STRAIN RATE BEHAVIOR OF METALS AND COMPOSITES

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ABSTRACT: Understanding the behavior of metals and composite materials behavior, development of appropriate constitutive equations, and defining fracture mechanisms in the dynamic loading regime continue to evolve. Models developed must include an accurate representation of the physical processes occurring, be mathematically tractable, and incorporate the appropriate material parameters. Examination of these issues in the context of metals and composites is the focus of this paper.

INTRODUCTION

The variation in material strength with applied strain rate is an important consideration in the design of classes of materials used in structures subjected to suddenly applied loads. It has been observed that for many materials the stress is found to increase rapidly with strain rate for a given suddenly applied load. This effect is shown in Figure 1, which shows schematically the threshold value at which such changes are observed as related to a particular material type and specified dynamic load. Generally, such changes are observed to occur at strain rates of the order of magnitude 30/sec for metals. The physical significance of events as related to the rate behavior of metals is shown in Figure 2, which also depicts the difference between loading mode and strain rate. In order to understand this behavior and gain insight into the development of suitable mathematical models for describing the behavior of materials at high strain rates, a number of important issues are needed. Among these issues are

- Direct measurement of strain rate by experiment.
- Development of constitutive models
- Understanding the physical process involved in dynamic failures.

It is with these issues that form the present paper.

EXPERIMENTAL TECHNIQUES USED FOR MEASUREMENT OF STRAIN RATE

- The dynamic problem is complicated by such factors as the intensity of the loading, which influences the loading rate, which in turn this effects wave propagation through the material and subsequently the type of damage occurring in the material and/or structure. In order to design experiments to characterize and model materials/structures subjected to dynamic events, it is necessary to study the interactive nature of dynamic events occurring during the loading process. For example, in order to determine dynamic properties necessary for modeling dynamic events, it is necessary to understand stress wave propagation as well as to know a priori the material constitutive relations.

