

The fatigue design of threaded connections is a complicated task due to the high stress concentration factors, the multi-axial stress state at the thread root and the fact that the tightening torque plays a very important role in the fatigue performance of the connection. In an industrial context, the design of threaded connections is largely based on empirical relationship, handbook recommendations and the experience of the designer. The French company SERTA manufactures hydraulic actuators and are regularly confronted with this issue. This work was motivated by their need to have a fatigue design strategy that gives them greater confidence and flexibility in their designs. The threaded connection between a piston and a piston rod of a hydraulic cylinder is studied in this work (see the figure below).

A local fatigue approach, based on the concept of elastic shakedown at the thread or notch root is proposed, and shown to be well suited to the relatively short fatigue lives targeted (i.e. less than 300000 cycles). Two-dimensional, axisymmetric, elasto-plastic finite element models are developed to determine the local cyclic stress state. Contact elements and a piston / rod geometry with an initial inter-penetration are used to model the tightening torque. A non-linear combined kinematic and isotropic hardening law (Lemaitre and Chaboche) is used to describe the cyclic plastic behaviour of the material. Constant strain cyclic tensile tests have been done to identify the hardening parameters of the steel investigated.

It is shown that the local cyclic stress, at the most severely loaded thread notch root, can be classed as either: elastic shakedown, plastic shakedown or cyclic racketing. And that this behaviour is dependent on both the applied hydraulic pressure and the tightening torque. The phenomenon of "loss of contact" at the shoulder between the piston and rod can also be predicted. Full scale experimental tests conducted by SERTA provide good correlation with the results of the proposed methodology, for the targeted number of cycles.

This work was conducted within the framework of commercial collaboration between SERTA and Arts et Métiers ParisTech Angers, hence due to reasons of confidentiality, this article focuses on the proposed methodology and contains only limited, normalised results.

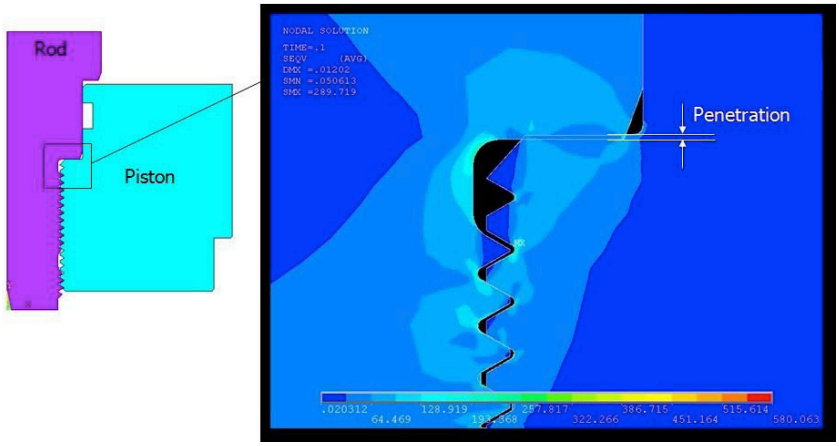


Figure 1 – Finite element analysis of the threaded connection taking into account the tightening torque

Designing Adhesively-Bonded Joints for infinite lifetime when subjected to creep and (or) fatigue loadings

J.P. Jeandrau
(Cetim, 7, rue de la Presse, BP 802, 42027 Saint-Etienne, France)

A methodology for designing structural adhesively-bonded joints made with metallic, composite or glass adherends and structural elasto-plastic adhesives subjected to fatigue and (or) creep loadings is described in this paper.
This methodology is based on analytical methods [1], [2], [3], [4] for simple configurations or the finite element method for complex structures enabling the designer to calculate the stress distribution in the adhesive layer .

In previous studies [5], [6], it was shown that the intrinsic mechanical characteristics of the adhesive could be determined on "bulk" specimens in tension or on thick-adherend shear test (TAST)specimen (NF-EN 14869-2) and that the Von-Mises strength criterion could be used within the linear elastic behaviour of the adhesive.

In this present study, the TAST is used to characterise two structural adhesives at room temperature under static and fatigue loadings.
SN curves up to 10^7 cycles (frequency: 30 cps) are given and the fatigue limits (maximum shear stress) are derived from these curves for both adhesives. The non-failed specimens (after 10^7 fatigue cycles) were tested in static shear and no damage was observed.
It was shown also that the fatigue limit was slightly higher than the static elastic limit of the adhesive in "pure" shear.
Fatigue tests were also monitored on single-lap shear specimens (NF-EN 1465) with these two adhesives in the same conditions (frequency, RT ..). SN curves and fatigue limit (maximum load) were obtained. Stress distributions in the single-lap shear specimens bonded with these two adhesives were calculated using Hart-Smith analytical method [1].
A good correlation was observed between the experimental fatigue limit (maximum load) at 10^7 cycles obtained on single-lap joints (SLJ) and the predicted one determined by stress distribution computation using the Von-Mises criterion and the "static" elastic limit of the adhesives obtained on TAST specimens.

Further work is carried out on adhesives with visco-elasto-plastic or hyper-elastic behaviours and more complex strength criterions.

Références :

[1] : Hart-Smith, L.J, NASA CR 112236, (1973).
[2] : Williams, J.H, J Adhesion, N°7, (1975), p 97.
[3] : Lubkin, J.L and Reissner, E, Trans ASME, vol 78, (1956), p 1213.
[4] : Adams, R.D and Peppiat, N.A, J Adhesion, N°9, (1976), p 1.
[5] : Jeandrau, J.P, Int J Adhesion and Adhesives, vol 6 - N°4, (1986), p 229.
[6] : Jeandrau, J.P, Int J Adhesion and Adhesives, vol 11- N°7, (1991), p 71.

A probabilistic high cycle fatigue model applied to cast Al-Si alloys

I. Koutiri, D. Bellett, F. Morel
(Lampa, Arts et métiers ParisTech, Centre d'Angers, France)

In this work, the high cycle fatigue behavior of cast hypo-eutectic Al-Si alloys is investigated. It has been observed that different fatigue initiation mechanisms can occur in these materials depending on the presence of different microstructural heterogeneities (i.e. micro-shrinkage pores, Si particles, Fe-rich intermetallics, DAS of the Al-matrix, etc).

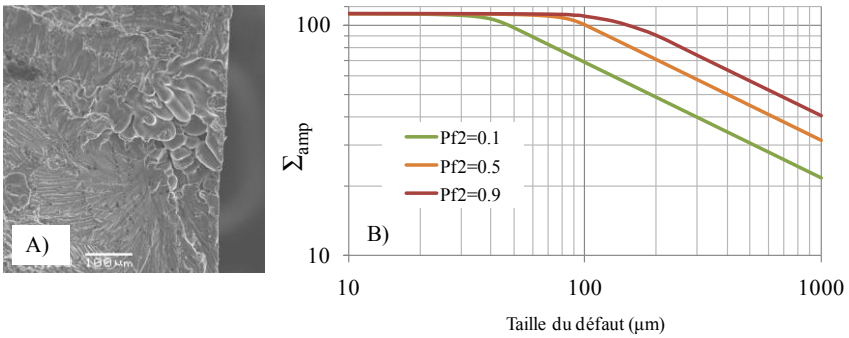
These mechanisms can be summarized as follows:

- For an alloy subjected to a HIP treatment, whereby the presence of micro-shrinkage porosity is minimized, [Gao et al 2004] observed that fatigue crack initiation is controlled meso-plasticity in the Al-matrix which is largely influenced by the presence of Si-particles and intermetallic precipitates. These authors propose a "micro-cell" model containing these microstructural features which is assumed to be the basic unit of microstructure.

- For alloys in which the micro-shrinkage porosity volume fraction is higher, these features are responsible for crack initiation. Moreover, higher experimental scatter is observed, which can be linked to the distribution of the pore size. Plane bending fatigue tests have been performed on material extracted directly from cylinder heads, cast by PSA, to estimate this scatter.

For the first mechanism, meso-plasticity plays a fundamental role. Hence the classical multiaxial fatigue framework based on the concepts of elastic shakedown, originally proposed by Dang Van is appropriate. However, for the second mechanism, where fatigue crack initiation is controlled by the micro-shrinkage pores, a fracture mechanics type approach appears more suitable.

In this work a high cycle multiaxial fatigue criterion, which is capable of describing these two mechanisms, is proposed. The model contains the same principal ingredients as the one developed by [Pessard et al 2011]. It uses a probabilistic framework to link the two different damage mechanisms that are observed, and can take into account the mean stress and the effect of a biaxial stress state.



A) SEM Image of fatigue crack initiation from a micro-shrinkage pore
B) Probabilistic Kitagawa type diagram resulting from the proposed model

Development of a Two Scale incremental model for multiaxial fatigue in an industrial context

A. du Tertre (Snecma Space Engines Division, Vernon, France)
R. Desmorat (LMT, Cachan, France)

Since 2005 a complete development program based on the LMT incremental Two Scale Model for fatigue life prediction in multiaxial high cycle fatigue has been conducted by the Space Engine Division of Snecma in order to cope with high stress ratio loadings applied on components, eventually locally plastified. This project went through an evaluation phase followed by improvement works and finally a validation approach implying several multiaxial fatigue tests campaigns on different materials.

This article aims at summarizing the principal theoretical evolutions obtained so far.

