Stress Analysis and Modeling of Surface Treated 20MnCr5 Gear Samples

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Industrial Sponsors: American Axle & Manufacturing (AAM), Engineered Abrasives

20MnCr5 steel is widely known for its superior tensile strength and has therefore been a material of choice in several **automotive applications**. Surface enhancement of metal parts, by any number of processes, have been shown to introduce beneficial stresses and surface conditions which can further improve the performance attributes of many metals including 20MnCr5 steel. AAM and Purdue MSE have previously shown an ability to produce a **desirable combination of surface stress and finish** for 20MnCr5 test coupons. Using this background, as well as modeling that is being developed by MSE's Center for Surface Engineering & Enhancement (CSEE) that is available to AAM, *the purpose of this study will be to further the understanding stress profiles and surface roughness for a series of controlled processing conditions. Additionally,* ***modeling relationships between the processing parameters and resultant stress profile and surface conditions*** *will be studied.*

This work is sponsored by American Axle & Manufacturing, and Engineered Abrasives

Engineered Abrasives® MANUFACTURERS OF THE FINEST AUTOMATED BLAST FINISHING & SHOT PEENING EQUIPMENT

Background & Objectives

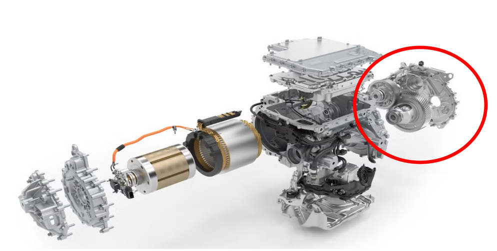
Gears designed for use in electric vehicles made from 20MnCr5 steel were sent to Purdue after being shot peened using various shot types and peening times:

	CCW 14 20s	CCW 14 40s	CCW 32	Glass Beads	CCW 32 + Glass
As-Peened	2 gears	2 gears	2 gears	2 gears	2 gears
As-Ground	2 gears	2 gears	2 gears	2 gears	2 gears

Purdue also received two ½ gears that were "as-heat treated" and "as-grit blasted" for control specimens

The objectives for the project are:

- Analyze and collect identical **residual stress, microhardness, and surface finish measurements** from "as-peened" and "as-ground" samples
- **Model the relationship** between the **processing parameters** and **residual stress and surface conditions**



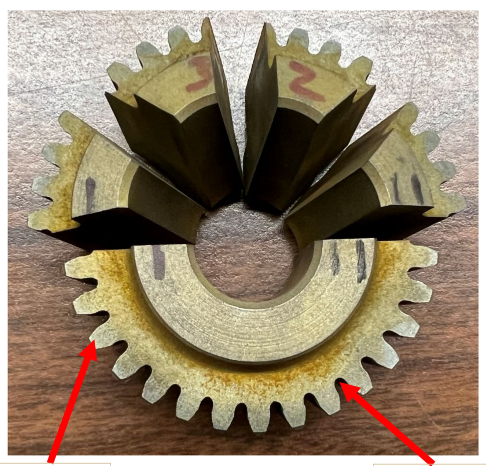
Electric vehicle engine showing where gears are used

Gear provided by AAM

Experimental Techniques

Sectioning

Gears were sectioned by **wire EDM cutting** into five parts. Four 1/8 gears were cut to be used in surface roughness and microhardness tests, while the remaining half gear was used in residual stress analysis

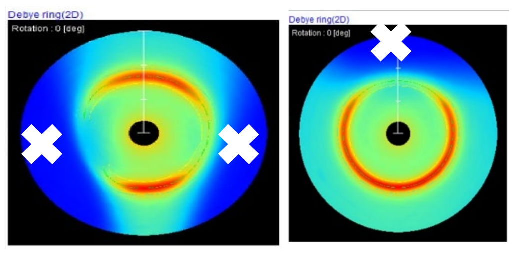


Residual Stress

Measurements were collected using a **Pulstec μ-X360S**

- Surface measurements taken across the contact surfaces of the teeth and in roots
- Average stress across **2mm diameter spot size**
- Metal was removed via electropolishing to create a stress depth profile of each root.

