Materials Database Development for Ballistic Impact Modeling

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A set of experimental data is being generated under the Fundamental Aeronautics Program Supersonics project to help create and validate accurate computational impact models of jet engine impact events. The data generated will include material property data generated at a range of different strain rates, from $1 \times 10^{-4}$ sec$^{-1}$ to $5 \times 10^4$ sec$^{-1}$, over a range of temperatures. In addition, carefully instrumented ballistic impact tests will be conducted on flat plates and curved structures to provide material and structural response information to help validate the computational models. The material property data and the ballistic impact data will be generated using materials from the same lot, as far as possible.

It was found in preliminary testing that the surface finish of test specimens has an effect on measured high strain rate tension response of AL2024. Both the maximum stress and maximum elongation are greater on specimens with a smoother finish. This report gives an overview of the testing that is being conducted and presents results of preliminary testing of the surface finish study.
Materials Database Development for Ballistic Impact Modeling

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Issues

1. Lack of consistency in material modeling practices

2. Lack of high quality set of data to develop and verify impact models
   - Data typically assembled from a number of different sources
   - Lack of quantitative measurements to evaluate model accuracy
   - Limited pedigree
Outline

- Overview of project
- Status of impact testing
- Status of material property testing
- Results of work done on the effects of specimen surface finish on material property measurements
Anatomy of an Aircraft Turbine Engine

- **Fan Containment Structure**: Contains debris in the event of a fan blade failure.
- **Compressor Blades**: Compresses intake flow into the combustor.
- **Turbine Blades**: Turn the fan via the rotor shaft.
- **Intake Air**: Generates the thrust for the engine.
- **Combustor**: Where fuel is injected and ignited to turn the turbine.
- **Hot Exhaust Gas**: Accounts for most of the engine's thrust.
Objectives

- Develop a set of data to help improve and validate computational impact models
  - Material property data
  - Ballistic impact test results
- Develop improved methods for modeling impact problems
Initial Materials

- **Ti-6Al-4V**
  - 0.090 in
  - 0.140 in
  - 0.25 in

- **Al 2024-T3/T351**
  - 0.125 in (T3)
  - 0.25 in (T351)
  - 0.50 in (T351)
Database Contents

- Material Property Data
  - Shear, compression and tension
  - Different strain rates
  - Different temperatures

- Ballistic Impact Test Data
  - Flat plate tests
  - Subcomponent tests

- Damage Characterization
Material Property Measurements

- Tension, shear, and compression tests will be done at various strain rates ranging from $10^{-4}$ to $5 \times 10^{3}$ s$^{-1}$. Tests at various elevated temperatures will be done at one of the strain rates.

- Tests at strain rates from $10^{-4}$ to $2$ s$^{-1}$ will be done using a hydraulic Instron machine. Tests at strain rates from 300 to 5000 s$^{-1}$ will be done using the tension, compression, and torsion split Hopkinson bar techniques.
Ballistic Impact Tests

- Flat panel tests
- Subcomponent tests
Flat Panel Tests

- Design projectile so that the penetration velocity is between 600-900 ft/sec
- 15” square panels rigidly clamped on four sides with a 10” round aperture
- Cylindrical projectile with a large radius nose, normal impact
Impact Gun
Test Fixture
Instrumented plates
Test Fixture
Projectiles
Subcomponent specimen

Half Ring Specimen

Projectile
Large gas gun
Instrumentation

- Point strain on backside (strain gages)
- Impact velocity
- Exit velocity
- Projectile orientation
- Full field displacement/strain (stereo photo instrumentation)
Test Program Status

- Flat plates have been instrumented
- Test fixtures have been fabricated
- Material property test specimens have been designed and testing has begun
- Surface finish study has been completed
Split Hopkinson Bar Apparatus

- $u_1$
- $u_2$
- $\varepsilon_i$
- $\varepsilon_t$
- $\varepsilon_r$

Output Bar

Incident Bar
Effects of Surface Finish on High Strain Rate Material Property Measurements

- No standards exist for design of Split Hopkinson Bar test specimens
- Preliminary Study initiated to determine the effects of tension specimen surface finish
# Number of Repeats per Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Quasistatic (1/sec)</th>
<th>High Strain Rate (1000/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDM Specimen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unbroken Edges</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Machined Specimen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ra 32 or better Unbroken Edges</td>
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<td>3</td>
</tr>
<tr>
<td>Machined Specimen</td>
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</tr>
<tr>
<td>Ra 63 or worse Unbroken Edges</td>
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<td>3</td>
</tr>
</tbody>
</table>
Tension Specimens
Tension Split Hopkinson Bar
Quasistatic Apparatus
SHB Tension Specimen
SHB Specimen – Post Test
# Surface Roughness Measurements

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Parallel to Specimen Axis (Ra)</th>
<th>Perpendicular to Specimen Axis (Ra)</th>
<th>Gage Section Edge (Ra)</th>
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</thead>
<tbody>
<tr>
<td>EDM</td>
<td>107-118</td>
<td>107-118</td>
<td>15</td>
</tr>
<tr>
<td>Rough Machined</td>
<td>125-170</td>
<td>84-124</td>
<td>111-180</td>
</tr>
<tr>
<td>Smooth Machined</td>
<td>13-22</td>
<td>8-20</td>
<td>16-22</td>
</tr>
</tbody>
</table>
High Strain Rate Results

Test # M1-SF1-SR2-N1

- Time (μs)
- Strain Rate (1/s)
- Engineering Stress (ksi)
- Computed Strain
- Specimen gage
- Strain Rate
- Stress
Surface Finish Study Results
1000 in/in/sec

Surface Finish Test Series Data

- Rough Machined
- Smooth Machined
- Broken Edges
- EDM

Engineering Stress (ksi)

Engineering Strain
Conclusions

- Increase in elongation in smooth specimens
- Small increase in strength in smooth specimens
- EDM specimens show slight reduction in strength and elongation
- All testing should be done with smooth machined specimens