Thus, a first evaluation of the model's prediction performances on a batch of Titanium alloy notched specimen at low temperature allowed to identify different improvement axis. Among them, the implementation of Drücker-Prager term into the plastic criterion function (Barbier & al. 2009) was a significant one. It allowed to improve the model's ability to take the mean stress effect into account.

Since then, the model has been evaluated on different bi-axial tests and appeared to be easy to use and to identify thanks to the associate DAMAGE 2009 post-processor software.

Relationship between microstructure and fatigue damage of alternator fans

F. Léaux[1] , J. Bouquerel[1], J.-B. Vogt[1], F. Palleschi[2]

Key words: Low cycle fatigue, fatigue life prediction, damage parameter, local plasticity, finite element method.

Summary: Car alternators are cooled by fans, which are subjected to start-stop cycles, causing fatigue damage and finally fracture. The geometry of these fans is optimized to ensure the best heat evacuation with the smallest size. However, it also results in a complex fatigue behaviour and makes the life time predictions difficult. Thus, to assess the life time of the component in real conditions of use, an appropriate damage parameter needs to be found. In this study, a damage criterion method is developed with a metallurgical approach. This is based on evolutions of the material during cyclic loading, such as fatigue behaviour, microstructure changes...

Fatigue specimens are subjected to various fatigue test conditions in order to understand the influence of loading parameters on the stress-strain response. Besides, a multi-scale metallurgical study allows to understand microstructural evolutions of the material. Indeed, the development of dislocations structures, discernible by Transmission Electron Microscopy (TEM), reflects the accommodation of the cyclic plasticity. Nevertheless, since the so-found observations are qualitative and limited to the grain, a larger-scaled and quantitative method is needed to complete the metallurgical study. Electron Back Scattered Diffraction (EBSD) method, based on the diffraction of the crystallites, allows to go further. Indeed, the use of different criteria based on misorientation distribution approaches leads to a correct evaluation of the local plastic strain at a mesoscopic scale. In addition, this method can be applied at any place of a part (e.g. in the root of a notch) and is able to make allowance for stress concentration effect of a notch.
All these microstructure changes are cyclic plasticity accommodation markers (see Figure below) and are connected to the cyclic solicitation during fatigue life of lab specimens or of fans after real use.
These understanding and quantifications lead to establish a damage criterion and a life time model based on the fatigue characteristics of the material.

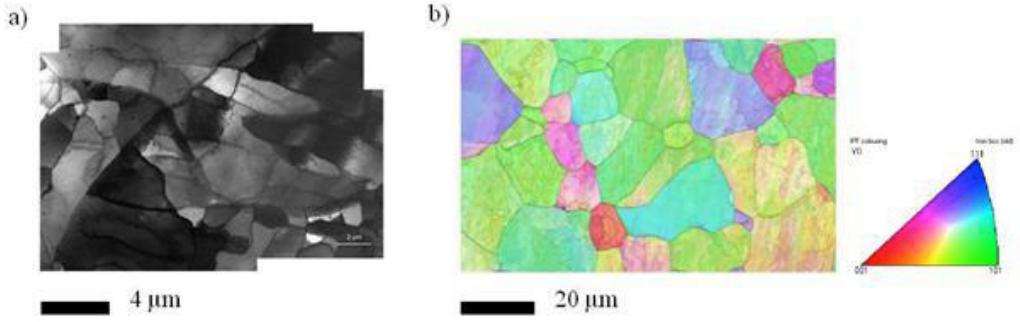


Figure: Dislocations cells in a grain a) and Orientation Imaging Map b).

Moreover, a numerical approach using finite elements software is added to the study in order to take into account the complex geometry of the real part. Our experimental results will allow to refine the finite element method. A life time model for the part in real use conditions will be proposed and matched to real life time of part in test bench.

1. Umet – UMR CNRS 8207, team Métallurgie Physique et Génie des Matériaux.
Université Lille 1, 59655 Villeneuve d'Ascq, France
2. Valéo Systèmes Électriques, 2, rue André Boulle, 94046 Créteil

Accelerated fatigue test for automotive chassis parts design: an overview

P. Beaumont[1], M. L. Facchinetti[1], G. Martin Borret[1], F. Guerin[2], P. Lantieri[3]

Fatigue strength is of prior concern for automotive chassis parts design. In a reliability framework, its assessment still requires long and expensive test campaigns. In particular, high-cycle endurance tests usually involve several specimens undergoing million-cycle procedures.

In order to reduce the specimen number (e.g. expensive prototypes) and to shorten testing procedures (i.e. time-to-result delay), Accelerated Life Tests (AFT) are developed under the constraint of the needed high-reliability assessment. These methods do not involve high frequency load cycling, but are mainly based on stress magnification and fatigue damage equivalence.

In this paper, at first a review of the fatigue test procedures currently used in the automotive industry (e.g. Stair Case and Locati) and AFT state-of-the-art from academic research is addressed (e.g. Step-Stress ALT [-]). Thus, numerical simulations are used in order to assess the reliability of these test procedures and to compare their performance with respect to a cost function based on the number of specimens and the number of cycles required. Finally, the application of AFT for chassis parts is introduced and discussed.

1. PSA peugeot Citroën, 2. ISTIA Université d'Angers, 3. Arts et Métiers Paris Tech

Fast determination of the influence of a plastic pre-strain on the high cycle fatigue properties of steel sheets from self-heating measurements

R. Munier[1,2], C. Doudard[1], S. Calloch1, B.Weber[2]

The high cycle fatigue (HCF) is a major element for a great design of automotive parts. A wide part of the steel sheets for the automotive industry are stamped, sometimes deeply. During this operation, the steel is plastically strained in different directions inducing thickness and cumulated plastic strain variations. In other words the material has changed and its current fatigue properties are no more the same as initial ones. A good prediction of the fatigue behavior requires the determination of the fatigue properties of the pre-strained material.

Nowadays, the evolution of HCF properties is often neglected. There are two major reasons for this lack. On the one hand, a good finite element simulation of the forming operation to predict pre-strain field is still a difficult task. On the other hand the time dedicated to traditional fatigue test campaigns (e.g. staircase method) to quantitatively identify this influence is prohibitive. One month at a load frequency of 30 Hz and 25 specimens are necessary to obtain one S/N curve. To determine faster this influence, it is proposed to use self heating measurements under cyclic loadings.

To illustrate this approach, several steel grades are under interest. By using a two scale probabilistic model, describing the microplasticity appearance, at the origin of fatigue phenomenon, a link between the self-heating curves (representing the steady-state temperature elevation relating to the stress amplitude) and the fatigue properties of the steels is obtained. From the parameters of the model, identified on the self-heating curves, the evolution of the fatigue properties according to the pre-strain level is shown for different pre-strain levels. Fatigue results confirm the evolution obtained with self-heating measurements.

1. Laboratoire Brestois de Mécanique et des Sytèmes (LBMS), Ensta-Bretagne, Brest, France
2. ArcelorMittal Maizières Research & Development, Maizières-les-Metz, France

Fatigue Testing by Means of Miniature Test Specimens

J. Volak,
(Skoda Research Ltd., Plzen, Czech Republic),
V. Mentl
(University of West Bohemia in Pilsen, Czech Republic)

Keywords
Fatigue, S - N curves, miniature test specimens.

The steam turbine rotors represent large components both in radial and axial directions. Their local properties generally differ from one forging to another, or if we compare head and bot-tom parts of the original ingot, or central and circumferential locations of one rotor body respectively, or if we compare the properties of separate discs e.g. in the case of welded rotors. These differences stem from both even slight changes in the chemical composition (of separate heats or even within one ingot) and thermo-mechanical treatment and in the differences in technology with re-spect to the real shape and size of the forgings in question [1].

At present, questions on quantitative evaluation of remaining lifetime become urgent and because fatigue is the most frequent cause of materials degradation and resulting structural compo-nents failures, the most important means of remaining lifetime assessment is the evaluation of fati-gue properties before and after some time of service. The original material data are usually tested by means of classic test specimens, which can be hardly used in case of components in service, where there is no possibility to withdraw sufficient volume of representative material for the classic test specimen manufacturing. In such cases today, new modern methods of semi-destructive removal of a small volume of test material by grinding or an electro-discharge are utilized. This makes it possi-ble to produce a miniature test specimens.

The paper describes the results of fatigue tests performed on miniature tests specimens in comparison with classic fatigue tests for several steels applied in power producing industry. Special miniature test specimens fixture was designed and manufactured for the purposes of fatigue testing at the Zwick/Roell - Amsler 10HPF5100 test machine. The miniature test specimens were produced by water-jet cutting from the large test specimens. With respect to the specimen shape, stress concentration and multiaxial stress situation had to be taken into consideration for the purpo-ses of comparison with the classic test specimens [2].

References

[1] Mentl V.: Mapping of Fracture Toughness Values in Large Forgings, Proc. ECF 18, Dres den, Germany, 2010, ISBN 978-3-00-031802-3.
[2] Volak J., Mentl V.: A Comparison of Fatigue Characteristics of Structural Steels Measured by means of Classic and Miniature Test Samples, Proc. ICMFF9, Parma, Italy, 6/2010, ISBN 978-88-95940-31-1.

