LASER HARDENING OF CUTTING DIES (SEMI INDUSTRIAL) TRIAL

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(for Auto/Steel Partnership)

GREAT DESIGNS IN STEEL™

GOALS AND OBJECTIVES

Value Statement:

Industry claims that trim inserts can be laser hardened from bar steel (as-received) with no post-hardening machining, providing a low-cost option for trim inserts

Goal:

Use a laboratory-based die trial to assess the performance of laser hardened trim inserts against more traditional trim materials/processes.

Objectives:

- **Compare the performance of the following trim inserts:**
  - Laser hardened S7 annealed (S7-LH) - Lowest Cost
  - Laser hardened 4140 pre-hard (4140-LH) - Medium Cost
  - Caldie through-hardened (Caldie-TH) - Highest Cost

TRIM INSERT PROCESSING OPTIONS				
THROUGH HARDENING	ROUGH MACHINE	GRIND	HEAT TREAT	FINISH MACHINE
INDUCTION HARDENING	ROUGH MACHINE	GRIND	HEAT TREAT	FINISH MACHINE
LASER HARDENING	ROUGH MACHINE	GRIND	HEAT TREAT	

Reduced Operation

- **Determine if the starting microstructure affects laser hardening with respect to case microstructure, surface hardness, and effective case depth***
- **Determine if laser hardening affects trim edge dimensions**

**Effective Case Depth = Distance from the surface where the hardness equals 50 HRc.*

PREPARE INSERTS

S7-LH Manufacturing Process	4140-LH Manufacturing Process	CALDIE-TH Manufacturing Process
Receive S7 annealed bar stock (Alro Steel)	Receive 4140 Pre-Hard bar stock (Alro Steel)	Receive CALDIE bar stock (Voestalpine)
Rough machine inserts (Microfixtures)	Rough machine inserts (Microfixtures)	Rough machine inserts (Microfixtures)
Grind trim edges (Microfixtures)	Grind trim edges (Microfixtures)	Grind trim edges (Microfixtures)
Laser hardened trim edge (Synergy)	Laser hardened trim edge (Synergy)	Heat Treat (Sun Steel Heat Treating)
		Grind trim edges (Microfixtures)
Bluelight scan trim edge	Bluelight scan trim edge	Bluelight scan trim edge
Measure Radii (GM)	Measure Radii (GM)	Measure Radii (GM)

S7-LH Insert	4140-LH Insert	CALDIE-TH Insert
		

Edge Radii
- S7-LH = 136 µm
- 4140-LH = 13 µm
- CALDIE-TH = 13 µm

- Rough machining of S7 annealed with a hardness less than 20 HRc resulted in edge breakage and thus larger trim edge radii
- 4140 prehard and CALDIE-TH had similar trim edge radii, which were much sharper than the S7-LH

LASER HARDENED INSERTS

S7-LH Insert

4140-LH Insert

The hardened area of the S7-LH inserts showed a periodic oxidation pattern.

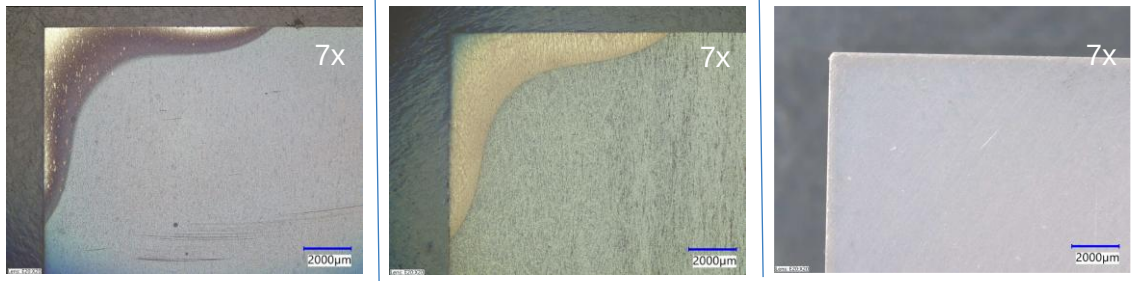
- The S7 material oxidized more than that of the 4140 material, which may have affected the hardening process. Surface hardness was found to vary slightly throughout the oxidation pattern.
- The cause of the increased oxidation may be due to the richer chemistry of the S7 or the non-homogenous annealed microstructure.

