Physical Analyses and Modeling of Surface Treated 20MnCr5 Steel

PURDUE UNIVERSITY
School of Materials Engineering

Student Names: Ethan Lutgen, Chadwick Choy, and Deepika Rao
Faculty Advisors: Dr. Mark Gruninger and Professor David Johnson
Industrial Sponsors: American Axle & Manufacturing, Sinto America, and Electronics Inc.

Abstract: EN10084 Steel (20MnCr5) is widely known for its superior tensile strength and has therefore been a material of choice in several automotive applications, including gears, axles & pistons. Surface enhancement of metal parts, including grinding, shot peening & finishing, introduces beneficial stresses and surface conditions which can further improve performance attributes. *The purpose of this study is to gain a deeper understanding of the effects on select/controlled surface processing of 20MnCr5 by analyzing, testing & modeling 20MnCr5 samples, for "new" automotive applications including EV's.*

This work is sponsored by American Axle & Manufacturing, Sinto America, and Electronics Inc.

Project Background

- Our team aimed to characterize the effect of varying **shot peening** media types on the surface and mechanical properties of **carburized 20MnCr5 steel strips**
- **20MnCr5 steel strips** allow engineers to model property changes to characterize the effects over the entire treated part
- **Shot peening** imparts **compressive residual stress (CRS)** that affects surface and mechanical properties (finish, hardness, fatigue)
- **Carburization** hardens the surface through carbon diffusion
- **Superfinishing (SF)** creates super polished surfaces with low roughness

Short-Hand Notation	Peening Regime	Peening Media	Nozzle Pressure (psi)
NP	Nominal Peen	S-170 H	35 psi
FP S-70	Fine Peen	S-70 Hard	95 psi
FP CCW-14	Fine Peen	CCW-14	95 psi
DP	Dual Peen	S-230/ AGB-35	40 psi/ 22 psi

