Datapoint

Reporting on developments in material properties for engineering design

COVER STORY

Polymers present unique challenges for FEA

Today, polymeric materials are omni present in the engineering world. Their low cost and ease of manufacture make them attractive for the designer. Although inferior to metals in structural applications, today's research increases their mechanical capabilities and extends the range of their applications.

Very often in mechanical design, the engineer uses numerical methods to predict the behavior of structural parts. Finite element analysis is one of these methods, and provides the engineer with a very powerful tool to solve problems with complex geometries and loading conditions. Today's finite element packages offer a large material library, providing many different models for engineering material. However, for the analysis of glassy polymers, the analyst often uses models initially developed for metals because he is not aware of their limitations when applied to polymers, or because the exact model is not available or to complex to use. This discussion emphasizes some differences in the mechanical behavior of metals and polymers. The analyst should keep them in mind to choose models more appropriate to polymers, and to be aware of the assumptions he makes when using models developed for metals. This article focuses on the uniaxial test and the differences in the resulting stress-strain curves between metals and polymers. Future articles will discuss other aspects (creep, fatigue, fracture).

The uniaxial test

The uniaxial test describes the mechanical behavior of a material when loaded along a single direction. These tests are usually performed on a universal testing machine machine. For very high strain rate tensile tests (useful for impact analyses), an inexpensive solution is currently in development at Datapoint Testing Services, using a Dynatup impact tester.

The resulting stress-strain curves are very different for metals and polymers (Figure 1). For metals the behavior is linear within a very small range corresponding to the elastic response of the material. The elastic limit, or yield point, is usually defined as the point where the linear prediction deviates from the actual curve by 0.2% (called the 0.2% offset point). At larger strains, plastic flow occurs and the curve becomes non-linear. Most of the plastic deformation occurs by slip within the crystalline structure of the metal. At the ultimate stress, the specimen breaks.

The stress-strain curve of a typical polymer is very different from metallic materials. The elastic region is wider than for metals but non-linear. The yield point is therefore more difficult to find and requires special experimental procedures: the specimen is loaded and unloaded, increasing the load at each cycle until a permanent deformation is observed. That point is then taken as the yield point. For larger strains, plastic deformations occur by homogeneous viscoplastic flow, shear bands or formation of crazes at the surface of the specimen.

Compression versus tension

For metals, compressive and tensile deformations imply the same mechanism and the stress-strain curves are consequently similar (same elastic moduli and yield strengths when the material has no plastic loading history). To analyze a metallic part experiencing multiaxial loads, a stress strain curve in either tension or compression is sufficient. For investigations on plasticity in tri-dimensional

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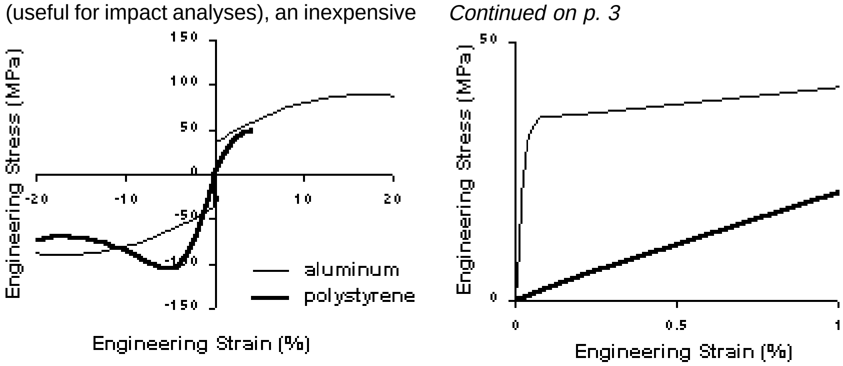

Figure 1. Typical stress-strain curves for aluminum and polystyrene.

