RDECOM

Influence of Cartridge Case Material Properties on Small Caliber Weapon Function

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Cartridge Case Requirements

- Hold and contain propellant, primer and projectile
- Securely hold projectile and orient cartridge components in chamber. Align projectile with bore axis for proper engraving.
- Provide obturation during firing (seal off chamber gases)
- Recover after firing to permit easy extraction
- Act as a heat sink to reduce amount of heat transferred to chamber

General Design Considerations

- Geometries and material properties carefully selected
- Case Mouth:
  - Relatively thin and ductile
  - Permits easy bullet unseating and effective obturation
- Case Shoulder:
  - Tapered to improve extraction
- Case Sidewall:
  - Progressively thicker and stronger towards head of the case
  - Thinner towards mouth/shoulder for progressive rearward obturation
  - Ductility and strength carefully balanced
    - Too brittle: circumferential rupture and splitting
    - Too ductile: extraction problems
- Case Head:
  - Unsupported portion is strongest and thickest part of the case
  - Resist deformation due to firing pressures, contain primer in pocket

Summary of Caliber .50 Efforts

- In late 2008, ARDEC Small Cal notified of weapon stoppage issues using ammunition of particular manufacturer.
- Failure investigation identified root cause as improper material properties
- FEA model of Cal .50 weapon-ammo system constructed to predict influence of case properties and weapon setup
- Model illustrates impacts on bolt load, extraction force and case obturation

Comparison of Weapon Function

Figure 1: Firing different ammunition types in training

- “Case 1” ammunition cyclic rates 50-100 rpm lower than standard
- Weapon stoppage rate of approx 3% typical for “Case 1” ammo
- Stoppage rate appeared highly weapon-dependent

High Speed Capture of Stoppage

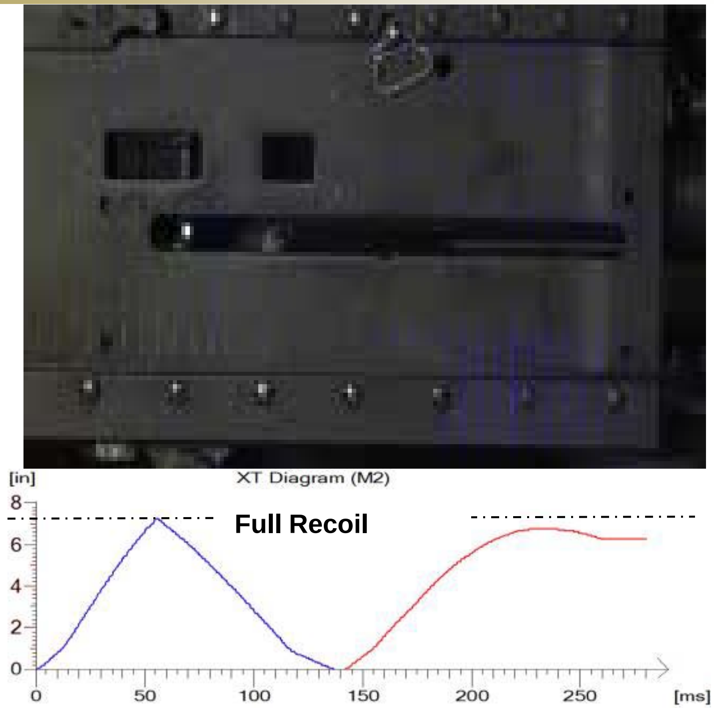


Figure 2 and 3: High speed video and bolt displacement, Ref 4

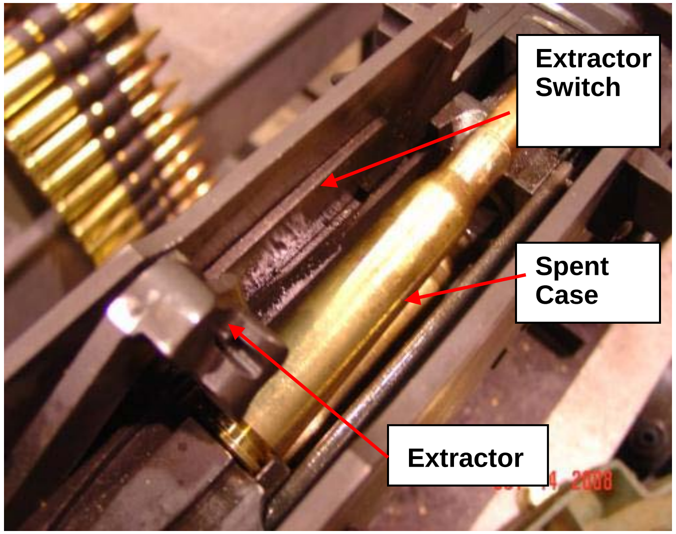


Figure 4: Depiction of a typical stoppage, Ref 4

- Bolt fails to travel fully to the rear (second shot)
- Extractor arm fails to clear the switch on the left side of receiver
- Extractor does not cam down; next cartridge does not properly align
- Drive spring forces bolt forward jamming weapon
- Failures occurred after firing M17 tracer

