OilDoc Conference & Exhibition

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Lubricants
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Metal Forming and Deforming – An overview

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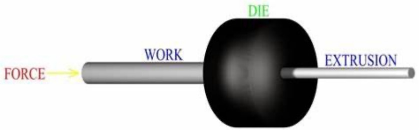
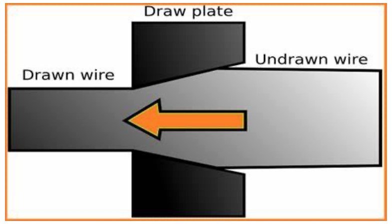
Overview

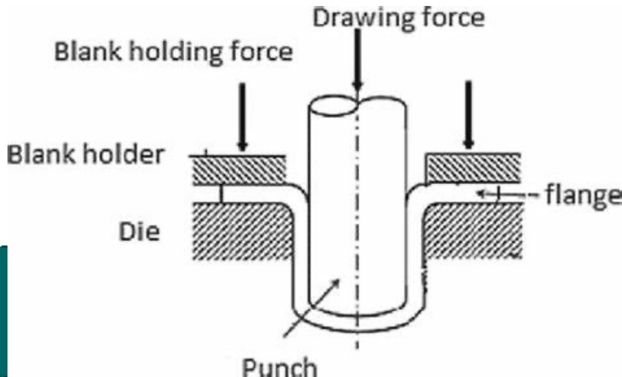
- Common Metal Forming Techniques - Overview
- Applications
- Metal Working Fluids and Tribology
- Benchtop Experiments – 2 applications:
  - Cold forming
  - Deep drawing
- Conclusions

Common Metal Forming Techniques

- Forging – via a hammer
- Rolling - heated and then formed into its desired shape by using a tool or die – also called bulk forming
- Extrusion - Small amount of metal forced through a die to create a long, thin piece of metal (i.e. rods, tubes)
- Drawing - die to draw the metal into the desired shape (wires)
- Deep Drawing - sheet of metal is placed into a die and then forced into the die using a punch

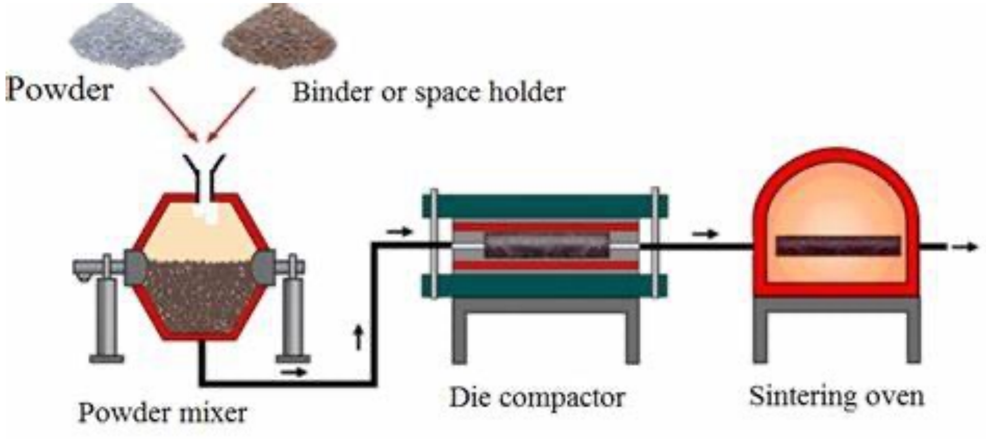






Common Metal Forming Techniques

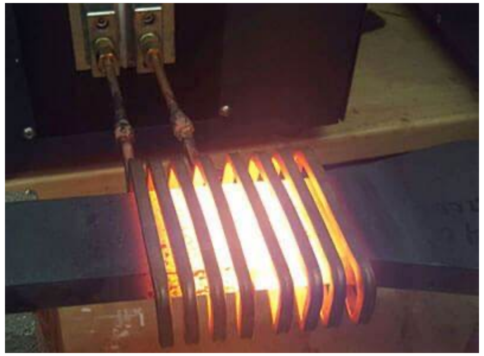
- Sheet Metal Forming - heated and then formed into its desired shape by using a tool or die
- Powder Metal Forming - small amount of metal heated then forced through a die to create a small, powder-like piece of metal. Used to create gears, bearings, and other small parts



Common Metal Forming Techniques

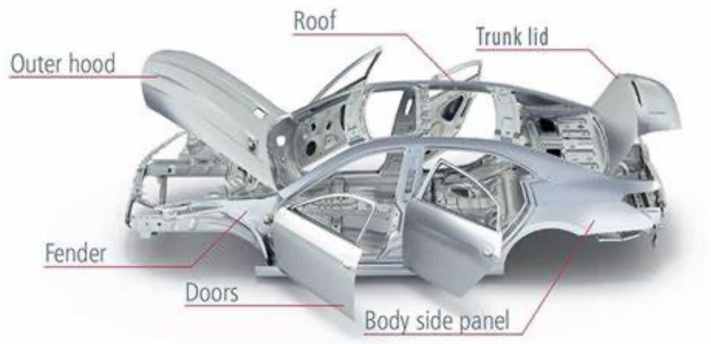
- Hot Forming - shaping metal at a temperature above its recrystallization temperature. High temp allows metal to deform easily, so can be shaped into complex parts. Used to make large parts with a high degree of accuracy
- Warm Forming – shaping metal below its recrystallization temperature
- Cold Forming - shaping metal at a temperature close to its ambient temperature

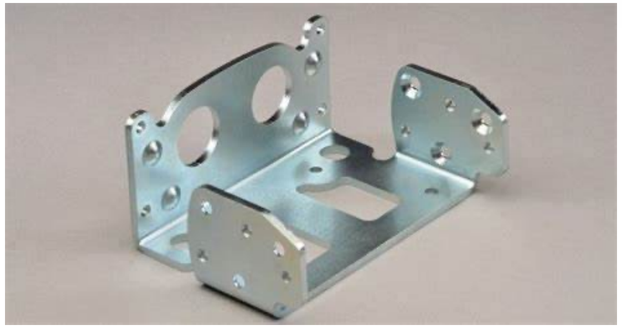
Complexity

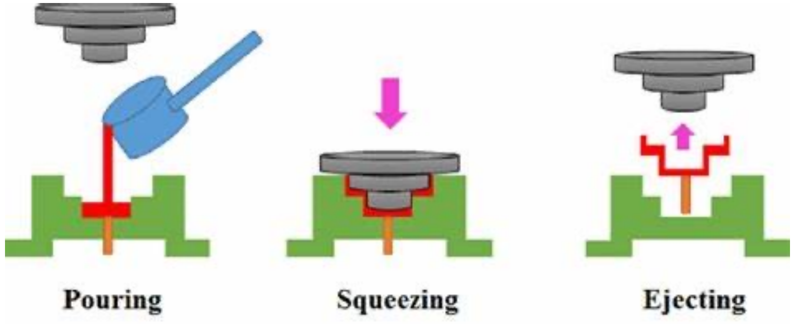


Applications of Forming Techniques

- Automotive Manufacturing – Body Panels
- Aerospace Engineering - fuselages, wings and engine components
- Construction - Pipelines
- Press working - squeezing, stamping or bending

