fatigue design 2013

27 and 28 November 2013 - Senlis, France

5th edition of the International conference on fatigue design

ABSTRACTS BOOK

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Introduction Message

On behalf of the Fatigue Design 2013 International Scientific Committee and Organizing Committee, we would like to welcome you all to the 5th edition of Fatigue Design 2013 taking place at Cetim, Senlis, France on November 27 & 28 2013.

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

Cetim and its partners organizing the Fatigue Design International conference since 2005 to promote the most innovative approaches, scientific and technological progress in design methodologies, testing methods and tools to evaluate and extend the fatigue life time of the industrial equipment. The papers are mostly focusing on the industrial applications.

The 5th edition of the Fatigue Design conference is organized, for the first time, in collaboration with Elsevier editor for the proceedings publication through Elsevier Procedia. The papers will be published online on ScienceDirect, which will be made available worldwide for a better dissemination and maximum exposure. In this respect the selection and peer review of the papers have been done with collaboration of the International Scientific and Organizing Committees. We would like to thank all involved people who allowed us to improve the quality of the papers at high international standard level.

The topics of this conference are covering not only the traditional one as fatigue analysis of the welded structures but also the topics as composite and elastomers fatigue behaviour, complex loading and fatigue behaviour with the transport applications, manufacturing process impact, 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 new modeling and simulation techniques in the area of fatigue are the valuable tools for fatigue analysis and design of the mechanical components and structures and are welcome by the industries.

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

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

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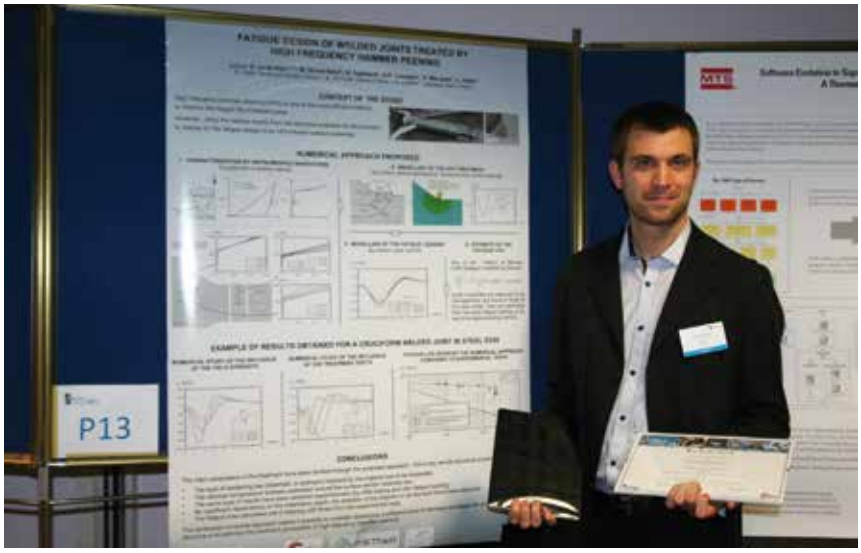
Poster Award 2013

The poster session of the 5th edition of the Fatigue Design conference includes more than 15 posters. This session will offer the opportunities for the technical exchanges between the scientists, industry participants, PhD students.

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

During the 4th Fatigue Design 2011 conference, the Poster Award has been dedicated to Guenael Le Guillec for his thesis work and poster on "Parachèvement des joints soudés par martelage" / "High frequency hammering of welded structures".



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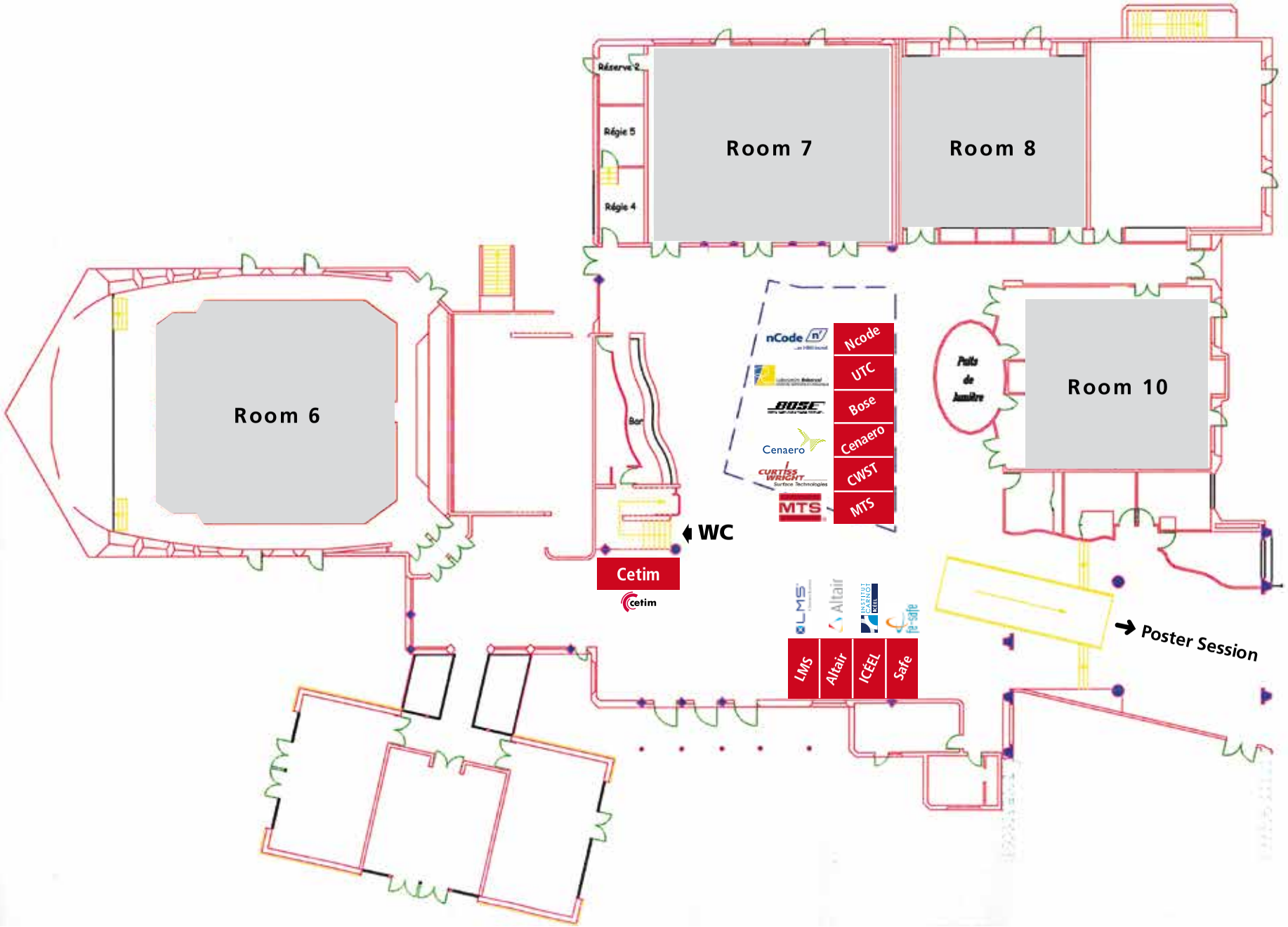
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FD13-K01

Assessment of existing steel structures – Recommendations for estimation of the remaining fatigue life

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Abstract

In many countries and regions, the traffic infra-structure projects suffer from low funding. There budget is tight for new infrastructure building and, thus, the importance of inspection, maintenance and assessment of the existing traffic infrastructure increases. A new fatigue assessment guideline for the estimation of the remaining fatigue life of steel bridges has been written by technical committee 6 from ECCS [Kühn et al. 2008]. It will be a useful tool for the complementation of bridge management systems, used commonly for condition assessment.
Design specifications and rules are harmonised throughout Europe. They are under constant development, but there is still a lack of forwarding and concentrating experiences as well as developing rules for the fatigue assessment on existing steel structures. This paper presents a guideline with a proposed fatigue assessment procedure for existing steel structures embedded in information about old materials and non-destructive testing methods for the evaluation of details. Particular attention is paid on remedial measures which are proposed for weak details and damages caused by fatigue. The developed fatigue assessment procedure can be applied to existing steel structures under cyclic loading in general, but the guideline concentrates on the existing traffic infrastructure made from old steel, because of the public importance. The proposed procedure summarizes, regroups and arranges the knowledge in the field of assessment on existing steel to be applied by practicing engineers. The procedure is a milestone in knowledge transfer from a state of scientific knowledge to state-of-the-art.

According to the agreement between the Joint Research Centre (JRC) of the European Commission in Ispra and the European Convention for Construc-tional Steelwork (ECCS) a series of reports are publisher as Joint-JRC-ECCS-Scientific Technical Reports, that may be downloaded from the e-bookshop of the Commission, see:http://eurocodes.jrc.ec.europa.eu.

These Technical Reports are being prepared by experts from CEN/TC 250/SC3, the CEN-Technical Committee responsible for the preparation and further development of Eurocode 3, and from ECCS Technical Committees related to the subject in question.

They aim at:

- Giving the scientific background and further explanations to the Eurocode 3 rules as published,
- Presenting the state of the art and preparing the field for the maintenance, further harmonisation and further development of the Eurocode 3 rules.

A high priority project of CEN/TC 250 is to include in the Eurocodes technical rules for the assessment and retrofitting of existing structures, which becomes more and more important in the context of sustainable development in the construction field. To this end the presented JRC-ECCS-Joint Report has been published. In meantime the Technical Committee is working on the 2nd edition of these recommendations. The keynote will also presents the new extensions of the recommendations e.g. dealing with the specifics in an assessment of a existing crane structure or a wind power plant or dealing with information on actual retroffiting technics for orthotropic bridge decks.

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Laplace moving average model for multi-axial responses in fatigue analysis of a cultivator

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Abstract

Multivariate Laplace processes are used as statistical models of multi-axial loads represented by forces and moments measured at some locations of a cultivator. These models account explicitly for transients that have a common origin vibrations that can be caused by large obstacles encountered by a cultivator or a vehicle driving into potholes. The model is characterized by a low number of parameters accounting for fundamental characteristics of multivariate signals: the covariance matrix representing size of loads and their mutual dependence, the excess kurtosis that in the model is related to relative size of transients, and the time scale that accounts for the vehicle speed. These parameters can be used to capture diversity of environmental conditions in which the vehicle operates. Distributions of parameter values that are specific to a given market or encountered by specific customers can be then used to describe the long term loading. The model is validated by analysis of the resulting multi-axial damage index. It is shown that the parameters enter this index in a multiplicative and explicit manner and, for a given damage exponent, only the factor representing dependence on the kurtosis has to be obtained through regression approximation based on Monte Carlo simulations. An example of actual cultivator data are used to illustrate the accuracy of damage and fatigue life prediction.

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Keywords: Fatigue damage; multi-axial rainflow; Laplace moving averages; multi-axial loads; transients; cultivator frame durability,

References:

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Fatigue analysis issues and strategies for electronic assemblies for high-reliability and harsh environment applications

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Abstract

The use of electronic assemblies in high-reliability domains such as Defence, Aerospace and Security demand a comprehensive reliability evaluation including fatigue analysis. Moreover, electronic technologies are mainly developed for consumer markets (mobile phones, game consoles and computers) where operation conditions requirements are much more lower than high-reliability ones.

The fatigue analysis of electronic assemblies is an endless story due to this the fast development cycles which increase continuously the density and the use of complex materials and structures. One can highlight mainly five characteristics increasing the fatigue analysis: the use of organic material with low glass-transition temperatures, application of low-melting point alloys with creep behaviour at room temperature, the mix of materials with different thermal expansion coefficients and very deformed aspect ratio, up to 100 times between width and thickness.

The main issues to design electronic assemblies compliant to high-reliability and harsh environment applications are related to robustness improving techniques, the study of material behaviour, and acceleration of failure mechanisms. To respond to those issues, the main strategies are based on mission profile analysis using data acquisition equipments, the characterization of the failure modes of new generic bricks (components, materials, assemblies). Experimental reliability tests must take into account wear-out mechanisms generated by cyclic thermomechanical stresses and in-situ measurements are key to detect failures in very small structures. Finite element analysis is useful in particular for sensitivity analysis associated to design of experiments techniques. Material behaviour characterization and multi-physics (thermal, magnetic, electrical and mechanical) are crucial to develop this kind of activity.

To address properly these issues, electronic assemblies development teams must seek support from mechanical expert domain in particular for material behaviour characterization, and acceleration factors.

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Fatigue Damage Modeling of Composite Structures

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Abstract

Fatigue of composite materials is a subject of growing interest for the aircraft industry. A lot of experimental work was focused on fatigue damage and life prediction of composite structures during the 70s-80s. At that time, the conclusions drawn from these studies were that composites have an excellent fatigue resistance, making them being considered as fatigue insensitive. The requirement for no growth of defects, such as manufacturing defects and accidental damage, has always been assumed to be enough for composite airframes under fatigue loading, i.e. damage tolerance philosophy. Lately, this assertion has been questioned by aviation industrial sector. Indeed, with (i) the continuous improvement of composite design methods during the last decades and (ii) the imperative of structural mass minimization for recent airliners, composite structures are subjected to loadings during in-life service closer and closer to their static strength. Therefore, fatigue of composite structures is increasingly concerning the aviation industry. Then, since fatigue of metallic materials is a well-known phenomenon, first attempts to account for fatigue in composites consisted in adapting the already existing methods for metallic materials to composites. Unfortunately, these methods are unsuitable and strongly not recommended for composites. Actually, the failure of composite laminates under fatigue loading is usually characterized by the combination of various onset of damage such as delamination, matrix cracking, debonding, ply failure and fiber breakage. These complex damage mechanisms cause changes in material properties such as the residual strength, stiffness and life duration while performance specifications for composite structures require that materials maintain certain minimum properties throughout their service life. For all these reasons there is a need to propose fatigue damage models adapted either for conventional laminates or woven composite structures, in particular for organic and ceramic matrix composites. The models, presented in this keynote lecture, are based on sophisticated static damage models built within the continuum damage mechanics framework. They have been developed at Onera, validated for several test cases over the last years and are already used by our industrial partners. We will focus on the different fatigue damage mechanisms of the two aforementioned categories of composites, their mechanical modeling under fatigue loadings and the numerical implementation of the models in FE code in order to predict the lifetime duration of composite structures.

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FD13-K05

Reliable fatigue design, by rigid rules, by magic or by enlightened engineering

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Abstract

This paper discusses some basic differences between engineering approaches to fatigue reliability assessment. The comparison is based on the fact that mechanical fatigue is a highly empirical science with large uncertainties in prior knowledge, both regarding observed data and model accuracy. It is claimed that the amount of available prior physical knowledge should decide the level of complexity in reliability tools, not computer resources nor mathematical theory. As a result the second moment statistics is put forward as a useful tool in fatigue reliability assessment, either in the regulated form like in Eurocode or in a free engineering form like through the Variation Mode and Effect Analysis. The latter method is outlined in certain detail and its practical usefulness demonstrated for some engineering reliability problems.

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Keywords: reliability; fatigue; spectrum; safety factor.

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Assessment of Very High Cycle Fatigue (VHCF) Effects in Practical Applications

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Abstract

Fatigue designing of high-stressed engine components is a key factor for reliable power train systems in automotive industry. In this context load assumptions are very important since this is attended with a pre-designing of important machine elements. Load analyses are done usually by experimental methods since the accuracy of load simulations are often not precise enough. For example concerning VHCF problems, modern high pressure pumps for gasoline direct injection systems have load spectra with a large amount of cycles up to 10^9 including a very powerful shape of the load spectra.

At the same time it is necessary to consider the properties of fuels in service since they might affect the fatigue strength significantly. For example ethanol-based gasoline fuels are used in a lot of countries worldwide and may lead to significant corrosion fatigue effects. In addition it is well known that material inclusions play an important role for the VHCF behaviour especially for high-strength steels. Both effects are superimposing at the surface of high loaded components.

This paper deals with possibilities to avoid VHCF problems of components in service to maintain reliable systems.

Keywords: Very High Cycle Fatigue (VHCF), automotive components, fuel injection, bio-fuels, corrosion fatigue, testing concepts, fatigue design concepts

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S01 - Welded components and structures

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Comparison between the Eurocode for fatigue of steel structures, EN 1993-1-9, and the Eurocode for fatigue of aluminium structures, EN 1999-1-3

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Abstract

The fatigue behaviour of aluminium shows not only many similarities, but also some differences with the fatigue behaviour of steel. There exist separate Eurocodes for the fatigue design of steel and of aluminium structures, EN1993-1-9 and EN1999-1-3, respectively. The latter standard was developed after the draft version of the first one was available. However, a number of aspects are considered in a different way in the two standards. Are these differences justified and desired? What can we learn from the two standards for future improvement of the documents? This paper presents and discusses the agreements and differences between the two Eurocodes. The paper evaluates the advantages and disadvantages of the approaches adopted in one or another of the two standards. It may serve as a starting point for future harmonization of the two standards.

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Keywords: Fatigue; steel; aluminium; welded joints; fracture mechanics;

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S-N Curves for Welded, Non-Welded or Improved Welded Details of Marine Structures

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Abstract

Fatigue cracking is surely the more common failure mode of marine structures. The return experience shows that in the majority of the cases, cracks start at welded joints and so the verification methods developed since the 70s deal with welded joints. More recent cases on FPSOs have shown that cracks can also start from non welded areas and the development of the ULCS (Ultra Large Container Ships) points out the necessity of methods for the hatch corners which are non welded areas. To provide a solution for the design of these ships Bureau Veritas developed a local stress S-N curve formulation including as-welded, non welded and improved welded details. The formulation is based on the accumulated knowledge in fatigue verification approaches since the 70s, the marine return experience and the analysis of available published data. The paper presents the development of the formulation starting by the definition of a S-N curve for as-welded joints covering the low and high cycle domains, then the extension of to the stress release welded joints with different R levels and finally the generalisation to non welded and improved welded details. The non-welded detail S-N curves include the effects of the yield strength on the low cycles domain and of the mean stress level on the slope of the high cycles domain. The defined S-N curves are calibrated versus existing methods for welded joints and mechanical component fatigue verification and also versus test data. Finally, an illustration of a practical application on two ship deck details is given showing acceptable results.

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Keywords: Cyclic fatigue, S-N curves, Welded details, Improved welded details, Non-welded details, Marine structures

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Influence of Weld Defects on the Fatigue Resistance of Thick Steel Plates

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Abstract

Multi-wire submerged arc welding (SAW) process is conventionally used for long welds with large cross sections in tubular steel tower manufacturing. By applying non-vacuum electron beam welding (NVEBW), the number of passes and the heat input can be notably reduced. For plate thicknesses of 20 mm or more the continuous appearance of solidification cracks inside the weld cross section rouse a great challenge. The fatigue resistance is reduced significantly and the safety of the component cannot be ensured. In this paper analytical and experimental investigations are discussed for predicting fatigue life of defective welds.

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Keywords: heavy welded steel structures, submerged arc welding, non-vacuum electron beam welding, fatigue tests on defective welds, notch strain approach, crack propagation appoach

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FD13_20

Geometrical Influence of a Butt Weld in the Low Cycle Fatigue Regime

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Abstract

This contribution deals with the low cycle fatigue behaviour of butt-welded joints of austenitic stainless steel (Type 347). The influence of the geometrical notch of a butt weld on the fatigue life in LCF regime is of particular interest in this context. For the purpose of comparison different weld geometries – as-welded and machined – are investigated. Fatigue tests reveal that the weld notch does not always constitute the failure location in the LCF regime. Accompanying numerical simulations are based on 3D scans with a resolution of 30 μm in order to receive accurate local strain amplitudes at the weld notch or rather the failure location. The combination of experiments and numerical simulations results in local strain life curves.

