NISTIR 6236

Standard Test Methods and Data for Modeling Crashworthiness

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Prepared by:
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Background

Major research efforts within the US auto industry are driven by the need to reduce the weight of future vehicles to meet USCAR and PNGV goals. This can most readily be accomplished by the substitution of lighter-weight materials and structures for those currently used. However, this substitution must be made with no reduction in the current level of safety for the occupants. DOE and DOT have models that predict the behavior of vehicles involved in a crash. Use of models greatly facilitates the determination of crashworthiness compared to actual crash tests. Many more tests parameters can be investigated in less time and at greatly reduced cost. To be realistic, these models require accurate and extensive data on the material structures which make up a vehicle.

Introduction

This report determines what data are typically needed for models predicting crash behavior, reviews the methods available to obtain such data, and identifies standard test methods that need to be developed to supply these data. The data needed are those required to run finite element codes that can credibly predict structural behavior under crash conditions. The review of test methods includes both standard test methods and informal industrial and academic test methods that have not been standardized. This review has been done by searching NIST's Standards Library and by contacting leading experts and research groups in the field. Proprietary methods have not been included.

Data Needs for the Prediction of Crashworthiness

The material and structural behavior that is of interest in a crash [1] is listed below:

Elastic Behavior
Plastic Behavior
Fracture Behavior
Bending
Bulging
Tension
Compression
Shearing
Multiaxial Stressing and Straining
Strain-to-fracture (forming limits)
Buckling Instabilities
Energy Absorption
Fracture Toughness
Joint Strength
Friction

Not all of these need be measured. For instance, bending behavior can be predicted in principle from a knowledge of elastic, plastic, and fracture behavior in tension and compression. In fact, that is what finite element programs do in complex deformation situations, using data from simple tests like uniaxial tension tests. An examination of two powerful finite element codes, LS-Dyna3D* [2] and Abaqus [3], provided a list of materials properties which are needed to predict the above behavior and thus structural behavior under crash conditions:

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*The names of specific products and companies are included for completeness and identification purposes only and do not constitute endorsement by NIST.

1.) Elastic Properties - Young's Modulus, Shear Modulus, and Poisson's ratio.

2.) Plastic Properties - Yield strength (variously defined), ultimate tensile strength, workhardening (variously defined), strain rate sensitivity, stress-strain curve, r-ratio.

3.) Failure Properties - Strain-to-fracture, fracture toughness (indirectly), reduction-in-area.

Multiaxiality issues

Most of the data are uniaxial. The FEM codes use assumptions or other measurements to extend the results to multiaxial states of stress. No critical assumptions are needed for elastic deformation. For plastic deformation, the hardening occurring past yield is assumed almost universally to occur by enlarging the von Mises ellipse in a self-similar manner in stress space [4]. Other possibilities exist [5] and are probably closer to reality. However, little information on these advanced hardening models is ever available and they are rarely implemented. For crashes, this is not so important because loading is probably nearly proportional, i.e. radial in stress space, and unloading and reloading behavior is irrelevant. What may be important are changes in the shape of the yield surface with strain. If vertices form or other significant changes in curvature take place, accelerated thinning or strain localization may result with a corresponding reduction in strain to tearing or fracture.

With regard to failure under multiaxial stressing or straining, the commonly adopted approach is to use the forming limit diagram [6] which plots the failure locus as a function of strain state. It can be used as an end point in FEM analyses much as the uniaxial strain to fracture is used to indicate to the code when material separation should begin. In the absence of measurements there is no way for any code to identify this point and assumptions like the von Mises ellipse for plastic yielding are extended to fracture, based on the uniaxial behavior.

Strain rate issues

Assuming an upper speed of about 40 m/s, stopping in about 1 meter, an average strain rate of about 40 per second is obtained. There will clearly be situations in which the strain rate is higher or lower, but 40 per second represents an order of magnitude estimate and applies to major energy absorbing events like panel crumpling. All properties used in FEM codes to predict crash behavior must be appropriate for this strain rate range. While elastic properties determined quasi-statically will not change significantly at these rates, plastic and fracture properties are notoriously sensitive to rate. In the absence of measurements at crash relevant rates and since a spectrum of rates occurs in a crash, some material model (e.g., Johnson-Cook [7], Perzyna [8] or Bodner-Partom [9])must be used in FEM to permit estimation of plastic properties at one rate from data obtained at other rates. These models work quite well, but it would seem best if the data used to evaluate them were measured at rates near those for which the models were to be used. Estimation of fracture properties at different rates is not well formulated at this time and must rely on measurements at the appropriate rate.