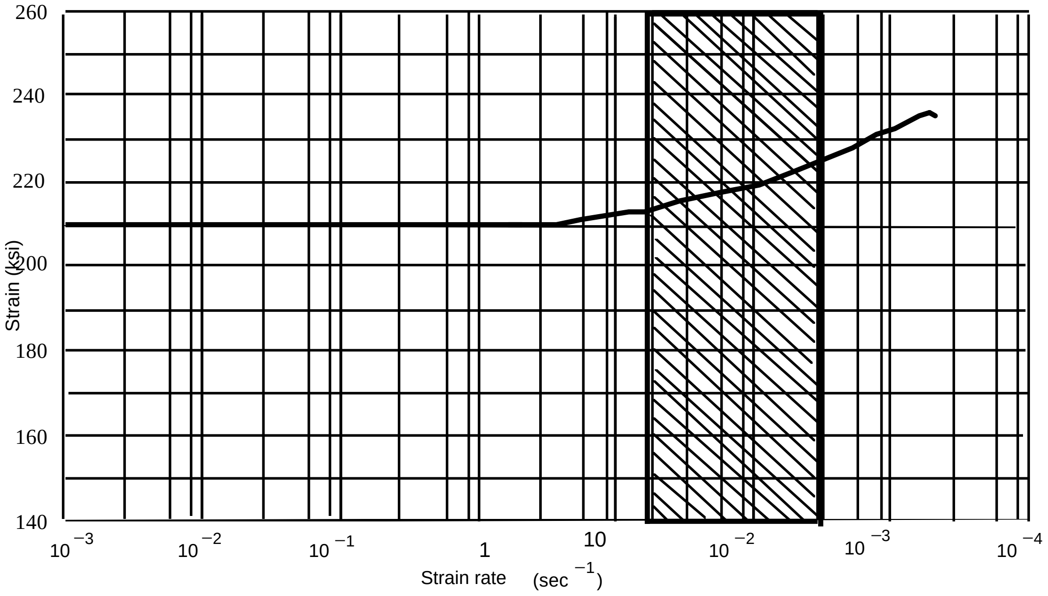


Figure 1. Stress vs. strain rate

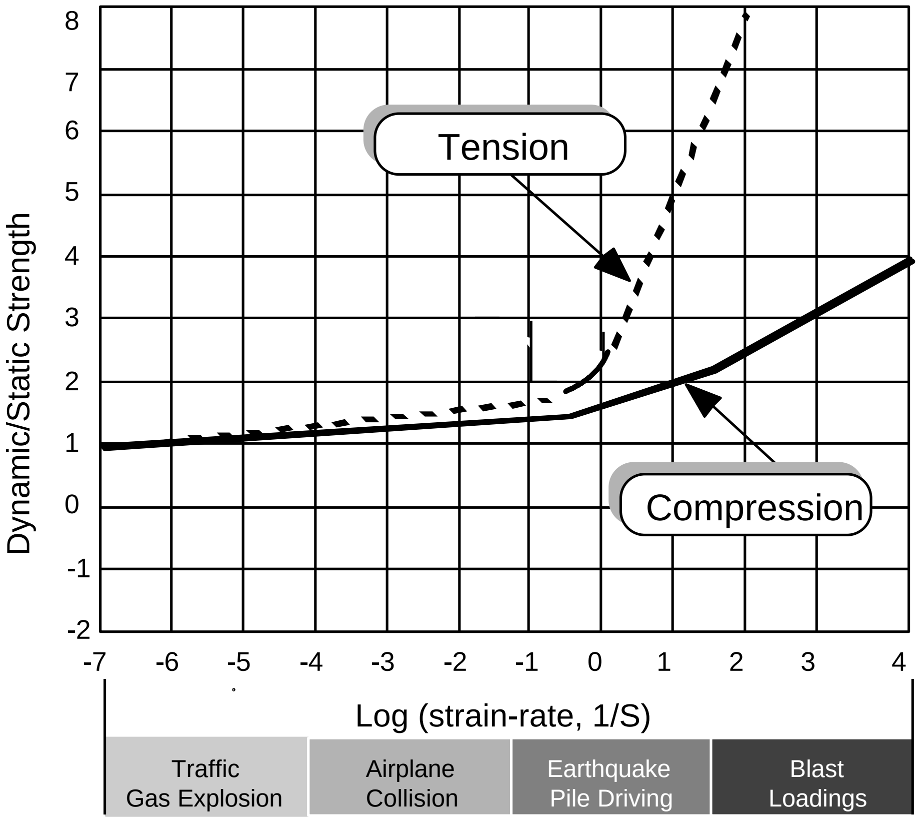


Figure 2. Stress vs. strain rate. The physical significance of events as related to the rate behavior of metals.

However, to understand the wave propagation events the very same properties which are being sought must be known in order to input these parameters into the constitutive equations which are to be determined. Understanding all three events must, therefore, be synthesized in order to both understand and quantify dynamic effects. In addition, it is necessary in the design of experiments to clearly delineate between material and structural response (Harding, 1986). Some considerations in this regard are

- Material Response: Identified by insensitivity with respect to load
- application and specimen geometry

- Structural Response: Identified by sensitivity to both specimen geometry and material properties.

The aspects of dynamic testing related to characteristic loading times and strain rate regions have been described by Lindholm (1971) and are shown in Figure 3. This diagram shows the method of loading, strain rate regime, and the important dynamic events needed to be considered for testing in the specified regime. The dynamic test methods described can be used for obtaining data such as

- Dynamic Strength
- Dynamic Modulus
- Fracture Toughness
- Fracture Surface Energy
- Fracture Behavior
- Failure Mechanisms
- Properties Degradation
- Pulse Attenuation
- Notch Sensitivity

For strain rates exceeding 1/sec, which can be considered as an initial starting point for evaluating dynamic load effects as related to material rate sensitivity, the following types of tests have been used:

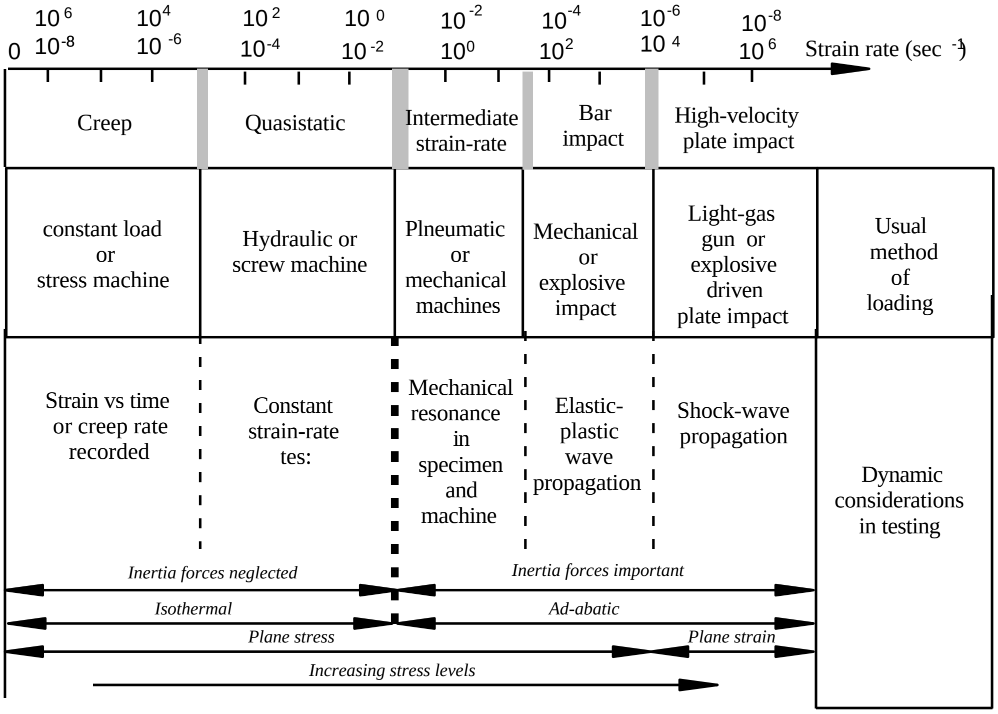


Figure 3. Dynamic aspects of mechanical testing (Lindholm, 1971)

DYNAMIC TEST METHODS

- Punch Tests
- Izod, Charpy Impact
- Drop Weight Tests
- Hydraulic/Pneumatic Machines
- Hopkinson Pressure Bar
  - compression
  - tension
  - shear
  - flexure
- Flyer Plate

Each of these test methods can be used to describe a certain range of load/strain rates and each technique can be used to obtain particular information on the dynamic response and behavior of materials. Some specific comments on each of the test techniques follow.

Punch Tests are related to loading rate and generally used on beam and plate type specimens. Information obtained from such tests is related to the maximum punch load for a given speed of load.