Methodology to account for corrosive environment on accelerated fatigue test on mooring chains within the Chain Out of Plane Bending (OPB) fatigue Joint Industry Project (JIP)

L. Rampi (Engineering - Mooring Structures, SBM Offshore, Monaco)

Eight years ago, several mooring chains of an offloading deepwater buoy failed prematurely within a very small time frame. These chains were designed according to conventional offshore fatigue assessment using API recommendations. With this first deepwater buoy application, a new mooring chain fatigue mechanism has been discovered. High pretension levels combined with significant mooring chain motions caused interlink rotations that generated significant Out of Plane Bending (OPB) fatigue loading. Traditionally, interlink rotations are relatively harmless and generates low bending stresses in the chain links. The intimate mating contact that occurs during the proof loading and the high pretension of the more contemporary mooring designs have been identified as aggravating causes for this phenomenon.

A Joint Industry Project (JIP), gathering 25 different companies, started in 2007 to better address this fatigue mechanism and propose some mooring chain fatigue design recommendations.

Within this project, full scale fatigue tests are in progress to mimic the OPB fatigue mechanism. To obtain results in a reasonable time-frame, these full scale tests are running on a dedicated fatigue bench at 1 Hz (instead of a normal offshore frequency of 0.1 Hz) in a corrosive seawater environment, on 2 different chain sizes. In parallel, tests on small samples, taken from mooring chains, have been done to better understand the influence of the corrosive environment on chain fatigue, by separately addressing the crack initiation and the crack propagation stages.

This paper will describe the tests done on small samples and the global methodology proposed to account for the higher frequency in the full scale tests (i.e. 1 Hz rather than the normal offshore frequency of 0.1 Hz) on the mooring chain OPB fatigue performance. This will also address the chain size effect.

Fatigue des engrenages de boîte de vitesses

P.E. Dumouchel
(Bureau de calcul boîte de vitesses, PSA, La Garenne Colombes, France)

Les engrenages de boite de vitesses sont soumis à un grand nombre de cycles et peuvent présenter un mécanisme de ruine des dentures en fatigue (fatigue polycyclique). Ce mode de ruine est pris en compte dans les processus de dimensionnement des engrenages, mais présente cependant quelques lacunes. Plus particulièrement les approches de dimensionnement classiques en fatigue intègrent uniquement l'amorçage de la fissure en ne prenant pas en compte sa propagation. La prise en compte de la propagation des fissures sur les dentures est primordiale car lors de l'apparition d'une fissure sur une dent, l'énergie élastique associée aux dents en prise est redistribuée sur les dents saines se trouvant à proximité de la dent fissurée. De ce fait la tenue des engrenages en fatigue est sous estimée lorsque le dimensionnement est réalisé à l'amorçage.

Ce mécanisme de décharge élastique sera présenté au cours de cette communication.qui s'articulera autour de trois points. Un premier point présentera une simulation numérique de ce phénomène de décharge élastique à partir d'une simulation de la propagation de fissure en 3D sur un couple de dent en prise. Un deuxième point permettra de présenter les règles de dimensionnement mise en place afin de traduire ce phénomène de décharge élastique. Plus précisément une méthode énergétique du problème simplifié sera introduite afin de s'affranchir de la complexité du calcul 3D de propagation de fissure. Et pour finir un troisième point présentera un cas pratique d'utilisation de cette méthode sur des engrenages de boite de vitesses.

Computational and experimental investigation of fatigue life under fretting conditions

M. Španiel, J. Jurenka, J. Kuželka, M. Nesládek, J. Růžička
(Czech Technical University in Preague, Fac. of Mech. Eng.)

The fretting fatigue is special type of fatigue damage which takes place usually near contact interface of bodies with no or small relative movements. There are three basic factors with major influence: field of stresses at the vicinity of contact interface, partial slipping of contact surfaces and friction between contact areas. Contact conditions can be divided into three ranges regarding magnitudes of partial slips: the stick, slip and gross sliding range. Fatigue life considerably decreases in range of partial slips. The paper summarized in this brief text deals with research of phenomenological fatigue criteria applied on contact fatigue under fretting conditions.

Evaluation of fretting fatigue damage based on phenomenological criteria calibrated with relatively small set of experiments is objective of presented research. Verification and/or formulation of new fretting fatigue criteria have to be based on reliable experimental and computational results. In practice, quantities needed for fretting fatigue evaluation, including contact relative slips, are usually calculated using finite element method. Computational evaluation of contact conditions is strongly dependent on phenomenological description of friction. There are several commonly implemented models of friction in finite element codes. These models use experimentally determined parameters, as friction coefficient that may be dependent on specific conditions differing from experimental ones. Moreover, numerical enforcement of law of friction may be chosen from several possibilities in Abaqus FE code used in presented research. That is why we tried to verify numerical model of fretting experimental setup.

The displacement and strain field measurement at the vicinity of contact interface is very complex and difficult. Some of the optical measuring methods seem to be one of the possible ways to identify these fields. Optical measuring system DANTEC DYNAMICS Q-450 employing digital image correlation method for displacement field evaluation was used to verify numerical model of friction conditions. In order to test the system under similar conditions to fretting fatigue the flat notched specimens were treated.

Numerical analysis using finite element method was used to determine stress fields and relative slips in contact interface of specimen in experimental setup. These quantities serve as input to several fatigue criteria that are compared each to other and evaluated.

Influence of surface integrity by high precision hard turning on rolling contact fatigue

N. Jouini, P. Revel, M. Bigerelle
(Laboratoire Roberval, UMR 6253, UTC/CNRS, Centre de Recherche de Royallieu, Compiègne, France)
G. Thoquenne
(Cetim, Senlis, France)

Finishing components of hardened steels, such as bearings, gears, shafts, and rails produced by high precision turning are receiving increasing attention as an attractive alternative and environmental friendly to the grinding process. To replace it, it is important that it produce comparable surface integrity that would improve component life in rolling contact.

In this paper the effect of surface integrity on Rolling Contact Fatigue (RCF) of AISI 52100 bearing steel (60-62 HRC) is investigated. The surface integrity is characterized by surface roughness measurements, subsurface microstructure analysis and residual stresses evaluation.

Machining experiments are carried out varying cutting parameters cubic Boron Nitride (c-BN) cutting tools under dry condition using. Fatigue life tests are performed on a twin-disk machine. The SEM observations of the transversal cross-section show metallurgical transformation, the presence of very fine white layer (<1µm) on the top surface and thermal affected zone of 35 µm in the sub-surface. Experimental results suggest that the effect of surface roughness on RCF life is more signiﬁcant than the effect of the level of compressive residual stresses. Indeed, RCF life decreases with the increase of the average roughness (Ra). The roller bearing components can attain 5.2 million cycles with low Ra (Ra = 0.1 µm), and 0.32 million cycle with high Ra (Ra = 0.25 µm). In comparison with grinding processes, the bearing components attaint 1.2 million cycles with conventional grinding (Ra = 0.2 µm) and 3.2 million cycles with grinding followed honing (Ra = 0.05 µm). Therefore, the high precision hard turning allows to improve the surface integrity and RCF life of the roller bearing components.

Simulation of fatigue crack propagation under contact loading conditions

J. Jurenka, M. Španiel
(Czech Technical University in Prague, Technická 4, 166 07 Prague 6)

Numerical simulations of pitting arise phenomena on the gear teeth is presented in the article. The presented approach is based on the assumption that pitting (pits) are a result of fatigue crack propagation under complex (rolling, sliding, lubricated) contact loading conditions.

The solution approach consisted of numerical simulations of fatigue cracks growth in the FEM framework. Penetration of the fluid lubricant into fatigue (pitting) cracks is simulated using special cavity finite elements, which allow to include so called lubricant closure inside crack. Fatigue (pitting) crack growth predictions are based on the Paris law in conjunction with FEA of fracture criteria.

The simulations were carried out under the commercial code ABAQUS CAE FEM programme which allows to develop in-house codes using the Python scripting language and which is the basis of all FEA including the simulation of the contact loading conditions and the crack growth.

An acceptable agreement of the numerical and experimental results confirms (not proves) that fatigue crack propagation can present a true damage mechanism of the pitting wear rise.

Modeling of plasticity in spectral methods for fatigue damage estimation of random vibrations

H .Rognon, T. Da Silva Botelho, I.Tawfiq
(Lismma (EA2336) Supméca, Saint-Ouen, France)
A.Galtier, M.Bennebach
(Cetim, Senlis, France)

Many mechanical structures are subjected to random vibrations due to external forces (forces, acceleration,...). The best fatigue design should allow improving the safety of structures and reducing manufacturing cost and design. We present here, a spectral method for estimating the fatigue damage to the polycyclic and low cycle fatigue domains.
The fatigue phenomenon is usually studied in time domain because loads are quasi-static and so there are no dynamic response of the structure. Within the framework of random vibration, mechanical structures have a dynamic response. This implies some problems for the calculation of stress for fatigue analysis:
- Convolution integral (problem of computing time)
- Random aspect of vibrations (consideration of random processes)
- Potential local plasticity (nonlinear behaviour – material non-linearity)

A solution to these problems is to study the fatigue phenomenon in the spectral domain. In the frequency domain, random vibrations are represented by the PSD (Power Spectral Density). Spectral methods are currently applicable in polycyclic fatigue domain for stationary ergodic Gaussian vibrations. They are based on a frequency calculation in stress. Spectral methods are limited by assumptions such as material behaviour or geometrical linearities. The method developed in this work allows plasticity modelization in confined areas for damage calculus. Another advantage of the method relies on its strain formulation which allows fatigue law computation (Manson-Coffin-Basquin). This modification enables to extend application domain of spectral methods to policyclic and low cycle fatigue domains.