Root Scan Setup

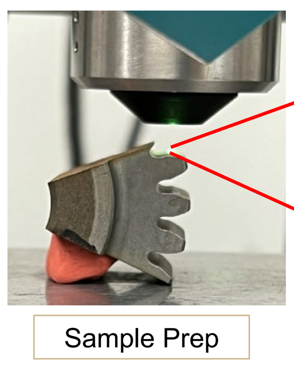


Occluded DS Rings, Root (L), Tooth Contact Surface (R)

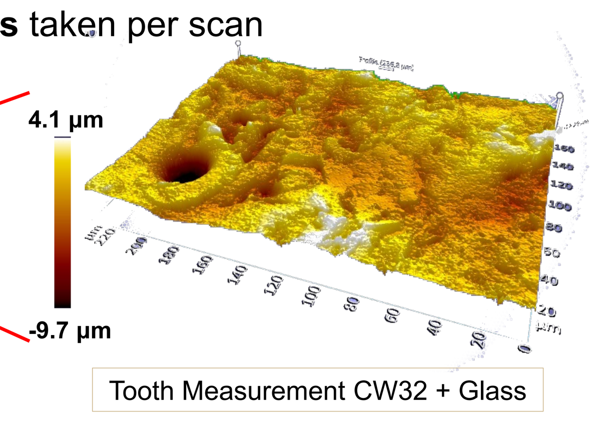
Surface Roughness

Measurements taken on the **Zygo optical profilometer**

- Surface parameter **Rz** used to evaluate roughness
- $R_z = \sum_{i=0}^{5} \frac{Max - Min}{i}$
- Curvature removed using a polynomial fit
- Two samples used ; **3 scans** taken across the surface for each area, **20 Rz values** taken per scan



Sample Prep

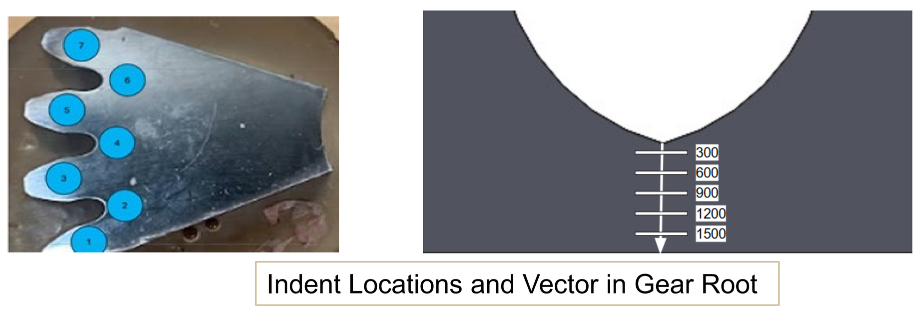


Tooth Measurement CW32 + Glass

Hardness

Measured using **LECO Vickers Microhardness tester, Amh43 software**

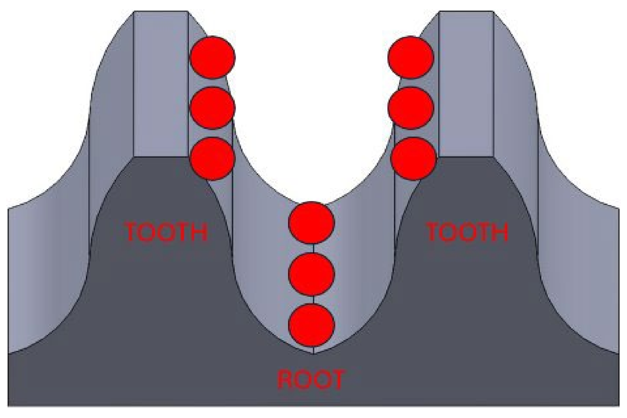
- **500 gram-force** load as recommended
- Depth of measurement from surface, local hardness recorded
- Indents made at 300 micron intervals from the surface



