Effect of Metallic Coatings on the Forming Characteristics of Automotive Sheet Steel

GDIS

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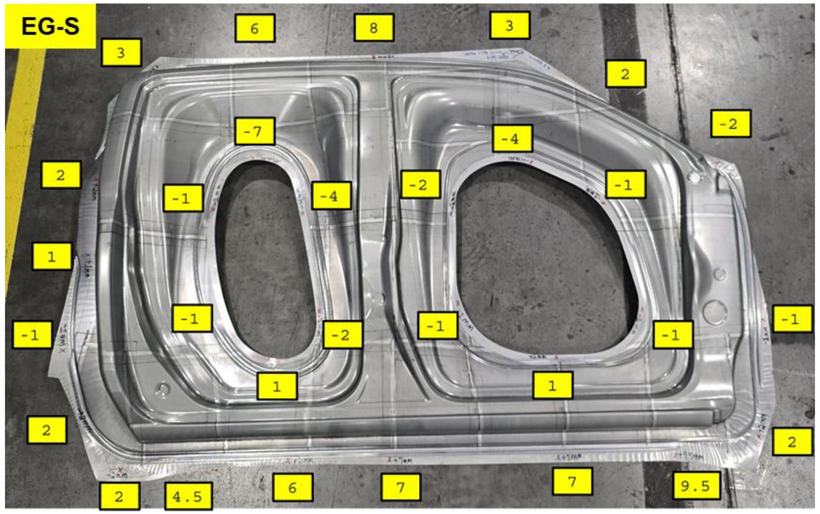
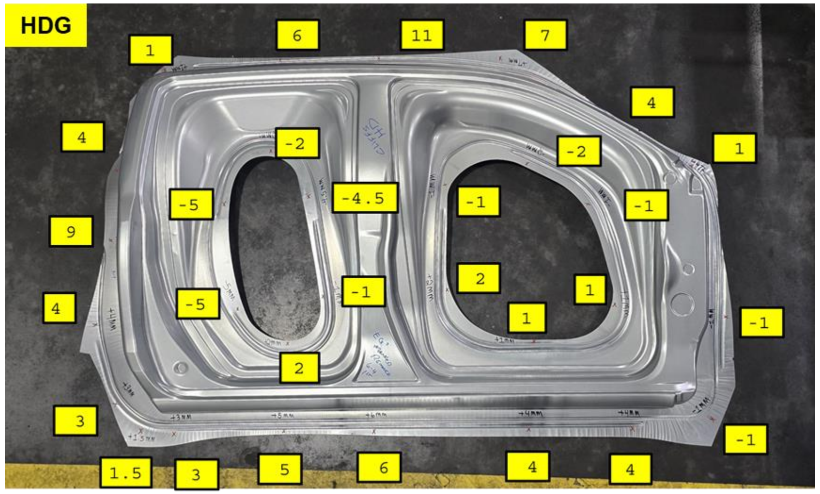
Background

- Metallic coating is often used in automotive sheet steels for corrosion protection.
- Zinc based Hot dipped galvanized (GI, HDG or HD) and electrogalvanized coating (EG) are two common coating types used in automotive applications.
- For exposed body panel applications, GI is often selected due to its excellent painted surface appearance characteristics.
- Cleveland-Cliffs has developed EG smooth (EGS), which has similar painted surface appearance characteristics of GI coating.
- A material source has changed recently for a body side panel that used CR4 GI. A different behavior was observed among GI from different suppliers and EGS.
- CR4 GI from a different supplier showed different material flow behavior that requires modifications to achieve a balance between feeding the material for draw-in to avoid fracture and controlling the material flow to avoid wrinkle while EGS required minimal adjustments
- To understand the forming performance difference between GI and EG smooth, a comprehensive study has been carried out by GM and Cliffs using lab simulative tests to understand the difference in forming performance of these materials.

Draw-in Comparison

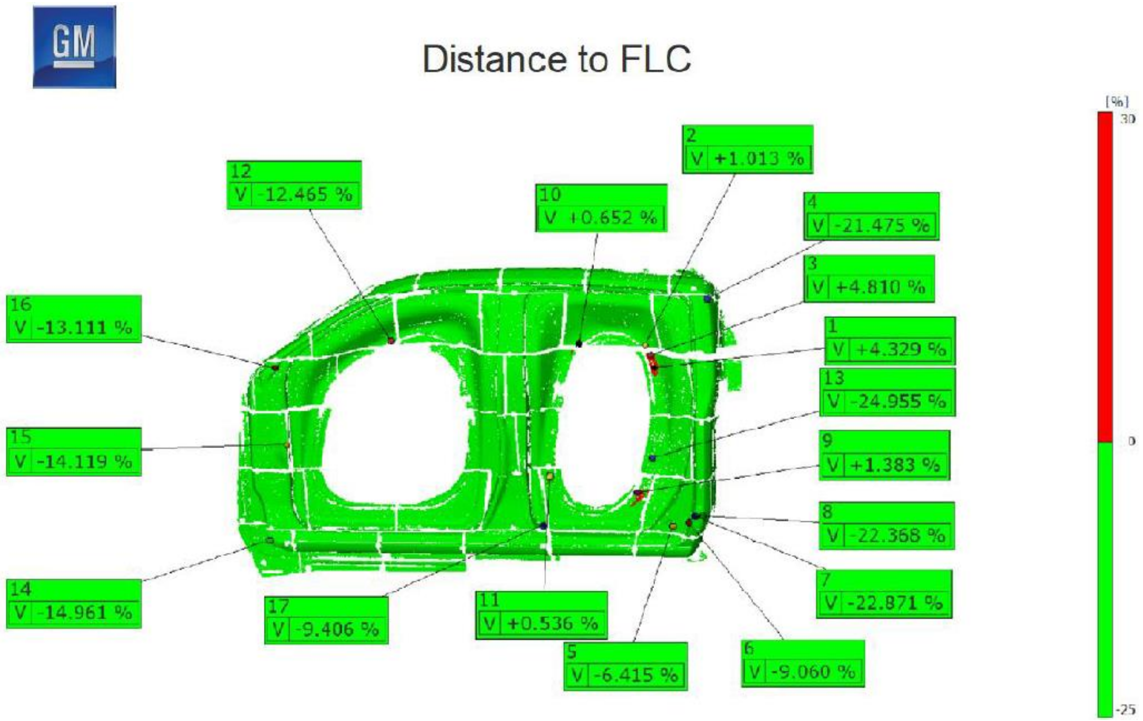
- Draw-in was measured with new material part on top of the reference draw-in panel, measured in mm
- Positive value is new-blank-material additional drawn-in
- Negative value is new material held out
- EGS and supplier 1 GI showed a slightly different draw-in and both were able to make the parts.
- No draw-in data is available for supplier 2 GI due to splitting under current die conditions.



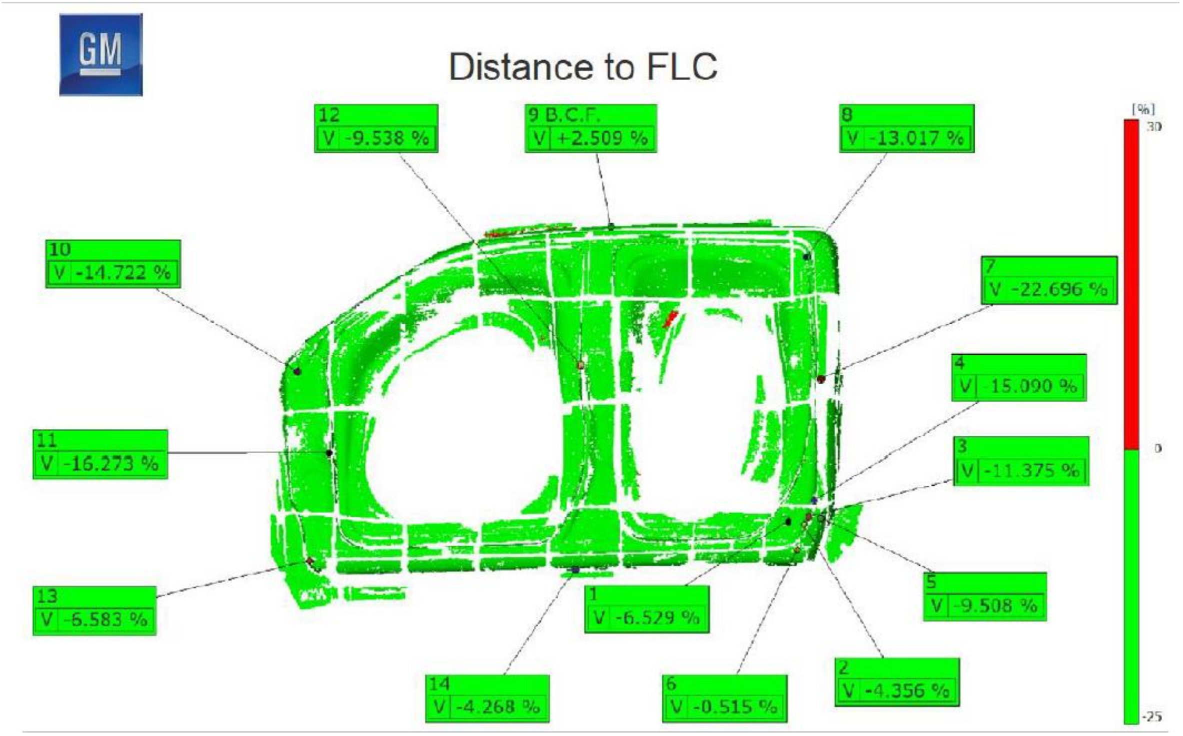


Argus Formability Analysis Results

Both EGS and Supplier 1 GI materials are safe based on Argus Analysis although EGS showed slightly less safety margin