Charpy/Izod Tests are related to loading rate and generally used on beam specimens which may be notched or unnotched-notched. Such tests are often used as part of a standardized testing program for obtaining information on material energy absorption, notch sensitivity, and the type of failure/fracture occurring in the material.

Drop Weight Services are related to loading rate and are generally used on beam and plate type specimens. Data obtained relates to material energy absorption, fracture toughness, failure mechanisms, and notch sensitivity.

Hydraulic/Pneumatic Devices test material strain rate sensitivity in specimens loaded in a uniaxial test mode. Data obtained from such tests in addition to material rate sensitivity include mechanical properties and material failure modes.

Hopkinson Pressure Bar Tests are used in a tensile, compressive, torsion or flexure mode of loading. Data obtained for such tests include information on material strain rate sensitivity, stress plus shaping, constituent properties, dynamic ultimate stress, fracture mechanisms, constitutive equation modeling, pulse attenuation and damage initiation.

Plate Impact/Flyer Plate Experiments are performed at very high loading and strain rates. Data obtained from these tests include information on spell information, failure processes, material properties degradation, stress wave induced damage, and constitutive modeling parameters.

Of the test techniques cited, pressure bar tests represent one of the most widely used test techniques for investigating the strain rate sensitivity of metals and composite materials. However, a number of the test methods described (see Figure 1) are needed in order to develop information on the shape changes occurring in the stress versus strain rate curves. In examining the dynamic test methods cited, punch type tests, Izod/Charpy

Impact tests, and drop weight tests—which are related to information generation in the region of the knee of the stress versus strain rate curve—are all run at controlled loading rates rather than directly identifiable strain rates. Furthermore, each of these test methods is performed upon a certain type of specimen configuration which includes specimen size, shape, and boundary supports. On the other hand, hydraulic/pneumatic devices, Hopkinson pressure bar, and flyer plate tests provide data at the high end of the strain rate curve. Thus, there is a need to develop test techniques which can provide information in the intermediate (knee rate) of the stress versus strain rate curve or alternatively to develop a relationship between loading rate to strain rate for existing tests. One suggestion in this regard is to introduce a dynamic stress parameter akin to damage numbers introduced by Johnson (1970) for Taylor type tests. It should also be noted that in testing advanced composite materials, care must be exercised in the selection of an appropriate specimen design. For example, in the case of a dynamic pressure bar test on a metallic based material in a tensile mode of loading, a traditional threaded cylindrical test specimen would be suitable (Figure 4). However, for a composite material specimen, the machining of fibers in a threaded type specimen would introduce fiber effects which could significantly alter the resultant data. Thus, a non-threaded type of specimen, depicted in Figure 5, has been introduced as a test specimen. This type of test arrangement requires that an examination of the changes introduced into the pressure bar should be considered in evaluating the data obtained.

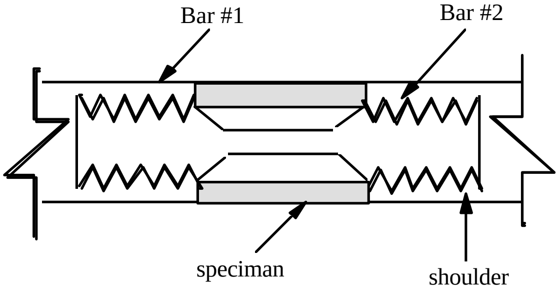


Figure 4. Threaded, un-notched specimen (Nicholas, 1981)

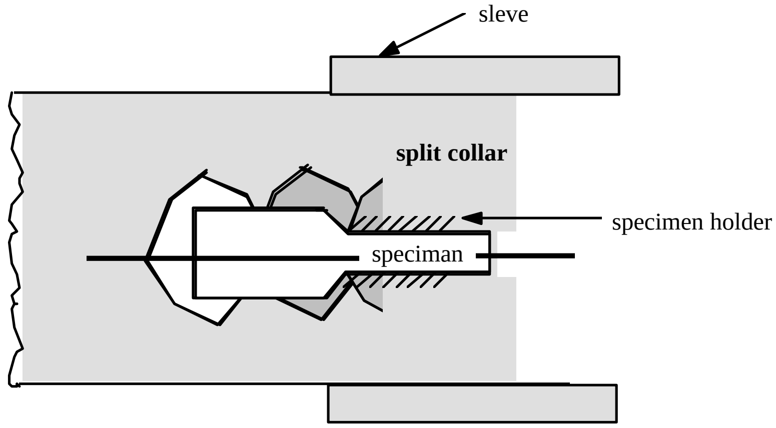


Figure 5. Non-threaded, un-notched specimen (Ross, et al., 1984)

Some typical stress versus strain rate data obtained for a metal and composite material are shown in Figures 6 and 7. Figure 6 shows strain rate effects in iron tested in a shear mode of loading, while Figure 7 shows strain rate effects in a W-Cu composite tested in a compression mode.