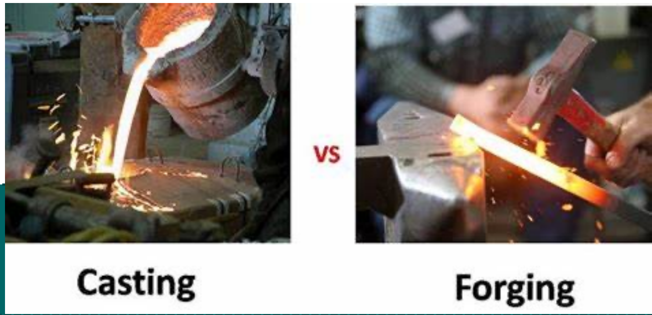






Advantages of Metal Forming

- Uses the simplest, most versatile, lowest-cost tools
- Can accommodate all shapes - thin sheet metal to heavy plate or tubing
- Little initial shaping, almost anything can be produced this way
- Forming processed products stronger, more durable than casting
- Cost savings for production companies that can operate metal-forming machinery at a faster rate than conventional tooling
- Processes allow for fabricating complex geometric shapes
- Great for shaping metal as quick, easy, and produces strong shapes that can often be reused



Advantages of Metal Forming

- Higher potential strength than forging or casting because it hammers through residual stresses before they get to the surface
- When using casting or forging, all stress concentrates at the surface making them more likely to crack or shatter if exposed to fatigue loads
- Minimum use of trimming means reduced scrap costs - benefit amplified in mass production
- Machines designed for both rough and fine metal forming processes
- Due to process efficiency, already reached a degree of automation not achieved with other sorts of fabrication processes

Disadvantages of Metal Forming

- High power input (large surface area contact) to ambient air - expensive equipment for heating and cooling
- Slow cycle time - up to 1 hour per piece if producing long rods or pipes
- Variations in part thickness can make it difficult to maintain accurate tolerances over the entire cross-section profile
- Requires investment in tooling upfront
- Forming Processes more expensive than casting
- Heating times depend on the material hardness, size, thickness, or weight
- Machine must be fully enclosed around the material as contact between steel parts will ruin their surface finish and lengthen their lifespan

Hot Rolling Ads vs Disads

- Low wastage of metal
- Elevated temps increase diffusion which can remove or reduce chemical inhomogeneities
- Decrease in yield strength hence lesser amount of force is required
- Greater ductility of material is available, therefore more deformation is possible

- Poor surface finish, reproducibility and interchangeability of parts
- Handling and maintaining of hot metal is difficult and troublesome
- Undesirable reactions between the metal and the surrounding atmosphere
- High electricity required for obtaining high temperatures

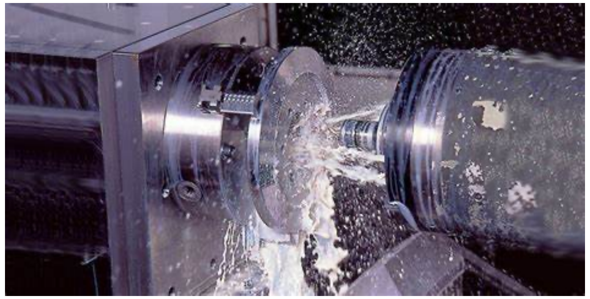
Cold Rolling Ads vs Disads

- No heating required
- Better surface finish obtained
- Superior dimension control
- Better reproducibility and interchangeability of parts
- Improved strength properties
- Directional properties can be minimized

- Higher forces required for deformation
- Heavier and more powerful equipment required
- Less ductility available
- Metal surfaces must be clean and scale-free
- Strain hardening occurs
- Imparted directional properties may be detrimental
- May produce undesirable residual stresses

Metal Forming Fluids

- Used to provide lubrication and cooling in metal bending, stretching and shaping operations
- Generally, four main types:
  - Water-based or soluble oils
  - Oil-based lubricants
  - Synthetic and semisynthetic
  - Solid lubricants



- Cold forming operations, fats, fatty acids, mineral oils, soap emulsions are generally used.
- Hot forming, glass, graphite, mineral oils are used as lubricants

Tribology Problems in Metal Forming

- Mainly in boundary lubrication regime
- High pressure at tool and workpiece interface and contact region is significantly wide
- Higher interfacial temperature
- Relative speed between tool and workpiece changes in the contact region
- Lubricants greatly influence workpiece surface
- Plastic deformation gives rise to new surfaces and change in surface morphology

Bench Top machines to simulate tooling

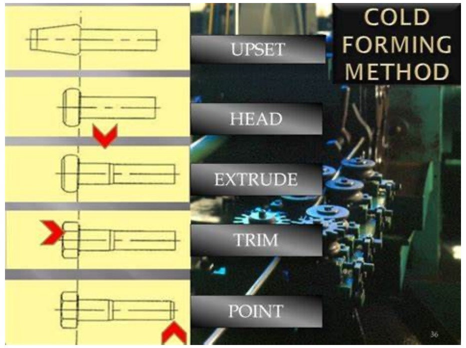
- Test machines for evaluating the effect of lubricant formulations
- Standard bench top equipment used include:
  - Pin-on-disc test, Ball-on-disc test, Block-on-disc test, Block-on-cylinder test, upsetting sliding test, sliding compression test, ring compression test, double cup extrusion test
  - Smaller prototypes of metal forming machines with friction transducers can also provide results closer to real time scenario