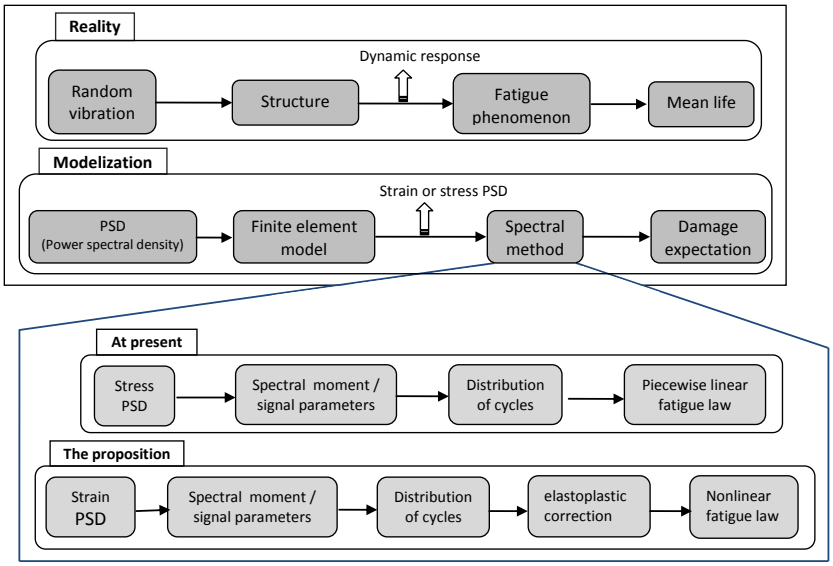


Fig1 : Description of vibration's fatigue process and spectral methods

To validate the method, we performed several correlations between experimental, numerical analysis and Monte-Carlo simulations. Random vibration used are a narrow band with a uniaxial strain state, a narrow band with a multiaxial strain state, a white noise with a multiaxial strain state.

Contact: herve.rognon@supmeca.fr

Vibration fatigue analysis of a strut for airborne radar

R. Luo, J. Lindahl
(Electronic Defence Systems, SAAB, Gothenburg, Sweden)

Struts for airborne radar are subjected to a random form of loading such as wing flutter, vortex shedding or engine vibrations, vibration of the aircraft and the radar, and so on. Vibration measurements have been performed on the struts to characterization the "strut noise" fatigue problem which has introduced a detailed characterization of noise, vibration and fatigue life. Transverse forces on the struts due to the random vibration should be considered when estimate the fatigue life of the struts.

To estimate the transverse forces at end of the strut due to the strut vibrations, an inverse analysis is performed. First, a frequency response analysis is performed on a finite element model to compute the transfer function. Then the PSD response at the measured location that caused by PSD input loading is obtained by multiplying the transfer function by the input loading PSD.

Two kinds of external loads have been assumed here. One is a uniform distributed external load that applied across the aluminium profile as excitation source, while the other one is a base excitation, e.g. acceleration at the end of the strut. The PSD load that can generate the same acceleration response at the measured location is used to calculate the PSD of the shear force.

The fatigue life of the strut can then be estimated using frequency based fatigue techniques.

Obtaining a Swept Sine on Random Vibration profile for powertrain mounted component qualification

B. Beaum[1], F. Kihm[2], A. Halfpenny[3], J.M. Chambord[4]

As part of the design and validation of engine-mounted components, it is essential to be able to specify precisely the vibratory mechanical environment in which they will operate. The scope is to optimize the reliability of such components submitted to loads coming from both the engine and road profile. It also allows reducing development costs and time scales.

This article presents a methodology which enables to superimpose a swept sine and a power spectral density of acceleration to check the mechanical durability of engine- or gear box-mounted components. The first part covers the extraction of the deterministic parts from the random process using an order tracking method in the time domain to obtain the wave form of the dominant engine orders. The second part presents a mathematical process for the assessment of fatigue damage and extreme response spectra of a Swept-Sine-On-Random profile. In the third part, based on the test tailoring approach, the harmonic and random parts are superimposed to define a Swept-Sine-On-Random loading function that includes the customer's engine usage profile. Finally, some use cases showing the application of this methodology on industrial engines are described.

1. PSA Peugeot Citroën, La Garenne Colombes, France
2. HBM nCode Durability Products, Roissy-en-France,
3. HBM nCode, Advanced Manufacturing Park Technology Centre, South Yorkshire, United Kingdom,
4. 01dB Metravib, Limonest, France

Modelling Fatigue Spectrum of Aircraft Structure under Gust Loads

T. Reytier, C. Bes
(Université Paul Sabatier)
M. Bianciardi, A. Santgerma
(Airbus Opérations SAS, France)

The main purpose of the present work is to develop a new computation process in order to perform Fatigue and Damage Tolerance analysis on aircraft structure under gust loads.

Random gusts with various amplitudes and directions are considered, which leads to random multiaxial loads on the aircraft structure. In order to analyse these loads and induced high-cycle fatigue, the authors propose various methodologies in order to improve the computation of the dynamic response of the aircraft structure, the stress computation and the gusts statistics as well as the computation cost. Comparison between the various proposed methods will enable to choose the best process for F&DT analysis of aircraft structure under gust loads.

The numerous gusts encountered by the aircraft during its flight phases are represented by the Continuous Turbulence model as recommended by the certification authorities. The latter model considers the gust velocity as a stochastic process having a Von Karman Power Spectral Density (PSD). The loads¿ and stresses¿ Power Spectral Density functions induced by gusts are computed via the structural finite element model. The PSD computations entail the use of the aircraft¿s transfer functions.

The Fatigue Spectrum is the input for F&DT analysis. It describes all impacting events for the aircraft structure during its life and gives the stress values at each computation point. We stress that gusts are only one part of these events and it is the only one defined in the frequency domain. From the PSD functions, temporal stress sequences have to be obtained in order to be included into the Fatigue Spectrum and combined with other events.

A first method will consist in distributing the gusts randomly according to external gust statistics built from in-flight measurement. Another way would be to distribute directly the stress occurrences following an analytical formula provided by certification authorities. The last method considered by the authors generates correlated stress time histories from the PSD functions. This method provides relevant mathematical results and enables to create directly stress temporal sequences that will be used in the Fatigue Spectrum.

Comparison between the three proposed methods aims at assessing the better way to represent the gust in the aircraft Fatigue Spectrum in terms of accuracy, computation cost and lead time of the process.

UCAV's dynamic behavior under rough aero-acoustic loading

F. Vidal de Saint Jean, M. Pouzargue
(Dassault Aviation, France)

This article presents the last improvements of Dassault Aviation in the field of aero-acoustic loads and vibrations resulting from the in-flight opening of a drone's weapon bay.

Within the context of the nEUROn programm, Dassault Aviation computes the aero-acoustic loads applied on the weapon bay panels and analyses their effects in term of acoustic fatigue and equipment's vibrations. Due to the frequency band involved and the aero-acoustic loads complexity, new methodologies and tools have been developed to predict the dynamic behavior of the structure in the middle frequency band field. Those methods have been validated and their limits identified through a wind test tunnel.

The real application of this work during the development phase is pointed at through: on the one hand, the acoustic fatigue impact on the structure design, on the other hand, the vibrations specifications for equipment qualifications. This last point is, for the first time, entirely computed with numerical simulations by Dassault Aviation.

Finally, the first confrontations of the specified environment with the equipments behaviour during qualification tests lead to discuss the method and consider prospects and improvements.

Vibratory fatigue qualification process for a helicopter-mounted turret

A. Khelifi
(Nexter Systems, 78022 Versailles, France)
L. Fouché-Sanseigne
(Nexter Systems, 18000 Bourges, France)

This publication describes the process of synthesis of the vibratory environment of an equipment item mounted on a carrier, from the measurements performed on the carrier to the equipment item's qualification test specification.

The standards supply standard values for the qualification tests of equipment mounted on a carrier but strongly recommend using actual levels measured on the carrier with putting in place of a synthesis process which we describe in this presentation.

The process of synthesis of the measurements relies mainly on the standards recommendations and the use profile of the carried over a given use duration. It thus makes it possible to guarantee the mechanical integrity of the equipment item over its complete lifetime.

The communication concerns the fatigue qualification of a helicopter-mounted turret. The multi-scale process developed by Nexter from 1997 onwards was applied. In this application case, it is based on measurements carried out in flight on the carrier and characterisations of the turret (Modal analysis, digital simulations, etc.).

The first stage of the process consisted in adjusting the model on the basis of the experimental modal analysis results: this analysis performed for several stress levels made it possible to update behaviour non-linearities (evolution of natural frequencies as a function of the loading levels).

The second stage of the multi-scale process consists in evaluating the dynamic response of the structure followed by the location of the critical areas (weak point location, risk of cracking). The last stage concerns the thorough study of the risk areas by including precisely the details and the geometric singularities of the sensitive areas identified previously; this stage results in an estimation of the fatigue life crack initiation.