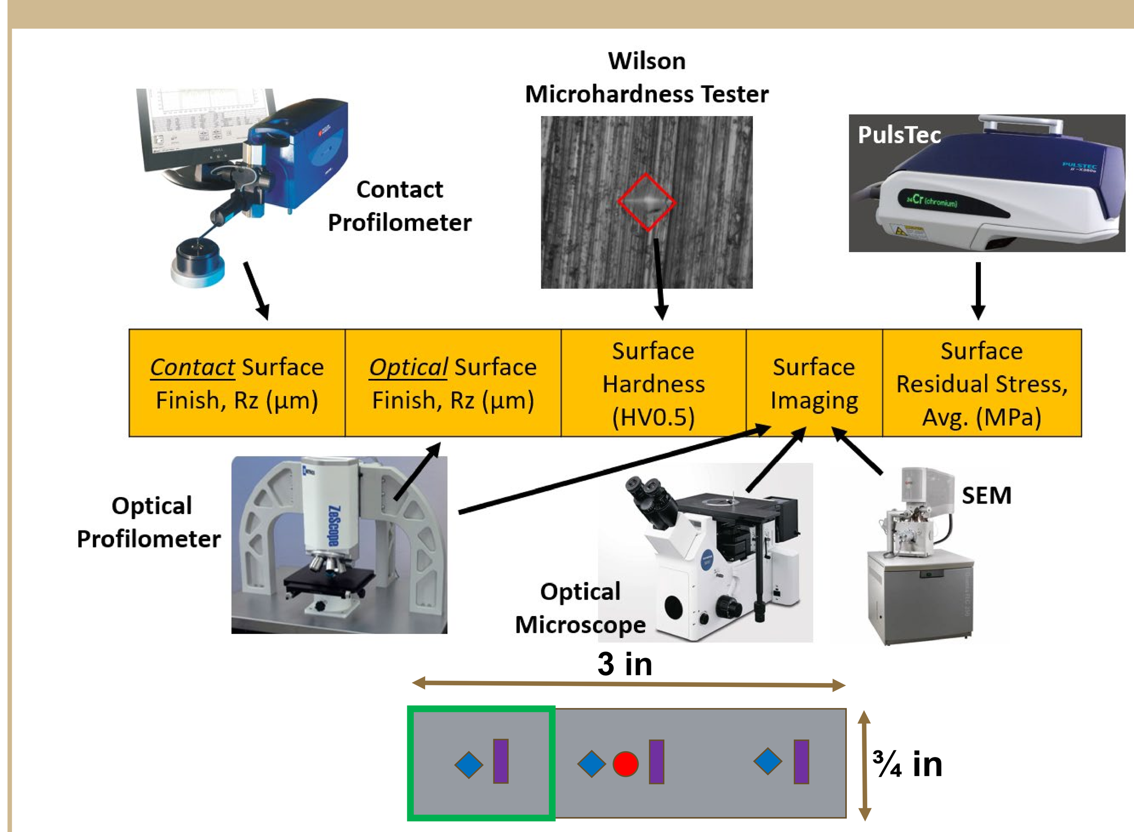

EI Shot Peening Machine


Baseline Strip *Peened Strip* *Superfinished (SF) Strip*

Main Project Objectives

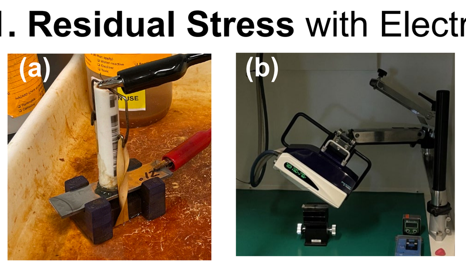
1. Is it possible to obtain the **same standard compressive residual stress with a smoother surface finish** without post-processing?
2. **Can the effects of the surface processing parameters be modeled or connected to the measurements collected?**

Experimental Techniques



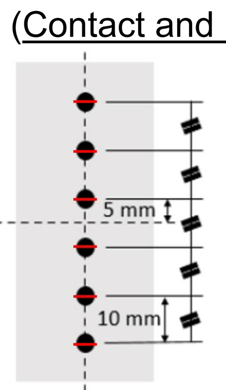
Experimental Testing and Location:
1. **Residual Stress** with Electro-etching (PulsTec XRD)
2. ***2.*** **Surface Finish** Testing (Contact and Optical Profilometer)
3. **Hardness** Testing (Wilson Microhardness Indenter)
4. **Surface Imaging** (SEM and Optical Microscope)

1. Residual Stress with Electro-etching (PulsTec XRD)



a) Apply a current load through salt water to etch away the surface
b) Measure residual stress using x-ray diffraction throughout the depth profile

2. Surface Finish Testing
(Contact and Optical Profilometer)



Contact: 6 scans of length 5 mm were taken, with the stylus moving 0.1 mm/s with a sampling rate of 50 Hz

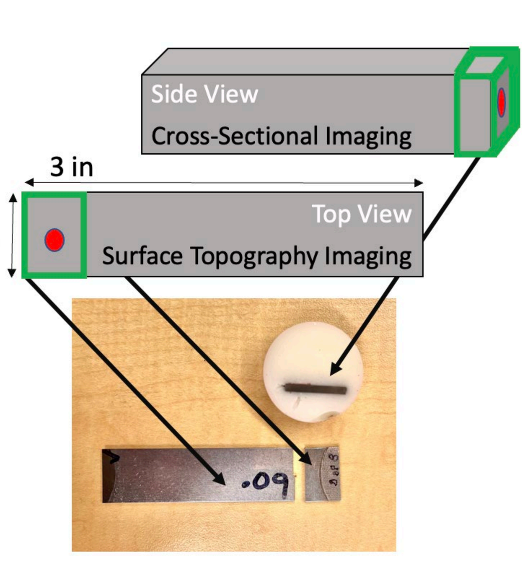
Optical: 3 scans of 900 by 700 μm were taken in the center of the strips