Benchtop Applications

1) Cold Forming Investigation

"A New Look at an Old Idea : The Torque Curve Revisted",

Helmtag, Katherine et al ASTM STP 1404

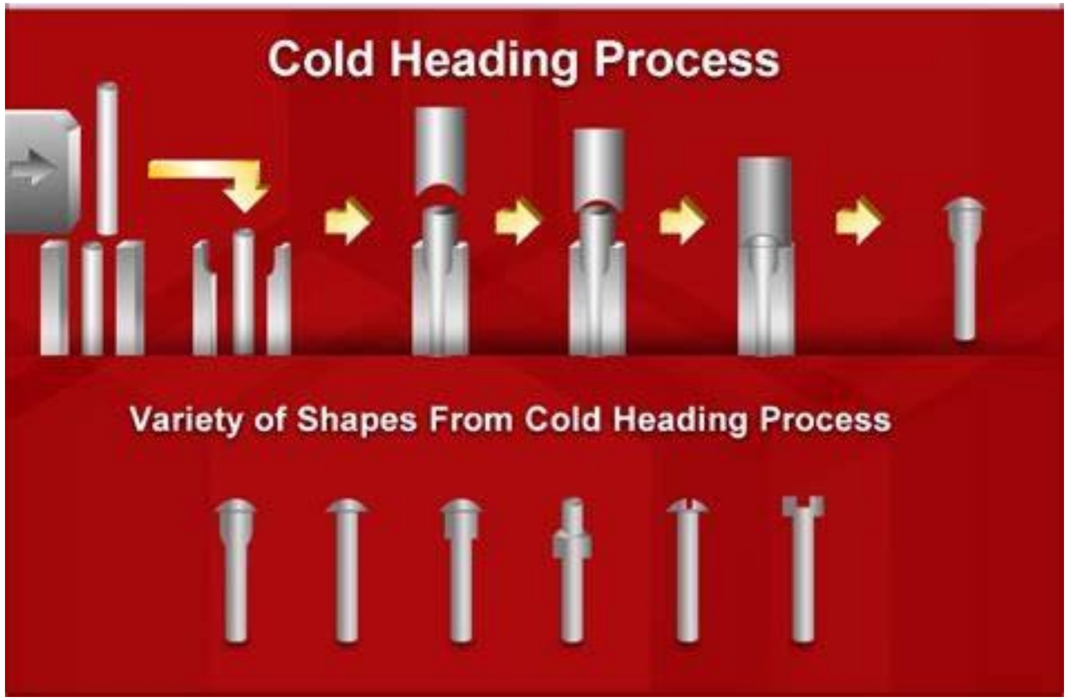


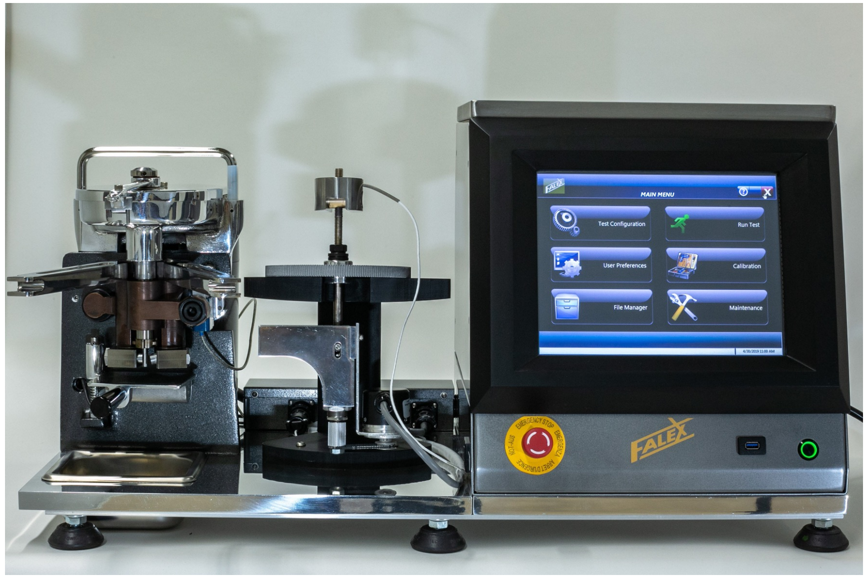
2) Deep Drawing Application

"A New Test Method to Simulate Deep Drawing Phenomena on the Lab Scale",

E. P. Georgioua et al Tribology Transactions 2022, VOL. 65, NO. 5, 892–900

Cold forming investigation



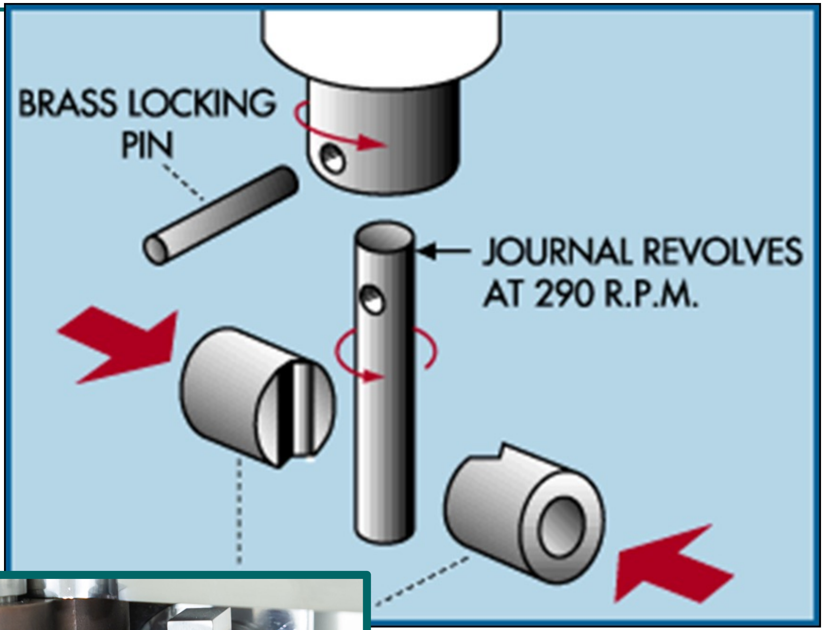


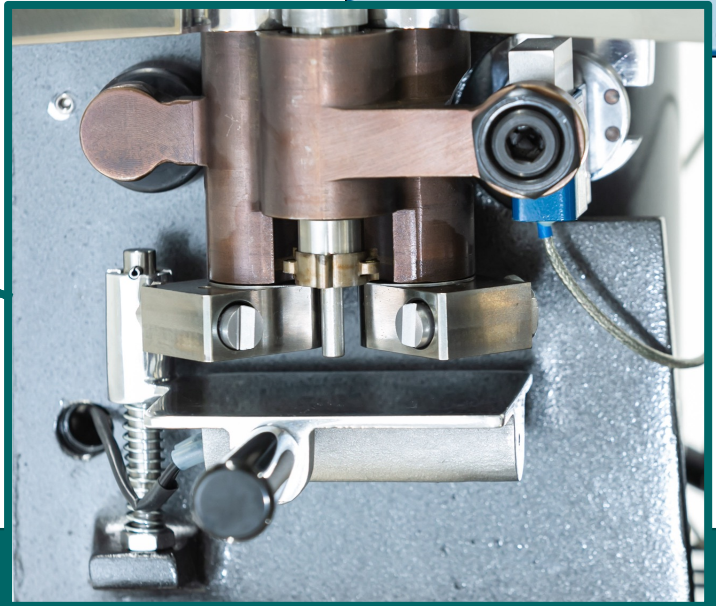
Problem

- Fastener manufacturer produced variety of parts by cold heading/forming
- Most parts cold formed with chlorinated, sulfurized forming oil applied after the wire was sheared into the slugs
- Goal – replace chlorinated oil for environ. friendly lubricant
- Process involved forward and backwards extrusions and involves considerable metal movement
- Great deal of heat generated by internal friction & sufficient to insure activation of most EP additives

Bench Top Tribometer 1 – Pin & Vee

- Falex Pin & Vee instrument





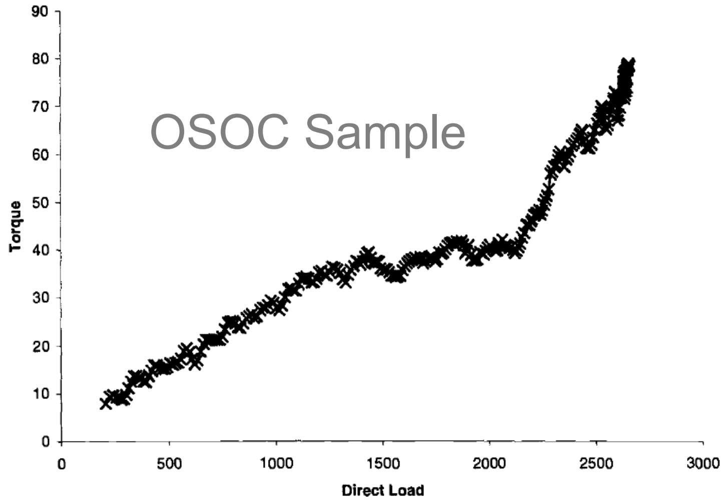
Cold Forming Benchtop Test Conditions

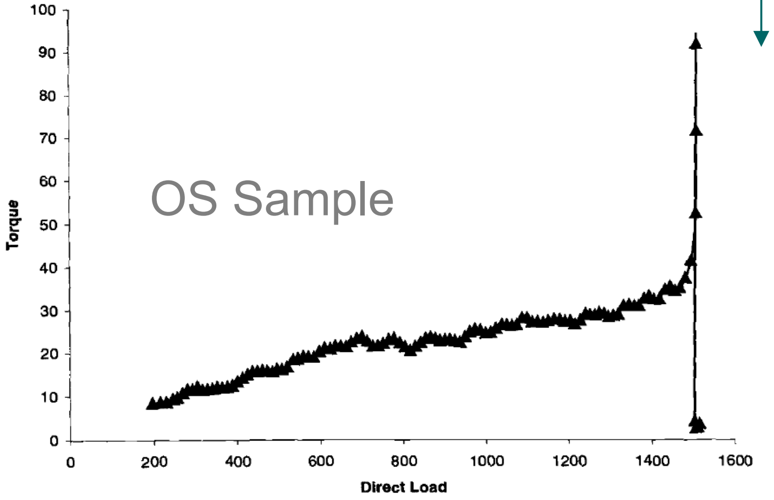
- Modified ASTM D3233 Method A used
- Run-in 90 seconds 200 lb (90kg) direct load
- Load ramp
- Speed 290 RPM
- Room Temperature
- Oil, 60ml volume