Determination of Root Cause

- Failure investigation focused on cartridge dimensions, cartridge output (EPVAT), case material properties (hardness)

- Close examination of bolt time-displacement data indicated that recoil velocity prior to extract was very similar between manufacturers, but decelerated to a greater extent with “Case 2” ammunition

- Conclusion: Higher extraction forces resulting in weapon stoppages

- Dimensional differences between manufacturers were found to be statistically insignificant; Case hardness measurements were found to be significantly different

- Proposed Root Cause: Insufficient material properties as evidenced by hardness measurements result in higher extraction forces

Strength Properties vs. Hardness

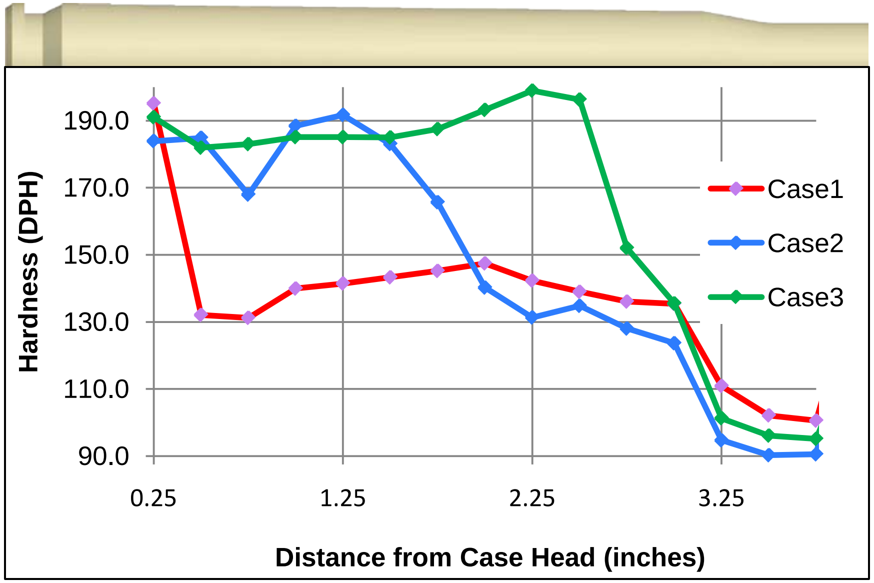


Figure 5: Case Hardness Profiles of Different Manufacturers

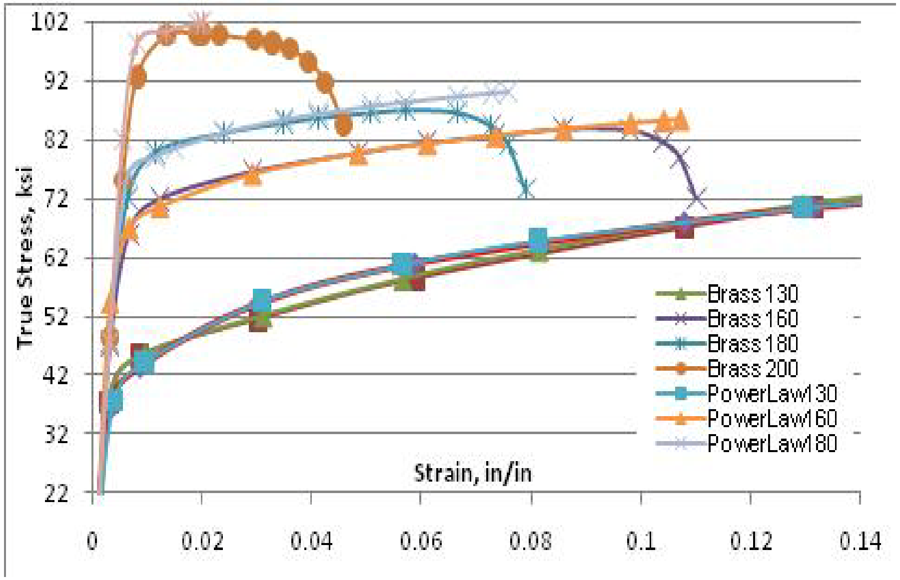


Figure 6: Stress-Strain Curves, Ref 8

- Notice relatively low hardness of “Case 1” ammunition
- As hardness goes up, yield strength increases and ductility decreases