3. Hardness Testing
(Wilson Microhardness Indenter)

- Used a Vickers tip with a 500g load applied for 10 s
- Indented the non-prepared surface that was peened

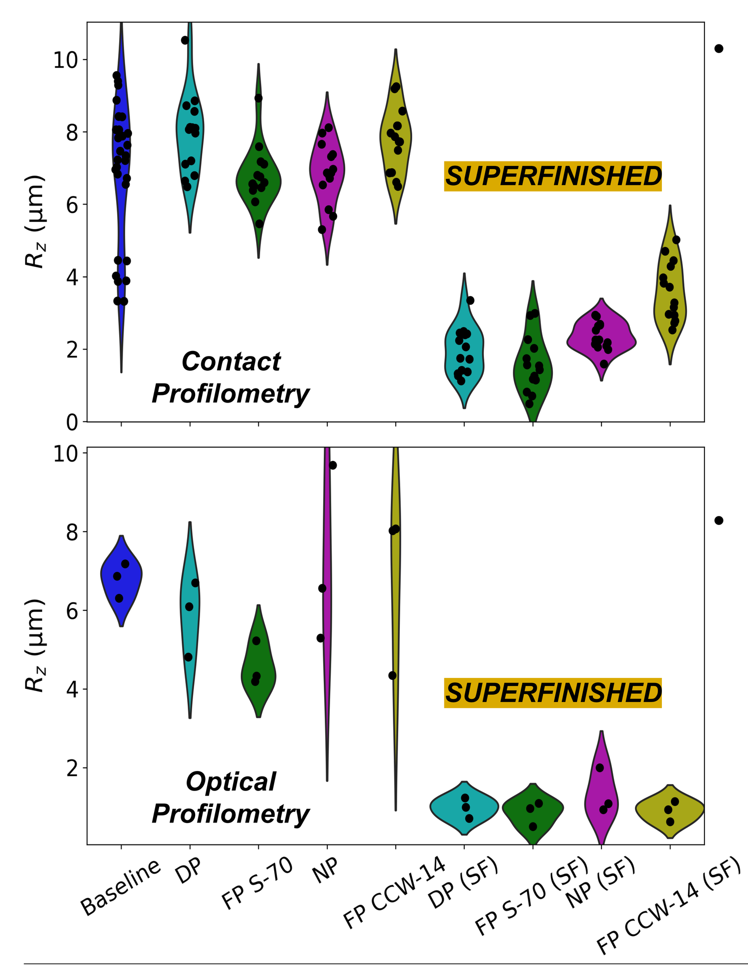
4. Surface Imaging
(SEM & Optical Microscope)

- **SEM** – Secondary electron imaging done on Quanta 650 FEG SEM
- **Optical Microscopy** – Olympus-GX51, metallurgically prepared & polished up to a 6 μm surface finish