Datapoint has always looked to improve the material modeling abilities of the readership through the publication of short articles, book reviews and other forms of information. This issue of the newsletter is no exception. What is new, however, are the advances that Datapoint Testing Services has made to make it easier for CAE analysts and design engineers to use their software products more easily. Ready-to-load capability now exists for a number of CAE packages accompanied by pre-sales and post-sales support in the selection and use of material models in these programs.

In this issue...

Read about the importance of quality systems in the generation of material properties with an article by Paul Graboff. Of interest to structural analysts is the cover story on selection of material models for plastics FEA.

ISO/IEC GUIDE 25

A2LA accreditation ensures laboratory competence

For a laboratory to be accredited by A2LA (American Association for Laboratory Accreditation) it must meet all of the requirements of ISO/IEC Guide 25, "General Requirements for the Competence of Calibration and Testing Laboratories". To accomplish this, the laboratory must show that it complies with the quality system requirements of ISO 9002 (Quality Systems: Model for Quality Assurance) and it must demonstrate that it and its staff are competent in the tests which appear on its scope of accreditation. This is no small feat.

In order to be accredited by A2LA the laboratory must submit a laboratory quality manual describing the operation of its quality system. It must also have written test methods, policies and procedures for document control; procedures for achieving traceability of measurements; calibration, verifica-

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ANNOUNCEMENTS

Increased demand for services drives major expansion

In response to the growing need for accurate material data for design, Datapoint Testing Services has acquired additional laboratory and office space, added an engineer and two test technicians to its staff, and purchased additional test equipment.

New personnel

François Barthelat has joined Datapoint Testing Services in the position of Applications Support Engineer. François, who holds an M.S. degree in mechanical engineering from the University of Rochester, brings expertise in performing structural analysis.

Datapoint Testing Services also welcomes Brigitte Nassar and Gregory Urbancik, who join our staff as Laboratory Technicians. Brigitte holds a diploma in Theoretical and Applied Physics from the University of Heidelberg; Greg graduated from the College of New Jersey with a B.S. in Biology.

New equipment and test offerings

Datapoint Testing Services has purchased a Satec fatigue tester, used to determine the number of cycles to failure as a function of stress. The fatigue tester has been outfitted to perform measurements at elevated temperatures. A moisture analyzer, a surface tension measurer, a compression set fixture, and an optical stage for microscopic determination of transition temperatures have also been acquired.

Course introduces properties for FEA

Datapoint Testing Services and MARC Analysis Research Corporation are currently developing a material properties course for designers and engineers in the plastics industry. The two-day course, to be held on the West Coast at the end of this summer, will combine lectures and hands-on experience. Attendees will perform mechanical tests and use the resulting data for simulations with MARC software. For details, contact Gary Timpe at 206-729-5740.

Lab passes 2000th material milestone

As of February of this year, Datapoint Testing Services has performed measurements on more than two thousand materials.

Make your point.

*We welcome your comments and invite submissions for future issues. Call **1-888-DATA-4-CAE** or visit our website: **www.datapointlabs.com**.*

TestPaks™ for MSC/NASTRAN, MARC are offered

Datapoint Testing Services has expanded its structural analysis test offerings by creating *TestPaks* for MARC and MSC/NASTRAN. Each *TestPak* contains all the measurements required to characterize a material according to a particular material model. The resulting data is supplied both in a written report and electronically, ready to load into the structural analysis package. *TestPaks* for MARC and MSC/NASTRAN range from simple linear material models to more complex non-linear models, including hyperelastic models. Effects of temperature and rate-dependency can be included, and creep and viscoelastic effects can also be characterized.

With the addition of MARC and NASTRAN, Datapoint Testing Services now provides *TestPaks* for 17 of the most widely used FEA software packages in the world today.

***TestPaks* are available for...**

Injection Molding
- C-MOLD
- Fillcalc
- I-DEAS
- Moldex
- Moldflow
- TMConcept

Extrusion/CFD
- EXTRUD
- FIDAP
- Flow 2000
- Nekton
- Polycad
- Polyflow

Thermofoming
- T-SIM

Structural Analysis
- ABAQUS
- ANSYS
- MARC
- MSC/NASTRAN

Upcoming events

ANTEC'99: Plastics–Bridging the Millenia. Meet Hubert Lobo and Gary Timpe at our booth. May 2 - 6, New York, NY.