The laser hardened area of the 4140-LH inserts appears uniform across the entire length of the insert.

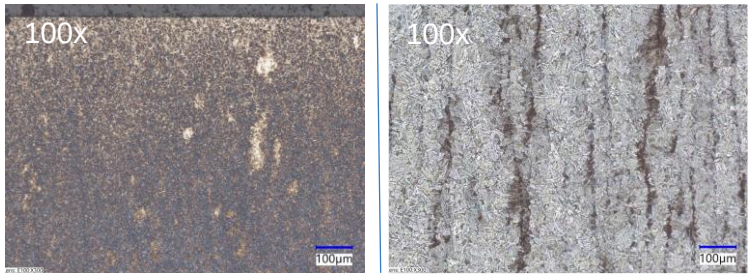
METALLURGICAL RESULTS

S7-LH	4140-LH	CALDIE-TH

Case Profile



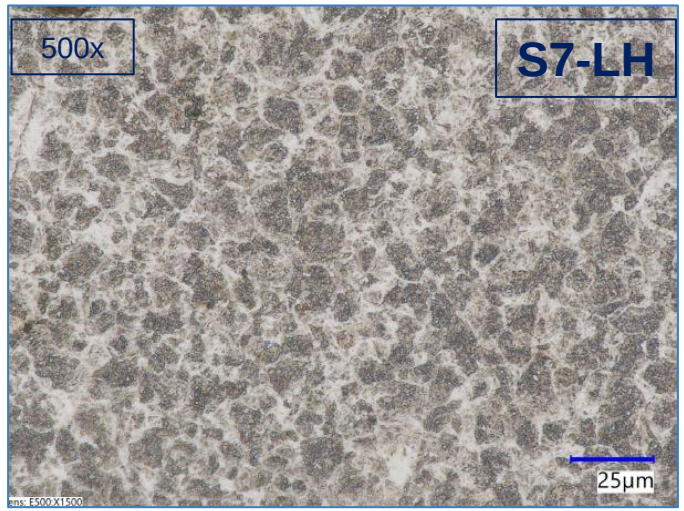
Case Microstructure

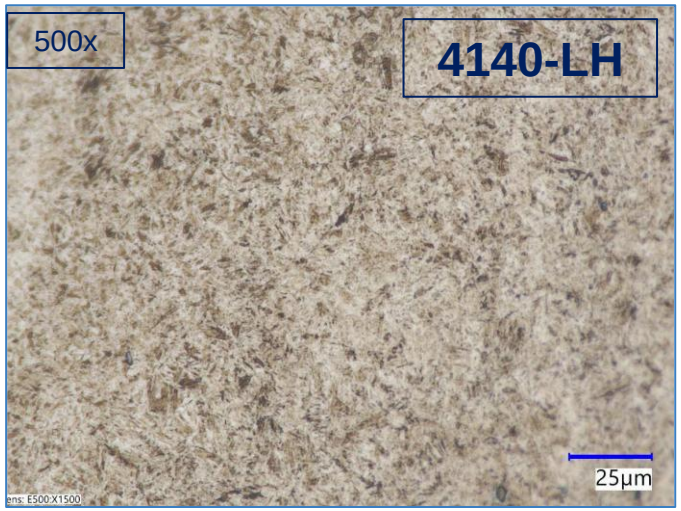


Core Microstructure

- The laser is applied at a 45° angle to corner
- The laser hardened case profile is similar for S7 and 4140
- Caldie was not laser hardened

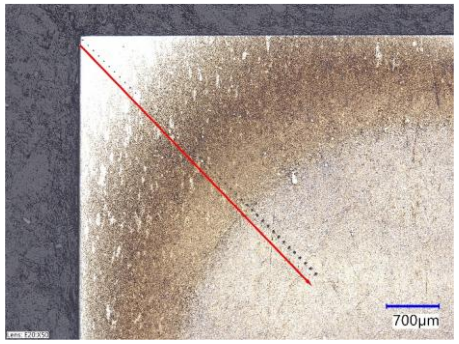
- The 4140-LH case microstructure is homogenous
- The S7-LH case microstructure is not homogenous
- **Conclusions:**
  - The S7 annealed microstructure did not fully austenitize within the time of the laser pass producing a mixed microstructure, which may impact insert durability