Yield Strength vs. Residual Chamber Clearance

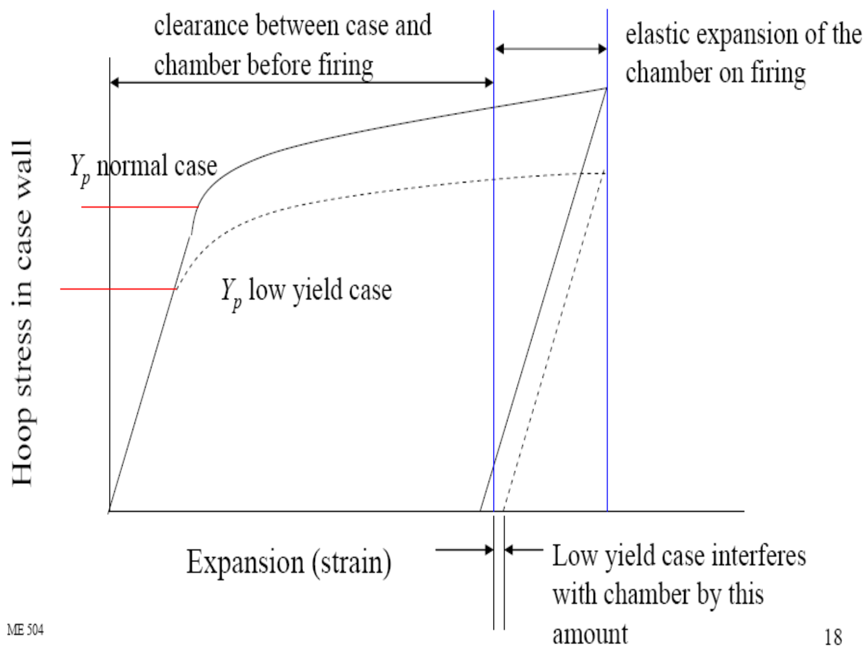


Figure 6: Effect of Yield Strength on chamber interference, Ref 1

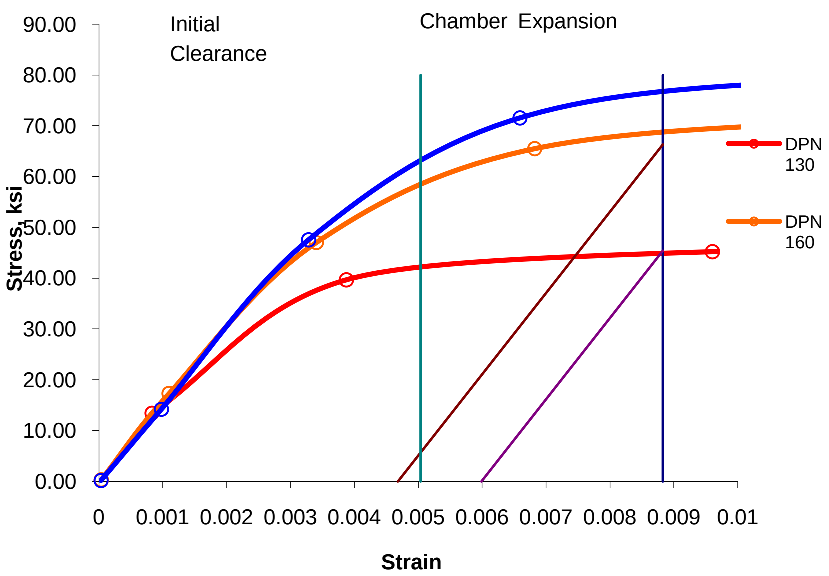


Figure 6: Analytical prediction of interference condition for 60 kpsi max internal pressure

- **Initial firing pressures force case sidewall against chamber**
- **Case expansion continues as chamber expands elastically under firing pressures**
- **As pressures subside, both case and chamber recover elastic deformation; chambers recovers fully, cartridge recovers partially**
- **Depending on initial clearances and material properties, interference may exist (increased extraction load)**

Finite Element Model

- Quarter symmetry model was constructed and included case, liner retainer, gun tube and bolt
- Interference between liner retainer and gun tube (sometimes case and chamber)
- Chamber (retainer) dimensioned such that headspace was nominal at minimum and maximum breeching space

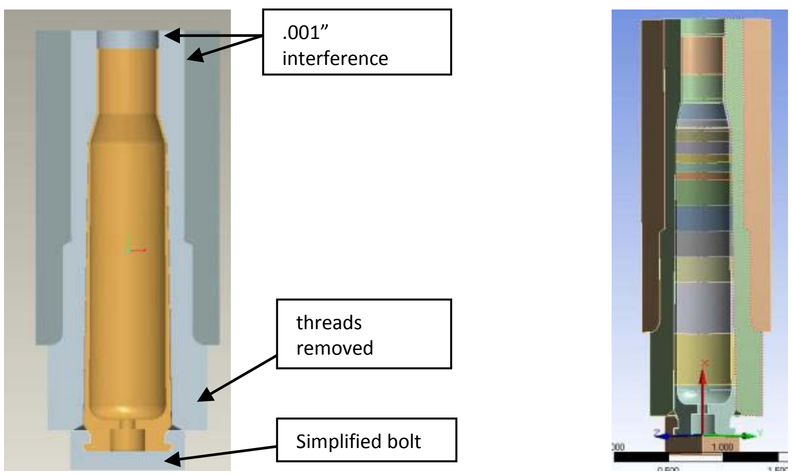


Figure 7 and 8: Geometries of FE Model showing features and case divisions

- Brass case divided axially to permit assigning local material properties
- Plasticity Power Law assigned to case areas (Figure 6)
- 130 DPH curve used for areas at or below that hardness

