STRUCTURAL INTEGRITY of FASTENERS

Including the Effects of Environment and Stress Corrosion Cracking: 3rd Volume

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Pir M. Toor
Joseph Barron
Editors

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Structural Integrity of Fasteners Including the Effects of Environment and Stress Corrosion Cracking: 3rd Volume

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Peer Review Policy

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The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editor(s), but also the work of the peer reviewers. In keeping with long-standing publication practices, ASTM International maintains the anonymity of the peer reviewers. The ASTM International Committee on Publications acknowledges with appreciation their dedication and contribution of time and effort on behalf of ASTM International.

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Foreword

This publication, Structural integrity of Fasteners: Third Volume contains papers presented at the Third Symposium on Structural Integrity of Fasteners including the Effects of Environment and Stress Corrosion Cracking, held in Washington, DC on November 10, 2004. The sponsor of this event was ASTM Committee E08 on Fatigue and Fracture and its subcommittee on Application. The Symposium Co-Chairman were Dr. Pir M. Toor, Bettis Atomic Power Laboratory (Bechtel Bettis Inc.), West Mifflin, PA and Joseph Barron, Newport News Ship Building, Newport News, Virginia. Those who served as Session chairmen were Pir M. Toor,. Joseph Barron, symposium co-chairman. Professor Ralph I. Stephens, Iowa University, Iowa City Iowa.

A NOTE OF APPRECIATION TO REVIEWERS

The quality of the Papers that appears in this publication reflects not only the obvious effort of the authors but also the unheralded though essential work of the reviewers. This body of technical experts whose dedication, sacrifice of time and effort, and collective wisdom in reviewing the papers must be acknowledged. The quality level of this STP is a direct function of their respected opinions. On behalf of ASTM Committee E08, I acknowledge with appreciation their dedication to a higher professional standard.

Pir M. Toor
Technical Program Chairman

Arij de Koning studied mechanical engineering at the Technical University of Eindhoven. He joined the Structures and Materials Division of the National Aerospace Laboratory of the Netherlands (NLR) in 1971 remaining until his retirement in 2003.

Arij's research began with studies of slow stable crack growth, leading to the concept of Crack Tip Opening Angle (CTOA) as a characterizinparameter. During 1980's he developed an empirical model, CORPUS, including crack-closure induced retardation, for predicting fatigue crack growth in thin sheets under variable amplitude loading. And a strip-yield model for fatigue crack growth. These models were continually improved into the NASA/FLAGRO and ESACRACK programs.

Arij started work on the important problem of fatigue crack growth in bolts in the early 1990's. Successive combinations of modeling and test verifications led to Damage Tolerance descriptions of 3-D fatigue crack growth in bolt/nut assemblies. This work is considered to be the benchmark for bolt crack growth.

Recently, Arij developed and verified models of through and part-through fatigue cracks in Fiber/Metal Laminates, specifically the glass fiber/aluminum laminates GLARE used in the AIRBUS A380. These models have become the standard “toolkit” for AIRBUS predictions of fatigue crack growth in GLARE. He also turned his attention to Friction Stir Welding (FSW) of aerospace aluminum alloy sheet, including the outer skin welding of GLARE. He continued this work into retirement and up to his untimely death in February 2007.

Arij was distinguished by his power of mind, his insights and analytical abilities. He opened up new territories for practical applications. He will be greatly missed.

Contents

Overview

Fasteners are important structural elements and play a role in the strength and endurance of an efficient design and their structural integrity .is an important .factor in an efficient design. Fasteners analyses are typically carried out to determine the cause of failures due to, material deficiency, improper design, and improper fastener installation. These analyses are carried out considering the appropriate loading condition and environment under which fasteners are being used. Failure of fasteners related to any one of these issues results in expensive inspections and redesign of all similar threaded members assemblies. Therefore, it is imperative to accurately analyse the actual cause of the fastener failure. This third series of the fasteners structural integrity consists on the structural integrity of fasteners, including the effect s of environmental and stress corrosion cracking was organized into four topics as:

Fatigue and Crack Growth Experimental Techniques
Design/Environmental Effects
Fatigue and Crack Growth Analytical techniques
Design Consideration

The technical issues discussed in this publication represent the commitment of the ASTM subcommittee E08.04 to providing timely and comprehensive state of the art technology on structural integrity of the fasteners in the new design and continued use evaluation of the existing designs. A current bibliography on technical issues concerning fasteners is included at the end of the papers presented in this issue.

