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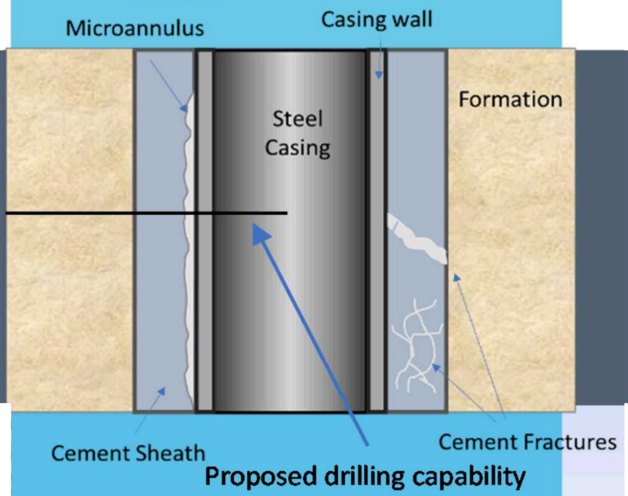
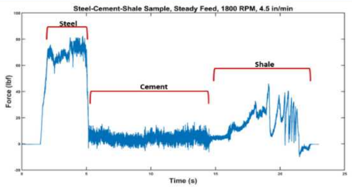
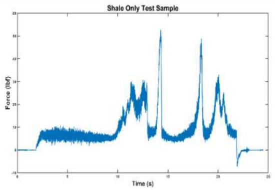
Material Transition Detection in Drilling Using Data Analytics







McBrayer, K.L.
Sandia National Laboratories, Albuquerque, NM, USA
Su, J.C., Gonzalez, L.M., and Pope, J.S.
Sandia National Laboratories, Albuquerque, NM, USA

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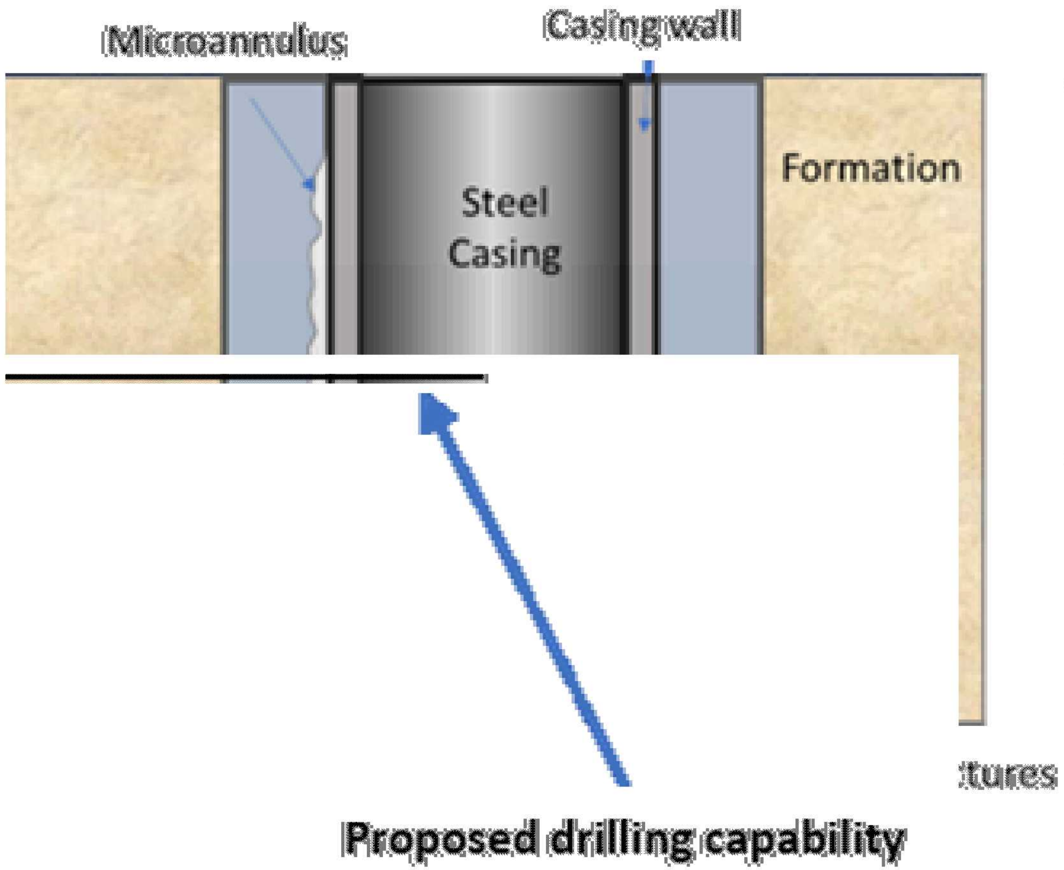
Introduction