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Keywords: geometrical influence ; butt weld; low cycle fatigue; high resolution 3D scans

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FEA Structural Stress of Modalohr system for semi-trailer rail transportation: weld root fatigue focus

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Abstract

In order to fulfill green requirement (reduction of CO_2 emissions given by French "Grenelle"), a great need appears concerning roll-on roll-off efficient technology. Heavy seam welded structures manufacturer has to present an optimized product to fulfill this requirement. In this purpose, the Modalohr system overcomes several challenges: transport 4m height and 38 tons semi-trailer in UIC kinematic gauging with a low floor rail vehicle, use of conventional large wheel bogie with maximum axle load, 9 million kilometers running over 30 years service life. For cost effectiveness, the compact vehicle design uses welded assembly and avoids systematic full penetration welds which may require costly preparation machining. The idea is to develop a one shot FEA which provides both global structural bending and torsional vehicle behaviors and also the fatigue focus on each joint for both weld toe and weld root. The local stress analysis requires too much effort and the structural stress using appropriate inclined shell element in a global system model complies such requirement. A home made tool implements these techniques. LOHR "Seam Sim" development deals with the partial automation of the FEA model generation based on the following key points: solid weld feature are generated in CAD, FEA model automation idealization is achieved without additional manual operation. Postal^2 post processing tool has been developed to allow standard FEA code results processing for both static and fatigue assessment. The final display is a scalar stress safety margin map associated for each element to the appropriate criterion over the system depending on the area type; plain metal, sheet metal edges, weld toe, weld root, bolt connection … "Seam Sim" theory [2,3] and Verification & Validation (V&V) has been presented during last fatigue Design conference in 2011 [4], today's aim is to present a highly fatigue demanding industrial application. Loads are applied at a system level to fulfill EN12663-2 standard and additional manufacturer load cases (including longitudinal dynamic fatigue load for 1050m long train and lifting, boarding kinematic load cases). The fatigue results are focused on each detail.

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Keywords: Freight wagon

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Fatigue tests of axially loaded butt welds up to very high cycles

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Abstract

Fatigue strength curves that are established from fatigue tests provide a basis for the fatigue assessment applying nominal stress approach. In the codes valid for steel structures, like the EC 3, the fatigue strength curves for constant amplitude loading have a knee point in the transition region. The fatigue strength curve beyond this knee point is commonly assumed to be a horizontal asymptote. However, the behaviour of the fatigue strength curve in the area of very high cycles and more importantly the existence of an endurance limit are much discussed. In the case of welded joints the experimental data beyond 10^7 load cycles is limited due to the possibilities in testing. Testing techniques with high frequencies are necessary to obtain experimental data with very high cycles in a reasonable period of time. In this scope a testing device with approximately 390 Hz operates by alternating current magnets and using resonance amplification, which was developed by a third party. This testing device was investigated and advanced for the application of long term tests reaching $5 \cdot 10^8$ load cycles. Fatigue tests on axially loaded butt welds with constant amplitude loading are conducted in three test series until very high cycles. The fatigue tests include the area of high and very high cycles. The influence of test frequency and stress ratio is investigated.

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Keywords: Welded joints; Steel; SN-curves; Very high cylce fatigue; Test frequency; Stress ratio

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A guideline for fatigue strength improvement of high strength steel welded structures using high frequency mechanical impact treatment

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Abstract

In the past decade, high frequency mechanical impact (HFMI) has significantly developed as a reliable, effective and user-friendly method for post-weld fatigue strength improvement technique for welded structures. This paper presents a proposed fatigue design and assessment guideline for HFMI improved welded joints. Stress analysis methods based on nominal stress, structural hot spot stress and effective notch stress are discussed. The document especially considers the observed extra benefit that has been experimentally observed for HFMI treated high strength steels. The proposal is considered to apply to steel structures from plate thickness 5 to 50 mm and for yield strengths ranging from 235 MPa to 960 MPa. Several fatigue assessment examples are also provided. Lessons learned concerning appropriate HFMI procedures and quality assurance measures are presented. Due to differences in the HFMI tools and the wide variety of potential applications, certain details of a proper treatment procedures and quantitative quality control measures are presented generally. It is proposed that specific details should be documented in a HFMI Procedure Specification for each structure being treated. It is hoped that this guideline proposal will provide a stimulus to researchers working in the field.

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Low Cycle Fatigue crack propagation in a welded T-joint with a residual stress field

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Abstract

Naval structures (cf. Figure 1) encounter fatigue loads because of the severe environment in which they evolve. As it has been experienced for decades (e.g. liberty ships in the 50's), failure of ships often occurs in welded joints. They present the drawback to generally combine a geometrical singularity with a material heterogeneity and residual stresses due to the welding process. In the worst situation, these stresses are in tension and cannot be relaxed by retreatment. For this reason, it is required to have a robust and precise method to evaluate the fatigue life expectancy (initiation and propagation of a crack) of the parts at the design phase and also to provide remaining life evaluation for in-service detected cracks (propagation only). The present work is oriented on the latter case, with the additional constraint of high loads, assuming a Low Cycle Fatigue behaviour. Thanks to the recent advances in crack propagation simulation methods, the authors will present a methodology to treat the aforementioned issue, based on comparisons between experiments and simulations.

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Keywords: Low Cycle fatigue, residual stress, crack propagation

Fig. 1. Examples of naval structures, Aquitaine Class Frigate (left) and Wind Turbine (right).

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Use of martensitic stainless steel welding consumable to substantially improve the fatigue strength of low alloy steel welded structures

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Abstract

An iron base alloy containing 10 wt.% Cr and 10 wt.%Ni with a martensite start temperature around 180 °C has been developed by Ohta et al. Numerous studies have shown that Low $\gamma \rightarrow \alpha'$ Transformation Temperature (LTT) welding consumables enable weld beads to be in compression after cooling. Owing to this, fatigue strength can be substantially improved. Low carbon martensitic stainless steel consumables (EN ISO 17633-A – T Z 16 5 1) are widely available on the market in Europe, which also exhibit $\gamma \rightarrow \alpha'$ low temperature transformation (around 225°C), despite dilution with base material. Experimental work conducted on partially penetrated symmetric and asymmetric fillet welded test pieces have shown good results with respect to weld root crack initiation and a substantial improvement of fatigue resistance with respect to weld bead toe crack initiation (m = -5, FAT > 160). These results are all the more interesting because the weld bead connecting radius obtained with a heterogeneous welding consumable is smaller than with a homogeneous consumable such as G3Si1. This study shows that using a LTT –type consumable with designation G 16 5 1 is an interesting alternative to more conventional techniques such as TIG re-melting or high frequency mechanical impact to improve fatigue strength of welded structures.

Keywords: LTT, fatigue, martensitic, M_s, cored wire, stainless steel, residual stress, fillet weld

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TIG-dressing of high strength butt welded connections – Part 2: physical testing and modelling

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Abstract

Weld improvement techniques are aimed at reducing the notch effects of welds and generally focus on two aspects: a change of geometry of the weld toe and a change of the weld residual stresses. In this paper, fatigue tests are discussed, performed on butt welded specimens in steel grades ranging from S460 to S1100 in the TIG-dressed condition. The test results are compared with modelled fatigue strength according to the notch stress theory and similar specimens in the as-welded condition. The changed notch geometry of the joints is based on the results of a parallel program of weld toe geometry measurements.
The individual data points and their failure mode give good qualitative insight in the effect of TIG-dressing on butt welded joints in high strength steel. Overall, a positive effect of TIG-dressing on the weld toe is visible.
On the basis of a large dataset of measured weld toe geometries a model has been developed based on the notch stress theory. The theoretical results of the model are compared with the results of the physical tests, showing significant differences between the model and the fatigue tests.

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Keywords: TIG-dressing, butt weld, notch stress approach, fatigue testing

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Fatigue designed CL-cutting shape: A new economic steel-concrete connection system and some applications for bridges

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SÉTRA – Cerema - Innovation and Large-bridges Division

Abstract

Continuous shear connection, using a cut steel strip, is an upcoming solution for composite beams. With the activation of friction on the sides of the steel strip this method has already been used to design and build large durable bridges during the sixties. However direct shear transmission into the steel strip though teeth of the cut is also possible and has been scrutinized with the support of the European Research Fund for Coal and Steel. It is characterized by a high initial stiffness, bearing capacity and ductility. It allows new and economic construction methods, as the PreCoBeams (Prefabricated Composite Beam used as formwork).

PreCoBeams are for instance composite beams associating steel T-sections acting as tension member with a concrete top chord acting as compression member. Steel parts are generally obtained from rolled steel profiles that are longitudinally cut in two identical T-sections. The cut is performed with a special shape to allow the shear longitudinal transmission between steel and reinforced concrete. In general, prefabricated, composite, longitudinal PreCoBeam bridge elements are produced in factory. They consist of at least one steel T-section associated to a precast first phase concrete flange. Second phase concrete layer is then completed in-situ after erection of the bridge elements on abutments. These PreCoBeam bridges are very economic in design and construction, though the main market drawback for PreCoBeams is the missing design rules for the shear connection.

This paper introduces the static and fatigue design of continuous steel plate shear connections used for PreCoBeams derived from the recent research activities. The CL shape of the cutting has been tested in fatigue, ultimate and service limit states and validated in the scope of a bridge application. This concept aims at developing a competitive solution for small span bridges. The various solutions realized in the last years in many European countries, some of them presented in the paper, show clearly its interest.

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Keywords: Steel-concrete connection; dowel; fatigue; clothoidal cutting shape

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Assessment of the surface hardening effects from hammer peening on high strength steel

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Abstract

The effect of hammer peening on the fatigue resistance of high strength welded joints in high strength structural steel S690 has been investigated. Cyclic four points bending tests have been performed on butt weld samples, manually and automatically hammered.Microstructural and mechanical modifications induced by both methods and their subsequent influences in fatigue life have been studied using several characterization techniques. It was found that the roughness of manually hammered samples is different than that of automatically hammered samples for which a lack of correct treatment in some regions of the weld cordon has been observed. A comparison of residual stress measurements using X-ray diffraction shows also differences between both methods. On the other hand, hardness profile of the strain hardened region is very similar for both types of samples. The ultra-fine grain microstructure of the heat-affected zone (HAZ) induced by the hammer peening process has been studied by Field Emission Scanning Electron Microscopy and Electron Back Scattered Technique (EBSD). The strain-hardened depth determined by Kernel Average Misorientation (KAM), microhardness and residual stress are compared.

Keywords: Hammer peening; ultra-fine grains; Electron backscatter diffraction (EBSD); Local misorientation

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Fatigue strength of HFMI treated structures under high R-ratio and variable amplitude loading

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Abstract

High frequency mechanical impact (HFMI) is a post-weld treatment method for improving fatigue strength of welded joints. Much of the experimental research on fatigue performance of HFMI treated welded joints has concentrated on the beneficial compressive residual stresses created by the treatment and the fatigue strength of these joints under constant amplitude loading and relatively low mean stresses. Critical experimental data has been developed in a nearly completed European RFCS project. New mean stress and variable amplitude fatigue data are presented and evaluated with respect to a proposed International Institute of Welding (IIW) design guideline concerning HFMI treated welded joints.

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Keywords: High frequency mechanical impact (HFMI); Fatigue, Stress relaxation, Mean stress, Variable amplitude loading

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Diode laser weld toe re-melting as a means of fatigue strength improvement in high strength steels

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Abstract

Re-melting of weld toes to improve the surface profile and thus reduce stress concentrations is a known fatigue improvement technique. In the study reported here, a novel approach was taken, using a diode laser as heat source. Different diode laser treatment conditions were tested, using the diode laser power, spot size and shape, and the travel speed as main parameters. Fillet welded samples in S690QL and S960QL in 10 mm thickness were treated and fatigue tested with constant amplitude loading. In response to those initial results, further samples were welded and treated and variable amplitude fatigue testing was undertaken.

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Keywords: weld toe re-melting, diode laser, high strength steels, fillet welds, fatigue improvement

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Residual stresses in welded components following post-weld treatment methods

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Abstract

Weld seam is the weakest point of the structure. Weld defects, weld geometry such as toe radius, and residual stresses, which are typically tensile in the critical area, weaken the fatigue strength of the weld seam. These factors become more important with the welding of high strength steels (HSS) because structures containing welded seams loose the benefit from the strength of the steel.
The weld seam fatigue strength can be improved locally with several different methods. In this paper residual stresses of the weld area and their modifications for improving the fatigue strength are discussed.
The residual stresses of the toe area are changed from tensile up to compressive stresses, which are known to improve fatigue strength, with several methods. High tensile stresses can be relaxed mechanically or thermally as postweld heat treatment. Mechanical treatments are more common especially in large structures. Typical mechanical methods are burr grinding, TIG re-melting, hammer peening and needle peeing. A new method is laser re-melting method. All these methods also change the geometry of the weld toe by improving it.
This paper concentrates to needle peening (high frequency mechanical impact, HFMI), and presents some results from laser re-melting tests. Both surface measurements and depth distributions of stress measured by X-ray diffraction (XRD) method are presented.

Selection and peer-review under responsibility of CETIM, Direction de l'Agence de Programme.

Keywords: Welding; High Stregnth Steel; HFMI; Residual Stress; Fatigue Strenght Improvement

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Fatigue strength improvement of welded structures using new low transformation temperature filler materials

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Abstract

The results reported in this research study are part of a larger EU RFCS (Research Fund for Coal and Steel) project where the aim is to study the fatigue behavior of improved welds in high strength steels by utilizing different improvement techniques. In this particular study LTT (Low Transformation Temperature) weld filler material have been investigated and their possibility to improve the fatigue strength. The characteristic of these filler material is that they undergo phase transformation at temperature close to room temperature which will reduce the tensile residual stress in the weld and in some cases result in compressive residual stresses. Two different LTT alloy compositions have been developed, with different Ms (Martensite Start) temperatures in order to study the amount of tensile/compressive residual stresses produced by these wires. Welding residual stress measurements were carried out by X-ray diffraction technique. Plates with welded longitudinal attachments were fabricated in 700 MPa and 960 MPa steel grades using different LTT filler materials. These specimens were fatigue tested in constant and variable amplitude loading and the fatigue test results were compared with results from specimen welded with conventional weld filler material.

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Keywords: Residual stresses; LTT; Welded joints; Fatigue testing;

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Implementing High Frequency Mechanical Impact in industrial components: A case study

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Abstract

A recently more used method of improving weld quality at the weld transition to the plate called HFMI (High Frequency Mechanical Impact) has been investigated and tried on two demonstrators, a bogie beam in an articulated hauler and a dipper arm in an excavator, see fig. 1. The designs of the beams have been made so that thinner plates can be used and higher material strength can be utilized. Such an approach needs to make use of local based analysis methods and in this case the effective notch method was used. Recently made research has suggested SN-curves where the use of HFMI in combination with different material yield strengths are described and these FAT values have been used to develop allowed stress levels in the beams to fulfill the life requirements. All this resulted in components which were 24% and 18% lighter using plate thicknesses of 8-12 mm in material yield 700 MPa. They were then produced and tested in a rig to verify the designs. The results imply that the HFMI treatment is a very promising method to build lighter welded structures, however, the design needs to take some new considerations into account to succeed.

Figure 1 The boggi beam (left) and excavator arm (right).

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Keywords: welds; fatigue; design; post treatment; demonstrator;

S02 - Environmental effect and fatigue design

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Influence of temperature and long term ageing on the fatigue crack growth in a precipitation hardened martensitic stainless steel.

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Abstract

The high-temperature Fatigue Crack Growth (FCG) behaviour of a 15-5 PH (precipitation-hardened) martensitic stainless steel was investigated in three different metallurgical conditions, i.e., as-received, aged at 300°C for 1000h and 5000h. FCG tests were conducted at room temperature and 300°C under constant amplitude loading with two load ratios (R = 0.1 and 0.7) and under variable amplitude loading. The results indicate that the fatigue crack growth rates (FCGRs) increase with R-ratio at the lower ΔK regime and merge together in the high ΔK regime, regardless of ageing conditions and temperature. At 300°C, the FCGRs are higher than at room temperature for all ageing conditions. Under variable amplitude loading, the same retardation effect was observed for all the given ageing conditions at room temperature

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Keywords: Fatigue crack growth, temperature, thermal ageing;

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Physically short fatigue crack propagation in low alloy steel specimen under different environments

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Abstract

Many industrial failures are due to fatigue crack initiation and propagation in service. For the crack propagation stage, the fatigue life consists of the short crack propagation for which the initial crack length is about few hundreds of micrometers and the traditional long crack propagation which is sufficiently described by Paris' law. In this paper, the propagation of physically short fatigue crack (initial crack length of about 0.2 mm) in low alloy steel specimens under different environments is investigated by experiments. Fatigue tests for long cracks (initial crack length of about 2 mm) and mechanically short cracks in Compact Tension 40 (CT40) specimens were conducted in air and in vacuum to determine the threshold stress intensity factor (SIF) ranges and the crack growth curves. The experimental fatigue crack growth curves and threshold SIF ranges obtained from the long cracks in air are first analyzed to investigate the closure effects. Physically short fatigue cracks in the CT specimens are then created by gradually removing the plastic wake of the long pre-cracked specimens. The effects of the crack length on the threshold SIF ranges and the crack growth behavior near the threshold domain obtained from the specimens with the short cracks are investigated. The experimental results show that the short fatigue crack effects due to the reduction of the closure effect appear to occur for the crack length lower than 0.7 mm, as shown in Figure 1. The experimental results show that the threshold and the fatigue crack growth curve using the effective SIF ranges obtained from the long cracks in air are quite similar to those obtained from the long crack, as shown in Figure 2. These parameters can be considered as material properties. Finally, the experimental fatigue crack growth curves and threshold SIF ranges obtained from the long crack in vacuum are analyzed to investigate the environmental effects on the fatigue behavior of the material.

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Influence of surface finish in fatigue design of nuclear power plant components

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Abstract

The fatigue design of nuclear components is based on an S-N curve established in air at 20°C. To this curve, different penalty factors, representative of various effects (scale effect, material variability, surface finish, environmental effect, etc), are then applied. This method considers that these effects are independent from each other.

This paper is focused on the interactions between surface finish effects and environmental effects in the Low Cycle Fatigue (LCF) domain of an austenitic stainless steel type 304L. The aim of this work is to determine whether the effects of these two parameters are really independent or coupled. To better understand the environmental influence, high vacuum is used as reference. Tests were realized with a triangular waveform signal at a total strain amplitude of ± 0.6 % in different environments: vacuum, air and simulated Pressurized Water Reactor (PWR) water, at 300°C. Two surface finishes were considered: ground and polished.

Experimental results obtained on ground samples are here compared with results obtained on polished samples in a previous study. It appears that, while the cyclic stress response of the material is not affected by the surface finish, a ground surface finish decreases the fatigue life. Moreover, this surface finish effect seems to be less pronounced when the environmental effect is important, which indicates the presence of a coupling between surface finish influence and environmental effects.

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Keywords : 304L stainless steel, low cycle fatigue, fatigue life, PWR environment, ground surface finish, design curves

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High Cycle Thermal Fatigue Damage Prediction in Mixing Zones of Nuclear Power Plants: Engineering Issues Illustrated on the FATHER Case

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Abstract

Nuclear power plant piping may be submitted to High Cycle Thermal Fatigue phenomenon in mixing zones. French nuclear engineers have at their disposal a simplified approach for assessing the sensibility of the areas with regard to this kind of damage. The engineering tools are quite complex since they involve multi-disciplinary physic phenomena: thermal-hydraulics, mechanics and materials. The results are only qualitative and globally conservative, and this method is only used to identify and to classify the mixing zones which could present a risk. In this framework, this paper proposes to perform a more realistic application of this engineering method on the particular case of the FATHER experiment. The idea is to compare the numerical prediction results with the expertises performed on the FATHER mock-up. Some generic engineering issues raised by nuclear fatigue analyses are here illustrated by the sensitivity analyses which have been performed. The determination of the fatigue loading and the choice of the material criterion are particularly discussed since they are very significant parameters in the analysis.

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Keywords: Fatigue design ; High Cycle Fatigue ; Heat transfer coefficient ; Cycle counting methods ; Surface roughness ; Welds

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The effect of aqueous corrosion on the high cycle fatigue strength of an aeronautical martensitic stainless steel X12CrNiMoV12-3

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Abstract

Designing structures against corrosion fatigue has become a key problem for many engineering structures in particular in transportation and civil engineering, where structures evolve in complex environmental conditions of temperature and humidity particularly. In aeronautic structures, Corrosion fatigue processes can particularly develop in confined areas were, in addition, non-destructive damage detection technics can hardly be applied.

For this reasons, aeronautic materials with high specific strength are being developed to fulfil ever increasing requirements in terms of corrosion fatigue resistance.

