Development and Assessment of "T" Strips

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Abstract: Shot peening is a surface finishing process that involves bombarding the surface of a part with particulate matter to create a compressive surface layer that improves fatigue life. To quantify the amount of energy delivered by a particular process, manufacturers peen standardized strips of steel known as Almen strips. To address industrial demand for peening at lower intensities, our team conducted a wide range of experiments to aid in the development of new strips particularly suited for these low intensity shot peening processes.

This work is sponsored by Electronics Inc. of Mishawaka, IN and Progressive Surface of Grand Rapids, MI

Background

Shot Peening

- Creates compressive stress that reduces crack propagation and fatigue failure in cyclically loaded parts by shooting the surface
- Shot media, nozzle pressure and flow rate effect peening intensity

Almen Strips

- Measure energy imparted by peening to control intensity
  - Stress layer creates bending moment in area between screws holding the strip during peening (Bailey Zone)[1]
  - Measured as bending radius, also known as **arc height (H)**
    - Reported as 0.001" with strip type used (e.g. 0.004"=4N)
- Made of 1070 Tempered Martensitic Steel

$$H = \frac{0.75(L^2 + W^2)\sigma d(t-d)}{Et^3}$$

Predicted Arc Height Equation by Dr. David Kirk [1].

σ = Average Compressive Stress
t = strip thickness thickness
d = compressive layer thickness
E= Young's Modulus
L, W = Bailey Zone Length, Width

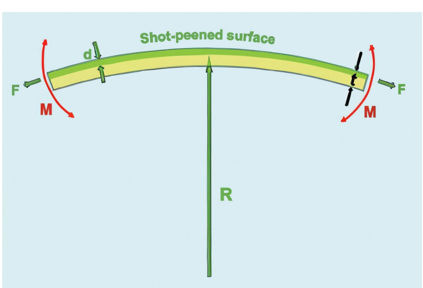
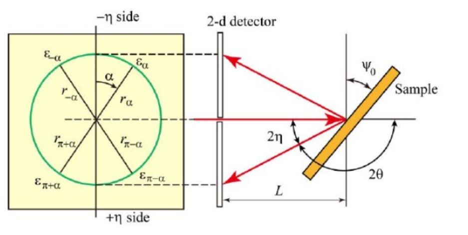


Diagram of bending moments. Adapted from [2].

Strips	N	A	C
Thickness	0.030 - 0.032 in	0.050 - 0.052 in	0.093 - 0.095 in
Hardness	44 - 50 HRC	44 - 50 HRC	44 - 50 HRC
Pre-bow tolerance	+/- 0.001 in	+/- 0.001 in	+/- 0.0015 in

Residual Stress Profiling by XRD

- Measures residual stresses on surface using cosine alpha method [3]
- Electroetching enables stress profiles
- **Profiles used to predict arc height**



Debye-Sher ring and Cosine Alpha Method [3].

Problem Statement

This project is motivated by a prevalent industrial **demand for a thinner Almen strip** than the N strip. The goal of this project is to develop and assess these new "T" strips by **proposing material choice, processing condition, and thickness.** Similar to last year's exploration of the N/C boundary, we combined a **quantitative understanding of how residual stresses cause a strip to bend** with measurements of **the residual stress profile, arc heights** and **hardness** at the lower intensity limits of the N strips to **propose specifications and limits for the thinner strips at the T/N boundary**.

Experimental Methods/Materials

Candidate Materials

1075/1095 Spring Steel (.015"/.016" and .020" Thickness)

Annealed 1.5 hours @ 400 °C

Average pre-hardness of 51.7 and 53.4 HRC (1075 and 1095)

Tempered Martensite

3 min.@ 900 °C, quenched in water to create martensite

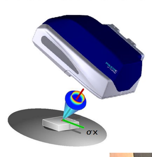
Temper for 20 min. @ 390 °C

Average pre-hardness of 50.3 and 51.6 HRC (1075 and 1095)