Sample	Additive Content	Viscosity, cSt @ 39^{o}C
OSOC	Organic Sulfur, Organic Chlorine	135
OS	Organic Sulfur	281
ISP	Inorganic Sulfur/Phosphorus	86
OSPOS	Organic Sulfur/Phosphorus, Organic Sulfur	106

Torque v Load

Sample	Method A Load	Method A Torque	Method B Load	Method B Torque
OSOC	2200	78	2600	72
ISP	2650	44	2700	52
OSPOS	3000	48	3000	47
OS	1500	92	1700	95



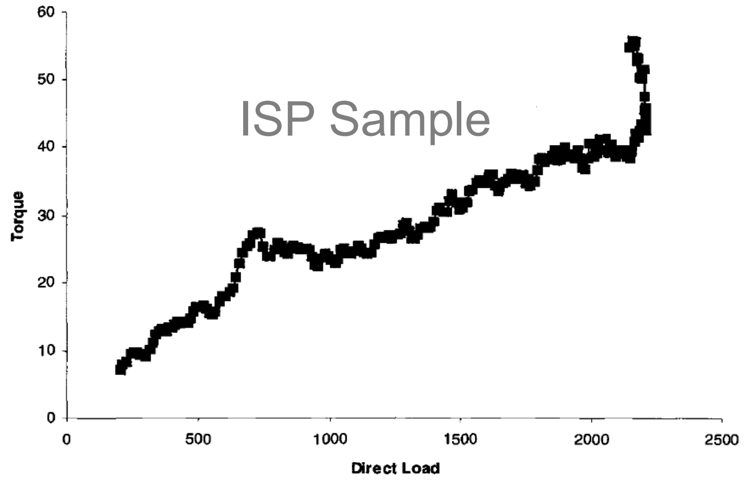


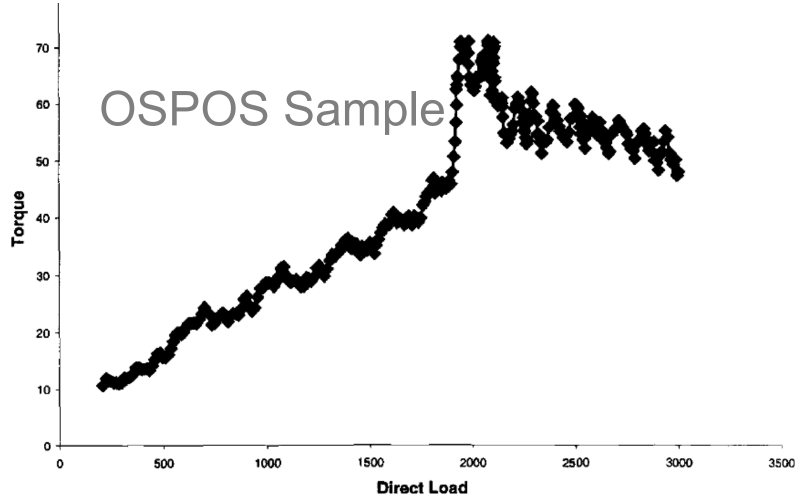
Test Results:

- Organic Sulfur/Phosphorus, Organic Sulfur (OSPOS)
- Organic Sulfur, Organic Chlorine (OSOC)
- Inorganic Sulfur/Phosphorus (ISP)
- Organic Sulfur (OS)

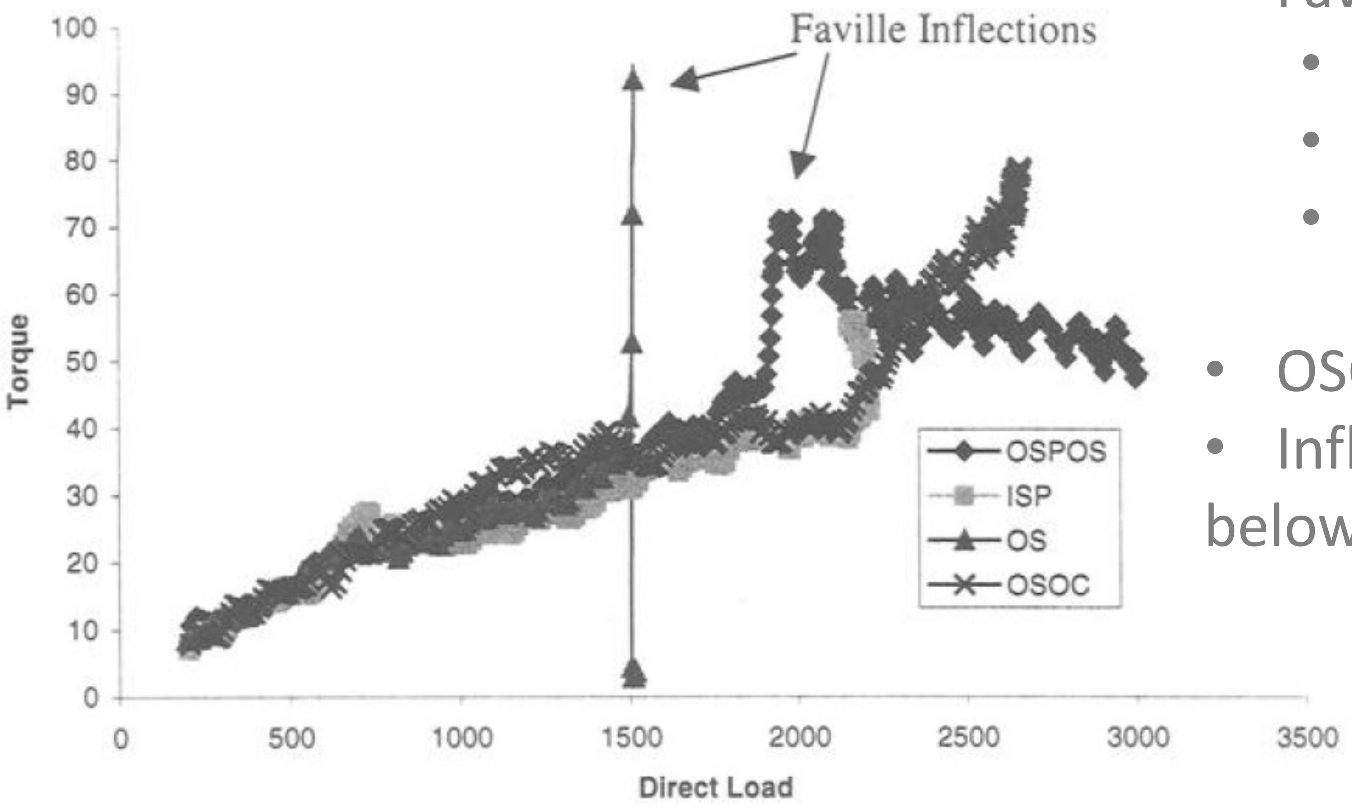
Field Lifetime Results

Sample	Parts Per punch	% Good Parts
OSOC	250,000	98
ISP	220,000	95
OSPOS	50,000	50





Torque v Load – Looking more closely



- OSOC relatively flat torque vs load curve
- Faville Inflections used to distinguish oils
  - OS inflection at 1500 lbs
  - ISP slight inflection at 700 lbs & large at 2200
  - OSPOS inflection at 2000 lbs

- OSOC and ISP Similar – as in the field
- Inflection for OSPOS occurs at direct load 200lb below ISP oil

