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Malcolm Baldrige National Quality Award 2007 Award Recipient

Lubrication's Contribution to Cartridge Case Failure

ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER PICATINNY ARSENAL, NJ

Presented to: ***NDIA, International Ballistics Symposium***
Presented by: ***Mark Minisi, RDAR-MEM-I, Picatinny Arsenal NJ***
Presented at: ***Miami, Fl.***
Date: ***SEP 2011***

Case Failure

During a U.S. Army test, 5.56mm NATO case ruptures were experienced when firing the M249 in the hot, 160 deg F (conditioned) environment.

Key points from early in the failure investigation

- M249 normally creates more case deformation than M16/M4
- Hot, 160 degree (Higher Pressures, different mechanical fits than at ambient temperatures)
- Low round count barrels
- Weapon was recently cleaned and lubricated
- Failures always occurred within the first 10 rounds of the ammunition belts
- Case bulging frequently observed in rounds preceding ruptured rounds on the belt
- Noticeably shorter cartridge shoulder neck length in ruptured cases
- Failures of this type are not occurring when firing the same ammunition from the M16/M4
- Material analysis of case suggests no significant variations from the norm

Investigation Path

Exploratory testing at multiple agencies (ARL, LCAAP, ARDEC)

- Comparative testing of various ammunition and weapons relevant to failure
- Evaluation of pressure
- Evaluation of temperature
- Evaluation of Lubrication
- Analysis and Identification of failure mechanism(s)

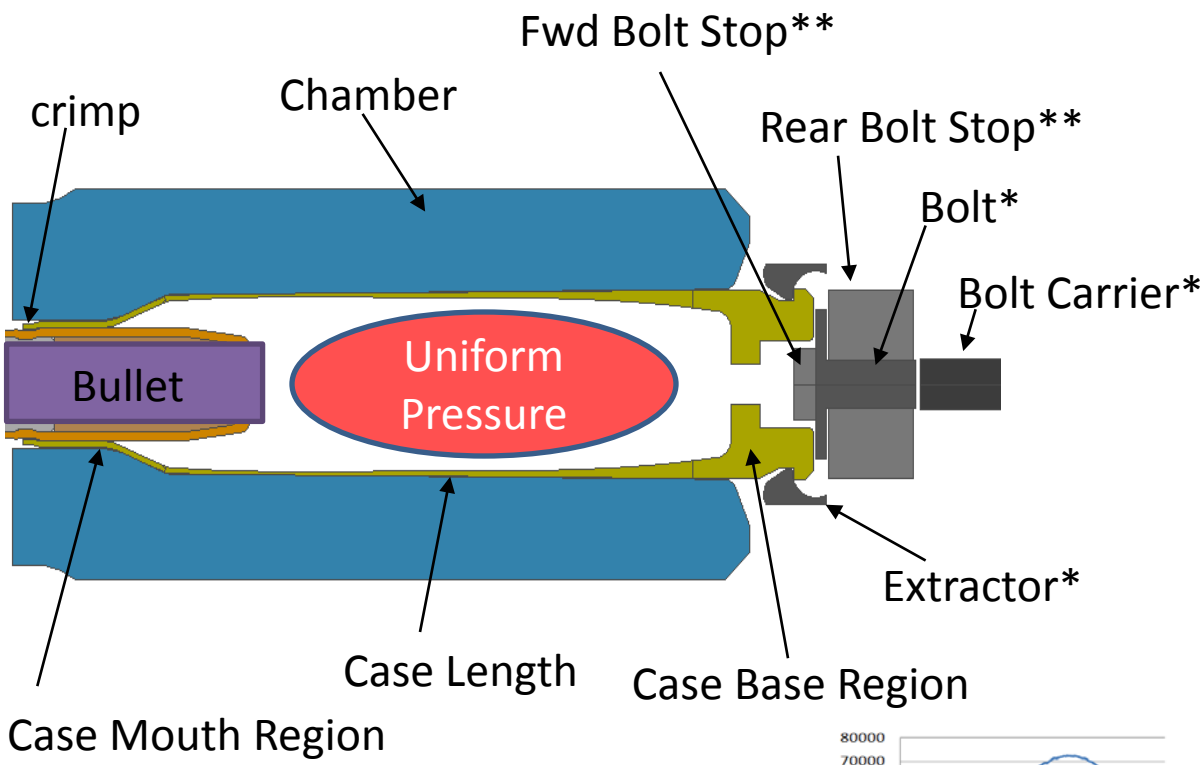
Modeling, Simulation and Engineering Analysis (ARDEC)

- Baseline the brass cartridge case using test data
- Apply loads/constraints to replicate failure
- Enhance knowledge of failure mechanisms by studying what can be shown in testing
- Identify/Quantify failure mechanism(s), verify with testing
- Provide thorough understanding of mechanism(s) to support corrective action

This Brief is focused on the simulation and analysis conducted at Picatinny Arsenal used to support the overall investigation

Initial Models

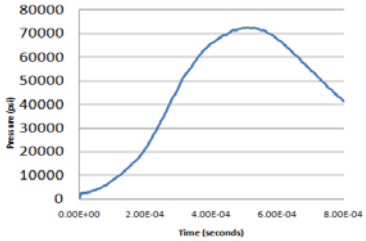
2D Axis-symmetric FEA Models

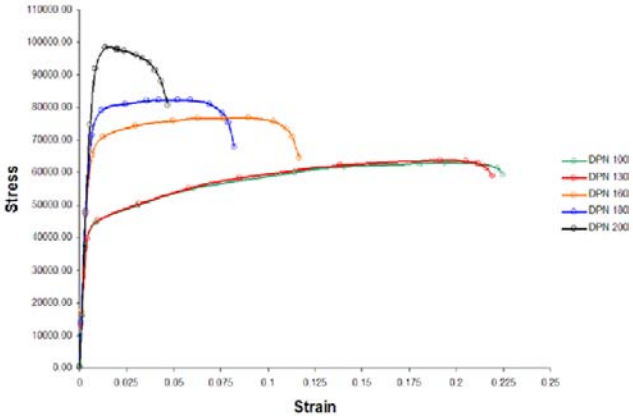


**Simplified for Axis-symmetric model*
*** This geometry sets the head space*

Analyses:

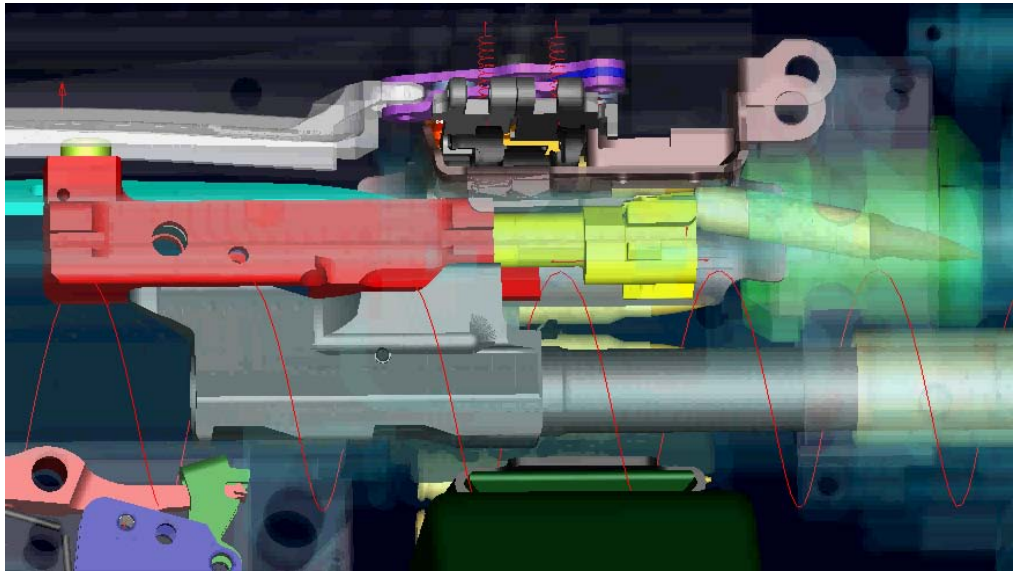
1. Pressure variation
2. Bullet drag on case
3. Head space variation and cartridge location
4. Extraction loads
5. Potential Case defect
6. Friction variation along case length
7. Bolt Face variation

