IMPACT BEHAVIOUR OF CARBON FIBER REINFORCED COMPOSITES UNDER BEND LOADING CONDITIONS

F.-J. BEHLER* and S. SIKORSKI**

**Fraunhofer-Institut für Angewandte Materialforschung, Abt. WBV/Faserverbundstrukturen, Lesumer Heerstrasse 36, D-2820 Bremen 77, Germany*

***Motoren-und Turbinen-Union München GmbH, Abt. ELN-Nr. 016-90M, Dachauer Strasse 665, D-8000 München 50, Germany*

Résumé - Nous donnons un récapitulatif des propriétés attendues des matériaux composites, lorsqu'il sont soumis à des chargements intenses et brefs engendrant des vitesses de déformations élevées. Nous présentons une technique d'essai pour la caractérisation mécanique au choc, et nous présentons quelques résultats expérimentaux.

Abstract - A review on the requirement of the mechanical behaviour of composite materials under high strain rate and impact loading conditions is given. A technique for the determination of the mechanical behaviour is described and some data and experimental results are presented.

1. Introduction

In a wide range of technical applications, loading-profiles and potential damage development of complex structural components are tried to be described by numerical simulation beforehand. A number of attempts has been made to apply finite element methods to the modeling of high strain rate and impact response of composite materials and structures /1/.

The numerical simulation requires - in addition to a soft- and hardware input, and the know-how on basic design with regard to the special problems of non-isotropy, and two or more phases - characteristic mechanical materials data. This data have to be evaluated under loading conditions, as close as possible to the loading conditions of the real structural components, with the aim to give a basic safety in construction and design.

2. Material Behaviour and Loading Condition

Strength and deformability of materials are strongly influenced by the loading conditions, e.g.

- temperature
- stress state
- strain rate.

The influence of temperature is well known for a large number of materials, for example a drop down of deformability with decreasing temperature, and a decreasing strength with increasing temperature for

steels, the influence of the stress state can be considered by some analytically based models (von Mises, Tresca etc). The knowledge on the mechanical properties of materials under impact and high rates of strain, especially in the field of advanced fiber reinforced materials is rather incomplete.

Different temperatures cause different material properties but don't cause principally different internal loading conditions. This is in opposition to the influence of strain rate and impact phenomena. An increasing strain rate - starting from the creep area over quasistatic conditions to the high strain rate and impact region - effects a change in the internal loading condition from a global to a local one, /2/.

For design and construction in the region of low strain rates stiffness, fatigue strength and elastic deformation are the main characteristic values. Under extremely high loading rate- and impact-conditions other problems are placed into the foreground like contact problems, shock-wave phenomena, spalling and hydrodynamic material flow. These different modi of internal loading have to be taken into consideration by the application of computer software/programs for the numerical simulation of high rate loading processes of structural components.

3. Impact, High Strain Rate Properties

The testing of materials and components under impact loading conditions gives information on

- damage, damage evolution, damage area
- energy consumption
- strength after impact, fig. 1.

fig. 1: Information of testing materials under impact loading conditions

High strain rate testing delivers the mechanical properties needed for design, construction and numerical simulation:

- yield

- strength
- elongation to fracture, fig. 2.

fig. 2: Information of testing materials und high strain rate conditions

Caused by the requirements of design one has to secure a minimum of deformability with regard to strain rate and temperature effects and so to prevent a catastrophic damage evolution.

4. Fiber Reinforced Materials

Fiber reinforced materials are in a preferred application where its non-isotropic properties high stiffness, high strength and low density can lead to a high quality design. Crucial areas of every design are the loading points. These advanced materials are not able to reduce local stress peaks by local flow as metallic materials do.

5. High Strain Rate Testing of Composite Materials

Investigations on some fiber reinforced materials were carried out by a number of research-institutes. Different testing techniques are in application to get characteristic values and to create a source of basic material properties for design and numerical simulation.

A number of results of different investigations with the use of different testing techniques was summarized, fig. 3, /3 to 6/. The general shape of all plots shows an increasing strength with increasing strain rate independently from testing technique and loading condition.

Most of these investigations are performed on glassfiber reinforced plastics and on woven material qualities. Also glass/carbon hybrids were tested under different strain rates, fig. 4, /7/. Proceeding from the all-glass-fiber quality a distinct increase of stiffness and strength can be noticed with increasing fraction of carbon-fibers and strain rate.

fig. 3: Strain rate dependent properties of some fiber reinforced plastics (/3 to 6/)

fig. 4: Glass/carbon hybrids, stress-strain plots, influence of loading rate (Harding /7/)

6. High Strain Rate Bend Tests on Different Qualities of CFRP

The wider establishment of advanced carbon fiber reinforced materials in the field of highly loaded engine- and structural components requests the knowledge of its mechanical properties. Within this scope, three different CFRP-qualities

- 1.: Epoxymatrix, Carbonfiber
Vicotex 6376, T 800 fiber
48 layers, unidirectional
- 2.: Epoxymatrix, Carbonfiber
Vicotex 6376, T 800 fiber
49 layers, 00 +45 00 90 00 -45
- 3.: PEEK-Matrix, Carbonfiber
APC 2, IM 6 fiber
48 layers, unidirectional

were characterized under quasistatic and high strain rate loading conditions in a modified flying-wheel apparatus, /8/. This apparatus enables to carry out cantilever bend tests in a strain rate range from $5 \cdot 10^{-3} \text{ s}^{-1}$ to 10^3 s^{-1} . Using strain gages, fixed in the area of medium (pure elastic) and maximum bending moment this technique delivers stress-time- and strain-time-diagrams from which stress-strain-diagrams can be evaluated by the elimination of time, /9/.

7. Results

The investigated different qualities of carbon fiber reinforced plastics show a coherently increasing flexural strength with increasing strain rate, fig. 5.

fig. 5: Flexural strength of the investigated CFRP as function of strain rate

In detail the investigated epoxy-matrix materials show an increase in strength from 900 MPa to approx. 1500 MPa and a nearly constant elongation to fracture (.5% to .7%) within more than 5 magnitudes of strain rate. In comparison the PEEK-matrix material reaches a rate independent maximum strain of approx. 1.8% and a high rate strength of 1400 MPa, fig. 6. This behaviour seems to be comparable with some brittle metallic materials.

fig. 6: Stress-strain behaviour of the investigated unidirectional CFRP, epoxy matrix and PEEK matrix

This investigation delivers a number of input data for numerical simulation applications and it might give a basic safety in construction and design of structures and engines loaded in a high velocity area.

8. Literature

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