In this study, we investigate the effect of aqueous corrosion on the high cycle fatigue (HCF) strength of a martensitic stainless steel (X12CrNiMoV12-3) with a high specific mechanical strength, used in aeronautic applications. HCF tests (between 1E5 and 1E7 cycles) were carried out in two environments : (i) in air and (ii) in a 0.1 M NaCl aqueous solution (pH = 6) at tow loading frequencies 10 Hz and 120 Hz. Surface crack initiation are observed in air, while in solution cracks initiated from corrosion defects. The fatigue strength at 1E7 cycles in aqueous solution was found to be 30 - 40% the fatigue strength in air. Electrochemical behaviour of passive the film was investigated during fatigue tests in aerated NaCl aqueous solution by monitoring the free potential and galvanostatic impedance EIS tests. Based on fractography analysis and electrochemical tests, fatigue crack initiation mechanisms in air and in aerated NaCl aqueous solution were investigated. A scenario of fatigue crack initiation is proposed based on physical evidences. This scenario implies combined processes of local passive film rupture (induced by the cyclic loading) stress assisted corrosion and enhanced pitting development. This aspects will be discussed by comparing the characteristic time of repassivation of the steel to the mechanical characteristic times (loading frequency, plasticity development)

Keywords : corrosion fatigue; martensitic stainless steel; sodium chloride aqueous solution; High Cycle fatigue; electrochemical impedance spectroscopy EIS; passive film; corrosion fatigue crack mechanism

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Influence of anodizing process on surface integrity and fatigue resistance of Ti-6Al-4V alloy

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Abstract

Fatigue test were realized on turned (reference), pickled and two different anodized (20 and 200nm) specimens. Pickling decreased the fatigue resistance of Ti-6Al-4V titanium alloy. The thin anodic film (20nm) did not modify fatigue resistance compared to pickled samples. On the contrary, thick anodic oxide film (200nm) decreased the fatigue resistance. To explain these fatigue modifications, microstructural, morphological, internal stress and presence of embrittling species (hydrogen and oxygen) analyses were performed. Dislocation rate was reduced after pickling but did not change after anodization. Surface roughness was not modified a lot by surface treatment. Hydrogen and oxygen concentration were not changed. In the present case, pickling does not modify initial compressive stress. After anodization, the compressive internal stresses decreased.

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Keywords: titanium alloy; pickling; anodization; surface integrity; fatigue

1. Introduction

Titanium alloys are increasingly used in aeronautic field due to both their good mechanical properties and low density. These pieces are often subjected to fatigue stresses. To improve surface properties like paint adhesion or corrosion resistance, some surface treatment are commonly applied [1]. Among them, anodizing process is often used due to its simplicity and its low cost. But some recent studies [2, 3] on anodized aluminium alloys demonstrated the high detrimental influence of anodizing process on the fatigue resistance. Thus, it is interesting to investigate the effect of anodizing on titanium alloys fatigue resistance.

2. Results

The surface integrity of Ti-6Al-4V alloy was studied through surface characteristics potentially influencing fatigue resistance. These surface characteristics were studied in detail after each step of anodization process (pickling and anodization) [4]. The main observations were the following (Table 1):

Ti-6Al-4V substrate showed equiaxe microstructure, including about 10±2% β grains. No significant microstructural changes were detected between sample core and surface, or after the pickling and anodization steps. However, the dislocation rate (DRX analysis) decreased after pickling certainly due to the removal of external machined layer (about 3mm thick removed).

SIMS analysis revealed then that no oxygen and hydrogen uptake occurred in the bulk alloy, whatever the surface treatment (pickling, anodizing). It was also proved that no hydride precipitates were formed but only diffusive hydrogen was present in our experimental conditions.

The morphological modifications of the surface were then analyzed through average roughness (Ra, Rz) or local K_t parameters [4], as well as using SEM and SPM (Scanning Probe Microscope) techniques to detect some possible localized and

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random defaults. After pickling, local K_t was not affected while there were slight roughness changes, attributed to different phenomena: preferential morphological dissolution of peaks, preferential chemical dissolution of the less noble α-phase and formation of local pits. No effect of the anodization compact film thickness in the 16-195nm range was found on either the roughness parameters or local K_t.

In contrast, XRD analysis showed that there were compressive initial internal stresses. After pickling the internal stresses are not modified but they decrease after anodization.

Table 1 : Summarize of surface parameters modifications obtained after pickling and after pickling then anodization (80V)

Surface parameter	Pickled	Anodized
Microstructure	Not modified	Not modified
Roughness	Slight increase	Not modified
Internal stresses	Not modified	Less compressive
Hydrogen absorption	No absorption	No absorption
Oxygen absorption	No absorption	No absorption
Dislocation rate	Decrease	Not modified

The values of endurance limits (corresponding to 10^7 cycles) are reported on Table 2. A decrease of endurance limit is observed after pickling and anodization. The decrease is of approximately 20MPa after pickling. This can be attributed to the decrease of dislocation rate noted after pickling as well as slight roughness modifications. The detrimental effect of anodization step (about 10MPa) could be due to the modification of internal compressive stresses. These results should be taken into account to improve the surface treatments from a fatigue point of view.

Table 2 : Endurance limit of turned sample, turned then pickled samples and turned, pickled then anodized at 80V

	Machined	Pickled	Anodized
Endurance limit (MPa)	837	821	813

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Fatigue Crack Propagation in a New Generation Aluminium Alloy

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New generation aluminum alloys are developed to improve their properties through optimized microstructures for conventional alloys as 2022-T851 and through lower density by mean of Lithium addition as for 2050-T84. Damage tolerance properties for aeronautic applications are evaluated through the resistance of these alloys against fatigue crack propagation with a focus on the influence of microstructure, atmosphere environment and crack closure.

. The microstructure of the peak-aged microstructure of the 2022 alloy consists of grains elongated in the rolling direction (670x200x80 µm3), with predominant incoherent θ' plates and a few S precipitates. The fibrous microstructure of the partially re-crystallized 2050T84 alloy consists of grains strongly elongated in the rolling direction (1000x100x30µm^3) and the hardening precipitation consisting in shareable T_1 plates. Crack growth tests were performed on a servo hydraulic testing machine under load control, at a frequency of 35 Hz and a load ratio R of 0.1. Crack closure measurements were carried out using the compliance method. High vacuum (3x10^{-4} Pa) tests were conducted using an environmental chamber

The Figure 1 shows a log-log plot of the crack growth rate, da/dN, versus stress intensity factor range, ΔK. For da/dN higher than 10^{-8} m/cycle, the Li bearing alloy 2050 and the 2022 alloy present a similar crack growth behavior. At lower rates, the 2050-T84 alloy exhibits higher growth rates leading to a lower threshold ΔK_{th}. The differences in the crack growth behaviour of the alloys are analysed in terms of microstructure, of sensitivity to atmosphere environment and of the crack closure contribution. Similar tests were performed in vacuum, and closure correction was done in all cases.

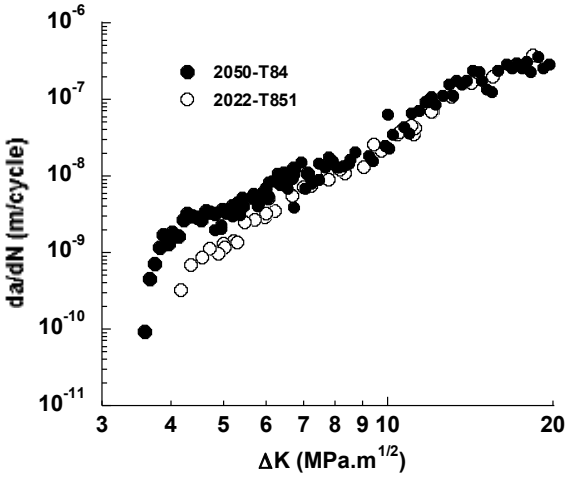

Figure 1: da/dN vs ΔK diagram in ambient air: room temperature, R=0.1 and 35 Hz.

The figure 2 shows effective crack growth data after crack closure correction in air and vacuum. A strong influence of environment is observed for the 2050 with a drastic change in the crack growth mechanism leading to a highly crystallographic path and very slow rates; in the 2022 alloy, the influence of environment is less accentuated and poorly affects the crack path. These results are analysed on the basis of a frame work modelling previously proposed [1].

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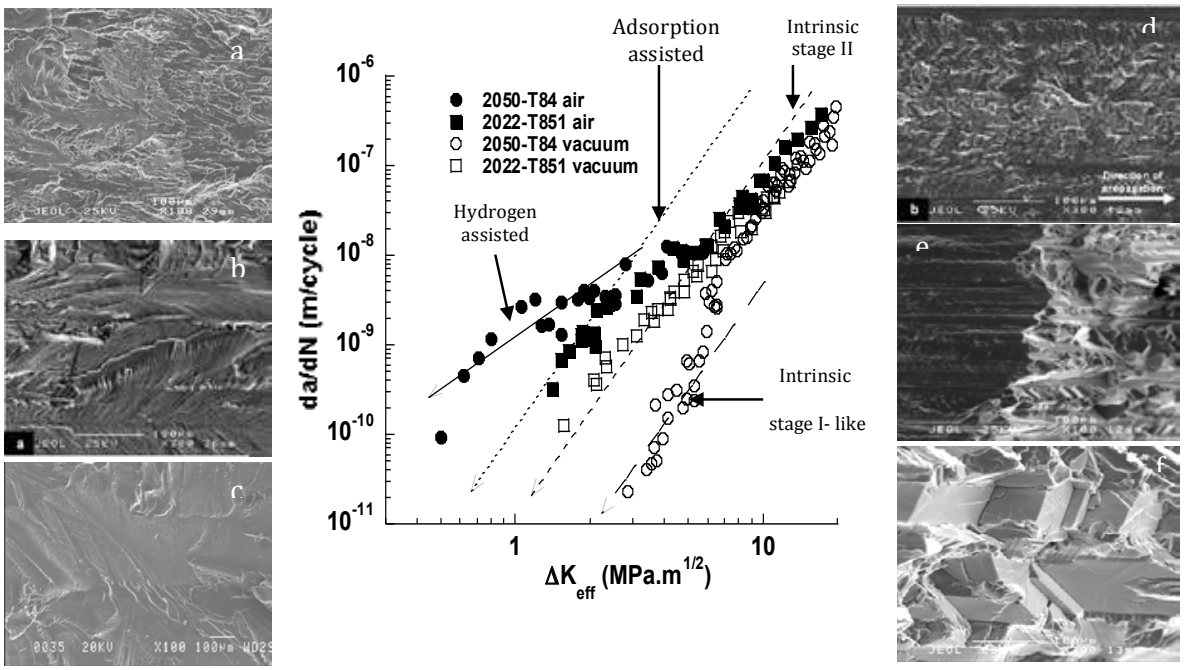

Figure 2: closure corrected effective propagation data compared to modeling frame work.

Four propagation regimes have been highlighted:

1) Two intrinsic regimes operative in inert environment: i) intrinsic stage II which is favored by peak aged microstructures as in the 2022 T851 alloy; ii) intrinsic stage I-like propagation promoted by fine shareable precipitates as T_1 in the 2050-T84 alloy, with a plastic deformation localized within each individual grain along the crack front; the associated retarded crystallographic crack propagation results from barrier effect of grain boundaries and crack branching and deviation [1,2].

2) Two environmentally assisted regimes operative in air and in moist atmospheres: i) water vapor adsorption assisted stage II, water vapor adsorption reducing the energy required to create new fresh surfaces [3], this regime prevailing in the 2022T851 alloy at any ΔK range, and in the 2050T84 at mid ΔK; ii) crack tip opening displacement (*CTOD*) controlled hydrogen assisted stage II propagation [4] which becomes operative near the threshold in the Li containing alloy.

In conclusion: i) both alloys present very similar behavior in the Paris domain in air, with higher specific properties for the 2050T84 alloy; ii) however, near the threshold, the Li containing alloy is more sensitive to the detrimental effect of air environment.

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Thermocracks®, a specific testing machine for evaluation of the thermal fatigue resistance of materials

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Abstract

Cracking by thermal fatigue is one of the major problems encountered during the operation of numerous parts such as exhaust manifolds or brake discs. One way to improve their lifespan is to develop new materials solutions. Estimating thermo-mechanical fatigue resistance of new materials can be performed with a specific test machine developed by CTIF, associating a multi-position wheel, an induction heating and a cooling by air blowing. Test consists in measuring the number of thermal cycles corresponding to the first crack appearance and to the complete failure of a specific versatile sample.
Two examples of studies performed with this machine are shown hereafter.

First tests were performed to compare the thermo-mechanical fatigue resistance of different grades of ferritic spheroidal graphite cast iron. These materials are an interesting alternative to alloyed steels or nickel-alloyed cast irons, for the constitution of exhaust manifolds and turbine housings working in the upper-middle temperatures (up to 950°C). The compared materials are SG irons alloyed with silicon (with or without molybdenum), and aluminium.

Truck brakes dissipate several megajoules of energy every few seconds, which leads to high thermal stresses in the rubbing discs. Therefore, truck brake discs are mainly damaged by thermal fatigue cracking. One improvement way is to evolve disc material with the aim of increasing their thermal fatigue resistance while keeping the braking performance. For the thermal fatigue tests being as close as possible to real brake conditions, a specific geometry of sample and inductor was developed, to reproduce the thermal gradients observed during tests on real brake discs. The test parameters were then chosen after a coupled numerical-experimental study on full-scale braking. Behaviour of different materials under cycling loading (microstructural changes and cracking) is compared with regard to the results obtained during braking tests.

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Keywords: Brake disc ; braking behaviour ; thermal fatigue ; cast iron ; exhaust manifold ; SG cast iron

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S03 - Manufacturing process and fatigue design

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Effect of Microstructure on the Fatigue Behavior of a Friction Stirred Channel Aluminium Alloy

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Abstract

The influence of microstructure on fatigue behavior was investigated on a friction stirred channel strain hardened 5083-H111 aluminium alloy. Friction Stir Channeling (FSC) is an innovative solid-state manufacturing technology able to produce continuous, integral channels in a monolithic plate in a single step. Four sets of FSC parameters were implemented in order to obtain channels with different microstructure and geometry. Fatigue tests were carried out under four-point bending loading. Detailed metallographic, geometric and fractographic analyses were obtained via OM and SEM. It is shown that the fatigue strength is dependent on the channel's nugget (friction stir zone) width.

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Keywords: Friction stir channeling; AA5083-H111; Microstructure; Microhardness; Fatigue behavior

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Influence of surface integrity of 15-5PH on the fatigue life

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Abstract

In this study, the effect of surface integrity parameters on fatigue life has been investigated. Various surfaces had been manufactured with a controlled surface integrity in order to achieve fatigue test and to compare the influence of each parameters independently (residual stresses, surface roughness, microstructure). Difficulty to reproduce the same surface integrity on each sample had been pointed out. It is necessary to characterize the surface of all the samples before testing and take it into account in the fatigue test procedure. Staircase tests have been carried out to determine the average fatigue strength at 2.10^6 cycles for each case of surface integrity. First results show that very good surface finish conditions combined with compressive residual stresses are beneficial.

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Keywords: Surface integrity; residual stresses; fatigue life; rotating bending; surface roughness

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Influence of the base material strength and edge preparation on the fatigue strength of the structures made by high and ultra-high strength steels

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Abstract

In recent years the high and ultra-high strength steels have been developed and applied for light-weight constructions such as the structural members of mobile equipment in order to reduce weight and fabrication costs as well as to contribute to the performance. In many applications, especially in the use of ultra-high strength steels, the welds are tended to locate outside of the highly stressed regions and use the post weld improvement for the critical welds. This means that the non-welded sections are in load-carrying positions and have to take into the consideration in the design of the structures.

Novel test results have shown that the fatigue strength of the base material increases by increasing the yield strength of steel and the maximum fatigue class in the design codes FAT 160 and a slope, m=5, is conservative when the yield strength of steel is equal and higher than 355 N/mm2. Only standard EN 13001-3-1:2012 allows to apply for the higher fatigue classes by increasing the yield strength in cranes.

In this paper the fatigue test results from high and ultra-high strength strip rolled steels are presented and compared with the fatigue classes in standard EN 13001-3-1:2012. Also a cross-member brace connection to main chord flange in vehicle chassis is presented as a design example.

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Keywords: Fatigue strength; High strength steesl; Base plate; Thermal cut; Surface roughness; Hardness; Residual stress

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FD13_75

A new methodology for designing heat treated components in fatigue

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Abstract

This study is dedicated to the effect of the heat treatment on the fatigue strength of an automobile rear axle beam and aims to propose a suitable and reliable methodology for the fatigue design. The rear axle beam is made of sheet metal (22MnB5); the microstructure is initially ferrito-pearlitic before the heat treatment and is martensitic after. A vast experimental campaign has been undertaken to investigate the behaviour, and more specially, the fatigue damage mechanisms observed for both treated and non-treated material, under different loading conditions: tension and shear test with different load ratios. In order to test the sheet metal in shear an original fatigue test apparatus is used.

A probabilistic approach using the weakest link concept is introduced to model the fatigue behaviour. This approach leads naturally to a probabilistic Kitagawa type diagram, which in this case explains the relationship between the influence of the heat treatment and the microstructural heterogeneities.

Integrate in a numerical model, this methodology permit to predict the effect of a local heat treatment on the fatigue strength of the components.

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Keywords: Heat treatment, fatigue, self-heating, damage mechanisms, Kitagawa type diagram

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FD13_91

Fatigue behavior of crankshafts (extended abstract)

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Abstract

In the new types of motors, the crankshaft loads increase dramatically, and in the fillet (one of the weakest point of the component) one of the most used process for crankshaft fatigue resistance strengthening is the deep rolling. This process induces a field of high residual stresses in depth that can stop cracks initiated from the surface. The analysis of stress intensity range function of depth explains the observed crack arrest, and that strengthening is due to the compressive residual profile combined with the decreasing of stress intensity factor in depth. A simple model to predict the fatigue strength has been developed on the base of cyclic plasticity. Both experiments and predictions show that the fatigue strength can be strongly improved with the grade of steel.

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Keywords: Type your keywords here, separated by semicolons ;

Introduction

With the new types of motors, the crankshaft loads are increasing significantly. This effect, coupled with the lightening necessity due to the petrol consumption and to exhaust fumes reduction, constrains the car manufacturers to use high characteristics material, specially forged steel ([1] N.V.Allicheri). For in service properties, there are two critical weak points in the crankshaft: the crankpin fillets and the lubrication holes, those fatigue resistance can be analysed and optimised with classical multi-axial endurance criterion.

In addition, the most used process for improving fatigue resistance of crankshaft grooves is the deep rolling ([2] A. Benamar). Thus, today, for the most of European car builders, the weak spot in service of crankshaft is the crankpin fillets, and they have done a lot of work for analyzing the fillet bending fatigue resistance. So, in the literature, we can found their general approaches described by PSA [3] Ph.Auburtin, by Renault [4] A. Diboine, by Volkswagen [5] C.Achmus and by Rover [6] D.E.Taylor.

In the first part of this paper, we describe our experimental fatigue approach, and in a second part, we shall analyse the successive damage mechanisms: i) crack initiation, ii) depth crack stopping due to the residual stresses field, iii) final rupture. Afterwards, we analyze the main parameters of fatigue behavior strengthening by deep-rolling: steel grade, rolling load, etc.

1. Experimental procedure

In service, the crankshaft grooves see bending fatigue with R=0 cycling for low motor rotative speed, and R=-1 for high motor speed (inertia effects). For studying the fatigue resistance with these two cycling types, we have developed with PSA ([7] H.Michaud), a bending test on special specimen with the same fillets than crankshaft.

This fatigue specimen can be deep-rolled with industrial Hegenscheidt head ([8] G.Felgentreu), exactly like industrial crankshaft fillets. On Figure N°1, we have described the process for the crankshaft and specimen fillets evolution after deep rolling.

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The fatigue strengths at 2.10^6 cycles are determined with the iterative method, which is based on the sample failure or no-failure. As shown in figure 1, cracks have been observed even on unfailed specimen at 2 million cycles.