Temperature issues

For most cases, the properties available to crash simulations would be measured at standard temperature and pressure (20° C and one atmosphere). While high rate deformation results in heating (and FEM analyses can estimate it based on plastic work dissipation), this effect is implicitly included in the testing so these properties would not have to be altered. Fracture at low temperatures might be an issue if brittle fracture were possible. Some engine components may be hot and it would be appropriate to use the expected temperature for these components. Many constitutive laws use an Arrhenius type correction for temperature effects. While satisfactory for aluminum alloys, this is not appropriate for most steel components as they exhibit temperature insensitivity or even strength increases for temperatures 100-200° C above room temperature. However, the range of temperature variation is likely to be small compared to other effects and will not be addressed further.

In consideration of the above, the properties most needed by crash test simulations and most sensitive to the conditions of measurement are the plastic and fracture properties. The search of standard test methods focussed on these with particular attention paid as to whether the method covered rates relevant to crash conditions.

Standard Test Methods

Publications of the following standards organizations [10-16] were searched for materials properties test methods relevant to crash conditions:

AMERICAN NATIONAL STANDARDS INSTITUTE [10]
AMERICAN SOCIETY OF MECHANICAL ENGINEERS [11]
AMERICAN SOCIETY OF TESTING AND MATERIALS [12]
AMERICAN WELDING SOCIETY [13]
INDUSTRIAL FASTENER INSTITUTE [14]
INTERNATIONAL STANDARDS ORGANIZATION [15]
SOCIETY OF AUTOMOTIVE ENGINEERS [16]

In addition, discussions were had with individuals familiar with approriate federal codes, regulations, and standards, and military specifications. Also, discussions were had with a member of the North American Deep Drawing Research Group. The results of this search is compiled in Appendix A. Strictly speaking, the only standard test method that permits measuring any of the desired properties at strain rates close to 40 per second is ASTM E209, Compression Tests of Metallic Materials at Elevated Temperatures with Conventional or Rapid Heating Rates and Strain Rates. While testing sheet metal in compression would be challenging, this standard could be used on thicker components. This standard does not have an upper strain rate limit, although it suggests that rates not exceed 0.083 per second. In contrast, the frequently used ASTM standard E8 [12] does not permit testing steel above a strain rate of 0.00006 per second up to yield. After yield, the rate may be increased to a maximum of 0.01 per second. Many of the other standards permit variation in the testing rate, but these rates are all quasi-static. A high rate standard is the most pressing need. Simply extending the permitted rate of testing of uniaxial stress/strain response would provide a great improvement. However, the testing equipment and data collection systems would probably be quite different from what now satisfies the standards. Also, the tests are almost entirely uniaxial in nature.

There are several standard tests which could be very useful in characterizing the multiaxial behavior. One is ISO Standard 12004:1997 [15] for measuring the forming limit diagram, i.e. the locus of multiaxial strain states at which material failure begins. Because this method suffers from a lack of specificity, it is not restrictive. Tests can be performed under conditions appropriate to a crash and still satisfy the criteria of this standard test method. Another test method (ASTM D4173 [12]) was originally established to rank the suitability of lubricants for various forming operations. This method explicitly permits strain rates up to about 3 per second and includes various multiaxial loading geometries. There is no requirement that a lubricant be used and, so, this method can be used to obtain material properties at high rates (though not high enough for crashworthiness testing) and under multiaxial loading conditions.
The Charpy (ASTM E23 [12]) and dynamic tear tests (ASTM E436 and E604 [12]) are carried out at rates that might be observed in 6.7 m/s (15 mph) collisions and measure the energy absorbed in deforming the material all the way to fracture. There is no way of using this data if the actual material in the car does not fracture, which is often the case. Also, these tests must be performed on gauges of material that would be thicker than normally used in cars.

Besides the published standard test methods, there are commonly used tests for which standards have not been developed. The Hopkinson bar test [17,18] is routinely used for high rate studies. It involves loading the sample by a stress wave and usually takes place at strain rates of 100 per second or higher. The Hopkinson bar and similar stress wave tests like the flyer plate test, the Taylor rod test, the pressure-shear plate impact, and the expanding ring test occur at rates that are on the high end of the range of interest and they cannot be slowed down [18,19]. Quasi-static tests can be sped up and have been. Nadai [20] used a rapidly rotating flywheel to load tensile specimens at rates up to 1000 per second. A similar system has been used successfully for many years at the Materialprufunganstalt in Stuttgart [21]. A commercially available instrument consisting of a swinging pendulum (normally used for Charpy impact tests) has accessory grips for tensile testing [22]. Instumented drop weight testers have measured rapid compressive behavior [23]. Modern servo-hydraulic universal test machines have been fitted with pressure accumulators and tested materials at strain rates up to 100 per second [24]. The cam plastometer [18] has been available since the 1950's to provide constant strain rate tests in axial compression at strain rates up to 200 per second. Thus, while the ability to test materials at rates applicable to crashes have been available for 50 years, no test standards have been developed to assure the validity of the resulting measurements or to limit unwanted effects of various testing parameters on the data.