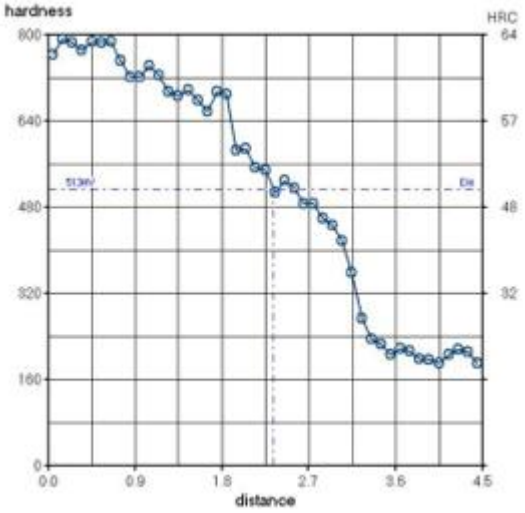




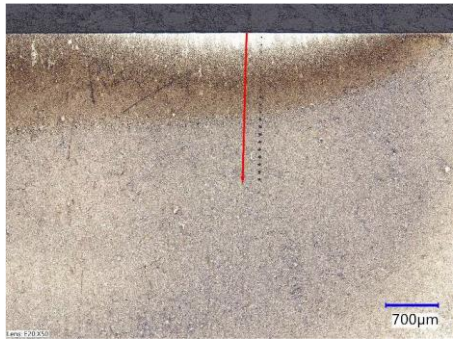
CASE HARDNESS PROFILES (S7-LH AND 4140-LH)

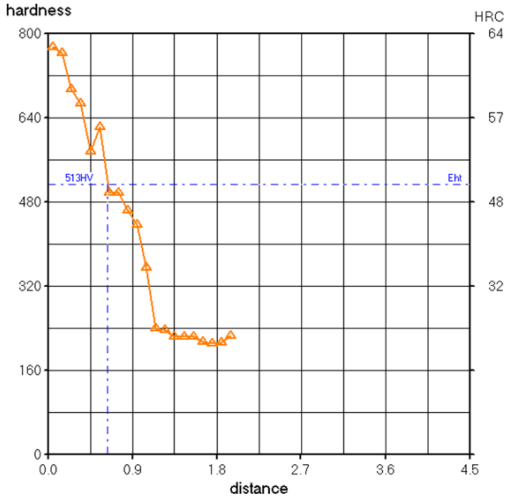
S7-LH Case (corner)



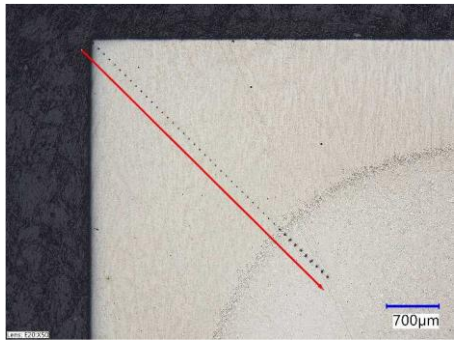


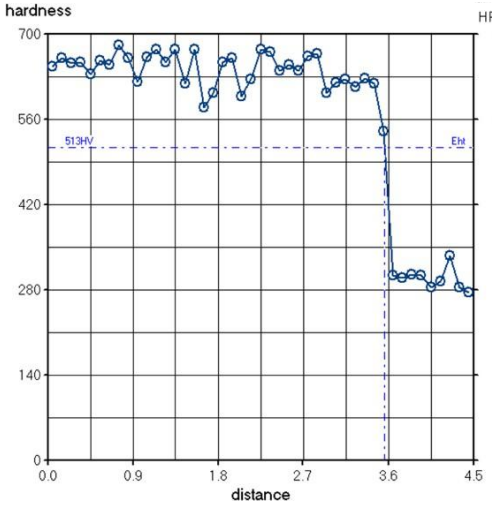
S7-LH Case (7 mm from corner)



