C. Strain Rate Characterization

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Objectives

- Develop new experimental setups for characterization of crashworthiness and strain-rate sensitivity of both high-strength steels (HSSs) and structural designs.
- Replicate impact conditions that occur in automotive impact by simpler and more manageable experiments to generate meaningful data for computer modeling.

Accomplishments

- Developed experimental setup procedures for new crashworthiness characterization test based on parallel-plates buckling (procedure was developed at the University of Dayton Research Institute).
- Developed and conducted constant-velocity crash experiments on circular tubes made of dual-phase (DP) and transformation-induced plasticity (TRIP) steels.

Future Direction

- Develop experiments for characterizing strain and strain-rate history in tubular components (circular and rectangular tube crush tests).
- Provide high-quality data for material and finite-element method (FEM) modeling development.

Introduction

Crashworthiness characterization of high-strength steel (HSS)[1] requires testing of materials and structures under increased strain rates, large plastic strains, and large displacements that are characteristic of actual impact events. Aside from providing a physically quantitative measure of crashworthiness, the experiments also provide benchmarks for verification of finite-element method (FEM) models that are used for automotive design and analysis. Typical crashworthiness experiments involve crushing of tubular objects, such as circular or rectangular tubes.[2] Because of a combination of relatively high velocities and force levels required for progressive crushing, the experiments are usually conducted in inertia-based equipment, such as drop towers or impact sleds. For example, in a drop tower, the drop height and the drop mass can be adjusted to generate desired crush force and length. However, there are practical limits on the mass and the velocity that can be used in a drop tower. The kinetic energy of the impact must be such that it can be expended in the deformation of the specimen and the safety restraints in order not to damage the testing equipment. Vibrations of the falling mass are practically impossible to eliminate, and the lateral forces are not easily measured, nor controlled. The velocity of impact cannot be kept constant and gradually reduces from the onset of impact.

The objective of this project is to develop and conduct coupon- and component-level experiments for characterization of crashworthiness of HSS. The project will also provide high-quality data for development of material and structural FEM models, and, therefore, enable more accurate modeling and design of lightweight crashworthy vehicles.

Design of Experiments

Parallel-Plate Impact Test

A new coupon-level test based on parallel-plate drop tower test by Tam and Calladine[3] has been developed for the servo-hydraulic testing machine. The University of Dayton Research Institute (UDRI) was contracted to perform double-hinge buckling tests at different strain rates as part of the Auto/Steel Partnership (A/SP) work to develop structures for the automotive industry that will improve passenger safety in crashes. Results from drop tower tests were used to develop a model of energy absorption. The results from the servo-hydraulic test will be used for characterization of material under impact and bending. The tests under three different crush speeds have been conducted during 2004.

The test is developed with the objective to replicate deformation history of automotive structures made of polygonal tubular components that occurs during impact. The simplicity of the specimen allows for semianalytical extraction of data and simple correlation with the FEM experiments. The instrumentation includes force cell, strain gages, and a digital camera that will be used to correlate the measurements. The fixture design is shown in Figure 1.

Up to eight strain gages are used to record strain history for a test. Gages are arranged as seen in Figure 2, with gages 4, 5, and 6 placed back-to-back with 1, 2, and 3.

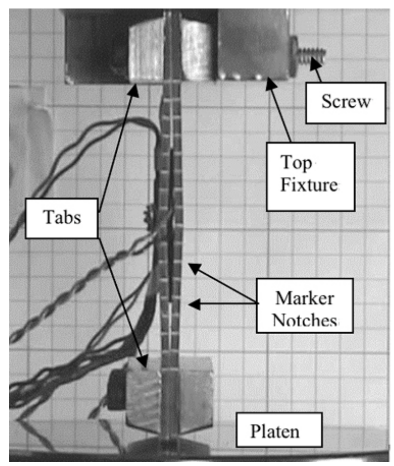

Figure 1. Parallel-plate impact specimen.