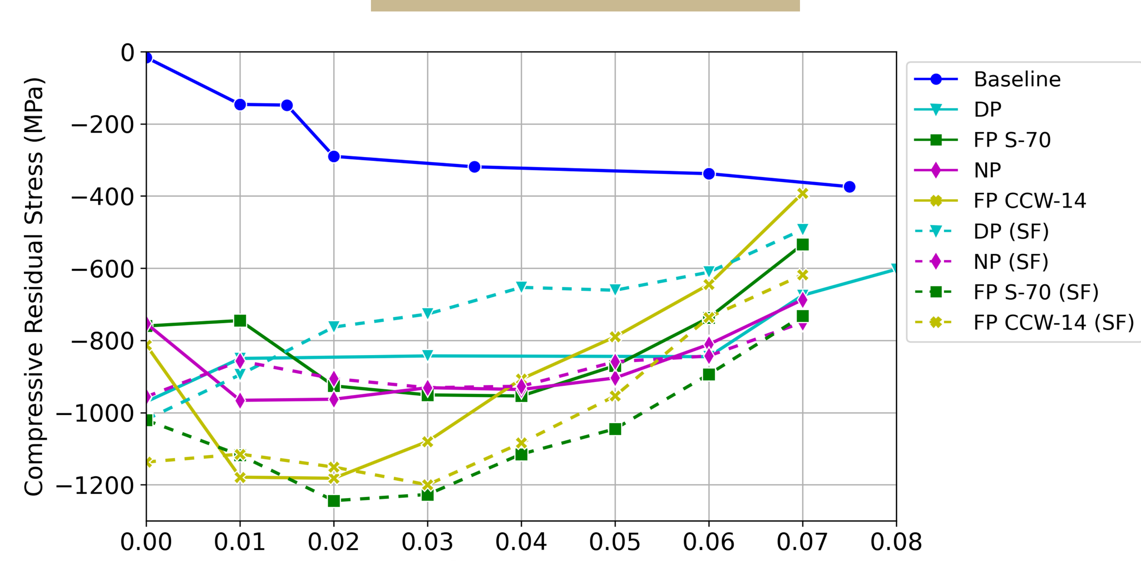
Results & Discussion

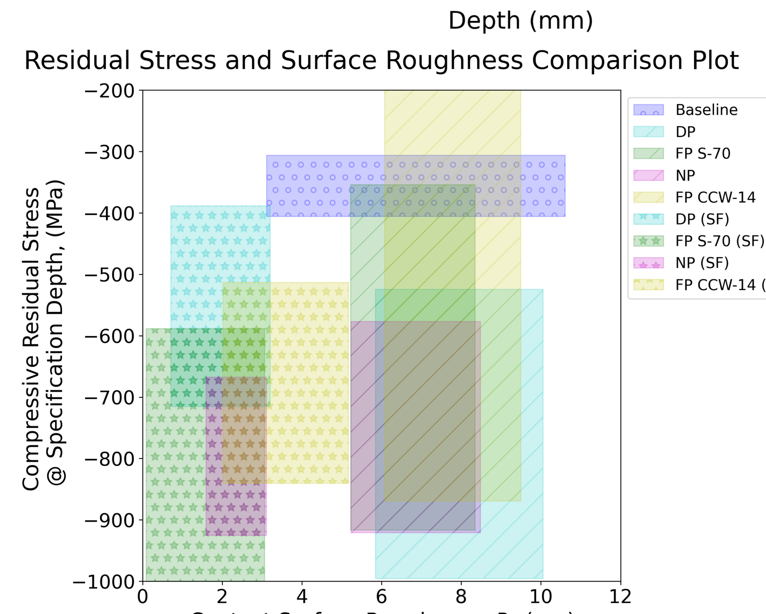
Surface Roughness



- The distribution of data (shown by kernel density estimations) suggests:
  - **As-peened samples** and baseline have similar roughness
  - **Superfinishing** the as-peened samples significantly improved their roughness by at least half
- **Optical Profilometry** measurements tended to be lower compared to **contact** measurements
  - Differences could potentially arise from the resolution of each testing method (stylus dimensions vs. laser spot size)

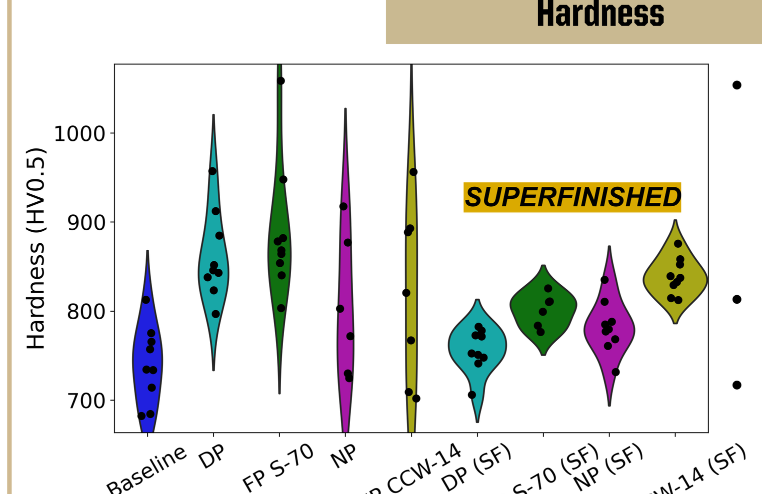
Residual Stress





- Peening media **FP S-70 (SF)** displays the highest CRS within the at depth and highest peak CRS across the depth profile
- To meet **Objective 1 FP S-70 (SF)** shows the lowest R_z and CRS within 95% confidence intervals