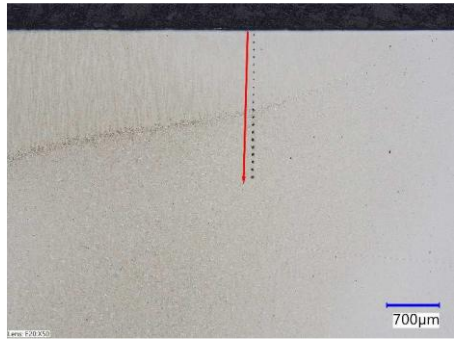


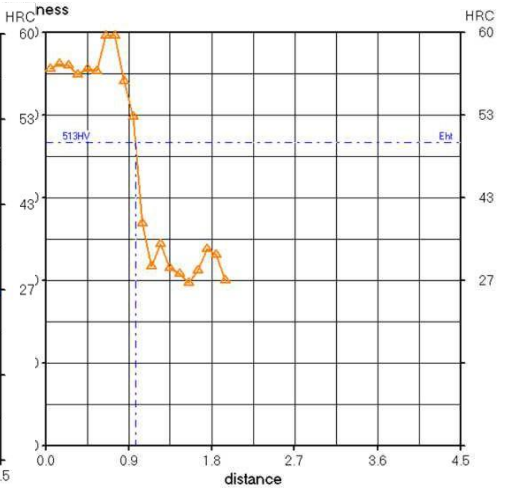
4140-LH Case (corner)





4140-LH Case (7 mm from corner)





The case profile from the corner is deeper than that away from the corner due to heat transfer from two directions

S7-LH case did not exhibit a hardness plateau, but rather a hardness gradient

4140-LH case exhibited a sustained hardness plateau followed by a steep hardness gradient

The distance of 7 mm from edge was chosen as this is the point where the case profile changes from concave to convex.

HARDNESS RESULTS

- S7 has a higher Carbon Equivalent (CE) than 4140, which typically suggests better response to laser hardening
  - S7 CE = ~2
  - 4140 CE = ~0.8
- This is proven by the S7-LH's higher surface hardness:
  - S7 = 63 HRc
  - 4140 = 58 HRc
- However, 4140-LH had a deeper effective case depth than S7-LH
  - 3.5 mm vs 2.3 mm at corner
  - 1 mm vs 0.7 mm at 7 mm from edge

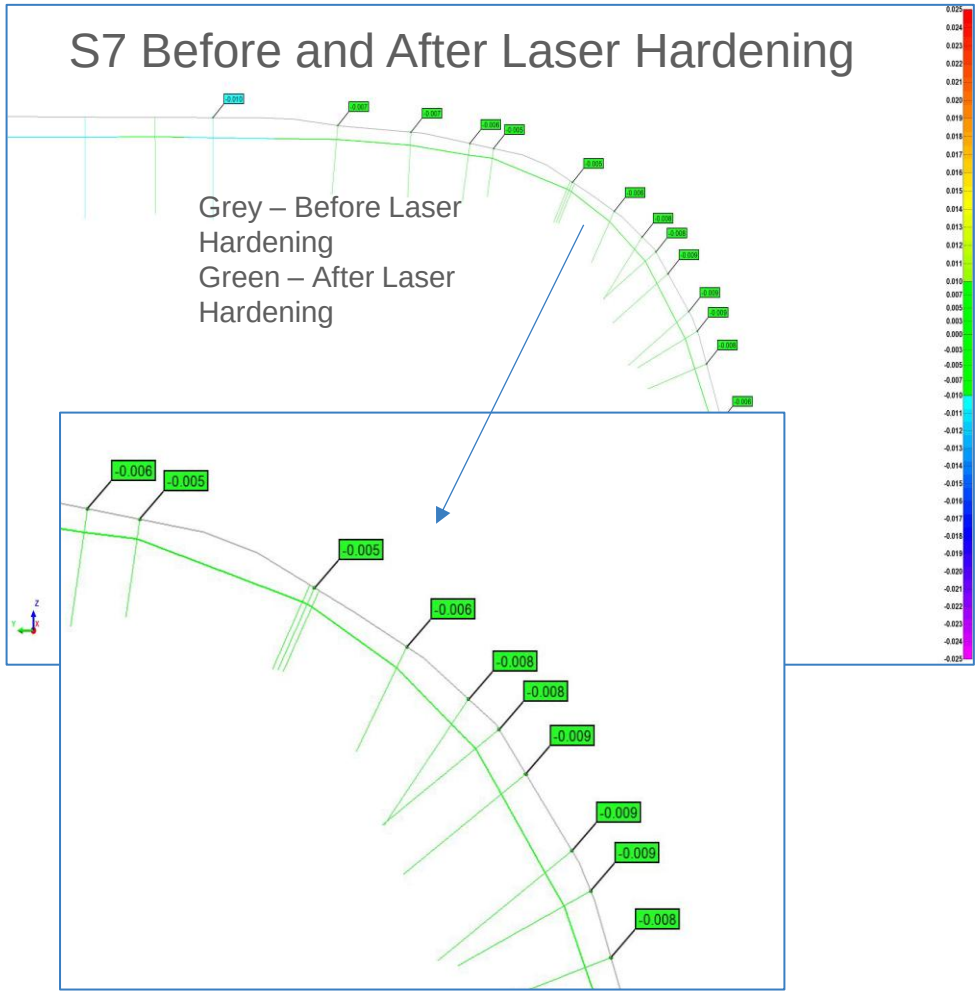
	S7-LH	4140-LH	CALDIE-TH
Core Hardness (HRc)	<20	30	~20**
Surface Hardness (HRc)			
Corner	63	58	63
7 mm from Corner	63	58	60
Effective Case Depth (>50 HRc, mm)			
Corner	2.3	3.5	
7 mm from Corner	0.7	1	

