Graphene-Based Solid Lubricant for Automotive Applications

Project ID# mat178

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2020 DOE Vehicle Technology Office
Annual Merit Review Meeting
June 3, 2020, Arlington, VA

Overview

Timeline
- Project start date: August 2018
- Project end date: August 2020
- Percent complete: 63%

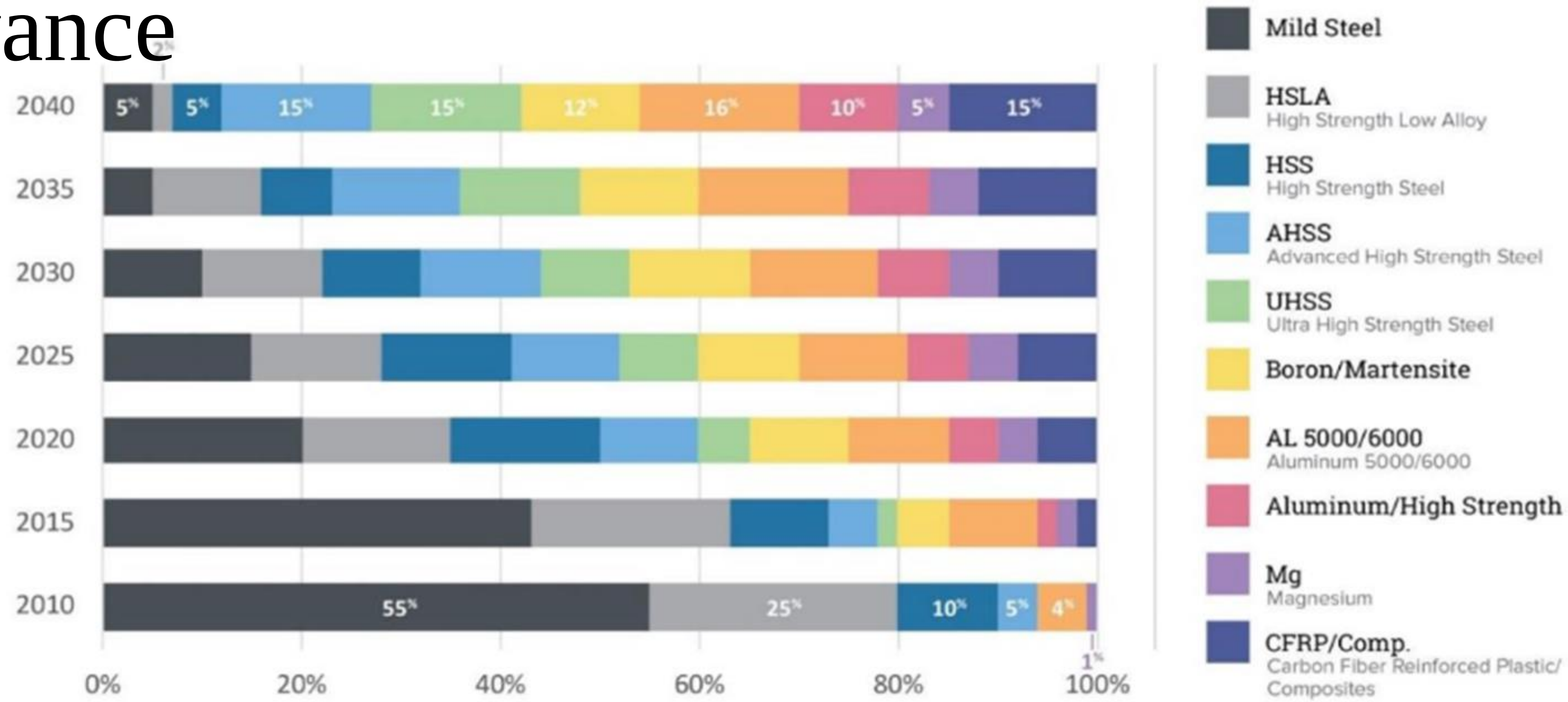
Barriers and Technical Targets
- Performance at elevated temperatures
- Cost of high temperature lubricants
- Compatibility with downstream processes

Budget
- Total project funding
  - DOE share: $640,000
  - Contractor share:$10,000
- Funding for FY 2018: $315,340
- Funding for FY 2019: $267,681
- Funding for FY 2020: $66,979

Projected costs incurred in 2020 will predominately be incurred as by Magna, as part of the Industry 50% in-kind cost contribution commitment.

