B. Intermediate-Rate Crush Response of Crash Energy Management Structures

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Contractor: Oak Ridge National Laboratory
Contract No.: DE-AC05-00OR22725

Objective

- Develop a unique characterization facility for controlled progressive-crush experiments, at intermediate rates, of automotive materials (polymer composites, high-strength steels, and aluminum) and structures.
- Study the deformation and failure mechanisms of automotive materials subjected to crush forces as a function of impact velocity.
- Obtain specific-energy-absorption and strain data, and correlate with deformation and failure mechanisms to describe the unknown transitional effects from quasi-static to high loading rates for polymer composites.
- Characterize the strain-rate effects for metallic materials and components.
- Provide access to unique test capability to university, industry, and government users for collaborative research.

Approach

- Develop a unique, high-force (500 kN), high-velocity (8 m/s) servo-hydraulic machine to conduct progressive-crush experiments on structural components at intermediate rates.
- Use high-speed imaging to observe and document deformation and damage mechanism during the crush event.
- Conduct strain measurements at discrete locations and explore full-field measurements of strains and curvatures.
- Coordinate polymer composites investigations with the Automotive Composites Consortium (ACC) Energy Management Group (see 4.G).
- Coordinate steel investigations with the Auto/Steel Partnership.

Accomplishments

- Completed tube testing in support of Crash Analysis of Adhesively Bonded Structures (CAABS) project (see 4.H).
- Completed tube testing in support of the Auto/Steel Partnership Strain Rate Characterization project (see 2.U).
- Developed improved data-acquisition software for strain-gage measurements.
- Developed streamlined software for interfacing force-displacement data with high-speed video.
- Completed procurement and installation of a high-rate (18 meter/second) test machine for conducting complementary coupon-level testing.

Future Direction

- Explore techniques for full-field measurements of strains and curvatures.
- Develop User Interaction Plan.
- Support user collaboration as required.

Introduction

Progressive crush is an important mechanism by which the kinetic energy of a traveling automobile is dissipated in a collision to protect the safety of occupants. Unfortunately, the mechanisms governing the progressive-crush response of some emerging automotive materials are not well understood. Additionally, many of these materials are known to exhibit responses that are sensitive to rate of loading.

Understanding the influence of impact velocity on the crush response of materials and structures is critically important for crashworthiness modeling inasmuch as collisions occur at a range of velocities. Additionally, from a structural standpoint, the deformation (or strain) rate is generally not unique from either a spatial or temporal standpoint. Consequently, it is important to quantify the behavior of materials at various strain rates.

Test Machine for Automotive Crashworthiness (TMAC)

Typically, standard test machines are employed for experiments at quasi-static rates, whereas drop towers or impact sleds are the convention for dynamic rates. These two approaches bound a regime within which data for experiments at constant impact velocity are not available by conventional experimental practice. This regime is termed herein the “intermediate-rate” regime and is defined by impact velocities ranging from 1 m/s to 5 m/s. Investigation of rate effects within this regime requires experimental equipment that can supply a large force with constant velocity within these rates.

Using a drop tower or sled at intermediate rates, although technically possible, is problematic due to the prohibitively large mass required to maintain constant velocity during the crush. Consequently, ORNL and the ACC collaborated to define specifications for a unique experimental apparatus that mitigates the shortcomings of existing equipment. MTS Systems Corporation designed and built the servo-hydraulic test machine, referred to as the TMAC. TMAC is uniquely capable of conducting controlled progressive-crush tests at constant velocity in the intermediate velocity range (i.e., less than 5 m/s) because of the large energy available at those rates and to the sophisticated simulation and control software that permits velocity uniformity to within 10%.

The new experimental facility will be used to understand the crush behavior between the static and dynamic (8-m/s) conditions. The installation of the TMAC at its National Transportation Research Center (NTRC) Knoxville, Tennessee location is shown in Figure 1.

Figure 1. Installation of TMAC in the NTRC.

Status

Since the last reporting period, activities have focused on supporting users, developing and promoting user interactions, improving data acquisition, and expanding test capability for higher-rate coupon tests.

Interactions have taken place with Rutgers, Massachusetts Institute of Technology, SAE High Strain Rate Plastics Consortium, General Motors, Ford, Imperial College (London, England), Washington University, University of Utah, and L&L Products. Also, discussions continued with the University of South Carolina and Correlated Solutions towards developing a full-field dynamic strain measurement using digital image correlation techniques.

In addition to promoting user programs, continued support was provided to the development of a crashworthiness chapter for the military's composite design guide, MIL-HDBK-17, and the start of a technical division on the Dynamic Response of Materials within the Society for Experimental Mechanics.

Project Support Activities

Extensive testing was completed on TMAC in support of both the ACC Crash Analysis of Adhesively Bonded Structures (CAABS) project (see 4.H) and the Auto/Steel Partnership (A/S-P) Strain Rate Characterization project (see 2.U). For the CAABS project, 30 additional tubes were tested that quantified the effect that adhesive bonds have on energy absorption. In support of the A/S-P project, 30 tubes were tested for determining strain-rate sensitivities in high-strength low-alloy steels and dual-phase steels. Strain gages were used in these tests to locally measure the strains associated with plastic hinge formation in metal tubes undergoing progressive crushing (see Figure 2). Developing the full-field strain measurement technique using digital image correlation would eliminate the need for strain gages and their exact location for capturing the peak strains at the hinges.