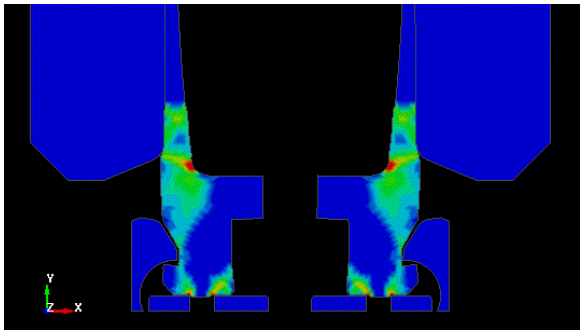




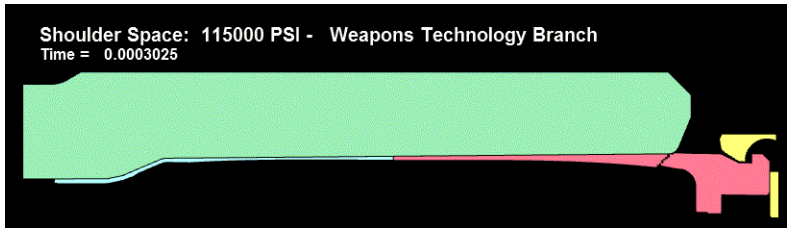
M249

Dynamic rigid body models used to capture timing and loads





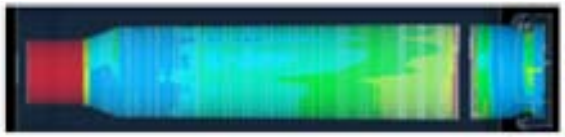
Case bulge from forceful feed of case with out-of-spec length



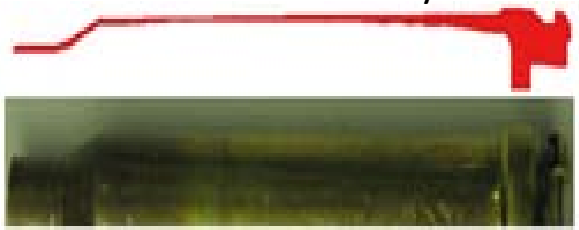
Typical fracture from too much head space: *no bulge*

Close, but backwards

Too much head space typically results in material separation due to exceeding the plastic strain material limits of brass . The failures experienced were not of this nature.



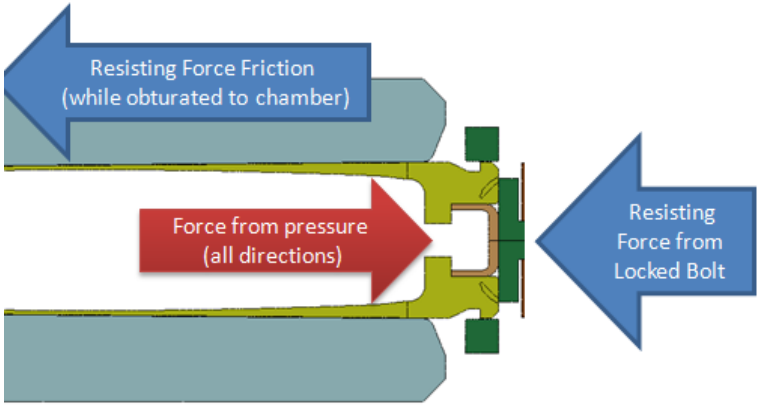
Initial simulations closely replicated case deformation by preventing case to seat properly, or by having a case length that was out of spec. However, M249 operating group was shown (simulation and testing) to be unable to lock and fire if cartridge case prevented from seating in this manner. These simulations created this case deformation by FORCING the bolt closed.



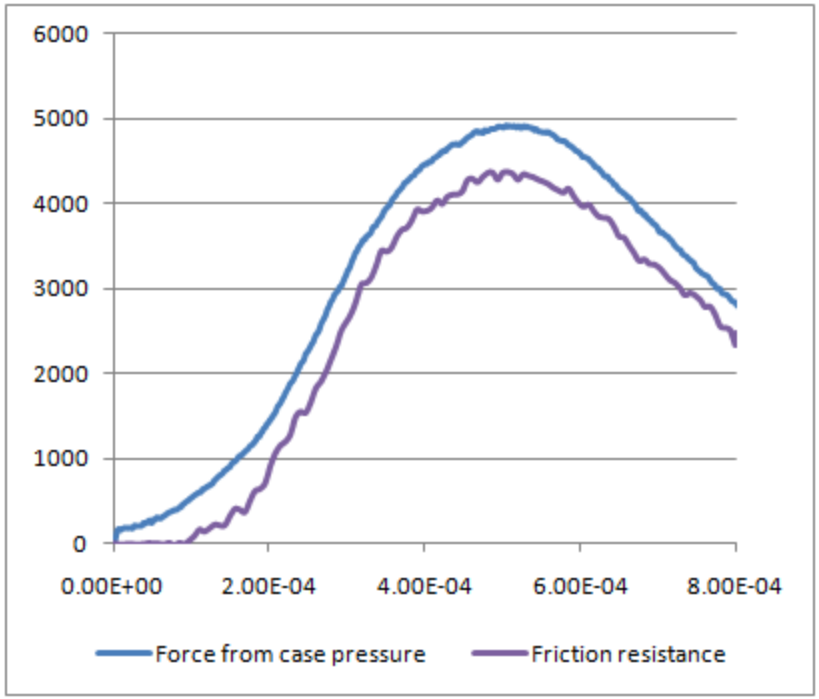
True: Case deformation comes from excessive force at the contact surface of the case and bolt face. However, the increase in force is not caused by head space, and not by pressure alone.

To generate enough bolt face force from a pressure increase alone, the 2D simulations suggested peak pressures well over 90,000 psi would be required, if all else is nominal.