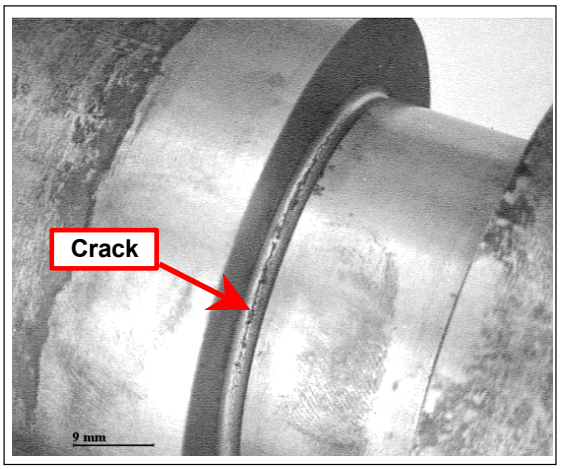

Fig. 1. Example of cracks on unfailed specimen.

2. Crack propagation modeling

The technique of crack propagation modeling for prediction of fatigue failure in a crankshaft has been already used ([6] Taylor). An important point is to predict the residual stresses induced by the deep-rolling and also their evolution during the test. The combination of residual stress and applied load lead to a ΔK curve with a valley that corresponds to 1.2 -1.5 mm depth. This value is in a good agreement with the maximum crack length observed on unfailed specimens. So when the stress intensity factor decreases below the material threshold the crack will stop to propagate. It is thus interesting to develop grades with high Stress intensity factor threshold in order to increase the fatigue strength.

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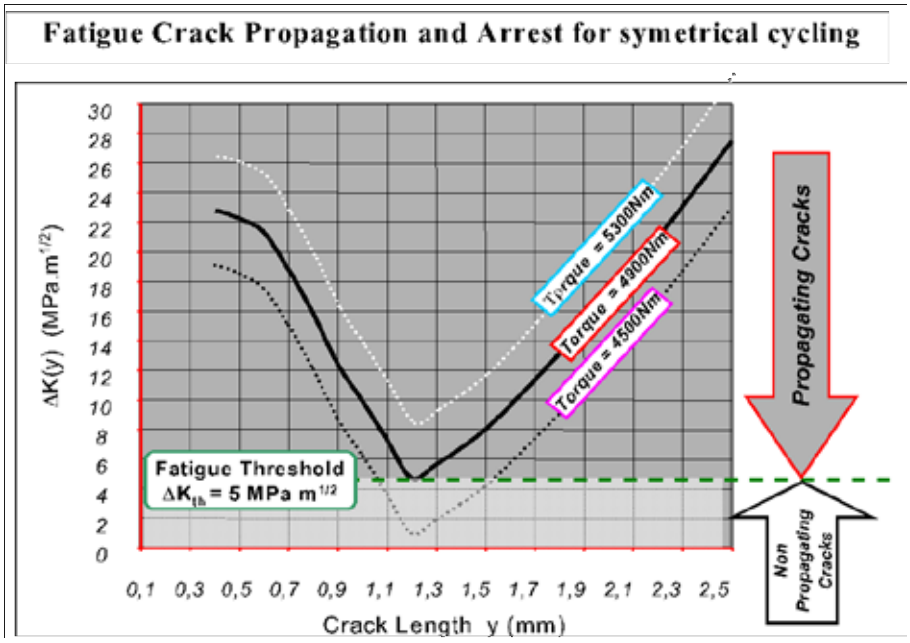

Figure 2: Depth distribution of ΔK for different loading levels.

3. Cyclic plastic modeling

In addition to the previous modeling, a simplified model has been developed based on the calculation of cumulated plastic strain. In this model, a non-linear part of the hardening is introduced in isotropic hardening through memory effects that represent the change of loading direction during fatigue cycles.

Using the latter formulation, the circumferential residual stress profiles calculated after deep rolling can be correlated with the ones measured by R-X technique. It is then assumed that the fatigue strength corresponds to the minimum load level for which plasticity occurs at 1.3mm depth. Predictions are in good agreement with experimental data (figure 3).

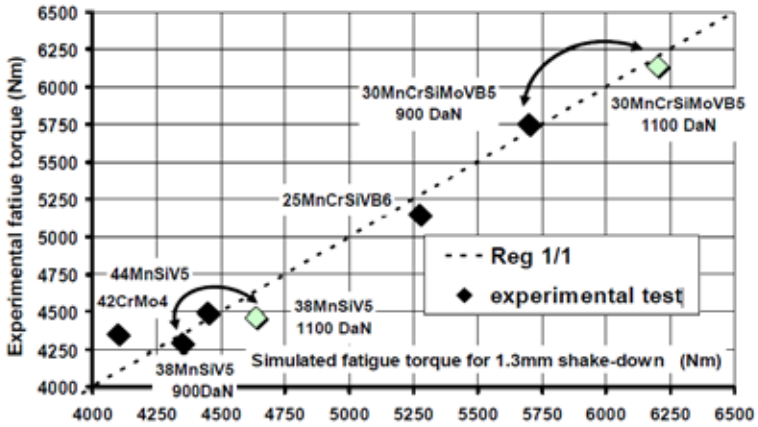

Figure 3: Comparison between experimental data and predictions for different steel grades and rolling conditions.

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4. Conclusion

Residual stresses induced by a deep rolling operation can be modeled using FE or semi-analytical model. These stresses will act as a barrier for crack propagation and thus can stop initiated cracks. The analysis of stress intensity range function of depth, can explain the observed crack arrest mechanism. This phenomenon of crack arrest in the bending cycled grooves, makes the deep rolling process very robust industrially (usual surface defects do not influence the fatigue resistance), and it can be strongly improved with the grade of steel. A model based on the cumulative plastic strain has been developed and lead to good predictions of fatigue lives.

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FD13_99

Fatigue life model for 7050 chromic anodized aluminium alloy

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Abstract

Fatigue investigation on 7050-T7651 chromic acid anodized aluminium alloy has been realized in order to develop a fatigue life predictive model which includes the different experimental aspects of fatigue cracking. In particular, it has been observed that, for this alloy and the sub-mentioned anodizing process conditions, degreasing process used after machining had no influence on fatigue resistance; the essential of the important fatigue resistance decrease was due to pickling process, leading to production of numerous pits which were found to be crack initiation sites; then anodizing process was responsible for a supplementary increase of fatigue resistance decrease. Failure surfaces observations have shown that these pits were responsible for cracks and numerous crack coalescence phenomena have been pointed out.

The fatigue life predictive model presented in this paper is based on Suraratchaï's model, developed at ICA-Toulouse, which is built on the stress concentration effect of machining surface roughness: here pickling pits are considered as stress concentrators from which cracks could occur if stress intensity factor is high enough; considering the very low size of pickling pits, ??less than middle recrystallized grain size, this implies the introduction in the model of short cracks considerations such as short crack stress intensity factor range threshold and short crack growth rate law. Coalescence conditions are also introduced. Calculation are conducted from a 3D finite elements built from experimental topographic measurements which allow the determination of stress concentration coefficients induced by machining surface roughness and the presence of the pits. Anodized surface are rebuilt from pickled surface in order to overturn the lack of accuracy during topographic surface measurements. Predictive results fit very well with experimental results whatever the surface state.

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Keywords: pickling, anodizing, fracture mechanic, short crack growth rate law, life prediction, aluminium alloys,

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Influence of DEFect on the FAtigue behaviour of As7g06T6 aeRonautical alloy (IDEFFAAR)

Y. Nadot, A. Chabaud, I. Serrano Mura, P. Mu, C. Verdu, J.Y. Buffiere, P. Emile, C. Richard, L. Anssems

The objective of IDEFFAAR is to propose an engineering tool to assess the influence of casting defects on the fatigue behaviour of cast Aluminum alloys. The project is focussed on aeronautical applications but the active role of CTIF in the project allows extending the valorisation of results to other industries. The expertise and skills of the partners will support a quantitative evaluation of allowable casting defect in casting component production. Furthermore, fatigue tool proposed can be used to compute justification dispensation on a given component containing higher defect than expected. Industrial partners (MESSIER, HISPANO and AIRBUS) will have the opportunity to validate the tool on real components so that the methodology will result in a compromise between scientific advance and reasonable computational cost.

IDEFFAAR aims to work on the following topics in order to overpass scientific issues on this topic.

- Produce fatigue samples with representative defects (or bigger) in order to define allowable defect criterion.
- Study 3D fatigue mechanisms from defects using high resolution X-ray Tomography. A special focus will be the competition between surface and internal defect regarding environmental effect.
- Determine the role of environment on the fatigue behaviour in order to characterise the representative environment for an internal defect.
- Define the equivalent defect size and morphology regarding fatigue. This definition should include relevant physical characteristics of the defects (morphology and microstructure) as well as constraints induced by the final implementation in an industrial FE code.
- Propose a fatigue assessment methodology for structural components integrating directly the defect size. This methodology should be easy to use and time efficient.
- Validate the Through Process Modelling proposed on industrial component (casting / NDT / fatigue) by the mean of fatigue tests performed on the structure.
- Evaluation of the methodology in the case of temperature (150 °C) on fatigue samples.
- Evaluation of the role of HIP and associated welding repair on the fatigue behaviour of fatigue samples.

The whole project should allow doing scientific advances in fatigue mechanisms from defects and simulations while keeping a reasonable complexity in order to be used by fatigue design engineers.

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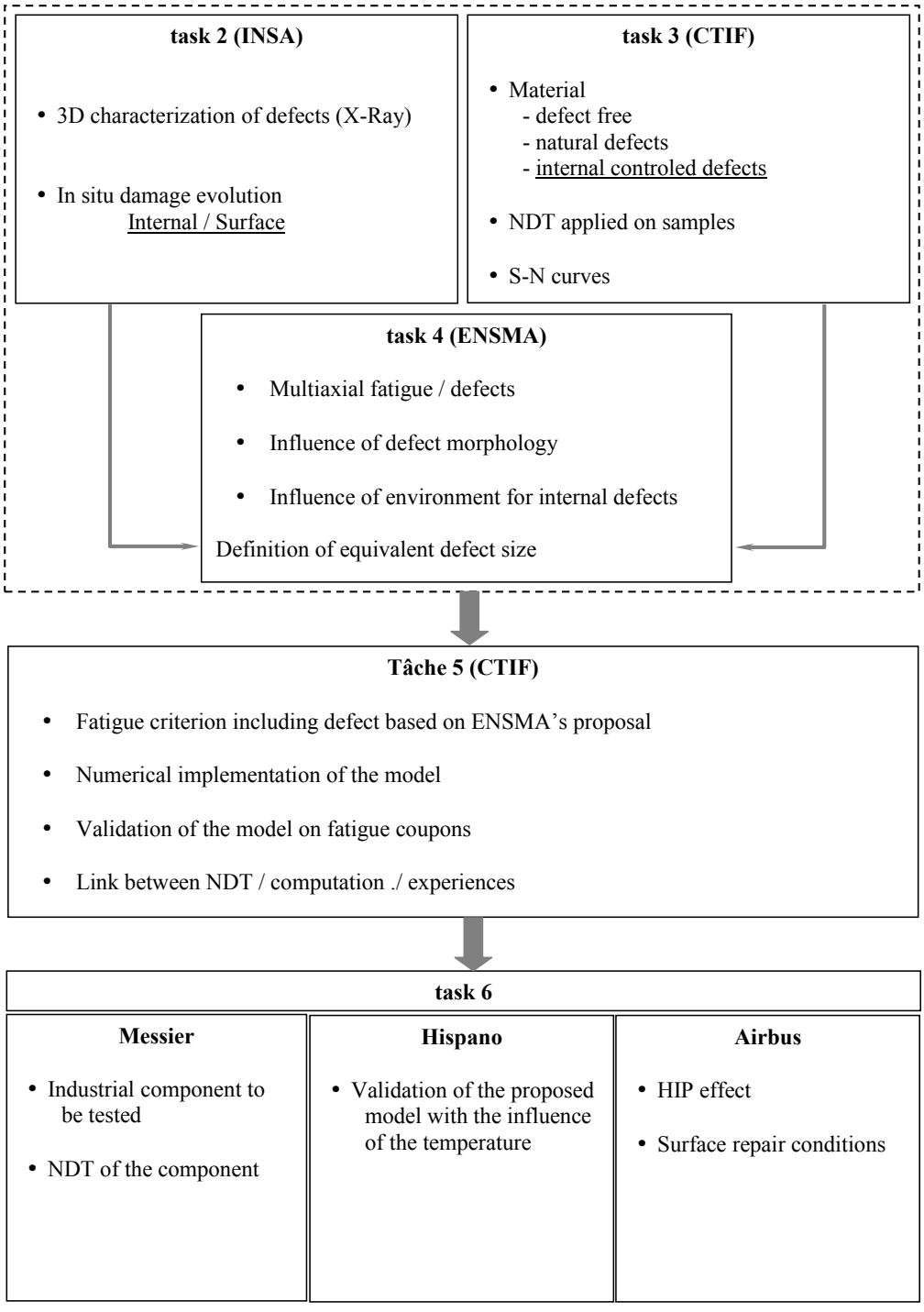

S04 - Fatigue crack propagation assessment

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Accelerated Fatigue Crack Growth in 6082 T651 Aluminium Alloy Subjected to Periodic Underloads

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Abstract

This paper presents a review of available evidence of higher than expected crack growth rates obtained under variable amplitude loading, and explanations for such behaviour. New findings based on fatigue tests performed using 6082 T651 aluminium alloy under a simple loading sequence that was expected to cause crack growth acceleration are presented. Crack propagation was monitored using both optical and the direct current potential drop (DCPD) method. In addition, electrical resistance strain gauges were used to detect the presence of crack closure. Scanning electron microscopy was also performed to correlate observed striations on the fracture surfaces with applied load sequences.

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Keywords: Fatigue; Periodic underloads; Crack acceleration; Fatigue crack growth rate (FCGR)

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Estimation of notch sensitivity and size effect on fatigue resistance

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Abstract. This paper addresses the problem of high cycle fatigue resistance associated to notches and the role of short crack propagation in the fatigue notch sensitivity quantified by the notch factor k_f. An integrated fracture mechanics approach is proposed to estimate the fatigue notch sensitivity, by including the effect of both blunt and sharp notches.

Whether fatigue strength at a given life is controlled by crack initiation (very blunt notches, $k_f = k_t$), by microstructuraly short cracks (blunt notches, $k_f < k_t$), or by mechanically short crack propagation (sharp notches, $k_f << k_t$), depends on the stress concentration k_t, the notch length D and the material threshold to crack initiation $\Delta\sigma_{eR}$, to short crack propagation ΔK_{th} and to long crack propagation ΔK_{thR}.

The approach includes the prediction of the fatigue crack propagation threshold for short cracks, previously developed to analyze the short crack behavior in metallic materials with or without blunt notches, and is integrated adding the influence of sharp notches and accounting for the controlling parameters. It estimates the fatigue resistance of the component by comparing the threshold for fatigue crack propagation as a function of crack length, ΔK_{th}, with the applied ΔK for the given configuration. Estimations for results reported in published bibliography are presented.

The proposed fracture mechanics approach allows accounting for the effects of notch acuity, notch size and intrinsic material fatigue properties on fatigue notch sensitivity. It opens the door to a new simple method for predicting fatigue notch sensitivity and fatigue strength of components with geometric concentrators by using parameters that can be easily measured or estimated, without the necessity of any fitting parameter.

Keywords: Fatigue resistance; Blunt notches; Sharp notches; Fatigue notch sensitivity; Size effect; Estimation.

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Numerical simulation of the total service life time of steel constructions including fracture mechanic concepts

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Abstract

The assessment of the total service life of steel constructions shall gain importance in the near future due to the increasing significance of building preservation and building modernization. The main cause for failure of existing structural steel constructions under cyclic loading effects is material fatigue. Most steel constructions are however failure tolerant. For economic reasons, this behavior can be considered by including the crack propagation phase into the assessment. In this contribution newly developed software tools and the results of some executed simulations of the total lifetime on existing structures will be presented.

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Keywords: steel construction; fatigue, life cycle; fatigue; crack propaganda; fracture mechanics; civil engineering

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Probabilistic prediction of fatigue life of cracked parts: Linear elastic fracture mechanics based approach

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Abstract

In the context of regular inspections of structures, the presence of cracks can sometimes be revealed. It is therefore interesting to know whether the structure can still be used or if a degraded mode of operation should be considered. It is of concern to assess the scatter of the remaining life of such cracked parts due to the uncertainties on the parameters of the prediction model. Thus for the purpose of the present study, a special attention has been given to the quantification of the uncertainty of each collected data (*e.g.*, material properties, crack measurements) to be integrated in the crack propagation model. Three families of uncertainties have been studied, namely, material properties, geometrical and loading uncertainties. A linear elastic fracture mechanics (LEFM) based approach has been used to predict crack propagation in a widely used pressure vessel steel. The model uses classical Paris' law where all the controlling parameters have been replaced by statistical distributions obtained from experiment, namely, crack growth tests, hardness tests, tensile tests and Charpy tests. Crack growth tests have also been carried out on thick notched specimen submitted to uniaxial cyclic load to obtain two dimensional cracks that can be representative of those to be found in industrial structures. During these tests, crack lengths have been measured simultaneously by time of flight diffraction (TOFD) ultrasonic method, digital image correlation (DIC) and some markings have been performed to estimate the crack length and crack front shape after the specimen failure. The comparison of data obtained from different observation techniques allowed for the quantification of the crack measurement uncertainty of the industrial TOFD technique. A sensitivity analysis has been carried out on the parameters of the model to evaluate and classify the influence of all sources of uncertainty on the residual life prediction. Last, results from crack growth tests on notched specimen have been used to assess the accuracy of the model prediction.

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Keywords: crack propagation; crack front marking; digital image correlation; time of flight diffraction; uncertainty analysis.

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FD13_96

Experimental Study of Crack Propagation Starting From Surface Defects in DA Inconel 718 Alloy

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Abstract

Aircraft engine manufacturers have to demonstrate to authorities that the presence of small surface defects introduced on engine parts during maintenance operations in critical areas do not lead to failure during service life. This paper presents a study undertaken to characterize the nocivity of surface defects and their influence on fatigue life of Direct Aged (DA) Inconel 718 alloy.

More precisely two typical maintenance defects are investigated in this study: scratches ("V-type" defect) and dents ("U-type defect). Specimens containing two surface defects and equipped with a potential drop method to perform crack growth measurements are used for fatigue experiments. The load conditions were selected in order to efficiently cover the stress field encountered during in-service operation of high pressure turbine discs.

Temperature seems to have an important influence on the defect nocivity. It is also observed that the defect depth plays a more important role for scratches than dents. Heat tints showed that the initiation part is very low in the conditions examined. Furthermore, it has been shown that the fatigue life is controlled by the very first stage of propagation (micropropagation). Indeed it seems that during the first stage of propagation, the crack growth rate is lower than expected for crack initiated from scratches or dents, so that an approach considering the defect as a long crack to calculate the specimens fatigue life is over conservative. Residual stresses, the notch effect, multiple crack initiation sites could explain this phenomenon and their respective influence is currently investigated.

Besides, numerical simulations of the potential drop measurments are also conducted. A parametrical study revealed that the crack front shape and the position of the measuring points are the most influent parameters which have to be taken into account in order to calibrate the potential drop method. The improvement of this method leads to a good agreement between the numerical and the experimental calibration curve and permits to refine the control of this method and the further analysis of the experimental results.

A large series of experiments is progressing and should permit an improved understanding of the mechanisms involved during the very first stage of propagation from the defect. The main objective is then to propose a new model for crack growth life which can take into account this micropropagation stage.

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Crack path assessment under non-proportional loading

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Abstract

Cost reduction of new industrial products implies weight and shape optimization while keeping a fail safe design. For other products, such as large parts of existing power plants, the extension of the predefined lifespan is the key issue. In both cases, the need of reliable simulation methods for cracking under cyclic conditions is growing due to the prototyping and experimental costs. The purpose of the damage tolerance analysis is to define the remaining life of a part embedding a crack, which size is the smallest detectable, in a critical area. The use of the Linear Elastic Fracture Mechanics benefits a lot from eXtended Finite Element Method (XFEM). The heart of this numerical tool is the ability to insert an implicit representation of a crack within a mesh and to simulate crack propagation without changing the underlying mesh.

Propagation laws have been essentially developed in 2D for simple configurations. However, when it comes to industrial parts, with complex shapes and non-proportional loadings, 3D aspects related to the criterion for selecting the crack path become critical. For that purpose, original test specimens and loading configurations have been developed in order to analyze the influence of mode mixity with on-proportional loading and 3D effects on the crack propagation direction and rate. The pre-design, and the comparisons, of the specimens has been performed with an XFEM based software in order to determine the material (hardened aluminium), the geometry and the loading conditions. A comparison between experimental results and modelling has been done to validate the hypothesis made on the effect of mode mixity on the crack path.