EG Smooth Material



Current Production HDG Material

Surface Roughness

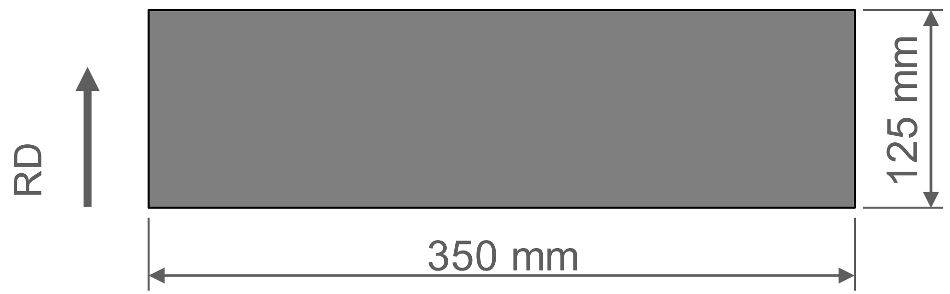
- Significant surface roughness difference among those three materials was observed.
- EGS has the lowest Ra/Rz and supplier 2 GI has the highest Ra/Rz.
- The difference in the forming performance is likely due to the different interface friction behavior

Material	Location	**Ra (μm)**	**Rz (μm)**	**Pc/cm**
Supplier 1 GI	1	0.8	4.6	59.3
	2	1.1	6.6	59.9
Supplier 2 GI	1	1.4	8.6	87.6
	2	1.5	8.7	80.3
EGS	1	0.5	2.8	50.3
	2	0.5	3.0	50.8

Materials and Test Samples

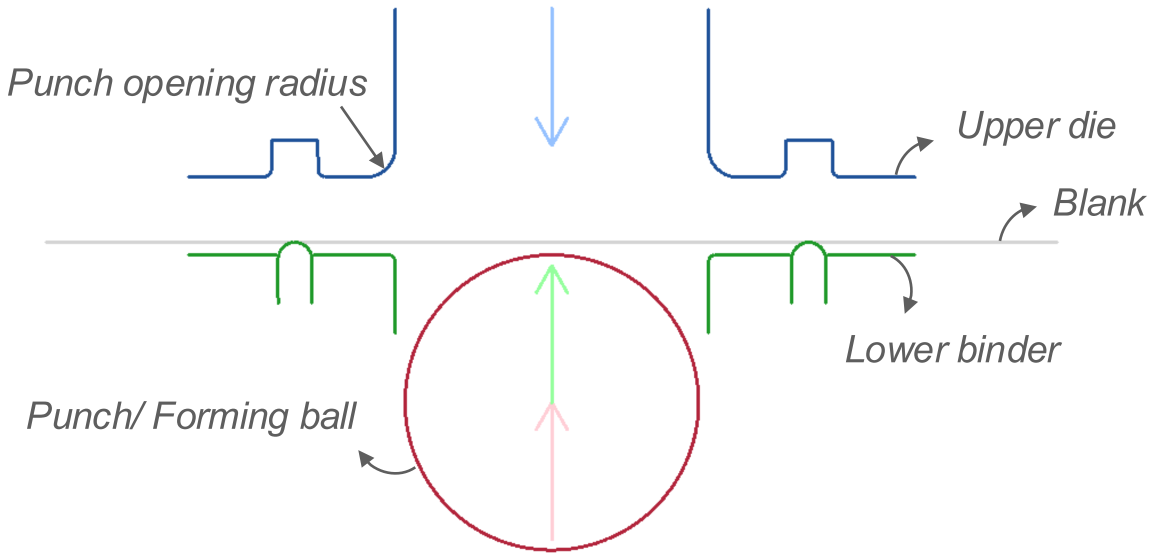
- 0.65mm CR4 with 3 different coatings (Coating weight for each blank: 60G60G), EG, EG-Smooth (EGS), and HDG (GI), sheared to 125 mm × 350 mm out of full width sheets.
- Tested in:
  - As-received condition, in which efforts were made to minimize the alteration of the oil film.
  - Dry condition, in which the oil film on the samples was removed using acetone.
  - Fully lubed condition, in which the samples were wiped clean with ethanol and fully lubed with mill oil.

Blank size



Experimental Test Setup

- Dies/tools:
  - Draw bead radius= 6mm
  - Draw bead width= 11.75 mm
  - Draw bead height= 4.3 mm
  - Punch opening radius= 10mm
  - Punch radius= 50.8mm (4” sphere)



- Binder tonnage was set to 7.0 Ton for as received, 3.0 Ton for dry, and 9 Ton for fully lubed samples.
- Press was allowed plenty of time to stabilize at the set tonnage before proceeding with each test.
- Punch speed set to 1mm/s.
- Before each test the die was cleaned with ethanol, the stuck zinc / debris removed by polishing with ultra fine emery cloth, and the die was cleaned again with ethanol, to ensure a repeatable surface interaction every time between die and sample.
- 10 replicate samples were tested for each condition.

Test and Analysis Parameters

- Three parameters were collected

  a. Draw height: from initial contact of the spherical punch with the sample surface up to the point of failure by load drop.

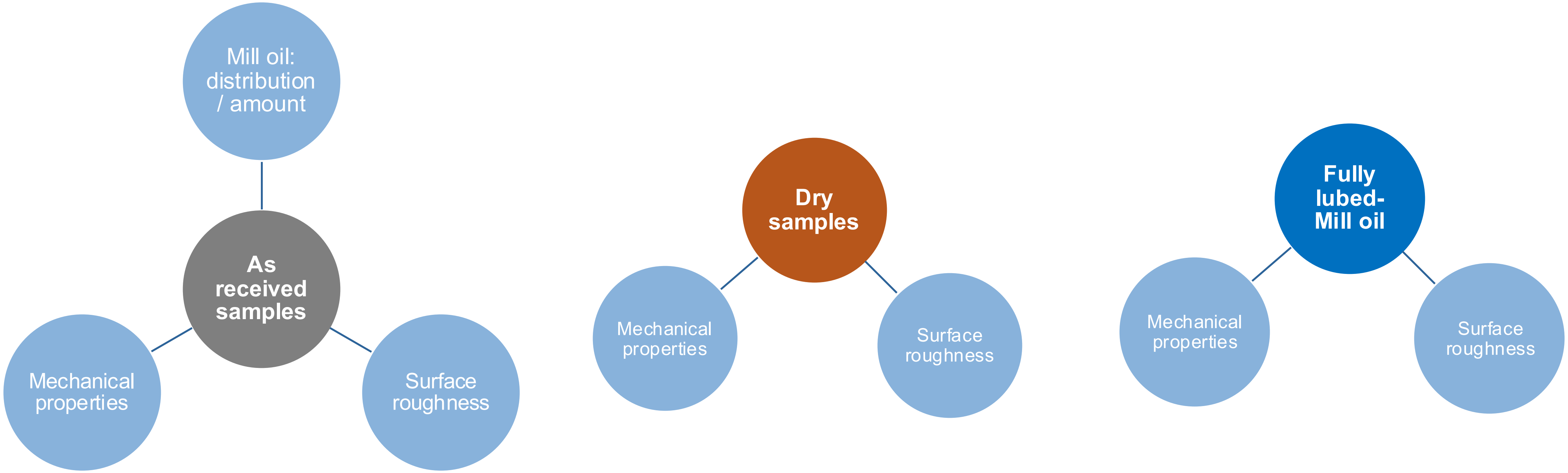
  b. Punch load.

  c. Amount of total Draw-in: from both sides, as compared to the binder wrap.

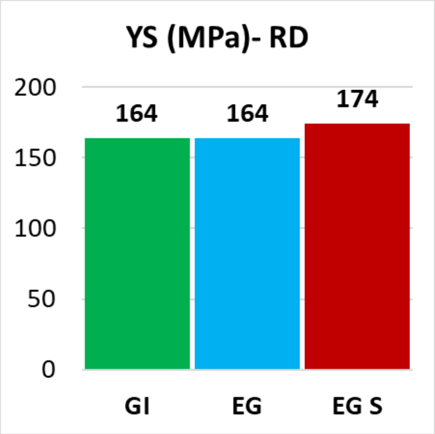
- Median is considered to measure the data’s center because of the skewed distribution of the data points.