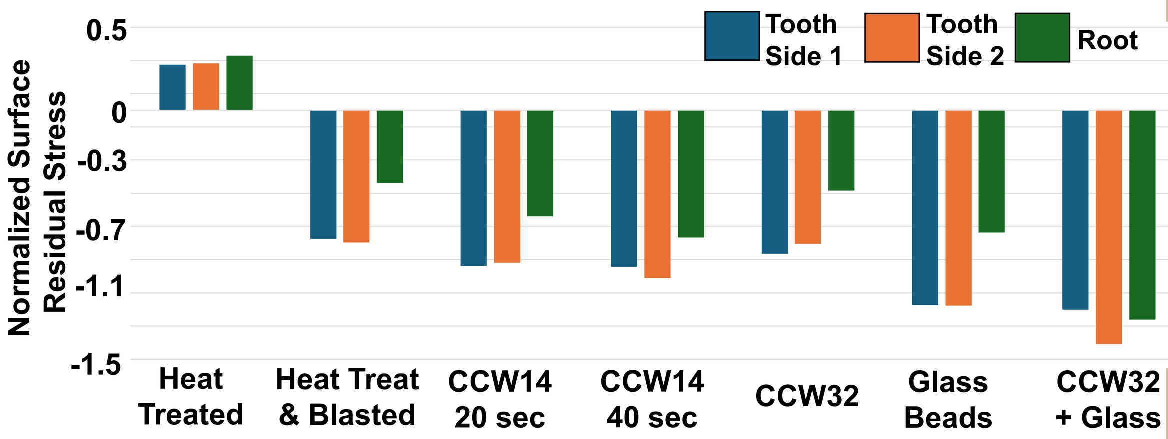
Indent Locations and Vector in Gear Root

Results & Discussion

Surface Residual Stress



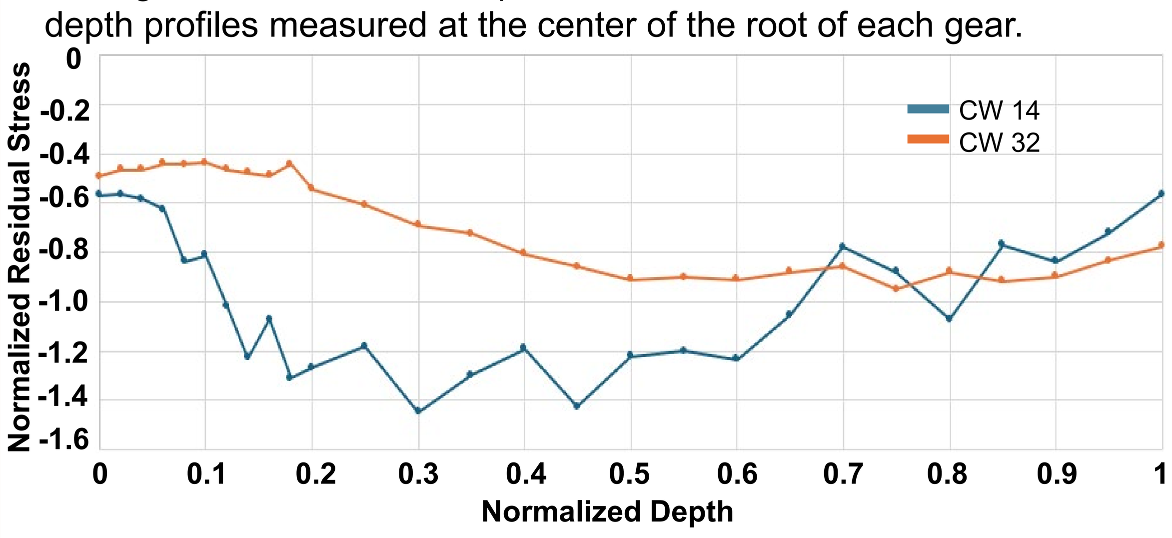
Residual stress measurements were collected from ten sites each containing nine measurement locations, as pictured to the left. These measurements were then averaged across each surface and normalized to produce the figure below.