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Experimental and numerical study for fatigue life prediction of bolted connection

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Abstract

This paper presents results of an experimental study carried out for developing a model to predict the low-cycle fatigue life of bolted connection. The test specimens are cantilever beams with one end fixed by a bolted connection and the other end free. Each cantilever beam is subjected to a mass at the free end. Different levels of cyclic loading are applied to the beam system by means of a vibration shaker. Moreover, a numerical analysis is performed to study the uncertainty of the experimental model and to predict the lifetime scatter of the bolted connection. Monte Carlo simulations are adopted to include uncertainties by generating samples of the different random variables. The effects of these variables on the fatigue life of the bolted connection are identified.

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Keywords: Bolted connection ; fatigue life ; shaker tests ; low cycle fatigue ; uncertainty ; Monte Carlo simulations

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FD13_58

Design of Experiment Based on VMEA (Variation Mode and Effect Analysis)

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Abstract

A great part of off-road transports are performed by construction equipment such as wheel loaders, articulated haulers, dump trucks and trucks. More energy efficient solutions of these applications could be accomplished by 1) more efficient usage of existing products by operator training or system supporting the operator, or 2) development of new products with more efficient transmissions and energy recovery. In both cases, it is necessary to have a good knowledge about the operation conditions in service.

The usage of construction equipment performing off-road transports varies greatly. The response, product characteristics, of the machines in terms of performance, fuel consumption, durability etc. is largely an effect of this variability. Thus, a machine with good performance and good fuel efficiency for one type of operation does not necessarily have the same response for another type.
In order to develop machines that meet or exceed customer expectations of a specific product characteristic in their application, e.g. fuel consumption, it is required that designers have a good knowledge about the actual usage and also understand what affects the product characteristic in mind.

A common approach to increase the knowledge of a product characteristic of a machine is to perform tests during service operation and during these tests measure the characteristic in question and then draw conclusions about the usage effect. These tests are generally resource intensive. The questions one should ask before these tests are what to measure and where.

The product characteristics are typically dependent on the operation. Thus if this is known the product characteristics for different designs and concepts can be estimated by aid of simulation tools. The common usage of this type of machines, e.g. articulated haulers, is to move material from one point to another along a route. This can be described with a set of operation characteristics. This approach has been used within the Volvo Group, where a set of 20 Global Transport Application (GTA) parameters [1] have been defined to describe the operation.

If a certain product characteristic is to be investigated one must know which parameters affect and to what degree, i.e. the sensitivity of the parameters with regard to the product characteristic. Then if the values of these parameters during service are known, the product characteristic can be quantified.
Performing a test to define sensitivity for all 20 parameters demands a large amount of resources and it is important to use all possible prior knowledge in order to find a proper test plan for studies of service usage.

There is often a good sense among practicing engineers of what is important based on years of experience of product usage. The problem occurs when this subjective knowledge should be structured and translated into numerically comparable values. Here we will put forward the Variation Mode and Effect Analysis method [2,3,4] to structure and quantify the different user parameters that affect fuel consumption of an articulated hauler during service use. This method is used to go from subjective in-house knowledge into measurable quantifications where both variations during service and sensitivity of the particular product characteristic in question are included in the analysis. These quantifications are compared and a reduced number of parameters are selected for further investigation.
For this investigation we only have a limited number of resources for different measurements. In order to get the most out of the measurements, a rational test plan based on statistical design of experiments [5] is created. As a base for the design, a fractional factorial design at two levels is used. The underlying assumption in such a design is that interaction effects are considered to be small compared to the main effect. It has to be kept in mind that the more the test is reduced the fewer interaction effects can be detected. One benefit of this type of design is that the test can be expanded later to estimate interaction effects and reuse the results from the first test set.
The procedure during the two-level factorial design is that the parameters are set to the two levels chosen, e.g. high or low, and then according to a pattern tests are performed so that the effects can be distinguished. Since this test is reduced this pattern must be created in such a way that possible interactions do not interfere with the results. One issue to deal with here is that when performing test during service operation the

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parameters cannot be controlled and fixed as in laboratory tests, which forces the analysis of the test result to be other than the standard two-level test method. Still, we believe that the powerful two-level test methodology is useful for the test planning.

This paper proposes a method using results from the Variation Mode and Effect Analysis to design a test plan for investigating usage effect on a product.
As a case study an articulated hauler is used as a product, and fuel consumption is used as product characteristic.

The outline of the paper is:

First the Variation Mode and Effect Analysis methodology and the Global Truck Application approach are described.
Then the procedure of the case study is presented with a following discussion. Finally some conclusions are given.

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Keywords: VMEA; construction equipment; design of experiments; factorial design

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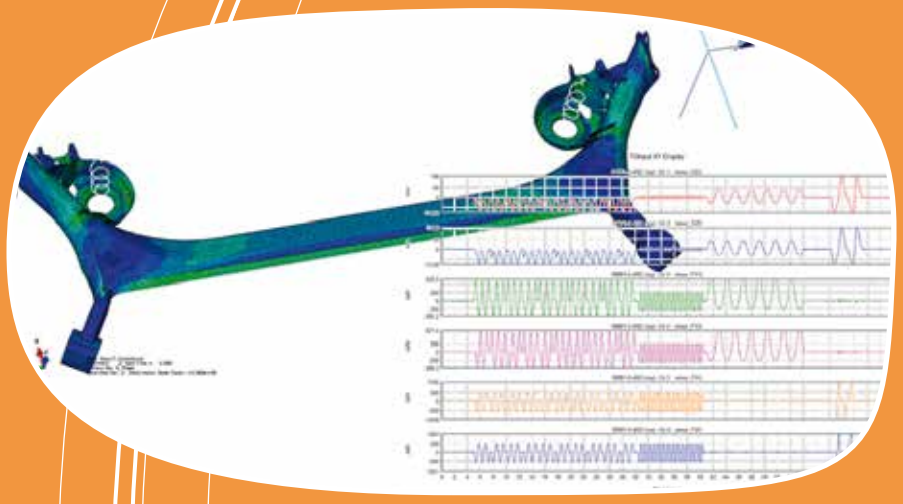
S05 - Complex loading and fatigue behaviour

Chairmen:

P. Joanhasson, M. Bennebach

I. Rychlik, R. Paquet

A. Bignonnet, A. Manitournam



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Breathing-induced fatigue in thin-walled construction

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Abstract

The cumulative damage behaviour generated by web breathing was analysed, the process of the initiation and propagation of fatigue cracks induced thereby was studied, and their impact on the failure mechanism and the fatigue limit state of the girders was determined. It was found out that the above phenomenon led to a significant "erosion" of the beneficial post-buckled reserve of strength. Therefore, S-N curves were established for (i) the fatigue limit state and (ii) the onset-of-the-first-fatigue-crack limit state, specifying those periods after which checks for the appearance of fatigue cracks in bridge plate elements need to be carried out.

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Keywords: slender webs; fatigue limit states; buckling; breathing; S-N curves;

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Multi-parameter Fatigue Equivalence Loadings for specification applications

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Abstract

This paper deals with a method to define Equivalent Fatigue Loads (EFL) from in-service load measurement in the case of a structure subjected to multiple variable fatigue loadings. EFL can be used in order to define tests on full scale structures for an experimental validation approach. It can be also used for the evaluation of the severity of the in-service loads, useful step in a reliability approach, in order to optimize the geometry with respect to the fatigue damage. The aim of the paper is to define the mathematical and mechanical concept of the Equivalence Fatigue Method in the case of multi-parameters loading for specification application. This method uses fatigue damage evaluation from statistical in-service measurement data. The specificity of the method presented here is to use a fully multi-parameters equivalence method. Damages is evaluated using life prediction method based on multiaxial criteria. The method is used for rotating structures, applied to a specific family of structure: train wheels. Train wheels are critical safety railway components mainly subjected to random multiaxial fatigue induced by multi-parameters loading. In this paper an approach to evaluate damage from this measurement in order to find the EFL with a damage equivalence optimization is developed.

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Keyword : high-cycle fatigue ; fatigue design ; fatigue equivalence ; damage accumulation,

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Use of multi-scale approach for vehicle weight reduction study

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Abstract

This paper presents the use of the multi-scale approach developed by Nexter, to study the weight reduction of military armored vehicles. The fatigue design of such mechanical system is often complex due to the gap between the scale of the system and the scale at which the fatigue phenomenon occurs. The multi-scale approach developed by Nexter involves first simulating the dynamic behavior of the mechanical system, then a dynamic finite element model coupled with a global fatigue criterion identifies the weak points location of the structure for different combination of loads. By focusing on these hot spots, local modeling including geometric singularities are done to assess fatigue life. This process is illustrated on a vehicle structure to study different concepts of weight reduction.

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Keywords : Weight reduction, design optimization, multi-scale approach, dynamic behavior, fatigue criterion, local modeling, welded joints

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FD13_122

Modelling of hydrogen transport in rolling contact fatigue conditions

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Abstract

Current work presents Finite Elements study of hydrogen diffusion into a metal substrate loaded by rolling contact. The main goal of the presented study is to investigate stress effect on hydrogen transport in rolling contact conditions. In this work, rolling contact is defined by the Hertzian pressure, moving along the bearing ring. Although, hydrogen diffusion with respect to bearing is studied here, very similar approach can be used for other components of machinery subjected to rolling contact. Governing equations are given in the current study in dimensionless form, and parametric study, analyzing influence of different dimensionless parameters on subsurface concentration of hydrogen, is presented.

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Detection of the Curves based on Lateral Acceleration using Hidden Markov Models

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Abstract

In vehicle design it is desirable to model the loads by describing the load environment, the customer usage and the vehicle dynamics. In this study a method will be proposed for detection of curves using a lateral acceleration signal. The method is based on hidden Markov models (HMMs) which are probabilistic models that can be used to recognize patterns in time series data. In an HMM, 'hidden' refers to a Markov chain where the states are not observable, however what can be observed is a sequence of data where each observation is a random variable whose distribution depends on the current hidden state. The idea here is to consider the current driving event as the hidden state and the lateral acceleration signal as the observed sequence. Examples of curve detection are presented for both simulated and measured data. The classification results indicate that the method can recognize left and right turns with small misclassification errors.

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Keywords: Hidden Markov models (HMMs); Markov chain; curve detection; event classification; lateral acceleration.

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Operation of The Bois plant hydraulic turbine in bypass operating mode: analysis of fatigue behaviour

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Abstract

During load tripping of the hydraulic turbine at the Bois power plant, the turbined flow is directly transferred and discharged into an external canal without releasing an alert flow. The operation of the turbine in bypass mode, which consists in maintaining flow through the penstock and the turbine nozzles, was therefore envisaged to reduce flow variations in the short-circuited section of the scheme, in which people may be found, particularly during the summer season (safety stake).

To validate the feasibility of this type of operating mode and, specifically, to verify the structural integrity in operation of the components impacted by the jet (deflector, control rod, jack...), studies were jointly carried out by EDF and CETIM, and a test-calculation program was initiated. This program included preliminary calculations using a finite element model, a campaign of tests in operating conditions (with vibration measurements and dynamic extensometric measurements) and an analysis of the potential damage due to fatigue. In the end, the study made it possible to show that the damage due to fatigue resulting from the operation of the Bois turbine in bypass operating mode remained in an acceptable range.

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Evaluation of the severity of fatigue loads on railway axles from in-service measurements

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Abstract

Railway axles as most of structures in transportation industry are designed to prevent fatigue failure. European standards defines constant amplitude fatigue loads for the design of such components. Today, these loads are based on safety coefficients related to experience. In real life, axles are subjected to random fatigue loadings.
The aim of this paper is to propose a method to evaluate the damage at the transition zone on the axle from in-service measurement. At this zone, the stress field is highly multiaxial and is dependant of several loads. The proposed method in the paper is to combine finite element computations and fatigue equivalence method to estimate damage levels in the structure. An extension of the Dang Van criterion in the high cycle fatigue finite life domain is used to evaluate the damage. A computation of an equivalent fatigue stress related to in-service loads is done in the paper and is compared to the equivalent fatigue stress related to the standard. This comparison gives an objective view of security margins in the fatigue design of railway axles.

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Pile fatigue assessment during driving

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Abstract

The aim of this paper is to present the methodology which is currently followed in the offshore industry for the prediction of the pile fatigue induced by pile hammering during installation. Evaluation of fatigue damages will depend on various parameters such as applied stresses, number of blows, Stress Concentration Factor (SCF) and S-N curves. It will be shown how fatigue damages are dependant on the choice of the values used for the SCF and S-N curves and also on applied stresses by the hammer, and in the end the impact of these parameters on the residual available fatigue life for the in-place conditions.

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Pile; Driving; Fatigue

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FD13_82

Laplace processes for describing road profiles

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Abstract

The Gaussian model is frequently used for modelling environmental loads, e.g. sea elevation, wind loads and road profiles. However, the Gaussian model is often only valid for short sections of the load. For example, for roads profiles, short sections of roads, say 100 m, is well modelled by a Gaussian process, whereas longer sections of roads, say 10 km, typically contain shorter sections with high irregularity, and the variability between sections is higher than what can be explained by the stationary Gaussian model. This phenomenon can be captured by a Laplace process, which can be seen as a Gaussian process with randomly varying variance. Thus, the Gaussian process is a special case of the Laplace process. Further, the expected damage can be computed from the parameters of the Laplace process. We will give examples of modelling road profiles using Laplace models. Especially, it will be demonstrated how to reconstruct a road profile based on sparse road roughness measurements, such as a sequence of IRI (International Roughness Index) for 100 metre road sections. Further, IRI data from the Finnish road network will be evaluated.

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Keywords: Road surface profile, road roughness, road irregularity, Laplace process, non-Gaussian process, power spectral density (PSD), ISO spectrum, roughness coefficient, international roughness index (IRI), vehicle durability, fatigue damage

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FD13_101

Gradient fatigue multiaxial models

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Abstract

Interest in micromechanics and new electromechanical devices shows the necessity to deal with size and gradient effects. The aim of this paperis to formulate new classes of high cycle fatigue models using stress gradient to account for both effects. The dependence of fatigue limit on these effects is analysed and modeled. These effects are integrated into only one through gradient terms. On this basis, new criteria with stress gradient terms introduced in the normal stress as well as in the stress amplitude, are formulated. Some classical fatigue criteria such Crossland and Dang Van are extended and illustrations are provided.

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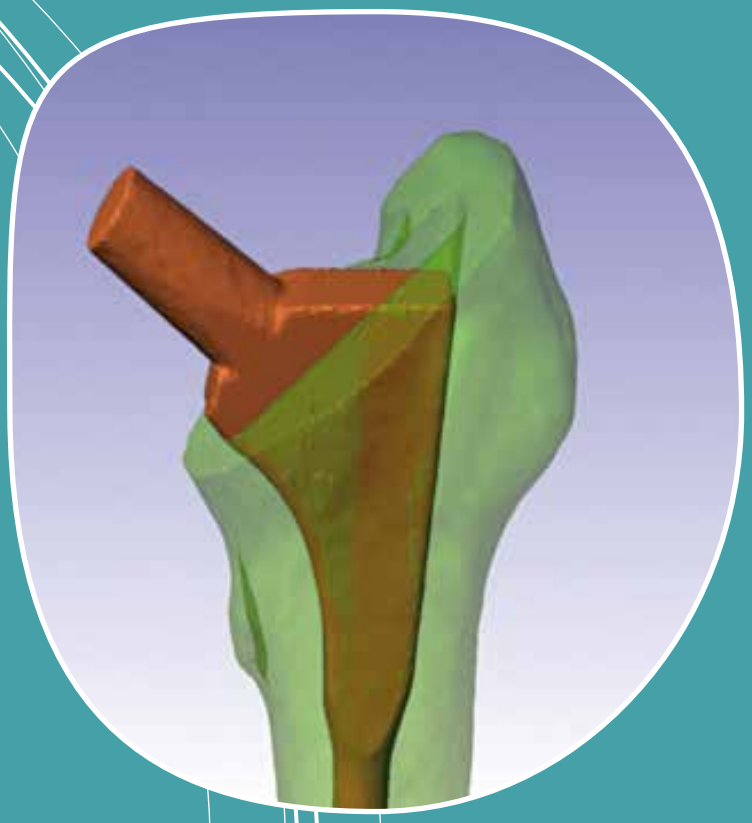
S06 - Reliability approaches in fatigue design

Chairmen:

T. Svensson, Y. Suchier



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Risk based fatigue inspection planning – state of the art

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Abstract

The present paper presents the methodology and the practical calculations for risk based inspection planning of fatigue cracks in welded offshore steel structures. Due to the uncertainty in the variables involved in the problem the planning has to be carried out by stochastic modeling and risk based assessments. Scatter in potential crack growth has to be analyzed by applied probabilistic facture mechanics and the uncertainty in the performance of the actual inspection technique has to be determined. With given risk acceptance criteria the practical outcome of the analyses is recommended inspection techniques and associated planned inspection time intervals. The classical theory is briefly outlined and the latest recommendations from a Joint Industry Project recently completed in Norway are included. A practical case study for life extension of an oil loading system in the North Sea is presented.

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Keywords: Fatigue cracks in welds;Inspection planning,Risk assessments;Aging of offshore Structures

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FD13_50

Stress-strength interference method applied for the fatigue design of tower cranes

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Abstract

Crane owners want to maximize the efficiency of their equipment and teams on a construction site in order to minimize the amount of time needed to complete their work. This leads to very intensive crane use and stress on crane structures made primarily of welded steel elements (plates and beams). Therefore, it is necessary for Structural Engineers to consider fatigue resistance during the design process. The aim of the paper is to demonstrate the utility of a probabilistic approach for a better optimization of the fatigue design of tower cranes elements (e.g. jib elements).

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Keywords: reliability, fatigue, crane

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Reliability approach in implant fatigue design

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Abstract

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

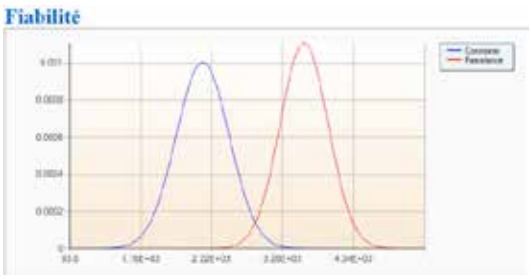
The objective of this study is to establish a statistical distribution of the uses of hip prosthesis in order to define at best a minimum value of strength required for a good fatigue design.

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 is based on:

- In vivo load recordings on hip prosthesis,
- Frequency of everyday activities,
- Activity level of different category of the population,
- Statistical distribution of key parameters, like weight, age…



These different parameters are processed with the software DEFFI® . The goal is first to assess the reliability reached by a “nominal” stem and compare it to the reliability described in implant registers. Another goal is to analyse the stress distribution and compare it to standard requests (ISO/DIS 7206-6:2011), in order to assess the reliability of an implant that succeeded this standard.

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S07 - Vibration Fatigue behaviour

Chairmen:

I. Rychlik, M. Bennebach

A. Galtier, Y. Goth

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FD13_110

Fatigue of structures in mechanical vibratory environment. From mission profiling to fatigue life prediction.

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Abstract

The durability of components operating in a mechanical vibratory environment is usually validated on shaker rigs, using an accelerated simplified test derived from mission profiling and test synthesis process. The basis of this method is damage equivalence, the accelerated test leading to the same fatigue damage content as that observed in real service conditions. Numerical simulation can help optimizing this process, allowing verifying that the synthetic test is realistic, and giving the damage distribution based on real material behaviour laws.
The complete approach will be described in this paper and illustrated by some real applications. Extension of classical spectral methods to confined plasticity is also presented with laboratory experimental validation.

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Keywords: mission synthesis; vibration fatigue; spectral methods

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Probabilistic Random Vibration Fatigue

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Abstract

Industrial components subjected to random vibration fatigue (loading with a power spectral density, PSD, or a sinusoidal spectrum) are frequently designed by the use of numerical simulations to estimate the lifetime and ensure the mechanical system behavior.

Finite element simulations need the use of a significant amount of input parameters to solve the problem (material properties such as Young's modulus, density, stiffness of joints between components, model element choice...). Some of these parameters are identified from tests with unavoidable uncertainty and others are subjected to inherent variability. It is important to know the influence of this variability/uncertainty on model responses. Innovative methods have been developed to determine the sensitivity of model responses to uncertain parameters in order to study the robustness of the design.