Hardness



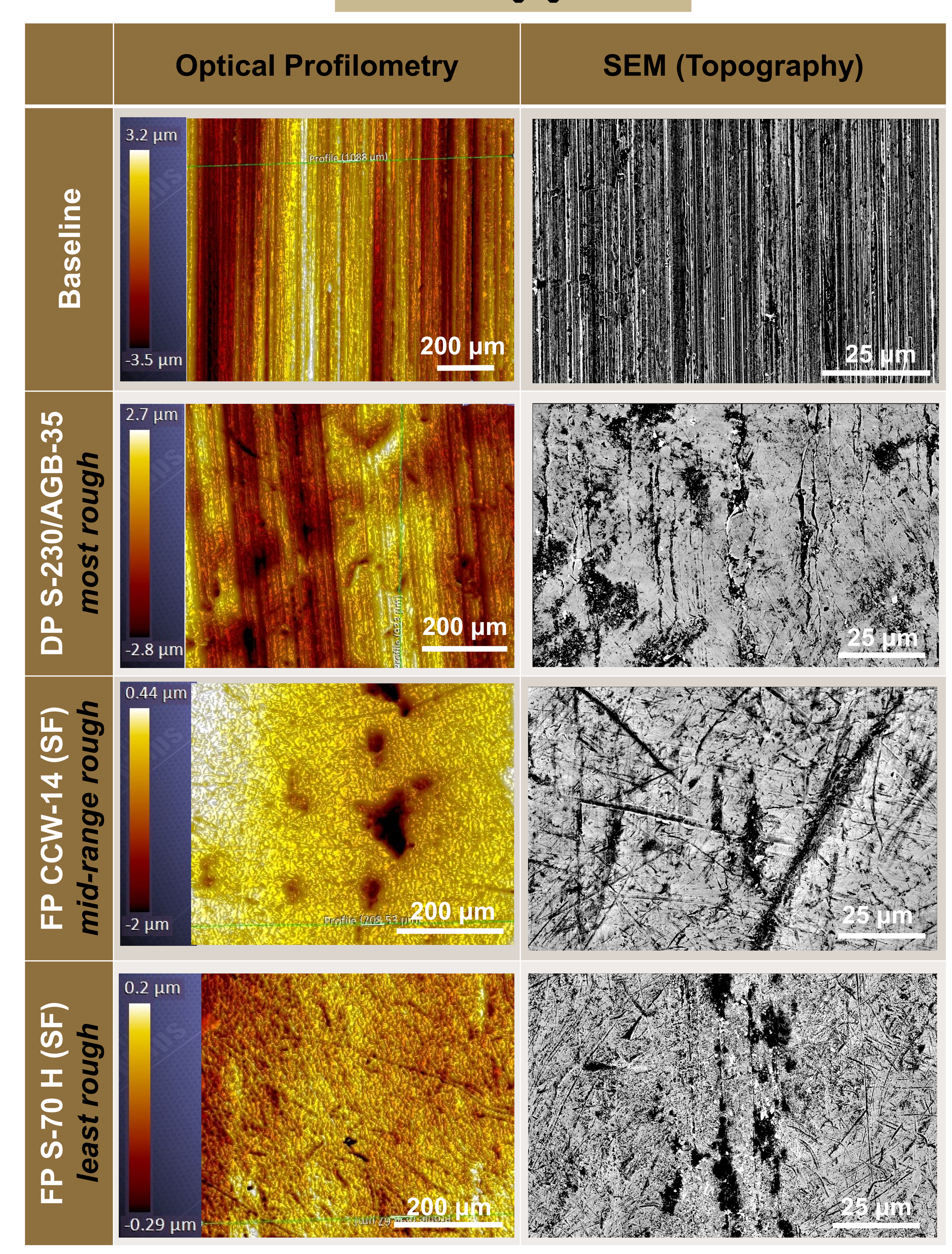
- The **wide range of measurements** for the as-peened samples are indicative of a surface's smoothness/polish
- **Superfinishing** only decreased DP hardness
- Though **FP CCW-14 got "harder" after SF**, no statistically significant difference was found

