Analytical and Experimental Methods for Residual Stress Effects *in* Fatigue

Champoux, Underwood, Kapp

editors

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Foreword

The Symposium on Analytical and Experimental Methods for Residual Stress Effects in Fatigue was held in Phoenix, AZ, on 20–21 October 1986. ASTM Committee E-9 on Fatigue sponsored the symposium. Robert L. Champoux, Fatigue Technology, Inc., John H. Underwood, Army Armament Research and Development Center, and Joseph A. Kapp, Army Armament Research and Development Center, served as chairmen of the symposium and are editors of the resulting publication.

Contents

Overview

Producing beneficial compressive residual stresses on the surface or interior of a structural component has been known for many years to increase service life. The converse is also well known, that tensile residual stresses reduce life. Application examples of beneficial residual stresses are shot peening of springs and other holes, and autofrettage of pressure vessels and piping. On the negative side, welding, heat-treating and metal forming, if carelessly done, can produce tensile residual stresses which could lead to premature failure.

Much attention has been given to residual stress in the testing and analysis of structural materials and components, because of both the beneficial and detrimental effects. Measurements of service life with residual stress present and measurements of the amount of residual stress have been common topics of study in symposia, and technical publications of ASTM and other technical groups. However, the topic here—determining by analysis and experiment the effects of residual stress on fatigue behavior—has not received much attention. The amount of stress present and the resulting life has been measured, but the understanding of the mechanisms and mechanics which control the increases or decreases in fatigue life has not been sufficiently addressed. An improved understanding in this area will lead to quantitative descriptions and, hopefully, predictions of safe service lives for structures containing residual stresses. Since most structural materials do contain residual stresses to some extent, reliable descriptions of their effects will be quite useful.

This Special Technical Publication (STP) has been published as a result of the October 1986 symposium on Analytical and Experimental Methods for Residual Stress Effects in Fatigue, held in Phoenix, Arizona. The purpose of the publication and symposium is: to gain a better understanding of residual stress effects in fatigue; and to communicate the current efforts in this area to the technical community. The symposium was organized by ASTM Committee E-9 on Fatigue and its Subcommittee E09.02 on Residual Stress Effects in Fatigue for the purposes stated above and also for the future of standard test and analysis methods in this area.

Sixteen papers were presented at the symposium, and due to the usual effects of deadlines and peer review, eleven appear in this STP. The papers can be discussed in two groups—those dealing primarily with effects of residual stresses near surfaces and those dealing with through-thickness or bulk effects. There is some overlap, some of it intentional, in order to develop methods of analysis which describe both surface and bulk effects. Surface effects deal mainly with shot peening applications, while bulk effects are studied mainly in relation to pressure vessel and piping. Heat-treat stresses are considered as both surface and bulk effects.

There is some balance in the publication, even though there is not a large number of papers. All but one of the applications mentioned above are addressed. Cold forming of holes is not directly covered, but the several papers on autofrettaged cylinders involve similar geometry and methods of analysis. Aluminum alloys are addressed in only two papers, but this is understandable, since the majority of applications involve steels. The symposium papers are described below, divided into surface and bulk effects categories.

Surface Effects of Residual Stress

The first two papers in the publication are in part reviews of methods used for analysis of residual stress effects at surfaces. They also include research results in this area. The Landgraf and Cherenkoff paper addresses stress patterns arising from shot peening and induction hardening of steels. They develop criteria to predict crack growth, stress relaxation, and fatigue life for prescribed conditions and then compare their predictions with results from the literature. In his paper, Fuchs describes a method of analysis for obtaining optimum shot peening conditions for a given component and applied loading. He checks the results of the analysis with experimental results from a notched steel specimen loaded in rotating bending.

The next two papers in this section are primarily experimental in nature. Childs performs tests to answer the difficult question of loss of residual stress due to exposure at elevated temperature. He found that shot-peened 403 stainless steel lost a significant amount of compressive stress at temperatures as low as 300°F (149°C). Bathias et al. performed a comprehensive experimental study of the near-surface residual stresses in 2024-T3 and 7075-T7 aluminum alloys using X-ray diffraction and a parallel study of the stages of crack initiation and growth in the same materials. Relating the stress details to the stages of growth, the authors were able to draw conclusions regarding fatigue mechanisms as affected by residual stress.

Bulk Effects of Residual Stress

The first two papers in the general category of bulk effects are primarily analytical studies of thick-wall cylinders. They address the practical application of autofrettaged pressure vessels and piping. Stacey & Webster use boundary integrals and weight functions to calculate a stress intensity factor due to the residual stress field through the full wall thickness of the cylinder. Results from the two methods of analysis and from experimental measurements are all in good agreement. Pu & Chen calculate fatigue lives for cylinders containing residual stress, based on stress intensity factor results from prior analyses. Modifying these stress intensity factors, they obtain good agreement with fatigue lives from the literature for A723 steel cylinders.

Kapp & Stacey reported the results of an analytical round robin program to predict the fatique life of notched four-point bend specimens of A723 steel. Both bulk and surface residual stress effects were considered by producing stresses in baseline specimens subjected to bulk specimen plastic deformation and surface shot peening. Stress distributions were calculated for both types of effects, and fatigue lives were predicted and compared with baseline test results.

Bulk effects due to heat-treatment of a steel and welding of an aluminum alloy were considered by Fletcher et al. and Kosteas, respectively. The steel was a C-Mn-B composition used for haulage chain, and it was found to contain tensile residual stresses near the surface and compressive stresses in the interior. The stresses were caused by the transformation volume changes during the quench. The 7020 aluminum studied by Kosteas was in relation to a research program on welded aluminum beams. Analysis of residual stresses and their effect on the fatigue behavior of welded aluminum structures was reviewed in general, and specific fatigue strength data of welded specimens were reported.

Two additional papers on residual stress effects in thick-wall cylinders complete the publication. Brown reported results from A723 steel cylinders with varying amounts of autofrettage residual stress. An optimum residual stress distribution was found, one in which fatigue failure occurred at about the same number of cycles on the inner and outer surfaces of the cylinder. Stacy & Webster, in their second paper in the publication, described the results of ring samples cut from steel tubing which contained residual stresses. By taking into account the differences between the ring specimens and the actual tubing as loaded in service, the authors found significant reductions in fatigue crack growth rates due to compressive residual stresses.

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