Partners
- Magna International Inc.
  Tim Skszek
- University of Waterloo
  Prof. Mike Worswick

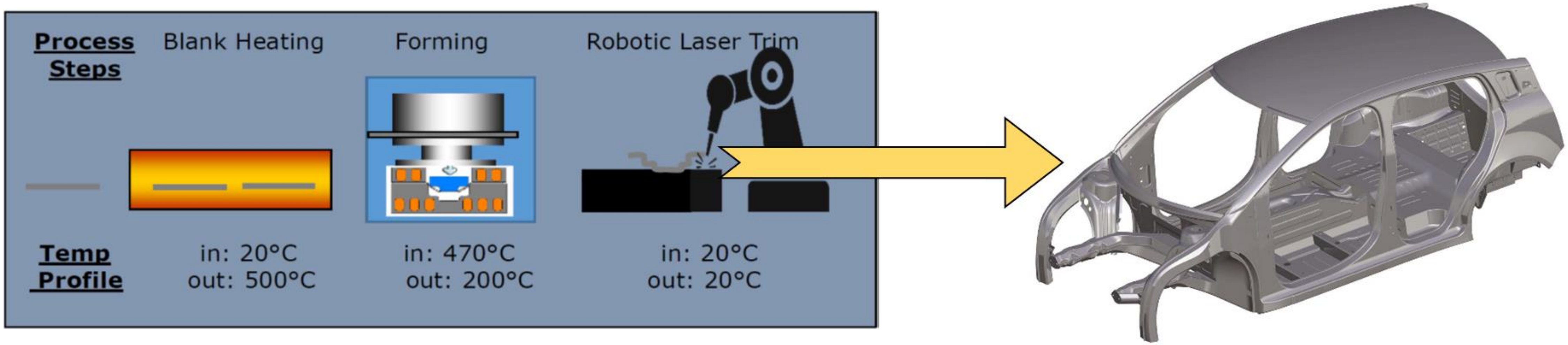
Relevance



Picture Source: CAR Research – Automotive Technology Roadmaps (2017)

- Friction between the sheet and die steel results in excessive die wear and inhibits product design freedom due to limited formability
- 2020 Model Year vehicles include 6 to 30 hot stamped components per vehicle
- Traditional solid lubricants are not used due to the cost of material and removal
- Application requirements exceed the functional use temperature of wax- and oil-based lubricants