Results Summary

Sample Type	Characterization				
	Contact **Surface Finish, Rz (μm)**	***Optical*** **Surface Finish, Rz (μm)**	**Surface Hardness (HV0.5)**	**Surface Imaging**	**Surface Residual Stress, Avg. (MPa)**
Baseline	**6.86** (n=28)	**6.79** (n=3)	**740** (n=9)	(n=2)	**-356** (n=2)
DP	**7.95** (n=14)	**5.87** (n=3)	**861** (n=9)	(n=2)	**-760** (n=2)
FP S-70	**6.79** (n=14)	**4.58** (n=3)	**889** (n=9)	(n=2)	**-635.5** (n=2)
NP	**6.86** (n=14)	**7.18** (n=3)	**804** (n=6)	(n=2)	**-749** (n=2)
FP CCW-14	**7.79** (n=14)	**6.81** (n=3)	**819** (n=7)	(n=2)	**-518.5** (n=2)
DP (SF)	**1.96** (n=14)	**0.98** (n=3)	**756** (n=9)	(n=1)	**-552** (n=2)
FP S-70 (SF)	**1.58** (n=14)	**0.85** (n=3)	**801** (n=6)	(n=2)	**-813** (n=2)
NP (SF)	**2.35** (n=14)	**1.34** (n=3)	**782** (n=9)	(n=1)	**-796.5** (n=2)
FP CCW-14 (SF)	**3.60** (n=14)	**0.90** (n=3)	**839** (n=9)	(n=2)	**-677** (n=2)

Results & Discussion

Imaging



SEM & Optical Profilometry imaging suggest:
- **Baseline** topography showed grinding striations which are representative of a **pre-peened surface**
- **Dual peening** had the largest impact on surface topography and roughness with folding and flattening of striations, which are likely caused by two peening medias (S-230/AGB-35)
- **SF samples** showed shorter and more isolated striations than as-peened samples
- **SF samples** showed less folding and flattening of striations, likely caused by **polishing** after the peening process

Conclusions

	OBJECTIVE 1: Same compressive residual stress with a smoother surface finish	**OBJECTIVE 2:** Connecting surface processing parameters to the measurements
Surface Roughness	• **FP S-70 (SF)** shows both **highest CRS** at **depth** & **smoothest surface finish** • **SF samples** had significantly **smoother surface** • **As-peened samples** resulted in **similar surface roughness** compared to the baseline set	• **Varying the peening regime** did not create noticeable differences in the as-peened samples' **surface roughness** • SF process helped to **reduce roughness** by **at least half**
Residual Stress	• As-peened samples showed an **increased CRS** compared to the baseline set • **Superfinished NP** set gave a **smoother finish**, but did not change the stress profile	• Peening the surface **increased compressive residual stress (CRS)** at **targeted depth**
Surface Imaging	• **FP S-70 (SF)** visually proved to have the **smoothest surface** with the **least peening striations** & the **greatest mean CRS**	• SF topography had **fewer grind striations** and **impact spots** compared to as-peened samples – which are also reflected in **optical and contact profilometry results**
Surface Hardness	• **Hardness** trends generally matched **CRS trends** between all samples	• **Large standard deviations** (or wide range) from as-peened samples indicate the **irregularity in surface finish**

Acknowledgements

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