Standard N Strips

1070 Tempered Martensitic steel, hardness of 44-50 HRC

Measurements Taken



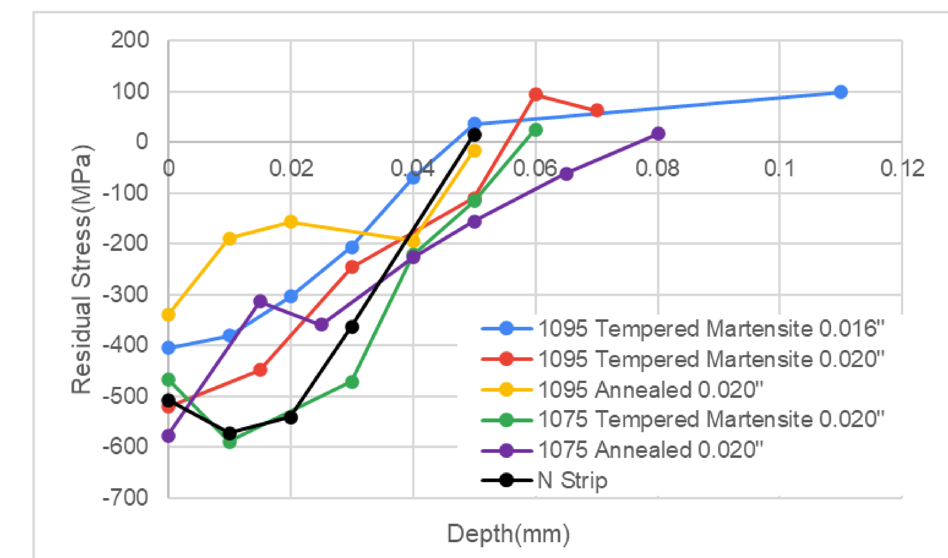
- Vickers Hardness(1kg & 10 kg loads)
- Residual Stress (Pulse-Tec XRD unit)

Peening Parameters

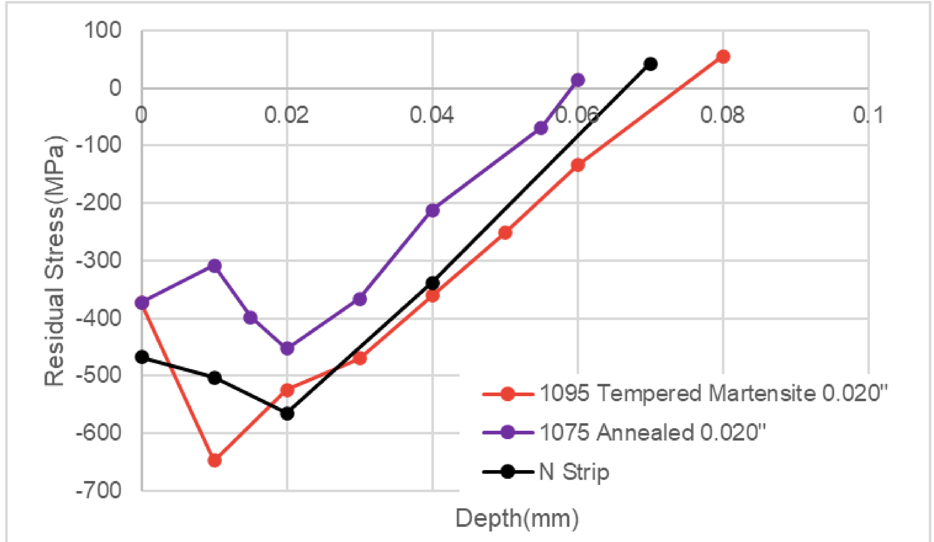
- 25° angle
- 10" standoff
- ASR S70 Shot
- 5/8 short venturi.
- N strips used to find N strip transverse rate
- Annealed 1095 0.020" strip used to find T strip transverse rate

Shot Peening Parameters				Arc Height Intensity	
Target Intensity	Air Pressure (PSIG)	Transverse Rate of N Strips (in/min)	Tranverse Rate of T Strips (in/min)	N-Strip (0.001 in)	T- Strip (0.001 in)
4N	7	7.04	4.59	4.02	8.34
6N	15	15.6	8.33	6.17	13.19
7.5N	23	30.3	23.26	7.57	15.15

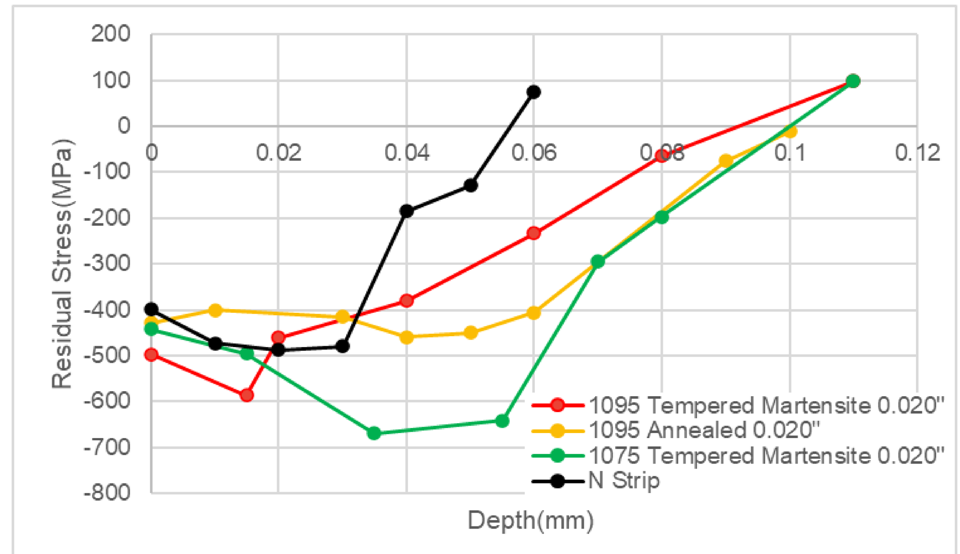
Residual Stress Profiles (RSP)