Reliability assessment of an aerospace component subjected to fatigue loadings: APPRoFi project

B. Echard[1], N. Gayton[1], M. Lemaire[1], M. Afzali[2], A. Bignonnet[3], P-A. Boucard[4], G. Defaux[5], J-L. Dulong[6], A. Ghouali[7], F. Lefebvre[2], A. Pyre[7]

The assessment of reliability is nowadays a major challenge in the design of industrial structures. Codified deterministic methods are employed in industry to design structures subjected to fatigue failure. However, these methods do not give information about the probability of failure of the structures or about the most influential factors on the design. To obtain an accurate idea of the probability of failure and to efficiently design a structure without endangering its integrity, probabilistic approaches should be used.

In sectors such as the aerospace industry, the probabilistic approaches have to be used to give reliable information about the risk of critical situations. For this reason, French public laboratories (IFMA-LaMI, ENS-LMT Cachan, UTC-Laboratoire Roberval) and companies (Cetim, Snecma, Phimeca, Modartt) considered as experts in their domains of interest have gathered together to create the APPRoFi project – APproche mécano-Probabiliste pour la conception Robuste en Fatigue". Funded by the ANR – Agence Nationale de la Recherche, this project is based on the application of probabilistic approaches to assess the reliability of two industrial studying cases subjected to fatigue crack initiation. The project aims at demonstrating the interest and the contributions of such probabilistic approaches for industry.

This paper presents an overview of the methodology implemented to assess the reliability of a rocket engine studying case called "blade support" whose geometry is modified here for confidentiality reasons. The "blade support" is defined by a deterministic geometry, a random strength derived from fatigue tests performed on structures and specimens and an elastic-plastic material whose properties are random variables.

A random time variant displacement load is applied to the structure. It is characterised using nine flight spectra and a strategy to generate virtual rainflow matrices. This strategy defines the scatter observed on the nine empirical cumulative distribution functions of the displacements to create new flights. Finally, the reliability of the structure is assessed using a numerical method called AK-IS based on Kriging and Importance Sampling. It is used to obtain an accurate estimation of the failure probability for a low computational cost.

This paper presents the whole reliability methodology developed here and compares it to the one proposed previously in the CETIM's DEFFI project (Démarche Fiabiliste de conception en Fatigue pour l'Industrie) for the same structure.

1. Clermont Université, Institut Français de Mécanique Avancée, EA 3867 Laboratoire de Mécanique et Ingénieries, BP 10448, 63000 Clermont-Ferrand, France, mail: benjamin.echard@ifma.fr, nicolas.gayton@ifma.fr
2. Cetim, 52 avenue Félix Louat. BP 80067. 60304 Senlis Cedex
3. AB Consulting, 4. ENS Cachan/ LMT, 5. Phiméca, 6. Université de Technologie de Compiègne, 7. Snecma/ Vernon

Reliability assessment of an aircraft engine assembly: APPRoFi project

P.-A. Boucard[1], D. Néron[1], N. Relun[1], B. Echard[2], N. Gayton[2], M. Lemaire[2], M. Afzali[3], F. Lefebvre[3], A. Bignonnet[4], G. Defaux[5], J-L. Dulong[6], A. Otsmane[7], H. Cherouali[7]

In sectors such as aerospace industry, the probabilistic approaches have now become a priority in the components' design. For this reason, French public laboratories (Ifma-Lami, ENS-LMT Cachan, UTC-Laboratoire Roberval) and companies (Cetim, Snecma, Phimeca, Modartt) considered as experts in their domains of interest have gathered together to create the APPRoFi project – APproche mécano-Probabiliste pour la conception Robuste en Fatigue". Funded by the ANR – Agence Nationale de la Recherche, this project is based on the application of probabilistic approaches to assess the reliability of two mechanical components subjected to fatigue failure and which are designed by SNECMA. The project aims at demonstrating the interest and the contributions of such probabilistic approaches for industry.

The assessment of reliability is nowadays a major challenge in the design of industrial structures. To obtain an accurate idea of the safety margin and to efficiently design a structure without endangering its integrity, probabilistic approaches should be used. Moreover, before managing a probabilistic approach, a sensitivity analyse should be performed to identify the most influential factors on the design. Both these studies lead to very high computational costs, as a large number of calculations must be carried out: the greater the number of parameters considered, the greater the number of calculations.

This paper presents an overview of the methodology implemented to assess the reliability of an unmarked aircraft engine assembly that represents typical problematic encountered by Snecma. A specific numerical strategy [1, 2], has been used to reduce the computational time from several months to a few days: more than 2500 set of parameters have been studied taking into account variations of geometrical details, bolt pretension, rotation rate, external forces, Young modulus. This sensitivity analyse allows us to identify the influential parameters and to provide a database of the results that can be used to evaluate safety margin.

A random fatigue load is applied to the structure. It is characterised by random percentages which define the number of occurrences of each flight mission. The equivalent fatigue theory is used to represent this fatigue load by a single scalar [3]. On the other side, probabilistic fatigue curves are modelled to define the strength of the structure. In the end, the safety margin is obtained by comparing the strength and the load. To reduce the computational time, the failure probability of the structure is assessed using a numerical method called AK-IS based on Kriging and Importance Sampling. This method is derived from AK-MCS which combines Kriging and Monte Carlo Simulation [4].

References:

[1] Boucard, P.A., Champaney, L. A suitable computational strategy for the parametric analysis of problems with multiple contact. Int Jal for Numerical Methods in Engineering, 2003, 57, p. 1259-1282.

[2] Boucard, P.A., Buytet, S., Guidault, P.A. Une stratégie multi-échelle pour l'étude paramétrique de détails géométriques au sein de structures en contacts multiples. Revue Européenne de Mécanique Numérique, 2007, 16(8), p. 1011-1036.

[3] Thomas J.-J., Perroud G., Bignonnet A., Monnet D., Fatigue design and reliability in the automotive industry, European Structural Integrity Society, 1999, 23, p. 1-11.

[4] Echard, B., Gayton, N., Lemaire, M., AK-MCS: An active learning reliability method combining Kriging and Monte Carlo Simulation, Structural Safety, 2011, In Press: Corrected Proof.

1. LMT Cachan (ENS Cachan/CNRS/UPMC/PRES UniverSud Paris), 61 av. du Président Wilson, F-94230 Cachan, France, mail : boucard@lmt.ens-cachan.fr, neron@lmt.ens-cachan.fr, relun@lmt.ens-cachan.fr

2. Clermont Université, Ifma, EA 3867 Laboratoire de Mécanique et Ingénieries, BP 10448, 63000 Clermont-Ferrand, France, mail: benjamin.echard@ifma.fr, nicolas.gayton@ifma.fr

3. Cetim, 4. AB Consulting, 5. Phiméca, 6. Université de Technologie de Compiègne, 7. Snecma/Villaroche

A new reliability approach for the fatigue design of railway wheels

X. Lorang, T.M. Nguyen, C. Roux
(SNCF, Direction de l'Innovation et de la Recherche)
A. Ouradi
(MATIS Technology)

Wheels are part of the safety critical railway components. Hence, they are designed, manufactured and maintained in order to avoid any in-service failure. One of the main potential causes of breaking is the fatigue of the web. Therefore, to make the homologation of a wheel, fatigue requirements are defined in national and European standards which describe the numerical simulations and the tests procedures, the loads to be tested and the acceptable limits which include some safety margins.

These design, production and maintenance rules enable the railway industry to offer one of the most safe transport technology. Though, as they have essentially been established on the basis of the feed-back on existing materials and traffics, they are interdependent and do not leave place to innovations that would bring lighter or environmentally friendly solutions. At least, when a new design is introduced, some precautions in the maintenance have to be taken, increasing considerably the costs for the operators.

These observations indicate that existing design and maintenance rules need to be reviewed - or at last verified - so as to be adapted to a fast changing market environment and to allow for the safe introduction of innovations.

The aim of the study presented in this paper is to develop a new comprehensive fatigue design approach for the railway wheels in order to guaranty their in-service durability and reasonable maintenance costs.

The methodology starts with a loading analysis consisting in transforming temporal in-service load measurements into more simple "Fatigue-equivalent" loads, building the operating loads severity distribution and deducing relevant specifications. The resistance distribution of the wheels is then characterized. A probabilistic treatment of the data, based on the Stress and Strength Interference Analysis, determines the probability of failure. A correlation between the results obtained in this project and the current standards for existing wheels is finally made. The final objectives are to bring some technical elements to facilitate the homologation of innovative solutions or to quantify the impact of an evolution of the operating usages and, from a scientific and technical point of view, to help to switch from a traditional "safety margin approach" to a reliable approach.

Mechanical reliability approach in heterogeneous welding design in vibratory environement

A. Boucly, T. Grunenwald
(CEA DAM centre de Valduc)
P. Bonnet
(Société I-Comète)

This work presents a mechanical reliability application for the fatigue design of a welded structure under dynamic loading.

Numerical toolboxes are used. The main steps of the development are:
- Modal identification of the structure ;
- Probabilistic definition of the random variables (local geometry, material data, loading, resistance). The loading is established as the equivalent displacement associated with a distribution law regarding to damage of the structure ;
- Numerical parametric study to cover efficiently the range of interest of each variable ;
- Input of a damage criterion by means of local stress analysis ;
- Analysis of an optimized response surface to identify the distribution law of the local stress.
- Sensibility analysis of the structure reliability according to the random variables.

As an illustration, we applied this method to evaluate the resistance of an heterogeneous Tantalum – Ta6V welded structure. The effect of the selected parameters on damage and therefore on the structure reliability is evaluated. This method leads to a precise knowledge of the reliability sensibility to each parameter and is therefore a powerful tool to optimize the design of the structure.