- Residual stress analysis showed **significant variation in surface condition** across peening treatments
- Some variance in stress between leading and trailing sides of teeth
- **Some treatment conditions produced pronounced differences between tooth contact surface and root** residual stresses

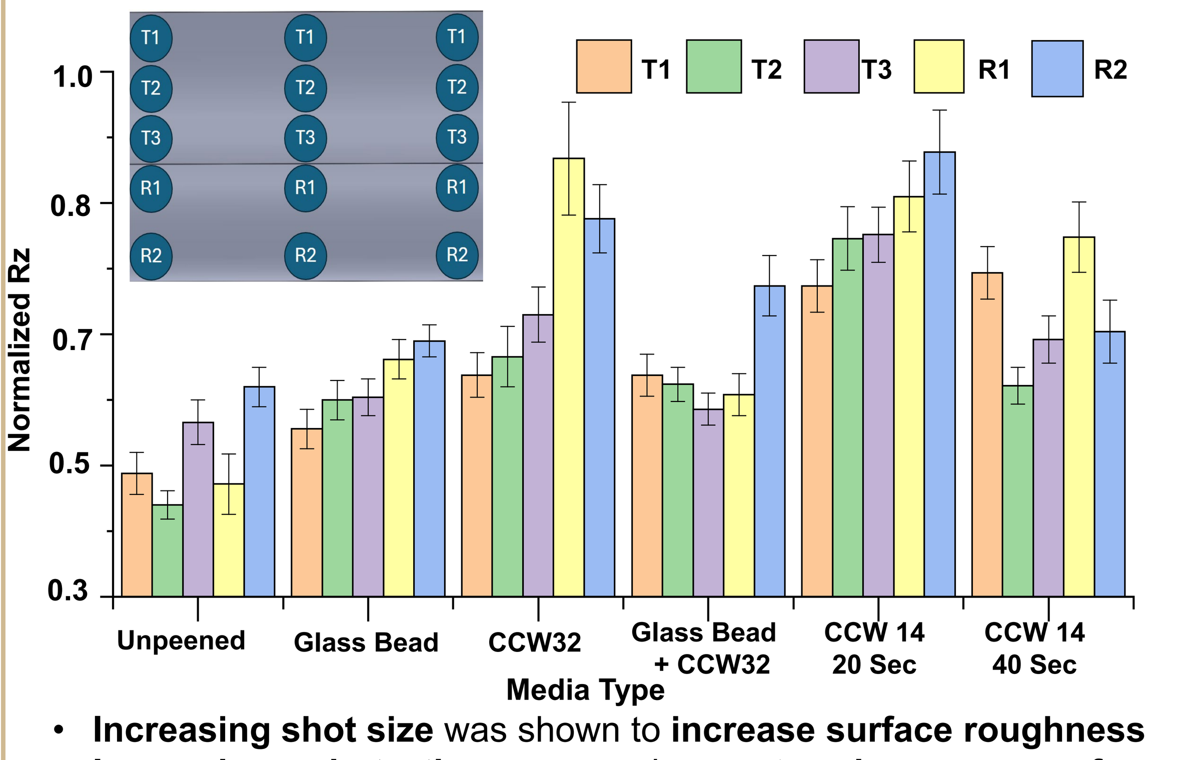
Residual Stress Depth Profiles

The figure below shows comparative normalized residual stress depth profiles measured at the center of the root of each gear.