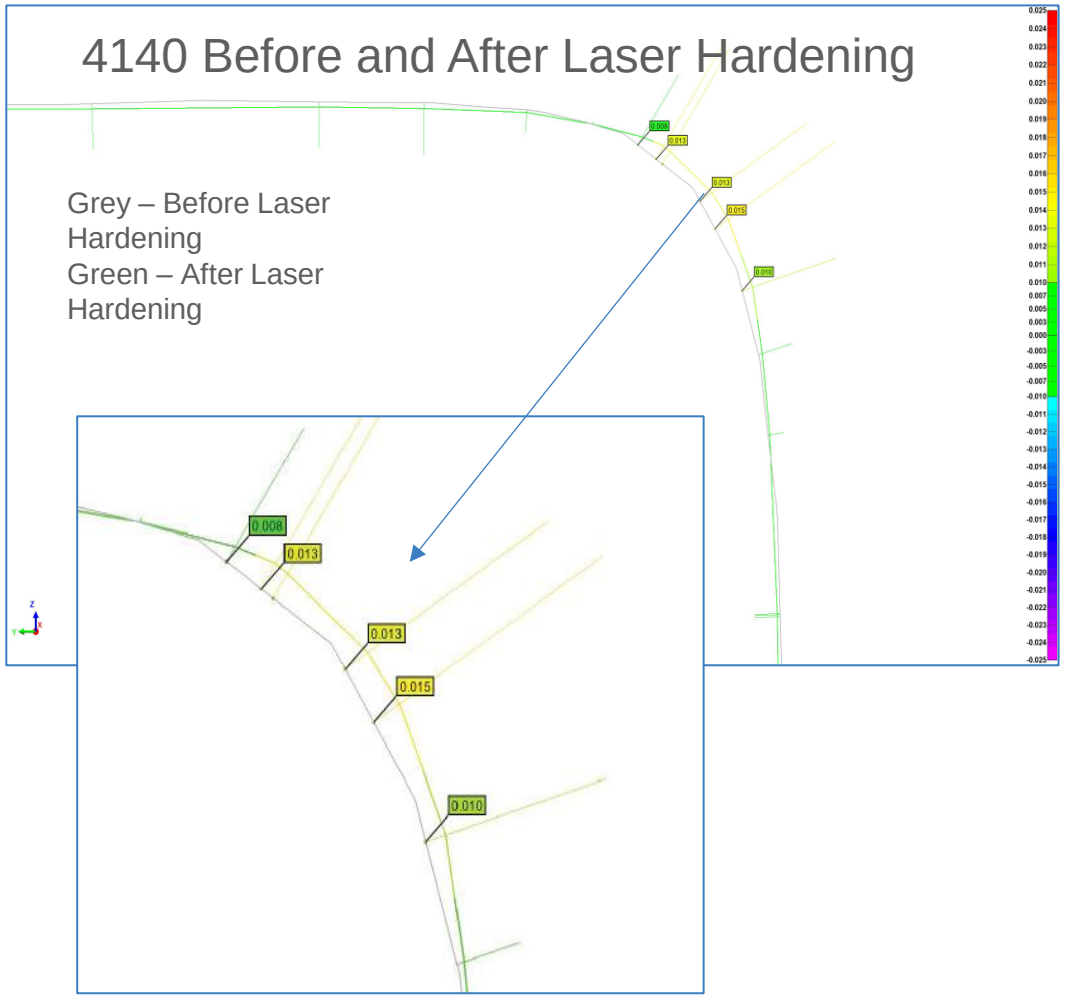
- **Conclusion:**

  The pre-hard microstructure of 4140 enabled a better case profile and effective case depth from laser hardening than the S7 annealed microstructure.

***The CALDIE through hardening heat treatment may not have been performed correctly*

EDGE DIMENSIONS AFTER LASER HARDENING





- There is a 15 µm or less change in edge dimensions
- **Conclusion:** Laser hardening had a minimal impact on edge dimensions

LIMITED DIE TRIAL – 1000 HITS

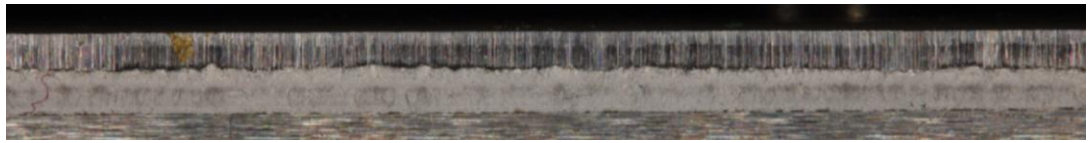
GDIS

Limited Die Trial Results

- Run a 1,000 hit die trial on each insert using 1.4 mm DP980 steel
- Assess edge damage on tool
- Characterize trim edge condition (part)

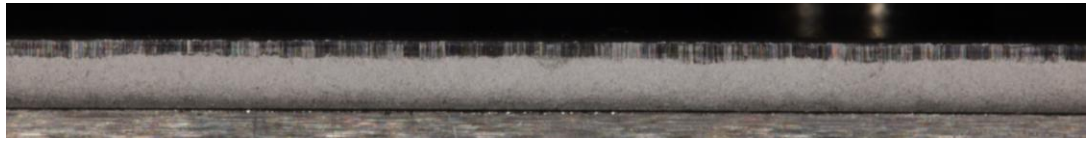
Results after 1000 hits

- S7-LH inserts had to be resharpened due to unacceptable trim edge condition
- Resharpened S7-LH, 4140-LH, and CALDIE-TH produced acceptable edge condition with minimal burr
- No chipping or significant wear observed on any insert material



S7-LH-ORIGINAL, Edge Radii = 136 µm

4140-LH , Edge Radii = 13 µm



S7-LH-RESHARPENED, Edge Radii = 10 µm

CALDIE-TH , Edge Radii = 13 µm

Observations:

- No obvious wear on parts, although witness marks were larger for the S7-LH inserts, less for the 4140-LH, and almost not noticeable on the CALDIE-TH inserts
- The larger radii of the S7-LH inserts created a larger burr in the trimmed parts. Resharpening of the inserts resulted in improved trim edge with minimal burr.
- The parts created from the 4140-LH had a minimal and acceptable amount of burr
- The parts created from the CALDIE-TH inserts had superior trim edge condition with a minimal amount of burr

DURABILITY DIE TRIAL – 37,500 HITS

Durability Die Trial Results

- Run a 37,500 hit die trial on resharpened inserts using 1.4 mm DP980 steel
- Assess edge damage on tool
- Characterize trim edge condition (part)

Results:

