

# STRUCTURAL INTEGRITY *of* FASTENERS

*Second Volume*

**PIR M. TOOR**

*Editor*

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# *Structural Integrity of Fasteners: Second Volume*

*Pir M. Toor, editor*

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# Foreword

This publication, *Structural Integrity of Fasteners: Second Volume*, contains papers presented at the Second Symposium on Structural Integrity of Fasteners, held in Seattle, Washington, on May 19, 1999. The sponsor of this event was ASTM Committee E08 on Fatigue and Fracture and its Subcommittee E08.04 on Application. The Symposium Chairman was Pir M. Toor, Bettis Atomic Power Laboratory, (Bechtel Bettis, Inc.) West Mifflin, PA. Those who served as session chairmen were Harold S. Reemsnyder, Homer Research Labs, Bethlehem Steel Corp., Louis Raymond, L. Raymond and Associates, Newport Beach, California, and Jeffrey Bunch, Northrop Grumman Corporation, Pasadena, California.

## **A Note of Appreciation to Reviewers**

The quality of papers that appear 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

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# Overview

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This book represents the work of several authors at the Second Symposium on Structural Integrity of Fasteners, May 19, 1999, Seattle, Washington. Structural integrity of fasteners includes manufacturing processes, methods and models for predicting crack initiation and propagation, fatigue and fracture experiments, structural integrity analysis and failure analysis. Papers and presentations were focussed to deliver technical information the analyst and designers may find useful for structural integrity of fasteners in the year 2000 and beyond.

The papers contained in this publication represent the commitment of the ASTM subcommittee E08.04 to providing timely and comprehensive information with respect to structural integrity of fasteners. The papers discuss failure approaches, fatigue and fracture analysis techniques, and testing procedures. A current bibliography on matters concerning fastener integrity is included at the end of the technical sessions.

## *Failure Approaches*

The intent of this session was to present failure evaluation techniques to determine the structural integrity of fasteners. Failure mechanisms were discussed in real applications of fasteners from assembly process of a hybrid nylon and steel agricultural wheel to high strength failures in steel components. The primary emphasis was to find the mechanism of failure in the fasteners and to predict the structural integrity.

One of the papers in this session discussed fastener failures in which design inadequacy was identified as a cause of failure. Environmental effects and the accuracy of the loading history were evaluated by reproduction of the failure mode via laboratory simulation. Two possible service conditions that may have contributed to failure were simulated in the laboratory to identify the loading rate and the weakness in the assembly design. Quantitative fractographic methods were used to determine the service loads. The authors concluded that the fatigue stress range and maximum stress can be estimated by quantifying the fracture surface features. The authors suggested that accurate results can be obtained if the tests are conducted using the actual material of the failed studs along with the expected service environment, loading rate, and stress ratio, if these variables are known.

Another paper in this session discussed the life prediction methodologies for fasteners under bending loads. The authors compared the S-N approach with fracture mechanics methodology to predict the bending fatigue life of the fasteners. The authors concluded that the tensile S-N data does not accurately predict the bending fatigue life and the fracture mechanics approach yields a conservative prediction of crack growth.

The last paper in this session discussed the failure analysis of high strength steel army tank recoil mechanism bolts. The bolts failed at the head to shank radius during installation. Optical and electron microscopy of the broken bolts showed black oxide on the fracture surfaces with the characteristic of quench cracks. The crack origin was associated with a heavy black oxide that was formed during the tampering operation. The cause of failure was attributed to pre-existing quench cracks that were not detected by magnetic particle inspection during manufacturing. The author stated that to preclude future failure of bolts, recommendations were made to improve control of manufacturing and inspection procedures.

*Fatigue and Fracture*

The purpose of this session was to highlight the fatigue crack growth state-of-the-art methodology including testing and analytical techniques. An experimental program to investigate the effect of fasteners on the fatigue life of fiber reinforced composites that are used extensively in the industry discussed the failure mode of these composites. The technical areas where further research is needed were also discussed. Another paper discussed the experimental results of low alloy steel fasteners subjected to simultaneous bending and axial loads. The authors concluded that for a bending to axial load ratio of 2:1, fatigue life is improved compared to axial only fatigue life. The fatigue life improvement was more pronounced at higher cycles than at lower cycles. The authors noted that their conclusions are based on limited data. Another paper in this session discussed the stress intensity factor solutions for cracks in threaded fasteners and discussed the development of a closed-form nondimensional stress intensity factor solution for continuous circumferential cracks in threaded fasteners subjected to remote loading and nut loading. The authors concluded that for  $a/D = 0.05$ , the nut loaded stress intensity factors were greater than 60% of the stress intensity factors for the remote loaded fasteners.