Applied Loads and Constraints

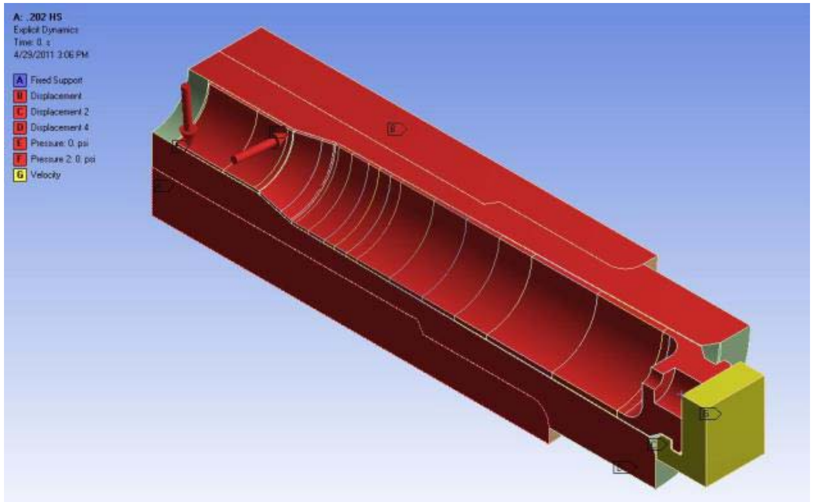


Figure 9: Applied Loads and Constraints

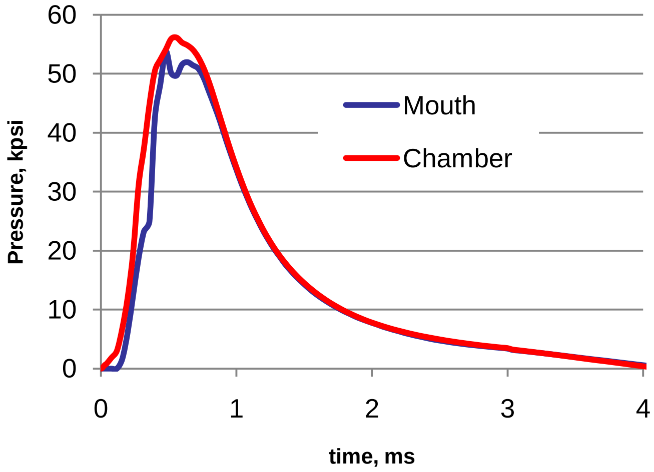


Figure 10: Pressure-time histories

- Constraints: Symmetry, Radial (Threaded Section of Retainer), Barrel Front
- Pressure Loads: Pressure-time histories mapped to all case faces
  - Separate P-t curves for mouth and case; No gradient was assumed
- Bolt time-displacement based on relative bolt/barrel velocity data
- Interference contact used for retainer-tube and case crush contact pairs
  - Initial interferences eliminated in dynamic relaxation phase of explicit run