Relevance

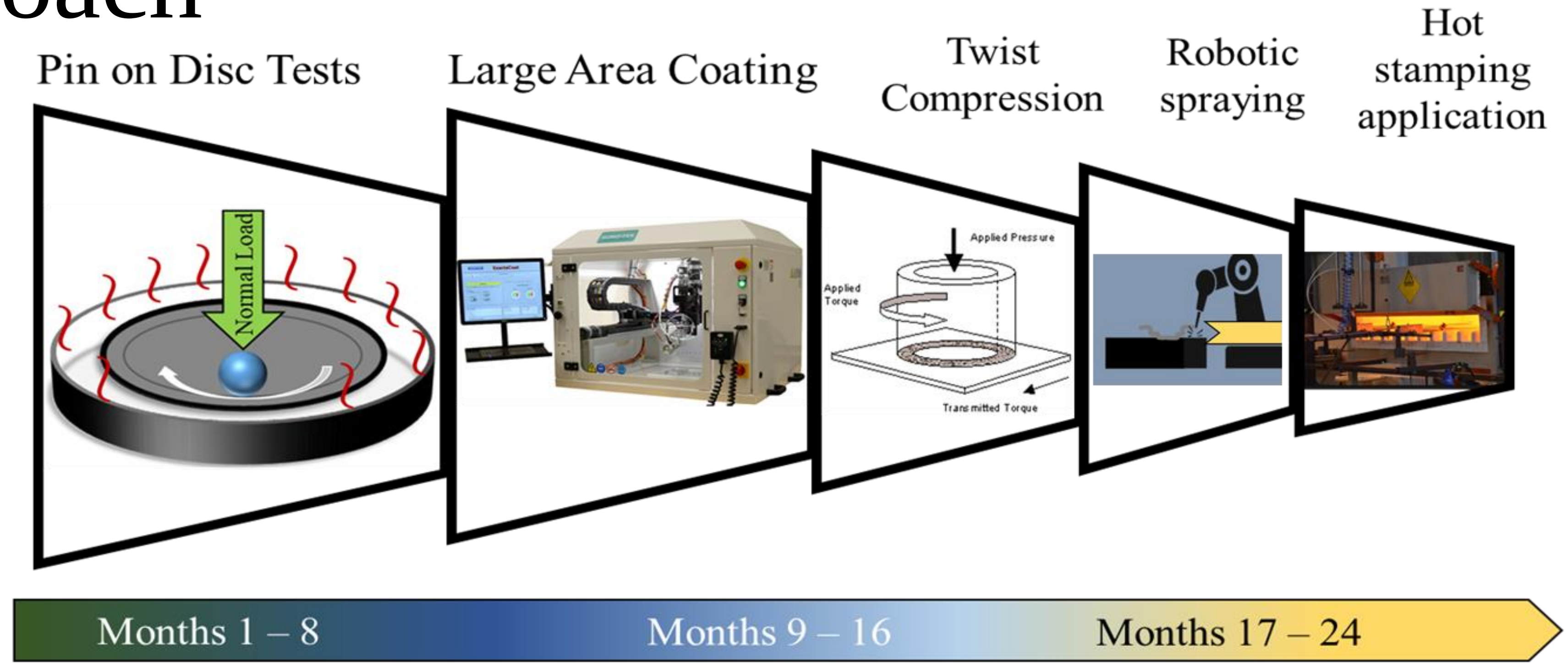


- **Motivation:** Expected market size **$180 billion** by 2022.
- **Objective:** Replacement of existing lubricants based on oil with graphene will significantly reduce emission of hazardous waste, reduction is cost and savings in energy
- **Impact:** A marginal reduction of friction in stamping process will translate into savings of **$100M** in manufacturing cost

Milestones

Task	Milestone	Deliverables	Timeframe
✓ Complete Development and characterization of an optimized graphene-based die coating for **Al sheet metal forming**	**Determine best possible graphene based solution** that can **withstand elevated temperatures** and **provide low friction and wear**	Optimized graphene based lubricant to be used for the next phase **W**ater-based **H**igh **T**emperature **L**ubricants **(WHTL)**	Months 1 – 8
✓ Complete Development of graphene coatings for high temperature (790 ^{o}C) **Steel sheet metal stamping**, establish longevity and contamination	Design, develop and validate lubricants that sustain 790 ^{o}C for steel sheet metal forming multiple turns in TCT tests	Optimized graphene based lubricant for steel **SL1 and SL2**	Months 9 – 16
In Progress Process validation and performance testing using production scale forming press and die to manufacture side door intrusion beam	Scale-up of graphene spray coating from prototype testing to real-world testing	Implementation of the graphene as a solid lubricant for metal forming process at industrial scale	Months 17 – 24