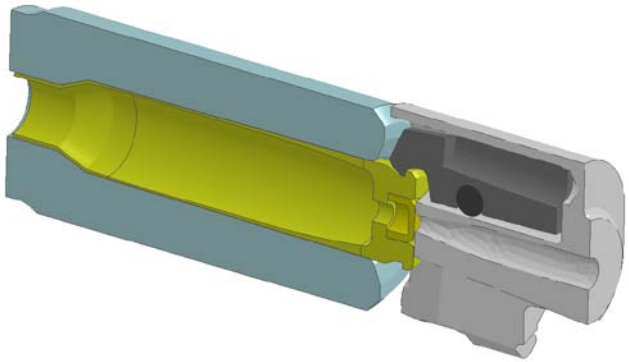
Mechanics of Case loading



Inside area of cartridge case near base:	$A_{case} := 0.068in^2$
Outer diameter of case length:	$OD_{case} := 0.375in$
Length of obturating case:	$L_{case} := 1.230in$
Peak pressure of P/T curve:	$P := 72000psi$
Force against bolt face from Pressure:	$F_{press} := P \cdot A_{case}$ $\quad F_{press} = 4896lbf$
Pressure at contact surface between case and chamber:	$P_{wall} := 12000psi$
Coefficient of Friction between case and chamber:	$\mu := 0.25$ ← Highly Variable
Resistance force from obturation friction:	$F_{\mu} := P_{wall} \cdot (\pi \cdot OD_{case} \cdot L_{case}) \cdot \mu$
	$F_{\mu} = 4347lbf$

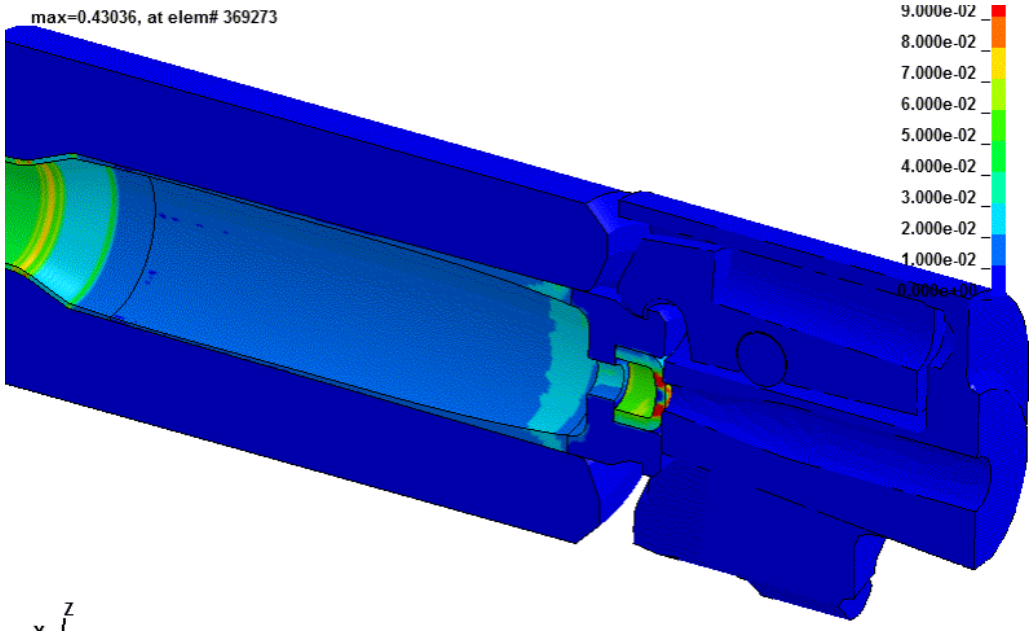


3D Models



Modeling info

- ½ symmetry (along bolt geometry)
- 500,000 nodes, 2hr run on 32 cpu
- Tet-mesh bolt and extractor
- Hex meshed case and chamber
- Extractor Spring simplified to force
- Uniform pressure assumed