DEVELOPMENT OF CONSTITUTIVE MODELS

Metals

Elementary constitutive models relating stress to strain are generally independent of loading rate and history of loading. The relative complexity of such models depends upon the application of the model to a specified problem as well as the availability of experimental data and the degree of sophistication needed in order to describe the behavior of the material. For example, a specific application may require information on only the dynamic yield stress of the material which can be obtained from Taylor impact tests. Alternately, requirements of certain computer codes can require a complete description of the behavior of a material. Stress will, in general, be dependent upon strain, strain rate, temperature, and history of loading, however, a specific application may not require a complete and sophisticated description of material behavior. Thus, an assessment of the degree of sophistication to be used in material model sections is needed on an application basis. This, in turn, focuses attention on what—if any—dynamic material properties may be needed for a solution on an available basis or as to be determined from experiment. A desirable goal in dynamic modeling, therefore, is the development of a widely applicable model which has the following attributes:

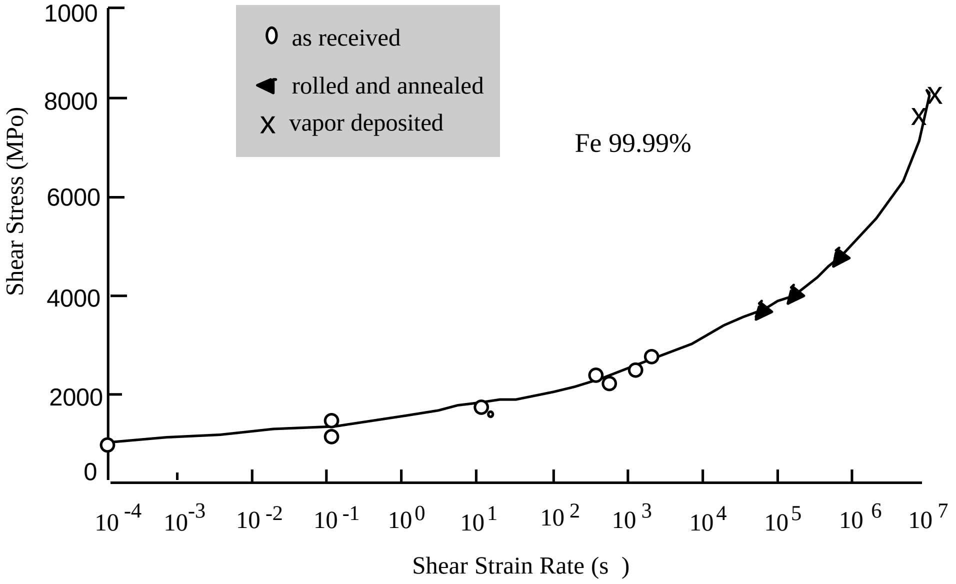


Figure 6. Shear strain rate sensitivity of high purity iron (Klopp, et al., 1985)

- Captures the dynamic behavior of the material
- Is mathematically traceable and computationally principle
- Minimizes the required parameters to be obtained from experiments

Since the models developed have been based on observations related to metals, the subsequent discussion summarizes the salient features of such models.