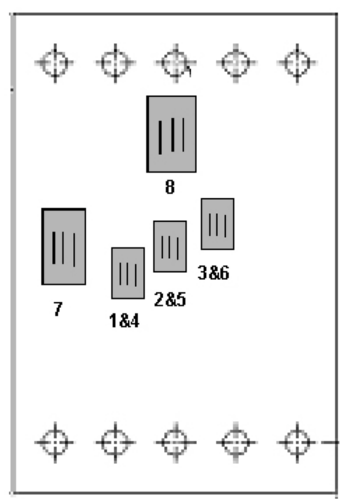

Figure 2. Strain gage locations.

Gage equipment was calibrated to record up to 10% or 20% strain as appropriate. Results from a successful high-rate test setup are shown in Figure 3.

A typical record of experimental data is shown in Figure 4, where left and right ordinates denote the impact force (lb) and strain gage data, respectively.

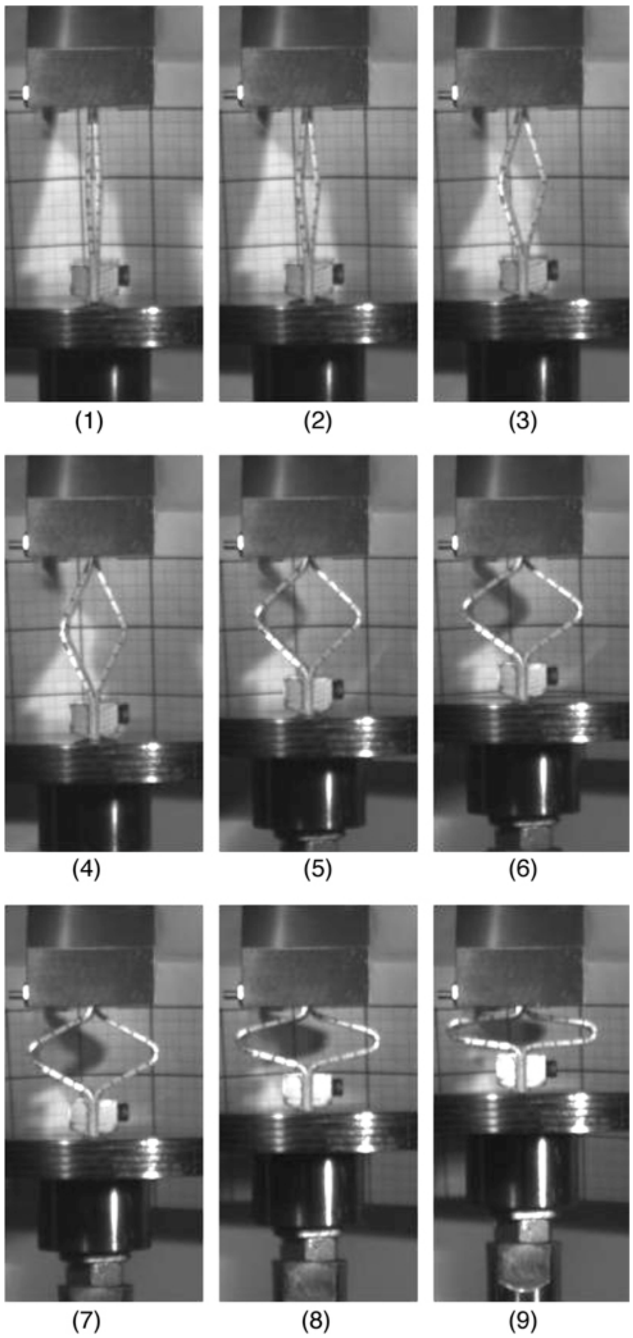

Figure 3. Double-plate test (numbers below the photographs denote the relative time sequence).

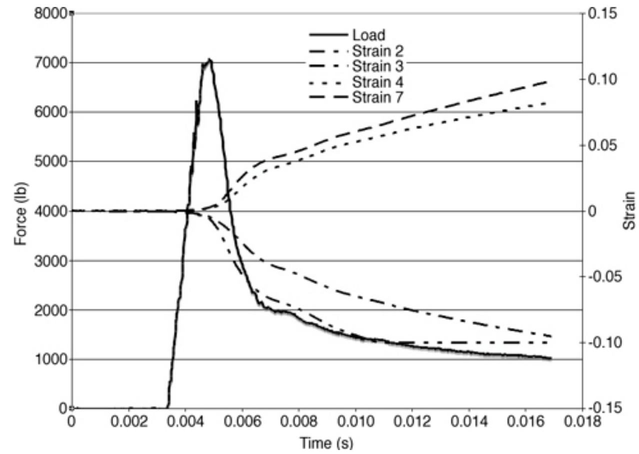

Figure 4. Double-plate test experimental data.