- Wellbore Integrity is a significant environmental and energy security problem for our nation
- 30% of the 4 million wells worldwide show signs of integrity failures (Davies et al., 2014)
- Current industry paradigms for well design include using cement as a barrier, however many cementing problems go undetected (Yakimov, 2012)
- Evaluation, characterization and remediation of wells has become a priority for industry, regulators and the public

Challenges and Approach

- Wellbore integrity assessment relies on a combination of indirect measurements (through casing) and models to assess these very complex systems



- We propose a new capability to drill precision holes (at depth) through the sidewall casing
- These small diameter holes would enable direct, precise measurements in the cement that indicate potential failures

Current methodologies

- Existing methods require fiber optic or sensor placement during well construction
  - Expensive, technically challenging, could introduce fluid leaks
  - Applies only to NEW wellbore installation—does not address aging wells that may be failing
- Our approach would entail intentionally breaching the casing in a controlled manner to enable precise assessment
  - Enables the future development of smarter, effective, remediation techniques/materials that are tailored to the wellbore flaw, reducing risk to the entire well

Focus

- Data analysis to characterize mechanisms of micro-drilling in wellbore material (shale, cement, steel)
  - Develop ability to predict properties and transitions ahead of drilling
  - Enables optimization of drilling conditions to suit wellbore formation
  - Enables precise placement of sensor package for long term monitoring

- Foundational step towards the development of fully autonomous well drilling that could automatically adjust drilling parameters to minimized or avoid drilling dysfunctions

Bench Top Testing Set-up

- Simulates micro-drilling into a wellbore casing

-ball-screw driven
-carriage mounted spindle actuated using servo-driven ball screw
-Linear rail guides
-Plastic shield for protection
-EMO switch
-servo motor that acts as pulse generator and controls step size and direction
-CNC machine controller software
-NEMA23 stepper motor
-Lathe head with multi-axis bearings

Test Samples

- Simulates materials in a wellbore—Mancos shale, cement, and 1018 steel
- Bonded together with epoxy
- Samples were made with the materials in different orders and separately
  - Allows better understanding of the force interaction between the drill and the individual material

Drilling Data Analysis

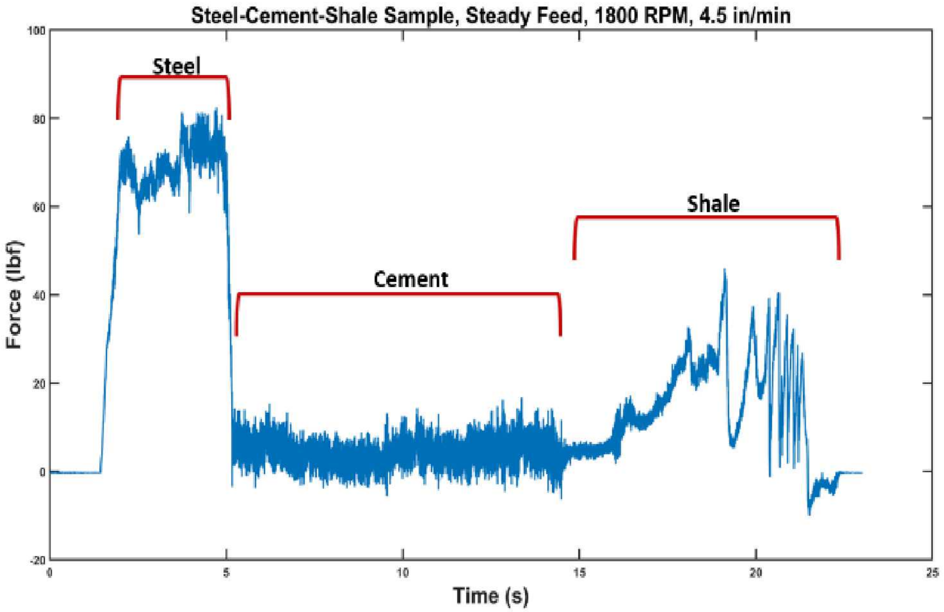
- “Standard” data was collected at 1800 RPM with a 4.5 in/min feed rate