RSP of samples peened at 4N intensity. The overall crossover point (compressive layer depth) is **relatively small** compared to the other RSP plots, highlighting the **effect of intensity on the strip response**. The experimental T strips have a **similar shape to the N strip** RSP (black), with similar peak stress and compressive layer depth.



RSP of samples peened at 6N intensity. The compressive layer depth **is larger** than 4N, highlighting an **increase of compressive residual stresses** with higher peening intensity. The T strips have a **similar shape to the N strip** RSP (black), notably the tail of the profile.



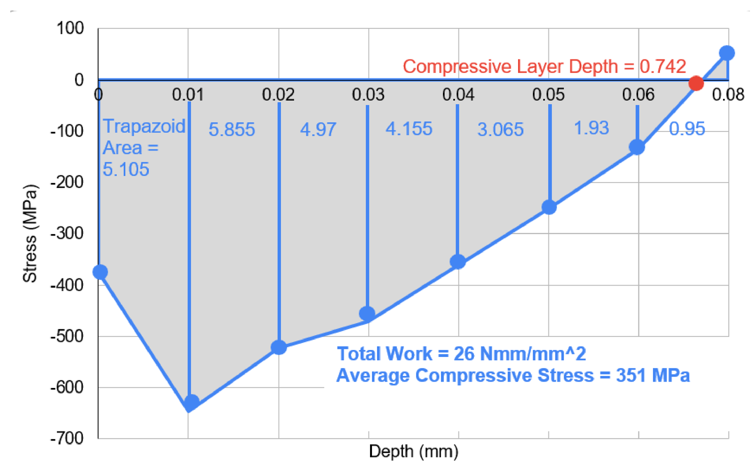
RSP of samples peened at 7.5N intensity. The compressive layer for the T strips is **higher** than previous intensities, **further supporting the trend**. The N strip, however, has a **lower compressive layer** than the T strips, highlighting a **deviation** from similar behavior between the N and T strips at the **highest peening intensity**.

Predicting Arc Height

By following the below process, **the arc height of the strip due to the stresses measured in the RSP can be calculated.** Since this value **represents the elastic energy stored in the strip,** it is a good indicator of the **true intensity, the stress level and depth of the residual compressive layer**. Therefore, the difference between the predicted and measured arc heights **helps us quantify the accuracy of the strips in reporting the intensity.**

Step 1: Linearly interpolate points from RSP with stresses near 0 to find **compressive layer depth(d)** at the point where the stress is 0

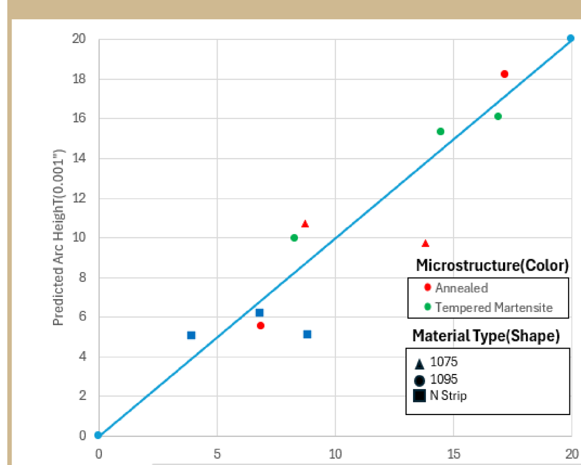
Step 2: Sum the area of the trapezoids made from the RSP data points to find the total work due to the elastic stresses through the compressive layer. **Divide this value** by the compressive layer depth(d) to find the **average compressive stress(σ).**



RSP with graphical representation of d and σ calculation

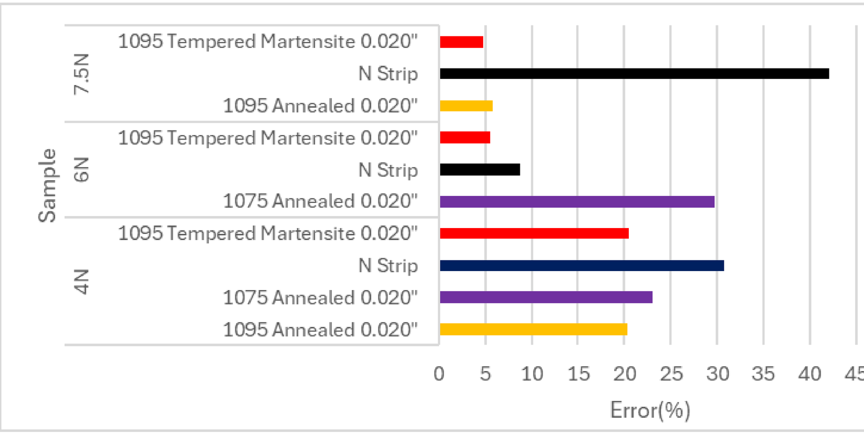
Step 3: Plug σ and d values into the bending equation(see background) to predict arc height