There are also informal methods for measuring multiaxial behavior. The motivation for most of these methods is to quantify formability of metals. A partial list of these methods follows:

plane-strain compression test[18]
plane-strain tension test[25]
bulge test[18]
elliptical hollow punch test[18]
torsion test[6]
limiting dome height test[18]
stretch bend test[18]
wedge drawing test[26]

The main drawback with these tests is that they have not been standardized. Thus, the performance of these tests is largely up to the researcher. The effect of varying the test parameters is usually poorly known and it is extremely difficult to assess the validity of the measurement.

Standard Test Development Needs

Having reviewed the data needs of crashworthiness prediction methods and standard test methods for material properties, it has become clear that there are no standards for performing tests at rates near the actually occurring conditions that are being simulated. In addition, there are no standard tests for stress or strain states other than uniaxial except ones for determining deformation limits or lubricant effectiveness.

With modern test machines, instrumentation, and data collection systems, there is no reason why existing standard uniaxial test methods cannot be performed at higher rates. The only requirement would be that the equipment operate correctly and in a demonstrably reproduceable fashion at the rates of interest. Thus, a standard practice that could be followed to show that the test equipment functioned correctly at the desired high rates would be of great benefit to those wishing to acquire high rate data. There is such a standard presently available for determining whether a test system has the response characteristics necessary to perform high frequency fatigue and collect the resulting data, i.e., ASTM E467 - Standard Practice for Verification of Constant Amplitude Dynamic Loads and Displacements in an Axial Load Fatigue Testing System [12].

In a collision, two types of behavior dominate: plane-strain bending and bulging of sheet metal. These deformation modes can be described using stress-strain data collected in the quadrants of stress space where both in-plane stresses are of like sign, be it tensile or compressive. A test or set of tests which could characterize material stress-strain behavior in these quadrants and be performed at relevant rates would satisfy the needs of the simulators. Two types of test have been identified in the forming literature which could be used to provide the needed data: the modified plane-strain tensile test (in which the strains are of opposite sign) and the elliptical hollow punch test(in which the strains are of like sign). In the first, a wide sheet of metal with side notches is pulled in uniaxial tension. By varying the geometry, this test can provide data from uniaxial to plane-strain. The elliptical hollow punch can provide data from plane-strain to equibiaxial by changing the eccentricity of the elliptical hollow punch. Thus, all stress/strain states in this quadrant can be characterized. In principle, both tests can be run at rates relevant to crash simulation. While the applied load can be measured in both cases, its conversion to stress in the hollow punch test requires evaluating the effects of friction.

Conclusion

Simulations of automobile crash tests are carried out using finite element analyses. To be realistic these types of analyses use elastic, plastic, and fracture properties data appropriate for the materials involved in the simulation. Of these data, the plastic and fracture data are most critically sensitive to the rate and multiaxiality of the situation. No standard test methods currently exist for providing this data at the rates or all loading conditions required. Parts of some standards appear useful, and there are tests that have not been standardized which would provide the needed data. The following steps would greatly improve the standard test situation for high rate and multiaxial testing and provide consistent means of developing data bases for crashworthiness simulations:

1.) Develop a standard procedure for verifying the correct measurement of load, displacement, and strain as well as data collection at high rates of testing (up to 100/s) similar to the ASTM E467 (Standard Practice for Verification of Constant Amplitude Dynamic Loads and Displacements in a Axial Load Fatigue Testing System). This would permit, in time, many standard test methods to be carried out at high rates.

2.)Standardize a well-known procedure for testing notched sheets to obtain stress-strain data under conditions ranging from uniaxial to plane-strain with the possibility of being performed at high rates.

3.)Standardize a well-known procedure for testing sheet metal to obtain stress-strain data under conditions ranging from plane-strain to equibiaxial strain with the possibility of being performed at high rates.

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APPENDIX A

Standard Reporting Form

- Source of Standard: **ISO**

- Title of Standard Test: **ISO 10113:1991 "Determination of Plastic Strain Ratio in Sheet and Strip Metallic Materials"**

- Summary of Test

This standard summarizes the determination of plastic strain ratio (width strain / thickness strain) in thin sheet and strip materials. A piece of material of unspecified dimensions is loaded in uniaxial tension and strains are measured. Because of the difficulty in measuring thickness strains, a substitute method is given whereby the constancy of volume requirement allows for measurements to be made of thickness and length strains. Formulations are given for accounting for the variation of plastic strain ratio as a function of orientation of the test specimen with respect to the rolling direction in the sheet by calculating average values. The test is invalid for regimes of inhomogeneous deformation or for transverse bowing of the sample. Temperature regime for a valid test is defined as between 10 and 35 degrees C.

