PURDUE UNIVERSITY
School of Materials Engineering

Comparison and Model Development of Surface Finish and Residual Stress of 20MnCr5 Steel Before and After Shot Peening With CCW Media

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Industrial Sponsors: American Axle Manufacturing, Toyo Seiko North America, Engineered Abrasives

Abstract: 20MnCr5 steel is utilized in automotive industries for its high tensile strength, wear resistance, and ease of surface enhancements. Common surface enhancements include grinding, carburization, shot peening, and various finishing techniques. These processes introduce beneficial residual stresses and surface conditions which improve the performance of the part. *The purpose of this study is to investigate the relationship between peening media size and resulting surface effects, as well as to create a model to simulate the peening process and subsequent creation of said effects.*

This work is sponsored by American Axle & Manufacturing, Toyo Seiko North America, and Engineered Abrasives

TOYO SEIKO North America, Inc.
Engineered Abrasives® MANUFACTURERS OF THE FINEST AUTOMATED BLAST FINISHING & SHOT PEENING EQUIPMENT

Background & Objective

- 20MnCr5 Steel that has been formed into gears is bombarded with cast, wrought, and conditioned (CCW) steel shot media in a process called **shot peening**.

Media	Diameter (mm)
CCW 20	0.5
CCW 28	0.7


Steel CCW media


Peening machine

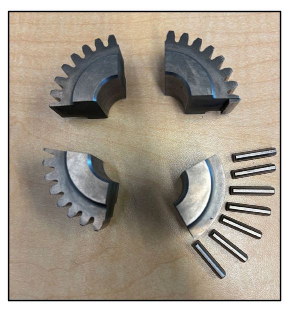
- **Shot peening** induces a layer of **residual compressive stress** as well as lowering the **surface roughness** leftover from machining.
- AAM specs outline a **target residual stress** at some depth, as well as a **target surface roughness**.
- If the targets are reached, these artifacts **increase properties** such as wear resistance, fatigue life, and strength.
- The **primary focus** of this project is to investigate how the size of media used affects the **residual stress** and **surface roughness**. We also aim to **model** the peening process to help gain a better understanding of the mechanisms causing the final surface effects.

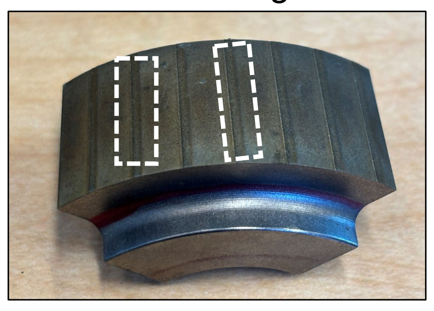
Experimental Techniques

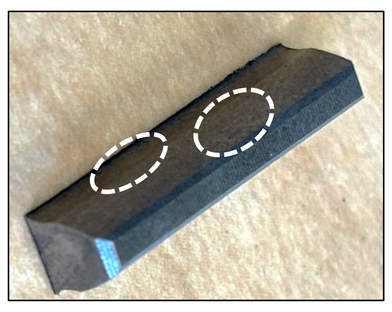
Sectioning

Target locations:
1. **Tooth Contact:** the portion of the tooth that contacts other gear teeth
2. **Tooth Flank:** the lower curved portion of the tooth that meets the root
3. **Gear Root:** the portion of the gear surface in-between the teeth

Gears were sectioned into 4 quarters using an EDM Wire Cutter, and additional circular cuts were made to gain access to the roots and teeth.

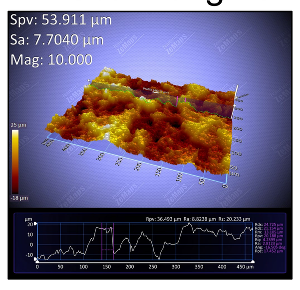

Sectioned gear

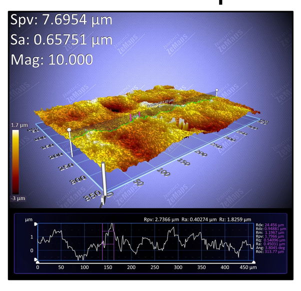

Exposed roots


Flank (L) & contact (R)