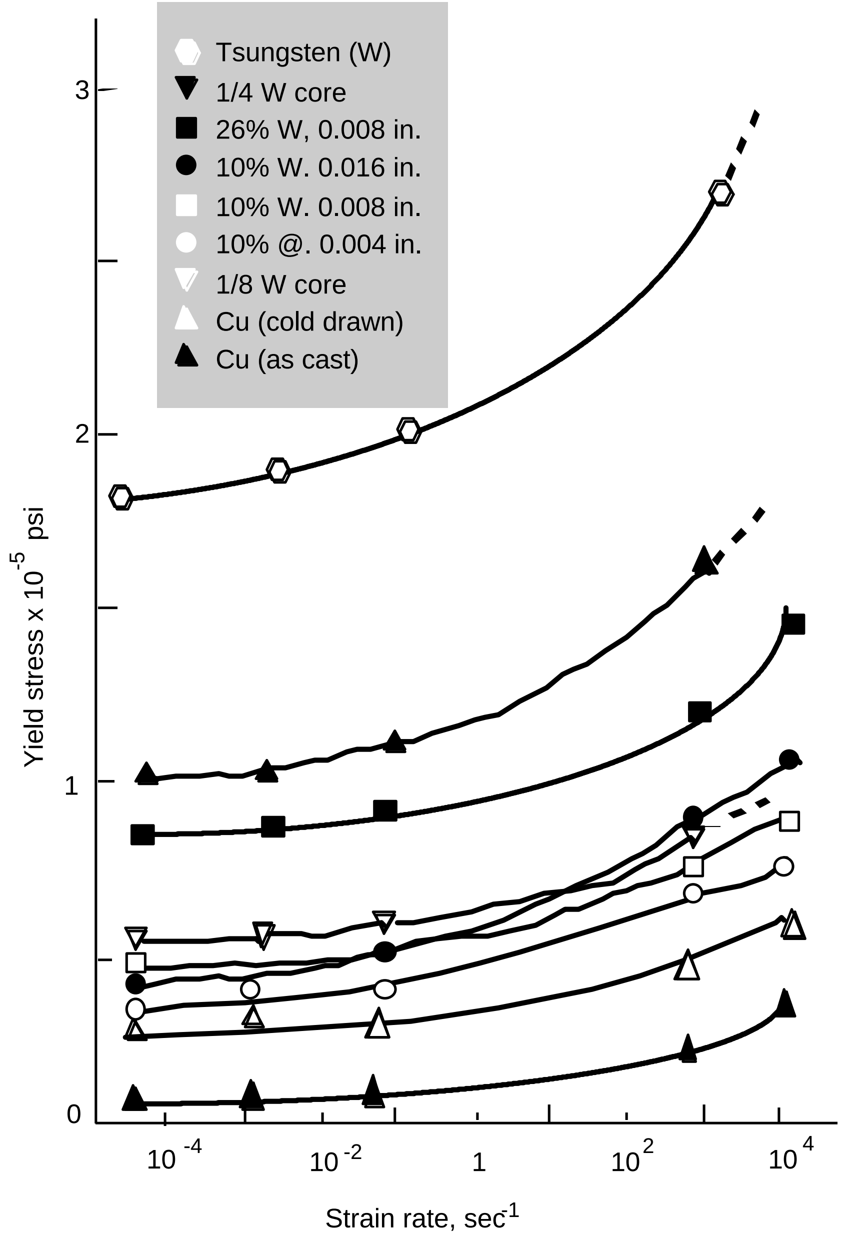


Figure 7. Stress-strain rate curves for Cu-W (Ross and Sierakowski, 1971)

In general, constitutive equation development can be classified by constitutive equations involving internal state variables and those which contain no internal state variables. The latter type equations can be expressed in terms of the gradient of a potential function, this form leading to a connection with a thermodynamic formulation. A brief discussion of some of the key constitutive models describing the behavior of materials subjected to one-dimensional and multiaxial stress states follows. For one-dimensional stress states, the following table of models is introduced

One-Dimensional Models

Model	Key Parameters	Reference

$\sigma_y \sim \tau_o$	Material Yield Strength	Nicholas (1982
$\sigma \sim \tau_o (1 + C \log \dot{\varepsilon})$	Material Yield Strength/Strain Rate	Lindholm (1964)
$\sigma \sim A\varepsilon^n \left[1 + mla\left(1 + \frac{\dot{\varepsilon}}{B} \right) \right]$	Material Yield Strength/Strain Rate Temperature Strain Hardening	Campbell (1977)
$\sigma \sim (A + B\varepsilon^n)$ $(1 + C_{\ln}\dot{\varepsilon}) \ \ (1 - T)^m$	Material Strain Material Strain Rate Temperature	Johnson/Cook(1985)

Further refinements of one-dimensional models have been advanced on the basis of physical processes such as dislocation dynamics to explain the temperature and strain rate behavior of materials. Other physical processes, such as thermally activated mechanisms which are prevalent at low temperatures and intermediate strain rates, have been incorporated analytically in terms of Arrhenius-type relations. For example, the following form of such an equation as introduced for pure aluminum, is given by

$$\dot{\varepsilon} \sim \exp(\beta\sigma) \ \ \exp(-Q / RT)$$

Other forms of the equation based on dislocation dynamic concepts which also account for strain, strain rate, and temperature effects in a coupled manner have been discussed by Zerilli and Armstrong (1987). Forms of these equations for fcc and bcc metals take the form

$$\text{(fcc)} \quad \sigma \sim C_o + C_2\varepsilon^n\left[\exp(-C_3T + C_4T\ln\dot{\varepsilon})\right]$$

$$\text{(bcc)} \quad \sigma \sim C_o + C_1\left[\exp(-C_3T + C_4T\ln\dot{\varepsilon})\right] + C_5\varepsilon^n$$

Still, other refinements have been advanced to include strain rate history effects. Such a formulation has been advanced by Campbell *et al.* (1977) in the form

$$\sigma = A\varepsilon^n + mA\varepsilon^n \ln\left(1 + \frac{\dot{\varepsilon}}{B}\right) + mA(\varepsilon - \alpha)^n \ln\left(1 + \frac{\dot{\varepsilon} - \alpha}{B}\right) - mA(\varepsilon - \alpha)^n \ln\left(1 + \frac{\dot{\varepsilon} - \alpha}{B}\right)$$

The right hand side of the above equation can be described as follows

- The first term represents the flow stress in a vanishingly small strain rate test.
- The second term represents the overstress at a constant plastic strain rate $\dot{\varepsilon}$.
- The third and fourth terms represent the history effect.

A number of three-dimensional models have been advanced in recent years and have been discussed by Nicholas and Rajendran (1990) and Meyer (1992). Among these models, the state variable model of Bodner and Partom (1975) is representative of a class of unified viscoplastic models. This three-dimensional constitutive model incorporates a number of important features including the modeling of a broad range of loading histories, easily determined parameter values, and adaptability to numerical codification. This model has been used to describe material response to suddenly applied loads but also cyclic and time dependent loading conditions. Thus, this model has the feature of covering strain rate over the range from 10^{-6} *to* 10^{3}/sec. The major features of the model are described and presented for reference.

The total strain rate is assumed to be decomposable into elastic and inelastic components.

$$\dot{e}_{ij} = \dot{e}_{ij}^{e} + \dot{e}_{ij}^{p}$$

Both of the above components of strain rate are non-zero for all loading and unloading conditions. The elastic strain rate is related to the stress rate through the technical engineering constants, while the inelastic strain rate is assumed to be a function of the stress σ_{ij} and a state variable z. The flow rule introduced by Prandtl and Reuss is used to relate the deviatoric plastic strain rate to the deviatoric stress components according to

$$\dot{e}_{ij}^{p} = \dot{e}_{ij}^{p} = l\, S_{ij}$$

The second invariant of the plastic strain rate and second invariant of the stress tensor are introduced as

$$D_2^p = D_o^2 \exp\left[-\left(\frac{Z^2}{3J_2}\right)^n \left(\frac{n+1}{n}\right) \right]$$

where D_o is the limiting value of the plastic strain rate in shear, and n is a parameter relating to strain rate sensitivity. The parameter Z is a measure of the overall resistance of the material to plastic flow that is plastic work, and depends upon the loading history