- Usefulness of Test to Crashworthiness Prediction

Has the potential to give a parameter critical to crashworthiness simulations, but the accuracy is in question (see below) and slow rates may be a problem.

- Failings of Test

Specific methodology and sample geometries that give homogeneous deformation in sheet materials not specified. Rate effects are totally neglected. Transverse bowing invalidates test, and without a definition of a test geometry that allows a wide section to be tested, this limits the investigator to narrow gage section samples, where edge effects are large. Use of constant volume arguement with loose tolerances for measuring length and width strains gives very poor accuracy in thickness strain determination. Likely source of initial inhomogeneity of plastic strain will be in the thickness direction, and no observational methodology is detailed.

- Comments

Standard could be augmented with a standardized sample geometry.

Standard Reporting Form

- Source of Standard: **SAE**
- Title of Standard Test: **SAE J1882 AUG87, "Method For Evaluating the Cleavage Strength of Structurally Bonded Fiberglass Reinforced Plastic (Wedge Test)"**
- Summary of Test

Standard test for quantifying failure loads and energies in structurally bonded reinforced plastic cleavage plaques. Uses test apparatus described in ASTM D1002.

- Usefulness of Test to Crashworthiness Prediction

- Failings of Test

Only tests specimens at a fixed crosshead speed of 5"/min. This is much too slow for crash situations. Also, fiberglass reinforced plastics are unlikely to be used as major structural members in automobiles in the foreseeable future.

Standard Reporting Form

- Source of Standard: **SAE**
- Title of Standard Test: **SAE J1216 , "Test Methods for Metric Threaded Fasteners"**
- Summary of Test

  For externally threaded fasteners, test provides data for:
  - Product hardness
  - Surface Hardness
  - Proof load
  - Yield strength
  - Axial tensile strength
  - Wedge tensile strength
  - Elongation
  - Reduction of area

  For internally threaded fasteners, test provides data for:
  - Product hardness
  - Proof load

- Usefulness of Test to Crashworthiness Prediction
- Failings of Test
- Comments

Computer Crash Simulations should be compared with results of crash tests using following barrier and rollover tests.

Standard Reporting Form

- Source of Standard: **SAE**
- Title of Standard Test: **SAE J1525 JUN85 , "Lap Shear Test for Automotive-Type Adhesives for Fiber Reinforced Plastic (FRP) Bonding"**
- Summary of Test

Standard test for shear strength of adhesive bond between fiber reinforced plastics to themselves and to metals. Uses test apparatus described in ASTM D1002. Although this test only provides data on peak load values and failure modes, this is probably adequate for computer simulated crash tests.

- Usefulness of Test to Crashworthiness Prediction
- Failings of Test

Only provides for a single pull rate of 0.5"/min. This is much too slow for crash situations. Also, FRP's are unlikely to be used as major structural members in automobiles in the foreseeable future.

- Comments

A modified test may provide useful data for computer simulations of crash tests.

Standard Reporting Form

- Source of Standard: SAE
- Title of Standard Test: **SAE J1863 APR87 "Coach Joint Fracture Test"**
- Summary of Test

Standard test of cleavage strength of adhesive bonded metal sheets. Uses test apparatus described in ASTM D1002. Provides data on peak load values and failure modes for joint fracture. This data is probably adequate for computer simulated crash tests.

- Usefulness of Test to Crashworthiness Prediction
- Failings of Test:

Only provides for a single pull rate of 0.5"/min. This is much too slow for crash situations.

- Comments

A modified test may provide useful data for computer simulations of crash tests.

- Source of Standard: **SAE**
- Title of Standard Test: **SAE J416 DEC83 "Tensile Test Specimens"**
- Summary of Test

Design standards for tensile test specimens for metals. Includes suggestions for "Full Section Test Specimens," "Flat Test Specimens," and "Round Test Specimens." Design specifications are given for specimens of various sizes.

Standard Reporting Form

- Source of Standard: SAE
- Title of Standard Test: **SAE J1523 JUN85, "Metal To Metal Overlap Shear Strength Test For Automotive Type Adhesives"**
- Summary of Test

Standard test for shear strength of adhesive bond between metal sheets. Uses test apparatus described in ASTM D1002. Although this test only provides data on peak load values and failure modes, this is probably adequate for computer simulated crash tests.

- Usefulness of Test to Crashworthiness Prediction
- Failings of Test

Only provides for a single pull rate of 0.5"/min. This is much too slow for crash situations. A modified test may provide useful data for computer simulations of crash tests.

- Comments

A modified test may provide useful data for computer simulations of crash tests.