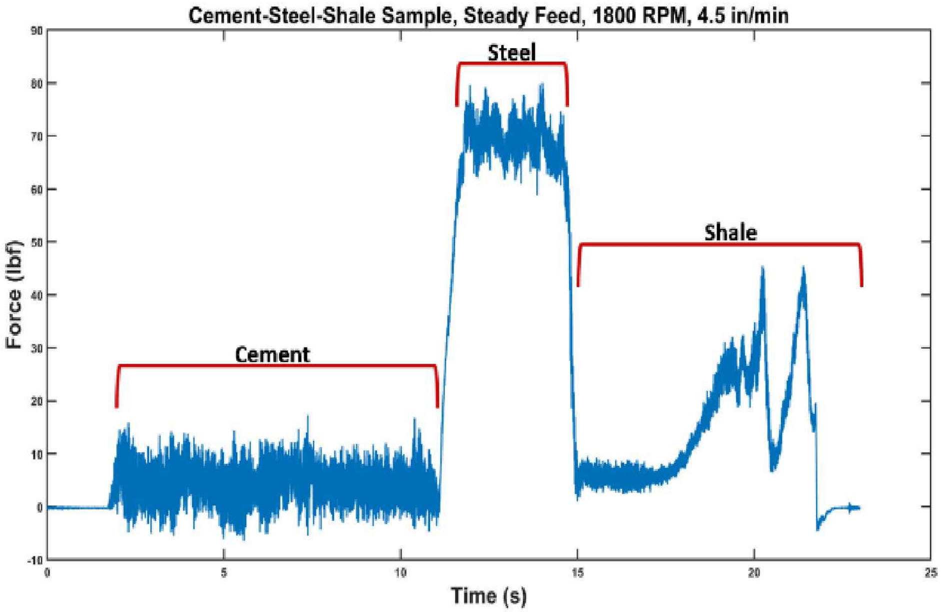
- Force and torque data were collected from the bi-axial load cell—highly correlated

- Chose to focus on force data
    - Focusing on fewer measurements better simulates real world applications and makes it easier to scale-up diagnostic tool later
    - Early indications show that the force data has a higher SNR than the torque data which allows for easier statistical analysis

Drilling Data Analysis—Material Sandwich

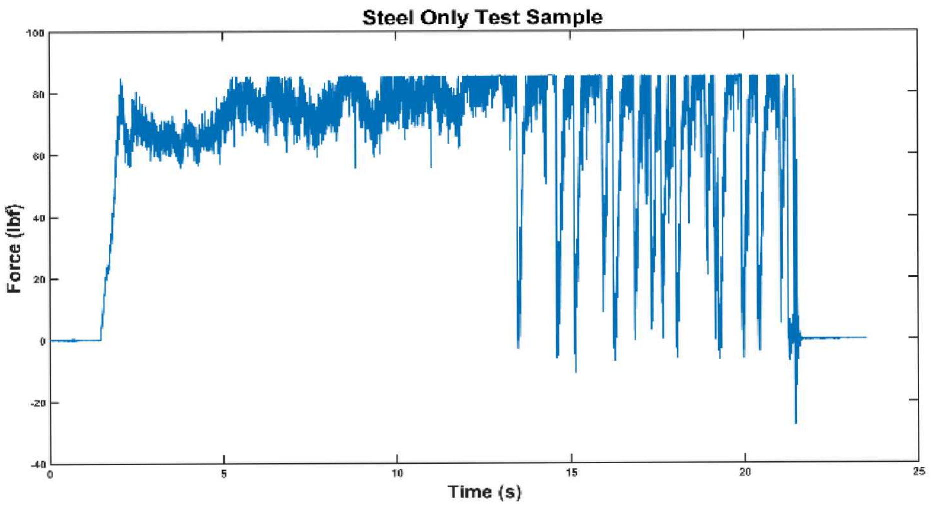
- Drill through 3 wellbore materials in succession, but in different order for each sample
- Shows unique force signature for each given material (steel, cement, shale) independent of drilling order