Surface Roughness

Surface Roughness measured using Zygo optical profilometer
- Measurements taken lengthwise along each section
- N=5 for root and flank, contact face was wide enough for 3 passes, with N=5 for each pass.
- Cylindrical features were removed from all measurements
- Scan lengths ranged from 30-100µm


Root surface sample output


Contact surface sample output

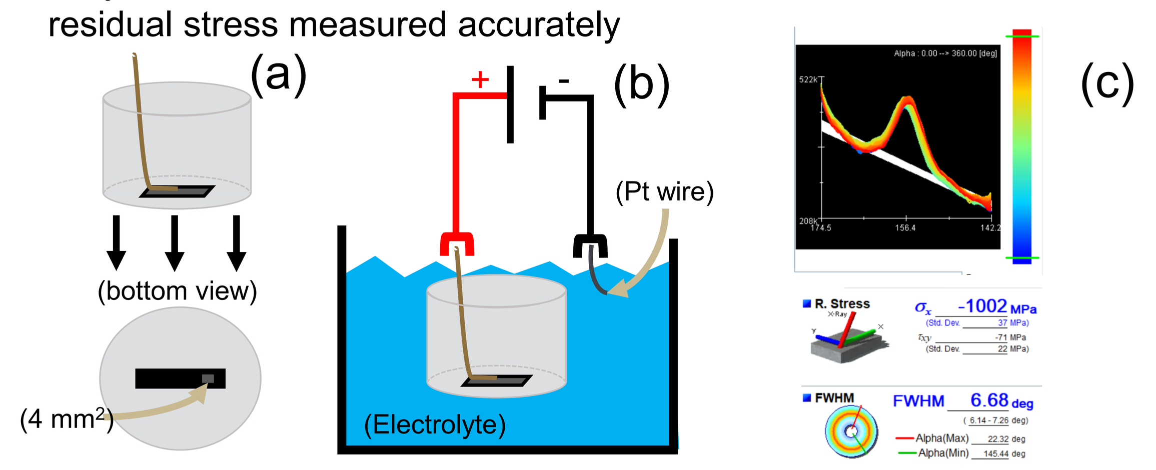

Optical profilometer

Residual Stress

Residual Stress measured using PulsTec XRD and Electro-etching

Considerations:
1. **Size of measurement area** must be > 2x2 mm to take measurements
2. **Surface must be flat** or measured stress will be inaccurate
3. **Surface must be accessible** for the electro-etching process

Conclusion:
Only the **tooth contact** fits the above criterion and can have its residual stress measured accurately



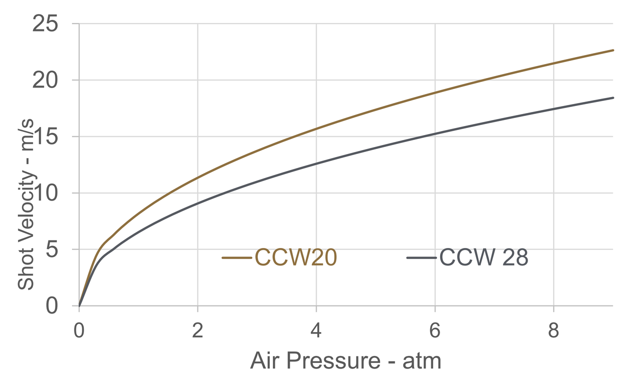
(a) Gear teeth are wrapped in a layer of tape to secure a copper wire to the tooth surface. This system is then **mounted in epoxy** with the other end of the wire exposed, and the bottom is polished down and a 2x2 mm section of tape is peeled away to facilitate
(b) electro-etching for 15 seconds at **30 milliamps and 22.4 volts** before
(c) residual stress is calculated from the output Debye ring measured using a **cosα XRD** [1].