Standard Reporting Form

- Source of Standard: **ISO**

- Title of Standard Test: **ISO 12004:1997 "Determination of Forming Limit Diagram"**

- Summary of Test

This standard summarizes the basic methodology for experimentally determining the extent of the forming limit diagram. Perform test that produces as uniform as possible a multi-axial strain state in a sheet metal sample. Data to be taken at a point just before necking or other failure. Determine strain state by measuring major and minor axes of pattern marked onto sample prior to testing.

- Usefulness of Test to Crashworthiness Prediction

Could potentially be used as a test to verify FEA codes, as it is relatively simple and axisymmetric. Simulates deformation modes not encountered in crash testing.

- Failings of Test

This standard could be considered the archetype of standards written by large committees that prune to the absolute minimum so that a consesus can be reached. It could essentially be taken word for word from any textbook written on metal forming since the 1960s. Provides no details on how to perform measurements, what tests are valid, etc. Taking a data point prior to failure involves some level of trial-and-error or ESP.

- Comments

Modifications are proposed to the test to allow for compensation for changing sheet thickness within one type of material by moving the curve of the forming limit diagram up or down, but not standardized. This could form the basis, in addition to a set of standardized tests that produce a prescribed set of strain states, of a forming limit diagram test methology. In particular, a metrological apparatus could be developed to give information on multiaxial deformation at all stages of the test.

Standard Reporting Form

- Source of Standard: **ISO**

- Title of Standard Test: **ISO 8490:1986 "Modified Erichsen Cupping Test"**

- Summary of Test

This standard summarizes the procedure for the Erichsen Cupping test of formability. A sphere-tipped punch is pressed through a clamped blank of sheet metal until the blank breaks. The displacement and load at failure are recorded. Temperature range of validity 10-35 degrees C.

- Usefulness of Test to Crashworthiness Prediction

Could potentially be used as a test to verify FEA codes, as it is relatively simple and axisymmetric. Gives data for the biaxial strain state of deforming metal sheet, though over a very small area at the tip of the hemisphere.

- Failings of Test

Limited area of biaxial strain state. Only final conditions at failure are recorded. Rate effects neglected. Overly simplistic.

- Comments

Standard Reporting Form

- Source of Standard: **ISO**

- Title of Standard Test: **ISO 10275: 1993 "Determination of Tensile Strain Hardening Exponent in Sheet and Strip Metals"**

- Summary of Test

This standard summarizes the determination of strain hardening exponent (in the power-law hardening relationship) in thin sheet and strip materials. A piece of material of unspecified dimensions is loaded in uniaxial tension and strains are measured. The strain rate hardening exponent is determined from a plot of ln (stress) versus ln (strain), over either a portion or the entire stress-strain curve. Temperature regime for a valid test is defined as between 10 and 35 degrees C.

- Usefulness of Test to Crashworthiness Prediction

Has the potential to give a parameter critical to crashworthiness simulations.

- Failings of Test

Specific methodology and sample geometries that give homogeneous deformation in sheet materials not specified. Rate effects are not treated, which is probably the biggest failing, as the hardening exponent is extremely rate dependant. Upper limit of rate is 50% of the gage length per minute, which is orders of magnitude slower than strain rates seen in collisions. Transverse bowing invalidates test, and without a definition of a test geometry that allows a wide section to be tested, this limits the investigator to narrow gage section samples, where edge effects are large. Surface finish of the sample specified as important with no upper limit to roughness given.

- Comments

Standard could be augmented with a standardized sample geometry and details on multiple rate tests.

Standard Reporting Form

- Source of Standard: **ISO**

- Title of Standard Test: **ISO 10531:1994 "Earing Test for Metallic Materials"**

- Summary of Test

This standard summarizes the determination of ear heights produced by punching of cups and cans from sheet metal. Specifications are made for die geometries, blank sizes and surface roughnesses. Lubricant standards are to be agreed upon by interested parties.

- Usefulness of Test to Crashworthiness Prediction

Could potentially be used as a test to verify FEA codes, as it is relatively simple and axisymmetric. Simulates deformation modes not encountered in crash testing.

- Failings of Test

Many empirical parameters ("draw ratio as large as possible without tearing risk at the bottom", "lubricant as specified in the relevant standard or by agreement between parties", "blankholder force just sufficient to prevent wrinkling of flange")

- Comments

Standard Reporting Form

- Source of Standard: **SAE**
- Title of Standard Test: **SAE J850 NOV88 "Fixed Barrier Collision Tests"**
- Summary of Test

Specifies conditions and testing requirements for automobile crash tests using fixed barriers.

- Usefulness of Test to Crashworthiness Prediction

Allows validation of crash simulation results.

- Failings of Test

Standard Reporting Form

- Source of Standard: SAE
- Title of Standard Test: **SAE J972 DEC88 "Moving Rigid Barrier Collision Tests"**
- Summary of Test

Specifies conditions and testing requirements for automobile crash tests using moving barriers.