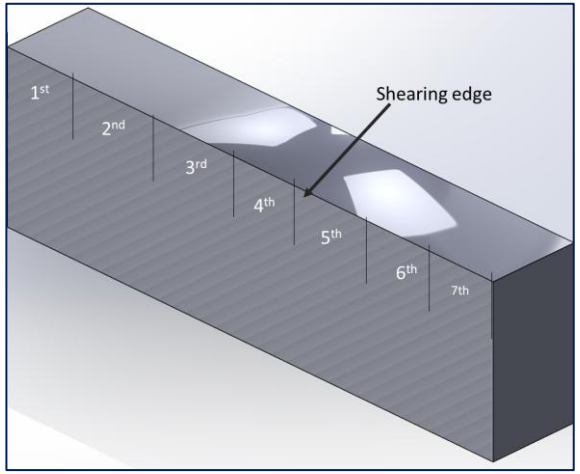
- Completed 37,500 hits on S7-LH and 37,500 hits on 4140-LH.
- Die trial of CALDIE-TH is planned
- No significant wear or chipping shown on S7-LH nor 4140-LH inserts
- Trim components of S7-LH show increased burr
- Trim components of 4140-LH did not exhibit significant burr increase

S7-LH ORIGINAL (lower insert, middle)

S7-LH 1000 hits (lower insert, middle)

4140-LH ORIGINAL (lower insert, middle)

4140-LH 1000 (lower insert, middle)



Observations:

- No signs of tool breakage after 37,500 hit die trials.
- Profilometry of the tool edges has not been performed but is planned. However, this is not a practical in-trial test.
- Trim edge condition changed continuously for both S7-LH and 4140-LH inserts