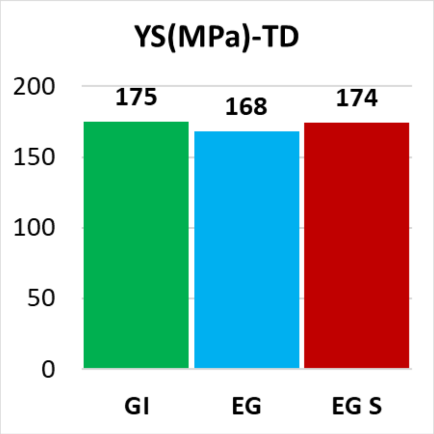
- Median Absolute Deviation (MAD) is considered to calculate the deviation of the data points from median.

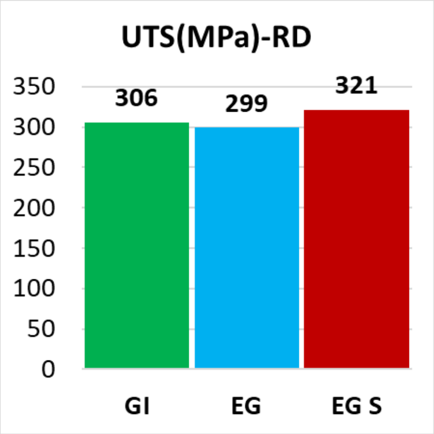
Parameters Affecting the Forming Process

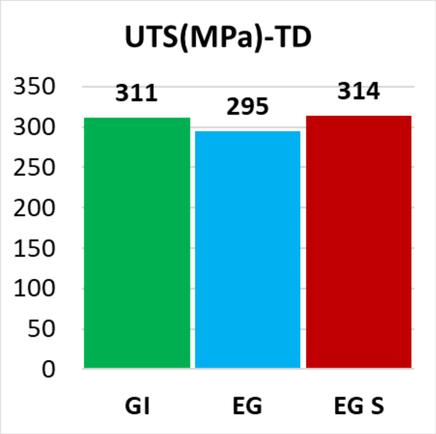


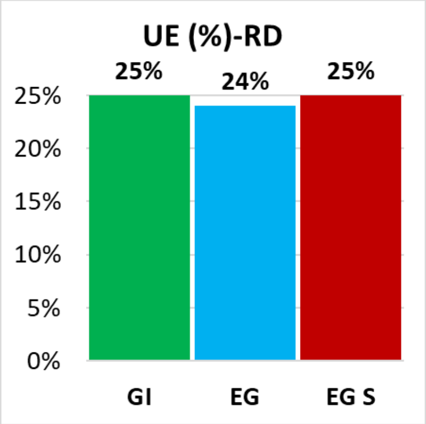
Mechanical properties

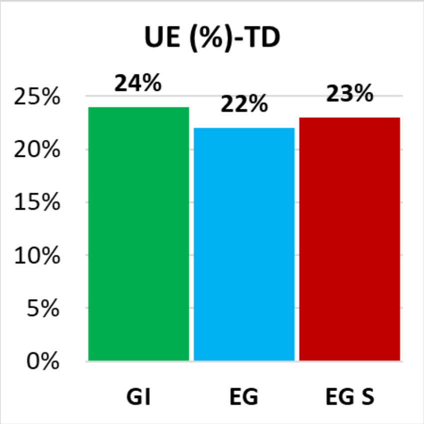


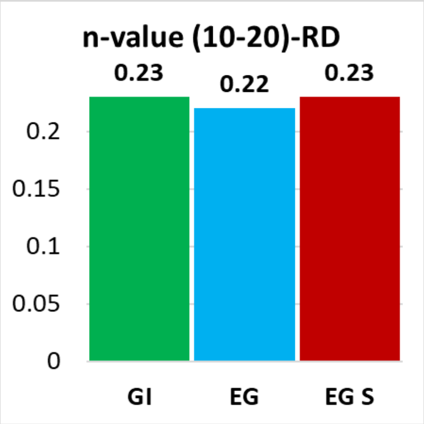


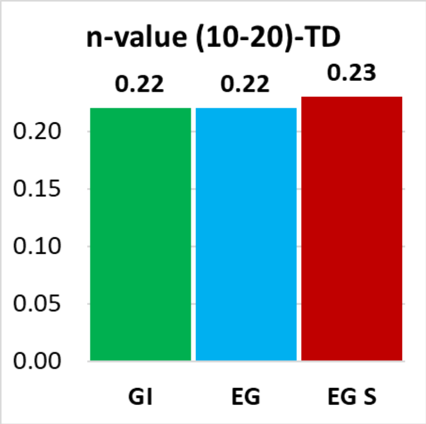


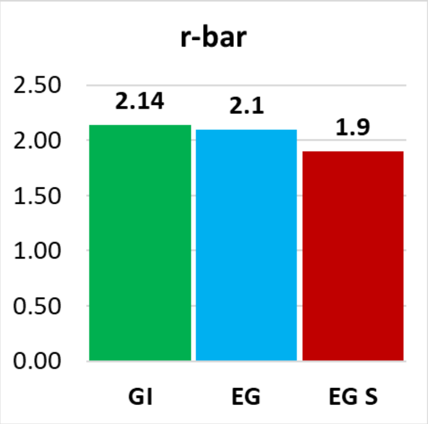








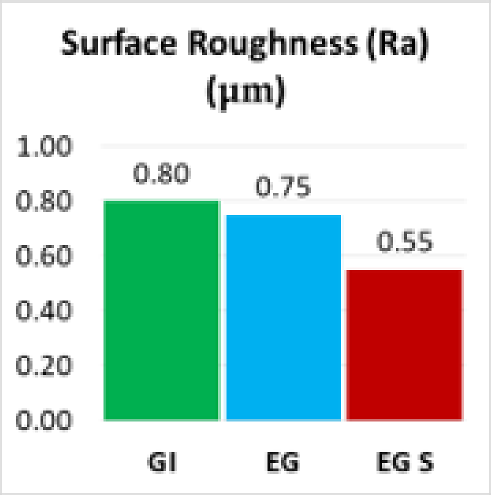


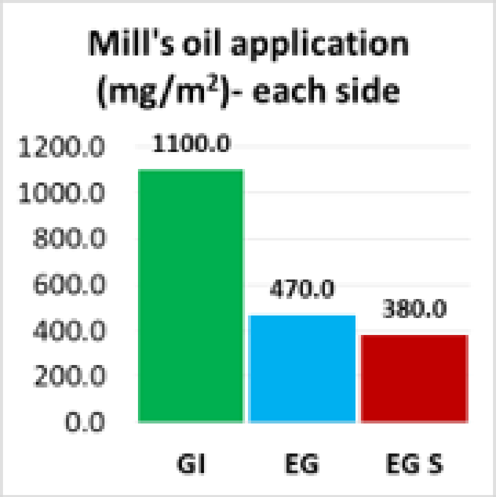


- Differences in mechanical properties are insignificant.

Surface Roughness, Mill Oil Distribution & Amount

- Surface of EGS is smoother than the other two.
- Mill oil amount is significantly higher for GI than EG and EGS.
- Mill oil distribution: uneven



