High Strain Rate Shear Failure of Metals in High-Speed Machining

Precision Machining Research Consortium
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Applications

- Manufacturing: machining, metal forming & welding
- Structure integrity: vehicle crash-worthiness
- Material processing: consolidation
- Tribology: wear and lubrication
- Composites: MMC’s and IMC’s
- Armor & Armor penetration
Dynamic Deformation and Failure: Issues

Ductile Plastic Flow
- Shear Banding
  
  Ductile rupture and failure

Brittle Failure
- Rapid Crack Growth
  
  Brittle fracture, fragmentation, and pulverization
Dynamic Response vs. Quasi-Static Response

- Strain Rate Sensitivity
- Transition from thermally activated mechanism to a linear viscous mechanism-high dislocation velocities
- Inertia Effect
- Time-Dependent
- Highly Nonlinear
- Heat Generation
- Thermal Softening
- Phase Transition
Dynamic Shear Failure Experiment
Constitutive Dynamic Response
Split Hopkinson Pressure Bar
Current Research (supported by ONR)

- Objectives:
  - Characterize evolution of load-carrying capacities of structural metals under predominantly shear conditions.
  - Quantify the shear failure resistance of the materials.
Materials

- High Yield 80 (HY-80)
- High Yield 100 (HY-100)
- High Strength Low Alloy 80 (HSLA-80)
- Al 4340 VAR
- Ti-6Al-4V
Dynamic Constitutive Response

HY-100

Stress (MPa)

Strain

2.6 x 10^3 s^{-1}

1.7 x 10^3 s^{-1}

2.0 x 10^3 s^{-1}
Dynamic Constitutive Response

![Graph showing the dynamic constitutive response of Ti-6Al-4V with stress-strain curves at different strain rates: 2.0 x 10^3 s^-1, 2.4 x 10^3 s^-1, 5.0 x 10^1 s^-1, and 1.2 x 10^3 s^-1. The graph includes stress (MPa) on the y-axis and strain on the x-axis.]
Dynamic Constitutive Response
Shear Failure

![Graph showing shear stress vs. shear strain for different materials at various strain rates.]

- **Ti-6Al-4V**: $1.0 \times 10^4$ s$^{-1}$
- **HY-100**: $1.98 \times 10^4$ s$^{-1}$
- **4340**: $1.20 \times 10^4$ s$^{-1}$
- **HSLA-80**: $2.0 \times 10^4$ s$^{-1}$
- **HY-80**: $1.9 \times 10^4$ s$^{-1}$
Shear Failure

HY-80

Shear Stress (MPa)

(c) $1.65 \times 10^4$ s$^{-1}$
(b) $1.6 \times 10^4$ s$^{-1}$
(a) $2.2 \times 10^4$ s$^{-1}$
(d) $1.90 \times 10^4$ s$^{-1}$

Shear Strain
Maximum Strain 2.0
Maximum Strain 2.5
Summary and Work Ahead

1. Steels vs. Titanium
2. Rupture mechanism
3. Void coalescence
4. Shear band toughness

1. Constitutive model
2. Numerical simulation
3. Void damage model