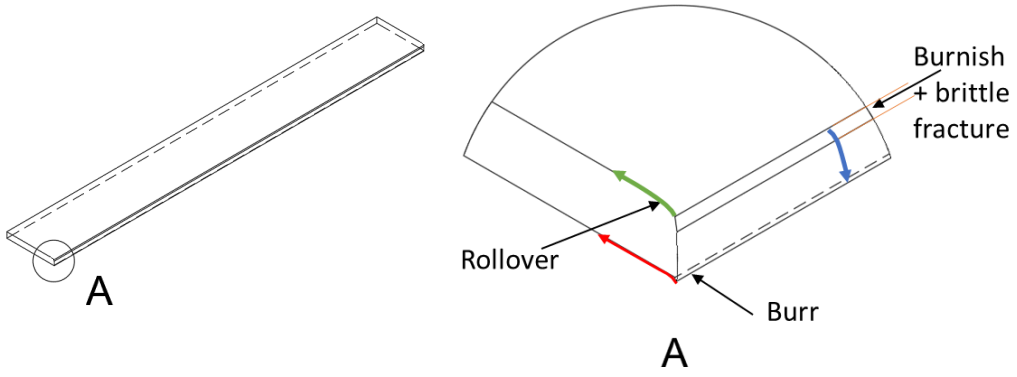
DURABILITY DIE TRIAL – 37,500 HITS

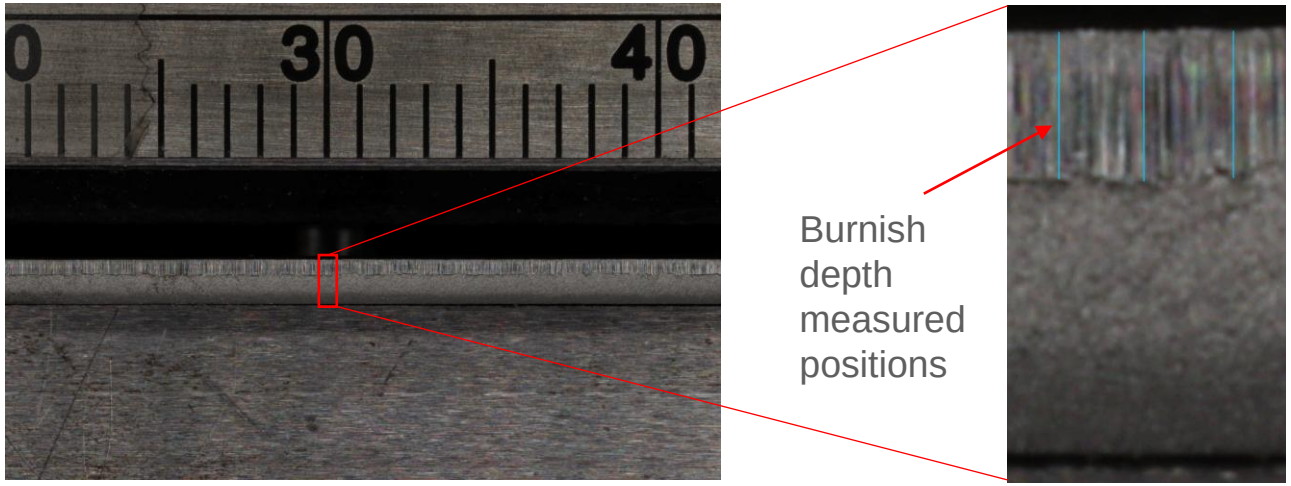
Durability Die Trial Results

- The trim edge of the stamped components changed with every hit
- Oakland University measured the width of the burnished zoned from the first hit to the 37,500th hit
  - S7-LH showed an increase of 0.070 mm and increased burr height
  - 4140-LH showed an increase of 0.177 mm but no significant increase in burr height

Insert	Initial	37,500	Delta
S7-LH	0.386	0.456	0.070
4140-LH	0.256	0.433	0.177

Burnished Width (mm)





Observations:

- Burnished zone width and burr height may be useful criteria for assessing trim edge tool wear performance.
- A longer durability die trial is needed to determine which trim edge performance metrics are most effective.
- At this point, the team can only conclude that laser hardened trim inserts are performing as intended, however, there are concerns with the steadily increasing burr zone width and burr height, especially for the S7-LH inserts.

SUMMARY OF RESULTS

- Objective #1: Compare the performance of the trim inserts:
  - **Initial Assessment (1,000 hits) - COMPLETE**
    - **All three inserts performed well in the die trial with no tool damage noted**
    - **The burr condition on the trimmed parts off the S7-LH were not acceptable, due to excessive edge radii. Parts from the resharpened S7-LH produced acceptable trim edge condition.**
    - **The trim edge condition ranked from best to worst is as follows:**
      - **CALDIE-TH → 4140-LH → S7-LH Resharpened → S7-LH Original**
  - Durability Assessment (up to 37,500 hits on each insert) – **IN PROCESS**
- Objective #2: Determine if the starting microstructure affects laser hardening with respect to case microstructure, surface hardness, and effective case depth
  - **Despite S7's hardenability advantage, 4140-LH prehard produced a superior case with respect to case profile and effective case depth than S7-annealed**
- Objective #3: Determine if laser hardening affects trim insert edge dimensions