Simulation Run and Results

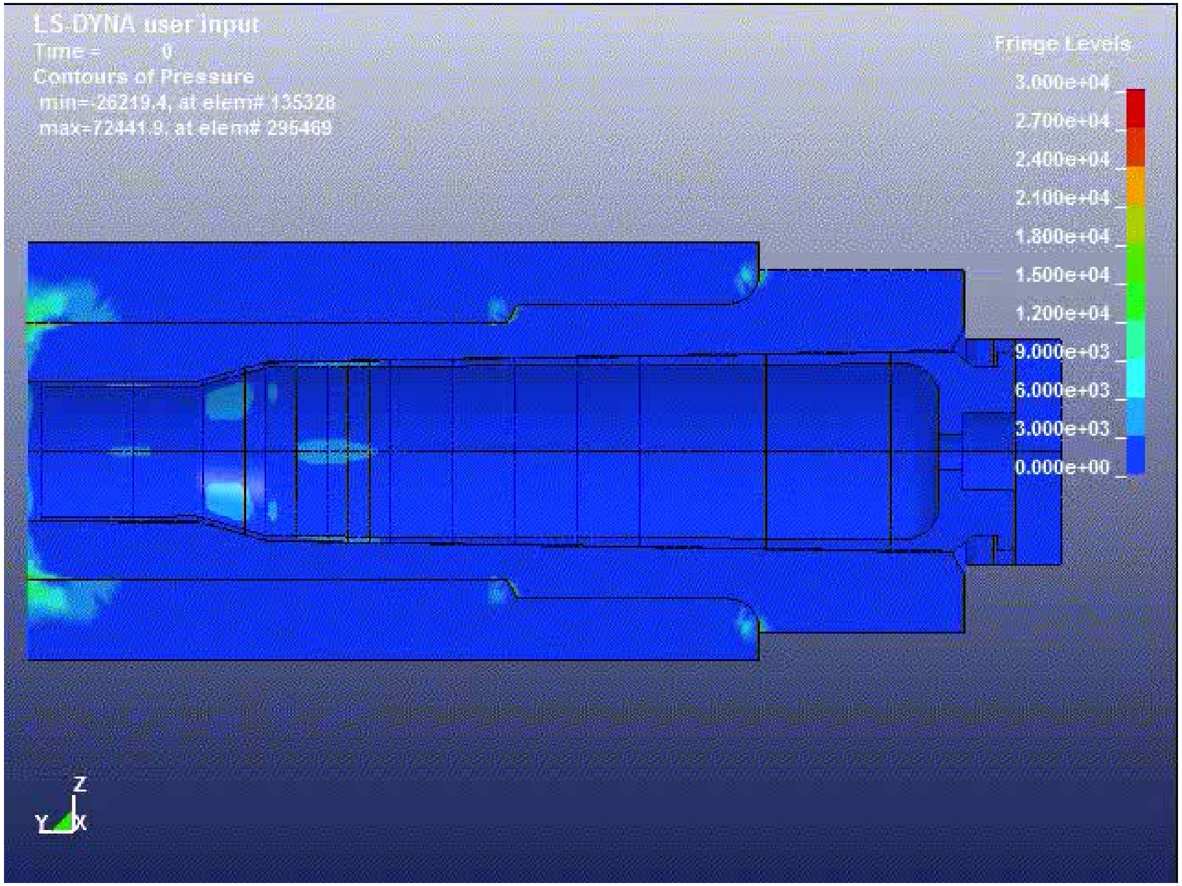


Figure 11: Case Pressurization and Extraction Simulation

Simulation Results and Validation

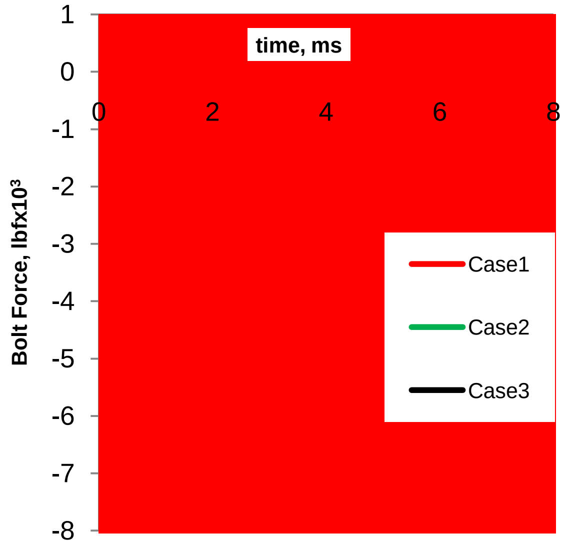


Figure 12: Bolt Loads vs. hardness gradient

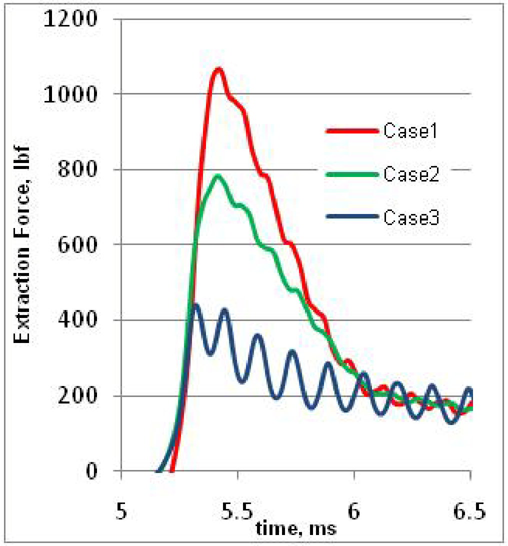


Figure 13: Extraction Force vs. hardness gradient

	Case 1			Case 2		
Distance from Head, in	0.64	1.144	2.25	0.64	1.144	2.25
Simulation Final OD, in	0.7954	0.7780	0.7394	0.7934	0.7760	0.7400
Simulation Change OD, in	0.0086	0.0073	0.0054	0.0070	0.0054	0.0052
Measured Final OD, in	0.7928	0.7765	0.7401	0.7920	0.7759	0.7401
Measured Change OD, in	0.0081	0.0082	0.0078			