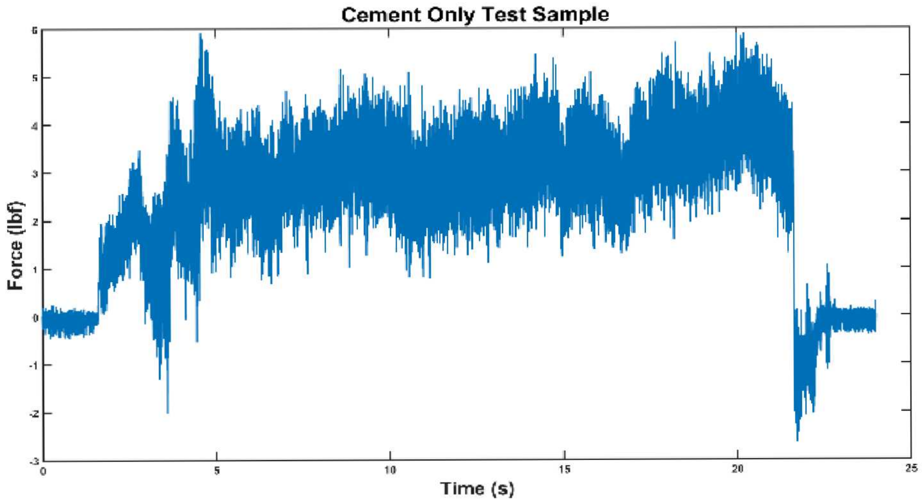


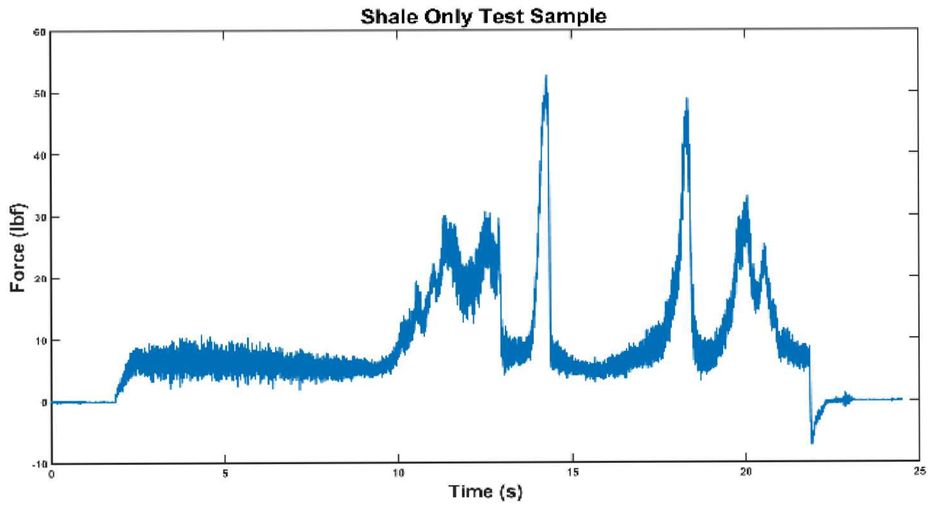


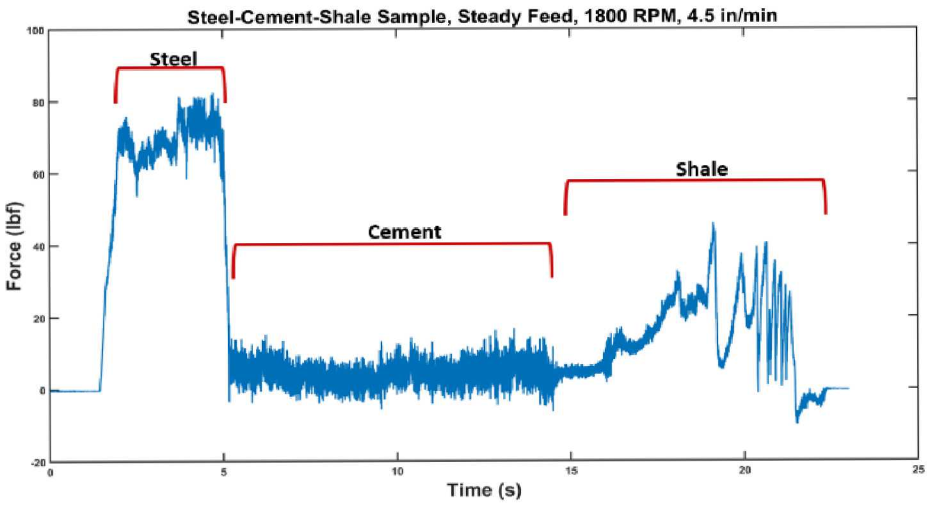
Drilling Data Analysis-Individual Material