Model Development

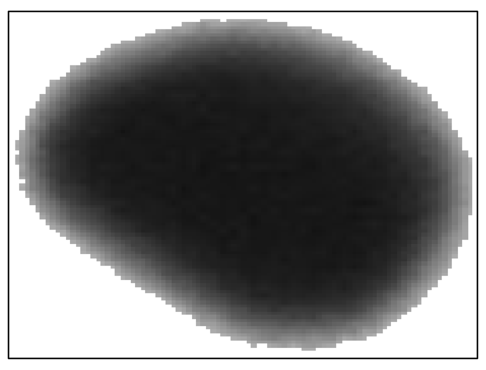
Modeling is used in tandem with experimental results. The experimental setup guides the starting geometry, materials properties, and boundary conditions of the model. *The goal of modeling is to create an idealized reference with which to evaluate against experimental results, gaining insights into the interactions between the shot media and surface in the process.*

Peening Media

- The **size distribution** of the peening media is measured with a CANTY SolidSizer to simulate the natural variation in the media size.
- The velocity of the media is calculated using the set air pressure of the peening machine [2].



Shot velocity as a function of pressure


Measured shot particle (0.8 mm diameter)

Modeling Approach

Abaqus, an FEA suite, was used to perform simulations of the axle gear peening. **The Johnson Cook hardening model (below)** was used for the plastic behavior or the gear, with values coming from literature [3].

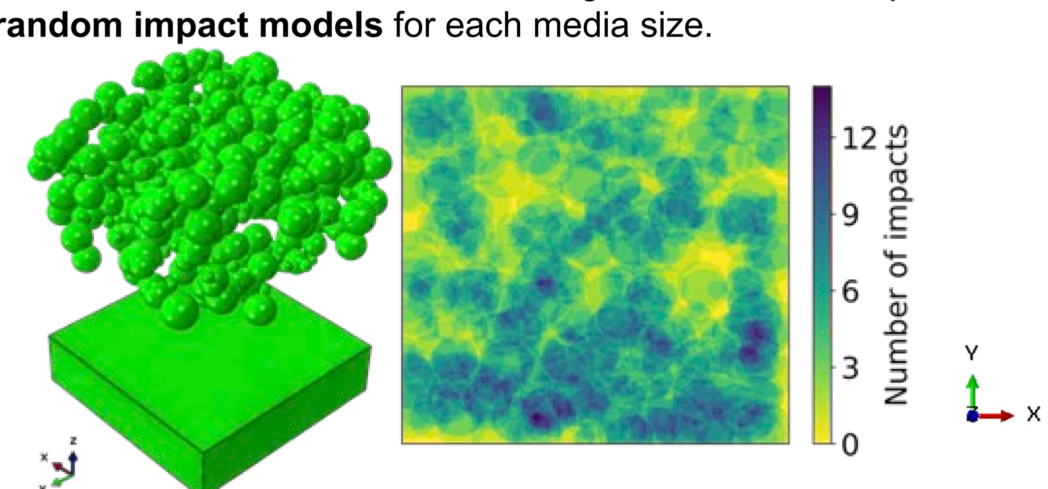
$$\sigma = (A + B\varepsilon^n)(1 + C\ln\dot{\varepsilon}^*)(1 - T^{*m})$$

A (yield stress)	1.408
B (strain hardening constant)	3.27
n (strain hardening coefficient)	0.66
C (strengthening coefficient of strain rate)	0.028
m (thermal softening coefficient)	0.753

Carburization is done pre peening—hardening the surface, increasing the yield, and inducing compressive stresses. The yield stress increase from carburization is accounted for in the model by increasing the yield parameter (**A**). Residual stress from Carburization is not included in the modeling

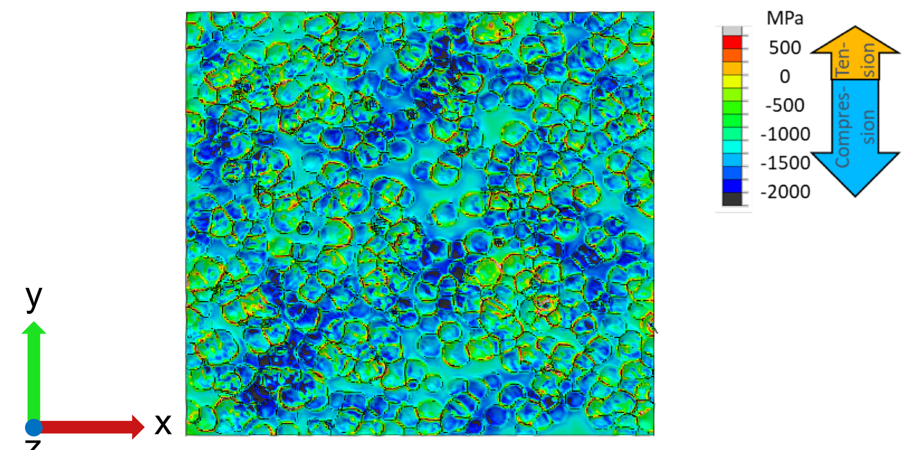
Output

The mass flux of the media and contact angle were used as inputs to build **random impact models** for each media size.