Moreover, a related application of the method is presented. The power spectral density solicitation shows several critical frequencies ranges with high excitation levels. The first modal frequency of the structure must be dissociated from these frequencies ranges. Depending on location of this frequency, the structure reliability is quite different. By using reliability methods, one can evaluate a distribution law of this parameter in order to maximize the structure reliability. This distribution law has to be checked on the structure.

POSTERS

Multiparametric strategy dedicated to probability of failure calculation

N. Relun
(LMT / ENS cachan, 61, avenue du président Wilson 94235 Cachan cedex, France)

We propose a strategy to tackle the costly problem of performing parametric analysis in the case of non linear (elastic-viscoplastic) evolution problems, even if a large number of degrees of freedom and time steps are involved.
Parametric analysis can be used to determined parameters with the most influence but also in a probabilistic framework to determined the probability of failure knowing the probabilistic laws of parameters.
This later use is done in the ANR project APPROFI to deal with fatigue failure. This work is part of this project.

The strategy is based on two main techniques. The first one is the LATIN method which is a non incremental in time non linear solver. This solver works at each of its iterations on the entire time space domain. During a parametric analysis, the solver can be initialized with an already calculated solution when searching for the solution with new input parameters values. As two solutions with close input parameters values are also usually close, the number of iterations to compute the new solution very small.

The second technique is the Proper Generalized Decomposition.
It is a reduced model technique, that allows to decrease dramatically computational cost. The solution at each iteration of the LATIN method is search with this reduction technique.

With these two techniques, a CPU gain up to 30 were founded in our test, with 3 parameters and 1,000 parameter sets. In that case the parametric study were performed in 30 hours instead of 900 hours, for a 150,000 DOFs and 60 time steps elastic-viscoplastic problem.

High cycle fatigue reliability approach based on Kakuno and Kawada criterion with an application for design an Equal-Leaves Spring

A. Doukh[1], R. Ben Sghaier[2]

The developed reliability based design methods have the advantage to exploit the uncertainty of the different parameters defining a fatigue criterion. In this paper, we analyze the High Cycle Fatigue (HCF) behavior taking into account the dispersion effects of the loading and the materials parameters and using the multi-axial HCF criterion of Kakuno and Kawada. The reliability based design of the HCF behavior was computed using the Artificial Neural Networks (ANN). This approach leads to obtain iso-probabilistic criterion diagrams corresponding to fixed scattering parameters.

In an automotive suspension system, the leaf spring design has an important role to provide essentially the safety for the vehicle occupants. Accordingly, an application of this approach for design an Equal-Leaves Spring (ELS) is achieved as well as an effect analysis on the HCF reliability of the different random ELS design parameters is studied in this work by using the Design of Experiments (DoE) method.

Keywords:
High cycle fatigue; Artificial neural networks; Reliability; Design of Experiments; Leaf springs.

1. IPEIM - Université de Monastir, mail : Akram.doukh@gmail.com
2. ISSATSO- Université de Sousse, mail : rabibensghaier@gmail.com

PROBADUR : Probabilistic Durability of Structural Laser Assemblies made of Continuous Fibre Thermoplastic Composite Materials

Ph. Castaing[1], C. Peyrac[1], P. Boutet[1], J. Renard[2], M. Oumarou[2], C. Binetruy[3], M. Deléglise[3], W. Knapp[4], A. Giessl[5]

As a result of their advantages, i.e. recyclability, weld-ability, environmental compatibility, long (continuous) fibre thermoplastic composites (LFTPC) are increasingly used in many industrial sectors (automotive, aeronautic, medical devices). Indeed, in the next ten years, the environmental rules (petrol & fuel oil consumption reduction, CO2 reduction, recyclability of materials…) will put the pressure on the use of new structural materials like composites.
A lot of industrial sectors of the mechanical engineering industry should be impacted by this evolution in a positive way. For example, the weight reduction of heavy equipments on wheels, using petrol/fuel oil will be more and more essential. But various industries may use new structural composite parts like civil engineering equipment manufacturers, lifting equipment manufacturers (cranes…), agricultural equipment manufacturers or industrial coachbuilders (truck sub-frames, tubs, tippers, rolling tanks…). This trend gives a good opportunity for the introduction of lighter and more environmental friendly composite materials instead of metals in the structures and will lead to the development of thermoplastic composite instead of thermoset composite materials.
To get structural complex parts, several joining techniques have been developed (induction welding, resistance welding, adhesive bonding, and laser welding) but a real lack of knowledge about the mechanical resistance after welding remain in literature especially for thermoplastic reinforced composites.
A French-German research and development project between Fraunhofer and Carnot Institutes (ENSMP, ENSMD, CETIM), PROBADUR, (Probabilistic Durability of Continuous Fibres reinforced Thermoplastic Composites) was initiated in 2008 in order to build the basement of a mid-term probabilistic approach of the fatigue behaviour of LFTP (continuous fibres) composite materials (PA66/GF) and of welded assemblies by laser of these materials for structural applications. The main objectives and the results of the project lead to :
- master the quality of structural welded assemblies of LFTP parts with an optimized welding process. This step requires to understand and simulate what happens at the interfaces between the parts involved in the assembly during the welding process, but also to evaluate the impact of the assembly process on the long term behaviour of the structural parts under fatigue.
- optimize, the laser welding process both on samples (coupons in PA666/GF) and on a structural part (a stiffener welded on a plane part), to improve the welding processes and the way to assembly the parts among themselves (welding speed, laser seam geometry…)
- evaluate the behaviour of LFTP composites, mainly in terms of mechanical characterization, fatigue loading by performing S/N tests and quasi static tests (Arcan test, lap shear test…)
- introduce in the design offices new design methods of structural LFTP parts based no more on a deterministic approach but on a probabilistic approach in order to take in a better way the specifities of the materials and of their manufacturing and assembly processes.

Keywords:
Laser welding, thermoplastic composite, composite bonding, lap shear test, Fatigue test, probabilistic approach, long term behaviour

1. Cetim, France, 2. ENSMP Paristech, France, 3. ENSMD, France, 4. CLFA-Fraunhofer ILT, Germany, 5. Fraunhofer LBF, Germany

On multi-instrumentation technics for damage identification of 3D composite materials

J. Henry[1,2], Z. Aboura[1], K. Khellil[1], S. Otin[2], L. Olivier[2]

The development of new materials, in industry such as aeronautic, needs to acknowledge their behavior under loading. In order to achieve this objective, numerous testing are done and the data such as initial Young modulus or life for a certain fatigue loading are known. However, complex loadings existing in real life are not so easy to predict, so models have been developed to simulate such loadings. For quasi-static loading in 3D composites, a model has been created and uses damage accumulation as the main factor impacting mechanical properties. The accuracy of the model depends on the data that can be obtained through testing investigation. As we know, 3D composites have a really complex frame and the internal stress and strain can hardly be known without a sophisticated instrumentation. Investigation has been made during quasi static loading, hardly showing the links existing between damages and mechanical properties. This present work extends the quasi-static work to the fatigue loading problem. It focuses on extending the instrumental methodology developed previously on life testing. Thus, the measurement tools used for this purpose are DIC, Acoustic Emission, strain measurements, Infrared thermography, microscopy and micro-tomography. All these techniques are often used almost alone. This paper manages to present all this tools, their specific uses in this case, and the connections that can be done between them.

1. Laboratoire de Roberval, Rue Personne de Roberval, BP 20529, 60 200 Compiègne Cedex
2. Snecma Villaroche, Rond-point René Ravaud- Réau, 77 550 Moissy-Cramayel

Multi-scale modeling of fatigue damage of continuous fiber reinforced polymer composites

D. Vasiukov, S. Panier, A. Hachemi

(Composite materials, Fatigue damage, Multi-scale analysis, Life prediction)

Key words:
Composite materials, Fatigue damage, Multi-scale analysis, Life prediction.

Composites materials (CM) are wide used in vary application. Structure made from those material subjected to multiaxial loading during exploitation and exhibits degradation of the material properties. Since the beginning of the composite's investigations have been proposed different type of models in order to described non-linear behavior. These models can be classified as empirical, phenomenological and micromechanical.

In this work were developed phenomenological and micromechanical approaches. Former is based on the continuous damage mechanics (CDM) model assumes that plies are continuous. As well known, damage mechanism of the composite material is more complicated to metallic one by reasons that CM is anisotropic and inhomogeneous. Damage tensor describes three damage variables associated with matrix/fiber debonding, fiber breakage and transverse plies' cracking. Stress-based constitutive model used damage surface defined from thermodynamic forces driven by damage. The latter approach represents composite from microscopic point of view, i.e. consider two constituents unit cell (matrix and fiber). Polymer matrix has a non-linear behavior due to isotropic damage. Initiation criterion built on maximum principal stress and maximum shear stress criteria. The interface was represented in geometrical model as third material with reduced material properties.

Both constitutive models were developed in FORTRAN code for ABAQUS user subroutine UMAT. To validate models number of numerical simulation were performed. Phenomenological concept has been applied to 3D biaxial geometry. During microscopic analysis the unit and cross-ply unit cells were simulated. Comparison of results and tests data shows a good agreement.