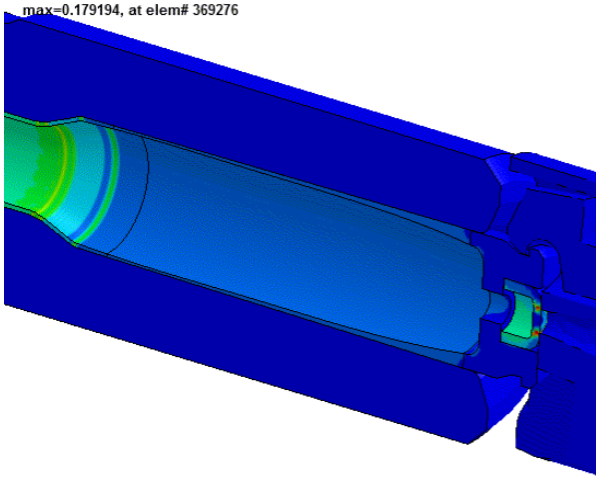


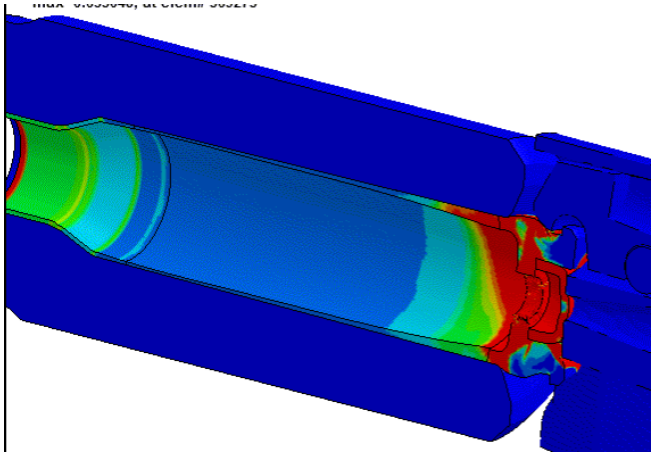
Baseline model

- 72ksi peak pressure
- Friction 0.3s/0.15d
- Red= Plastic strains exceeding 10%

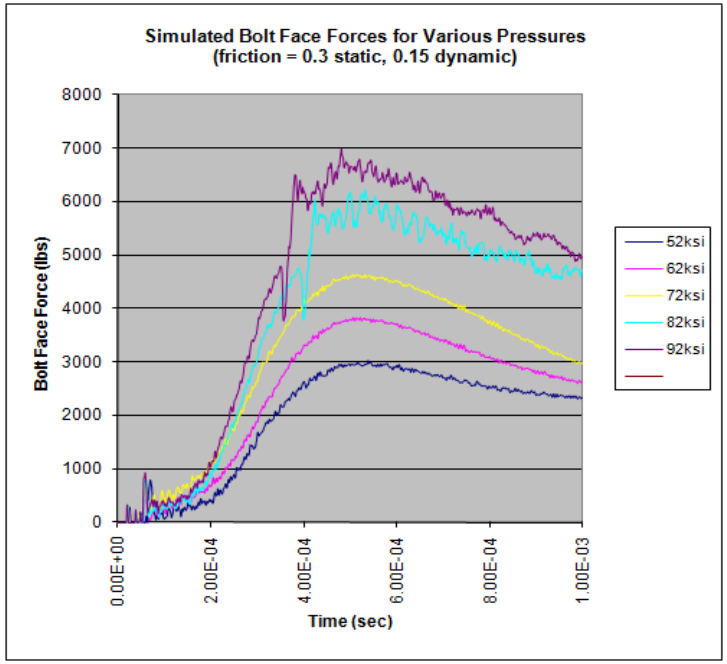
Bolt Face Forces…from Pressure

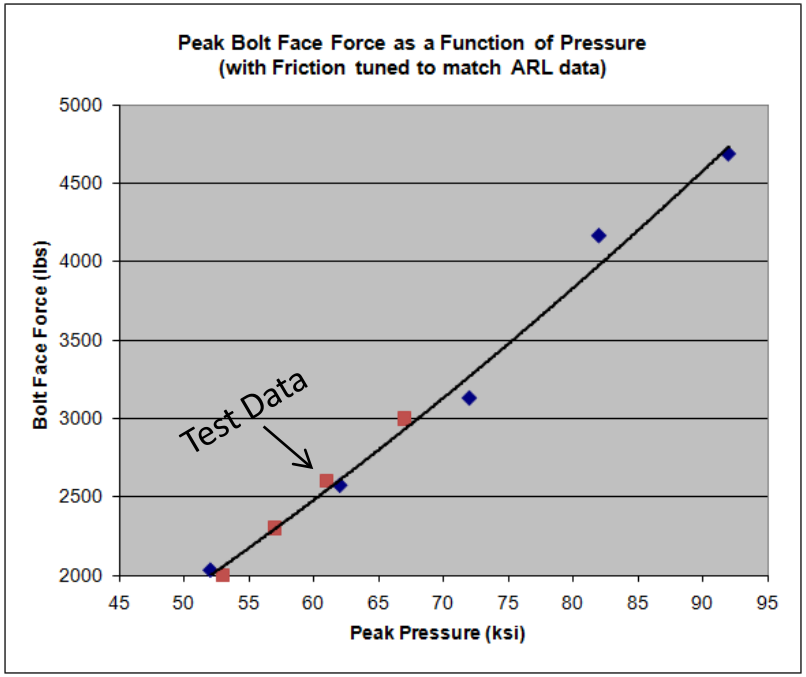
50 ksi





90 ksi

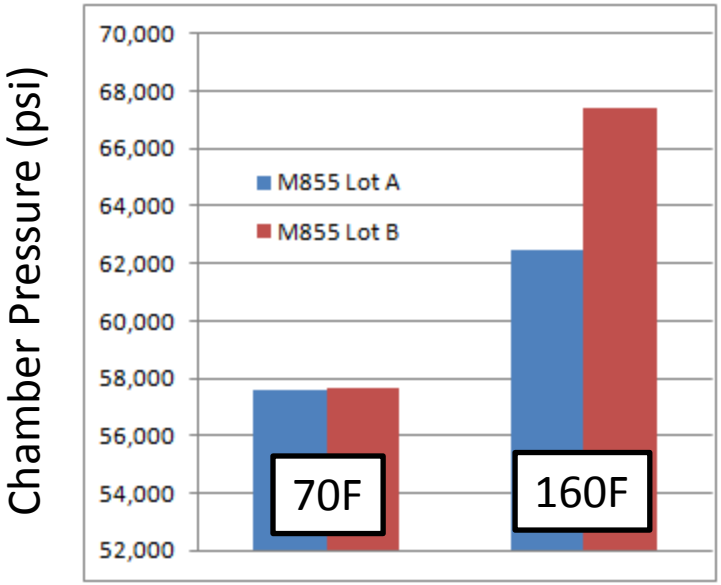




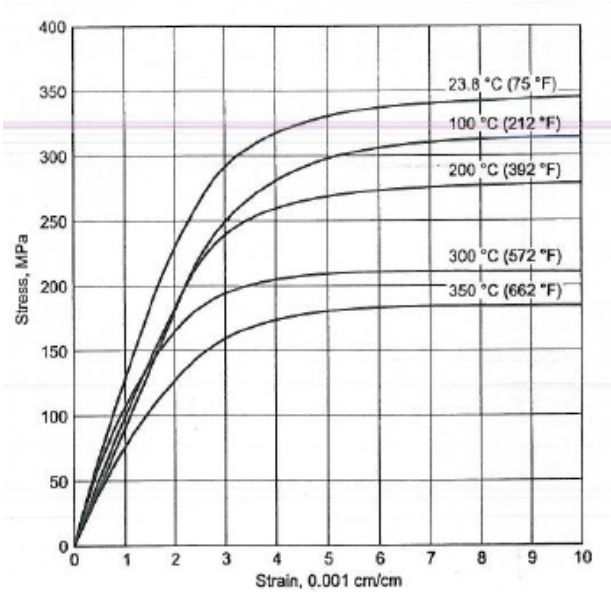
Bolt Face Forces…from Temperature

Pressure variation as a function of temperature.

(Test data generated by ARL (Brosseau/South) showing pressure increase with temperature increase for M855)



Stress Strain response to temperature increase, for a given hardness

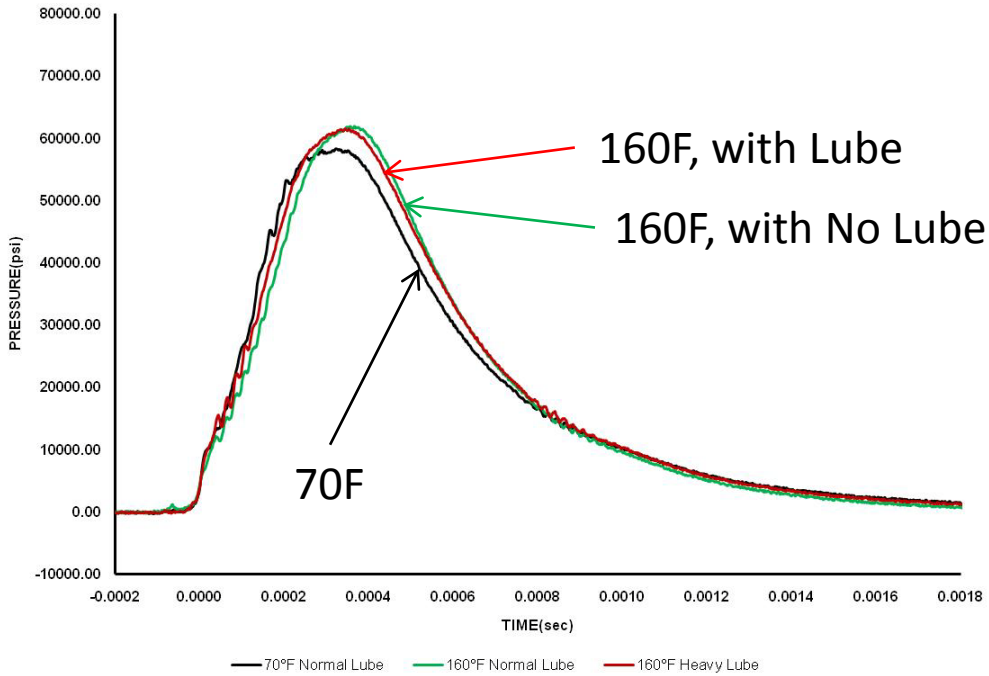


Pressure variations from lot-to-lot, and test-to-test broaden the scope of the analysis. Evaluate concepts, not individual products.

Yield Strengths and flow stress are reduced at higher temps. However, only slightly (~10%) in the temp range of interest.

