Surface Enhancement of Weld Metallurgy for Infrastructure and Related Applications

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This study aims to investigate a surface enhancement treatment of weld metallurgy for infrastructure and related applications. The specified sample geometry, resembling perpendicularly joined bridge beams, is commonly referred to as a T-joint fillet weld, and are also extensively used in other metal structure fabrication. The edges of the fillet welds, known as weld toes, act as stress concentrating regions. Surface enhancement treatments are applied to the weld toes to address the stress concentration. Following surface enhancement, the samples underwent X-ray residual stress analysis, which revealed that compressive stress decreased with increasing distance from the weld toe. Shot peened samples had higher compressive stresses across the material but needle peened samples had compressive stresses concentrated at the weld toe.

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Project Background

When constructing bridges, on-site welding is a must as these infrastructures are too massive to build in a warehouse. However, during welding, this process creates a heat affected zone (HAZ) that induces tensile residual stresses concentrated at the weld toes. The tensile stresses accounts for fatigue failure, the most common failure mechanism for bridges. Fatigue failure occurs at weld toes due to the induced tensile stresses from welding causing initiation of cracks, followed by propagation. One way to delay crack initiation and propagation is to impact treat the weld toes.

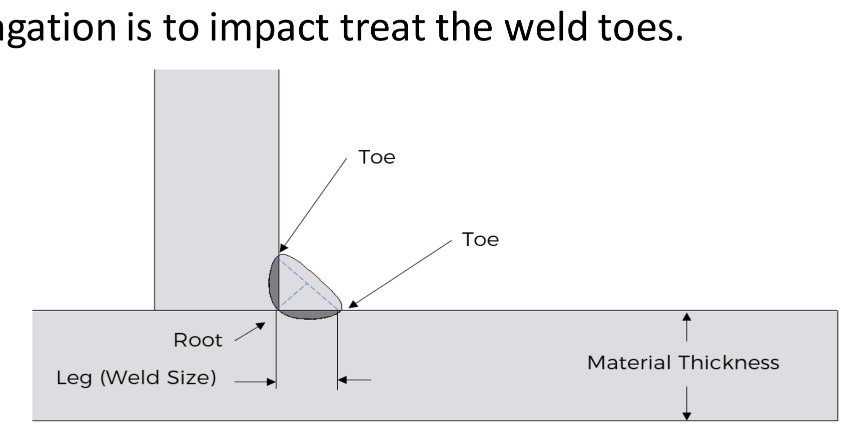

Figure 1: Schematic of a T-joint sample showing the location of weld toes.

The purpose of this project is to determine the advantages and disadvantages of two impact treatments for weld metallurgy, shot peening (SP) and ultrasonic needle peening (UNP), for infrastructure and related applications. Impact treatments delay crack initiation by inducing compressive stresses on the weld toes. UNP applies high frequency impacts on weld toes to induce compressive stresses, while SP does this by bombarding shot uniformly on a material surface to create distributed plastic deformation. To compare the types of impact treatments, XRD is used to measure the residual stresses on and near the HAZ by measuring the crystallographic lattice deformation induced by stresses on the material.

**Due to COVID-19 complications, further data was not obtainable as Purdue shut down all labs.

Experimental Procedure

The first step in our experiment was to find suitable steels that have similar properties to infrastructure steels or related applications. The two steels chosen were ASTM A709, a low carbon industrial grade infrastructure steel, and AISI 1018, a stainless steel (SS) used mainly in machine parts because of its high corrosion resistance. A709 steel samples were cut and welded by research machining services (RMS) at Purdue to sample dimensions shown in Figure 2 (a), and the 1018 SS samples were cut and welded by EI, Figure 2 (b). The T-joint fillet weld design was chosen because of its similarity to I-beams used in infrastructure across the country. The steel samples were then impact treated for XRD characterization to measure and compare the internal residual stresses.

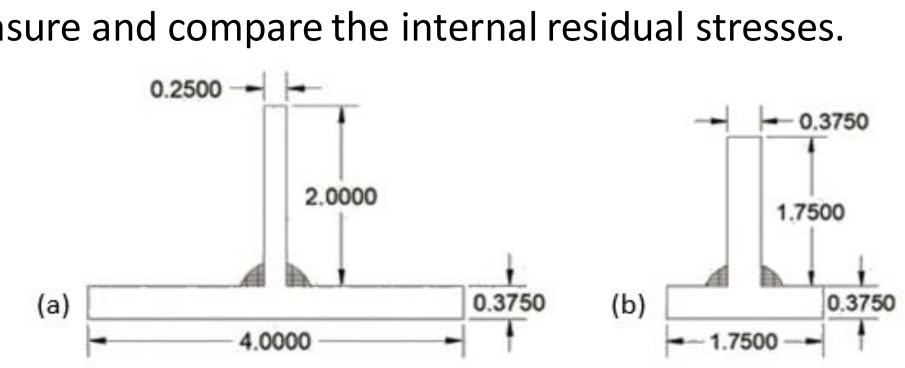

Figure 2: Rendering schematics of our sample dimensions, (a) ASTM A709 and (b) AISI 1018