*Analysis Techniques*

The intent of this session was to discuss the current analysis techniques used to evaluate the structural integrity of fasteners. The breaking load method, which is a residual strength test, was used in the assessment of stress corrosion in high strength steel fasteners. The authors claim that there is a clear relationship between material, and length of exposure time where SCC is present. The authors concluded that by testing a component rather than a tensile specimen, the effects of materials, machining processes and geometry on SCC resistance on the component can be observed.

Another paper in this session discussed the structural integrity of fasteners by measuring the thread lap behavior using finite element analysis along with the fracture mechanics approach. The author started the discussion by defining, "thread laps," using the fasteners industry definition as a "Surface defect, appearing as a seam, caused by folding over hot metal or sharp corners and then rolling or forging them into the surface but not welding them." The author cited the thread lap inspection criteria in the Aerospace industry as ambiguous and difficult to implement. The author analyzed thread lap using two dimensional, axisymmetric, full nut-bolt-joint geometry finite element models. Elastic-plastic material properties, along with contact elements at the thread interfaces, were used in the analyses. Laps were assumed to propagate as fatigue cracks. The author developed a thread profile with a set of laps and their predicted crack trajectories. It was concluded that laps originating at the major diameter and the non-pressure flank were predicted to behave benignly while the laps originating from the pressure flank are not benign and such laps should not be permitted. An inspection criterion was proposed by superimposing a polygon on the thread. The laps within the polygon would be permissible; laps outside the polygon area would be non-permissible. The author claims that this is a more rational method for the acceptance or rejection of the thread laps.

The last paper in this session discussed some recently developed stress intensity factor solutions for fasteners and their application in NASA/FLAGRO 3.0. The stress intensity factor solutions using a three-dimensional, finite element technique were obtained for cracks originating at the thread roots and fillet radii with a thumb-nail shape. A distinction was made between the rolled and machine cut threads by considering the effect of residual stress. These solutions were coded in the NASA computer code NASGRO V3.0.

### *Testing Procedures*

The first paper in this session discussed the criterion for lifetime acceptance test limits for larger diameter rolled threaded fasteners in accordance with the aerospace tension fatigue acceptance criteria for rolled threads. The intent of this paper was to describe a fatigue lifetime acceptance test criterion for thread rolled fasteners having a diameter greater than 1 in. to assure minimum quality attributes associated with the thread rolling process. The author concluded that the acceptance criterion (fatigue life limit) can be significantly influenced by both fastener and compression nut design features that are not included in aerospace fasteners acceptance criteria.

Another paper in this session discussed an experimental technique to evaluate fatigue crack growth in preflawed bolt shanks under tension loads. The intent of the paper was to discuss the state-of-the-art crack growth testing with respect to applied loads, initial and final crack configuration, and the stress intensity factor correlation. The author concluded that the front of a surface flaw in a round bar can be accurately modeled by assuming a semi-elliptical arc throughout the entire fatigue crack growth process. The author also pointed out that the crack aspect ratio changes during cyclic loading and has a marked influence on the crack propagation characteristics. Therefore, the stress intensity factors in a circular specimen must be determined by accounting for the crack depth to bar diameter ratio and the crack aspect ratio.

The third paper in this session discussed the accelerated, small specimen test method for measuring the fatigue strength in the fracture analysis of fasteners. The method consisted of the use of the rising step load (RSL) profile at a constant R-ratio of 0.1 with the use of four point bend displacement control loading. Crack initiation was measured by a load drop. The application of the procedure was demonstrated by presenting a case history.

Finally, an up-do-date bibliography giving references on stress intensity factor solutions related to fasteners application under axial and bending loading is included for engineering use in determining the structural integrity of fasteners.

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