- Also shows unique force signature for each material



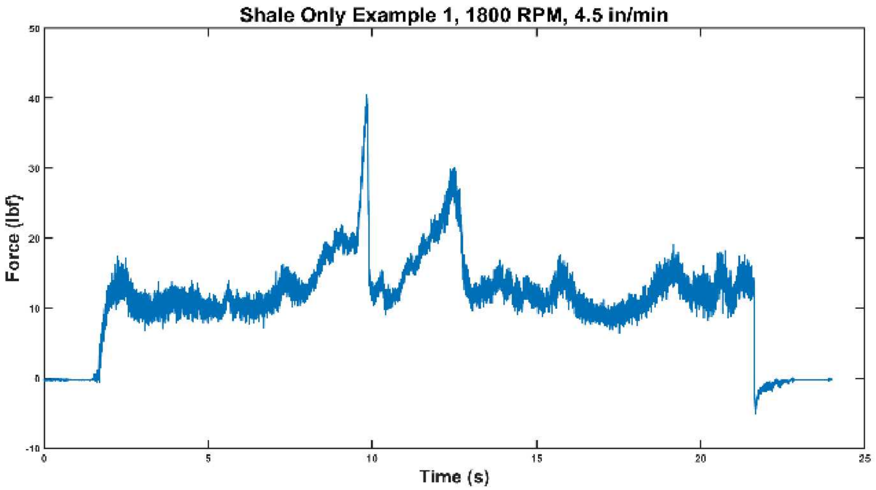


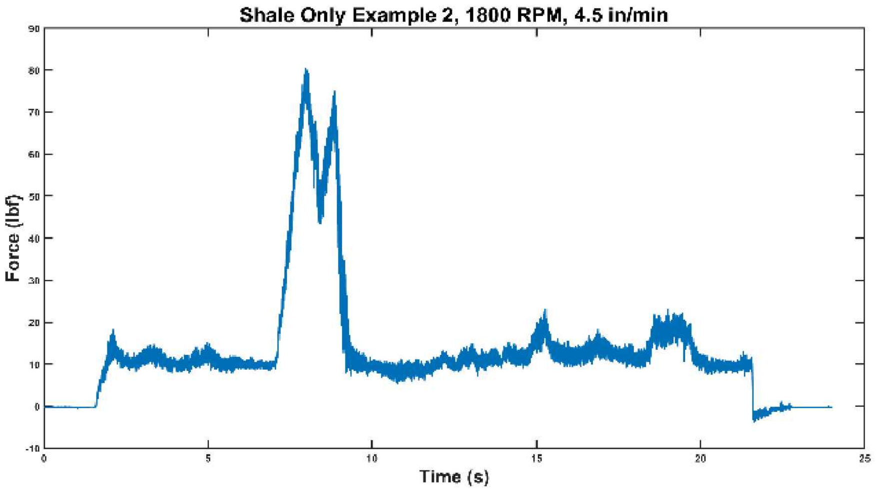


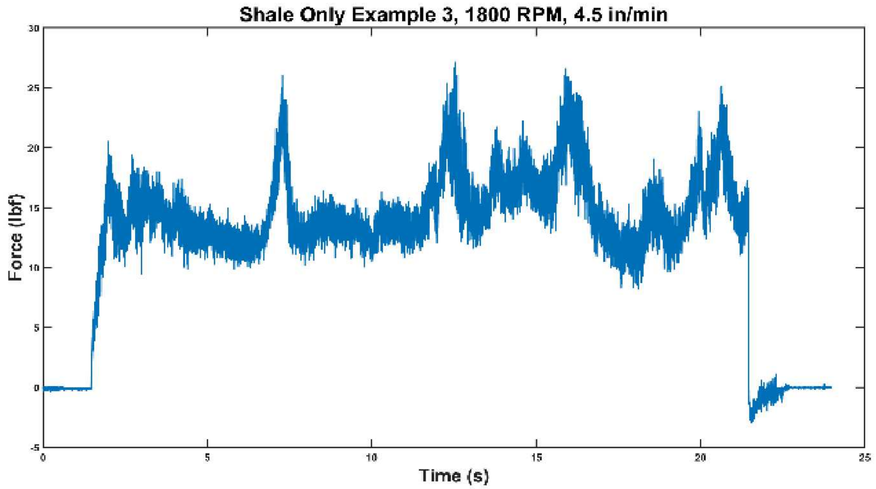


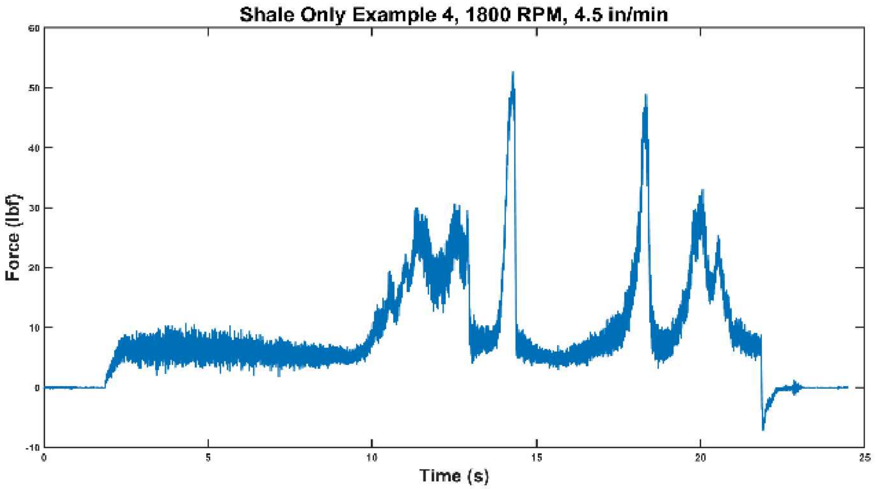
Drilling Data Analysis—Shale

- Nonhomogeneous composition that could caused unexpected force variability from sample to sample