Introducing these expressions into the plastic stress rate can be expressed in the following form

Bodner-Partom Model

$$\dot{e}_{ij}^{p} = D_o e^{\left(-\frac{(n+1)}{n}\left(-\frac{Z^2}{3J_2}\right)\right)^n} \frac{S_{ij}}{\sqrt{J_2}}$$

$$\dot{Z} = m(Z_1 - Z)\dot{W}_p$$

D_o = is the limiting strain rate; n is strain rate sensitivity parameter
m = strain hardening parameter
Z_o and Z_1 = initial and saturated values of the internal state variables Z
Z = resistance to plastic flow and loading history dependency
n = temperature dependent constant
W_p = plastic work

A summary of the parameters used in the Bodner-Partom model is included below.

Bodner-Partom Model Constants

	Z_0	Z_1		m_0	m_1

Material	(GPa)	(GPa)	n	GPa^{-1}	GPa^{-1}	α	A	B
C1008 Steel	5.5	7.0	0.4	15	0	0	0.245	46
HY100 Steel	2.4	3.6	1.2	10	0	0	NA	NA
1020 Steel	0.64	0.93	4.0	30	0	0	NA	NA
MAR-200 Steel	2.2	2.4	4.0	5	0	0	NA	NA
Armco Iron	2.65	4.2	0.58	56	0	0	NA	NA
OFHC Copper	0.8	6.6	0.4	11	150	1500	NA	NA
6061-T6 Aluminum	0.45	0.55	4.0	120	0	0	-2.86	2343
7039-T64 aluminum	0.56	0.76	4.0	28	0	0	NA	NA
Pure Tantalum	1.3	3.1	0.74	20	0	0	NA	NA
W-2 Tungsten	8.75	10.0	0.58	150	0	0	0.166	134
Nickel 200	0.32	0.82	4.0	40	0	0	NA	NA
MAR-250 Steel	2.5	2.7	5.0	20	0	0	NA	NA
AF1410 Steel	2.4	2.75	5.0	15	0	0	NA	NA

Note that the effect of temperature on flow stress defined by the parameter n is calculated based upon experimental evidence, suggesting a relationship of the form

$$n = A + B/T$$

For strain rates above 1000/sec for metals, a number of investigators have noted a significant increase in flow stress above this threshold limit. Thus, data in the high strain rate regime has been described by an equation of the form,

$$s = s_b(e) + b\dot{e}$$

where the constant β may or may not be a function of strain. In general, experiments at strain rates in excess of 10^4/sec are difficult to perform and a common approach has been to extrapolate the above equation beyond the region over which it has been fit. Several investigators, such as Follansbee *et al.* (1984), have suggested that specific physical mechanisms for particular metallic materials control the deformation process.

Composites

Constitutive equation development for composite materials is extremely limited as compared to metals. In fact, that which has been discussed is of recent vintage and based upon a derivative of experience with metals. For a thermoplastic composite AS4/PEEK(APC-2)/ Weeks and Sun (1995) have constructed a rate-dependent model covering the strain rate range from 10^{-6} to 10^3/sec. This rate-dependent model was evolved from a one parameter plasticity model introduced earlier by Sun and Chao (1989) and is based upon a modified form of the Johnson *et al.* (1983) rate-dependent model.

For the composite material studied, and considering room temperature, the model introduced was of the form

$$s_x = s_x^* \left[1 + C_{\ln} \frac{\dot{e}_x}{\dot{e}_x^*} \right]$$

where $\sigma^{*}_{x1}, \dot{\varepsilon}^{*}_{x}$ represents the stress and strain rate in the loading direction for the reference strain rate, and C is an experimentally determined constant. The strain rate dependency on temperature was considered negligible and the prediction of stress is made at each corresponding strain from the reference strain rate to the desired strain rate.

For material response in the strain rate regime 10^4-10^5/sec. some studies by Espinosa *et al.* (1995) have been made on glass reinforced plastics. These studies have been based upon a viscoplastic model proposed by Argon (1973) to model glossy polymers. A feature of this model is the notion of overcoming the intermolecular resistance of the amorphous polymer in reducing plastic flow. Using plate impact shear experiments, a plastic strain rate equation of the following form has been suggested,

$$\dot{\gamma}_p = \dot{\gamma}_o \exp\left[-\frac{A\hat{s}}{\theta}(1-\frac{\bar{\tau}}{s})^{5/6}\right]$$

where

$\dot{\gamma}$ = shear strain rate parameter
A = constant related to activation volume divided by Boltzmann's constant
θ = absolute temperature
$\hat{s}$ = $(s+\alpha p)$ a pressure dependent thermal shear strength
$\bar{\tau}$ = effective shear stress

For high strain rates, an equation of the form

$$\sigma = \sigma_o + \beta\dot{\varepsilon},$$

as previously introduced for metals, has been used by Powers *et al.* (1995) to evaluate the strain rate behavior if a large number of composite materials, including

- Unidirectional E-glass/epoxy
- Random non-woven glass/polyester
- Unidirectional T40/ERL 1908 graphite/epoxy
- Unidirectional AS4/350/ graphite/epoxy
- Quasi-isotropic A54 cloth/3501 graphite/epoxy
- SiC/Al
- C/Al