Then, the identification of the most influential parameters, associated with the study of their variations, allow to determine result dispersions for the modal analysis (eigen frequencies, mode shapes), the calculation of random vibration (RMS constraints) and damage calculation.

This methodology provides an estimation of the probability of system failure instead of a binary result obtained by a deterministic design method.

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Keywords: Vibration fatigue; Reliability; Surrogate model; kriging

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Multiaxial Load Situations in Random Vibration Fatigue - Phasing and Cross Correlation

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Abstract

Traditionally fatigue damage is associated with time dependent loading, in the form of local stress or strain histories. But there are load situations both in the lab testing as well as in the real world, where the determination and definition of the loads are more efficiently conducted in the frequency domain. Be it as deterministic sine sweeps or random stationary processes. For uni-axial loads the simulation of these signals on shaker tables has been analyzed in the past.

But if we go to multiple loads which are somehow correlated new aspects have to be taken into account as the correlation or phasing have an important impact on the fatigue life – imagine the loads on a truck frame where there is a definite correlation between the loads from the front and rear axles.

In this paper we present the methodology to handle multiple loads and also how to correctly handle the local stresses evaluated from multiple correlated signals, if used for a fatigue analysis. We show why traditional equivalent stress approaches bases on von Mises or principal stresses are problematic and the critical plane approach should be used. We discuss on how information on the behavior with respect to in-phase and out-of-phase loading can be analyzed and how it can be used to design better test setups on the shaker table.

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Keywords: Vibration Fatigue; Multiaxial Fatigue; Shaker Table

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Time Domain Analysis Method of the Impulse Vibro-Acoustic Signal for Fatigue Strength Characterisation of Metallic Material

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Abstract

This paper proposes an alternative statistical approach that can significantly characterise the fatigue strength property of metallic material. In this study, a simple impulsive excitation technique based on ASTM E1876 is conducted to measure the vibro-acoustic signal simultaneously using data acquisition consisted of an accelerometer-microphone configuration. The considered metallic material in the proposed design is composed of rectangular bar in cross section of medium carbon steel S50C, stainless steel AISI 304, cast iron FCD 500 and brass with a similar size of dimension as a specimen. To take into account the effect of noise existance, an alternative Z-stem filter de-noising technique is derived and applied to minimise the noise frequency components. Moreover, the effectiveness of this filtering technique is calculated. The filtered vibro-acoustic signal has been statistically analysed using an alternative time domain analysis method known as Mesokurtosis Zonal Nonparametric (M-Z-N). The accurate curve fitting equation for every metallic material is obtained using the combination of the calculated M-Z-N coefficient for vibration and acoustic impulse signals. The fatigue strength characterisation is carried out by the comparison of the experimental results with fatigue strength properties obtained in the literature. Correlation between the slopes of the curve fitting and fatigue strength values validate the proposed method.

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Keywords: Fatigue strength; impulsive excitation technique; vibro-acoustic signal; statistical signal processing; time domain analysis method.

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FD13_60

Defining Representative Dynamic Environmental Tests using Mission Synthesis

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Abstract

This paper presents a methodology for defining dynamic environmental test specifications (for single axis tests) from operational measurement of the vibratory environment. This technique is also referred to as '*test-tailoring*'. The aim of test tailoring is to design vibration tests specifications which are representative of those experienced by the Device Under Test (DUT) during its operational life. I so doing, it can be argued that a products which has successfully passed such a test will be more reliable when in operation without having to make use of over-testing in order to push the limits of the product. The main difference with standard tests is that test tailoring allows personalising the tests to the real environment, reducing any over/under-testing that is inherent in standard tests. The test tailoring technique has wide applications in defense and it is described in the French military standard GAM EG13. Further investigations and development have been performed by LMS International within the ENVIB European Esprit Project. In addition, the latest version of MIL STD 810 (release G) also suggests the use of test tailoring technology. The general overview of the test tailoring technique to define vibration test specifications consists of five steps: i) mission definition, ii) data acquisition, iii) analysis of environments for damage potential, iv) calculation of overall damage curves and time compression and v) test profile synthesis.
The aim of the first step in mission synthesis is to define which environments the product is going to encounter during its real life. After the definition of the environments, the second step is the characterisation of the vibrations that are related to each of these environments. Most of the time, this means that the user has to perform measurements in order to specify the loadings that are related to each environment. After the data acquisition, each of the environments has to be analysed for damage potential: a damage equivalence model is calculated that characterises how damaging each of the environments is for the product. The damage incurred to a product by vibration loads arises from the stress exceeding a maximum or the accumulated fatigue due to cyclic loading. When all phases of the life cycle are quantified with measurements, the damage potential for each phase can be calculated. Two damage evaluators are available, one for each type of damage: Maximum Response Spectrum (MRS) and Fatigue Damage Spectrum (FDS). At this stage is then possible to specify a requirement for an accelerated test. In fact, criteria for FDS/MRS can be included in a way to reduce test time compared to the operational exposition time using a well-defined scaling law. In a subsequent stage, the damage spectra of all the different environments are merged into an overall MRS and FDS. The resulting FDS (MRS) is thus representative for the most damaging path in the life profile. The last (but not least) step of the test-tailoring process is to calculate a representative excitation profile in the frequency domain (sine or random) and to perform the closed loop vibration test.

Herein all the theoretical/numerical aspects will be discussed together with a real life engineering application.

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Vibration fatigue and simulation of damage on shaker table tests: the influence of clipping the random drive signal

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Abstract

Suppliers of shaker controllers often use a technique called 'sigma clipping' to prevent the amplifier from encountering too high amplitude peaks. Sigma clipping is most commonly used to make sure a shaker system will be sufficiently powerful to reproduce the required random spectrum. The level of clipping is measured via the crest factor, which is expressed as a ratio between the absolute maximum of the signal and its root-mean-square (RMS) value.

Such clipped drive signals are therefore no longer Gaussian, since their probability distribution functions (PDF) are truncated at high values. The clipped drive signal is then amplified and filtered by a system made up of the shaker itself followed by the unit under test. Although the local stress and strain responses do not show any obvious clipping, their statistics may be affected. This can feed through to fatigue damage, which is known to be exponentially related to strain amplitudes. A legitimate question is therefore "how does clipping affect damage?"
This paper studies and quantifies the influence of clipping experimentally, numerically and theoretically. There are many objectives and underlying questions to consider. For the test technicians, what level of clipping to choose in order to represent the damage due a Gaussian environment? Whereas for the simulation engineers, how to enhance damage estimations by taking into account the level of clipping?

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"Keywords: Fatigue; crest factor; Sigma clipping; random shaker tests, gaussian, statistics"

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S08 - Fatigue damage mechanisms

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On the fatigue reliability of hydroelectric Francis runners

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Abstract

The reliability assessment of large rotating structures like hydroelectric Francis runners is often limited by our capacity to define a proper limit state combined with a relevant degradation model. In this paper, we propose that the proper limit state for fatigue reliability of such structures is the onset of high cycle fatigue (HCF). Based on this premise, a prior interval for our limit state based on available literature is presented. The prior assumptions are believed to be the first step toward validation of the applicability and suitability of the proposed model. The paper includes an overview of the theoretical background for reliability assessment of Francis turbine runners, the methodology used, and the results obtained from the information gathered from the available literature.

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Keywords: Reliability; High Cycle Fatigue (HCF); Hydroelectric turbine

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A new model for fatigue damage accumulation of austenitic stainless steel under variable amplitude loading

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Abstract

The application of Miner's rule using a loading issued from a mock-up of a RHR system (removal heat system) of PWR plant, made of 304 steel gives a very important non-conservative fatigue life in strain control when strain fatigue curve is used. This result is due to the absence of sequence effect in Miner's rule. Many non linear damage accumulation models have been proposed to get a sequence effect. Shortcomings of some non linear damage accumulation models are discussed. So Smith-Watson-Topper and Fatemi-Socie criterions with a linear damage accumulation rule are then applied to experimental data. A major issue is the need for an elastic-plastic constitutive law which is difficult to propose in the presence of high cycle secondary hardening observed in austenitic stainless steels. A conservative model for fatigue damage accumulation under variable amplitude loading is then proposed for austenitic stainless steels in strain control, which does not need a constitutive law, but takes into account plasticity through cyclic strain stress curve. The model uses a linear damage accumulation rule. This model is based on the fact that for stainless steels, pre-hardening is detrimental for fatigue life in strain control, while it is beneficial in stress control. In the presence of low mean stress, the model is approved based on a large number of tests. Moreover the model allows to explain the larger detrimental effect of a tension mean stress in strain control tests than in stress control tests.

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Key words : pre-hardening, mean stress, stainless steel, 304, fatigue, SWT, FS, damage accumulation, variable amplitude

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FD13_48

Quest for fatigue limit prediction under multiaxial loading

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Abstract

The paper discusses origins of fatigue data used for evaluating the prediction quality of various multiaxial methods intended for estimating the fatigue limit. The paper defines some requirements useful for processing similar data sets. It focuses on four most often used data sets, analyzes the way they were prepared and the way they are transmitted over various research papers. These sets are commented and objections to some their items stated. Weight coefficients enabling their application in validation studies are proposed. The final reduced total set has approximately one half of its original size. The reduced set is re-analyzed by several fatigue limit calculation methods and the results are compared to the origin. Though the relative probability distribution of the output is quite well kept, the importance of evaluating the second hand data sets carefully is clearly highlighted.

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Keywords: multiaxial fatigue; fatigue limit; multiaxial fatigue limit estimation; experimental fatigue data; fatigue database

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FD13_63

Two-scale time homogenization for isotropic viscoelastic-viscoplastic homogeneous solids under large numbers of cycles

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Abstract

A two-scale time homogenization approach for coupled viscoelastic-viscoplatic (VE-VP) homogeneous solids and structures subjected to large numbers of cycles, is proposed. The main aim is to give a description of the long time behaviour, by calculating the evolution of internal variables within the structure, while reducing the computational overhead. This method consists in decomposing the original VE-VP initial-boundary problem into coupled micro-chronological (fast time scale) and macro-chronological (slow time-scale) problems. The proposed methodology was implemented and studied for J_2 VP coupled with VE using fully implicit time integration and a return-mapping algorithm. An illustration of the time homogenization on a simple case is presented and a good agreement with the reference solution is observed.

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Keywords: Time homogenization, two-scale modeling, viscoelasticity (VE), viscoplasticity (VP), numerical algorithm.

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Fatigue damage assessment of alternator fans by EBSD

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Abstract

Components of new car alternators are subjected fatigue damage due to the start-stop cycles. Predicting their fatigue life still requires needs an experimental validation. Hence, identification of both monotonic and cyclic behaviour is required to integrate the right values in the models. Therefore a precise analysis of the dislocation arrangement produced by cyclic plasticty appears as a fatigue damage indicator. Here SEM-EBSD provide two plasticity markers: the Kernel Average Misorientation and the Low Angel Grain Boundaries that characterize dislocations arrangements in a quantitative way.

Based on these indexes, the comparison between lab fatigue specimens and component gives an estimation of the local cyclic plastic strain.

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Keywords: Fatigue, EBSD based damage criteria, TEM, local deformation estimation

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Very High Cycle Fatigue for single phase ductile materials: slip band appearance criterion

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Abstract

The DISFAT project is a French project financially supported by the French National Agency for Research (ANR). It aims at a deeper understanding of mechanisms leading to crack initiation in metals and alloys under Very High Cycle Fatigue loading (VHCF). The VHCF regime is associated with stress magnitudes lower than the conventional fatigue limit and as a result, numbers of cycles higher than 10^9. Tests were carried out using an ultrasonic technique at loading frequency of 20 kHz. In the case of pure copper polycrystals, we previously showed that slip band (SB) activity and intrinsic dissipation were closely related. Dissipation and slip band amount increased with the number of cycles. At very small stress amplitudes, no slip band appeared at the specimen surface up to 10^8 cycles but the material was found to dissipate energy. These results revealed that the material never reached a steady state and so could break at higher number of cycles. In this paper, the morphology and the location of slip bands were characterized. Different types of slip bands depending on the stress amplitudes appeared at the specimen surface. The stress amplitude required to show the first slip bands decreases with the number of cycles. It is twice lower than the stress amplitude required to break the specimen for the same number of cycles. At the smallest stress amplitudes, slip bands were mostly found at twin boundaries. Quasi 3D finite element simulations taking into account the polycrystalline nature of the material emphasized the key role of the elastic anisotropy in slip band initiation. A criterion for slip band appearance was finally proposed.

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Keywords : Very high cycle fatigue – VHCF ; slip band ; anisotropic elastic crystallinne ; finite element.

S09 - Fatigue Testing

Chairmen:

V. Favier, G. Thoquenne

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Characterization of fatigue damage in 304L steel by an acoustic emission method

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Abstract

The aim of this paper is to give a better understanding of damage mechanisms that control lifetime of austenitic stainless steel nuclear components under cyclic loading. The acoustic emission signals were analyzed, in order to identify the acoustic signatures corresponding to a specific damage mode. An unsupervised classification method allows differentiating signals resulting from the plastic deformation or fatigue crack growth. Both phenomena are the two main sources of acoustic emissions in isotropic materials. The main results are the classification of acoustic signals by multivariate statistical methods in different classes. A relation can be established between each class and the present deformation mechanisms and damage, and their order of appearance according to the loading amplitude.

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Keywords: Low cycle fatigue; austenitic stainless steel; acoustic emission; multivariate statistical analysis

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Thermal measurements on elastomeric materials: from the characterization of the dissipation gradients to the prediction of the fatigue properties

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Abstract

The design of elastomeric parts against fatigue remains a difficult task because of their complex microstructure that mixes a highly non linear smooth matrix with a complex network of hard fillers. This furthermore involves a strong coupling to the manufacturing effects, from compounding to mixing, injection and curing. The influent parameters are therefore very numerous, and their optimization requires speeding up the fatigue characterization. In the present study, the goal is to propose a fast characterization of the fatigue properties based on thermal measurements and applying an energetic criterion. First, experimental protocols are developed to obtain dissipation mappings using very thin samples (0.2mm of thickness) with geometric heterogeneities. Then, these protocols are applied on hourglass-shaped fatigue samples, and the data used to predict the fatigue lifetime throughout an energy based criterion.

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Experimental facility for high cycle thermal fatigue tests using laser shocks

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Abstract

A new thermal fatigue testing facility is proposed in which thermal shocks are conducted with a pulsed laser beam. The temperature field on the surface of the specimen is measured with an infrared (IR) camera. Moreover, a speckle is created on this surface prior to applying the thermal shocks and an estimation of strain variations is proposed using Digital Image Correlation (DIC) techniques. This experimental strain variation is compared to the prediction obtained by Finite Element (FE) analyses conducted in previous experimental studies.

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Keywords: Thermal fatigue, High cycle fatigue, Laser shock, Full-field measurement

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Fast Fatigue Properties Identification by "Self-Heating" Method: Application To Automotive Welded Joints

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Abstract

The welded assemblies' high cycle fatigue properties identification for the automotive industry is a long and expensive process which has to be very efficient to perform both safety and lean design. Fatigue properties determination is a time and cost consuming process, it requires several days and specimens to be performed. The self-heating method offers the possibility to dramatically shorten the test duration. It consists in measuring the temperature of the structure under cyclic loading, and then linking it to fatigue properties. Only one specimen and few hours are required for fatigue properties identification providing important cost and time reduction. Thus, an experimental protocol is proposed to measure the rise of temperature of a lap joint welded specimen, with the use of infra-red thermography. Assuming that only self-heating and thermoelastic phenomena are responsible of the temperature evolution, self-heating temperature is extracted from experimental data. A 1D thermal model is proposed to describe the evolution of the temperature of the specimen due to self-heating. The welded joint concentrates dissipative phenomena, which corresponds to a concentrated heat source. This heat source field is then identified by fitting the model to experimental results, and its evolution with the applied loading is used to determine the welded assembly endurance limit. Self-heating method results are proven to be consistent to those obtained by classical fatigue tests.

Selection and peer-review under responsibility of CETIM, Direction de l'Agence de Programme.

Keywords: Fatigue ; Welded Joint ; Steel ; Self-heating ; Thermography

S10 - Composites and elastomers fatigue behaviour

Chairmen:

A. Bignonnet, C. Peyrac

L. Gornet, N. Roche

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Rapid Determination of the High Cycle Fatigue Limit Curve of Carbon Fiber Epoxy Matrix Composite Laminates by Thermography Methodology: Tests and Finite Element Simulations

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Abstract

Self-heating measurements under cyclic loading allow a fast estimation of fatigue properties of composite materials. The tensile fatigue behavior of a high stress carbon fiber epoxy-matrix composite laminates is examined at room temperature. Tension-tension cyclic fatigue tests are also conducted under load control at a sinusoidal frequency of 5 Hz to obtain high-*cycle* fatigue stress curves (S-N). The fatigue limits of the different composite lay-ups tested were successfully compared with data resulting from the self-heating test method on the same laminates. This comparison reveals a good agreement between the two methods dedicated to stress fatigue limit determination. In addition, a tomographic analysis is used to perform comparisons at the microscale between both fatigue methods. The nonlinear heat transfer laminate theory is used for self-heating tests simulation. Self-heating simulations involving conduction, convection, and boundary radiation are performed with the Finite Element code Cast3M.

Selection and peer-review under responsibility of CETIM, Direction de l'Agence de Programme.

Keywords: fatigue; self-heating; damage; thermomechanical behavior

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Influence of elastomers formulation on fatigue crack growth properties

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Abstract

Elastomers exhibit complex fracture mechanical properties. The crack growth rate depends on various factors such as polymer type, fillers, curing state... For numerous applications elastomeric parts often work under complex periodic loadings. The new Fatigue Test Analysers of Metravib ACOEM allows performing fatigue crack growth tests at controlled tearing energy in pure shear samples. This method of loading is strongly recommended to compare dynamic fatigue properties of elastomers.
This study deals with crack growth rate measurements and performance comparison of several rubber compounds. The influence of the formulation and mixing parameters of formulation and mixing would be presented on an SBR compound: the dispersion of filler, the antioxidant quantity, and the curing system. All compounds are characterized with normalized mechanical tests such as uniaxial tensile, monotonic tearing, hardness; one is also tested with normalized fatigue tests as FTFT (Fatigue To Failure Tensile), DeMattia Flexing Fatigue Tester (in initiation and propagation).

Selection and peer-review under responsibility of CETIM, Direction de l'Agence de Programme.

Keywords : crack growth, fatigue,elastomers, ageing

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Low-cycle fatigue of the light advanced materials

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Abstract

Low-cycle fatigue (LCF) of 6061-T6 Al alloy plated with nickel, gold and silver as well as thermally-cycled carbon-epoxy laminate was studied at constant strain in a purely bending mode. The tensile and fatigue properties of the alloy coated with multi-layered deposits depend on the thickness of the inner electroless nickel layer that drastically decreases the ductility of th e system. Electroplating by the second ductile Ni layer increases the lifetime of the alloy in comparison with that coated only by the electroless Ni layer. Thermal cycling of the carbon fiber reinforced polymer (CFRP) composite at maximum and minimum operating temperatures of 180°C and −195.8°C, respectively, shortens the fatigue life of samples in the high-cycle fatigue range corresponding to the number of cycles *N* exceeding 20,000. However, in the low-cycle fatigue region, the fatigue life of thermally-cycled laminates was slightly longer than that of the reference one, probably, due to the stress distribution between small cracks, which retards the fatigue failure and prevents fast propagation of the main crack.

Keywords: plated 6061-T6 Al alloy, carbon fiber reinforced polymer, low-cycle fatigue

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Fatigue damage modelling of continuous E-glass fibre/epoxy composite

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Abstract

Static and fatigue tension tests have been performed on continuous E-glass fibre reinforced epoxy composite.

All tests were followed by non-destructive techniques: acoustic emission records (AE) and microscopic observations in addition to stiffness monitoring with an extensometer in order to investigate damage mechanisms occurring under both static and fatigue loadings.

The data obtained were used to identify the modes of damage and its effects on the macroscopic behaviour of the composite material under both static and fatigue loading. Then, a fatigue model was used to predict the fatigue life of the composite under tension-tension cyclic tests. This model reduces drastically the number of fatigue tests required to obtain S-N curves.