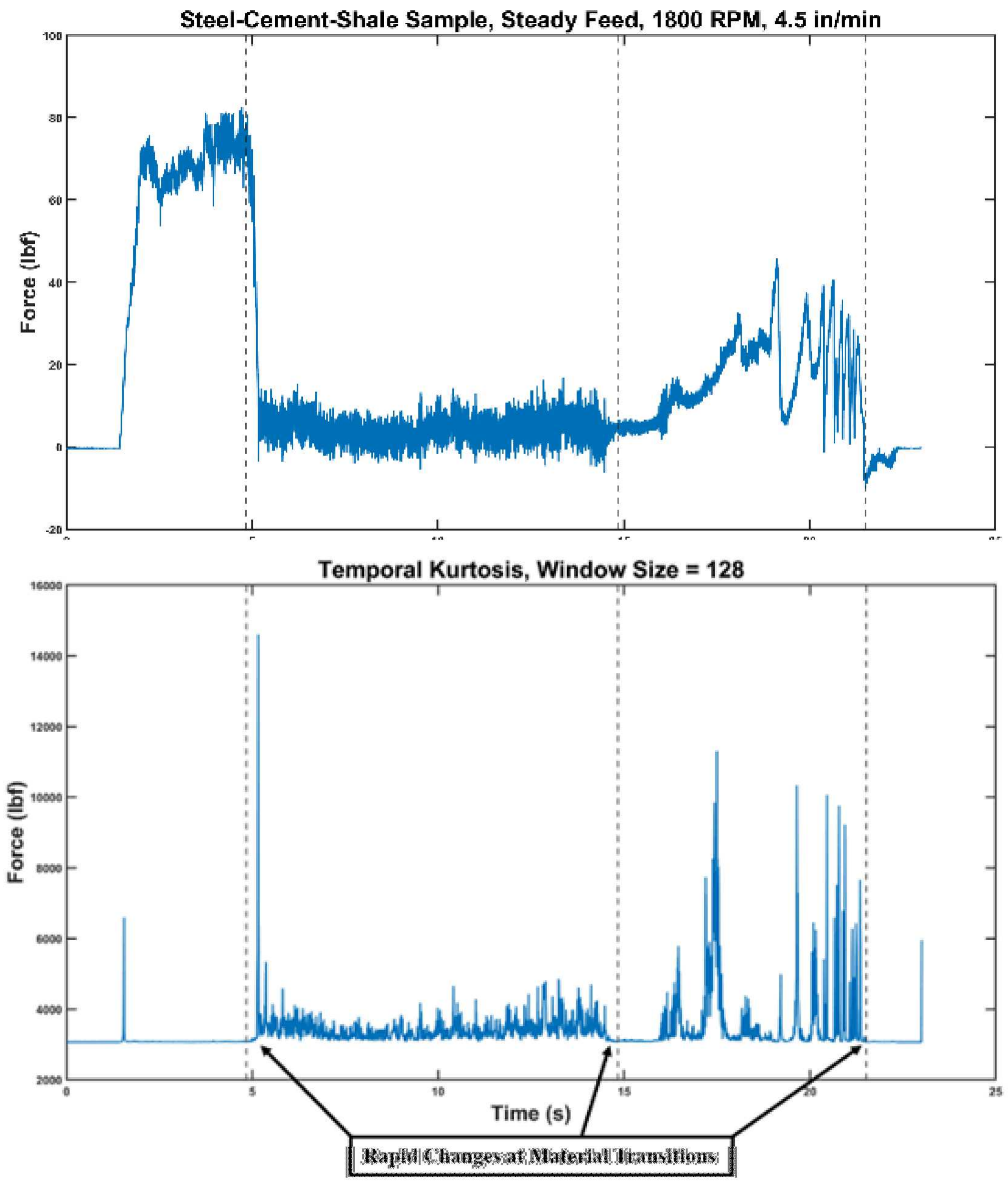
Drilling Data Analysis—Temporal Kurtosis

- Shows the extreme values of either tail of a distribution representing the “tailedness” of the distribution (Decarlo, 1997, Song and Cha, 2016)
- Identify any rapid changes in the force data which we hypothesize to be related to the drill’s transition between materials in real time

$$\boldsymbol{TK} = \frac{\frac{1}{N}\sum_{i=1}^{N}(\mu_i - \mu)^4}{\left(\frac{1}{N}\sum_{i=1}^{N}(\mu_i - \mu)^2\right)^2}$$

- Temporal kurtosis was chosen for a variety of reasons:
  - Variance alone proved to not be a reliable statistical measurement
  - Higher order statistics can reveal changes not seen at lower statistical levels
  - Simple measurement that could be performed quickly in real time and used as a feedback to our control system
  - Heuristic approach based on past algorithms we have used

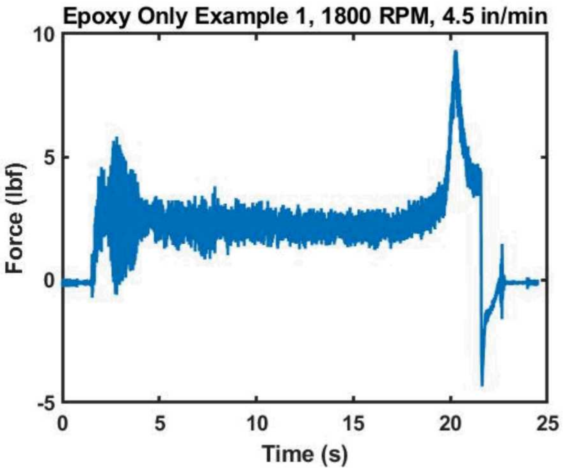
Drilling Data Analysis—Temporal Kurtosis