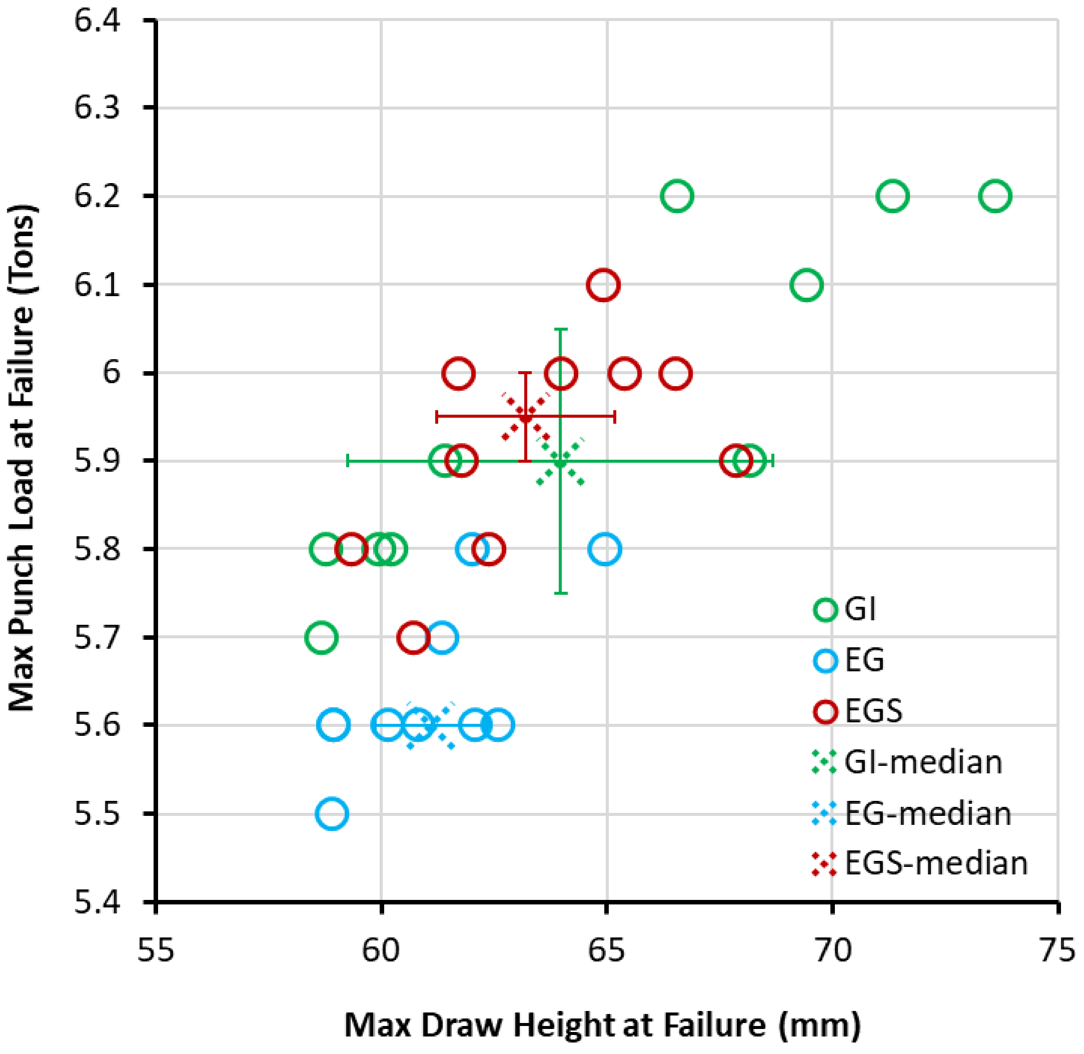


Test Results for Dry Samples, Draw Height

- The max draw height is similar to each other for all the three coatings.

	EG	EGS	GI
Draw Height (mm) (Median)	61.09	63.19	63.98
Median Absolute Deviation	1.23	1.97	4.705

Binder Pressure= 3 Tons

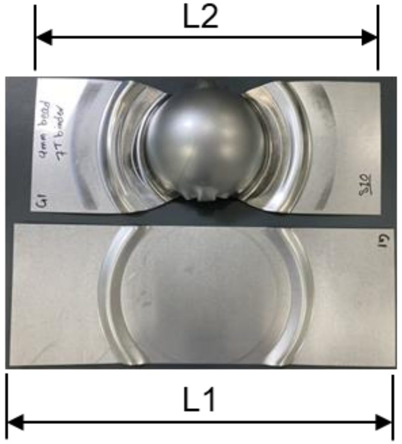


Test Results for Dry Samples, Draw-in

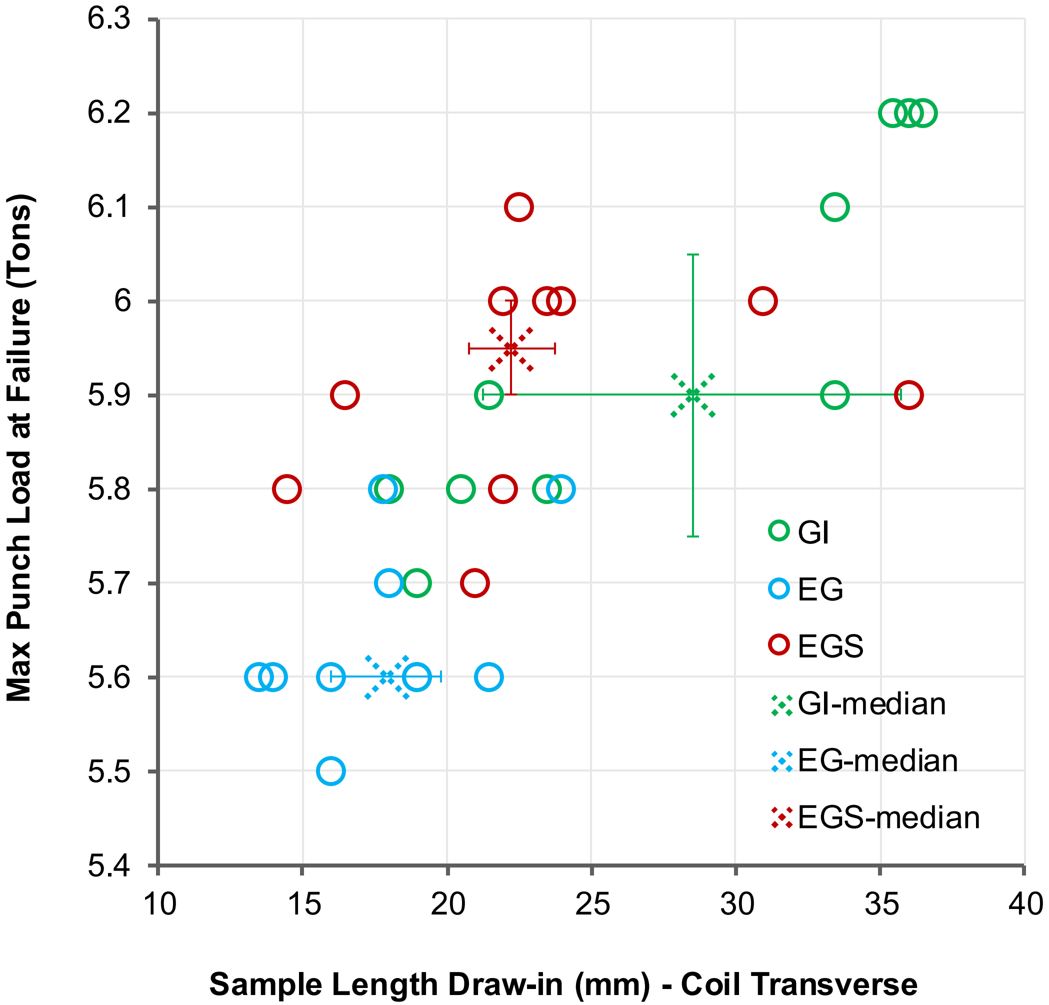
- Draw-in for GI is significantly more.

	EG	EGS	GI
Draw-in (mm) (Median)	17.9	22.25	28.5
Median Absolute Deviation	1.9	1.5	7.25

Binder Pressure= 3 Tons



*S*ample Length Draw-in (Coil Transverse) = L1 - L2



Test Results for As Received Samples, Draw Height

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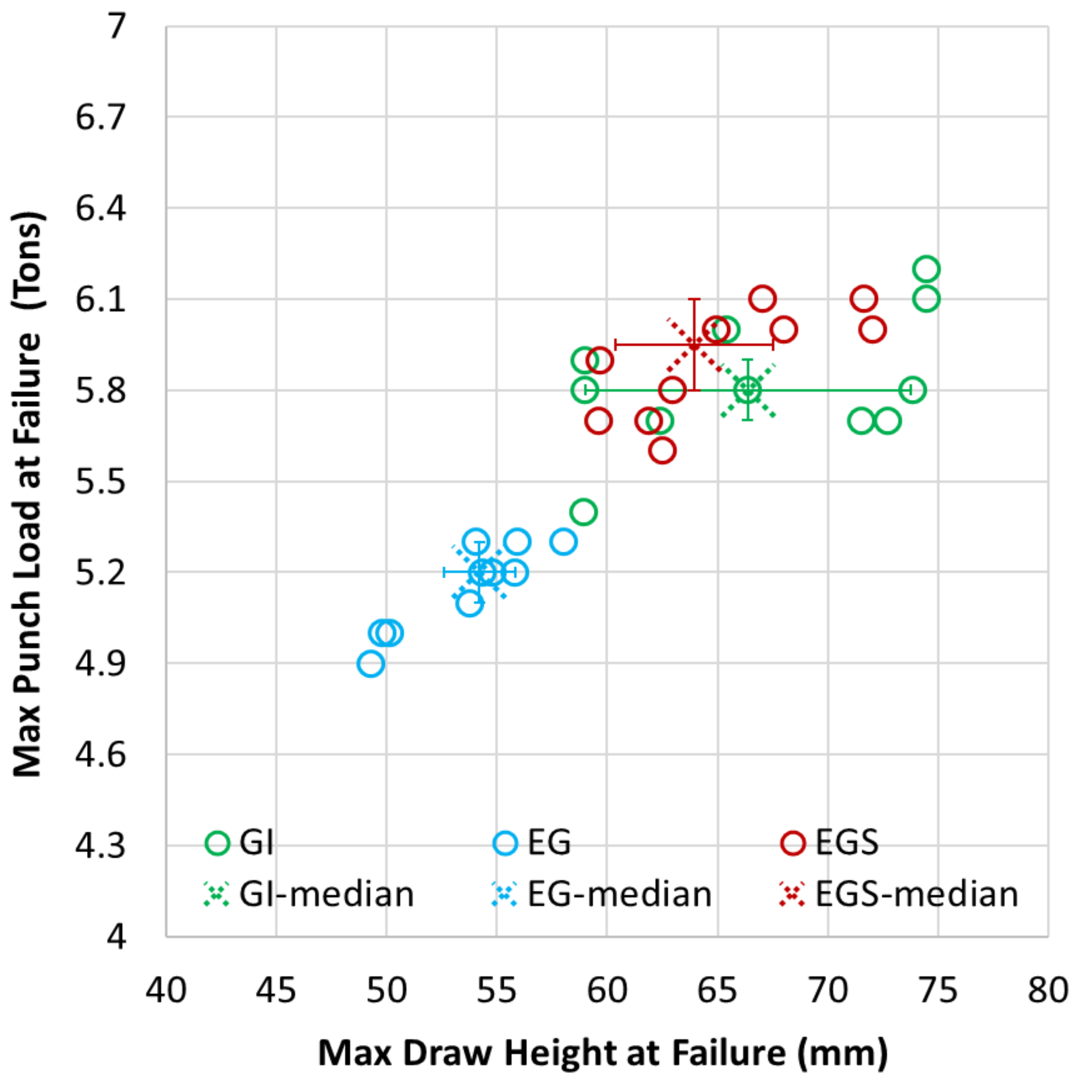
- Max draw height for EG is less than the other two.