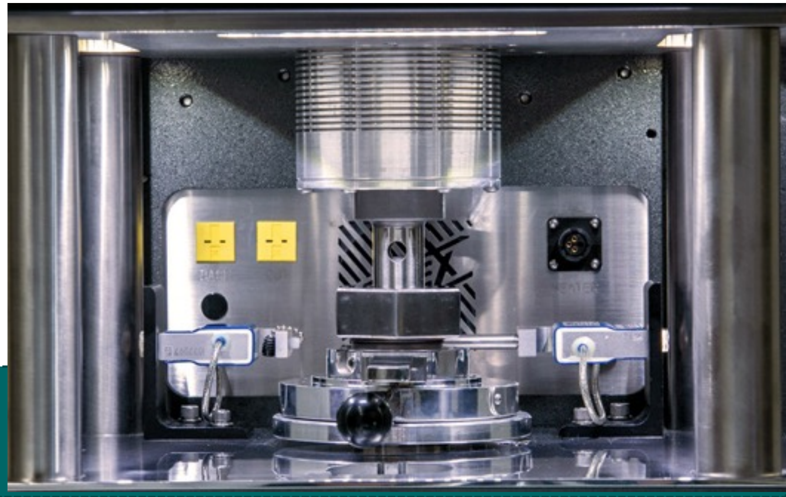
Sample	Parts Per punch	% Good Parts
OSOC	250,000	98
ISP	220,000	95
OSPOS	50,000	50

Four-Ball EP Testing

- Additional testing was done using ASTM Test Method for Measurement of Extreme-Pressure Properties of Lubricating Grease (ASTM D2596)
- The load wear index (LWI) for each oil was calculated

Sample	LWI
OSOC	156.2
ISP	156
OSPOS	75.5

Sample	Parts Per punch	% Good Parts
OSOC	250,000	98
ISP	220,000	95
OSPOS	50,000	50



Baker, Rich – OilDoc Conference 2023 – From “A New Look at an Old Idea : The Torque Curve Revisted”, Helmtag, Katherine et al ASTM STP 1404

Conclusions

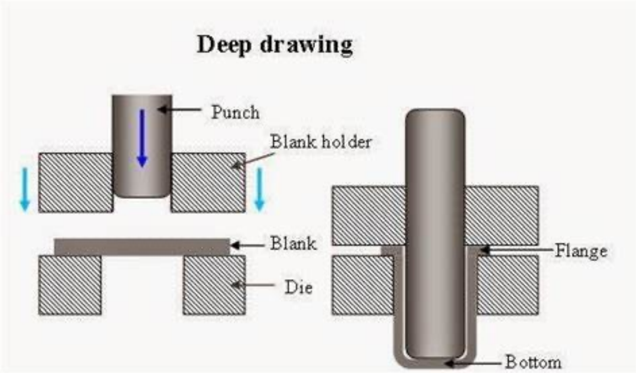
- New test method (based on standard test method) on the Pin & Vee instrument gives correlated results from in field oils
- With modified testing procedure and a modification to data analysis, vastly improved bench-field correlation can be found
- Confirmed with Four-Ball EP results

Sample	LWI	Faville Inflection Load
OSOC	156.2	2200
ISP	156	2300
OSPOS	75.5	2000

Sample	Parts Per punch	% Good Parts
OSOC	250,000	98
ISP	220,000	95
OSPOS	50,000	50

Application 2 - Deep Drawing

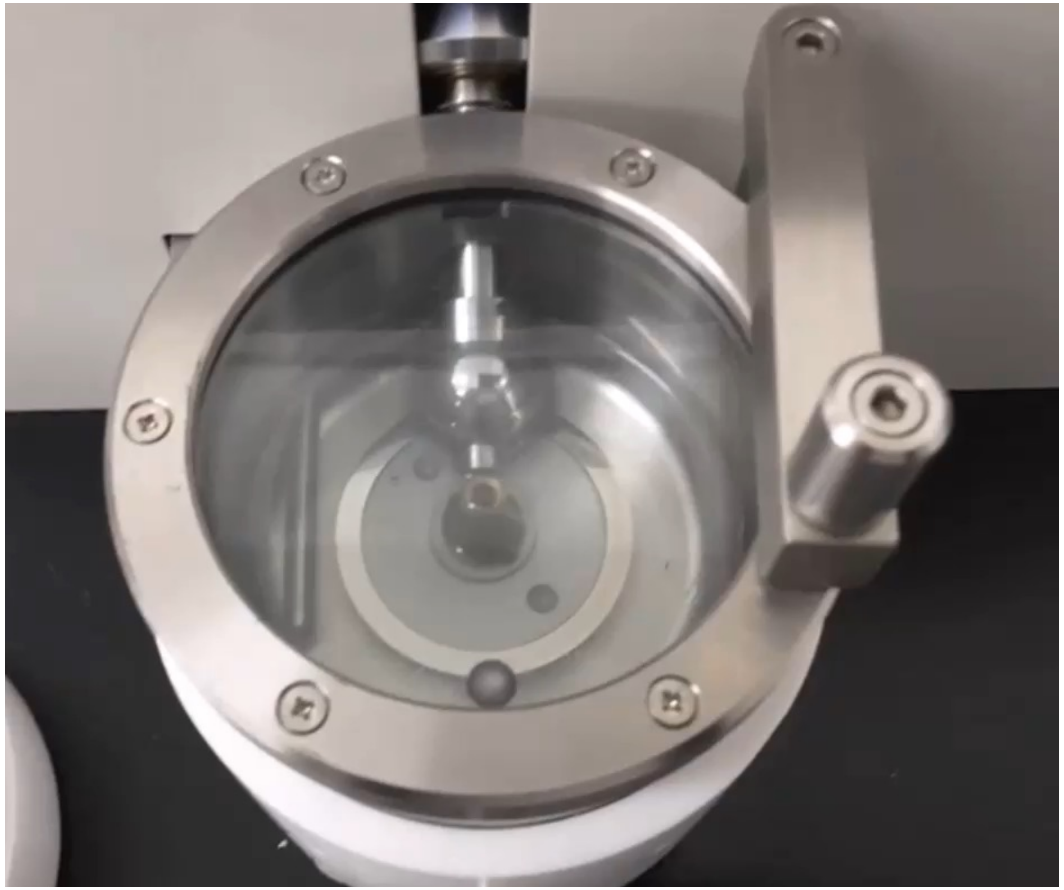
- Complicated process depends on material composition, lubricants, forming conditions & forming tools
- Strip drawing tests provide a good representation of reality but are complicated (and expensive) to set up