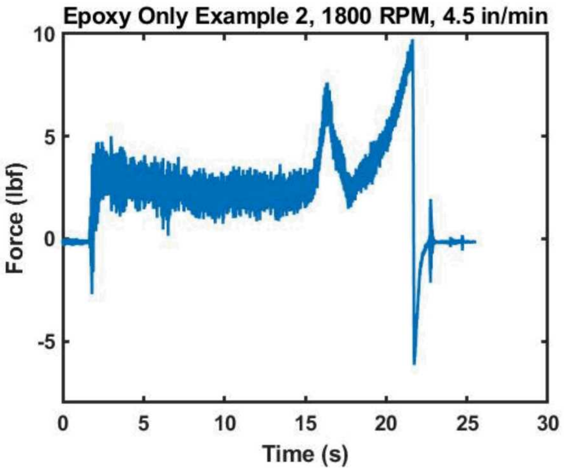


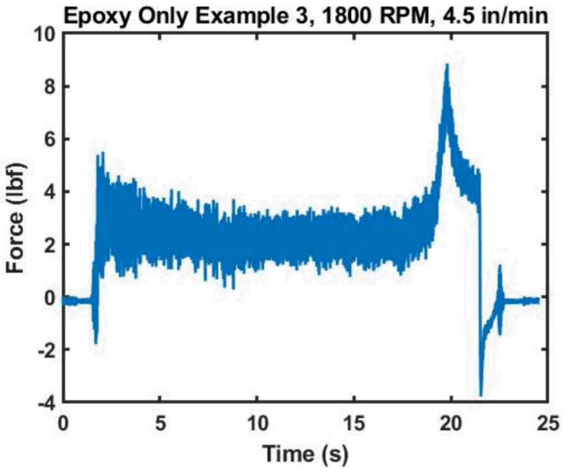
- Interesting phenomenon observed around 15 seconds—could be epoxy?

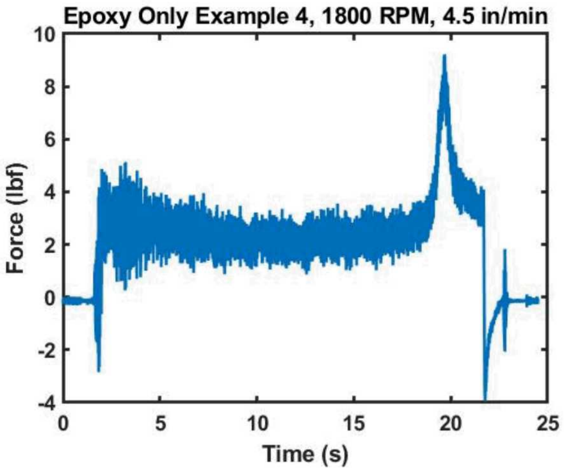
Drilling Data Analysis—Epoxy Only Samples

- Epoxy only samples show that it is possible that the material interfaces in the material “sandwich” test samples were affected by the epoxy
- Epoxy depth is unknown and could be affecting depth offset extrapolated from feed rate
- A linear position sensor was been obtained and hopefully will allow true depth of the drill bit with relation to the material.









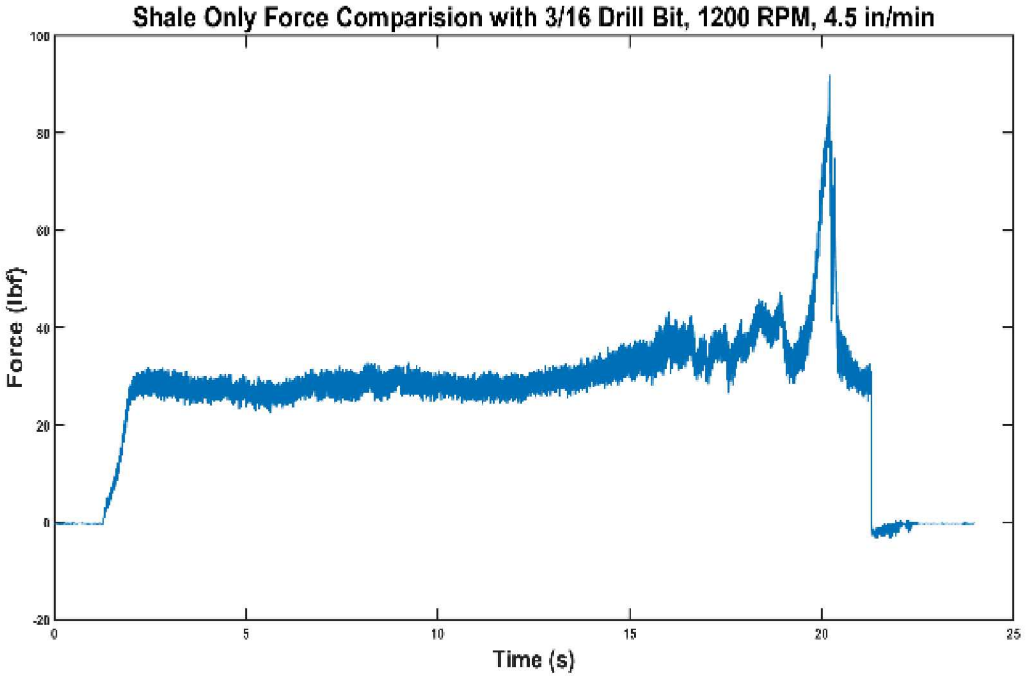
Drilling Data Analysis—Shale Cement Comparison

