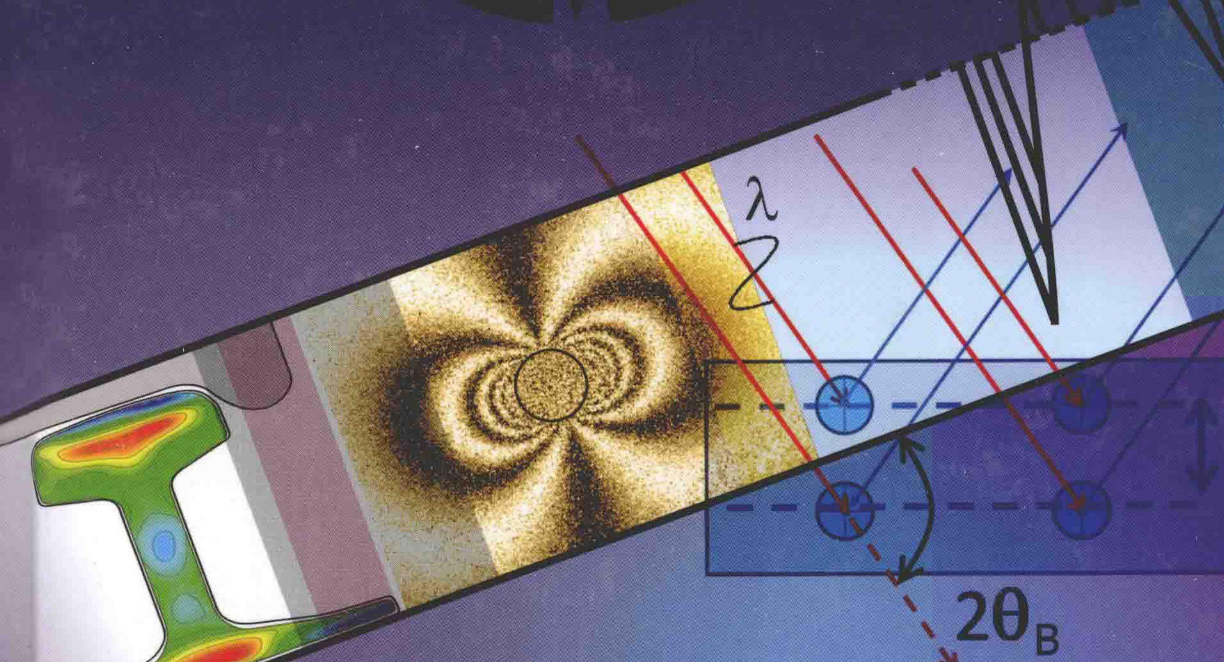
Practical

Residual Stress

Measurement Methods



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PRACTICAL RESIDUAL STRESS MEASUREMENT METHODS

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PRACTICAL RESIDUAL STRESS MEASUREMENT METHODS

This book is dedicated to the memory of

Iain Finnie

late Professor of Mechanical Engineering at the University of California, Berkeley, a pioneer developer of the Slitting Method for measuring residual stresses.

Respectfully dedicated in appreciation of his encouragement, teaching, mentorship and personal friendship.

The royalties from the sale of this book have been directed to the Leonard and Lilly Schajer Memorial Bursary at the University of British Columbia, to provide bursaries to Mechanical Engineering students on the basis of financial need.

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Preface

Residual stresses are created by almost every manufacturing process, notably by casting, welding and forming. But despite their widespread occurrence, the fact that residual stresses occur without any external loads makes them easy to overlook and ignore. This neglect can cause great design peril because residual stresses can have profound influences on material strength, dimensional stability and fatigue life. Sometimes alone and sometimes in combination with other factors, unaccounted for residual stresses have caused the failure of major bridges, aircraft, ships and numerous smaller structures and devices, often with substantial loss of life. At other times, residual stresses are deliberately introduced to provide beneficial effects, such as in pre-stressed concrete, shot-peening and cold hole-expansion.