FAILURE MODELS

Metals

Failure of materials subjected to dynamic loads is an important aspect of material characterization. This feature can involve complete material separation to changes which can occur in the stiffness and flow properties of the materials. Such processes have been studied for metals over the past several decades for both brittle and ductile materials. In general, dynamic failure processes are strongly influenced by the state of stress, the strain rate, and loading history. As an example, consider the ductile failure processes for the following two events:

- Uniaxial strain associated with plate impact
- Uniaxial stress associated with an expanding ring

The failure processes for these two events differ significantly. For example, in the uniaxial strain state, the stress state is triaxial while in the uniaxial stress state, the strain state is triaxial. The failure process in turn is represented by a uniaxial strain state and is related to nucleation, growth, and coalescence of microvoids and microcracks. For the uniaxial stress case, failure is controlled by initial flaw distributions and material imperfections.

These observations indicate that dynamic effects can play an important role in the ductile failure process. Furthermore, the complexity of the process prevents difficulties in the identification of the various mechanisms of failure as influenced by inertia, adiabatic heating and strain rate as well as to what extent each of these factors may play a role in the failure process. A definition of the particular type of damage and development of a linkage between the microscopic definition of damage and macroscopic definitions is needed. For ductile materials, the fundamental failure mechanism related to dynamic fracture considers the failure process as being initiated by nucleation of voids around inclusions, and their subsequent growth and coalescence. Approaches taken to examine such processes in ductile materials include micro-statistical, empirical based on physical observations, and continuum mechanics approaches.

Another important failure process in dynamically loaded ductile metals is related to the formation of localized instabilities exemplified by the formation of shear bands and their subsequent growth. Shear banding is observed to occur in metals subjected to high velocity deformations. Comprehensive reviews of this process have been presented by Rogers (1979) and Wright (1987). Shear bands occur as a major damage mechanism under high compressive and shear deformation rates, unlike tensile loading which tends to be controlled by void nucleation and growth, which prevents local deformation and shear banding.

Shear band modeling, in general, considers either a microscopic continuum damage or the nucleation and growth of shear bands, as macroscopic failure zones. Two distinct categories which are used to describe the shear banding phenomena are

> <u>Continuum Mechanics Approach</u> A single microscopic shear band is considered within an infinite or finite block of material. The treatment is macroscopic and relies upon satisfying applicable conservation laws and imposed

boundary conditions. The constitutive behavior of the material is important in this formulation.

Microscopic Approach: A number of shear bands in a plastic flow field is considered and emphasis is placed as developing equations that govern the nucleation and growth of these microscopic shear bands.

Such approaches have been discussed by Clifton (1984), Wright (1987), and Curren (1987).

For brittle materials, several approaches have been employed describing the failure of such materials under tensile and compressive loading.

Approaches

- Material stresses calculated using Hooke's law and failure predicted using a generalized Griffith criteria;
- Material behavior represented as an elastic-plastic solid with the stress-strain behavior is described using plasticity based models;
- Fracture mechanics based theories used to describe the failure process with modeling based upon a combination of fracture and continuum damage mechanics concepts.

Some global features of failure models introduced to describe the behavior of brittle materials subjected to dynamic loading are noted in the accompanying table.

Model Source	Rate of Loading	Tension Model	Compression Model	Strain Rate Effect	Pressure Effect
Seaman *et al.*, (1976)	Dynamic	Micro-statistical	None	Yes	Yes
Grady/Kipp (1980)	Dynamic	Microcrack	None	Yes	Yes
Taylor *et al.* (1986)	Dynamic	Microcrack	Plasticity	Yes	Yes
Margolin (1983a,1984b)	Dynamic	Microcrack	Microcrack	Yes	No

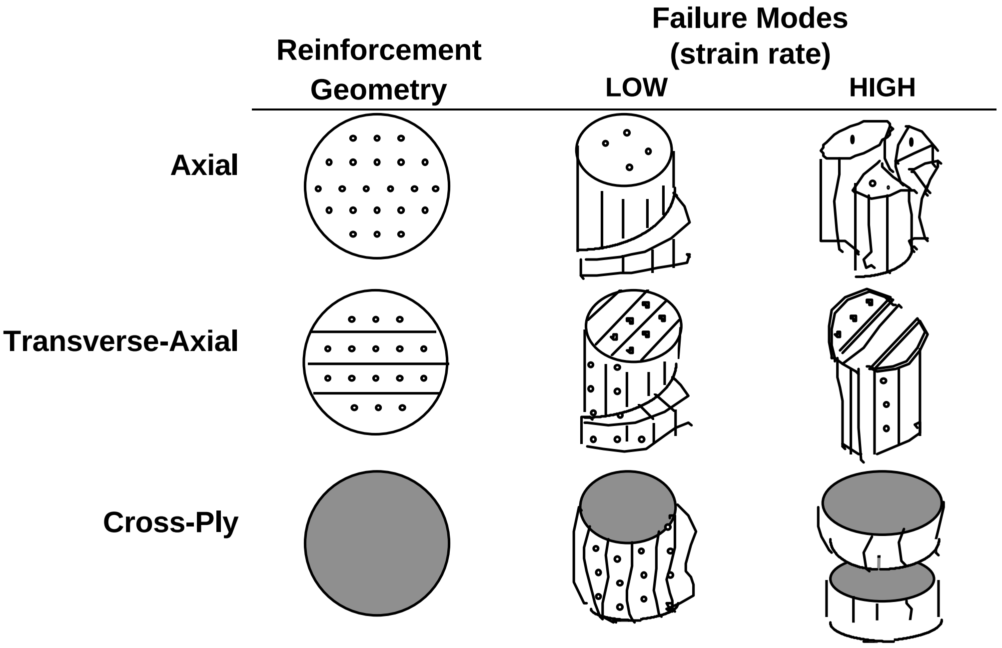
For the most part, failure models for brittle materials require several important features, including

