Mechanical Performance – Extreme Conditions

Objective

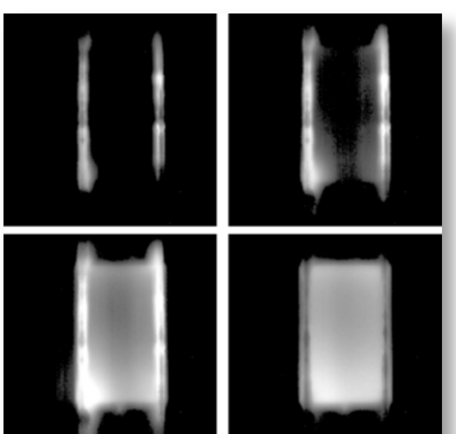
This project provides property data, metrology, and standard test methods for materials systems under extreme conditions for areas critical to US manufacturing, homeland security, and energy infrastructure. Machining research, soft body armor standards and building safety highlight our current materials focus areas of lead alloys, as well as steels for fire-resistant construction and pipelines.

Impact and Customers

- Advanced modeling and optimization tools supported by NIST research efforts are aimed at helping maintain the global competitiveness of the $200 billion US machining industry.
- The NIST Office of Law Enforcement Standards currently sponsors our investigation of the deformation behavior of civilian ammunition threatening officers on the street.
- In a three year collaborative effort with steel producers and consumers under the sponsorship of an ASTM International task group, we have recommended a method for evaluating the performance of new grades of structural steel in conditions relevant to building fires.

Approach

Optimizing high-speed machining processes through powerful finite element modeling techniques is an important pathway to American manufacturing competitiveness in an increasingly competitive global marketplace. Quantitatively accurate simulations of machining rely on robust constitutive models of workpiece materials under real machining conditions. To this end, the Metallurgy Division has worked with the Manufacturing Engineering Laboratory to develop measurement methods for the deformation behavior of steels at high strain rate during extremely high heating rates using a unique, electrically pulse-heated Kolsky bar.



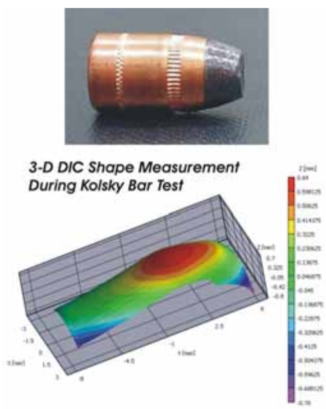
Next-generation soft body armor standards for law enforcement need to provide for performance against various classes of ballistic threats facing officers in the field. Crucial to this effort is better understanding how a bullet's materials and design influence its ability to penetrate soft body armor. Our state-of-the-art high-speed Digital Image Correlation (DIC) measurement tool allows us to study the deformation behavior of whole bullets under highly controlled simulated impacts using the Kolsky bar.

METALS

Accomplishments

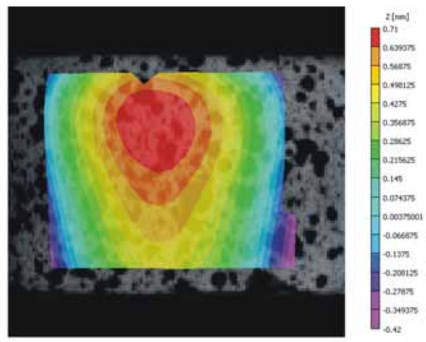
In 2008 we integrated a new, customized high-speed digital image correlation (DIC) measurement instrument into the Kolsky bar facility. This new instrument provides full-field displacement data on rapidly deforming specimens at a rate of up to 180 kHz. Time-resolved stereoscopic image pairs are acquired using a pair of ultra-high speed digital cameras and analyzed for shape and deformation information using the image correlation technique. With this instrument, high strain rate mechanical testing is advanced beyond the traditional limitations of uniform, uni-axial strain experimentation.