- Usefulness of Test to Crashworthiness Prediction

Allows validation of crash simulation results.

- Failings of Test

Standard Reporting Form

- Source of Standard: **SAE**
- Title of Standard Test: **SAE J857 JUN80 "Roll-over Tests Without Collision"**
- Summary of Test

Specifies conditions and testing requirements for automobile roll-over tests.

- Usefulness of Test to Crashworthiness Prediction

Allows validation of crash simulation results.

- Failings of Test

Standard Reporting Form

- Source of Standard: SAE
- Title of Standard Test: **SAE J996 JUN80 "Inverted Vehicle Drop Test Procedure"**
- Summary of Test

Specifies conditions and testing requirements for vehicle roll-over deformation of roof or roll bar structure.

- Usefulness of Test to Crashworthiness Prediction

Allows validation of crash simulation results.

- Failings of Test

Standard Reporting Form

- Source of Standard: **SAE**
- Title of Standard Test: **SAE J374 MAY91 "Vehicle Roof Strength Test Procedure"**
- Summary of Test

Test to evaluate the strength characteristics of roof systems. The test is intended to provide reliable and repeatable results and to permit numrical comparisons.

- Usefulness of Test to Crashworthiness Prediction

Allows validation of crash simulation results.

- Failings of Test

Standard Reporting Form

- Source of Standard: SAE
- Title of Standard Test: **SAE J367 JUN80 "Passenger Car Door System Crush Test Procedure"**
- Summary of Test

Test to evaluate the capability of passenger car door systems to resist a concentrated lateral inward load.

- Usefulness of Test to Crashworthiness Prediction

Allows validation of crash simulation results.

- Failings of Test

Standard Reporting Form

- Source of Standard: **ISO**
- Title of Standard Test: **ISO 83 Steel - Charpy impact test (U-notch)**
- Summary of Test

Determines energy required to break test bar with u-shaped notch using one blow from a swinging hammer.

- Usefulness of Test to Crashworthiness Prediction

Possibly useful to determine maximum strength of bolts during a crash, but does not provide usable data on deformation.

- Failings of Test

Standard Reporting Form

- Source of Standard: ISO
- Title of Standard Test: **ISO 148 Steel - Charpy impact test (V-notch)**
- Summary of Test

Determines energy required to break test bar with v-shaped notch using one blow from a swinging hammer.

- Usefulness of Test to Crashworthiness Prediction

Does not provide usable data on deformation.

- Failings of Test

Standard Reporting Form

- Source of Standard: **ISO**
- Title of Standard Test: **ISO 898-1 Mechanical properties of fasteners - Bolts,screws and studs**
- Summary of Test

Specifies mechanical tests on bolts, screws, and studs. Tests provide data on:

Tensile strength (using ISO 6892)
Hardness
Maximum load
Strength under wedge loading
Impact resistance

With the exception of Hardness, these tests results could be useful for crash simulations.

- Usefulness of Test to Crashworthiness Prediction
- Failings of Test

With the exception of the Impact resistance test, these tests are conducted at rates deformation rates that are much slower than those encountered during a crash.

Standard Reporting Form

- Source of Standard: **ISO**
- Title of Standard Test: **ISO 898-2 and ISO 989-6 Mechanical properties of fasteners - Nuts with specified proof load values**
- Summary of Test

Specifies mechanical tests on nuts. Tests provide data on:

Proof load
Hardness

- Usefulness of Test to Crashworthiness Prediction

These tests are not very usefull for crash simulations. The proof load test only provides a l o w e r tensile stress limit for failure.

- Failings of Test

Standard Reporting Form

- Source of Standard: **ISO**
- Title of Standard Test: **ISO 3800-1 Threaded fasteners - Axial load fatigue testing - Test methods**
- Summary of Test

Provides probability of survival data on fasteners subjected to N cycles with a specific stress amplitude.

Provides useful data on highly stressed fasteners after cyclic loading as in an engine mount.

- Usefulness of Test to Crashworthiness Prediction
- Failings of Test

Standard Reporting Form

- Source of Standard: ISO
- Title of Standard Test: **ISO 6892 Metallic materials - Tensile testing**
- Summary of Test

Test piece is strained by tensile force, generally to fracture, for the purpose of determining various mechanical properties. Includes specifications for producing test pieces with a wide range of cross sections, including bars, wires, thin sheet, tubes, etc.

- Usefulness of Test to Crashworthiness Prediction

Can provide very useful data on mechanical properties.