Experimental data were in excellent agreement with model predictions.

Keywords: Fatigue life model; E-glass fibre/epoxy composite; Damage mechanisms; Acoustic emission

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Fast prediction of the fatigue behavior of short fiber reinforced thermoplastics from heat build-up measurements

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Abstract

The fatigue design of short fiber reinforced thermoplastics components for structural applications in the automotive industry requires an accurate knowledge of the numerous factors affecting the fatigue lifetime (process, loading type, environment, etc). This paper aims at describing a method based on thermal measurements (using an infrared camera) that will reduce substantially the characterization duration of the fatigue properties compare to classical methods. Recent publications illustrated the relevancy of using an energy based criterion to predict the fatigue properties. In this study, a simple way to get the cyclic dissipated energy from thermal measurements is suggested, usable for homogeneous and heterogeneous dissipation fields. A so-called heat build-up protocol is used to relate the cyclic stress amplitude to the cyclic dissipated energy. The parameters of an energy based criterion can be obtained within one day and using only one specimen, which is of course of huge interest to investigate quickly the influence of numerous factors on the fatigue behavior. In this study, this protocol is applied on one sample geometry, for one given orientation, and one humidity conditioning, and should be challenged by tests lead for several variations of first order parameters (fibers orientation, water uptake).

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On the determination of a fatigue limit

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Abstract

The integration of more composite in jet engine requires knowing and understanding the mechanical behavior at the material scale before going any further. Initially well known for its good fatigue behavior, the development of complex weaving patterns, loading the fiber with shear stress, bring one to completely think back the design methods.
Snecma works on different ways to establish life predictive curves, such as Wölher curve or Goodman diagrams, in order to design safely its jet engines. One recommendation is to design in order to reach 5 x 10^8 cycles before changing the part. This work is based on a testing campaign of high cycle fatigue (1 x 10^7 cycles) and low cycle fatigue (1 x 10^5 cycles), PhD works and specific testing.

The testing campaign allows one to build designing curves directly from the material characterization. These curves are mainly derived from a log-log power law. The hypothesis is made that these curves can cross the null stress level.

On the university side, studies have been made on the experimental level first, in order to understand failure mechanisms. This work has focused, with a wide instrumentation, from acoustic emission to micro-tomography, on determining the first damages to appear and the different steps that lead to failure. The conclusions of the study were secondly brought to feed the phenomenological model ODM which has been modified to ensure fatigue modeling. This model can then be used to simulate Wöhler curves and then per extension Goodman diagram. This time, the hypothesis is made that a fatigue damage threshold exists and have to be determined. In order to ensure the reliability of the curves, one has to test material for a high number of cycles such as 5x10^8 cycles. Snecma and Cetim are developing alternate ways to produce high number of cycles non failed points in a reduce time than when tested at lower frequencies.

Selection and peer-review under responsibility of CETIM, Direction de l'Agence de Programme.

Keywords : Fatigue; Goodman; HCF; LCF; life prediction

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FD13_17

Damage of composite materials

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b Cetim, Fatigue Department, 52 avenue Félix Louat, 60304 Senlis, France

Abstract

Composite materials are used extensively in aerospace and more recently in automotive applications. Their high mechanical performances and good fatigue durability offer definite advantages compared to more traditional materials. However, in comparison with metal, damage mechanisms are complex and avoiding manufacturing defects is difficult.

To be able to design composite parts, understanding the micro-mechanisms of damage is essential. The article presents the main fatigue damage mechanisms on thermoset and thermoplastic composites. A state of art is done on numerous works on composite fatigue and fractographic investigations. Some case studies of in-service failure are discussed.

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Keynote: Fatigue composite

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FD13_87

Multi-scale damage model for mechanical High Cycle Fatigue (HCF) of short glass fibre reinforced thermoplastics (SGFRTP)

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Abstract

Light-weight structures with controlled cost is a major issue in all industries especially those related to transport. In order to achieve this objective, short glass fiber reinforced thermoplastics (SGFRTP) are used to replace some metallic parts. So far, their use in structural parts has been hampered by the lack of predictive numerical simulation tools especially under fatigue loading. In this paper an approach to model the HCF of the unreinforced thermoplastic polymers is presented. The idea of this model will be useful to obtain a HCF model for the SGFRTP.

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Keywords: Composite,Polymers,Fatigue

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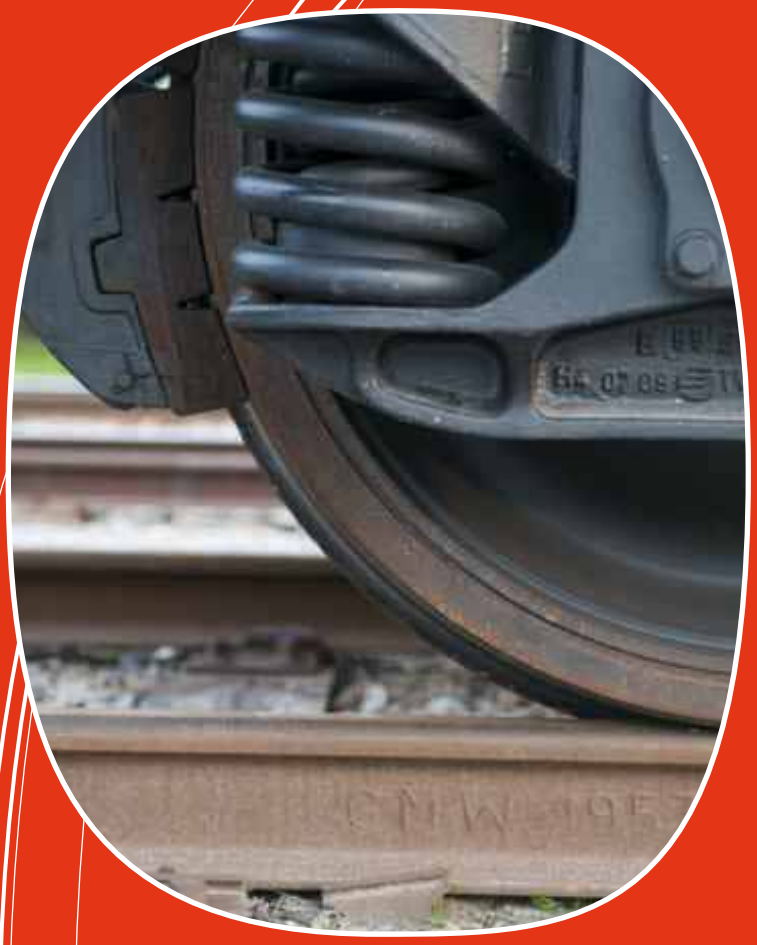
S11 - Mechanical behaviour in contact Fatigue

Chairmen:

S. Fouvry, G. Thoquenne

M. Octrue, G. Thoquenne



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Effects of residual stresses on rolling contact fatigue of railway wheels

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Abstract

This paper proposes a study of effects of residual stresses in Rolling Contact Fatigue of railway wheels. The work is focused on the numerical approach of how to predict the rolling contact fatigue crack initiation in a railway wheel. The material used for the manufacturing of railway wheels is the steel R7T. The main objective is to estimate the distribution of initial residual stresses present in the wheel after manufacturing. Even these stresses are considered in the rolling contact fatigue prediction. The finite element model (FEM) is built in two steps: 2D FEM of a wheel is developed for evaluation of residuals stresses, and a 3D FEM of wheel/rail is created in order to evaluate the mechanical stresses. The 3D model has been obtained by rotation of the 2D FEM (with residual stresses) around the axis of the wheel using the steady state algorithm. Results show the effects of residual stresses on the evolution of the equivalent stress in depth and on the local mechanical response of the material. The Dang Van fatigue criterion has been applied in order to predict a possible damage. Results show that the mesoscopic shear stresses and hydrostatic pressure have been influenced by residuals stresses. The effects of sliding and friction coefficient on residual stresses have been studied as well.

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Keywords: *steady-state algorithm, rolling contact fatigue, residual stresses*

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FD13_31

Modelling of surface initiated rolling contact fatigue damage

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Abstract

A parametric study was performed to investigate the contribution of surface roughness, friction and a constant residual surface stress to the rolling contact fatigue damage process. The effects on initiation, crack path and fatigue life were examined for a gear application. The asperity point load model could predict effects on rolling contact fatigue that are observed with experiments. The study of a ring/cone crack subjected to a rolling contact fatigue load allowed to explain the v-shaped cracks typical for surface initiated spalling. The results further support the asperity point load mechanism as a source behind surface initiated rolling contact fatigue.

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Keywords: rolling contact fatigue; spalling; asperity; fatigue life; crack path; initiation; surface crack; crack closure.

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X-FEM crack propagation under rolling contact fatigue

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Abstract

To assure the security, heavy monitoring and maintenance procedures for the fatigue of rails are set up by infrastructure managers. In order to go towards a more cost efficient railway system, it is essential to optimize the maintenance of rails: frequency of monitoring, rail replacement strategy, grinding policy...
To progress in this area, a numerical modeling tool has been developed thanks to a long-term collaboration between railway organizations (SNCF, RFF, RATP), rail producer (Tata Steel) and research institutes and universities (INRETS, LMS, MECAMIX, INSA) within the IDR2 consortium (Initiative for Development and for Research on Rail). This modelling starts with a dynamical simulation of the vehicle rolling on a track, from which the cyclic mechanical state of the rail is calculated by means of a 3D finite element simulation and an original and time-cost efficient direct stationary algorithm. Finally, a fatigue analysis of the rail is performed with the Dang Van criterion.
The modeling tool has been recently completed with the simulation of the crack propagation in the rails. A two-scale frictional contact fatigue crack model developed within the X-FEM framework is used to solve the crack problem. Using this approach, contact and friction between the crack faces is taken into account in the simulation. Realistic residual stresses, coming from dedicated software developed by SNCF are introduced in the propagation simulation via projection of the asymptotic mechanical fields. 2D Crack growth is performed taking into account the residual stresses. The results highlight their influence on the crack growth rate. Finally 3D preliminary results are introduced.

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Fatigue crack growth simulation ; Rolling-sliding contact fatigue of rails ; XFEM

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Experimental analysis and modeling of the crack arrest condition under severe plastic Fretting Fatigue conditions

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Abstract

The fretting-fatigue crack arrest condition is formalized as the condition for which a crack nucleates but stops propagating and so the sample never fails. Usually this domain is small as the fatigue loading greatly promotes the crack propagation. The aim of this research work is to investigate the crack arrest condition for severe plastic condition (maximal pressure is 2.5 times greater than the yield stress) and high fatigue stress ratio (R=0.94) thus for not much propagating conditions.

A low alloyed industrial steel flat specimen (IS) fretted against a 35NCD16 steel cylinder pad was studied in order to identify the crack arrest condition for various fretting loadings (shear amplitude). An original experimental monitoring has been implemented on a fretting-fatigue test device to observe on-line the crack arrest using the potential drop technic. To rationalize these results, a fretting-fatigue map concept which consists to plot the crack arrest boundary as a function of the applied maximum fatigue stress and the fretting tangential force amplitude is applied [1].

A 2D plain strain FEM modelling has been implemented to simulate the complex contact stressing including the contact plasticity. This plastic deformation promotes a significant extension of the contact and a proportional reduction of contact pressure and cyclic shear stresses. One consequence is that for a given contact and fatigue loading, this plastic accommodation of the interface tends to reduce the effective stress imposed to the material.

The crack arrest boundary was formalized applying a pure mode I effective intensity stress range approximation [2]. It is shown that combining elastic-plastic FEM modelling, weight function and an adequate estimation of the effective intensity stress range, it is possible to predict with accuracy the fretting fatigue crack arrest boundary.

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Keywords: fretting-fatigue; elastic-plastic modelling; crack arrest; K-factor

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Characterization of surfaces obtained by precision hard turning of AISI 52100 in relation to RCF life

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Abstract

Traditionally, components of hardened steels, such as bearings, gears, shafts and rails, are finished by grinding process. In this study, Precision Hard Turning (PHT) is proposed as an alternative finishing process to manufacture AISI 52100 bearing components (60-62 HRC), because PHT improves surface integrity and therefore increases the Rolling Contact Fatigue (RCF) life. An experimental design is used, under dry condition using cubic Boron Nitride (c-BN) cutting tools, to investigate the effect of cutting parameters on surface integrity characterised via surface roughness, microstructure analysis and residual stresses. Then, fatigue life tests are performed on a twin-disk machine. SEM observations of transversal cross-sections of all samples show the presence of a very fine and white layer (<1µm) on the top surface and a thermal affected zone of 40-50 µm in the sub-surface. PHT does not affect quantitatively the percentage of the different microstructural phases and leads to decrease the number of dislocations in the transition zone compared to the bulk material, which is correlated to decrease of nanohardness in the transition zone. Compressive residual stresses are measured in surface and sub-surface and their level is more in compression in the circumferential direction than in tangential direction. Levels of roughness decrease as cutting speed increases. RCF life of bearing steel components machined by PHT reached 5.2 (at Ra=0.11 µm) and 0.32 million cycles (at Ra=0.25 µm). Therefore, RCF life increases as the roughness amplitude Ra decreases.

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Keywords: High precision machining; roughness; bearing steel; residual stress; finishing process; rolling contact fatigue life

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Prediction of the Fretting Fatigue crack nucleation endurance of a Ti-6V-4Al/ Ti-6V-4Al interface: Influence of plasticity and tensile/shear fatigue properties

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Abstract

Fretting fatigue is a critical loading that appears on many structures such as the blade/disk contact of aircraft engines. It is characterized by small displacements between two bodies, one of which has an applied bulk stress. This phenomenon has been studied for a long time and induces damages which critically reduce the fatigue resistance. Fretting stressing are multi-axial and above all characterized by very severe stress gradient conditions. Besides, significant contact plastic deformations can be activated for LCF conditions which again complicate the predictions. To address this aspect a combined experimental – modeling analysis has been developed on a well known a Ti-6V-4Al alloy. Using an original double actuator fretting fatigue apparatus, the fretting fatigue cracking endurance of a cylinder/plane contact from 10E4 to 10E7 cycles was determined keeping constant the partial slip fretting loading (i.e. Q/P=0.32) and varying the fatigue stressing (700 MPa<σ_{max}<50 MPa, R=0.01). This research shows that the fretting fatigue crack nucleation endurance (b_{CN}=70 µm) can be predicted using a basic Crossland's stress invariant multi-axial fatigue description if the cyclic elasto-plastic (ep) response of the material is conveniently integrated in the FEM simulation, the stress gradient effect is taken into account by considering a stress averaging strategy defined on a ℓ_V=37µm cubic size previously calibrated from plain fretting experiments and finally if the ratio of tensile and shear fatigue limit is not assumed constant but expressed as a function of the loading cycles ($\sigma_{-1}(N)/\tau_{-1}(N)$). Using this complete analysis the crack nucleation endurance from $10E^4$ - $10E^7$ cycle is predicted with an error smaller than 10%. A parametric study shows that if the σ_{-1}/τ_{-1} ratio is assumed constant, defined at the fatigue limit conditions, the endurance predictions in LCF and most of the HCF domains are dangerously non conservative. Alternatively the application of plain elastic stress description leads to over conservative predictions when significant plastic accommodations are activated (N< 2 10^4 cycles).

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Keywords : Fretting Fatigue Endurance, Crack Nucleation, Crossland criterion, Non local Stress Averaging

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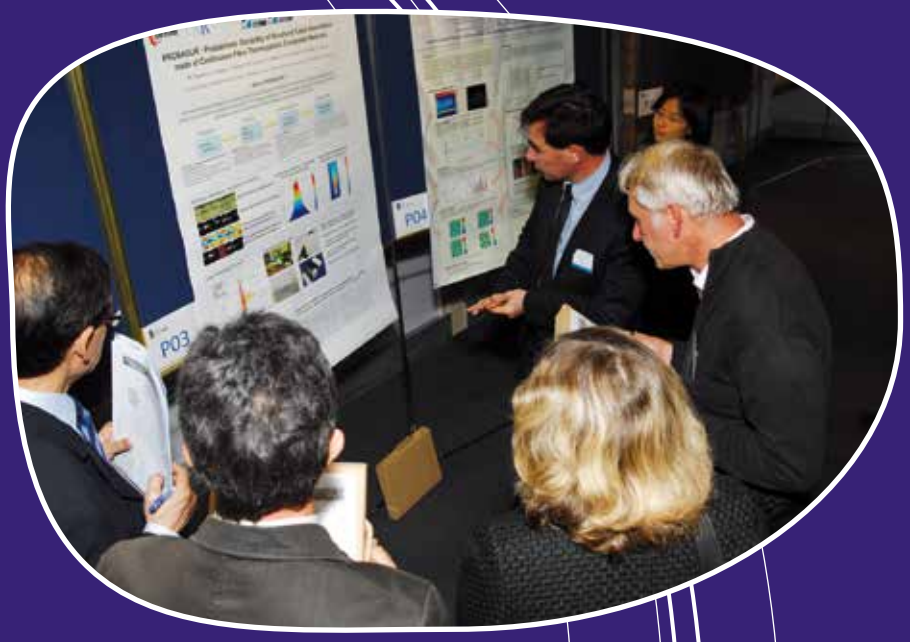
Poster Session



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FD13_P17

Damage of composite materials

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Abstract

Composite materials are used extensively in aerospace and more recently in automotive applications. Their high mechanical performances and good fatigue durability offer definite advantages compared to more traditional materials. However, in comparison with metal, damage mechanisms are complex and avoiding manufacturing defects is difficult.

To be able to design composite parts, understanding the micro-mechanisms of damage is essential. The article presents the main fatigue damage mechanisms on thermoset and thermoplastic composites. A state of art is done on numerous works on composite fatigue and fractographic investigations. New investigations are in progress to work on identification by emission acoustic (EA) of damage mechanism in fatigue. The first results show the EA signal signatures for cracks in matrix or fiber failure in a thermoplastic composite. Works in numerical simulation are also in progress.

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Keynote: Fatigue composite, EA

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Occurrence of Single and Double Slip Crossover Bands in Fatigued Alloys C460 and C22

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Abstract

Aluminium lithium alloy C460 and nickel chromium alloy C22 are used extensively in the aerospace industry for various aircraft components. In this study, fine and coarse -grained specimens of these alloys were subjected to fatigue testing in air and at room temperature in a servo-hydraulic testing machine to study fatigue behavior and the microstructures developed by cyclically deforming the specimens in a series of stress-strain hysteresis loops. Microstructural characterization revealed the development of single and double slip crossover bands within grains. Further, it was found that double slips crossover band density increased with the number of cycles to failure, with double slip crossover bands being more pronounced in C22 than in C460. Double slip crossover bands in C22 were readily observed by scanning electron microscopy (SEM), whereas, for C460 the clear observation of double slip crossover bands required transmission electron microscopy (TEM).

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Keywords: *C460; C22; coarse grain; cyclic deformation; double slip; fine grain; single slip.*

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The mobility of principal stress directions in Crossland criterion

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Abstract

This paper is a new proposal of a multiaxial fatigue criterion which takes better into account the mobility of principal directions of stress tensor. The model proposed is based on the Crosland Criterion and start by defining an equivalent stress with zero out-of-phase angles for the stress components with a phase difference, which apply to Crossland criterion gives the Crossland* criterion. Poor predictions are obtained from Crossland criterion for stress states with mobile principal stress directions. We impute this discrepancy not on the capacity of parameters appearing in the criterion to account for the complexity of the loading or to account the additional damage generate by the mobility of principal stress directions, but instead on the procedure of evaluation of parameters appearing in the criterion and also on the formulation of linear combinations of two scalar parameters proposed by Crossland. Assuming that the second invariant of the stress deviator and maximum hydrostatic pressure can account of the additional damage generate by the mobility of principal stress directions.
The re-formulated Crossland criterion gives good predictions of experimental data when stress states present mobility of principal stress directions. The results show that the predictions obtained using in general the equivalent stress should be more satisfactory than the initial Crossland criterion and Crossland*.

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TIG-dressing of high strength steel butt welded connections – Part 1: weld toe geometry and local hardness

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Abstract

This paper presents the results of extensive measurements on weld toe geometry of as-welded and TIG-dressed butt welded connections in high strength steels S460, S690 and very high strength steels S890 and S1100. Descriptions of the measurement techniques and data analysis are presented. Four weld toe parameters have been formulated to characterize the weld toe: weld toe radius, weld toe angle, weld height and undercut. From the data can be concluded that TIG-dressing, on average, has a beneficial effect on the geometry of the weld toe. However, TIG-dressed weld toes have different appearances and as a result, weld toe parameters show more variation after TIG-dressing. An improvement of the weakest link is therefore not guaranteed.