- Residual stress followed literature consistent trends at depth
- Consistent with surface measurements, **larger shot had a lesser effect in the root**

Surface Roughness



- **Increasing shot size** was shown to **increase surface roughness**
- **Increasing shot time** was shown to **decrease surface roughness**
- Rz values were seen to be **higher in root**, thought to be due to a **lower coverage of the shot media**

Hardness

Distance from Surface (um)	Glass	CCW32	CCW32+Glass	CCW14 (20 sec)	CCW14 (40 sec)
300	0.89	0.87	0.93	0.86	0.93
600	0.66	0.67	0.70	0.64	0.68
900	0.56	0.59	0.60	0.53	0.61
1200	0.54	0.56	0.57	0.50	0.53
1500	0.52	0.59	0.56	0.52	0.55

Hard – Soft

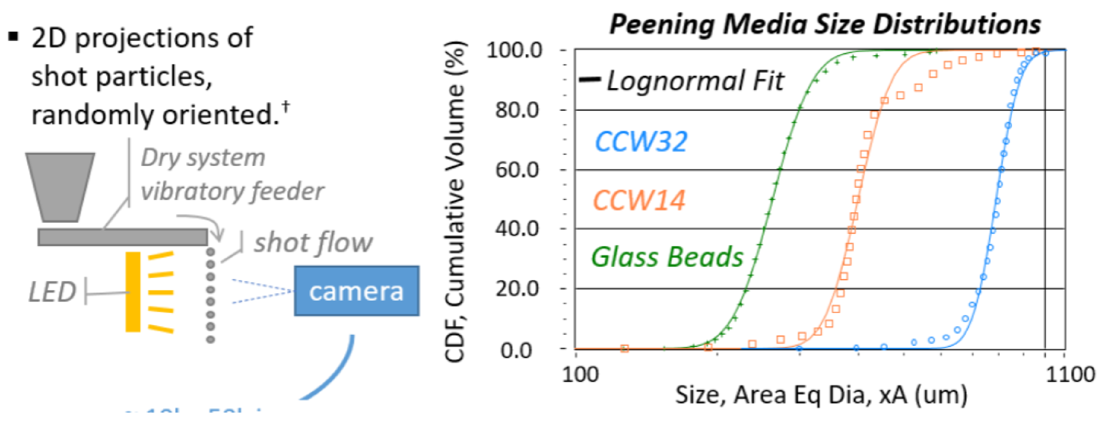
Normalized Hardness measurements in Root

- Hardness **decreases** as distance from surface **increases**
  - Peening media impart plastic deformation on surface layers
- Measurements **corroborate** trends in Stress Depth Profiles
  - Hardness is related closely to residual stress as hardness is a materials **yield strength** to indentation

Model Development

Media Characterization

Shot sizes were measured using a **JM Canty SolidSizer**. Size distributions were collected for CCW 32, CCW 14, and glass beads shot sizes.

