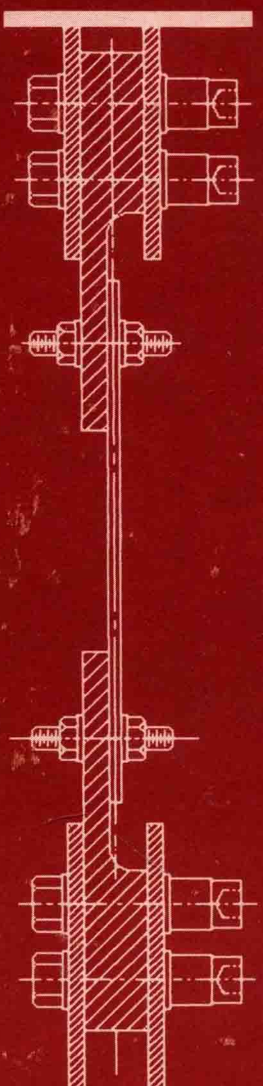
Fatigue in Mechanically Fastened Composite and Metallic Joints



John M. Potter *editor*

ASTM STP 927

FATIGUE IN MECHANICALLY FASTENED COMPOSITE AND METALLIC JOINTS

A symposium
sponsored by ASTM
Committee E-9 on Fatigue
Charleston, SC, 18–19 March 1985

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Foreword

The symposium on Fatigue in Mechanically Fastened Composite and Metallic Joints was held on 18–19 March 1985 in Charleston, South Carolina. The event was sponsored by ASTM Committee E-9 on Fatigue. John M. Potter, of the Air Force Wright Aeronautical Laboratories, presided as chairman of the symposium and also served as editor of this publication.

Related ASTM Publications

Automated Test Methods for Fracture and Fatigue Crack Growth, STP 877 (1985), 04-877000-30

Recent Advances in Composites in the United States and Japan, STP 864 (1985), 04-864000-33

Probabilistic Fracture Mechanics and Fatigue Methods: Applications for Structural Design and Maintenance, STP 798 (1983), 04-798000-30

A Note of Appreciation to Reviewers

The quality of the papers that appear in this publication reflects not only the obvious efforts of the authors but also the unheralded, though essential, work of the reviewers. On behalf of ASTM we acknowledge with appreciation their dedication to high professional standards and their sacrifice of time and effort.

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Overview

The symposium on Fatigue in Mechanically Fastened Composite and Metallic Joints was organized to define the state of the art in durability of mechanically jointed structures.

Mechanically fastened joints are used in many critical engineering structures, including buildings, machinery, power plants, automobiles, and airframes. The joint is the magic part that turns a series of material forms into a structure. The joint between one piece of material and another is often blamed for causing the design to be heavier than desired or for being the point at which fatigue or fracture problems initiate. The study of stress, fatigue, and fracture at joints, then, is of significant interest for the structural designer, as well as those interested in the durability and damage tolerance of the resultant structure.

This volume will serve as a state of the art of joint fatigue. Its usefulness is enhanced by the range of the papers herein, since they run the gamut from basic research to the very applied, from bridge structures to airframes, from adhesive bonding to welding, and from metallic to composite materials. The broad range of the topics covered in this Special Technical Publication makes it an excellent resource for designers, analysts, students, and users of mechanically fastened structures.

The initial paper, by *Speakman,* covers the development of high-performance fasteners in airframe applications. He provides an excellent review of the development of new fasteners and other joining methods for reducing weight and improving fatigue life. The paper is filled with practicality in its approach to improved mechanical fastening systems through methods and fasteners that are "forgiving to the hole." To this author, "forgiving to the hole" means that the fastener system is a practical one in which the hole manufacturing tolerances and the joint materials are taken into account, which results in a mechanical joint that has a large degree of compatibility and, therefore, good fatigue performance. In this wide-ranging paper, Speakman covers fasteners, corrosion, fatigue, fretting, tapered fasteners, sleeved rivets, solid rivets, special nuts, and high-performance bushings and bearings.

The paper by *Champoux and Landy* covers the experimental evidence for structural bushed hole fatigue improvement by using a hole expansion method that includes the simultaneous installation of an interference-fitted bushing. This new bushed hole expansion method is shown to provide a threefold increase in bushed joint fatigue performance while decreasing installation costs, in comparison with the cryogenic shrink-fit installation methods commonly used.