	EG	EGS	GI
Draw Height (mm) (Median)	54.21	63.94	66.37
Median Absolute Deviation	1.64	3.575	7.38

Binder Pressure= 7 Tons

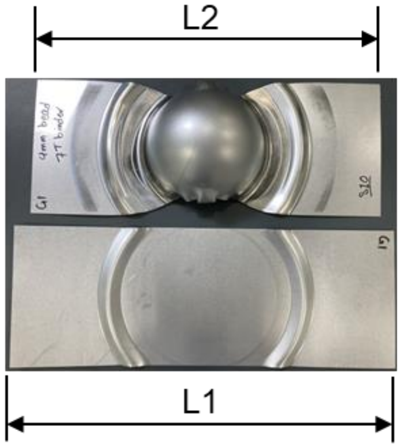


Test Results for As Received Samples, Draw-in

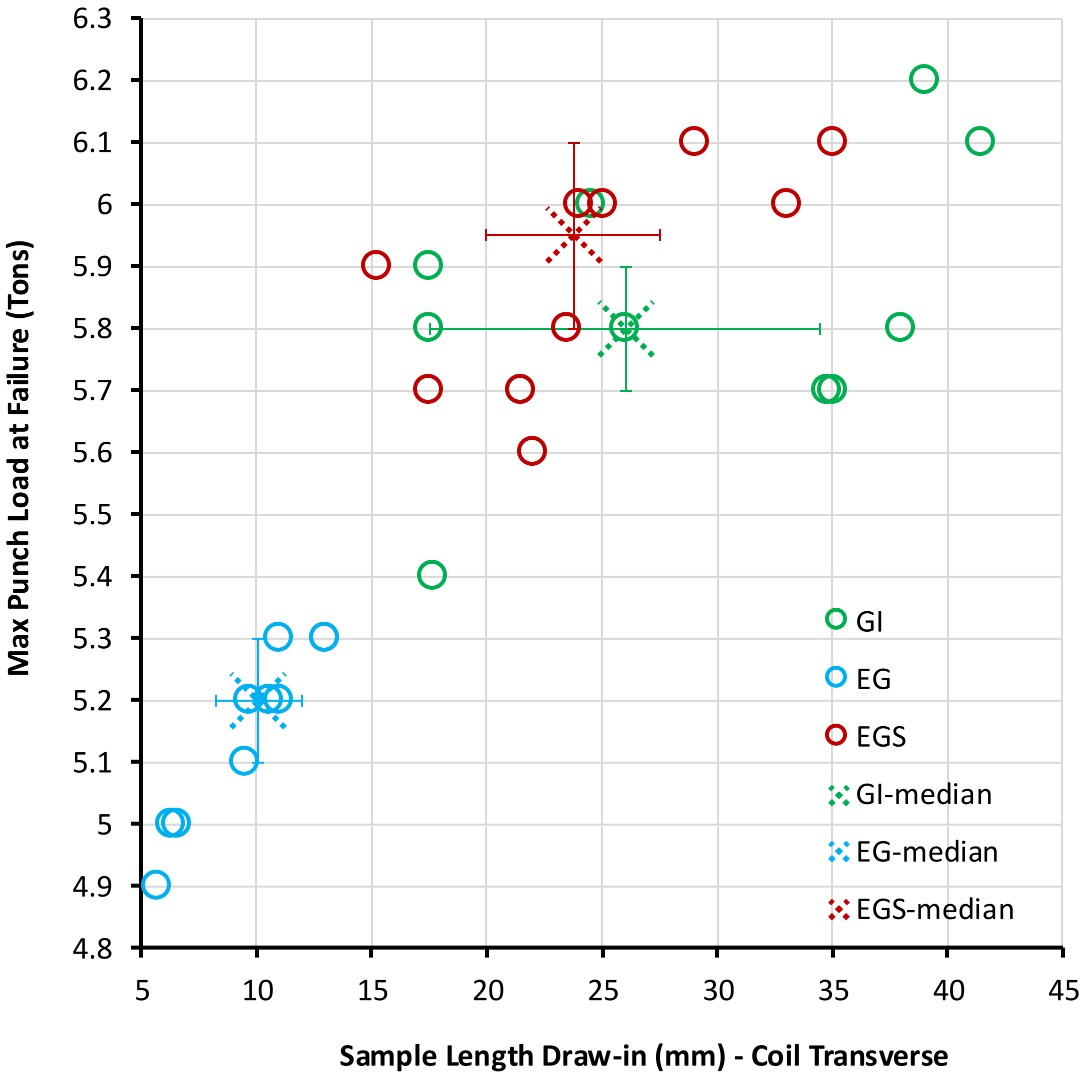
- The draw-in for EG is significantly lower.
- The draw-in of EGS and GI is similar.

	EG	EGS	GI
Draw-in (mm) (Median)	10.1	23.75	26
Median Absolute Deviation	1.9	3.75	8.5