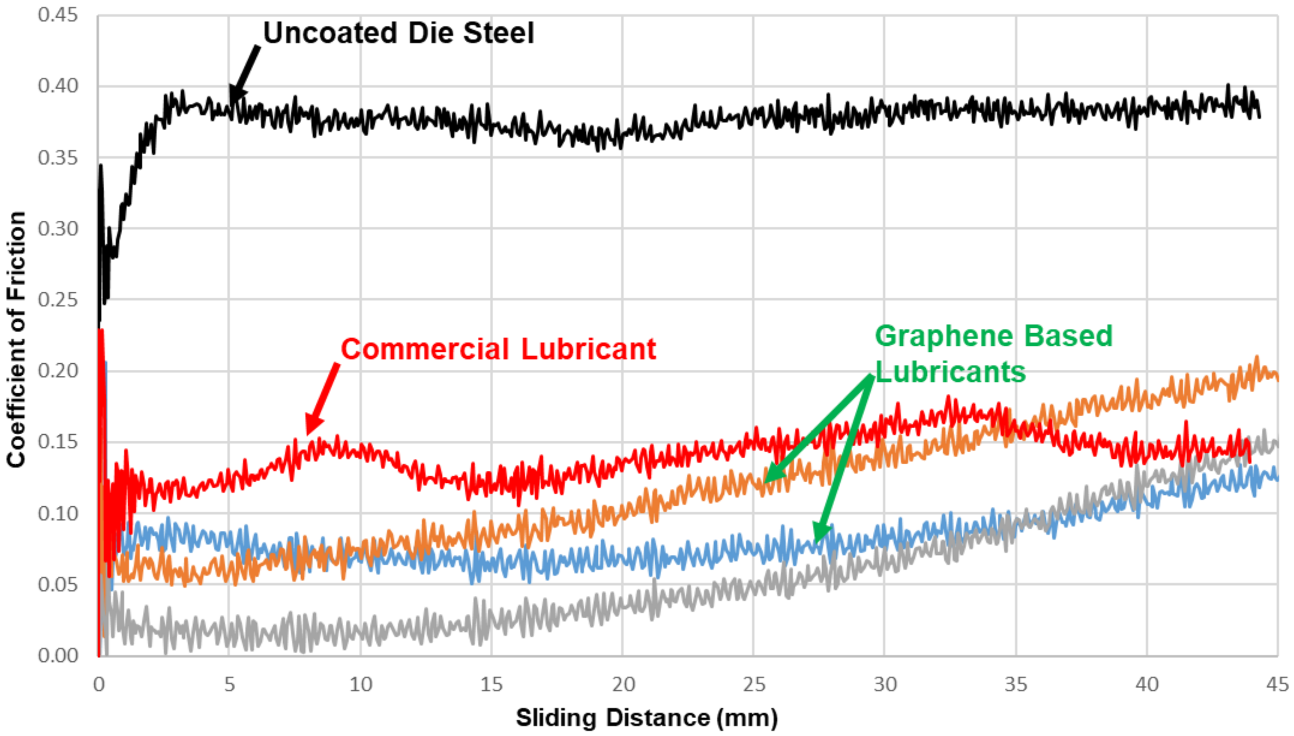
Approach



- Establish high temperature base-line friction metrics of steel-vs-steel
- Use Pin-on-disc measurements to identify lubricants producing low friction
- **Go/No-Go:** Friction values below that of commercially used lubricants
- Large area coating at high temperature covering 1’x1’ sheet metal
- Assess the lubricant efficiency under twist compression loading
- **Go/No-Go:** Longevity of lubricant under twist compression, full removal upon washing

Technical Accomplishments – Warm Form Al

Lubricants Tested at 230 °C	
Lubricant A	Graphene x_1% + Polymer y_1%
Lubricant B	Graphene x_2% + Polymer y_2%
✔ Lubricant C	Graphene x_3% + Polymer y_3%
✔ Lubricant D	Graphene x_4% + Polymer y_4%
✔ Lubricant E	Graphene x_5% + Polymer y_5%