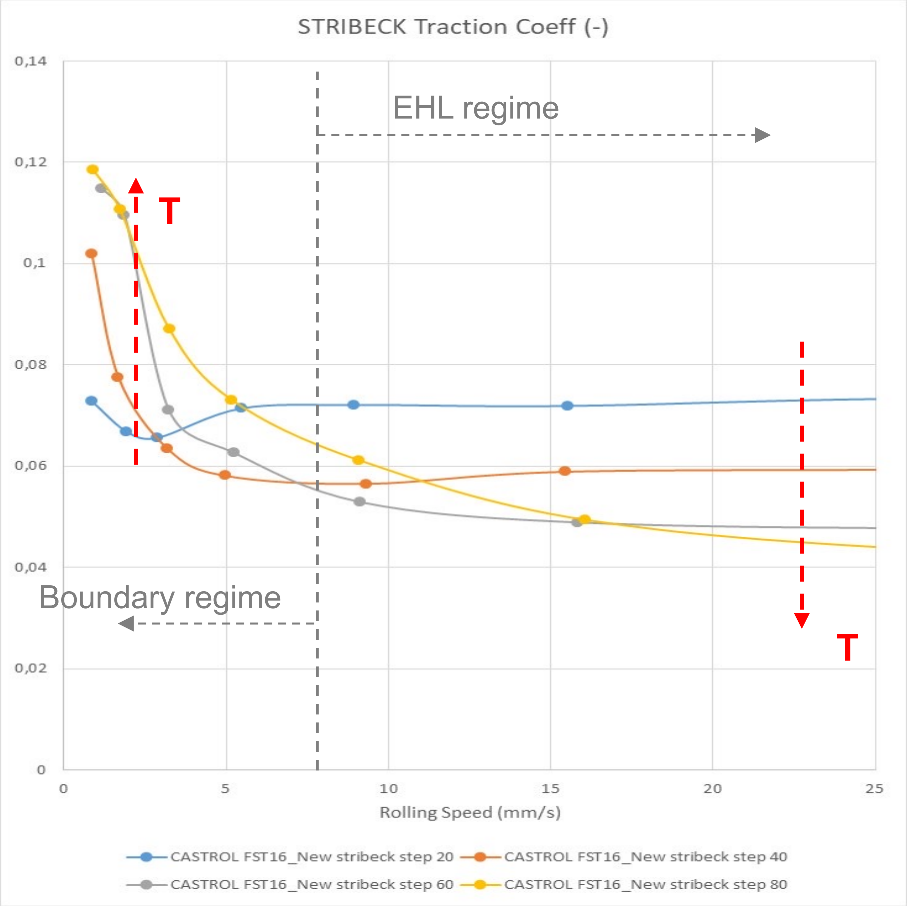


Questions :

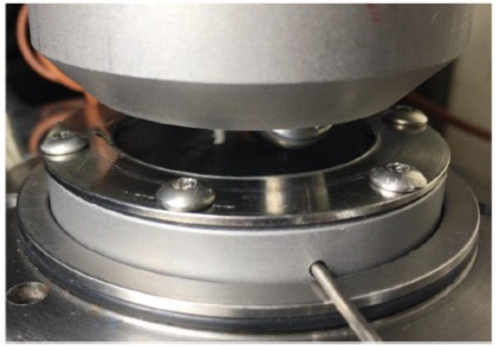
- Can we bridge the gap between simplified lab-scale tests and industrial practice
- Simplify the process with tribological lab-scale instrument measuring the friction repeatably for different lubricants
- Provide efficient prescreening and ranking of forming oils