ABAQUS User's Conference. May 26-28, Chester, UK.

1999 ICCON User's Conference. June 14-18, Anaheim, CA.

1st Worldwide MSC Automotive User's Conference. Sept. 20 - 22, Munich, Germany.

A2LA accreditation achieved

A2LA has accredited Datapoint Testing Services to ISO/IEC Guide 25 for technical competence in the field of mechanical testing. Our scope of accreditation also encompasses many thermal properties, including capillary rheology and thermal conductivity. For additional information regarding accreditation, contact our Laboratory Manager.

ISO/IEC GUIDE 25 CONT.

A2LA accreditation ensures laboratory competence

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tion, and maintenance procedures and schedules; and procedures for audit and review of the entire quality system in the laboratory. (This list of requirements is not all-inclusive.)

Before the laboratory can be accredited it must undergo a rigorous in house assessment by an auditor with knowledge of quality system requirements and expertise in the field of testing for which expertise is sought. Laboratory staff members must demonstrate to the assessor their competence to run and understand all methods for which the laboratory claims they are qualified. Any deficiencies found during this assessment must be satisfactorily resolved before accreditation is granted.

So what does this mean to anyone serviced by this accredited laboratory?

Working with an A2LA accredited laboratory provides to the client confidence that the lab equipment is properly calibrated and maintained, and that those who run the tests are trained, competent, and qualified. The client can be assured that the test results provided are reliable and accurate. The client can have confidence in the operation of the laboratory without having to perform its own on site audit.

Competence is the key word in accreditation to ISO/IEC Guide 25. This means that the laboratory has demonstrated that it has in place a quality systems program and that it performs tests both consistently and correctly, thus providing confidence to the client that the test results are accurate.

Paul Graboff is an independent plastics consultant based in Augusta, GA. He holds a BA and an MS in Chemistry, and has over 40 years experience in testing, quality assurance, and standardization.

COVER STORY CONT.

Polymers present unique challenges for FEA

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analyses, the Von Mises yield surface is widely used and gives excellent results. This criterion can be written as:

$$\bar{o} \le \sqrt{3}\acute{o}_y$$

Where $\bar{o}$ is the equivalent Von Mises stress and $\acute{o}_y$ is the yield stress obtained with a stress-strain curve.

For polymers, the symmetry of the stress-strain curve is not observed. Elastic and plastic deformations of polymers are sensitive to the hydrostatic pressure. These deformations imply entanglement of the molecules, and this mechanism is slowed under high pressures, as the molecules are compressed against each other. The immediate consequence is that the response in tension and compression is different: in compression (for high hydrostatic pressures), the material is generally stiffer and has a higher yield strength than in tension. A modified yield surface (Figure 2) should be used:

$$\bar{o} + \acute{a}P \le \sqrt{3}\acute{o}_y$$

Where *P* is the hydrostatic pressure and a is a constant.

In addition to this effect, tensile deformations result in the formation of crazes at the surface of the specimen. Crazes are crack-like deformations which reduce considerably the strength of the material in tension (see stress-strain curve for polystyrene).

Very often a structural parts endures both compressive and tensile stresses. In contrast to metals, the designer should use data in both tension and compression to obtain more realistic results.

Strain rate and temperature effects

When modeling a material, strain rate effects are taken in account when the temperature reaches typically one half of the melting temperature (viscoelastic and creep effects), or for high strain rates (damping in vibration analyses). For metals under low temperatures and quasi-static loads, the strain rate effect can be neglected.

For polymers, these effects cannot be ignored: due to their low melting temperature, rate dependencies are much more pronounced. Indeed, the non-linearity of the elastic region can be in part explained by the viscosity of the polymer. High strain rates lead to higher stresses within the specimen. Moreover, the viscosity of the material is very sensitive to the temperature. Decreasing the temperature increases the viscosity, and therefore increases the stresses. A successful analysis should therefore be performed using data obtained at strain rates and temperatures close to the actual loading conditions of the structural component.