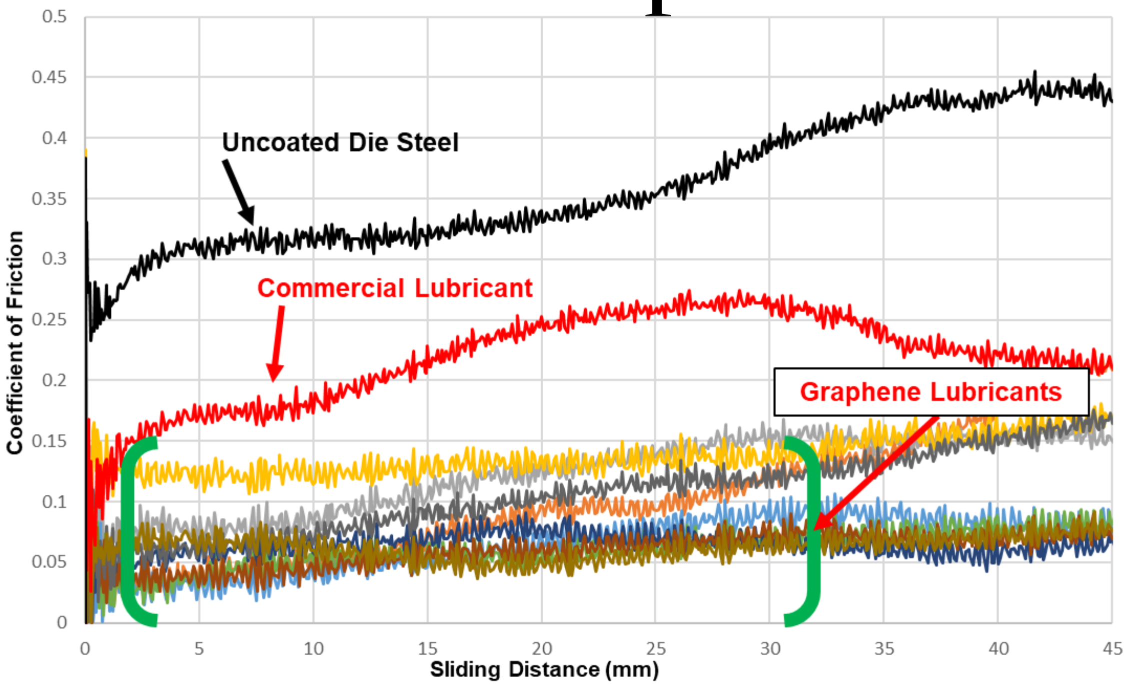


Technical Accomplishments – 1

- Five compositions were developed and tested for lubricity performance. The aluminum sheet was heated to 230°C and evaluated under TCT sliding conditions against a lubricated die steel surface.
- Three compositions were observed to out perform the commercial lubricant
- The friction was significantly lower, with equivalent longevity

Technical Accomplishments – Hot Stamp Al

Lubricants Tested at 480 °C	
✓ Lubricant A	Graphene a_1% + Polymer b_1%
✓ Lubricant B	Graphene a_2% + Polymer b_2%
✓ Lubricant C	Graphene a_3% + Polymer b_3%
✓ Lubricant D	Graphene a_4% + Polymer b_4%
✓ Lubricant E	Graphene a_5% + Polymer b_5%