An overview of the papers presented in each session is given below;

Fatigue and Crack Growth Experimental Techniques

In this session three papers gives fatigue crack growth experimental techniques. These are: Development of a fastener structural element test for certifying Navy fasteners material; Experimental crack growth behavior for aerospace application; and influence of cold rolling threads before and after heat treatment on the fatigue resistance of high strength coarse thread bolts for multiple preload conditions.

The first paper discussed experimental work on two new materials, Titanium Alloy (Ti-5Al-1Zr-1V-0.8Mo) and Co-Ni-Cr-Mo-Al-Fe Alloy. These materials are high performance marine grade fasteners at 95 and 159 ksi yield strength, respectively. Experiments were carried out to show that these materials can withstand plastic deformation at high loading rates in the presence of detectable flaw. According to the Naval Fracture Toughness Review Process (FTRP). Test specimen consisted of an initial FEDM flaw at the root of the first thread. Flaw Assessment Diagram (FAD) was used to analyze the test results whether the flaws specimen will fail by ductile overload of by rapid fracture. Analysis showed that the fracture mode was stable ductile crack growth Fracture surface was examined using the Scanning Electronic Microscope (SEM) to verify the fracture mode of the crack growth region This Fastener Structural Element Test (FSET) was recommend for fasteners material TO CERTIFY Alloys for critical navy shipboard application

The geometry consisted of a minimum flaw that could be detected with a typical nondestructive evaluation (NDE) technique. Tests were conducted under axial loading fatigue condition.

The second paper discussed the experimental crack growth behavior using stainless steel flawed and unflawed rolled thread test bolts. The tests were conducted under axial fatigue load condition. Test loads range was maximum stress ranging between ultimate limit strength to fatigue endurance limit at stress ratios $0.1 < R < 0.9$. Dr. Olsen discussed the many details of the crack initiation locations, crack front shapes and striation spacing along the crack growth. The observation from this work was that unflawed test bolts have many elliptical crack growth initiation sites at the thread root while for the flawed test bolt the initiation sites were at the location of the initial flaw location. He also observed that crack front shapes were different for flawed and unflawed bolts and in both cases crack shape changed as crack progressed. The striation were measured and directly related to crack growth rates.

The third paper was an another interesting paper which discussed the influence of cold rolling threads before and after heat treatment on the fatigue resistance of high strength coarse threads bolts for multiple preload conditions is written by Professor Ralph I. Stephen, et al, University of Iowa, Iowa City, IA. Bolts were made of SI class 19.2 high strength steel and the threads were 3/8 UNRC-16 coarse. The authors discuss detains bolt manufacturing process, threaded profile and residual stresses due to cold thread rolling. The tension fatigue test is discussed in terms of Smax versus Nf and Sa versus Nf. Cyclic fatigue ratcheting and fractopraphy is discussed in detail. The conclusion are made that the fatigue resistance of threads rolled after heat treatment with preload stress of 1% significantly increases the fatigue strength at 107 compared to roll before heat treatment.

Design/Environmental Effects

The session on design/environmental effects discusses design and environment issues. There were two papers. The first paper discussed the effect of tightening speed on threads and under head coefficient of friction. The paper examined the relationship between the tightening speed with friction and clamped-load. The applied load, clamp load, and under-head torque were measured as the fastener was tightened within a torque/tension load cell. The blot, washer, and nut were of similar hardness with different lubricants. The results indicated that the thread and under-head coefficient of friction decreased as the tightening speed increased and the amount of clamp load generated at target torque increased with increasing speed.

Another design/environment oriented paper in this session was optimum thread rolling process that improves SCC resistance to improve quality of design. Experiments exposed to an aggressive aqueous environment and stresses to 40% of the material yield strength showed that fasteners rolled after heat treatment have increased in SCC resistance. Under similar experiments conditions machined threads showed an inferior SCC resistance. The increased SCC resistance was associated to residual compressive stresses at the thread root. It was concluded that these aggressive environments types' tests can provide fastener acceptance criteria or failure analysis of fasteners with unknown or uncertain manufacturing processes.