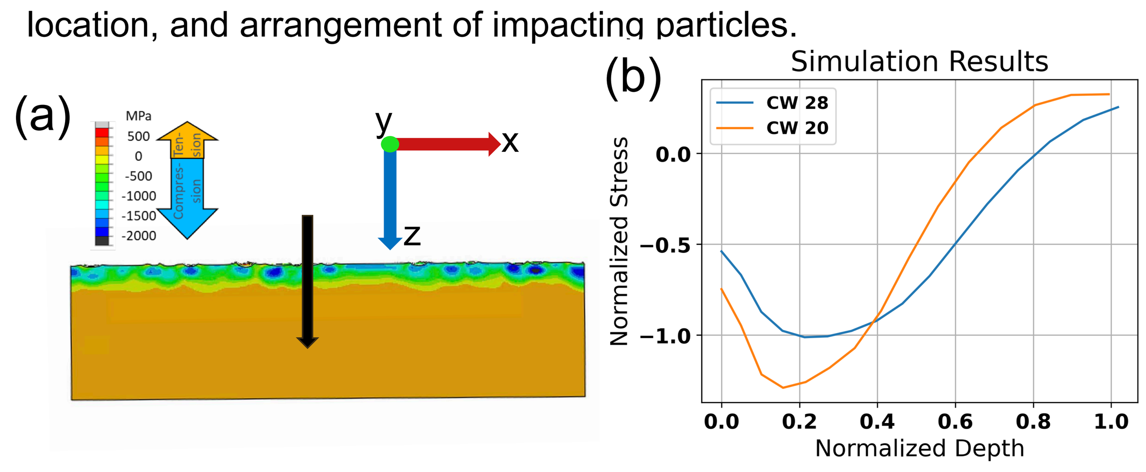
Random impact model

This yields a displacement and stress field



Surface stress field

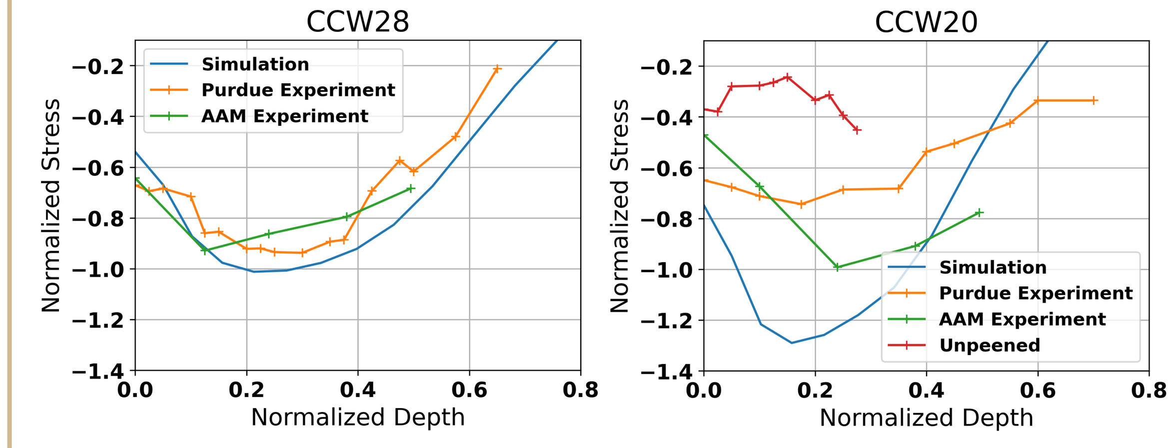
The **surface stress field** is stochastic due to the distributed size, location, and arrangement of impacting particles.