MXFAT
Logiciel de fatigue innovant
critère de Dang Van, fatigue modale, fatigue spectrale

K. Dang Van (Mecamix XTECH- Bat 404, Ecole polytechnique, 91128 Palaiseau Cedex)
B. Gallali (Imeca)

MXFAT est un logiciel destiné à analyser la tenue à la fatigue multiaxiale de structures mécaniques en post traitement de calculs réalisés sur les codes d'éléments finis très utilisés tels que ABAQUS, NASTRAN, ANSYS, CASTEM, PRO/MECHANICA.

Bases théoriques
Les structures industrielles mécaniques sont souvent soumises en service à des sollicitations multiaxiales complexes. Aux points critiques où la fatigue est susceptible de se produire (voisinage des accidents de géométrie, des entailles…) l'état de contrainte est la plupart du temps tridimensionnel non réductible à des chargements uniaxiaux équivalents. Pour répondre à cette problématique, MXFAT a été développé en s'appuyant sur une approche nouvelle de la fatigue basée sur la théorie de l'adaptation et sur l'emploi de méthodes multiéchelles résultant des travaux de Dang Van et collaborateurs, travaux qui ont permis de donner un cadre général unifié étudier ce phénomène, qu'il s'agisse du domaine de l'endurance ou celui de la fatigue plastique à faible nombre de cycle. Ainsi en fatigue polycyclique, le choix du critère de Dang Van, qui tient compte de la multiaxialité du tenseur des contraintes, rend inutile le recours à des paramètres ajustables ou à des coefficients correctifs et ceci, quelque soit le type de problème de fatigue étudié, y compris la fatigue de contact. De même le choix de l'énergie dissipée à la limite de la possibilité d'adaptation comme paramètre permet de tenir compte de trajets de chargement thermomécaniques complexes. Enfin une adaptation de cette approche a été faite pour étudier efficacement la fatigue des structures soudées. Elle est basée sur une extension de l'approche structurale en contrainte principale et permet sur des structures soudées de forme complexe, de tenir compte des états de contraintes multiaxiales.

Signalons enfin deux innovations importantes qui permettent d'aborder le dimensionnement à la fatigue vibratoire de façon complètement nouvelle.

MXFAT spectral
Les efforts auxquels sont soumises les structures mécaniques varient très souvent de manière aléatoire et pour lesquelles l'ingénieur souhaite que la probabilité de ruine par fatigue soit inférieure à un seuil choisi. Si on peut admettre que ces excitations sont gaussiennes, stationnaires et ergodiques, elles sont alors complètement caractérisées par leur densité spectrale de puissance. MXFAT SPECTRAL permet alors d'évaluer la probabilité de défaillance de la structure étudiée sans avoir recours au comptage des cycles longs et fastidieux et incertains.

MXFAT modal
Soumises aux vibrations induites par les chargements de service, les réponses des structures sont une combinaison de leurs modes propres. L'analyse modale permet alors une représentation fiable des sollicitations. MXFAT MODAL est l'outil de calcul à la fatigue qui permet d'évaluer directement le risque d'endommagement par fatigue multiaxial complexe dans l'espace des modes sans avoir à revenir à une décomposition temporelle. Grâce à cette avancée scientifique, des gains importants en précision et en temps de calcul peuvent être réalisés, rendant possibles des calculs difficiles à envisager jusqu'à présent.

Effects of single overload/underload on fatigue life of 350WT steel using FE-simulation of PICC

M. H.Gozin, M. Aghaie-Khafri
(Dept. Of Mechanical Engineering, K.N. Toosi University of Technology Tehran, Iran)

In present work, fatigue life of center cracked 350WT steel specimen subjected to single overload/underload(OV/UN) predicted by simulating plasticity induced crack closure(PICC) method. Finite element method is used for crack growth simulation and results are compared with Rushton and Taheri's experiments.

Many structural materials are subjected to variable-amplitude fatigue loading rather than constant amplitude fatigue loading. Sudden changes in the cyclic loading patterns during fatigue deformation could result in a considerable acceleration or retardation in the crack growth rate. There have been numerous efforts to account for the crack growth retardation phenomena. Among them, the plasticity-induced crack closure concept has been supported by many investigations. In present study, effects of single OV and single OV following by UN, on crack growth retardation of center-cracked specimen of 350WT steel is studied. A two-dimensional finite element model is built using four node plane stress elements, with one quarter of the specimen modeled because of symmetry. Mesh refinement procedure used around crack tip region to approach predefined convergence. Fatigue crack growth was modeled by repeatedly applying two loading-unloading cycles then advancing crack front. During each increment of loading, the nodal displacement of first node before crack tip was monitored. The purpose of the analysis is the computation of crack opening stress Sop and the corresponding stress intensity factor Kop. Calculating effective stress intensity factor and using base metal Paris parameters express the number of fatigue cycles which would cause one element length of crack growth. Using the same procedure at each step would result in calculating total fatigue life and determining effect of single OV/UN on crack growth retardation/ acceleration. The results are in good agreement with Rushton and Taheri's laboratory experiments on 350WT steel.

Single OV abruptly accelerates the crack growth immediately after overloading; however, crack retardation is the dominant effect following this acceleration period. Higher overload ratios (OVR) results in higher crack growth retardation which leads to increase in fatigue life of the specimen. UN would decrease the effect of OV but couldn't totally eliminate it. PICC is a reliable technique for fatigue life prediction under OV/UN conditions when the following criteria are satisfied.

-PICC should be the dominant mechanism of crack closure.

-Optimum mesh refinement is used.

-Crack advance scheme and exact crack growth data are available.

Influence of casting defects on the fatigue behaviour of an AlSi7Mg0,6-T6 aerospace alloy

I. Serrano-Muñoz, C. Verdu, J. Y. Buffière
(Université de Lyon, INSA-Lyon, MATEIS CNRS UMR 5510, 69621 Villeurbanne, France)

In aluminium cast alloys, fatigue crack initiation occurs on pores resulting from the material processing. Surface or sub-surface pores appear to be the most critical defects. Several specimens of alloy AlSi7Mg0,6 have been investigated by laboratory computed tomography. The 3D images are first used to extract the 3D stereological parameters of the pores and their distributions. In a second step, "realistic" 3D finite element models of the porosity are generated, allowing to calculate the local stress distribution and levels around the pores. Correlation between the image analysis results, the FE calculations, the observed fatigues lives and the damage mechanisms should help in sorting out which pore parameters have the largest influence on the fatigue resistance of this class of material.

Contact fatigue & wear of roller mills. Influence of hardfacing microstructure and residual stresses

M. Duquenne, A. Mouftiez, S. Hariri
(École des Mines de Douai, Department of Polymers and Composites Technology & Mechanical Engineering)
E. Romero, S. Devroe
(Fives FCB, Research Center)

The Horomill® grinder is a horizontal roller mill in which the material is ground between a shell and a roller grinding sleeve. The grinding pressure is applied on the material bed by means of hydraulic jacks.

The surface of the sleeve is subjected to abrasive wear. In order to control the wear of the part and to increase its service life, hardfacing is used. Besides the wear, the sleeve is also submitted to considerable cyclic contact loads and to residual stresses. These result from the shrinking of the sleeve on the shaft as well as from the hardfacing operation.

Fatigue crack growth affects Horomill grinders during operation which can result in local damage. Observations of cracks have been realized to identify the crack growth behaviour in the sleeve. The aim of this study is to assess the influence of the loading parameters (combination of residual and operating stresses) that are responsible for such damage.

Two approaches are being handled in order to improve the fatigue life of such parts. The first consists in studying various hardfacing processes in order to get the most favourable residual stress profile. The second aims at testing (by finite element modelling) different shapes of the sleeve, which needs an accurate model enabling to determine the fatigue life of such shrink-fit parts.

Numerical simulation of deep drawn components body of a vehicles subject to fatigue

O. Boussaid,
(Université de Annaba, Laboratoire de Mécanique des Matériaux et Maintenance, 23220 Algerie)
M. Rabahallah
(Université de Metz, Laboratoire de Physique et Mécanique des Matériaux, 57000 France)

The aptitude of structures in service and the determination of mechanical characteristics of the material can be realized today without resorting to the classical procedures, thanks powerful tools of calculation and simulation. Numerical simulation, currently allows to view virtually the behavior of the material and to undertake almost quantitative analyses on representative models of real pieces.
This work proposes a method for prediction the rupture by numerical simulation, using the Abaqus finite element code, on of deep drawn components body of the vehicles subjected to fatigue. This method, consist in to observe during the simulation, the evolution of the fields of the strains and stresses. The occurrence of heterogeneities of the deformation on the elements of the meshed structure, shows a discharge stress, occurs in the elements outside the location, as we approach the area of rupture. The reliability of this method is a way to visualize the appearance of the location and therefore the rupture of critical areas, such as the bottom of the deep drawing cup and the corners of some of deep drawn components in square box. This method, based on the analysis of the evolution of stress fields on the finite element mesh structure, shows that the approach of fracture, a stress concentration dominates the elements located in the area rupture. The number of elements unloaded reveals to be a pertinent informer to localize the rupture. The curves associated provide a convenient mean to view its location.
Finally, the simulation of more complex deep drawn components were modeled in Abaqus and allowed the localization of areas with strong local thinning phenomenon before rupture, thanks to the results of the configuration of the strains and stresses obtained in simulation.