Starting from early curiosities such as "Rupert's Drops," understanding of the character and mechanics of residual stresses grew with the rise in the use of cast metals during the Industrial Revolution. The famous crack in the Liberty Bell is due to the action of residual stresses created during casting. Early methods for identifying the presence of residual stresses involved cutting the material and observing the dimension changes. With the passage of time, these methods became more sophisticated and quantitative. Complementary non-destructive methods using X-rays, magnetism and ultrasonics were simultaneously developed.

Modern residual stress measurement practice is largely based on the early historical roots. However, the modern techniques bear the same relationship to their predecessors as modern jet planes to early biplanes: they share similar conceptual bases, but in operational terms the current measurement techniques are effectively "new." They have attained a very high degree of sophistication due to greatly increased conceptual understanding, practical experience and much more advanced measurement/computation capabilities. All these factors join to give substantial new life into established ideas and indeed to produce "new lamps for old."

Conceptual and technological progress has been a collective endeavor by a large group of people. The list of names is a long and distinguished one. To paraphrase Isaac Newton's words, the present Residual Stress community indeed "stands on the shoulders of giants." A particular one of these giants that several of the contributors to this book were privileged to know and learn from, was Iain Finnie, late Professor of Mechanical Engineering at the University of California, Berkeley. Professor Finnie was a pioneer of the Slitting Method, described in detail in Chapter 4 of this book. I join with the other authors in dedicating this book to him as a sign of respect and of appreciation for his encouragement, teaching, mentorship and personal friendship. Those of us who aspire to be researchers and teachers can do no better than look to him for example.

On a personal note, I would like to express my sincere gratitude and appreciation to all the chapter authors of this book. The depth of their knowledge and experience of their various specialties and their generous willingness to share their expertise makes them a true "dream team." They have been extraordinarily patient with all my editorial requests, both large and small, and have worked with me with grace and patience. Thank you, you have been good friends!

I also would like to thank the staff at John Wiley & Sons for the support and encouragement of this project, and for the careful way they have carried forward every step in the production process.

And finally, more personally, I would like to acknowledge my late parents, Leonard and Lilly Schajer, whose fingerprints are to be found on these pages. They followed the biblical proverb "Train up a child in the way he should go: and when he is old, he will not depart from it." In keeping with their philosophy, the royalties from the sale of this book have been directed to support students in financial need through the Leonard and Lilly Schajer Memorial Bursary at the University of British Columbia. All book contributors have graciously supported this endeavor and in this way hope to add to the available shoulder-space on which the next generation may stand.

Gary Schajer
Vancouver, Canada
April 2013

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Overview of Residual Stresses and Their Measurement

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1.1 Introduction

1.1.1 Character and Origin of Residual Stresses

Residual stresses are "locked-in" stresses that exist in materials and structures, independent of the presence of any external loads [1]. The stresses are self-equilibrating, that is, local areas of tensile and compressive stresses sum to create zero force and moment resultants within the whole volume of the material or structure. For example, Figure 1.1 schematically illustrates how a residual stress distribution through the thickness of a sheet of toughened glass can exist without an external load. The tensile stresses in the central region balance the compressive stresses at the surfaces.

Almost all manufacturing processes create residual stresses. Further, stresses can also develop during the service life of the manufactured component. These stresses develop as an elastic response to incompatible local strains within the component, for example, due to non-uniform plastic deformations. The surrounding material must then deform elastically to preserve dimensional continuity, thereby creating residual stresses. The mechanisms for creating residual stresses include:

1. Non-uniform plastic deformation. Examples occur in manufacturing processes that change the shape of a material including forging, rolling, bending, drawing and extrusion, and in service during surface deformation, as in ball bearings and railway rails.
2. Surface modification. Examples occur in manufacture during machining, grinding, plating, peening, and carburizing, and in service by corrosion or oxidation.

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