- Failings of Test

These standard tests were referred to in the SAE handbooks

ASTM A370
Standard Test Methods and Definitions for Mechanical Testing of Steel Products

ASTM E8
Standard Test Methods of Tension Testing of Metallic Materials

ASTM E517
Standard Test Method for Plastic Strain Ratio r for Sheet Metal

ASTM E646
Tensile Strain Hardening Exponents (n values) of Metallic Sheet Materials

ASTM E643
Standard Method for Conducting Ball Punch Deformation Test for Metallic Sheet Material

Forming Tests (Cup Drawing Tests) that are described but not standardized (3.22 vol. I)

- Swift Cup
- Fukui Conical Cup
- Hole Expansion
- Limiting Dome Height

Standard Reporting Form

- Source of Standard ASTM
- Title of Standard Test: **A370, Standard Test Methods and Definitions for Mechanical Testing of Steel Products**

Summary of Test: The tests described in this standard are the tension test, bend test, hardness test, and impact test. These tests are used to determine properties required in product specifications. The tension test is applied to steel plate, sheet, and bar. It is performed in a manner similar to ASTM E8. The bend tests are performed according to ASTM E190 or E290. The hardness tests are performed according to ASTM hardness test methods. The impact tests are Charpy impact tests similar to ASTM E23.

Usefulness of Test to Crashworthiness Prediction: The tension test data collected in this test is the yield strength, UTS, elongation, and reduction in area. The first three of these can be used in an FEM model. The Charpy impact test gives energy absorption at a rate only just slightly lower than crash tests. It also tells whether a ductile to brittle transition might be expected under crash conditions.

Failings of Test: It would be more useful to have the stress/strain curve, but this is not obtained in this method. The bend test gives a rather uninterpretable measure of ductility. Hardness can only be correlated with other more standard mechanical properties. Only the Charpy test is done at a rate relevant to crashworthiness.

Comments:

Standard Reporting Form

- Source of Standard ASTM
- Title of Standard Test: **D4173, Standard Practice for Evaluating Sheet Metal Forming Lubricants**

Summary of Test: This standard covers four multiaxial, high speed tests which can be used to evaluate lubricants. The tests are (1)sliding strip test with flat dies, (2)sliding strip test with beaded dies, (3)biaxial stretch cup test, and (4)deep draw cup test.

Usefulness of Test to Crashworthiness Prediction: These tests can be performed without lubricant to evaluate the material properties under stress/strain states relevant to crashworthiness. The sliding strip tests provide information about friction, elongation of sheet metal in one direction, and bending around a straight line. The biaxial stretch test provides information about friction, elongation of sheet metal in two directions, and bending around a curved line. The deep draw test provides information about friction, elongation in one direction and compression in the other, and bending along a curved line.

Failings of Test: While these tests may be performed at high rates, the test specifications are for 85 mm/s which is still slow compared to crash tests.

Comments:

Standard Reporting Form

- Source of Standard **ASTM**
- Title of Standard Test: **E290, Semi-Guided Bend Test for Ductility**

Summary of Test: The material is bent through a specified angle and to a specified inside radius of curvature. The sample is either successful bent by the desired amount or cracks. The only data recorded is material, dimensions, radius and angle of bend, whether the specimen passed or failed the test.

Usefulness of Test to Crashworthiness Prediction: As specified, this test only tells how much bending can be sustained before fracture. However, if the force required to achieve a given angle were recorded continuously, this test would be much more valuable.

Failings of Test: The rate of bending is quasistatic. Some assumption about rate effects would be required to use the data from this test in a crash prediction.

Comments:

Standard Reporting Form

- Source of Standard — ASTM
- Title of Standard Test: — **E855, Standard Test Methods for Bend Testing of Metallic Flat Materials for Spring Applications Involving Static Loading**

Summary of Test: This method describes three test methods for determining the modulus of elasticity in bending and the offset yield strength in bending for three offset strains (.01, .05, and .1%) with a maximum deflection angle of 30 degrees. The three test methods are cantilever beam, three-point bending, and four- point bending.

Usefulness of Test to Crashworthiness Prediction: The modulus data is extremely useful. Even though the test is quasistatic, the rate at which the elastic data is obtained is appropriate for crash prediction. The offset yield data can be used if some means of extrapolating them to crash rates of loading.

Failings of Test: Stress/strain data cannot be easily obtained from bend bars once significant plasticity has occurred. Rate of testing allowed in standard is too low for crash prediction.

Comments:

Standard Reporting Form

- Source of Standard — ASTM
- Title of Standard Test: — **E643, Standard Method for Conducting Ball Punch Deformation Test for Metallic Sheet Material**

Summary of Test: Press a ball of specified radius into held down sheet of metal. Measure the maximum load and cup height at either onset of visible localized thinning or fracture, or load drop.

Usefulness of Test to Crashworthiness Prediction: Provides a maximum biaxial strain and load for a given radius of curvature.

Failings of Test: Rate too low. Discards all intervening load displacement information.