Keywords: Fatigue, Rupture, Simulation, Abaqus

Stress-Based Analyses of Random Multiaxial Loading on a Specimen with a Hole

J. Papuga
(Czech Technical University, Technická 4, 166 07, Prague 6, Czech Republic)

The paper reports on two different ways of deterministic fatigue life prediction employed on a solution of a very complex problem. It concerns a set of experiments with multiaxial broad-band random loadings applied on torsion and push-pull load channels. The tubular specimen used for the experiments has a small hole drilled to one of its sides. In addition to the specific notch, which for various mutual relations between both load channels results in different hot-spots, the load history block, at which the load is randomized, is quite long - up to 600.000 time instants. The load histories at each load channels are constructed in such a way, that their power spectral density curves have specific forms: ascending, descending, pyramidal or white noise PSDs.

The applicability of stress-based solution method is discussed and prediction results of two specific solutions " one using the common load history decomposition to cycles, while the other integrating the load path differential by differential for obtaining damage " are provided and commented.

Software evolution to support advanced mechanical testing methods: an example about Thermo-Mechanical Fatigue Testing

M.Fajfrowski
(MTS Systems Corporation, Paris, France)
C.Leser
(MTS Systems Corporation, Minneapolis, USA)

The major improvements in mechanical testing systems rely on development in software usability and flexibility. In the case of Thermo Mechanical Fatigue (TMF) testing, we must take into account a number of different parameters and algorithms for all aspects of investigation that are defined in a standard definition , called "validated code of practice for strain controlled thermo mechanical fatigue testing". New software implements this code of practice by following all the individual steps: thermal control stability, zero stress test, modulus calculation, thermal strain measurement, test execution and reporting.

Examples are given on how to perform thermal strain compensation calculations with basic formulas or advanced algorithms using an open source programming language called Python. Further, an adaptable display allows the user to choose what information to show at what point in time. The complete test procedure is defined in a fully open environment with the possibility to modify any of the individual steps or calculations. Results are given on thermal strain measurement, modulus calculation and temperature gradient control.

Fatigue design of welded joints treated by high frequency hammer peening

G. Le Quilliec[1,2,3], M. Drissi-Habti[2], G. Inglebert[3],, H-P. Lieurade[1], P. Macquet[1], L. Jubin[1]

In comparison with the base and filler materials used, welded structures have relatively low fatigue strength. This is mainly due to the initiation stage which become very weak in the specific case of welded assemblies. Early initiation of fatigue cracks can be explained by the presence of residual tensile stresses, high stress raisers and an often poor surface roughness at the weld toe. It is therefore essential to have a design that takes into account the specific features in the case of exposure to cyclic loading. In addition, it is possible to apply post treatments such as TIG dressing, grinding, shot peening or hammer peening. It is generally observed that the gain will be all the more significant since the stresses will be limited and ultimate tensile strength will be high.

High frequency hammer peening (HFH) is a recent improvement method which is probably one of the most effective for treating welded assemblies. However, there is a certain number of technical difficulties that must be overcome to apply HFH whether for new or old structures. Using the various results available for this process is uneasy for the fatigue design of an HFH treated welded assembly for a given configuration and treatment parameters. The work presented falls within the framework of a project which should in the long run propose an industrially applicable approach with the aim of increasing the guaranteed fatigue life of new structures and to extend the one of existing structures.

The numerical approach developed in this study can be decomposed in 4 main parts. Firstly, the local properties of the considered welded joint have to be assessed in order to model it. The use of instrumented indentation coupled to a reverse method permits to estimate the local tensile curves (through the weld zone, the HAZ and the base metal) with a good accuracy and quickly than the mainly other existing solutions. Then, the treated weld toe can be modeled in a second part via the finite element method. To decrease the time consuming of the classical step-by-step incremental method, a direct method can be used in some cases. In our study, we modified and used the pass-by-pass stationary method proposed by Dang Van and Maitournam. Once the treatment simulated, the third part aims to predict the possible stress relaxation during the fatigue loading. Once again, a direct method have been used based on a combination of the work of Zarka and the direct method of Akel and Nguyen. The last part of the proposed approach aims to predict the fatigue life of the welded assembly considering the numerical results obtained. This can be done through various ways. In our case we directly used the Manson-Coffin-Basquin relation modified by Morrow. The cyclic properties required are assumed to be similar to those of the base metal and have been estimated by low cycle fatigue tests. Equivalent results have been also obtained by using directly the Uniform Material Law as well as the medians method which both allow to assess the cyclic properties needed knowing the static ones.

Finally, a good agreement have been obtained between the numerical approach and the experimental study. In addition, the proposed numerical approach permits to better understand the effect of the main HFH parameters and makes it possible to consider developing software to estimate the fatigue life of a treated structure.

1. Cetim, Senlis and Nantes, France,
2. IFSTTAR, Nantes, France,
3. LISMMA - Supméca, Paris, France

Crack propagation law identification by Digital Image Correlation

P. Boutet[1,2], F. Lefebvre[1], F. Hild[2]

In regular inspections of structures or components, it happens that the presence of cracks is detected. It is therefore important to know if the structure can continue to operate regularly or if a degraded mode of operation has to be considered. In order to make the right choice, it is useful to know as accurately as possible the crack propagation law of the material. Digital image correlation (DIC) is a good means to evaluate crack propagation since it provides information on the displacement field of a studied region. Some instrumented fatigue crack growth tests have thus been carried out and the exploitation of the data is presented.

With a DIC algorithm, the displacement field inside the region of interest is calculated. Based on the study of subsingular and supersingular displacement fields, a post-processing step is performed, and both crack length and stress intensity factor (SIF) are evaluated. A Paris' law is identified, and a parametric study is carried out in order to estimate the influence of some parameters on the identification error. In order to evaluate the relevance of this identification, the error made in this step is also studied. The coefficients of the crack propagation law are finally compared with those found in the literature, and a comparison between the evaluated SIF and the one calculated from the ISO standard is made.

1. Cetim, Senlis, France,
2. LMT-Cachan, France

Modeling of plasticity in spectral methods for fatigue damage estimation of random vibrations

H .Rognon, T. Da Silva Botelho, I.Tawfiq
(Lismma (EA2336) Supméca, Saint-Ouen, France)
A.Galtier, M.Bennebach
(Cetim, Senlis, France)

Many mechanical structures are subjected to random vibrations due to external forces (forces, acceleration,...). The best fatigue design should allow improving the safety of structures and reducing manufacturing cost and design. We present here, a spectral method for estimating the fatigue damage to the polycyclic and low cycle fatigue domains.
The fatigue phenomenon is usually studied in time domain because loads are quasi-static and so there are no dynamic response of the structure. Within the framework of random vibration, mechanical structures have a dynamic response. This implies some problems for the calculation of stress for fatigue analysis:
- Convolution integral (problem of computing time)
- Random aspect of vibrations (consideration of random processes)
- Potential local plasticity (nonlinear behaviour – material non-linearity)

A solution to these problems is to study the fatigue phenomenon in the spectral domain. In the frequency domain, random vibrations are represented by the PSD (Power Spectral Density). Spectral methods are currently applicable in polycyclic fatigue domain for stationary ergodic Gaussian vibrations. They are based on a frequency calculation in stress. Spectral methods are limited by assumptions such as material behaviour or geometrical linearities. The method developed in this work allows plasticity modelization in confined areas for damage calculus. Another advantage of the method relies on its strain formulation which allows fatigue law computation (Manson-Coffin-Basquin). This modification enables to extend application domain of spectral methods to policyclic and low cycle fatigue domains.

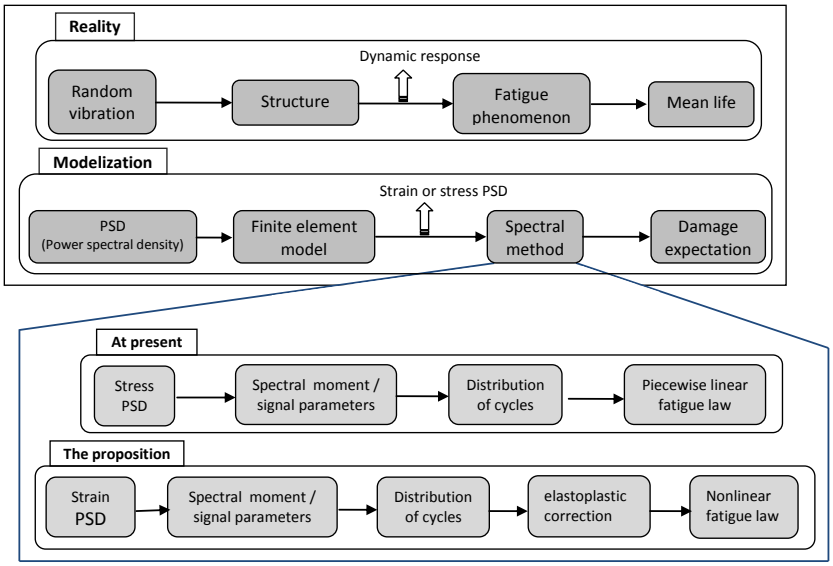


Fig1 : Description of vibration's fatigue process and spectral methods

To validate the method, we performed several correlations between experimental, numerical analysis and Monte-Carlo simulations. Random vibration used are a narrow band with a uniaxial strain state, a narrow band with a multiaxial strain state, a white noise with a multiaxial strain state.

Contact: herve.rognon@supmeca.fr

INDEX DES AUTEURS