

Stress Relaxation Testing

D.A. Woodford, MPA, Inc.

THE MAJORITY OF CREEP TESTING, as described in this Volume, uses a fixed load (or stress) at a constant temperature and measures the increase in strain as a function of time. However, materials may also creep under constraint with little or no dimensional change. This constraint then approximates a constant total strain, so a more appropriate test in such situations is one in which the material is deformed to a fixed strain, which is then held constant. Depending on the application, the corresponding initial stress may be below, at, or above the yield stress on loading. Whether or not there is permanent plastic strain on loading, there is an elastic strain that, in linear elastic materials, is proportional to the stress through the appropriate temperature sensitive modulus. If the temperature and stress are sufficiently high creep will occur, but since the total strain is held constant, this can only be achieved if the elastic strain decreases with a corresponding decrease in the stress. Creep at a fixed total strain, therefore, results in a time dependent stress relaxation.

A common practical example where stress relaxation is a major design issue is in high temperature bolting. After being initially torqued to ensure joint tightness the stress progressively relaxes at a rate that depends on the creep strength of the material. For major components such as steam turbine shell flanges, it is essential to avoid leakage by periodic bolt retightening. Alloys have to be used, which will ensure steam tight joints at least up to normal turbine overhaul periods that may now extend to 50,000 h (Ref 1).

In addition to many such mechanical fastener problems, stress relaxation is important in the wire of prestressed concrete (Ref 2), all types of springs (Ref 3), electrical contacts (Ref 4), soldered joints (Ref 5), and the relief of stress gradients induced by differential swelling in in-pile nuclear reactor tubes (Ref 6).

Stress relaxation is not limited to externally applied stresses. Residual stresses caused by metal working (Ref 7) or welding (Ref 8) may have to be reduced by stress relieving treatments prior to placing parts in service. Finally, parts such as gas turbine blades with internal cooling may develop severe stress and temperature gradients in service that will lead to stress redistribution under constraint, and temperature changes in cyclic operation may lead to resid-

ual stresses that relax at temperature. For repeated cycles the accumulated creep strain may eventually lead to cracking as a result of thermal fatigue (Ref 9).

From this discussion it is clear that stress relaxation and stress redistribution are major manifestations of creep deformation in practical applications. This is especially true for high-temperature cyclic operation. In many cases, however, suitable relaxation data does not exist, and analysis has to be made using existing constant load isothermal creep data. Thus there is much interest in predicting relaxation from creep data and vice versa. The problem is that most structural materials experience strong deformation path dependence. Thus, a material creeping under constant load and accumulating strain experiences a different deformation path from one subjected to a fixed total strain and decreasing stress. To convert one to the other requires a damage law such as time hardening or strain hardening or a mechanical equation of state, which incorporates one or more internal state variables (Ref 10). These approaches have

varying degrees of success and will not be further considered.

This article concentrates on metallic materials as covered by ASTM E 328 (Ref 11), although stress relaxation is very important in plastics. For plastics a separate ASTM testing standard (Ref 12) is available that recognizes the viscoelastic behavior. This means that the creep strain may be mostly or fully recoverable upon removal of the load. Recent work on engineering ceramics suggests that these materials also show viscoelastic behavior (Ref 13). Composites of all types are expected to show internal stress redistribution between the components as well as complex macroscopic stress relaxation depending on the component phases.

Testing Considerations

Figures 1 and 2 illustrate load characteristics and data representation for stress relaxation testing for the most convenient and common

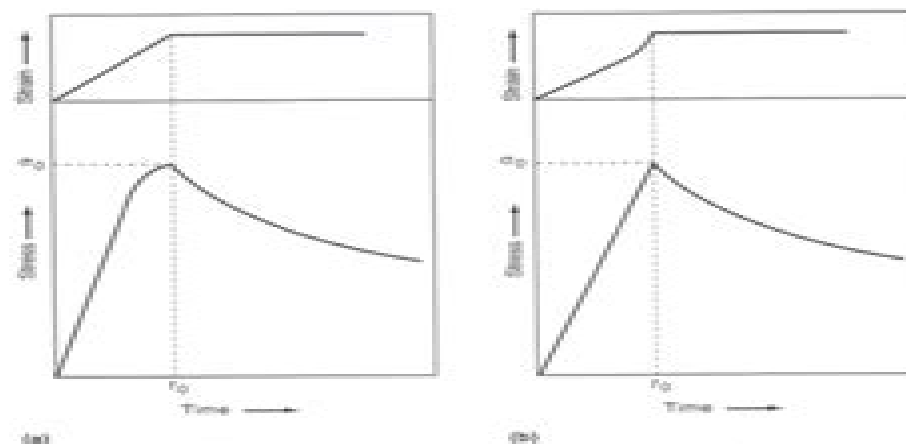


Fig. 1 Characteristic behavior during loading period in a stress relaxation test. (a) Constant strain rate, (b) Constant load rate. Source: Ref 11.

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Alfred Fox



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Table of Contents Stress Relaxation Testing A Symposium

1. Understanding the eBook Stress Relaxation Testing A Symposium
 - The Rise of Digital Reading Stress Relaxation Testing A Symposium
 - Advantages of eBooks Over Traditional Books
2. Identifying Stress Relaxation Testing A Symposium
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Stress Relaxation Testing A Symposium
 - User-Friendly Interface
4. Exploring eBook Recommendations from Stress Relaxation Testing A Symposium
 - Personalized Recommendations

- Stress Relaxation Testing A Symposium User Reviews and Ratings
- Stress Relaxation Testing A Symposium and Bestseller Lists
- 5. Accessing Stress Relaxation Testing A Symposium Free and Paid eBooks
 - Stress Relaxation Testing A Symposium Public Domain eBooks
 - Stress Relaxation Testing A Symposium eBook Subscription Services
 - Stress Relaxation Testing A Symposium Budget-Friendly Options
- 6. Navigating Stress Relaxation Testing A Symposium eBook Formats
 - ePub, PDF, MOBI, and More
 - Stress Relaxation Testing A Symposium Compatibility with Devices
 - Stress Relaxation Testing A Symposium Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Stress Relaxation Testing A Symposium
 - Highlighting and Note-Taking Stress Relaxation Testing A Symposium
 - Interactive Elements Stress Relaxation Testing A Symposium
- 8. Staying Engaged with Stress Relaxation Testing A Symposium
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Stress Relaxation Testing A Symposium
- 9. Balancing eBooks and Physical Books Stress Relaxation Testing A Symposium
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Stress Relaxation Testing A Symposium
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Stress Relaxation Testing A Symposium
 - Setting Reading Goals Stress Relaxation Testing A Symposium
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Stress Relaxation Testing A Symposium
 - Fact-Checking eBook Content of Stress Relaxation Testing A Symposium

- Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
- 14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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