Bolt Face Forces…from Lubrication

Testing shows NO increase in pressure from lubrication



M855 Test data generated by ARL (Brosseau/South)

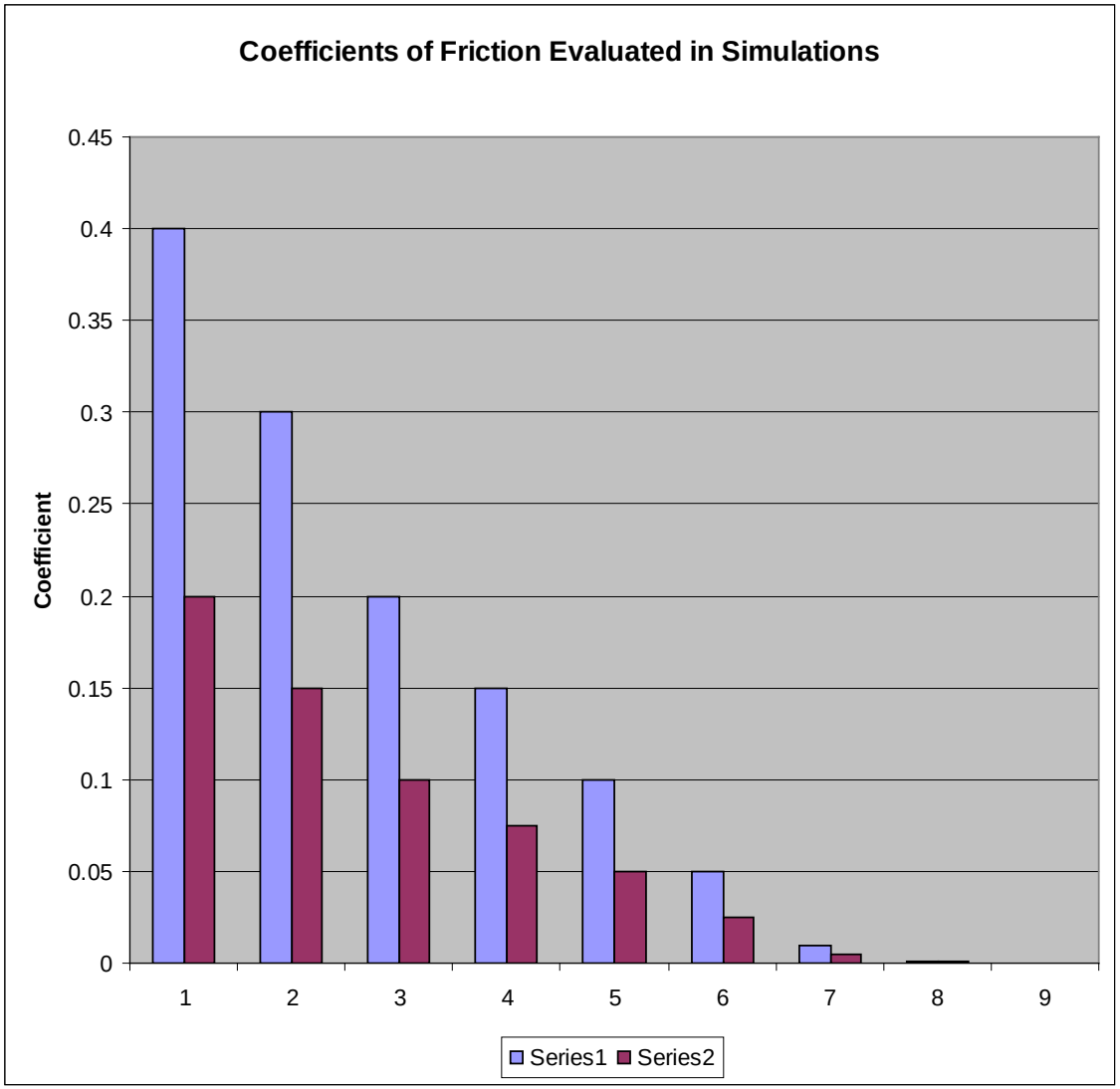
Friction in Chamber

Typical Static-Dry Coef. Frictions

Steel	Brass	0,35
Steel	Steel	0,78

Lubricated steel-brass can drop to μ = 0.05 or lower

Dynamic (sliding) Frictions are typically 25-75% of static

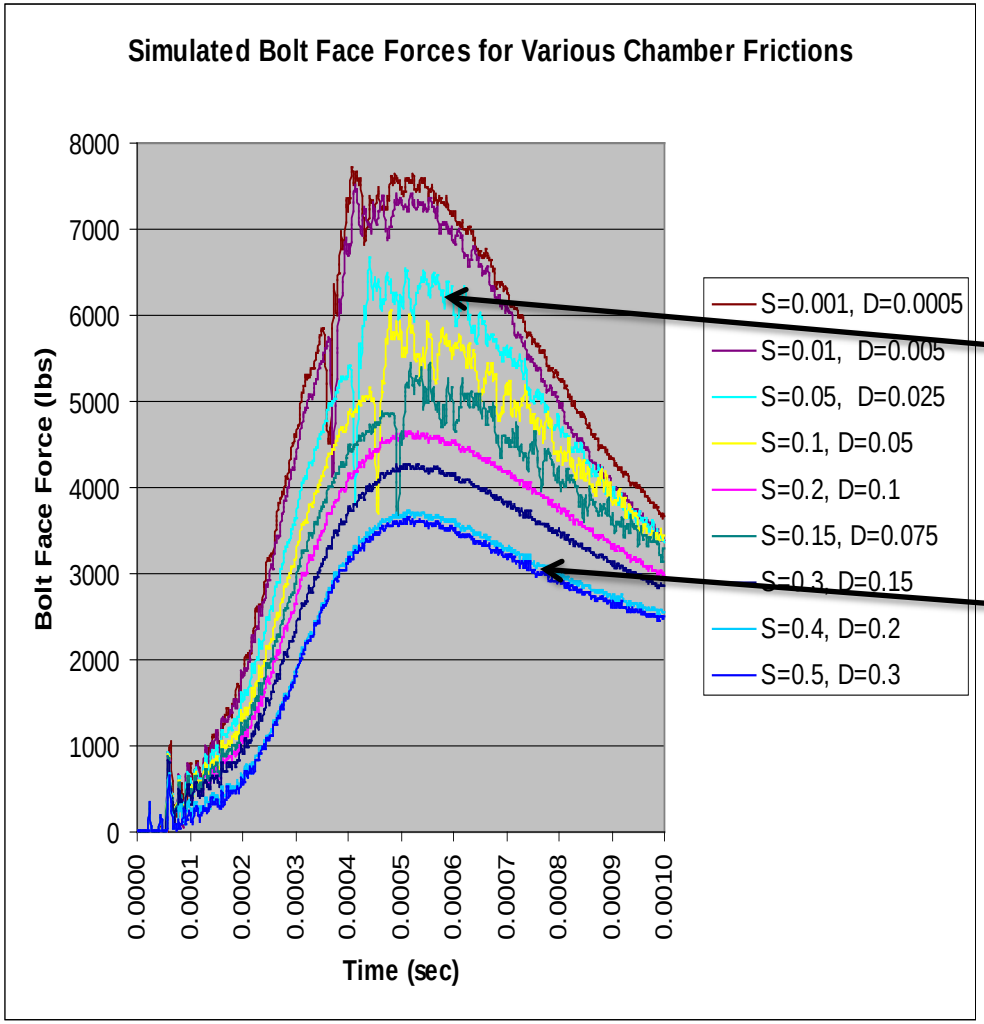


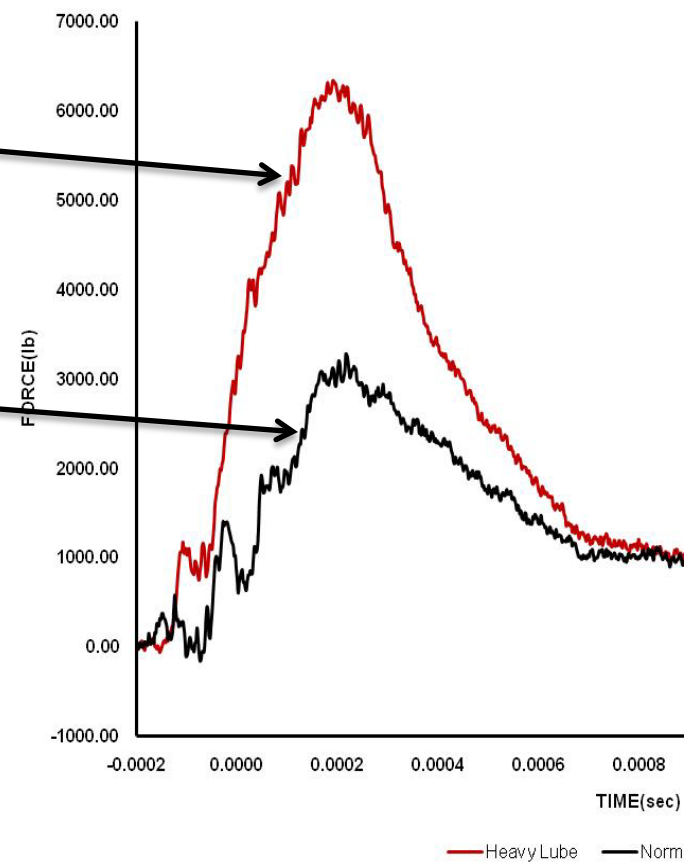
Bolt Face Forces…from Lubrication

S = Static coefficient of friction (μ)
D = Dynamic coefficient of friction

All sims done at 72ksi

Data gathered by Brosseau/South agrees with data generated by Minisi