Binder Pressure= 7 Tons



*S*ample Length Draw-in (Coil Transverse) = L1 - L2

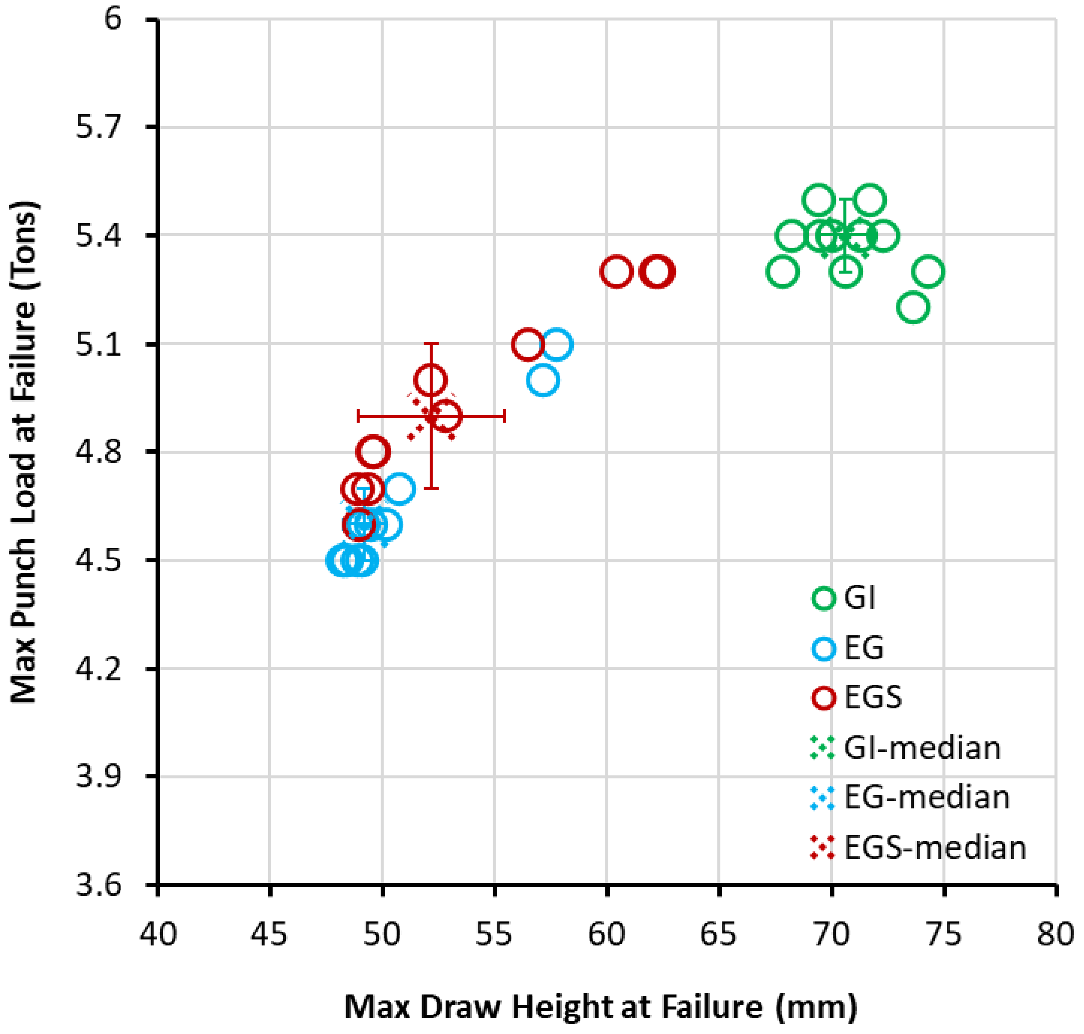


Test Results for Fully Lubed Samples, Draw Height

- The max draw height is significantly higher for GI.
- The max draw height for EG and EGS is similar.

	EG	EGS	GI
Draw Height (mm) (Median)	49.19	52.19	70.62
Median Absolute Deviation	0.91	3.24	1.16

Binder Pressure= 9 Tons

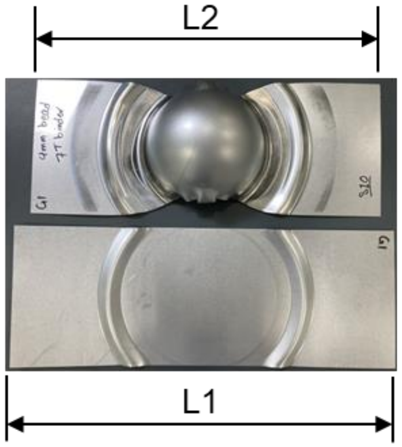


Test Results for Fully Lubed Samples, Draw-in

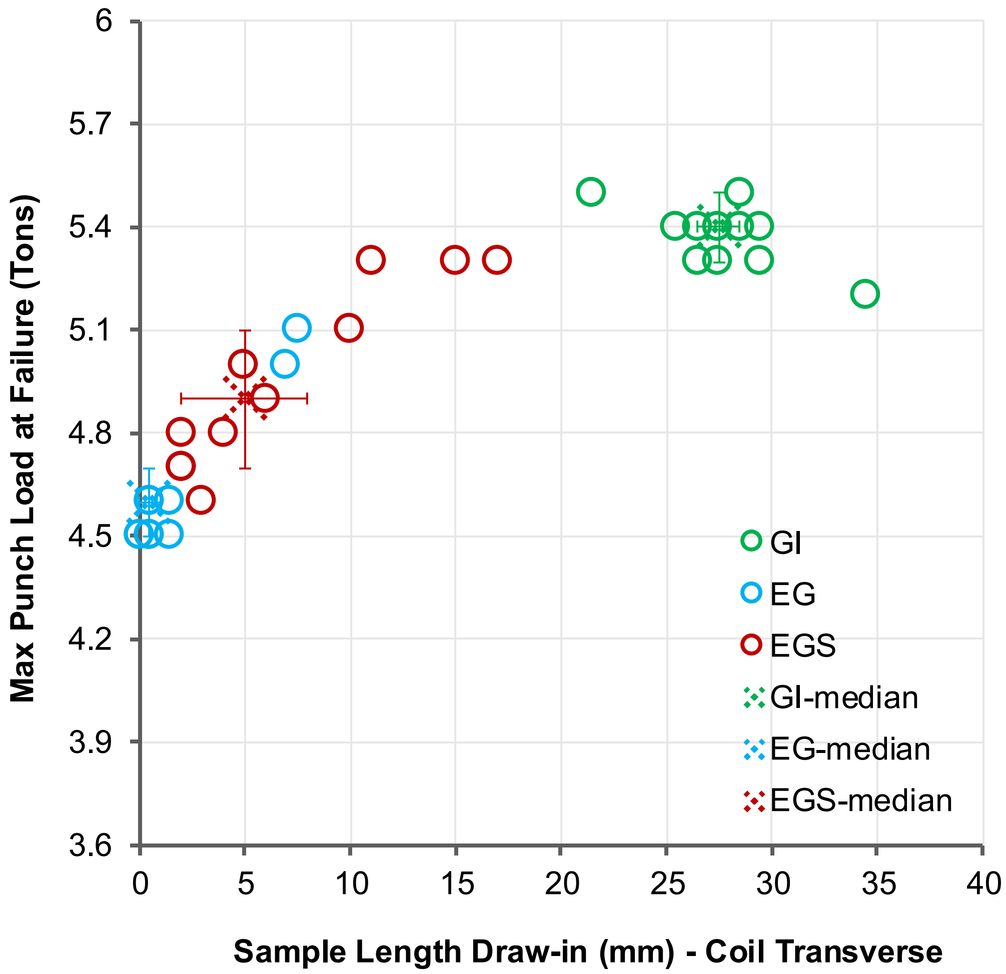
- The max draw-in is significantly higher for GI.
- Draw-in of EG and EGS is close together.

	EG	EGS	GI
Draw-in (mm) (Median)	0.5	5	27.5
Median Absolute Deviation	0.5	3	1

Binder Pressure= 9 Tons



*S*ample Length Draw-in (Coil Transverse) = L1 - L2



Test Results Summary

Blank type	Dry (3T binder load)			As received (7T binder load)			Fully lubed (9T binder load)		
Coating	EG	EGS	GI	EG	EGS	GI	EG	EGS	GI
Draw Height (mm) (Median)	61.09	63.19	63.98	54.21	63.94	66.37	49.19	52.19	70.62
Median of Absolute Deviation	1.23	1.97	4.705	1.64	3.575	7.38	0.91	3.24	1.16
Length Draw-in (mm) (Median)	17.9	22.25	28.5	10.1	23.75	26	0.5	5	27.5
Median of Absolute Deviation	1.9	1.5	7.25	1.9	3.75	8.5	0.5	3	1

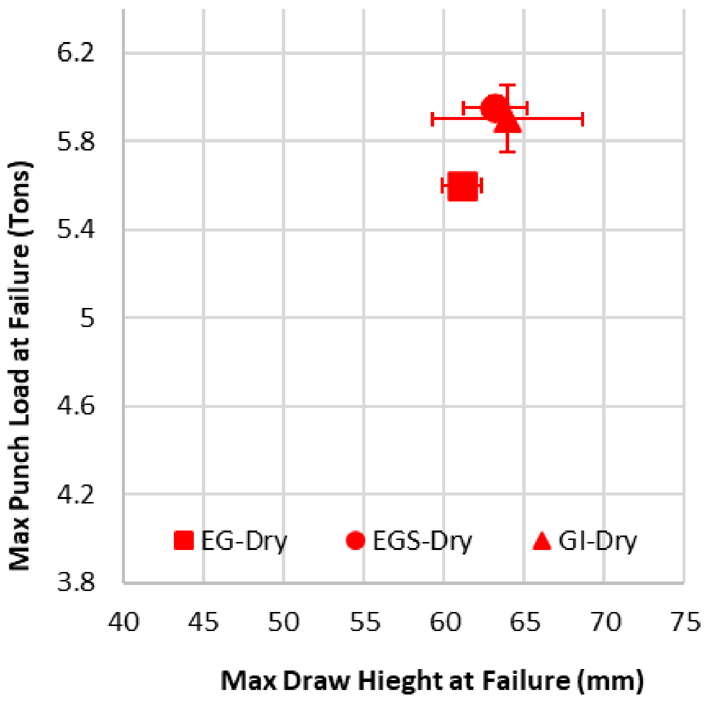
Coating	EG	EGS	GI
Mill's Oil Application (mg/m2)-each side	470	380	1100
Surface Roughness (Ra)(μm)	0.75	0.55	0.8
Coating amount	60G60G	60G60G	60G60G