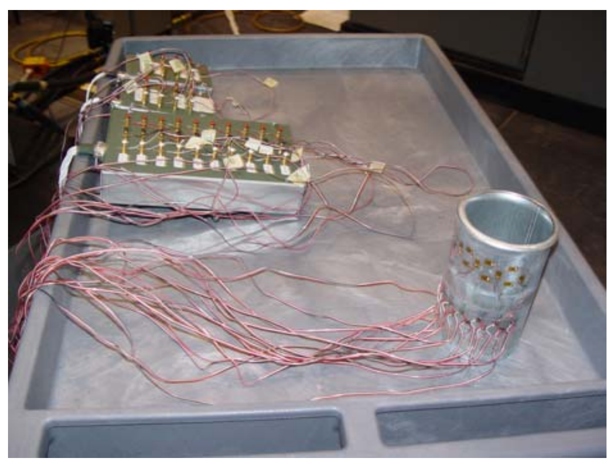

Figure 2. Strain gage pattern used for testing steel tubes.

High-Rate Coupon Test Machine

To complement the TMAC capability, a high-rate coupon test machine was designed, fabricated by MTS, and installed at ORNL. Where TMAC provides the capability for a large force (500 kN static) structural level test, this machine was designed to conduct low force (40 kN static) coupon-sized tests under primarily tensile loads. A typical-size coupon would be a dog-bone strip where the gage section is 15 mm wide with a thickness of 3 mm. This type of test is ideal for generating rate-sensitive stress-strain curves in development of basic material constitutive laws. The machine has a maximum crosshead speed of 18 meters/second with a 400 mm total stroke capacity. The actually working stroke is reduced to 175 mm when installing a slack adapter to allow for the actuator to get up to constant speed before loading the specimen. These specifications were accomplished by a using a 400 gallon/minute (gpm) servo-valve and 50-gallon accumulators (see pictures 3 and 4). Another feature of the test machine is the use of low mass grips designed to reduce ringing in the system thereby minimizing inertial effects in the load signal. The grips were based on a Colorado School of Mine design and are shown in Figure 5.

Figure 3. High-rate (18 meter/second) coupon test machine.

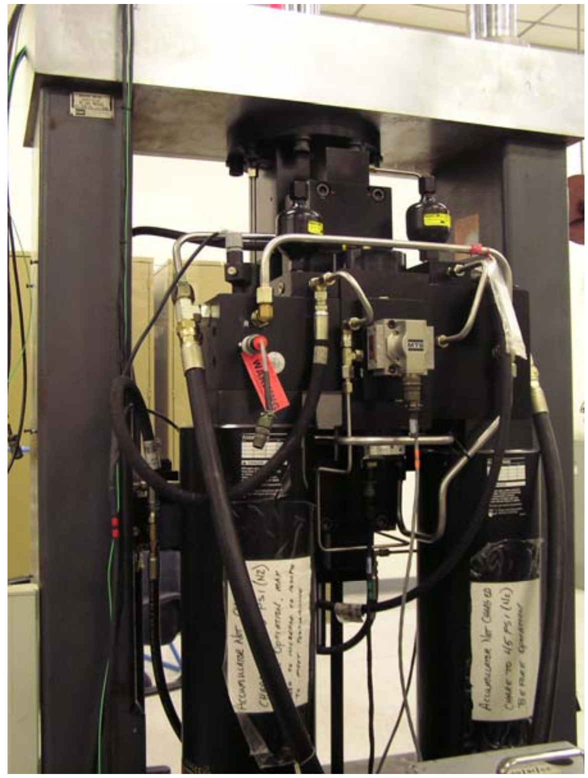

Figure 4. Accumulators and servo-valve for high-rate test machine.

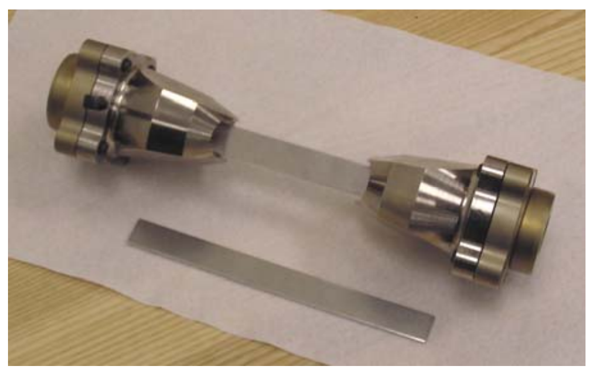

Figure 5. Low-mass grip used in high-rate test machine.

Conclusions

TMAC provides a unique capability to measure the specific energy absorption on crush tubes and other specimen geometries as a function of (constant) impact velocity within a range from quasi-static to 8 meters/second. To complement this capability, a new machine was installed for conducting coupon-level tests up to 18 meters/second.

User interest in this equipment remains very high with three potential projects being in the draft stage. TMAC was also instrumental in meeting project objectives for the CAABS and A/S-P projects. In all of these tests, high-speed video was recorded to document the failure mechanisms using a state-of-the-art CMOS camera that was procured for the TMAC installation.

Presentations/Publications/Patents

Dynamic versus Static Energy Absorption in Carbon Fiber Reinforced Tubes, presented at the Society for the Advancement of Material and Process Engineering (SAMPE), 2006 Symposium, Long Beach, California, April 30-May 4, 2006.