Deep Drawing – Lab Equipment MTM





Deep Drawing



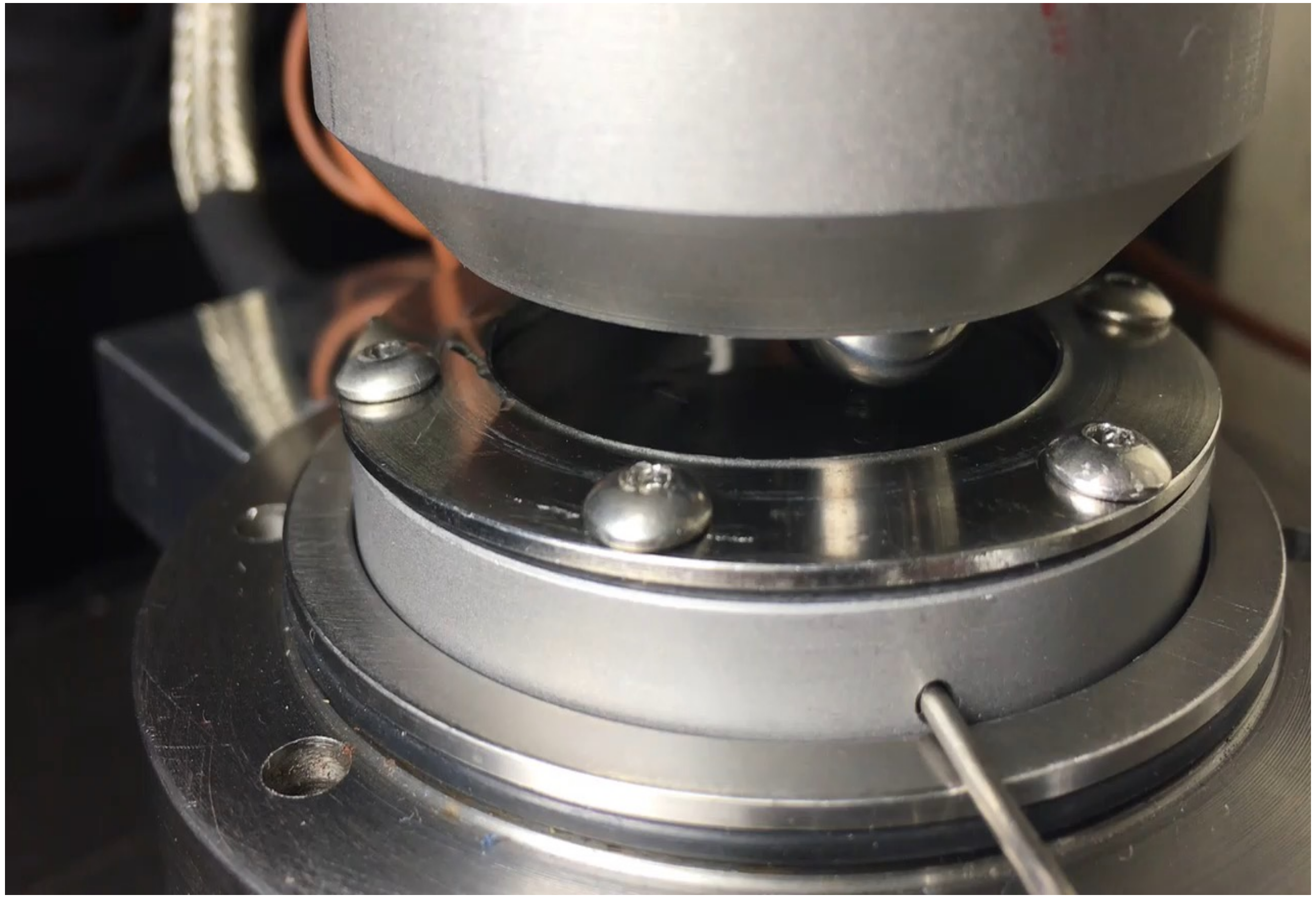
Test Specimens

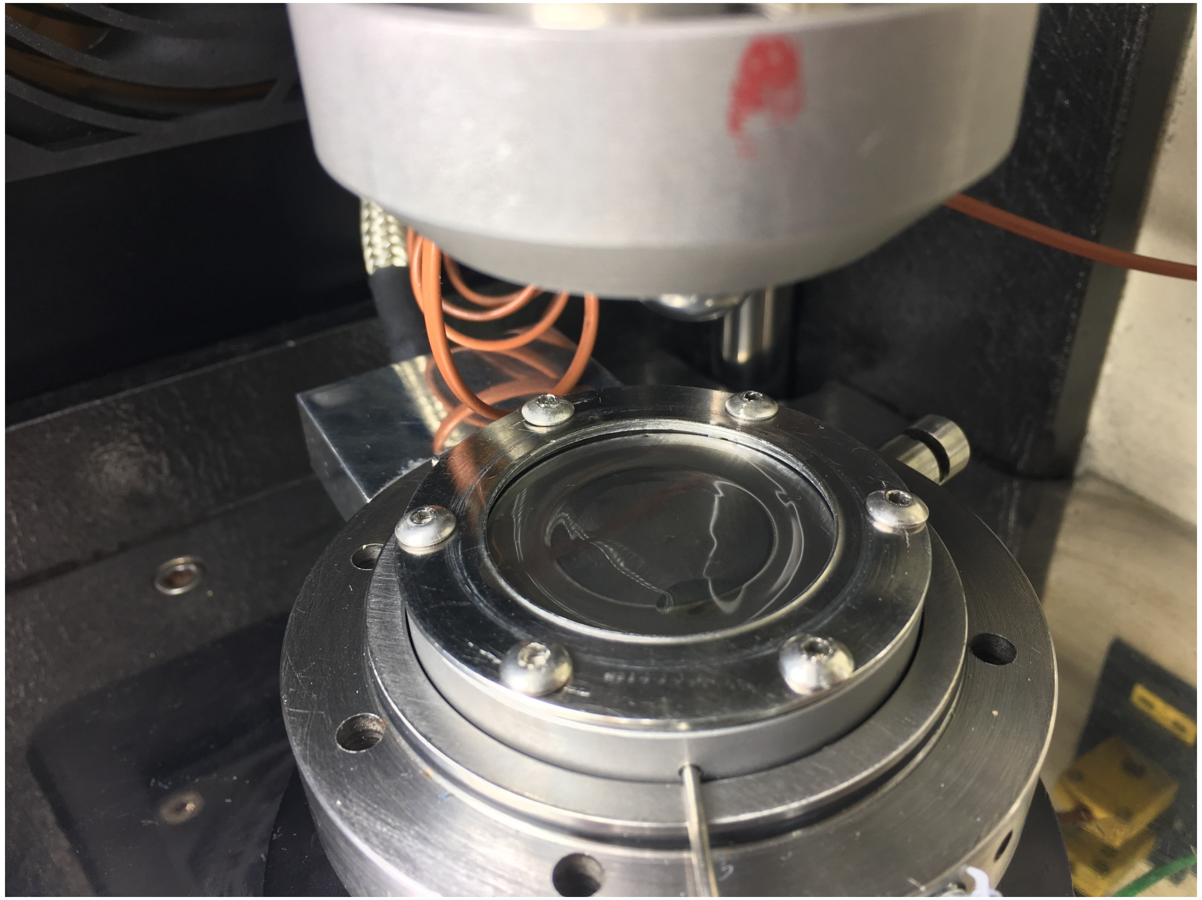
- Upper – ½” dia (12.7 mm) AISI 52100 ball Ra <0.02 mm, 66 HRC
- Lower - 45mm AISI 420 disks, 0.32mm thick, Ra 0.4 mm, 50 HRC

Test Conditions

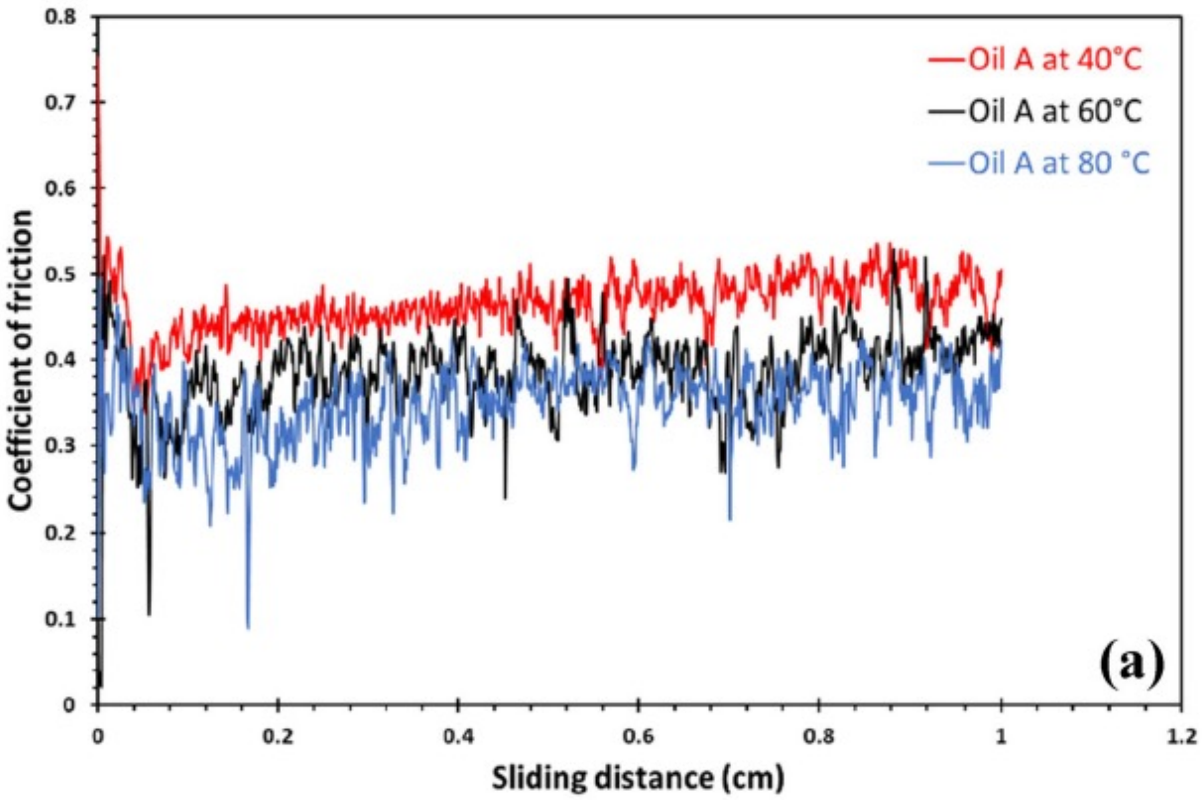
- Load : 445 N (2.9 GPa)
  - due to deformation nominal contact pressure 50-110 MPa
- 4 Sliding speeds
  - 1.18 (1 rpm), 2.36 (2 rpm), 5.9 (5 rpm), and 11.8 (10 rpm) mm/s
- Temperatures : 25-80 Deg C
- 4 commercial oils (0.02 mL/cm^2) and 1 grease (0.02 g/cm^2)
- 3 repeats per test

