Effects of Almen Strip Thickness on Shot Peening Attributes

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Almen strips, which are made of 1070 steel, are crucial for many industries including automotive and aerospace. There are three thicknesses (0.031", 0.051", and 0.094") for Almen strips that are used and are labeled as N, A, and C, respectively. We seek to validate current industrial standards of intensity for the A strip (4A to 24A) and investigate functional differences of the Almen strip types including mechanical behavior, stress, hardness and how it relates to microstructure. Measurements of deflection will be taken on all types of Almen strips using fixed locations on an Almen gauge.

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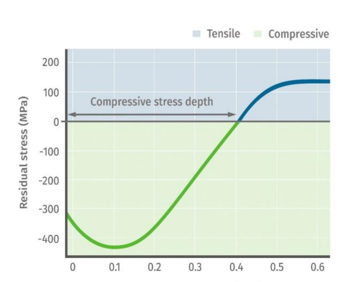
Project Background

Table 1: Summary table of Almen strip types and their respective thicknesses and industry used intensity ranges.

Strip Type	Strip Thickness (1/1000")	Intensity Range
N	0.031	< 4A
A	0.051	4A to 24A
C	0.094	> 24 A



- Shot Peening uses **spherical shot material** (~ 0.5 mm diameter seen in the second figure on the left). They are pelted at the surfaces of metallic parts to **impose compressive stresses,** improving fatigue that can elongate the lifetime of parts.
- The **residual stress** of a strip will increase in the compressive state before reaching a maximum value, before entering a tensile stress zone.
- The figure on the left shows the N, A, C strips (top to bottom) for the Perp. Medium experimental condition. Numbers labeled across the middle and top right of the strips showcase the **measured arc height** as a means of intensity and the **exposure speed** of the peening trial, respectively.

Experimental Procedure

Table 2 : Experimental peening conditions used at Progressive Surface.

Group Name	Incidence Angle (Degrees)	Air Pressure (PSI)	Media Feed Rate (lbs./min	T1 (1/1000" A)	Exposure (Transverse) Speed (in/min)	Nozzle Type
Perp. Low	90	20	20	8.6	17.86	⅜" Straight Bore
Perp. Medium	90	50	12	13.7	19.23	⅜" Straight Bore
Perp. High	90	80	3	24.9	8.47	½" Venturi
Angled Low	45	40	20	8.0	26.32	⅜" Straight Bore
Angled Super Low	45	20	20	5.5	19.2	⅜" Straight Bore

Experimental Peening conditions used at Progressive Surfaces, MI

- ½ inch diameter shot balls or S230 shot were used across all trial groups.

Almen Strip Deflection Gauge

- Deflection of the strips were measured using an Almen gauge, the measured deflection is related to the peening intensity.
- Deflection is measured using a magnetic 4-point hold.

Compressive Stress Measurement Using X-Ray Diffraction (XRD)

- The compressive stress values were measured using the Pulstec-µX360. Stress values were measured at 0.01mm increments using electropolishing.
- Compressive stress values at each depth of the strip were compiled to create a stress depth profile for each peening condition.

Hardness Testing

- Vickers microhardness testing was carried out on the peened and unpeened side of the Almen strips using the setup in the fourth image.
  - The loads used ranged from 5 to 50 kgf.
- Hardness values of peened side were compared against the unpeened side
  - Determine if there is a change in hardness due to the differences in thickness.