Using this instrument, non-cylindrical and non-homogeneous specimens, such as copper-jacketed bullets, can be rapidly strained in a Kolsky bar test while the deformation field is measured in real time. Coupled with finite element simulations, these new measurements produce an unprecedented insight into the constitutive behavior of materials and structures under extreme, yet well controlled, loading conditions. Constitutive models of bullet lead and jacket materials developed in-house are being evaluated, as well as those found in the literature, to determine their suitability for high-fidelity models of bullet impact on soft body armor being developed elsewhere.



3-D DIC Shape Measurement During Kolsky Bar Test

We are also applying high speed DIC measurements to the dynamic testing of very soft tissue-simulant materials, where acceptable test conditions are difficult or impossible to achieve using traditional methods. By applying the DIC instrument, the deformation field during specimen "ringup" can now be measured. These measurements, along with finite element analyses, provide useful data to describe the dynamic constitutive response of the material under non-equilibrium test conditions that were previously impossible to evaluate. Further applications for the DIC instrument will include strain localization studies on rapidly deformed tensile specimens and an improved assessment of measurement uncertainties for high temperature pulse-heated tests using the traditional cylindrical specimens.



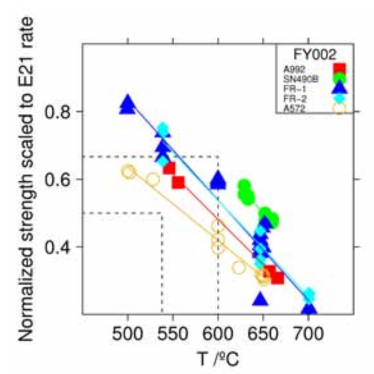
DIC Measurement of Tissue Simulant Material

Also in 2008, progress continued on measuring the high-temperature, high-strain-rate behavior of engineering alloys of interest to the machining industry. New materials tested this year included AISI 4140 steel, Ti-6Al-4V alloy and brass, which we added to extensive data on AISI 1045 and AISI 1075 steel, high-purity iron, and several tungsten, iron and aluminum alloys. Our particular focus is on measuring the effect of thermally induced phase transformations on plastic flow stress at high strain rates, and investigating the associated kinetics of these transformations.

We have worked through an ASTM-International task group to help develop standards for evaluating the performance of new grades of fire-resistive (FR) construction steels. These steels, intended as drop-in replacements for existing grades of construction steel, provide enhanced high-temperature deformation resistance. Their improved retained strength at high temperatures could allow extra time for occupants to exit buildings.

That task group recently completed its work and recommended a definition for fire-resistive steels based on retained yield strength at elevated temperature. The responsibility for developing a standard has passed from the testing committee (28) to the steel committee (A01).

The figure below shows that fire-resistive steels (SN490B-FR, FR-1, and FR-2), simultaneously improve temperature- and retained-strength performance compared to two ordinary structural steels (A992 and A572). The hashed boxes represent the commonly accepted performance of ordinary structural steel (1/2 of the room-temperature strength at 538 °C) and the new definition for fire-resistive steel (2/3 of the room-temperature strength at 600 °C).



Learn More

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Publications

Mates SP and Rhorer RL *High Strain Rate Tissue Simulant Measurements Using Digital Image Correlation* SEM Annual Conference, June 1-4, 2009, Albuquerque, NM, USA

Mates SP, Rhorer RL, Whitenton E, Burns T and Basak D *A Pulse-Heated Kolsky Bar Technique for Measuring Flow Stress of Metals Subjected to High Loading and Heating Rates* Exp. Mech., 48: 799 (2008)

Mates SP, Rhorer RL, Banovic S, Whitenton E and Fields R *Tensile Strength Measurements of Frangible Bullets Using the Diametral Compression Test* Int. J. Impact Eng., 35 (6): 511 (2008)

Banovic SW, Foecke T, Luecke WE, McColskey JD, McCowan CN, Siewert TA and Gayle FW *The Role of Metallurgy in the NIST Investigation of the World Trade Center Towers Collapse* JOM, 59 (11): 22 (2007)