Data from the test are used to develop information about material rate sensitivity and deformation during early impact and formation of plastic hinges. The data are also used for correlation with the modification of the computational FEM models.

Tube Crush Experiments

To improve experimental investigations of the material and structural behavior for automotive impact, the Oak Ridge National Laboratory (ORNL) and the Automotive Composites Consortium (ACC) of the U.S. Council for Automotive Research (USCAR) have developed a new integrated virtual and physical test system for hydraulic, high-force, high-velocity crashworthiness experiments of automotive materials and structures. This unique system, the test machine for automotive crashworthiness (TMAC), permits controlled, progressive crush experiments at programmable velocity profiles and high-force levels. More details about the TMAC system can be found on http://www.ntrc.org.

The tube crush experiments were conducted at the National Transportation Research Center user facility in Oak Ridge, Tennessee. The TMAC system is shown in Figure 5.

The ability to control displacement (velocity) and large lateral stiffness of the machine allows for strain-history measurements[4] that are not practical in drop tower equipment.

Experimental tube specimens were supplied by the Auto/Steel Partnership. A relatively large diameter provides better bonding with the strain gages and relatively tight manufacturing tolerances

Figure 5. TMAC.

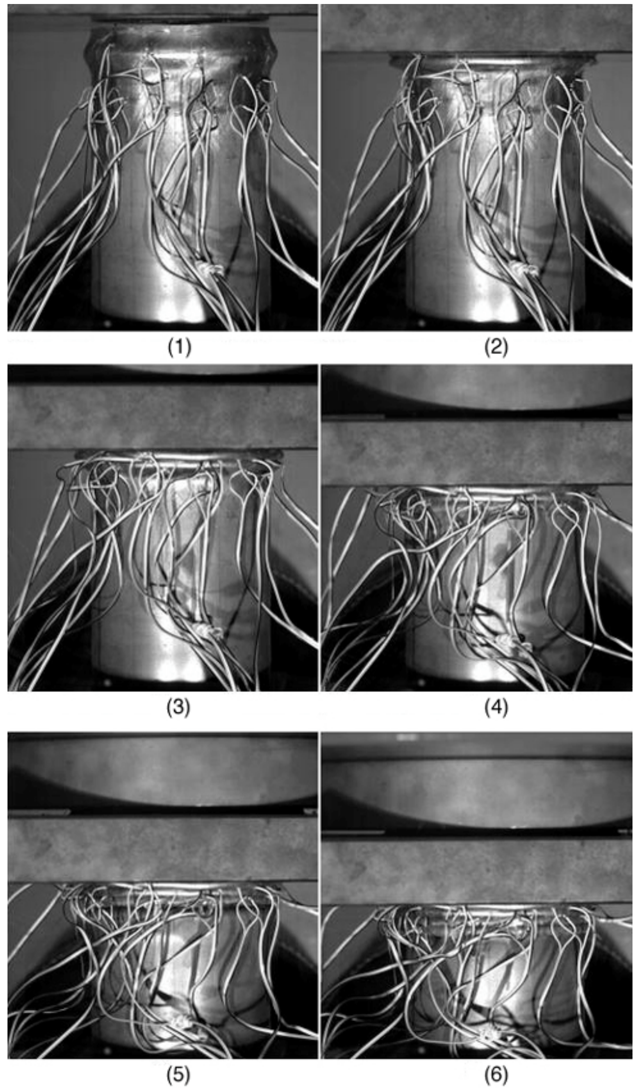

Figure 6. Progressive crush of a mild steel tube under constant velocity of 2 m/s (numbers below the photographs denote the relative time sequence).

alleviate uncertainties due to imperfection sensitivity of the circular tubes. Geometry of the tube specimens is defined by tube length 178 mm (7 in.), diameter 50 mm (2 in.), and wall thickness 1.6 mm (0.063 in.).