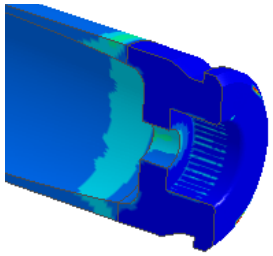




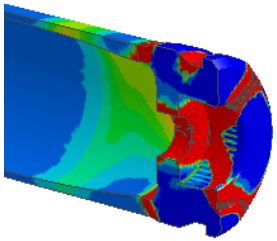
Bolt Face Forces…from Lubrication

All sims at 72ksi peak pressure

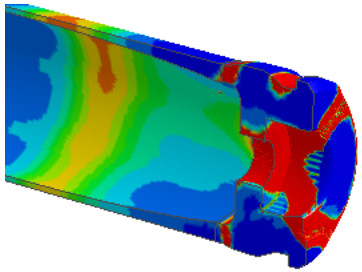
S=0.3, D=.15



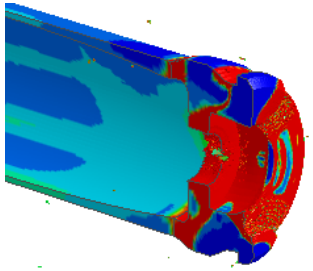
S=0.15, D=.075

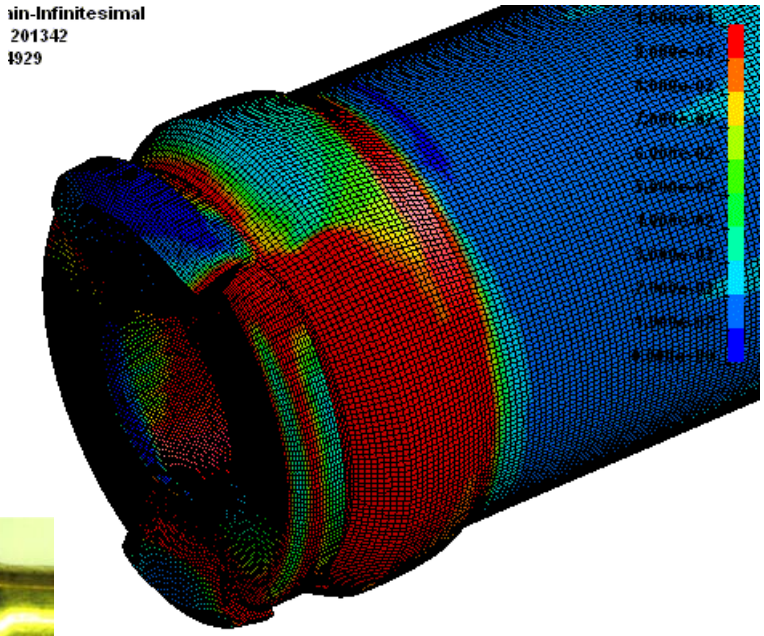


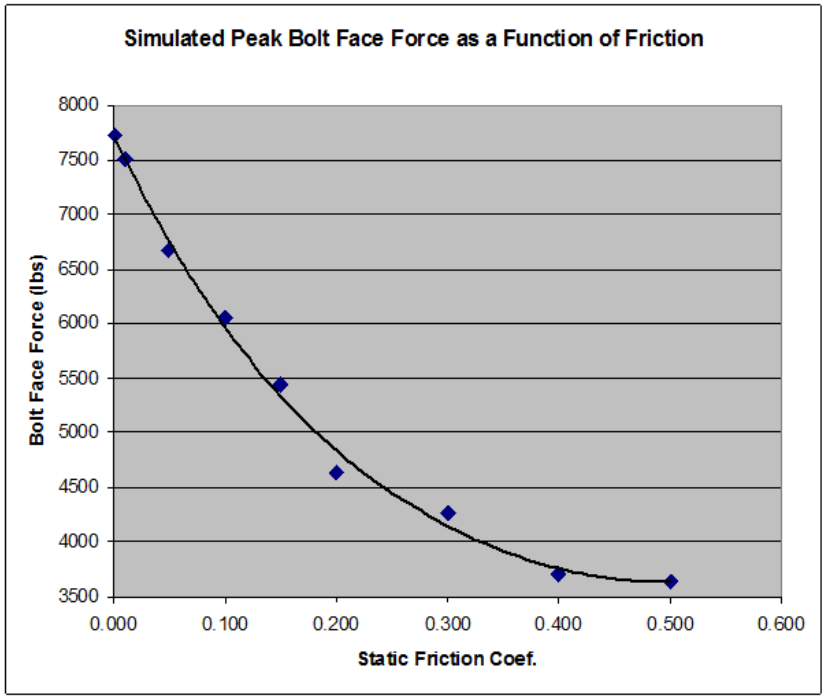
S=0.05, D=.025



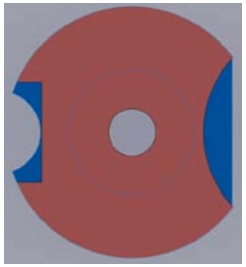
S=0.001, D=.0005



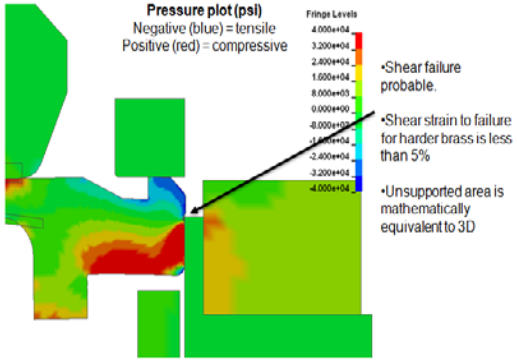


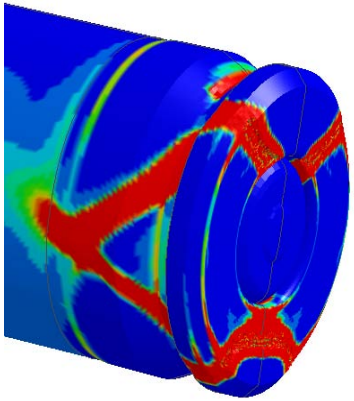


Bolt Face Geometry

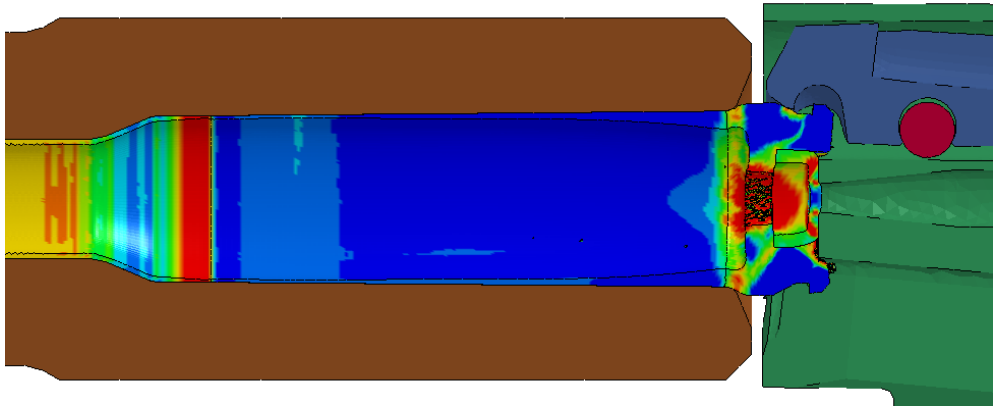


Pictures courtesy of ARL-TR-5377 (Brosseau/South/Michlin)



