Fatigue Testing and Analysis under Variable Amplitude Loading Conditions

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Foreword

The Symposium on Fatigue Testing and Analysis Under Variable Amplitude Loading Conditions was a joint international event conducted by ASTM International Committee E08 on Fatigue and Fracture and the Fatigue Commision of French Metallurgical and Materials society (SF2M).

The symposium was chaired by Dr. Peter C. McKeighan, Southwest Research Institute, San Antonio, Texas, USA and Professor Narayanaswami Ranganathan, Laboratoire de Mécanique et Rhéologie, University François Rabelais de Tours, Tours, France.

The symposium was held from 29–31 May 2002 in the prestigeous town hall of the city of Tours (Hotel de Ville).

The following two pages show the highlights of the three day symposium. The Symposium would not have been as successful as it was without the assistance from the city of Tours, the Ecole Polytechnique (Département Productique), the University of Tours and all of the other kind sponsors.

There are a number of groups that had a significant impact on the organization of the meeting. These groups functioned at a variety of different levels and are described further below.

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FIG. 1—*Attentive audience.*

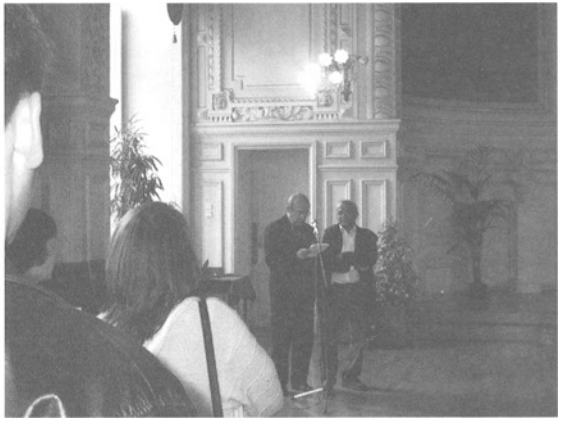

FIG. 2—*Welcome speech by the Mayor of Tours, M. Jean Germain, M. Ranganathan helps with the translation.*

FIG. 3—*Distinguished audience—listening to the mayor's speech.*

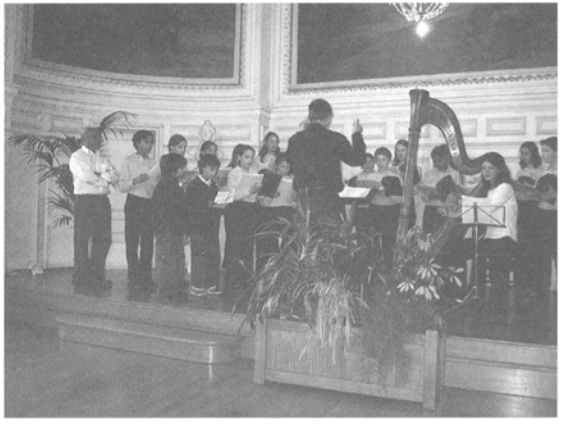

FIG. 4—*Concert by the children's choir.*

FIG. 5—*The students of the Polytechnique school who helped with organizing the meeting.*

FIG. 6—*A view of the ceiling of the Historic Town Hall of Tours.*

FIG. 7—*One of the speakers.*

FIG. 8—*Discussion in the corridor—Dr. Pete McKeighan.*

Contents

OTHER APPLICATIONS

LOAD INTERACTION

PROBABILISTIC AND MULTIAXIAL EFFECTS

Overview

The type of loading that a fatigue critical structure is subjected to depend largely on what the function of the structure is and what controls the loading applied. In some cases, for instance rotating machinery for power generation, the loading can be adequately simplified and represented by a constant load amplitude cycle. In this case, loading is dictated by function on an angular rotation-by-rotation basis. This is contrasted to the case of a fighter airplane where the loading is dictated by external aerodynamic loads combined with highly variable pilot inputs. In many cases, the use and function of a structure can significantly impact the loading. An example of this is the case of a passenger aircraft where taxis, takeoff, cruise at altitude and landing dictate a primary loading cycle. Given that most of the service time is spent at cruise, the magnitude of the repeated load for the fuselage is largely driven by the cabin pressurization.

Whatever the source and magnitude of the cyclic loading, the challenge for the structural engineer is to determine the amplitude of the variable amplitude spectrum loading and simplify it in a manner that can then be combined with analytical fatigue design approaches to adequately size the structure. Design tools and approaches have been available for many years to assist in accomplishing this objective. The term 'fatigue' was originally coined by Wohler in the 1840's when he examined railroad car axle failures. Sixty years later Goodman and Basquin examined the mean stress effect and developed the stress-life approach to design. The second World War spurred a significant amount of activity including development of the concept of linear damage as postulated by Palmgren and Miner. Methods to design and maintain aircraft when cracks are growing in a structure were developed after a series of high profile failures in the 1970's by the USAF. All of these developments have culminated in the design tools now available to treat fatigue crack initiation and propagation under variable amplitude loading.

Applying these fatigue design strategies often requires a significant mechanical testing effort to *tune* the analytical models to predict actual laboratory observation. Hampering this process is the absence of any standardized test method to perform fatigue testing under spectrum loading conditions. While standards have been developed to characterize material responses to fatigue loading, no methods yet exist for the more complicated spectrum loading test and laboratories have consequently developed their own custom approaches. Although little standardization also exists for fatigue analyses, there are some accepted methods and techniques available for treating variable amplitude loading. Nevertheless each organization that performs this type of work tends to have customized the methods to suit their needs and specific approaches. One of the primary goals of this symposium was to provide a forum to communicate amongst technical professionals involved in this type of work. Applications reported on include those focused purely on testing, fatigue design techniques/approaches as well as a combination of both.