  - **Laser hardening had a minimal effect on insert edge dimensions.**

CONCLUSIONS

- **All three insert materials/processes performed well in the initial die trial, suggesting that laser hardening is a viable manufacturing process for trim inserts.**
  - Pre-hard bar stock responds better than annealed bar stock to laser hardening.
  - Laser-hardened inserts may have less service life than through-hardened inserts with respect to resharpening
  - The case microstructure, case profile, and effective case of the laser hardened S7 annealed inserts was inferior to that of 4140 pre-hard inserts, which will likely impact tool durability.

- **The study did not support the premise that trim inserts can be laser hardened from annealed bar stock with no post-hardening machining.**
  - Machining of the softer as-received bar stock resulted in larger edge radii which in turn resulted in an unacceptable burr condition.
  - The trimmed edge condition from the both S7-LH and 4140-LH indicate that some post-hardening machining is necessary to achieve edge sharpness and desired part trim edge condition.
  - Pre-hard and through-hard bar stock is more ideal for holding edge radius during rough machining

NEXT STEPS

- Complete durability study (37,500 hits)
  - All three inserts performed well during the limited 1,000 hit die trial, but durability study is needed to assess the full life-cycle cost for each insert material and manufacturing process.

- Reduce test/validation time
  - Die trials are expensive and time consuming, especially when using production set-up conditions, e.g., 15% clearance.
  - The Team is considering options to increase the stress level during trimming to accelerate tool wear and failure
    - Increasing sheet metal thickness
    - Reducing clearance
    - Increase sheet metal tensile strength.

ACKNOWLEDGMENTS

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  - Voestalpine (Caldie)

- Services
  - Sun Steel Treating for through hardening
  - Synergy Additive Manufacturing for laser hardening
  - GIC Machining for machining

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