The paper by *Ozelton and Coyle* covers the fatigue improvement of aluminum airframe structures through the use of cold hole expansion by the split-sleeve technique prior to fastener installation. The process of cold hole expansion is being utilized in many applications to improve the fatigue performance of joints. This paper not only covers the fatigue performance of properly cold-expanded fastened joints but also looks into the fatigue improvement of holes with preexisting cracks and also improper reaming during manufacture. The Ozelton and Coyle paper provides excellent evidence of fatigue performance improvements that can be realized.

The paper by *Albrecht and Sahli* covers the fatigue performance of adhesively bonded and bolted highway bridge joints. The paper covers bolted joints, bonded joints, and bolted and adhesively bonded joints in many configurations. These joints are shown to provide increased fatigue performance in typical highway bridge beam splices when compared with conventional joints.

The paper by *Lee* covers the study of load transfer and its effect on fatigue performance in aluminum joints. The Lee paper uses no-load, low-, medium-, and high-load transfer joint specimens to define experimentally the crack initiation and propagation behavior. The results provide an experimental basis for methodology for service life prediction of joints.

The paper by *Yang, Manning, and Rudd* reports on a study of crack growth at fastener holes. The authors have developed statistical evaluations from a very large data base of crack growth at fastened joints for cracks of an extremely small size [less than 2.54 mm (0.10 in.)]. This analytical approach allows excellent predictions of the safety and durability of complex mechanically fastened joints.

The paper by *Nicoletto* covers the application of frozen-stress photoelastic techniques in the stress intensity determination of cracks in open holes and pin-loaded lugs. Pin-loaded lugs are an important branch of mechanically fastened joints, for which the stress distribution is not well characterized. The techniques and measurements presented by Prof. Nicoletto provide considerable insight into stress effects on these joints.

The paper by *Ekvall* covers the fatigue performance of lap joint and butt joint specimens made from recently developed aluminum alloy materials. These fatigue performance results were compared with those of conventional aluminum alloy product forms to assist in the process of defining improvement for the new materials.

Landy, Armen, and Eidinoff address the cold hole expansion repair of cracked fastener holes in structural joints. In this study, residual stress distributions from the cold hole expansion process were analytically developed. The resultant residual stress distributions were then superimposed with applied-load stress intensity factors to give a prediction of crack growth during fatigue exposure following the stop-drill hole repair process. Experimental evidence from mechanically fastened joints supports the prediction of an improvement in fatigue performance. The data indicate that the fatigue life following the cold expansion repair process of cracked joints can exceed the basic as-manufactured fatigue performance.

The paper by *Huth* covers the effect of the fastener in the stress redistribution of a fastened multiple-row joint. Dr. Huth provides compelling experimental evidence of the effect of many primary joint and fastener parameters, including fastener rotation and flexibility, on the predicted load transfer and resultant fatigue performance in the joint and subsequent structure. In this paper, Huth has developed a formula for load transfer within multiple-row joints which includes fastener flexibility. The formula can be used with a variety of fastener systems and joint materials to improve the general predictability of stress and fatigue performance in mechanically fastened joints.

The paper by *Ramkumar and Tossavainen* covers the fatigue performance of composite-to-metal fastened joints. Joint parameters such as the fastener type, stacking sequences and thickness, fastener head type, and joint configuration were investigated to define their effects on fatigue performance. Also studied were the effects of moisture conditioning and load spectrum type.

The paper by *Mallick, Little, and Dunham* describes the fatigue performance of fastened joints where the joint was made from a composite material used in the automotive industry. The composite [continuous fiber sheet molding compound (CFSMC)] joints were prepared with conventional fasteners and subjected to fatigue loading. The authors were able to define several failure modes in the CFSMC fastened joints, including bearing and fretting failures. The variables covered include the bolt clamping pressure, fastener pattern, and specimen width in comparison with the fastener head size.

Mechanically fastened joints have been with us since the first use of assemblies. People have used dowels, rods, screws, pins, keys, glue, bolts, and rivets as mechanical means of fastening. These mechanical fastening methods will be with us for the foreseeable future wherever efficient and inexpensive methods of fastening are required to ensure that a structure will serve the purpose for which it was manufactured.