Results

Stress Profiling

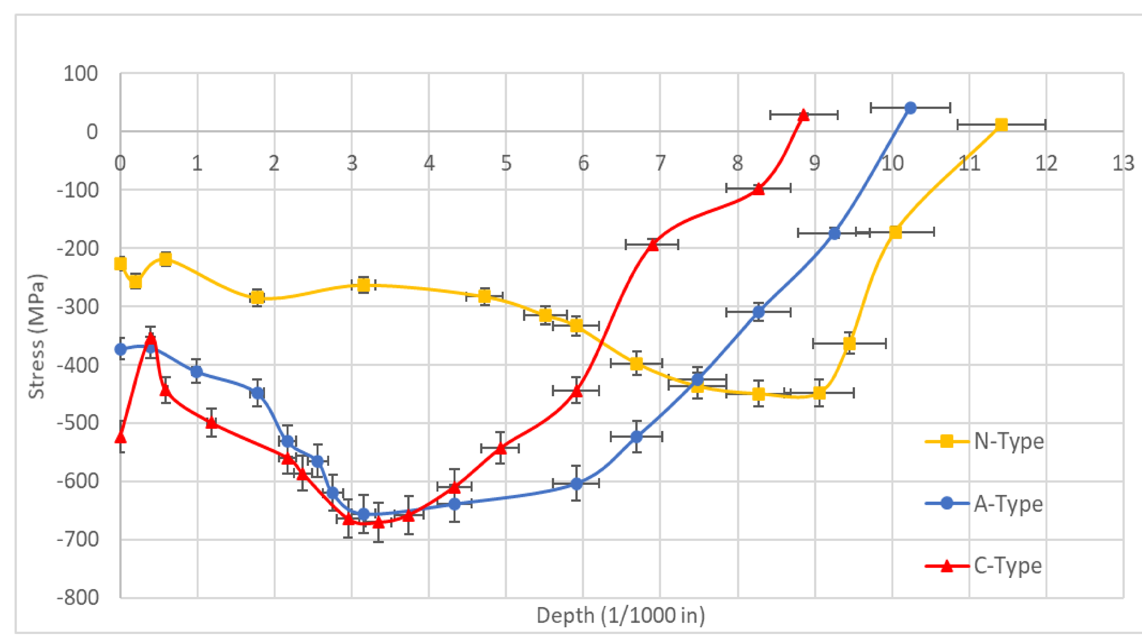


Figure 1: Measured stress-depth profiles for all strip types under the Perp. Medium experimental conditions.

Key trends:
1. As the thickness of the strip increased, the depth where the strip enters a tensile stress also increased.
2. The **maximum compressive residual stress** of the strips also increased as the thickness of the strip increased.
3. For the low intensity tests, the strips did not follow the same trend.

Work Transmitted During Peening

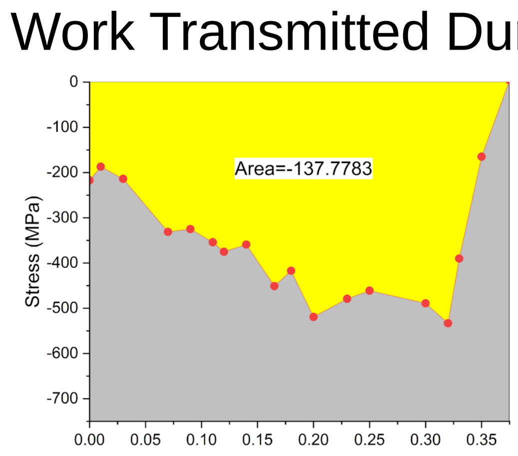


Figure 2: Integration analysis of the peening completed on the Perp. High A-type strip; The yellow region represents the area reported on the top of the plot.

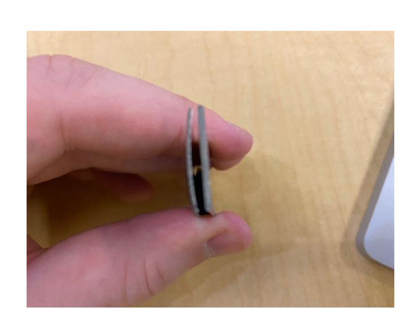


Figure 3: 60 N peened Almen strip (left) versus equivalent 25.1 A strip (right).

- Integrating the area under the stress-depth profile allowed for us to convert stress into work done on the strip, **a unit independent of thickness**.
- By converting to work, we can see what energies correspond to current limits and how the values differ between testing both inside and outside the current intensity limit range.
- The 60 N strip in Figure 3 has bowing in both the peening and transverse directions indicative of **over-peening**. This is qualitative evidence of exceeding the upper intensity limit.

Surface Hardness Testing

Figure 4: Vickers microhardness testing results at varying depths. Measurements made on both the unpeened surface (left) and peened surface (right).

The results show that the compressive stress from shot peening results in **increased hardness** in the Almen strips.

Key Trends:
1. The unpeened side showed constant hardness around 470 HV (which is **within spec** for the 1070 steel used in the strips). For the peened side we saw an increase to ~ 520 HV before leveling off.
2. A-type strips tended to have the highest readings whereas C-type strips tended to have the lowest hardness readings.

Optical Imaging

Strip thickness has an effect on the surface topography.

a.) N Strip b.) A Strip c.) C Strip

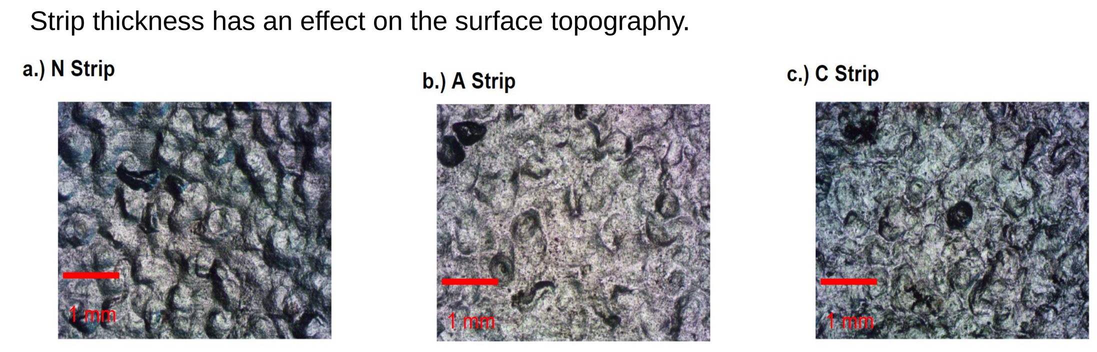


Figure 5: Optical micrographs of three strips (ordered by thickness, left to right) peened under Perp. High intensity peening condition.