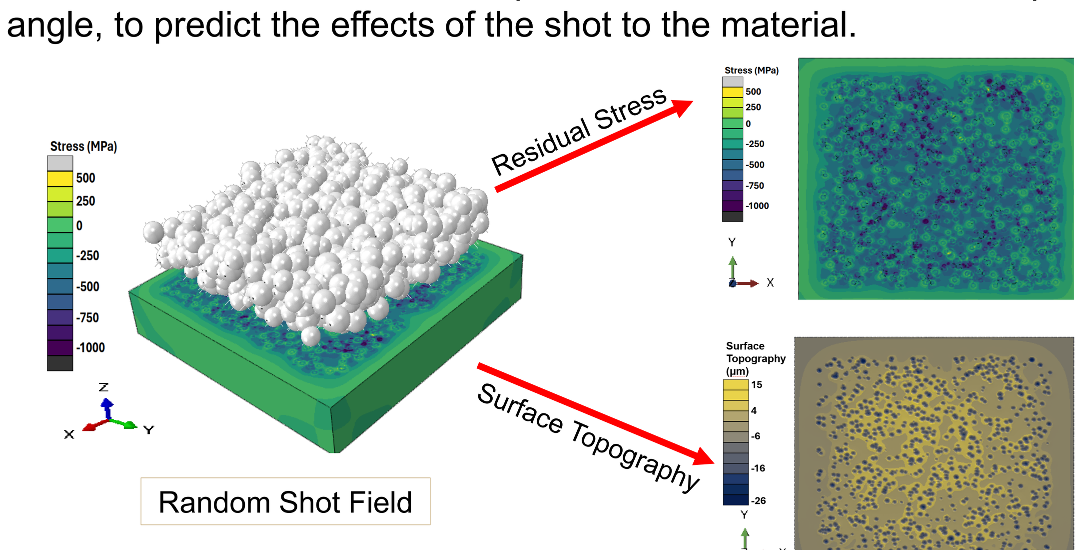


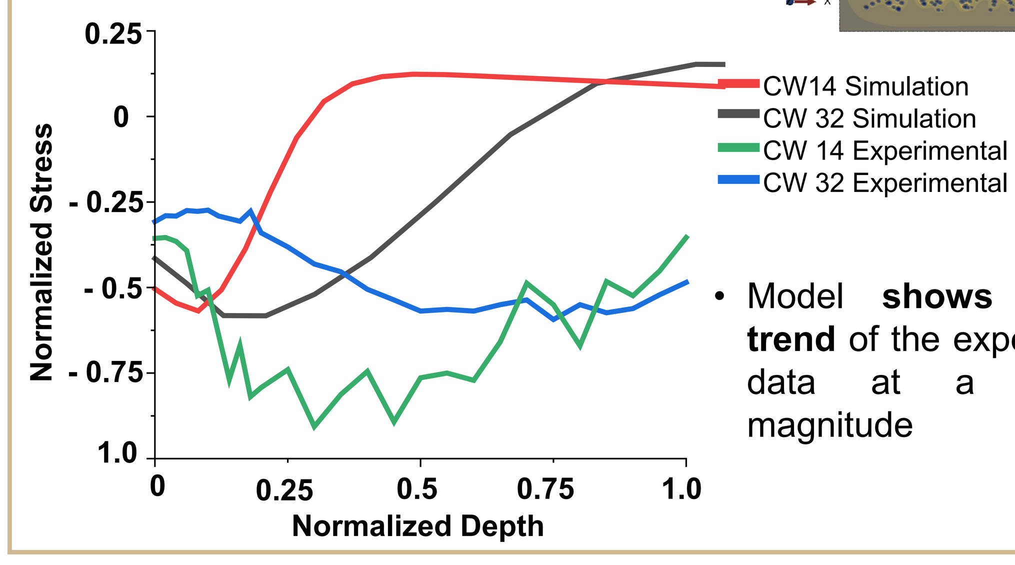
Previous Model

Media Size Distribution → Simulated Peening
Material Properties → Simulated Peening
Operational Parameters → Simulated Peening
Simulated Peening → Residual Stress Depth Profile
Simulated Peening → Surface Topography

Output

The shot size distribution and mass flow were used to create a **randomized shot field** that impact the surface at a known impact angle, to predict the effects of the shot to the material.





- Model **shows general trend** of the experimental data at a different magnitude

Conclusions & Future Work

Residual Stress Analysis

- Stress depth profiles match expected trends
- Smaller shot size creates larger residual stresses

Surface Roughness Analysis

- Increasing shot size increases surface roughness while increasing shot time decreases roughness
- The shot does not seem to be reaching the root as effectively as the teeth leading to the root being rougher than the teeth

Hardness Analysis

- Hardness follows the expected depth profile trend of decreasing hardness the deeper into the gear
- Hardness is related closely to residual stress as hardness is a materials yield strength to indentation

Modeling

- The model output is reasonably well correlated to experimental data and future work includes further iteration on this model to fit more types of shot

References

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2. Borina, N., Clyde, I., and Scott, B. (2024). Compression and Model Development of Surface Finish and Residual Stress of 20MnCr5 Steel Before and After Shot Peening With CCW Media
3. Feltner, L., Gruninger, M., Canty, T., & Mort, P. (2024). Characterization of particle size and shape distributions for shot peening media. *Shot Peener*.
4. Kennan, Z. (2005, June). Determination of the Constitutive Equations for 1080 Steel and VascoMax 300. https://scholar.afit.edu/cgi/viewcontent.cgi?article=4655&context=etd#page59.