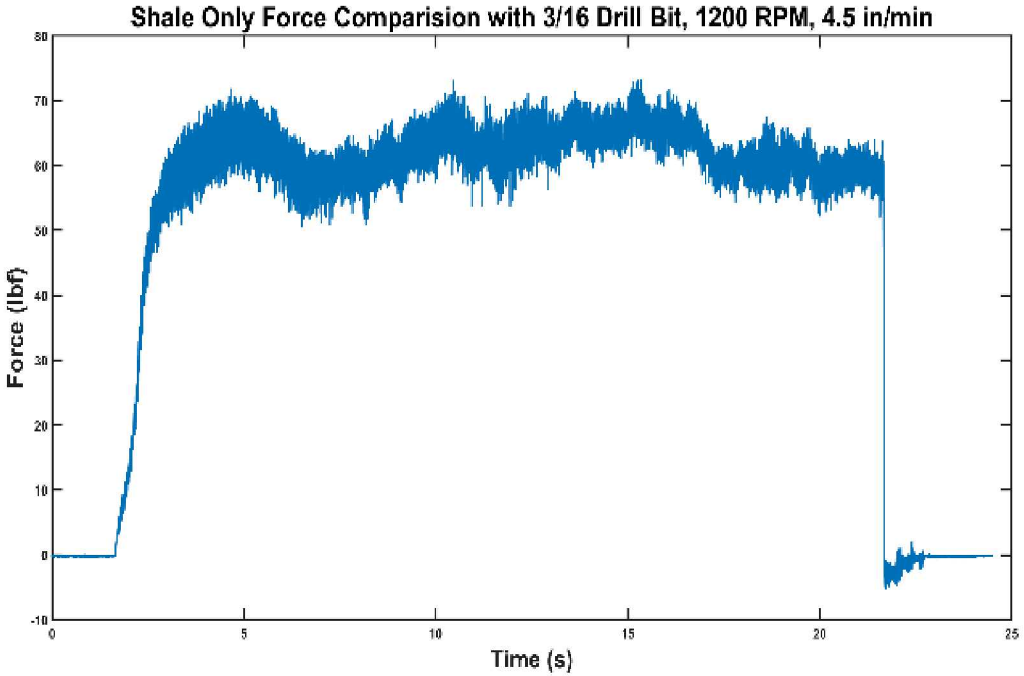
- Greatest Similarity observed between shale and cement materials
- Noticeable difference between variance observed in force data between the shale and cement materials
- Compared temporal variance between cement and shale materials
- Highlights inhomogeneous nature of the shale material versus the cement material

Shale Test #	Temporal Variance	Cement Test #	Temporal Variance
Shale 1	0.5773	Cement 1	0.2278
Shale 2	1.2759	Cement 2	0.2117
Shale 3	1.6078	Cement 3	0.2199
Shale 4	0.9323	Cement 4	0.2326
Shale 5	1.3284	Cement 5	0.2114
Shale 6	1.2656	Cement 6	0.2316
Shale 7	3.6535	Cement 7	0.2186
Shale 8	4.0809	Cement 8	0.2232
Shale 9	0.8130	Cement 9	0.2694

Future Work

- Experiment drilling at different rotational speeds, different feed rates, and/or different drill bit sizes
- Preliminary data was collected with a larger drill size of 3/16 inches (1200 RPM, 4.5 in/min feed rate)
- Seems to confirm inhomogeneity in shale material (independent of drill bit size)





Future Work

- Collect data with position sensor
  - Allow us to more precisely and accurately define exact moment of material transition with relation to depth placement
    - Better correlate temporal kurtosis as drill bit transitions between material
- Develop algorithm based around material variance differences—chi-square test?
  - IE: Large variance change = drill bit is in shale
- Explore machine learning applications and methods
- Explore higher order statistical methods to be used in coordination with machine learning algorithms
- Deeper analyze of torque data to possibly remove ambiguity seen in force data
- Determine whether there is a frequency dependence with variance

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