François Barthelat has joined the staff of Datapoint Testing Services in the position of Applications Support Engineer. (Announcements, p.2.)

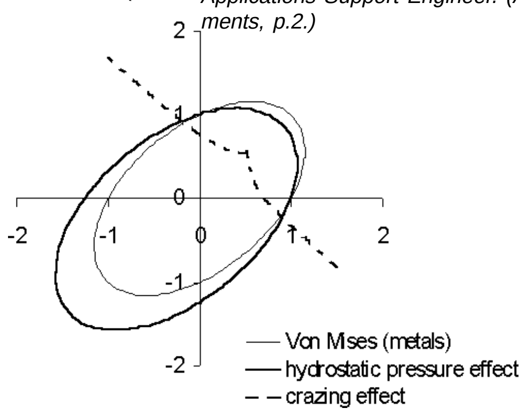

Figure 2. Yield surfaces predicted by the Von Mises criterion, with hydrostatic pressure dependence correction and with crazing effects.

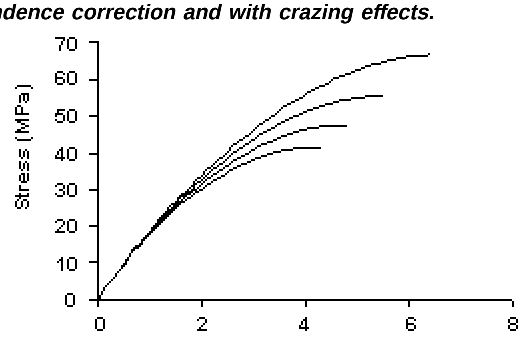

Figure 3. Stress-strain curves obtained at different strain rates and temperatures.

BOOK REVIEW

Principles of Polymer Engineering, 2nd Edition

N. G. McCrum, C. P. Bucknall, C. B. Bucknall. Oxford Science Publications, 1997. ISBN 0-19-856526-7. Reviewed by Hubert Lobo.

This book presents a concise and easily readable introduction to polymer behavior for design and production engineers. It seeks to explain the behavior of plastics and rubber using a materials science framework, by relating observed phenomena to changes in morphological and molecular structure. This presents a powerful way for engineers to grasp the underlying factors that make polymers the complex materials that they are. The reader is encouraged to step away from using linear-elastic metals concepts when designing with plastics. The pitfalls of such simplifications are pointed out and guidelines are presented to aid the designer in adopting a non-linear approach.

Numerous examples throughout the book illustrate how these concepts may be applied. Chapter 2 provides an introduction to the structure of a polymer, and to the phenomena of melting, solidification and orientation, which play such important roles in defining the morphology and performance of a polymeric component. This puts the reader in the right frame to examine the behavior of rubber, which is covered in the next chapter. Here, the implications of large deformation are considered while important distinctions between polymeric and metal behavior are made. The issue of viscoelasticity is covered next, along with its implications in the prediction of creep and stress relaxation. The treatment of this complex subject is easy to follow and is accompanied by well-developed insights, which make it possible for the engineer to apply these concepts to everyday design.

In Chapter 5, we see a presentation of the mechanisms of failure in plastics and rubber. This chapter has been extensively updated to reflect the new developments in this field. Yielding and necking phenomena are explained along with descriptions of brittle failure. The effects of fiber fillers, rubber as toughening agent and other reinforcements are covered.

The remainder of the book is devoted to the processing of polymers. Each of the major manufacturing processes is treated using the same framework. The last chapter is of particular interest to design engineers. Issues of material selection, the choice of processing technology and its effect on performance are considered. The sections on designing for stiffness and strength provide guidelines on the effect of different variables on the performance of a polymeric part.

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Visit our booth!

ANTEC '99
May 2-6

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