Discussion

Determination/Validation of Intensity Limits

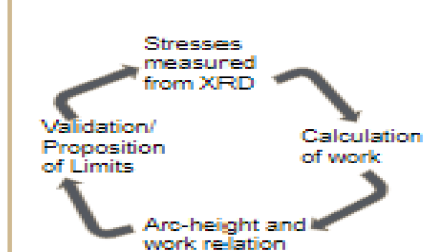


Figure 6: Progress cycle underwent to validate finite intensity limits for the A-type strips.

- By iterating through our experimental cycle (shown in Figure 6), we were able to find a relation between **residual stress, imparted work and intensity** which aided us in validating the intensity limits for A-type Almen strips.
- Figure 7 shows how work corresponds to arc heights for our A-type strips.

Key Trends:
1. The region within 4A and 24A shows a decaying growth curve, that resembles a logarithmic function.
2. Asymptotic behavior appeared near the edges. This abrupt change in functional behavior **indicates that these endpoints** may define region(s) where the A-strip is out of spec.

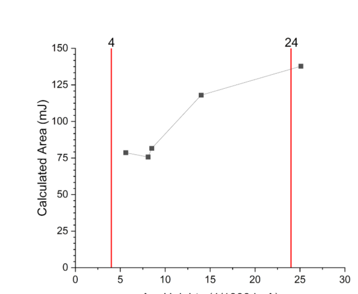


Figure 7: Calculated areas from integration of stress profiles as a function of arc heights for all A-type peening trials.

- In Figure 8, only the C strip has a maximum compressive residual stress matching **half of the yield stress** (green line) for 1070 steel (1300-1400 MPa).
- Looking back to Figure 1, both the A and C strips reached this maximum value close to **650 - 700 MPa.**

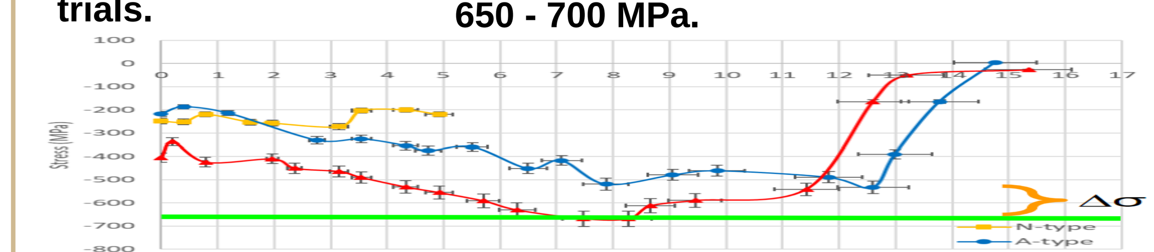


Figure 8: Stress-Depth profiles under Perp. High conditions and how the maximum compressive stresses compare to half of 1070 steels yield stress of 1300-1400 MPa.

Hardness Testing

- Hardness testing showed an increase in hardness comparable to the residual stress at a given depth.
- Hardness reached a maximum value before the indenter reached the compressive depth limit.
  - This can be attributed to the plastically deformed zone caused by the indentation crossing this threshold as seen in Figure 9.

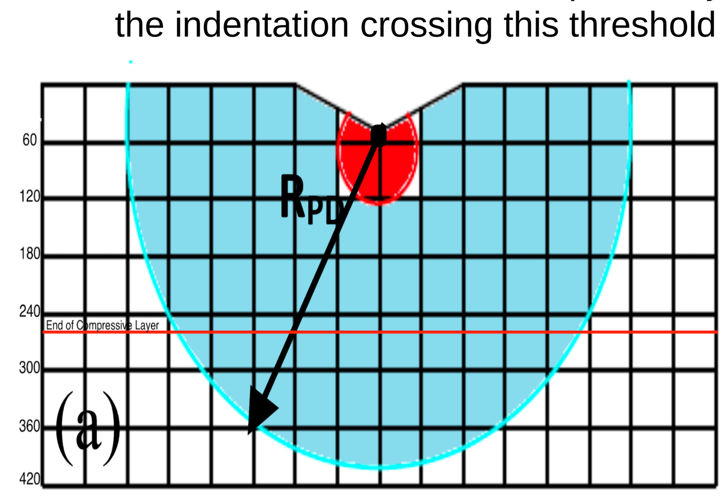


Figure 9: Schematic showing the elastic core (red) and plastically deformed zone (blue) caused by the Vickers indent. The red line depicts the end of the compressive layer and the measurements on the left are in microns.

Recommendations

Based on our findings, we suggest the following before putting our work into practice.

- We were able to validate the finite limits for the A strip of 4A to 24A.
- We need to conduct further testing **outside** the region of 4A to 24A to observe similar trends for the N and C type strips. This in turn will allow us to propose finite limits for these strips.
- Complete hardness testing at lower and higher loads than performed to see if there is an effect from the surface or the elastic core made by the indenter.
- Conduct SEM images at a larger scale so that the impression is in the image to see if there are shape or size differences between trials.

References

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