The technical papers in this book represent peer reviewed and approved papers of those presented at an international symposium focused on fatigue testing and analysis under variable amplitude spectrum loading conditions. To aid in assimilating this information, the papers are categorized into six sections: Fatigue Testing, Aerospace Applications, Design Approach and Modelling, Other Applications, Load Interaction, and Probabilistic and Multiaxial Approaches.

The first section begins with a historical overview paper by Sonsino, which presents the development of variable amplitude tests starting with the approach of Gassner in the 1930's. This paper lays the groundwork and background for the scientific problems addressed in the remainder of the symposium. The paper by Hopkins et al. presents the efforts made by different non-ASTM standardization organizations to develop a future standard for carrying out variable amplitude fatigue tests. This is followed by another standardization-related paper by McKeighan and McMaster presenting a framework for a standardization approach for fatigue crack growth testing under spectrum loading conditions. Donald and George follow this paper with an examination of a state-of-the-art variable load amplitude test control and monitoring system. The paper by Pöting et al presents a variable amplitude test facility using resonance principles. This is followed by a paper by George et al examining non-visual crack length calibration issues associated with part-through cracked specimens.

The section addressing aerospace applications leads off with three papers addressing full-scale aircraft testing. A paper by Sullentrup discusses one organization's experiences during full-scale testing of the F/A-18. Hewitt et al then discuss Canadian experiences on spectrum editing of a fighter aircraft wing. Loading spectra complications associated with commercial aircraft are then addressed in a paper by Le Divenah and Beaufils associated with spectrum testing Airbus aircraft. This is followed by a paper by Yanishevsky and Everett that examines the spectrum fatigue tests carried out on the CF188 Hornet in Canada. Transient load effects at different temperatures in a titanium alloy are next examined in a paper by Stephens et al. McMaster and McKeighan examine the topic of life improvement of fastener holes under spectrum loading considering the effect of cold working and different fastener geometries. This paper is followed by one by Gérard et al showing that fatigue crack initiation life can be treated as a short crack growth life considering the proper crack configuration. The section concludes with a paper by Tumanov presenting random fatigue tests for aircraft engine fan blades, using an equivalent load amplitude concept.

The paper by Marquis et al opens the section on design approaches and modelling with an examination of a high cycle variable amplitude fatigue test program on a nodular cast iron where a fracture mechanics based closure model is used to correlate the data. Newman and Phillips then explore the life prediction capability of a plasticity induced closure model applied to selected variable amplitude tests in a titanium alloy. This is followed by a paper by Ball examining a fracture mechanics approach to notch tip plasticity effects. McClung et al continue discussions of strip yield models, in this case examining spectrum loading on aluminum alloy materials. Sunder et al assess the broader implications of variable amplitude fatigue loading examining multiple mechanisms. This is followed by a paper by Song et al who show that fatigue life under selected narrow and broadband loading can be modelled using crack closure concepts for short and long cracks. Stress intensity factor calculation is addressed by Wu et al under complex stress conditions. The section concludes with a paper by El-Ratal et al concerning fatigue life modelling and accelerated testing.

The next section opens with a paper by McEvily et al examining reasons why the Palmgren-Miner rule deviates from unity with examinations of three variable amplitude loading conditions. Thomas et al then address some of the issues related to fatigue testing in the automotive world. Continuing in the automotive vane, Morel and Ranganathan then examine high cycle fatigue testing and analysis using a car wheel loading sequence. This is followed by a paper by Petermann et al considering composite materials and examining a two-stress block loading that exhibited load-sequencing effects. Tomita et al who again showed with analysis and experiment clear sequence effects then examine fatigue loading of ship structure with a paper. The section concludes with a paper by Hünecke and Schöne examining short crack behavior as applied to low carbon steel.

The section of the book examining load interaction opens with a paper by Romeiro et al who studied load interaction in carbon steel concluding that interaction effects are closely related to the cyclic plastic zone size and Bauschinger effect. Two papers continue with load interaction examining overload effects including (a) Ranganathan et al who examine plasticity and environmental considerations testing 7075 and 2024 alloy and (b) Tabernig et al who examined primarily the near threshold regime for two different aluminum alloys. Darcis and Recho deal with the reliability analysis of welded specimens using a probabilistic approach to the overload effect. Finally, the paper by Aubin et al deals with the effect of load history examining strain amplitude and loading path on duplex stainless steel.

The final section is devoted to probabilistic and multiaxial approaches starting with a paper by Akpan et al developing a fuzzy probabilistic approach to aircraft components that permits the estimations of the distribution of reliability index and failure probability. Huther et al focuses on the development of a probabilistic approach used in the ship building industry. The paper by Łagoda et al compare a rain flow analysis and that based on power spectral density to fatigue life estimations under uniaxial and multiaxial loadings. A paper by Fischer follows this on multiaxial laboratory tests on complex automotive structures. Finally, the paper by Banvillet et al applies different multiaxial fatigue damage models to the life estimation under random loading for tension and bending conditions.

In conclusion, this book reflects the state-of-the-art in fatigue testing and analysis under variable amplitude loading and can therefore serve as an important reference for engineers and scientists for years to come.

Finally, we regret to report that one of the authors, Michael Sullentrup, recently passed away under tragic circumstances. We offer our heartfelt condolences to his family. Many of us will miss Mike's wisdom, humor and technical contributions to the fatigue testing world.

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