Typical failure

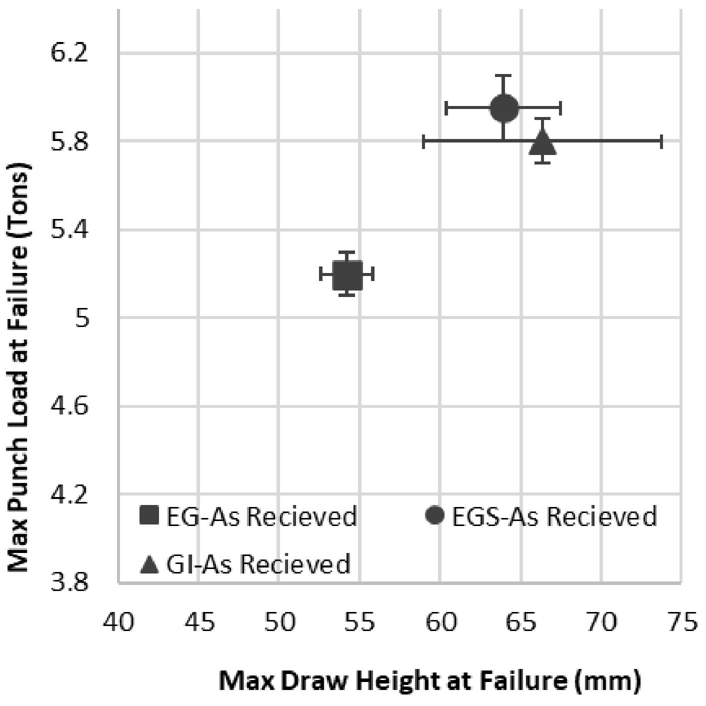
Test sample with DIC speckle pattern

Test Results Summary for Draw Height

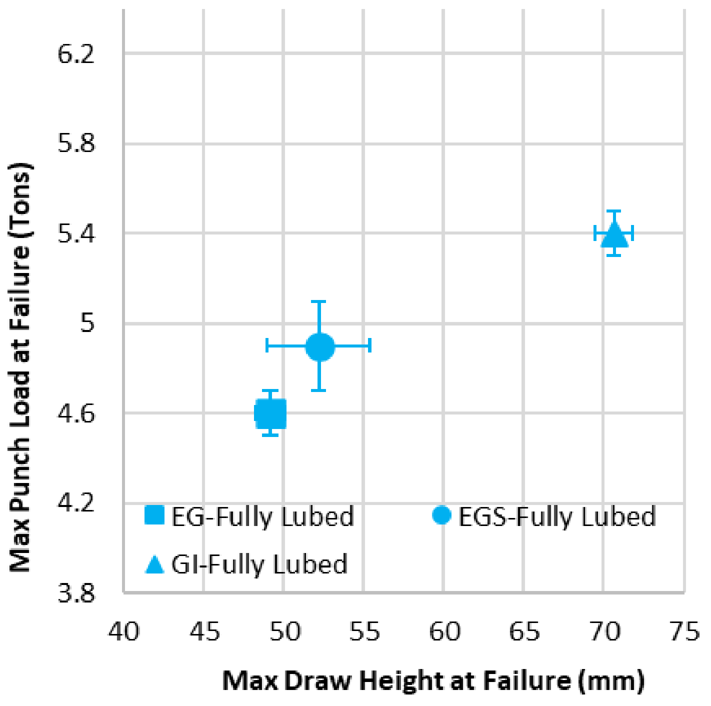
Dry- 3T binder load



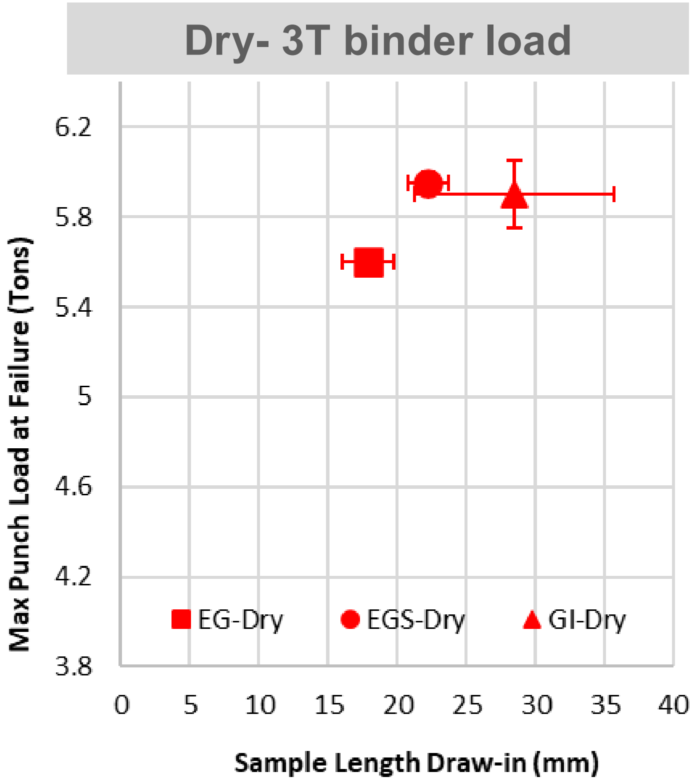
As Received- 7T binder load

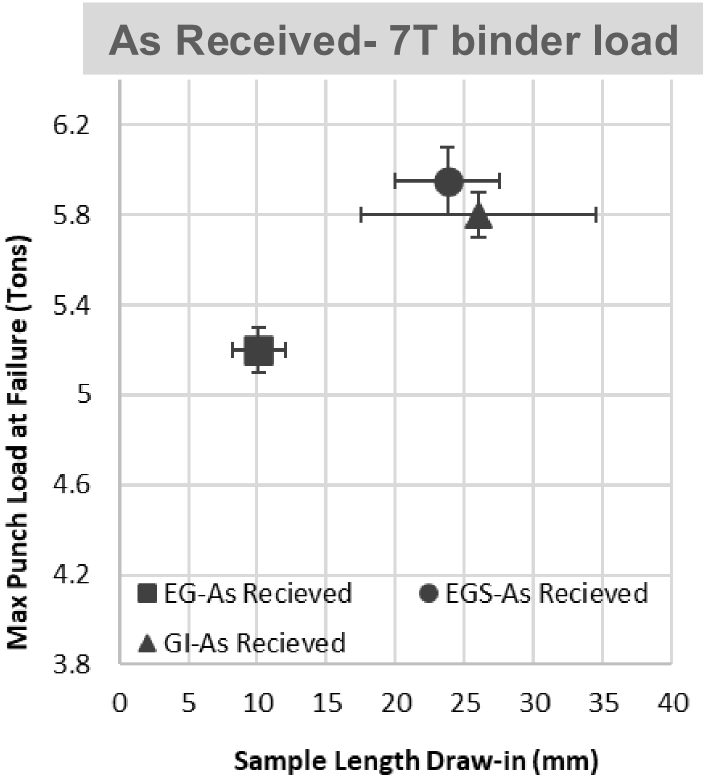


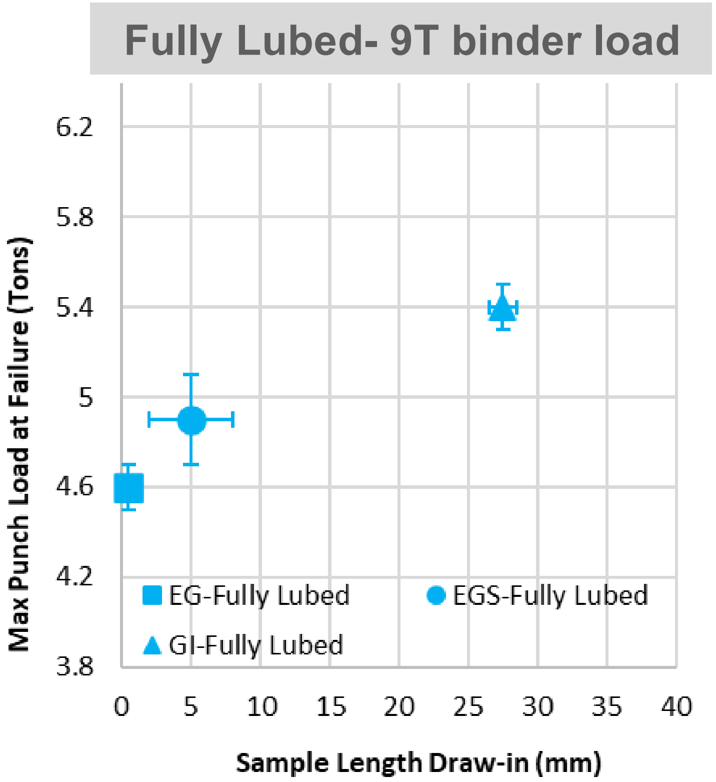
Fully Lubed- 9T binder load



Test Results Summary for Draw-In





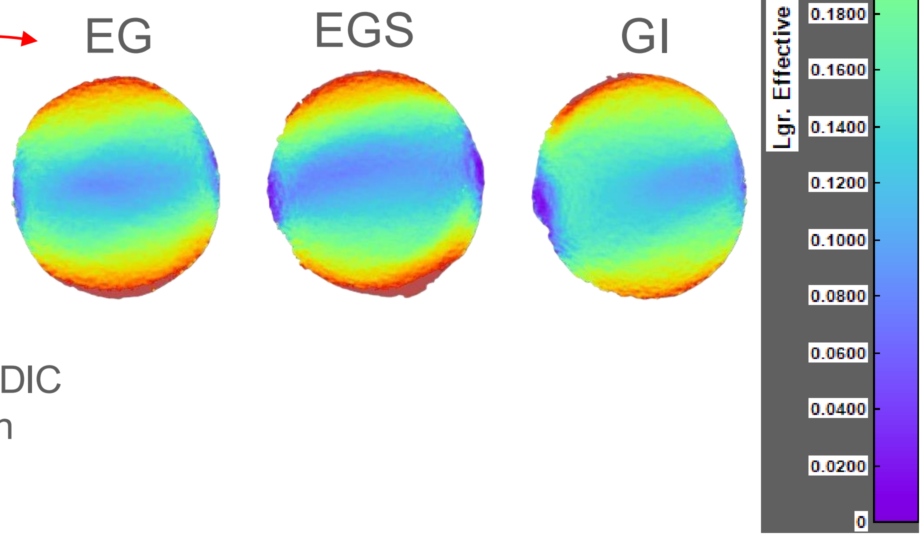


Conclusions

- **For dry condition:**
  - The max draw height is very similar to each other for all the three coatings.
  - The draw-in amount is the least for EG coating followed by EGS (24.3% more than EG) and GI (59.2% more than EG).
  - Largest deviation in the draw-in amount is for GI coating, followed by EG and EGS.
  - DIC results show a more uniform stretch for GI, while the strain map on EG and EGS show more strain gradient.

Blank type	Dry (3T binder load)		
Coating	**EG**	**EGS**	**GI**
Draw Height (mm) (Median)	61.09	63.19	63.98
Median of Absolute Deviation	1.23	1.97	4.705
Length Draw-in (mm) (Median)	17.9	22.25	28.5
Median of Absolute Deviation	1.9	1.5	7.25

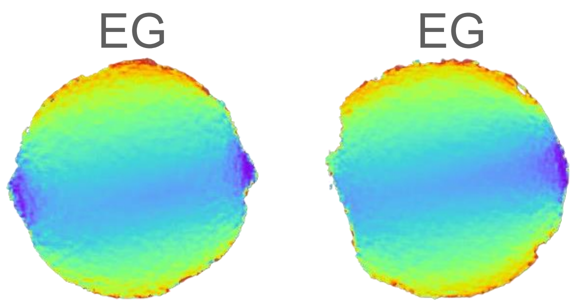
Test sample with DIC speckle pattern

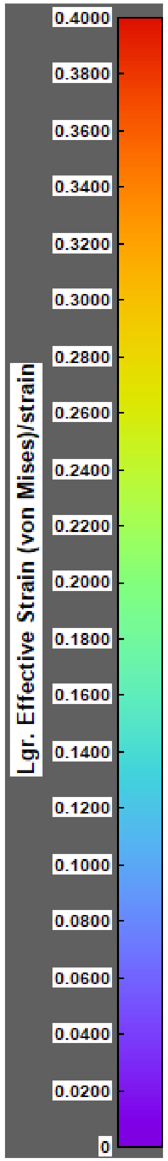


Conclusions

- For as-received condition:
  - The least draw height is related to EG followed by EGS (18% more than EG) and GI (22% more than EG).
  - The draw-in amount is the least for EG followed by EGS (135% more than EG) and GI (157% more than EG).
  - Largest deviation in the draw-in amount is for GI coating, followed by EGS and EG.
  - DIC results show almost similar strain gradient for EG and EGS.