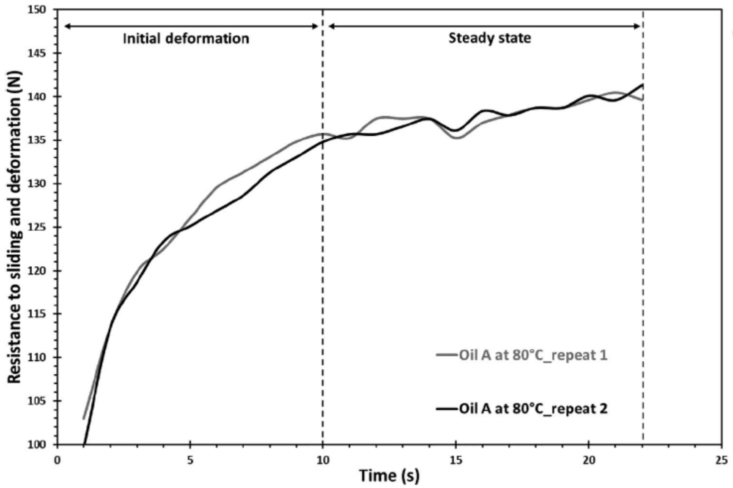
Deep Drawing - Video

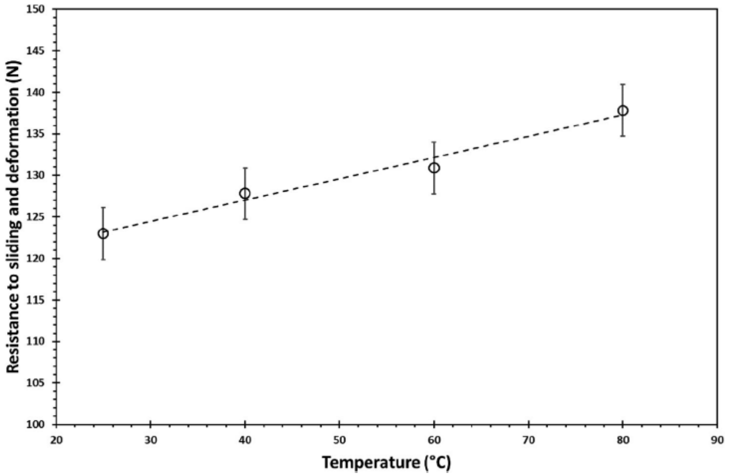




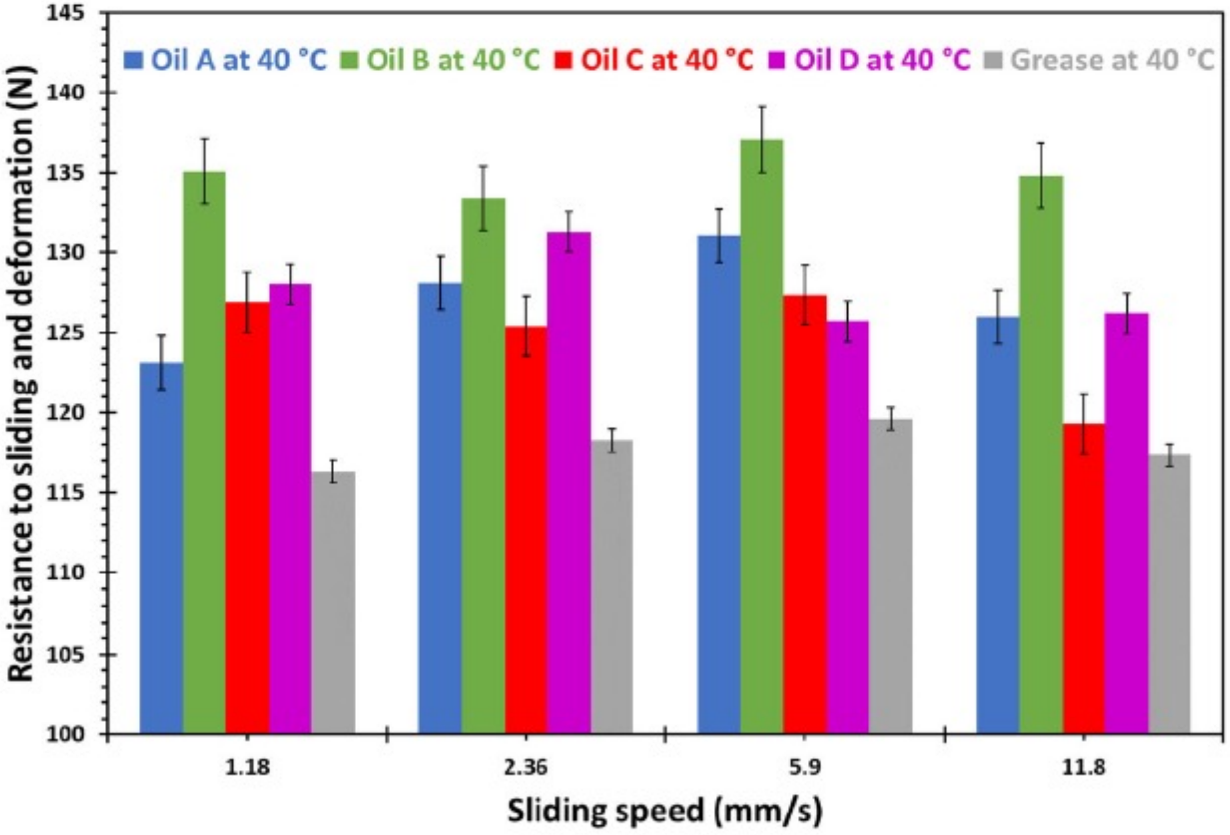
Deep Drawing – Test Results

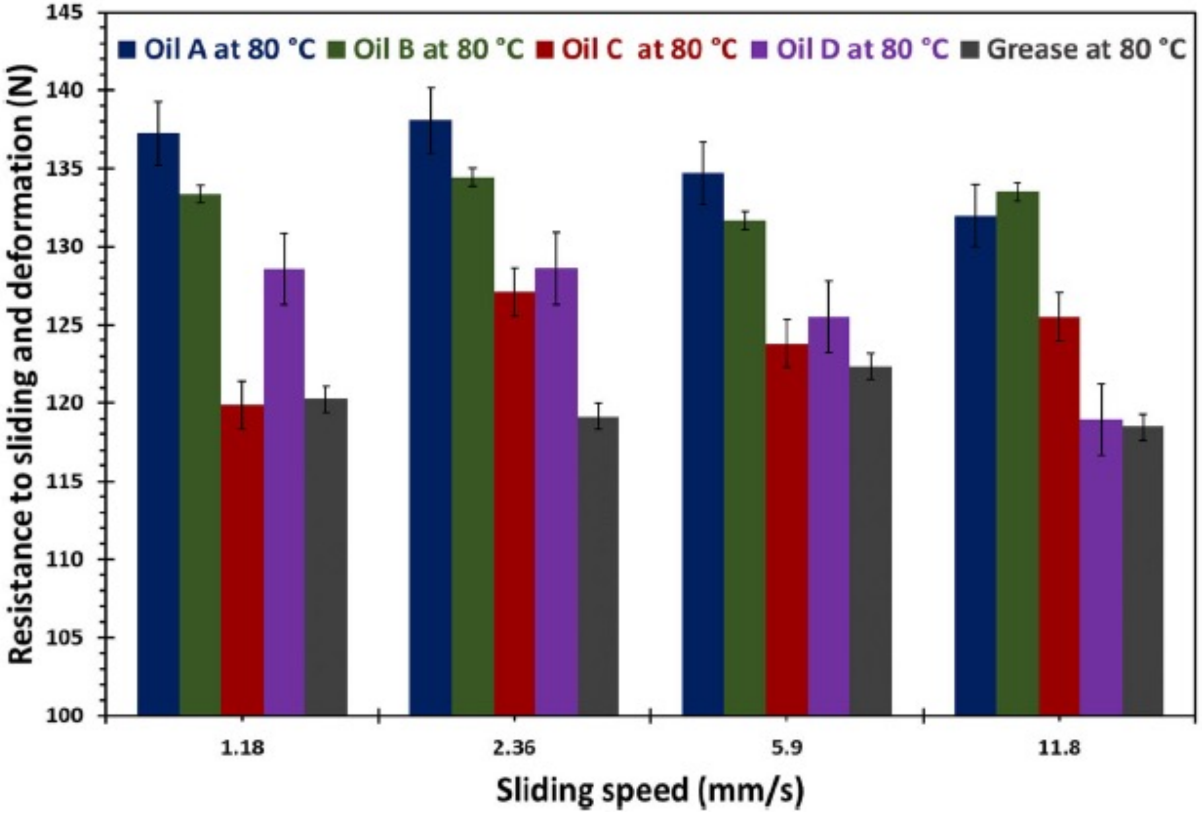






Deep Drawing - Results





Deep Drawing - Conclusions

- New method to simulate and measure resistance to sliding and deformation during deep drawing processes
- Predictive for forming applications where material deformed while sliding - stretching, deep drawing, and bending processes
- Plastic deformation considered, unlike most lab tests
- Multiple repeats in a short period of time - ideal tool for ranking resistance to sliding and deformation of various systems
- Average penetration depth can be assessed

Conclusions

- Tribology very important in metal forming – we wouldn't be here discussing it otherwise!
- Metal forming requires complicated environmentally friendly lubricants to help ensure smooth operation of the tools without wear of the tool (or counter-face) to be kept to a minimum to ensure accurate products
- Lubricants can help speed up production process which helps reduce costs
- Adapt existing lab instruments to match the application

Questions/Thanks?

Thank you to OilDoc conference for a great conference!

Thank you to Falex Tribology for application information