Quantifying Strip Accuracy



Parity plot comparing the predicted and measured arc heights. The blue line represents points where these values are equal. **Points closer to this line more accurately measure the true intensity of the shot peening process.**

$$Error(\%) = \frac{|Predicted - Actual|}{Actual}$$

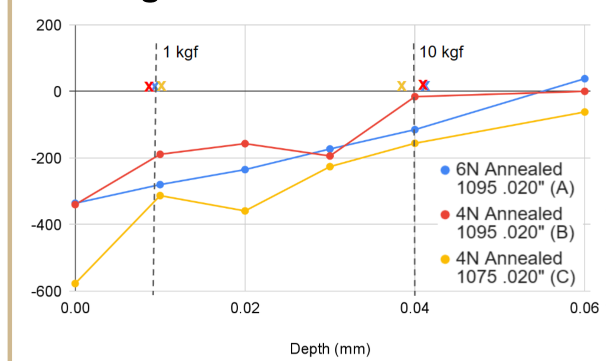


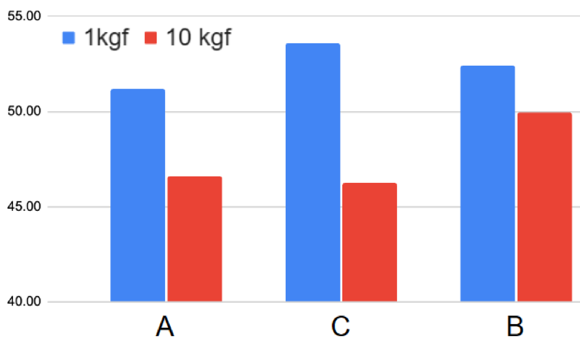
For all the tested intensities, the **1095 Tempered Martensite 0.020" has the one of the lowest percent errors.** This indicates that the arc heights measured using these strips **most accurately reflected the stress level and depth of the residual compressive layer created by shot peening.**

Additionally, the irregularly high error for **the N strip at 7.5N** underlines the need for thinner strips, as we can attribute **the high error** to **a relatively small error (3.7N) relative to a small value (8.8N).**

Hardness

The **post-peen** hardness shows the effect of **compressive residual stresses (CRS).** The Vickers hardness indenter generates a plastic region under the contact point, **due to a generated stress concentration.** The CRS affects hardness by **resisting against the indenter** and **resisting deformation.** This results in a **higher hardness reading**.





The dotted lines represent the **penetration depth** for 1 and 10 kgf loads respectively, and the respective hardness (HRC) is shown underneath.

The **1 kgf** hardness reads material in the **peak** CRS region, while **10 kgf** reads material **near the end** of the CRS region. The plastic zone for 10 kgf will be outside of the CRS.

The 1 kgf loads are all **higher** than 10 kgf, suggesting the effect of CRS. Because the compressive layer depth coincides with our RSPs, this method could be used to estimate the compressive layer depth.

Conclusions & Future Work

Conclusions

- 1095 Tempered Martensite is most accurate across tested range, shown by low error values for corresponding strips.
- By varying loading for hardness measurements, the depth of CRS layer can be estimated, as supported by RSPs
- Comparing accuracy of N and T strips shows a predictable overlap in peening response between 4 and 7.5N

Future Work

- Other dimensions of strips could be proposed with a better-suited procedure
- A better predicted arc height equation could be used, one that factors in more material properties to understand their effects
- Further experimentation could be performed to understand lower limit of T strips, and how method of measurement (e.g. Almen gauge) affects this limit.

Sources

[1] D. Kirk, "Quantification of Shot Peening Intensity Rating," Dec. 2015. Available: https://www.shotpeener.com/library/pdf/2015007.pdf. [Accessed: Dec. 08, 2023]
[2] D. Kirk, "Almen Strip Quality," 2018. Available: https://www.shotpeener.com/library/pdf/2018034.pdf
[3] K. TANAKA, "The Cosα method for X-ray residual stress measurement using two-dimensional detector," Mechanical Engineering Reviews, vol. 6, no. 1. Japan Society of Mechanical Engineers, pp. 18-00378-18–00378, 2019. doi: 10.1299/mer.18-00378.sm.hb.v10.a0001761.

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