Blank type	As received (7T binder load)		
Coating	**EG**	**EGS**	**GI**
Draw Height (mm) (Median)	54.21	63.94	66.37
Median of Absolute Deviation	1.64	3.575	7.38
Length Draw-in (mm) (Median)	10.1	23.75	26
Median of Absolute Deviation	1.9	3.75	8.5

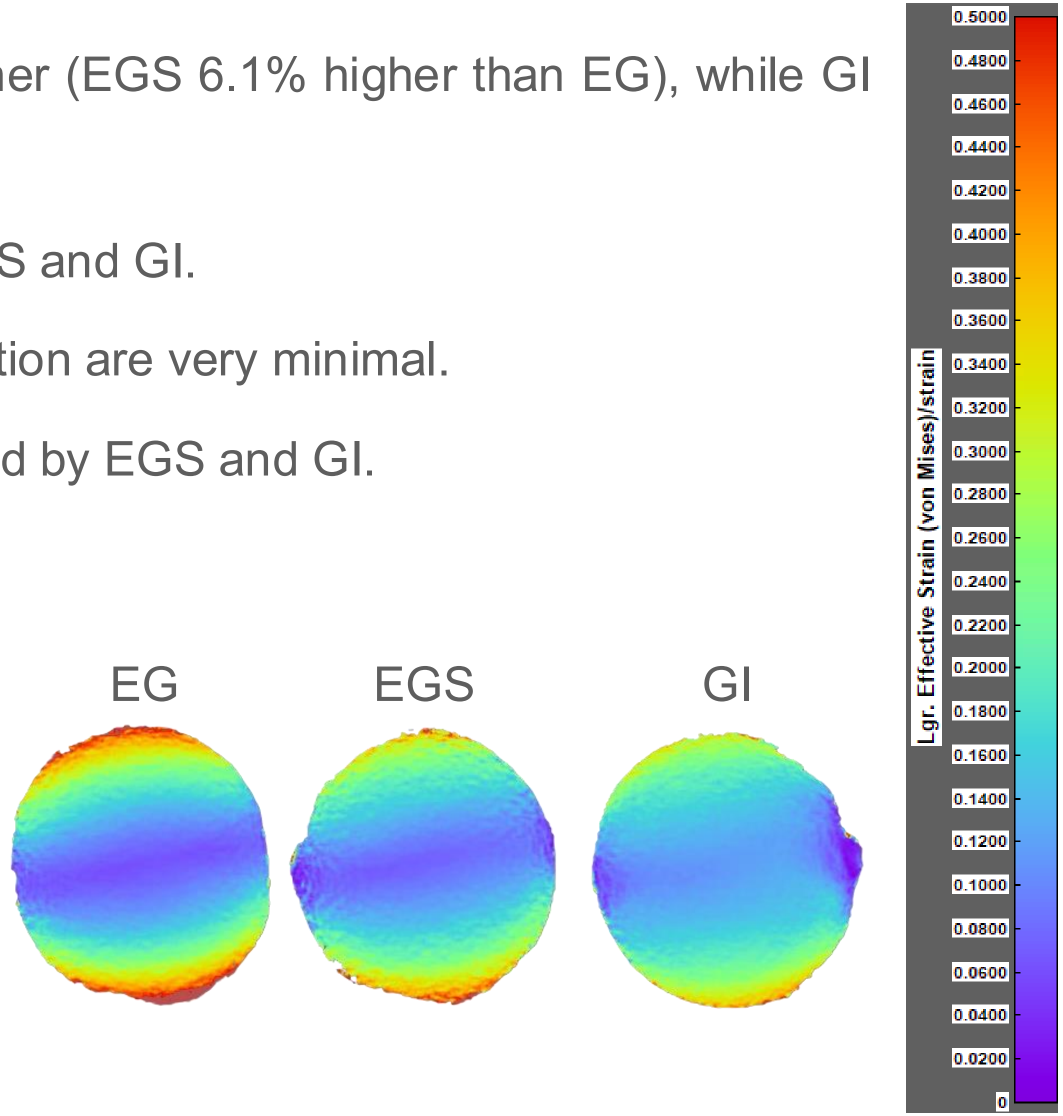




Conclusions

- For fully lubed condition:
  - The draw height of EG and EGS are very close together (EGS 6.1% higher than EG), while GI shows the most draw-height.
  - The draw-in amount is the least for EG followed by EGS and GI.
  - The draw-in and draw-height median of absolute deviation are very minimal.
  - DIC results show highest strain gradient for EG followed by EGS and GI.

Blank type	**Fully lubed (9T binder load)**		
Coating	**EG**	**EGS**	**GI**
Draw Height (mm) (Median)	49.19	52.19	70.62
Median of Absolute Deviation	0.91	3.24	1.16
Length Draw-in (mm) (Median)	0.5	5	27.5
Median of Absolute Deviation	0.5	3	1



Conclusions

- In dry condition the effect of coating on forming is minimized.
- When fully lubed the forming behavior of EG and EGS coatings becomes more similar to each other and less than GI samples, which are drawn-in the most.
- When the samples are fully lubed the draw height and draw-in amount are very consistent from sample to sample for each coating.
- To stamp a fully lubed sample, higher constraining force (bead height or binder pressure or the combination) is needed for the GI coating compared to EG and EGS.
- With the countermeasures applied to the die as identified in this research, the production process will require fine tuning to accommodate the differences in interface friction introduced by the various coatings.