Comments:

Standard Reporting Form

- Source of Standard — ASTM
- Title of Standard Test: — **E9, Standard Test Method of Compression Testing of Metallic Materials**

Summary of Test:

Usefulness of Test to Crashworthiness Prediction:

Failings of Test:

Comments:

Standard Reporting Form

- Source of Standard ASTM
- Title of Standard Test: **E8, Standard Test Methods of Tension Testing of Metallic Materials**

Summary of Test:

Usefulness of Test to Crashworthiness Prediction:

Failings of Test:

Comments:

Standard Reporting Form

- Source of Standard — **ASTM**
- Title of Standard Test: — **E646, Standard Test Method for Tensile Strain Hardening Exponents (n values) of Metallic Sheet Materials**

Summary of Test:

Usefulness of Test to Crashworthiness Prediction:

Failings of Test:

Comments:

Standard Reporting Form

- Source of Standard ASTM
- Title of Standard Test: E517, Standard Test Method for Plastic Strain Ratio r for Sheet Metal

Summary of Test:

Usefulness of Test to Crashworthiness Prediction:

Failings of Test:

Comments:

Standard Reporting Form

- Source of Standard **ASTM**
- Title of Standard Test: **E132, Poisson's Ratio;E143, Shear Modulus; E111, Young's modulus**

Summary of Test:

Usefulness of Test to Crashworthiness Prediction:

Failings of Test:

Comments:

Standard Reporting Form

- Source of Standard ASTM

- Title of Standard Test: E190, Bend Test; E209 Compression Test with Rapid Strain Rates

Summary of Test:

Usefulness of Test to Crashworthiness Prediction:

Failings of Test:

Comments:

Standard Reporting Form

- Source of Standard — **ASTM**
- Title of Standard Test: — **E436, Drop Wt testing; E338, Sharp Notch Tension Test of Sheet; E602 Sharp Notch Tension Testing of Cylindrical Specimens; E604, Dynamic Tear Testing; E 1304, E1290, E813, E399,E740, E992, B646, B645, E561 Various Fracture Toughness Test Methods.**

Summary of Test:

Usefulness of Test to Crashworthiness Prediction:

Failings of Test:

Comments:

FEDERAL REGULATIONS:

According to Mr. Timothy Hurd, the Information Officer at the NHTSA, all vehicles manufacturers are to build their vehicles and motor vehicle equipment to the Code of Federal Regulations 49CFR571-Part 571- FEDERAL MOTOR SAFETY VEHICLE SAFETY STANDARDS. It was hoped that included in this CFR would be a reference or references to standards by which the mechanical properties of the vehicle's steel or aluminum structure could be measured. However, there were NO references to such in the CFR.

The primary concern in vehicle safety is , of course, the survival of the human body in an impact. To simulate impact conditions the human torso, duplicated by a dummy, is subjected to crashes and if the dummy "survives" the crash, the vehicle passes the test.

There are numerous standards in CFR part 571 and they cover a number of tests. For example, part 571 contains standards pertaining to the controls and displays in a vehicle, 571.101 Standard No. 101 covering the Controls and displays to part standard 571.304 covering the compressed natural gas fuel container integrity for vehicles that are powered by natural gas. As for crash worthiness, there are several standards that place loading criteria on the for example, 571.208, Standard No. 208, Occupant crash protection, where in section S4.1.1.3.1c, it stipulates "When it perpendicularly impacts a fixed barrier, while moving longitudinally forward at any speed up to and including 30 m.p.h., under the test conditions of S8.1 with anthropomorphic test devices at each front outboard position, restrained by Type 2 seat belt assemblies, experience no complete separation of any load-bearing element of a seat belt assembly or anchorage." Section S8.1 does cover the general test conditions, but pertains only to the barrier, the road conditions, brake conditions, and vehicle orientation to the barrier.

Another section of CFR 571 , Standard No. 214; Side impact protection stipulates in S3 (b) "When tested under the conditions of S6, each passenger car manufactured on or after September 1, 1996 shall meet the requirements of S5.1, S5.2, and S5.3 in a 33.5 miles per hour impact in which the car is struck on either side by a moving deformable barrier. Part 572, subpart F test dummies are placed in the front and rear outboard seating positions ion the struck side of the car. However, the rear seat requirements do not apply to passenger cars with a wheelbase greater than 130 inches, or to passenger cars have rear seating areas that are so small that the part 572, subpart F dummies cannot be accommodated according to the position procedure described in S7."
Sections 5.1, 5.2, and 5.3 refer to the dynamic performance requirements for the crash dummy. The test conditions referred to Section S6, pertain to test weight, vehicle test attitude, adjustable seat, adjustable seat back placement, adjustable steering wheels, windows, convertible tops, doors, transmission and brake engagement, moving deformable barrier, and the impact reference line. No reference is given in these sections as to impact resistance of metal under these conditions or any high velocity conditions.