Figure 13: Dimensional Comparisons

- Case 1 Ammunition predicted to have greater bolt load and extraction forces
- Reasonable correlation with limited experimental data; exact chamber geometries of test weapons unknown

ADAMS Simulation

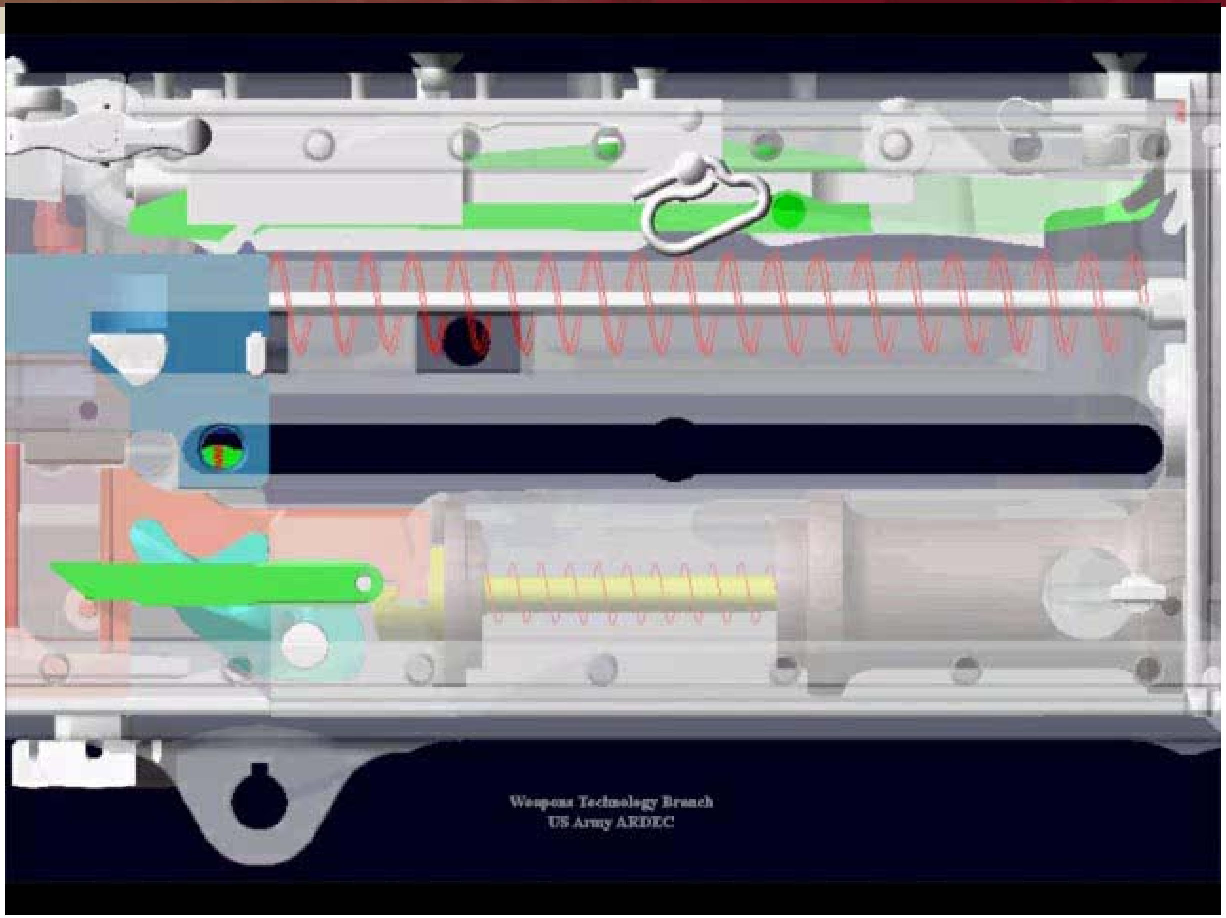


Figure 14: MSC ADAMS Simulation of M2HB, Courtesy ARDEC Weapons Technical Support Branch, Ref 3

- Firing sequence of M33 Ball Cartridge Followed by M17 Tracer Cartridge
- Applied extraction force profile obtained from explicit simulation