(a) The spatial stress field is averaged along its z-axis
(b) Residual stress simulation results for various peening conditions

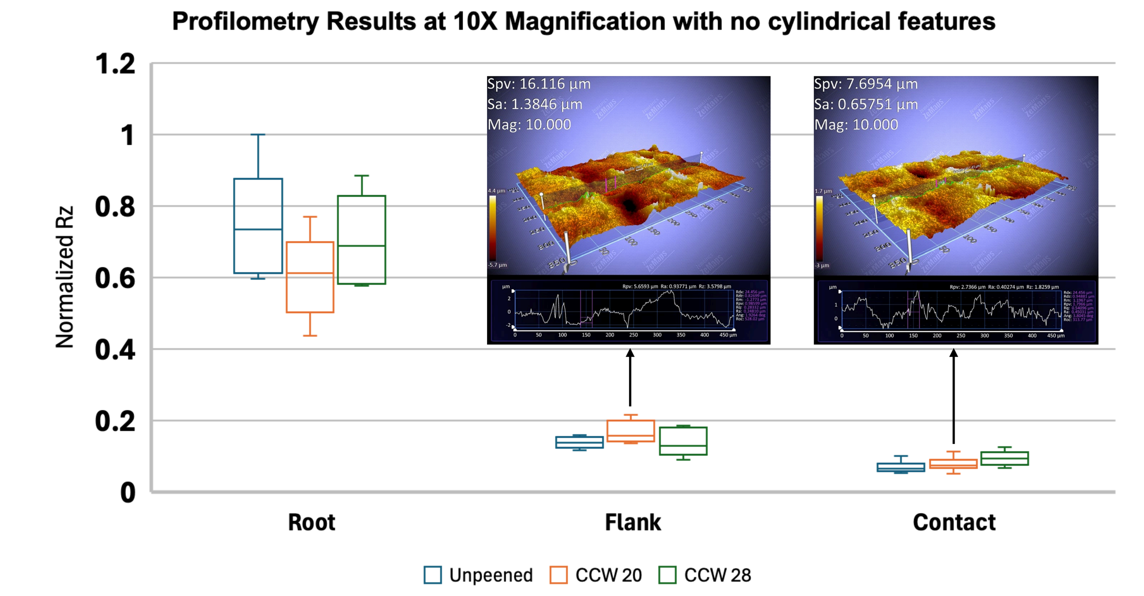
Results & Discussion

Residual Stress



- CCW 28 experimental values are ~10% more positive than that of the model which is close enough to **support the model**.
- The difference in residual stresses between unpeened and peened gears is substantial, with the **unpeened gears having 65% less residual stress on average**.
- Peening successfully induces the target amount of residual stress, with **CCW 28 peening media inducing more residual stress than the CCW 20 media**.

Surface Roughness



- **Gear roots have significantly higher Rz values** most likely due to post machining operations that specifically target the root.
- While peening with CCW 20 and CCW 28 does provide the targeted residual stress, it **does not affect the surface roughness**.

Conclusions & Recommendations

Conclusions

1. AAM stress measurements are well aligned with Purdue experimental values and show **CCW 28 imparting more residual stress** than CCW 20 peening media.
2. Using a cosα XRD and electro-etching allows for the creation of more detailed residual stress curves on appropriate surfaces, but not all gear surfaces can be measured using the method.
3. While shot peening does increase compressive residual stresses, surface roughness is not affected.
4. **Experimental results support our model**, but there is more work to be done.

Recommendations

1. **Future work should use larger media** to confirm/investigate trends. CCW media options should be exhausted to get the full picture of how media size affects surface effects.
2. **cosα XRD should be used when possible** due to its ease/quickness of use, but it should be used in tandem with the $\sin^2\psi$ method to measure other surfaces to fully understand the effect of surface angles and geometry blockage in the peening process.
3. Rz values are measured using just one line, but **arial measurements would be more representative** of the entire surface. This could be done with a script to read the files output by the optical profilometer.
4. To form a more robust model, the **geometry of the part** could be considered, and the **carburization process** could be approximated with a gradient. It is also recommended to **study the potential variation** that could occur from multiple simulations.

References

[1] Sarmast, A., Schubnell, J., Preußner, J., Hinterstein, M., & Carl, E. (2023). Residual stress analysis in industrial parts: A comprehensive comparison of Xrd Methods. Journal of Materials Science, 58(44), 16905–16929. https://doi.org/10.1007/s10853-023-09069-z
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