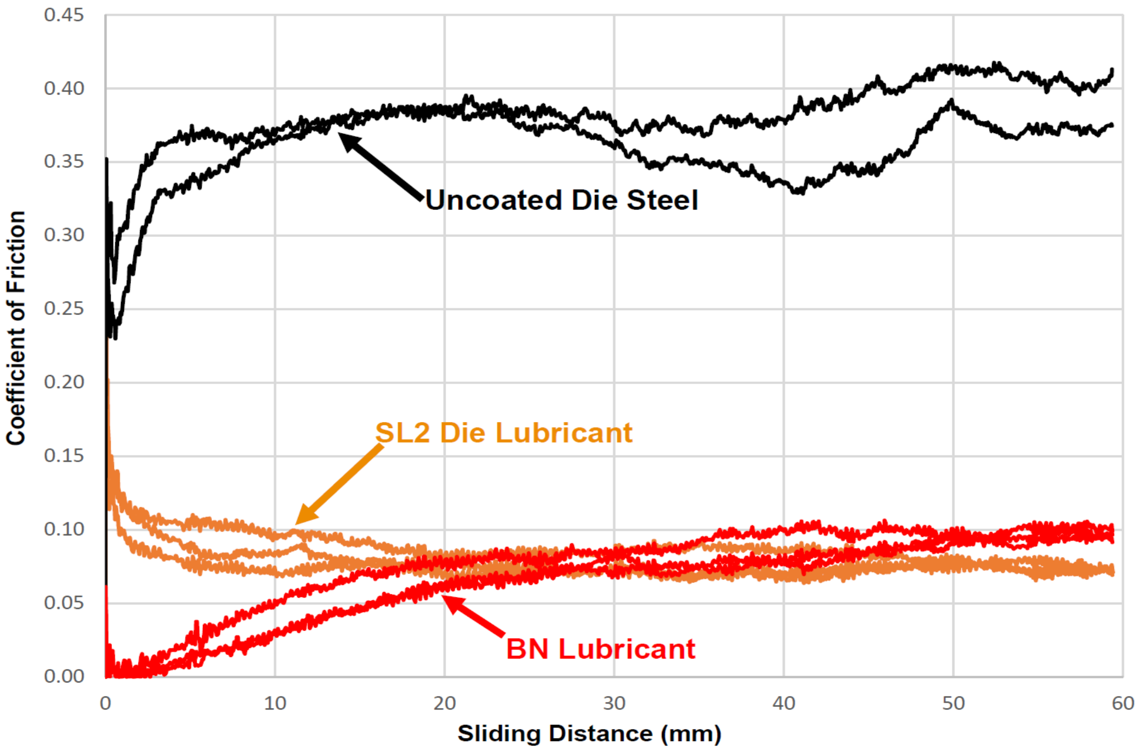


Technical Accomplishments – 2

- Five compositions were developed and tested for lubricity performance. The aluminum sheet was heated to 480°C and evaluated under TCT sliding conditions against a lubricated die steel surface..
- All five compositions were observed to out-perform the commercial lubricant
- The friction was about 50% lower than the commercial lubricant, as well as the durability better than the commercial lubricant

Technical Accomplishments – Hot Stamp Steel

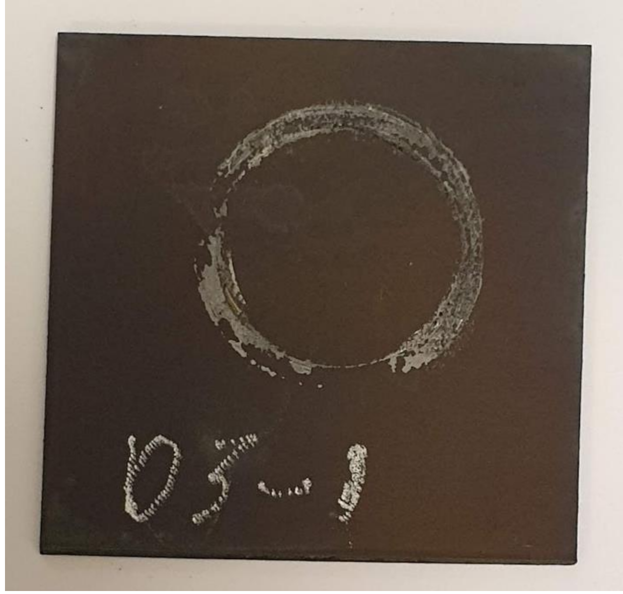
Lubricants Tested at 790 ºC	
✓ Lubricant SL1	Graphene u_1% + Polymer v_1%
✓ Lubricant SL2	Graphene u_2% + Polymer v_2%
✓ Lubricant SL3	Graphene u_3% + Polymer v_3%