ADAMS Results

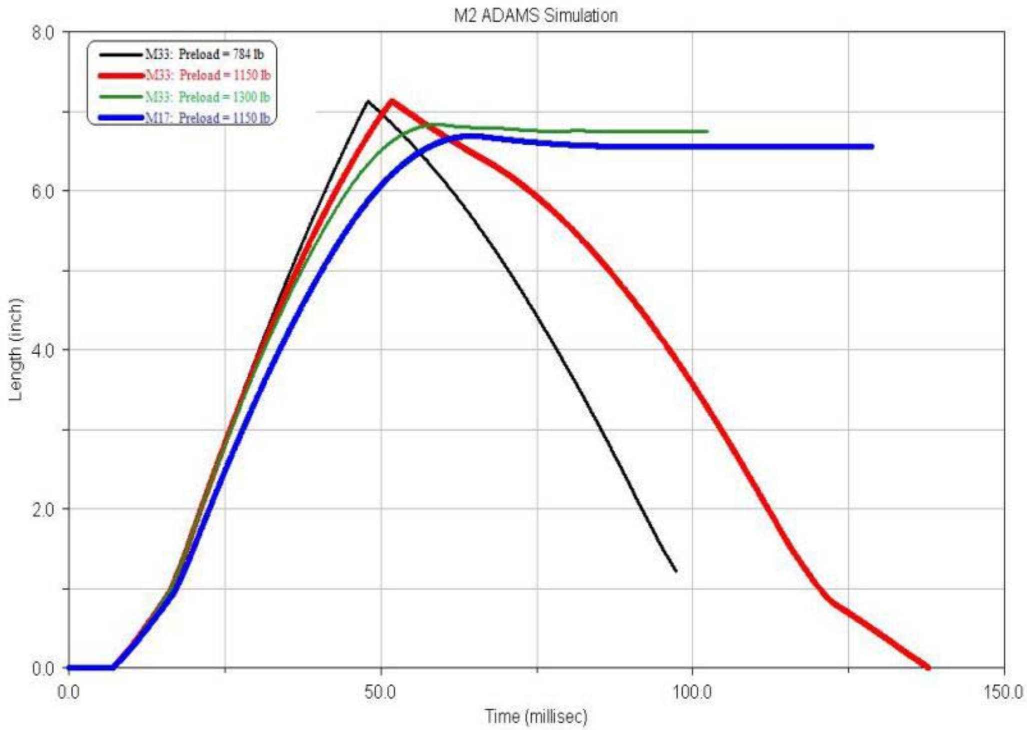


Figure 15: Bolt time-displacement simulation, Courtesy ARDEC Weapons Technical Support Branch, Ref 3

- Model illustrates the contribution of tracer fire to the weapon stoppage
  - Ball cartridge provides greater weapon impulse to overcome losses
- Simulation time-displacement curves correlate well with experimental data

Bolt and Extract Forces vs. Friction

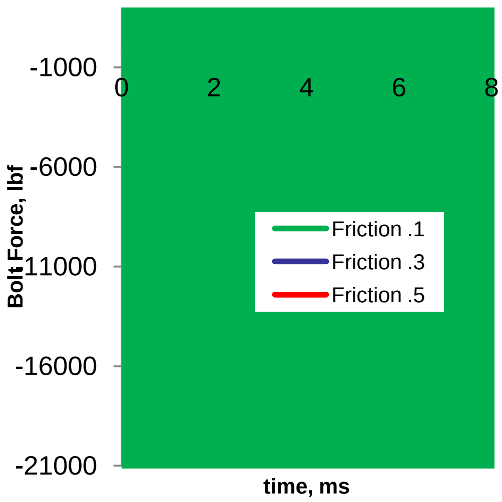


Figure 16: Bolt Loads vs. friction coefficient

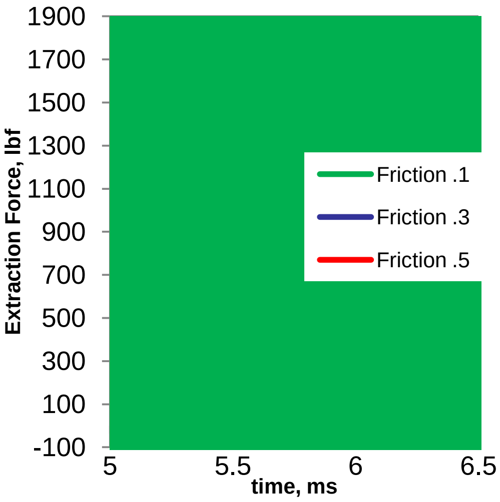


Figure 17: Extraction Force vs. friction coefficient

- Decreasing friction coefficients decreases extraction force; dramatically increases predicted peak bolt face force
- Higher friction coefficients lower bolt face force; dramatically increases predicted extraction force
- Illustrates dangers associated with lubrication of ammunition