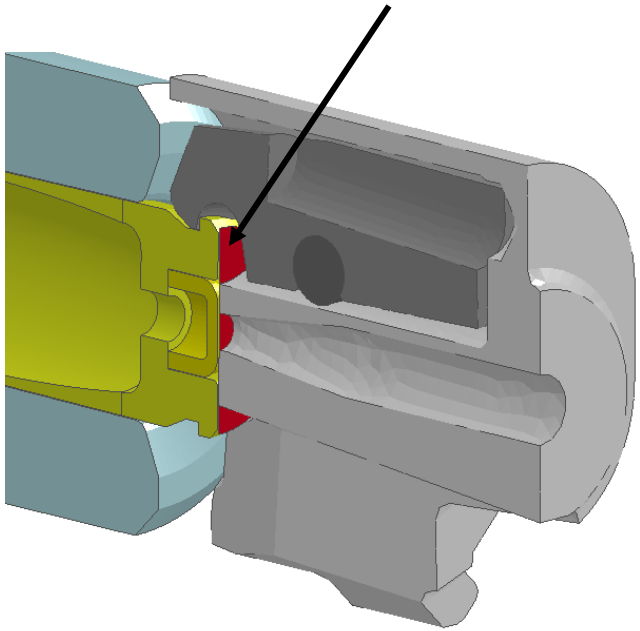


Recall:
Failures occurred on M249, not M4/M16



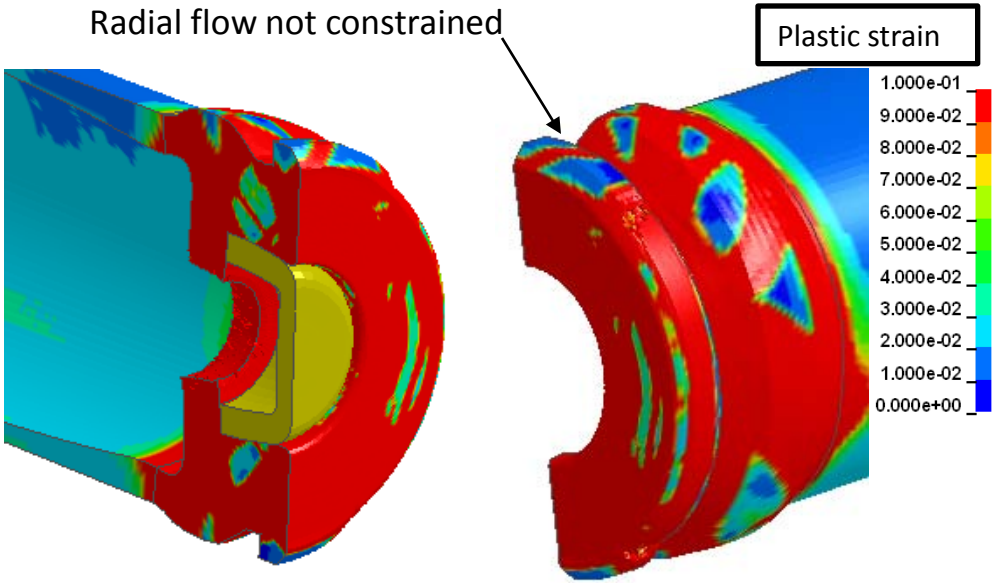
Supported Bolt Face

Rigid-body disc supports bolt face AXIALLY in this simulation

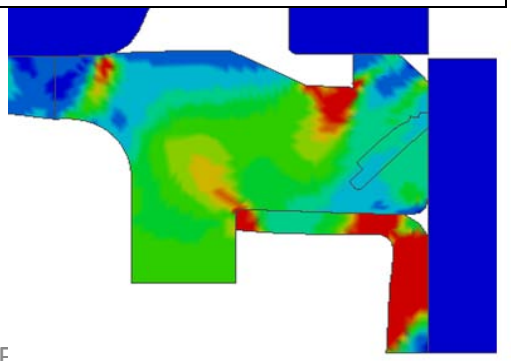


Simulations at 72 ksi

Radial flow not constrained



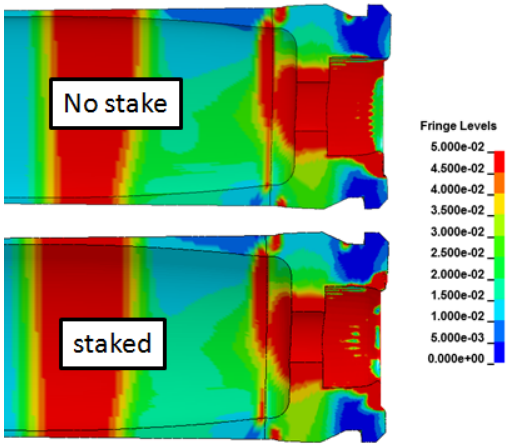
Radial flow contained, bulging in unsupported region is prevented

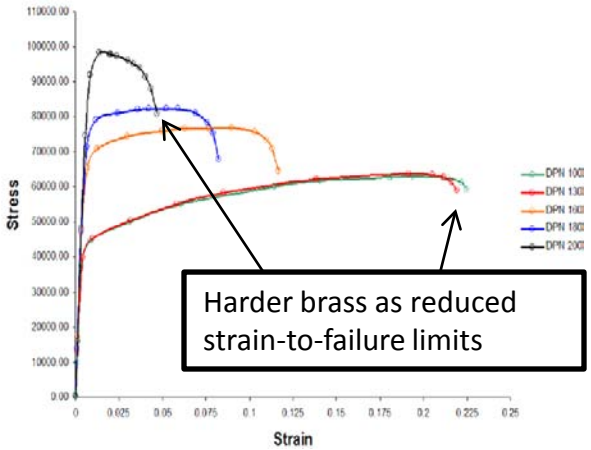


Prevention of axial flow ***alone*** is not enough to stop case bulge at 0-friction

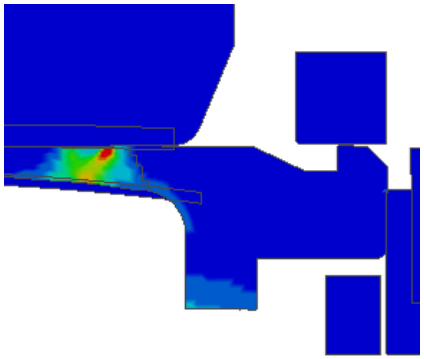
Staking and other "defects"