The objective of the project is to investigate the strain-rate histories that material experiences during the crush in order to improve predictive capabilities of the numerical models. The principal tools for strain-rate-history measurement are electric resistance strain gages. Materials experience large strains during progressive crush, and therefore, high elongation gages have to be used. Different aspects of gage placement, bonding, and data acquisition were studied to maximize the amount of data from the experiments. Several bonding materials and gage types were considered. The tube force was measured by a set of load cells and a load washer.

Different modes of deformation can be triggered with appropriate modifications of tube geometries[5,6] and boundary conditions.[7] Axially symmetric crush of a mild steel tube is shown in Figure 6.

An asymmetric crush of a high-strength low-alloy steel (HSLA) tube is shown in Figure 7.

The ongoing research involves investigations of different load measurement techniques in crashworthiness. The data from load sensors, displacement trace, and high-speed camera are synchronized and together provide comprehensive information about the progressive crush, and crashworthiness.

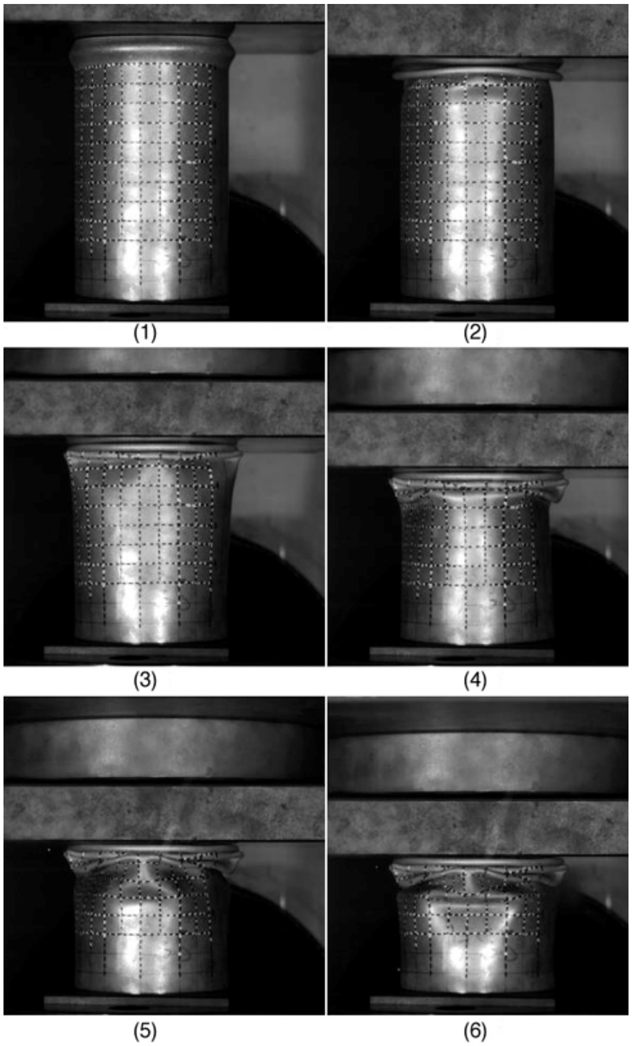

Figure 7. Progressive crush of a HSLA tube under constant velocity of 2 m/s (numbers below the photographs denote the relative time sequence).

Current efforts involve fixture modifications, calibration of high-speed camera equipment, and development of test procedures and test parameter tolerances.

Conclusions

Two new experimental setups have been developed for characterization of crashworthiness of HSS. The experiments are based on hydraulic-based testing systems. The systems provide unique, tightly controlled testing environments for structural and material characterization. The experimental data are used for validation and evaluation of modeling approaches and for development of modeling guidelines for HSS materials and structures under impact loads.

Acknowledgments

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Future Work

The future work on the project will focus on two remaining topics:

1. conducting circular tube crush experiments in TMAC test machine, and
2. development of experimental setup for crushing of rectangular tubes in the TMAC test machine.

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