The reheating of weld material and surrounding parent material results in a new fusion zone (FZ) and heat affected zone (HAZ). Hardness measurements have been performed in all different zones and show an increase of hardness as a result of TIG-dressing, with an occasional exception in the very high strength steels.

Keywords: TIG-dressing; butt weld; weld toe geometry; local hardness

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Design of Experiment Based on VMEA (Variation Mode and Effect Analysis)

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Abstract

A great part of off-road transports are performed by construction equipment such as wheel loaders, articulated haulers, dump trucks and trucks. More energy efficient solutions of these applications could be accomplished by 1) more efficient usage of existing products by operator training or system supporting the operator, or 2) development of new products with more efficient transmissions and energy recovery. In both cases, it is necessary to have a good knowledge about the operation conditions in service.

The usage of construction equipment performing off-road transports varies greatly. The response, product characteristics, of the machines in terms of performance, fuel consumption, durability etc. is largely an effect of this variability. Thus, a machine with good performance and good fuel efficiency for one type of operation does not necessarily have the same response for another type.
In order to develop machines that meet or exceed customer expectations of a specific product characteristic in their application, e.g. fuel consumption, it is required that designers have a good knowledge about the actual usage and also understand what affects the product characteristic in mind.

A common approach to increase the knowledge of a product characteristic of a machine is to perform tests during service operation and during these tests measure the characteristic in question and then draw conclusions about the usage effect. These tests are generally resource intensive. The questions one should ask before these tests are what to measure and where.

The product characteristics are typically dependent on the operation. Thus if this is known the product characteristics for different designs and concepts can be estimated by aid of simulation tools. The common usage of this type of machines, e.g. articulated haulers, is to move material from one point to another along a route. This can be described with a set of operation characteristics. This approach has been used within the Volvo Group, where a set of 20 Global Transport Application (GTA) parameters [1] have been defined to describe the operation.

If a certain product characteristic is to be investigated one must know which parameters affect and to what degree, i.e. the sensitivity of the parameters with regard to the product characteristic. Then if the values of these parameters during service are known, the product characteristic can be quantified.
Performing a test to define sensitivity for all 20 parameters demands a large amount of resources and it is important to use all possible prior knowledge in order to find a proper test plan for studies of service usage.

There is often a good sense among practicing engineers of what is important based on years of experience of product usage. The problem occurs when this subjective knowledge should be structured and translated into numerically comparable values. Here we will put forward the Variation Mode and Effect Analysis method [2,3,4] to structure and quantify the different user parameters that affect fuel consumption of an articulated hauler during service use. This method is used to go from subjective in-house knowledge into measurable quantifications where both variations during service and sensitivity of the particular product characteristic in question are included in the analysis. These quantifications are compared and a reduced number of parameters are selected for further investigation.
For this investigation we only have a limited number of resources for different measurements. In order to get the most out of the measurements, a rational test plan based on statistical design of experiments [5] is created. As a base for the design, a fractional factorial design at two levels is used. The underlying assumption in such a design is that interaction effects are considered to be small compared to the main effect. It has to be kept in mind that the more the test is reduced the fewer interaction effects can be detected. One benefit of this type of design is that the test can be expanded later to estimate interaction effects and reuse the results from the first test set.
The procedure during the two-level factorial design is that the parameters are set to the two levels chosen, e.g. high or low, and then according to a pattern tests are performed so that the effects can be distinguished. Since this test is reduced this pattern must be created in such a way that possible interactions do not interfere with the results. One issue to deal with here is that when performing test during service operation the parameters cannot be controlled and fixed as in laboratory tests, which forces the analysis of the test result to be other than the standard two-level test method. Still, we believe that the powerful two-level test methodology is useful for the test planning.

This paper proposes a method using results from the Variation Mode and Effect Analysis to design a test plan for investigating usage effect on a product.
As a case study an articulated hauler is used as a product, and fuel consumption is used as product characteristic.

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The outline of the paper is:

First the Variation Mode and Effect Analysis methodology and the Global Truck Application approach are described. Then the procedure of the case study is presented with a following discussion. Finally some conclusions are given.

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Keywords: VMEA; construction equipment; design of experiments; factorial design

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DAMAGE: experimental validation and prospects

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Abstract

The purpose is to present DAMAGE, a software devoloped by LMT-Cachan and supported by SNECMA Space Engine Division. Based on the LMT two-scale model, this software is dedicated to the prediction of HCF crack initiation, especially for high stress ratios and multiaxial loading. The experimental validation of DAMAGE on industrial applications will be presented and disscussed.

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Characterization of surfaces obtained by precision hard turning of AISI 52100 in relation to RCF life

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Abstract

Traditionally, components of hardened steels, such as bearings, gears, shafts and rails, are finished by grinding process. In this study, Precision Hard Turning (PHT) is proposed as an alternative finishing process to manufacture AISI 52100 bearing components (60-62 HRC), because PHT improves surface integrity and therefore increases the Rolling Contact Fatigue (RCF) life. An experimental design is used, under dry condition using cubic Boron Nitride (c-BN) cutting tools, to investigate the effect of cutting parameters on surface integrity characterised via surface roughness, microstructure analysis and residual stresses. Then, fatigue life tests are performed on a twin-disk machine. SEM observations of transversal cross-sections of all samples show the presence of a very fine and white layer (<1µm) on the top surface and a thermal affected zone of 40-50 µm in the sub-surface. PHT does not affect quantitatively the percentage of the different microstructural phases and leads to decrease the number of dislocations in the transition zone compared to the bulk material, which is correlated to decrease of nanohardness in the transition zone. Compressive residual stresses are measured in surface and sub-surface and their level is more in compression in the circumferential direction than in tangential direction. Levels of roughness decrease as cutting speed increases. RCF life of bearing steel components machined by PHT reached 5.2 (at Ra=0.11 µm) and 0.32 million cycles (at Ra=0.25 µm). Therefore, RCF life increases as the roughness amplitude Ra decreases.

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Keywords: High precision machining; roughness; bearing steel; residual stress; finishing process; rolling contact fatigue life

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Fatigue Damage Analysis on Aluminium Alloy Specimens under Strain Loading Sequences Associating with the Kurtosis-based Coefficient

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Abstract

Constant amplitude data obtained from smooth specimens have been used for many years to evaluate the fatigue life of components. However, most of the loadings used in real applications are variable or random. This paper discussed the analysis on fatigue signal of Al 6061 specimen under three types of loading sequences, i.e. constant loading (CL), Hi-lo (HL) and Lo-hi (LH) associating with Integrated Kurtosis-based Algorithm for Z-filter (I-Kaz) technique. Fatigue test was performed according to the ASTM E466-96 standard with attachment of 2 mm strain gauge at the gauge of flat dumbbell shape specimen. Fatigue test was carried out at all the three types of loading stress at the sampling frequency of 8 Hz. Series of strain data were collected throughout the test from initial until failure occur using a data acquisition system. The respective I-kaz coefficients and the three dimensional plot s were used to analyse and interpret the strain signals. Fatigue damage for thress loading sequences were compared, and it was found that the I-kaz coefficient was linearly correlate to fatigue damage, hence, it is worth to see the capability of this method to representing the fatigue damage of metallic materials.

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Probabilistic prediction of fatigue life of cracked parts: Linear elastic fracture mechanics based approach

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Abstract

In the context of regular inspections of structures, the presence of cracks can sometimes be revealed. It is therefore interesting to know whether the structure can still be used or if a degraded mode of operation should be considered. It is of concern to assess the scatter of the remaining life of such cracked parts due to the uncertainties on the parameters of the prediction model. Thus for the purpose of the present study, a special attention has been given to the quantification of the uncertainty of each collected data (*e.g.*, material properties, crack measurements) to be integrated in the crack propagation model. Three families of uncertainties have been studied, namely, material properties, geometrical and loading uncertainties. A linear elastic fracture mechanics (LEFM) based approach has been used to predict crack propagation in a widely used pressure vessel steel. The model uses classical Paris' law where all the controlling parameters have been replaced by statistical distributions obtained from experiment, namely, crack growth tests, hardness tests, tensile tests and Charpy tests. Crack growth tests have also been carried out on thick notched specimen submitted to uniaxial cyclic load to obtain two dimensional cracks that can be representative of those to be found in industrial structures. During these tests, crack lengths have been measured simultaneously by time of flight diffraction (TOFD) ultrasonic method, digital image correlation (DIC) and some markings have been performed to estimate the crack length and crack front shape after the specimen failure. The comparison of data obtained from different observation techniques allowed for the quantification of the crack measurement uncertainty of the industrial TOFD technique. A sensitivity analysis has been carried out on the parameters of the model to evaluate and classify the influence of all sources of uncertainty on the residual life prediction. Last, results from crack growth tests on notched specimen have been used to assess the accuracy of the model prediction.

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Keywords: crack propagation; crack front marking; digital image correlation; time of flight diffraction; uncertainty analysis

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Plasticity modeling in spectral methods for fatigue damage estimation:

Experimental application – Extension to multiaxial case

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Many mechanical structures are subjected in service to random vibrations due to external loads (forces, accelerations...). The fatigue phenomenon is now a major design criterion in the engineering industry. Integration of fatigue in the design optimization process allows improving the safety of structures, shortening development time, and also reducing manufacturing and maintenance costs.

Fatigue is usually studied in time-domain, where loads and responses are given as time histories. Stress-Strain responses may be calculated by simple methods such as linear superposition in quasi-static cases or transient analysis otherwise. Within the framework of random vibration, loads are given as spectra, in the frequency domain, and mechanical structures have a dynamic response. Fatigue damage may be then estimated by spectral methods.

Random vibrations can be modeled by a Gaussian stochastic process. For high levels of excitation, such as those obtained in accelerated tests, plastic behavior is not negligible; it involves non-linearities in the structure. In this case, the response of the structure to a random vibration will be a non-Gaussian stochastic process. In this context, traditional methods of fatigue design [1] [2] [3] are unusable. However, several other methods allow determining the life of a structure subjected to a non-Gaussian stochastic response. Those are the Hermite model (1993) or spectral methods modified using Neuber rule [5] [6] (2012). This paper shows how we can extend the spectral methods to low cycle fatigue and multiaxial stress-strain responses, based on Neuber notch rule and work from Preumont and Pitoiset [7].

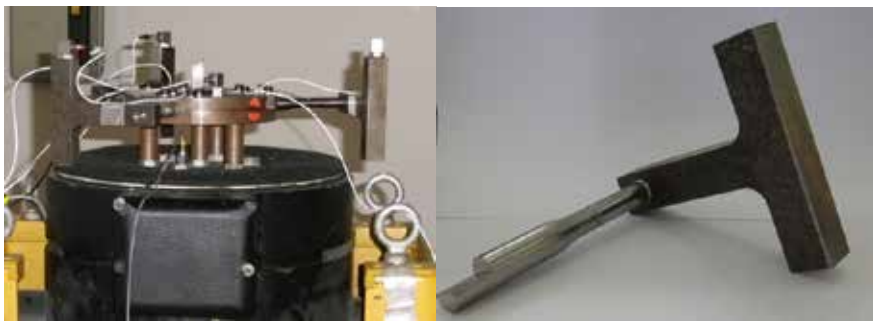

Figure 3: Test bench with specimens in a multiaxial configuration

Extensive numerical and experimental tests have been carried out, in order to compare the models and validate the proposed approach. We present here, the results of these comparisons.

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Operation of The Bois plant hydraulic turbine in bypass operating mode: analysis of fatigue behaviour

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Abstract

During load tripping of the hydraulic turbine at the Bois power plant, the turbined flow is directly transferred and discharged into an external canal without releasing an alert flow. The operation of the turbine in bypass mode, which consists in maintaining flow through the penstock and the turbine nozzles, was therefore envisaged to reduce flow variations in the short-circuited section of the scheme, in which people may be found, particularly during the summer season (safety stake).

To validate the feasibility of this type of operating mode and, specifically, to verify the structural integrity in operation of the components impacted by the jet (deflector, control rod, jack...), studies were jointly carried out by EDF and CETIM, and a test-calculation program was initiated. This program included preliminary calculations using a finite element model, a campaign of tests in operating conditions (with vibration measurements and dynamic extensometric measurements) and an analysis of the potential damage due to fatigue. In the end, the study made it possible to show that the damage due to fatigue resulting from the operation of the Bois turbine in bypass operating mode remained in an acceptable range.

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Microplastic Limit of Steels as a Means of Fatigue Limit Determination

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Abstract

The experimental determination of fatigue limit in case of steels represents an expensive and time consuming process not speaking about the necessity of a sufficient volume of representative material necessary for the specimens manufacturing, manufacturing of numerous test specimens, the need of an expensive (electrohydraulic) test equipment etc.

Microplastic strains occurring at stresses below the yield point play a significant role at cyclic loading of metals withinin high cycle fatigue region. The microplastic strains cannot be measured by common methods due to the discontinuity of their distribution and a varying character of their level in the metal structure, but however, owing to the magnetoelastic effect the threshold stress at which dislocation pile-up stresses begin to obstruct the magnetic domains in rotation to the direction of the tensile stress can be determined by means of changes in magnetic permeability during tensile loading.

In the paper, the changes of the magnetic permeability were measured indirectly – by means of the changes of the electrical impedance (a.c. resistance). The measurement was performed on the normalized low-carbon structural steel CSN 41 1375. The microplastic limit was determined by evaluation the ΔR-σ records. A comparison with the fatigue limit in a reversed fatigue loading showed that the MPL was below the fatigue limit. The microplastic limit can thus be considered to separate non-damaging and damaging cyclic stresses.

The paper presents the results of the abovementioned characteristics what may shorten and make cheeper the determination of the fatigue limit and non-damaging cyclic stresses of structural materials.

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Fast characterization of fatigue properties of an anisotropic metallic material: application to a puddled iron from a nineteenth century French railway bridge

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Abstract

Largely used as main material in railway riveted bridges during the second half of the nineteenth century, the puddled iron characterizes for having an anisotropic behaviour due to the large amount of non metallic inclusions that it posses. Its mechanical characterization is thus difficult. Since these ancient structures have supported variable cyclic loadings at least for a century, the determination of the puddled iron's fatigue properties becomes crucial to their maintenance. The self-heating method is proposed in this paper to accomplish this task. The obtained experimental self-heating curves show dispersion non observed in homogeneous materials, this phenomenon is explained by the lack of determination of the representative elementary volume of the puddled iron. However, this data gives us important information such as the minimum and maximum boundaries of the mean fatigue limit for several orientations. A two-scale probabilistic model for high cycle fatigue is also used to represent the dispersion on the experimental data by using Weibull's distribution law to describe several characteristics of each site where the microplasticity occurs. The influence of such parameters and the limitations of the model are also studied.

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Development of an Automated Image-Based Tool for Robust Analysis of the Performance of Cementless Hip Replacements

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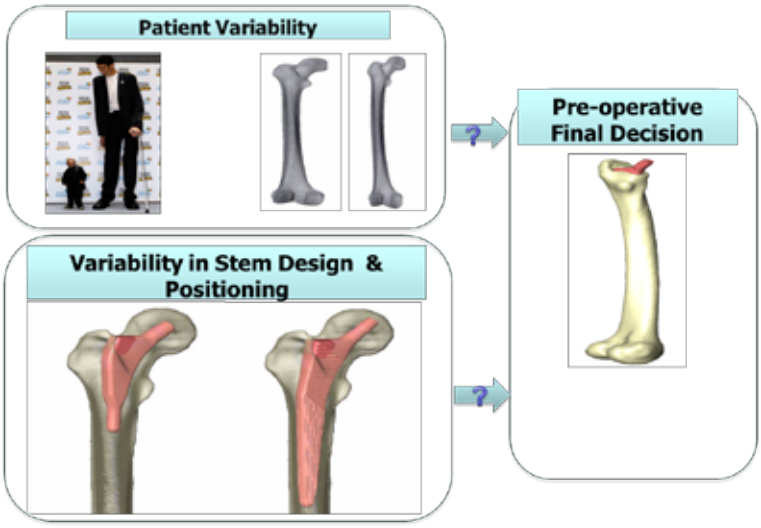
Abstract

There is a large variability in bone morphology and density, stem design, surgical approach and loading. Image-based modelling takes on a greater role in development of pre-clinical tools in understanding the human anatomy and gender differences and matching medical implants with specific male/female patient groups. This work was motivated by the need to capture the spectrum of this variability, to efficiently assess the performance of implants in a large population, to propose implants that are bio-mechanically more robust and more tolerant to fatigue failure.



A novel tool was developed that combines image-based modelling with statistical shape analysis to automatically generate new femur geometries and measure anatomical parameters to capture the variability across the population. To demonstrate the feasibility of the approach, the study used data from 62 Caucasian subjects (31 female and 31 male) aged between 43 and 106 years, with CT voxel size ranging 0.488x0.488x1.5mm to 0.7422x0.7422x0.97mm. The scans were divided into female and male subgroups and high-quality subject-specific tetrahedral finite element (FE) meshes resulting from segmented femurs formed the so-called training samples. To represent the variations in bone morphology across the population, gender-based Statistical Shape and Intensity Models (SSIMs) were developed, using Principal Component Analysis. These were then sampled using the principal components required to capture 95% of the variance in each training dataset to generate 1000 new anatomical shapes and to automatically measure key anatomical parameters known to critically influence the biomechanics after hip replacement.

Next, the developed tool was used to automatically select and position a stem (out of 12) in a large population of patients and conduct FE analyses to assess the implant primarity stability. To constrain the implanted femur, physiological boundary conditions were applied [Speirs et al., 2007]. A “complex” set of 34 muscle and joint forces from the musculoskeletal model of the lower limb [Heller et al., 2011] was applied during stair climbing. FE test results are presented for a left male femur (patient: 25 years, 57.5 kg) implanted with a short cementless stem.

The present study demonstrated that gender-specific statistical shape modelling can be a valuable tool for automatically generating a large specific population of femurs to support implant design, planning of femoral reconstructive surgery and pre-clinical testing. Further research will address implant robustness to fatigue failure

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APPRoFi project : Probabilistic methods for the robust fatigue design

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Abstract

Most of the industries use the deterministic methods codified in design rules or standards to design structures subjected to fatigue failure. Fatigue phenomena are highly affected by uncertainties (mainly fatigue strength of materials and loadings) which have to be taken into account in the design process to manage the structural reliability. This was the aim of the DEFFI project which dealt with the application of a probabilistic "Stress--Strength" Interference Method to five industrial applications (aerospace, railway, mechanical components, …). The APPRoFi project, funded by the French National Research Agency (ANR), was launched with industrial and academic partners with the objective to develop the generic methods and methodologies for the reliability assessment and robust design of structures subjected to fatigue loadings.

Advanced probabilistic methods have been developed for the statistical modelling of random variables with statistical correlation: material properties, fatigue strength (SN curves), uncertain loadings. To reduce the finite element computation time a multiparametric strategy based on LArge Time Increment (LATIN), multiscale methods with PGD decomposition have been developed. In addition, advanced reliability methods using meta-models techniques « Kriging » with adaptative and learning function have been developed to reduce the probability computation time. The APPRoFI methodology and developed tools have been applied to the industrials case studies with success and promising results for FE analysis computation time and reliability assessment.

To model the mechanical and material behaviour and the loading, the stochastic methods and software tools have been developed with appropriate law using the R software platform. A methodology guideline is provided to help the industrial users for better understanding of the theoretical background and how to use the software tools. For modelling the fatigue resistance, a methodology and data treatment is proposed and applied for the two industrial case studies.

To reduce the finite element computation time a multiparametric strategy based on LATIN method and multiscale technique have been developed. Two other techniques are developed and software tools are provided based on Sparse Grid and an original LDLT decomposition adjusted to stochastic context, called SLDLt technique. These techniques contribute to reduce significantly the FE computation time by 30 times.

For the reliability assessment and to minimize the number of FE analyses the advanced methods have been investigated and implemented. These methods are based on metamodels as Kriging and Sparse Grid with adaptative and learning function lead to more efficient solution which allows reducing the number of analyses by 33 times for the more complex case study.

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