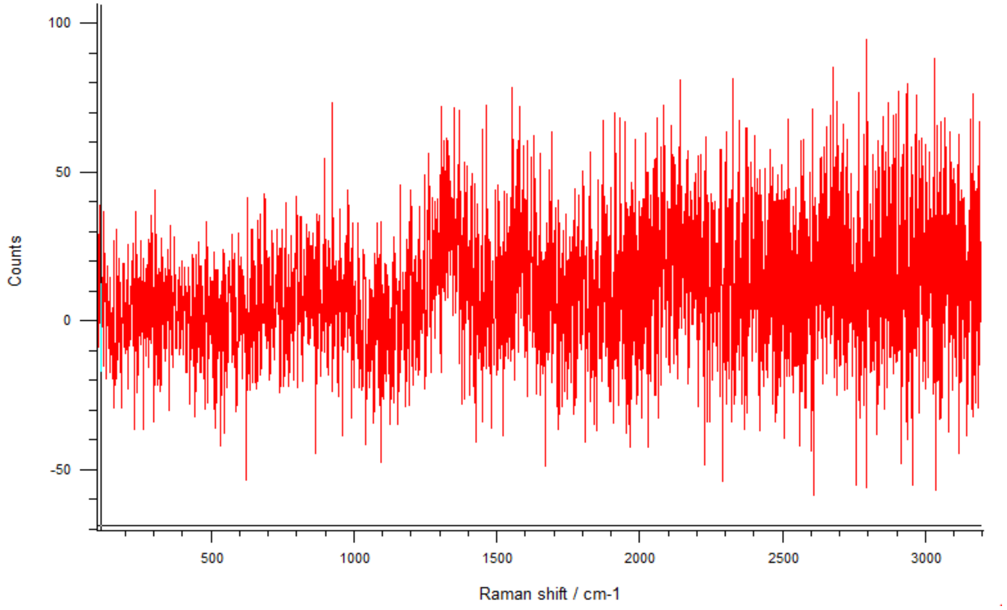


Technical Accomplishments – 3

- Three compositions were developed and tested for lubricity performance. The aluminized boron steel was heated to 790ºC and evaluated under TCT sliding conditions against a lubricated die steel surface.
- All three compositions were observed to perform equally or slightly better than a commercially available BN lubricant, which is prohibitively expensive and requires secondary operations to remove prior to application of structural adhesive, sealant or E-coat/paint.

Technical accomplishments





Technical accomplishments – 4

- Major milestone achieved is the successful performance of graphene-based lubricant for high temperature hot stamping (970^{o}C) application on steel substrate
- Following twist compression testing, the surface was cleaned using high pressure water and evaluated using Raman Spectroscopy(top right spectra) to assess material transfer
- All samples showed no sign of material contamination on the boron steel sheet

Collaboration with other institutions

MAGNA

- **Team:** Tim Skszek, Frank Gabbianelli and Tim Raeburn
- **Relationship:** Industrial partner

UNIVERSITY OF WATERLOO

- **Team:** Mike Worswick and Kaab Omer
- **Relationship:** University partner

Remaining challenges

1. **Scale-up of the graphene-based coating process and its demonstration for metal forming at industry scale:** Implementation of the graphene as a solid lubricant for metal forming process at industrial scale

Summary

1. **Successful Lubricant Formulation:**
   - Graphene + Polymer lowered friction on steel substrates at high temperatures as compared to commercial lubricants
   - The contamination from the lubricants on to the steel substrate was negligible
2. **High Temperature Stability:**
   - All solid lubricants were observed to have a high degree of material stability at high temperatures (970^{o}C) and shear stresses
3. **Production scale forming:**
   - Validation of lubrication die-worthiness underway by Magna, in collaboration with University of Waterloo, Promatek Research Centre and a Cosma US-based stamping facility.