- A definition of damage
- A description of degraded moduli
- Microcrack distribution
- Microcrack growth laws
- Microcrack coalescence

In addition to the above features, failure models should include the effects of strain rate, pressure, temperature, and observed loading history effects as related to the deformation and fracture of brittle materials.

Composites

Failure of composites, and in particular advanced composites, is a complex issue due to the multiphase nature of the material. The fundamental mechanisms as well as the failure/fracture modes of such materials is simply not well understood and remains a research task. For instance, failure modes generated from experiments run on carefully fabricated steel-epoxy composites tested at both low and high strain rates in a compressive loading mode, are shown below (Sierakowski, *et al.*, 1970).



The failure modes displayed clearly show the differences exhibited between low and high stress rates with the observation that a failure relation between the two distinct rates cannot be reconciled. While the results shown are representative of the macroscopic failure modes occurring, additional complexities occur at the microscopic level, that is, failure within the matrix at the matrix/fiber interface and breakage of the fibers. These features, and the order in which they occur, are suited to a probabilistic approach for assessing the contributions of the various types of damage. For example, the probability of matrix cracking occurring, associated with a particular crack direction, the density of the cracks distribution, and the growth and coalescence of cracks are all unknown. This type of approach for examining the dynamic fracture process in brittle composites follows recent developments on failure process modeling as introduced and based upon the existence of a randomly distributed crack network in the material (Chen, 1988). The array of randomly distributed cracks does not focus on modeling each individual crack but rather the growth and interaction of cracks as an internal state variable which is representative of the accumulation of damage in the material. A damage metric is used to indicate the degradation in material stiffness and, for an isotropic elastic medium, can be analytically expressed by

$$\overline{K} = K(1 - D)$$

where K and $\overline{\mathrm{K}}$ are the bulk moduli for the undamaged and damaged states, respectively. In attempting to transfer this model from an isotropic to an anisotropic medium, the complications occurring in the directionality of the bulk moduli becomes evident, as is the orientation and contribution of damage associated with the directionality of each of the material bulk moduli.

It is consequently a research task initiative to understand the damage mechanisms, their growth and coalescenc, for specified modes of loading, which is required for composite materials.

CONCLUDING REMARKS

A description of dynamic test methods developed for obtaining high strain rate data on the mechanical response of metals and composites has been discussed.

For metals, a relatively large data base exists on high rate behavior, however, it is not collected in concentrated sources but rather scattered throughout the literature. Also, experimental techniques, as currently developed, appear adequate for current materials as well as those yet to be characterized under high rate loading conditions. For composites information on strain rate behavior and the design of experiments to obtain high rate data is a research task. This is due to the multiphase characteristic of composites. While rate dependent data for non-metallic matrices has been studied, less information is generally available on the rate dependency of the fiber phase of composites due to the inherent difficulties in the testing of filaments and fiber bundles. The characterization of the constituents is indeed important to assessing the performance of composites of the fiber reinforced type, however, the complex interaction occurring between the reinforcing fibers and matrix phase results in difficulties in assessing the rate dependency of the constituent phases. This type of complex behavior has been noted as for example that as the rate of loading is increased, the corresponding failure mode changes. So, while some progress in extending dynamic techniques to composites and developing new rate dependent tests for composites has been made, assessing the mechanical behavior of composites will rest with the ability to clearly distinguish the response mode of the specimen tested, that is, to specifically note the geometrical and material properties features associated with the tested specimens. At issue are such important factors as the processing variables involved in specimen fabrication, quality control of same, role of the fiber/matrix interface, environmental conditioning of the specimens, and selection of individual constituent phases, or the respective matrices/fibers selected for study.

The development of constitutive models for metals subject to dynamic load has progressed over the years such that current models incorporate the features observed experimentally and data for the constitutive model appropriate to the range of strain rates encountered in reality. The situation for composites is an evolving research task with some models advanced for metal matrix composites as a derivative of the performance of metallic materials. For non-metallic composites, the information base is sparse.

Although the introduction of failure models for ductile and brittle metals has advanced, further studies on the microstructural behavior of metals is needed. Further in-depth studies relating to consideration of energy release mechanisms at the microscopic level (including all forms of energy and heat) need to be considered. For fiber reinforced composites, bond and shear effects at the interface have a different behavior than do traditional materials, thus, dynamic mechanistic principles should be different for such materials, as would be the failure process. In particular, for fiber composites, local instabilities would appear to be a significant mechanism. To investigate the failure of such systems modern statistical methods such as percolation theory and fractal concepts may be useful.

In summary, of the areas discussed, the following table simplistically indicates the current state of the art.

Issues	Metals	Fiber Composites
Strain Rate Data	Available	Evolving
Constitutive Models	Available	Research Task
Failure Processes	Evolving	Research Task

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