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Advanced Fastener Technology for Composite and Metallic Joints

REFERENCE: Speakman, E. R., **"Advanced Fastener Technology for Composite and Metallic Joints,"** *Fatigue in Mechanically Fastened Composite and Metallic Joints, ASTM STP 927*, John M. Potter, Ed., American Society for Testing and Materials, Philadelphia, 1986, pp. 5–38.

ABSTRACT: The investigations described in this paper were conducted to develop new fasteners and joining methods to reduce the weight and improve the fatigue life of aircraft structures. Three major modes of structural failure—fatigue, fretting, and stress corrosion—are discussed along with recommendations for improvement. Stress-coining was developed to cold-work aircraft structures for fatigue improvement. Fretting fatigue failures have been reduced by using Teflon coatings on fasteners and in faying surfaces of splice joints. Standard stress corrosion test blocks have been designed for evaluation of this failure mode. A crown flush rivet configuration has been developed that does not require head shaving after installation. Qualification tests were performed in compliance with MIL-STD-1312 to obtain Federal Aviation Administration and military approval.

Various new fasteners have been developed for aluminum, carbon-fiber composite, and titanium structures. These fasteners were designed to be "forgiving to the hole" in that they fill and prestress the hole uniformly without being extremely sensitive to hole-preparation tolerances. New low-cost specimens have been designed to provide a basis for screening and comparing fastener tests conducted by fastener manufacturers and aircraft companies. These programs are directed toward creating technology for achieving a more balanced fatigue-resistant aircraft structure.

KEY WORDS: fatigue life, fretting, stress corrosion, fasteners, joining methods, stress-coining, weight reduction

The state of practice in fastener installation has changed from clearance-fit to interference-fit holes to improve structural fatigue performance (Fig. 1). Hole preparation for interference-fit fastener systems is more costly. Experience has shown that inadequately prepared holes, exceeding design tolerances, reduce service life. Therefore, in order to reduce installation costs without degrading fatigue life, fastener installation methods that are "forgiving to the hole" must be developed. The large number of joints and splices in aircraft structures contribute to increased cost not only of newly produced aircraft but also of reworking of in-service aircraft. The design

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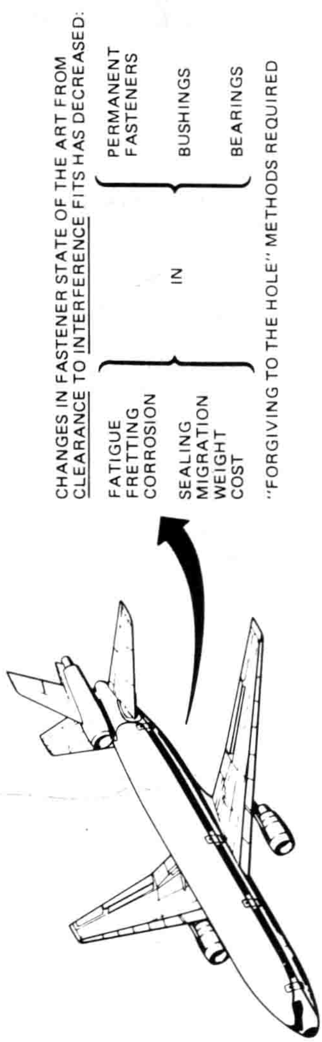

FIG. 1—*Advanced fastener technology.*

trend to higher stress levels and longer service lives also increases the need for high-performance and dependable fastening systems.

Fatigue Test Specimen Configurations

Fatigue specimens of various shapes and sizes are used throughout the industry to test new materials and attachments for new designs and rework of existing aircraft structures in the field. These specimens vary significantly and are usually tailored to determine the effect of a certain type of fastener on a specific structural design. These specimens are often more difficult to design and test than the full-scale structures they represent. It is practically impossible to simulate full-scale aircraft structure loading conditions with small test specimens (Fig. 2).