Fatigue and Crack Growth Analytical Techniques

The structural integrity of bolted joints primarily depends on reliability of fasteners. The intent of this session was to present current analytical techniques for fatigue and crack growth evaluations of fasteners. A very unique design oriented paper discusses the elastic-plastic, time dependent stress analysis of a real test fastener using finite element analysis is presented. A unique approach to incorporate the material data from multiple tests, material heats, and test temperature including a creep model are developed to perform the elastic plastic finite element analysis. The elastic-plastic finite element analysis develop in this paper simulates the loading procedure and the elevated temperature exposure under test condition. The authors state that by tracking the history dependence evolution of local stress at thread root and bolt head fillets, SCC characteristics can be studied.

The second paper in this session presents a numerical crack growth model using the finite element analysis generated stress filed. The axial stress field was directly mapped into the crack faces in the model using the superposition method including he residual stresses. The numeric model takes into account the stresses from nut loading, the residual stress, and the preload stress distribution. The initial crack shape in the model is assumed to be a semi-circular shape. The authors used the CRACAN3D computer code developed by the Cornell University Fracture Group, to develop the Y(a/d) stress intensity multiplication factor for crack grow evaluations. The paper describes evaluation using numerous parametric affecting all facets of the fastener design.

The third paper in this session describes the resistance of high strength fine thread bolts for multiple preload conditions. Most of the work was similar to the papers cited in session one for coarse threads. For fine threads authors conclude that the bolt fatigue mechanism were always fatigue crack nucleation and growth from the first engaged thread at the nut/bolt interface. Multiple nucleation sites dominated the roll before heat treatment specimens, the sites were significantly increased for roll after heat treatment threads. Log-normal distribution mode is appropriate for bolt fatigue reliability design. Rolling after heat treatment is cost effective.

Design Consideration

Engineering designs consist of many components joined together by various joining techniques. These techniques include bolts, rivets or welds. Residual stresses are natural results of these joining techniques. And realistic detail study of the components to evaluate the design is very important.

First paper in this session discusses the comprehensive nonlinear 3D finite element model to simulate a displacement controlled for riveted structure. Rivet head deformation and induced residual stress/strain field is evaluated to observe the variation in the tensile hoop stress that might occur from the presence of a hole misalignment, variation of hole size, stress/strain interface friction. Parametric relationships between the rivet-head deformation and applied displacement is developed which can be used to evaluate the rivet head deformation.

The second paper of the session presents the state-of-the-art fatigue crack growth analysis techniques which are used in various industries to damage tolerance evaluation of structures. Papers reviews the various crack growth stress intensity multiplication factor models based on experimental data, analytical equations, or FE methods used in the threaded fasteners evaluation. Paper presents a critical observation that there is a need for further research work based on the smaller cracks sizes located within the cold rolled threaded region of nut loaded bolts.

The first objective of this paper was to understand the material stress state within the thread of the bolt and the second object was to determine the fatigue strength in the thread of a nut loaded stainless steel rolled thread bolt under tensile fatigue conditions. The fatigue curve is then used to improve the fatigue life estimations. Flawed and unflawed blots were fatigue tested at a maximum stress ranging from the ultimate tensile strength to the surface endurance limit of the test bolt. The thread root residual compressive stress reached was reached 65% of the bolt UTS. The material of the bolt was PH 13-8 Mo, a precipitation hardened (PH), Martensitic, stainless steel. Paper gives details of the bolt characterization including the EDM flawed blots, Metallography and the test set up. The authors conclude that the EDM flaws were ideally shaped for crack growth in roll threads. However the size, thickness, and radius of the EDM flaw permitted multiple crack initiation locations and may not have the creation of striations close to the thread root. It is suggested that ideally, the initial flaw should be small enough and sharp enough to initiate a single crack all along its perimeter to enable striation formation close to the thread root ($a/d < 0.03$).

This is a very interesting paper which emphasizes on each parameter affecting the structural integrity of a bolted joint.

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