Extract Forces vs. Clearances and Weapon Setup

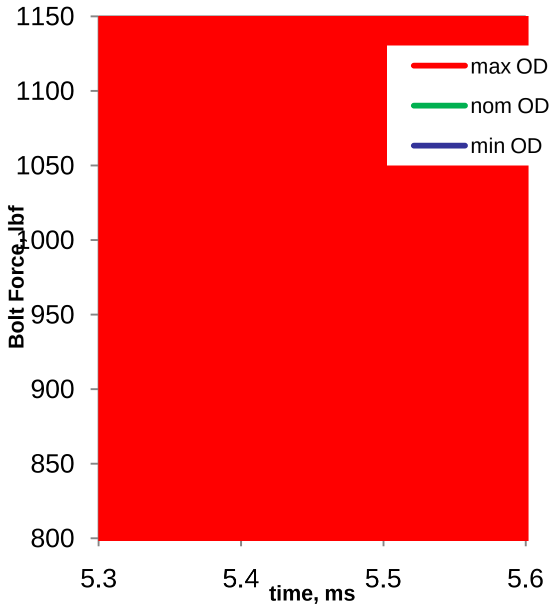


Figure 18: Extraction force vs. case OD

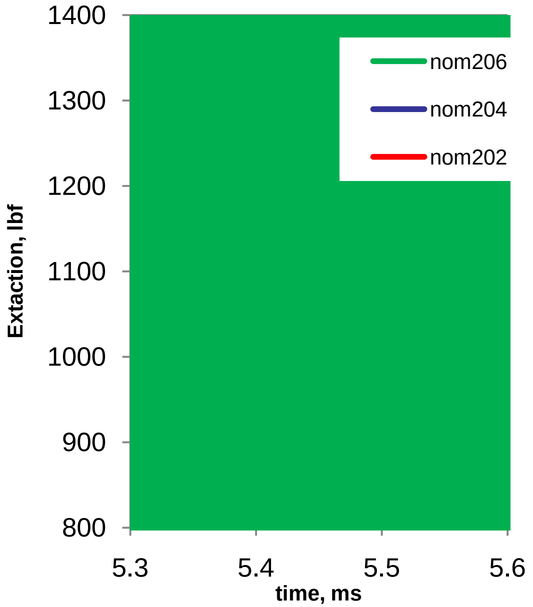
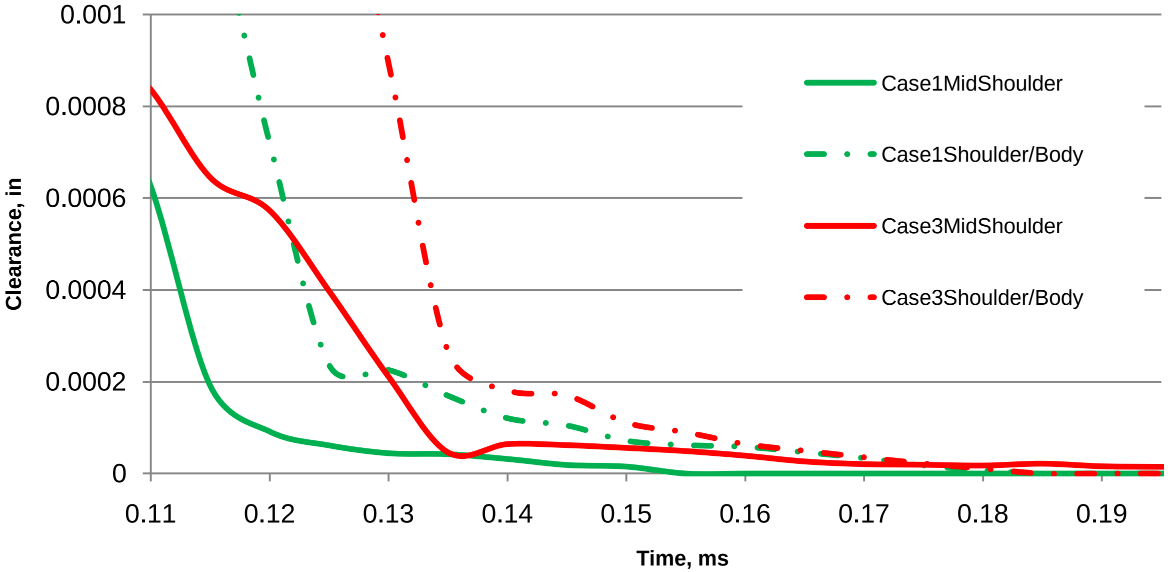


Figure 19: Extraction Force vs. breeching space

- Model predicts that extraction force decreases with greater initial clearance

- Model predicts that increasing weapon headspace (backing out barrel) can decrease extraction force
  - Especially when going from a case-crush to a non crush condition

Material Effects on Time to Obturate



Case-Chamber Clearance vs. time for Case 1 and Case 3 Cartridges

- Numerous cases of breech flames have been reported with "Case 3" ammo
- Inspection of explicit simulations predicted initial contact in the case shoulder
- Harder-shoulder Case 3 cartridges require longer time to contact chamber
- Results not conclusive, but provide an explanation for observed phenomena

Conclusions

- Root cause was assigned to weapon stoppage issue with particular ammo manufacturer
- Explicit FEA model was constructed to determine influence of material properties and weapon setup on bolt and extraction loads
- Extraction forces predicted to increase with friction coefficient/
- Extraction forces predicted to decrease with increase in case hardness, initial chamber clearance and weapon headspace
- Peak bolt force predicted to vary inversely with friction coefficient
- Increased localized hardness predicted to increase time to obturation

References

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