Specimen and end-grip premature failure due either to poor design or to sophisticated design techniques used in producing the test specimen is a costly and time-consuming hindrance to obtaining reliable test data. Coining and long-life-fatigue fasteners increase the cycle life of the specimen to a point at which fretting damage could initiate a premature failure. For these reasons, the present operating procedures used by fastener and airframe manufacturers to evaluate new fastener products are somewhat awkward and inefficient. Standard fatigue specimens (Fig. 3) have been designed to define a screening test and specimens that include the following criteria:

(*a*) specimen fabrication techniques to minimize manufacturing influence on the fatigue results,

(*b*) fastener installation using representative production equipment to

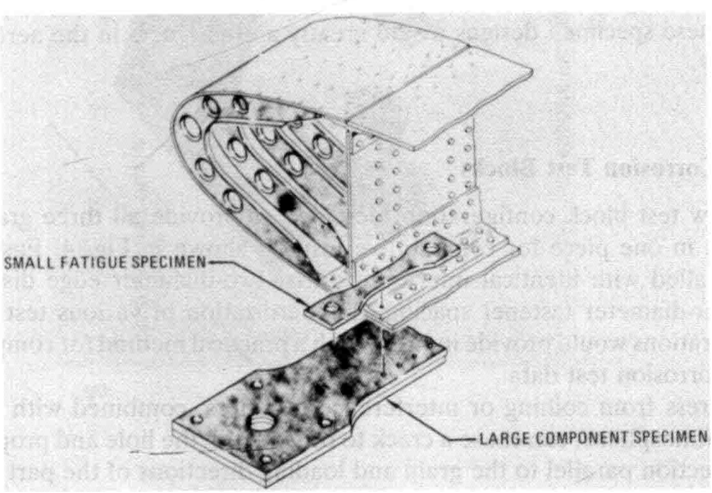

FIG. 2—*Application of test specimens to a full-scale aircraft structure.*

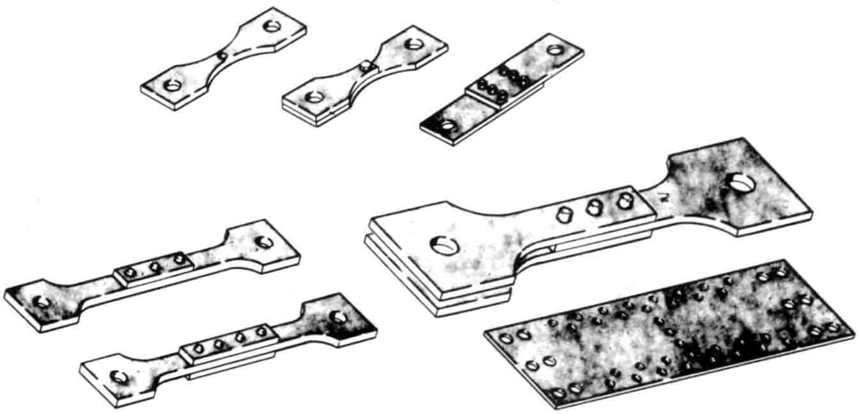

FIG. 3—*Various types of small, inexpensive fatigue specimens.*

obtain more accurate test data for the aircraft the specimens represent, and
(*c*) definition of the test criteria, load spectrum, and data recording.

All major airframe manufacturers have their own fatigue specimens that they use to certify fastening methods for new designs and rework. Adoption of standard fatigue specimen designs would make it possible for fastener and aircraft companies to prepare and test specimens for direct comparison. The savings in time and money produced by such a proper approach would more than justify this program.

The small, standard fatigue specimen designs shown in Fig. 3 would also be the first step toward establishing the performance characteristics of the various types of fasteners and hole-preparation methods for possible inclusion in a design handbook such as MIL-HDBK-5. Fatigue data developed using these specimen designs would greatly aid designers in the aerospace industry.

Stress-Corrosion Test Blocks

A new test block configuration, designed to provide all three grain directions in one piece for comparative tests, is shown in Fig. 4. Fasteners are installed with identical interference fits, two-diameter edge distance, and four-diameter fastener spacing. Standardization of various test block configurations would provide industry with a practical method for comparing stress-corrosion test data.

Prestress from coining or interference fasteners, combined with a corrosive atmosphere, can cause a crack to originate in the hole and propagate in a direction parallel to the grain and loading directions of the part in the aircraft. This phenomenon, which causes the cracks to travel in 90-deg-