72ksi with nominal friction



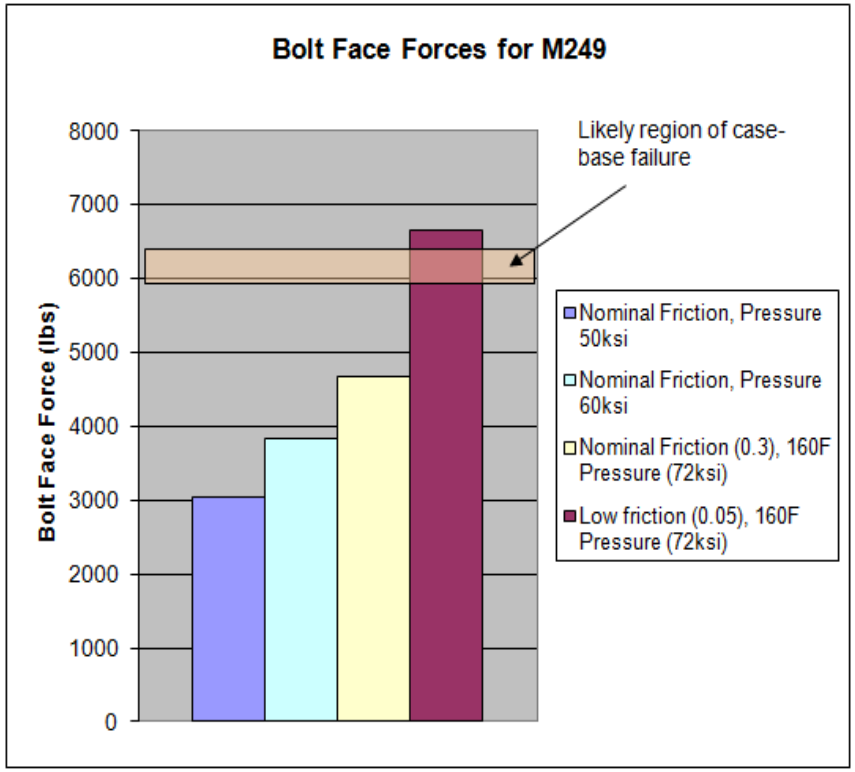


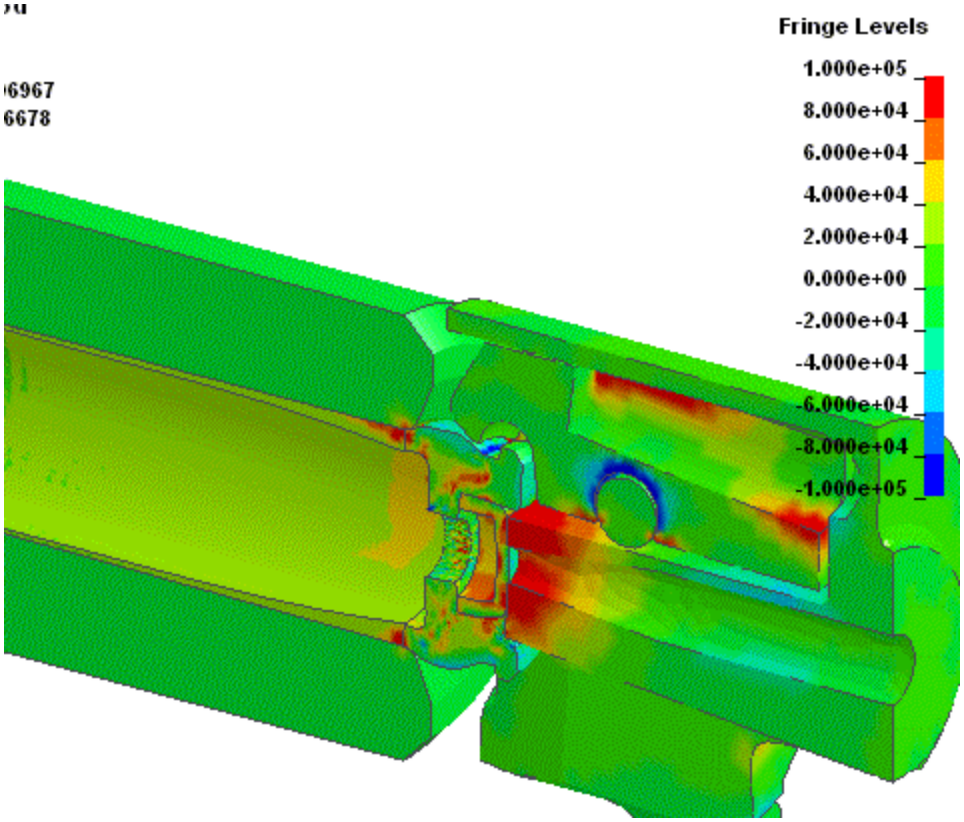
Proposed "roller defect"



- Stress/strains put into case from observed defects are overcome by the much larger stress/strains caused by material flow into bolt face
- Minor defects create stress concentration points
- Potential for crack propagation should increase wherever stress concentration point is placed in "hard" brass.

Combined loads





- 1000 lb jump in load for 10,000 psi pressure increase
- 2000 lb jump for reduction in obturation friction (μ= 0.05)

Summary

1. Nominal bolt face forces in ambient conditions (temp/friction) are around 3000 lb

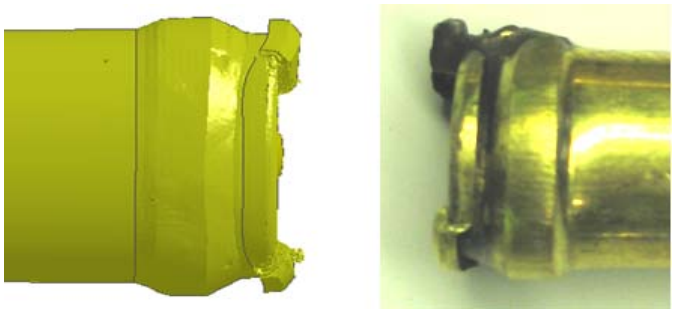
2. Case extrusion and resulting failure occurs around 6000 lbs of bolt face force, in M249

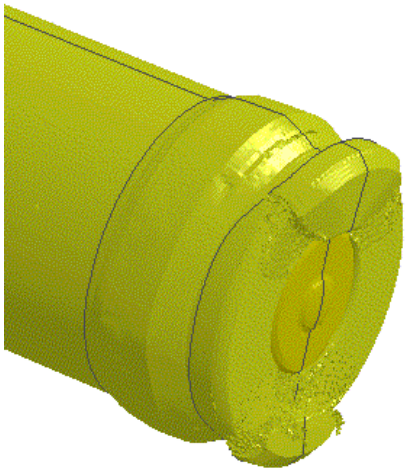
3. **Pressure** increase of ~10,000psi can increase bolt face load an *additional* 1000 lbs

4. **Lubrication** in Chamber can increase bolt face load an *additional* 2000 lbs (μ=0.05), 3000 lbs (μ near zero)

5. Failure less likely to occur on M16/M4 bolt face due to better **case support**

6. These failures should occur regardless of staking or other defects presence/absence





DO NOT ALLOW LUBRICATION TO COME BETWEEN CARTIDGE CASE AND CHAMBER