Acknowledgements

Special thanks to:

- Empowering Technologies for provision of the STRESSVOYAGER® Ultrasonic Needle Peener
- Progressive Surfaces for SP our samples
- Ervin Industries for donating the cast-steel shot used for shot peening our samples
- Dr. Robert Connor (Purdue), Kumar Balan (Ervin Industries), and Brandon Thornell (Empowering Technologies) for their expertise and guidance

Peening Treatments of Selected Steel

The T-joint welds were brought to Progressive Surfaces and were shot-peened (SP) with cast steel shot, S-330. This type of shot have a martensitic microstructure, meaning work-hardening is not an issue. The ultrasonic needle peening (UNP) of the samples was done on campus by the senior design team using the needle peener loaned to us by Empowering Technologies. The X-ray residual stress analyzer was used to characterize the peened samples after they were cut into smaller sections.

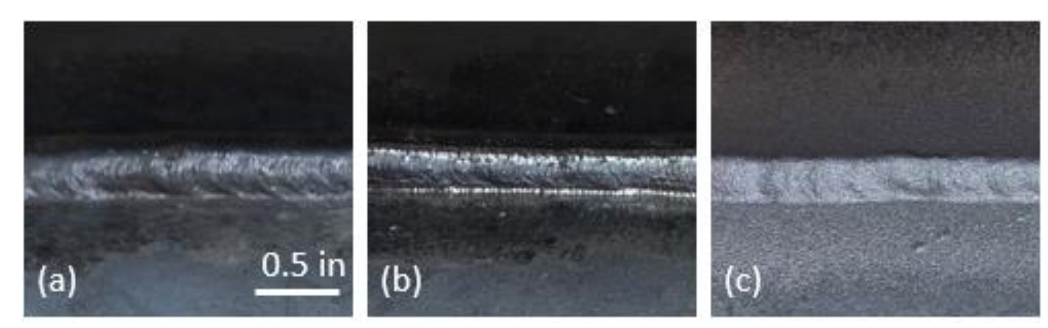

Figure 3: Close-up images of the A709 steel; (a) control, (b) UNP and (c) SP

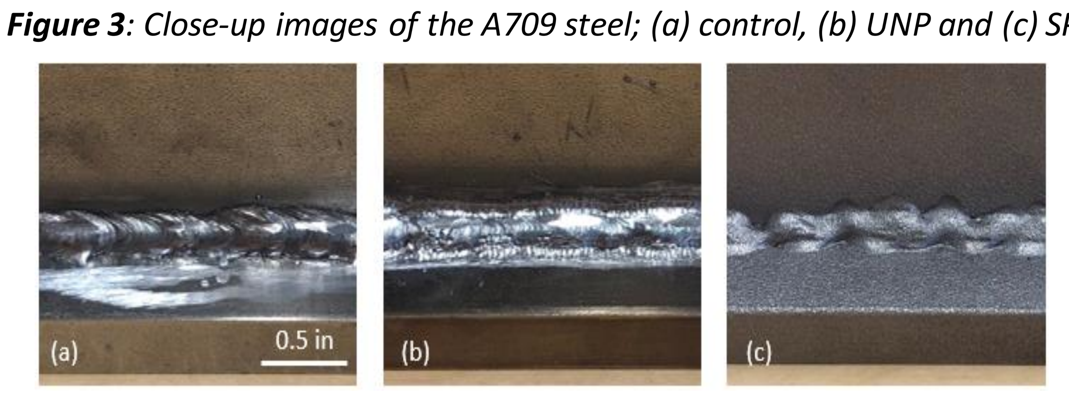

Figure 4: Close-up images of the 1018 steel; (a) control, (b) UNP and (c) SP

***Table 1**: Comparison of the different impact treatments.*

Criteria	Ultrasonic Needle peening	Shot peening
Mobility	Very mobile/on site use	Stationary/Facility only
Intensity	Higher intensity range	More controlled intensity range
Automation	Controlled by hand	Computer controlled
Weld coverage (complete/partial)	Covers just the weld toe/partial	Covers large area of T-Joint/complete
Time	Takes time	Covers larger areas faster

Results and Discussion

ASTM A709

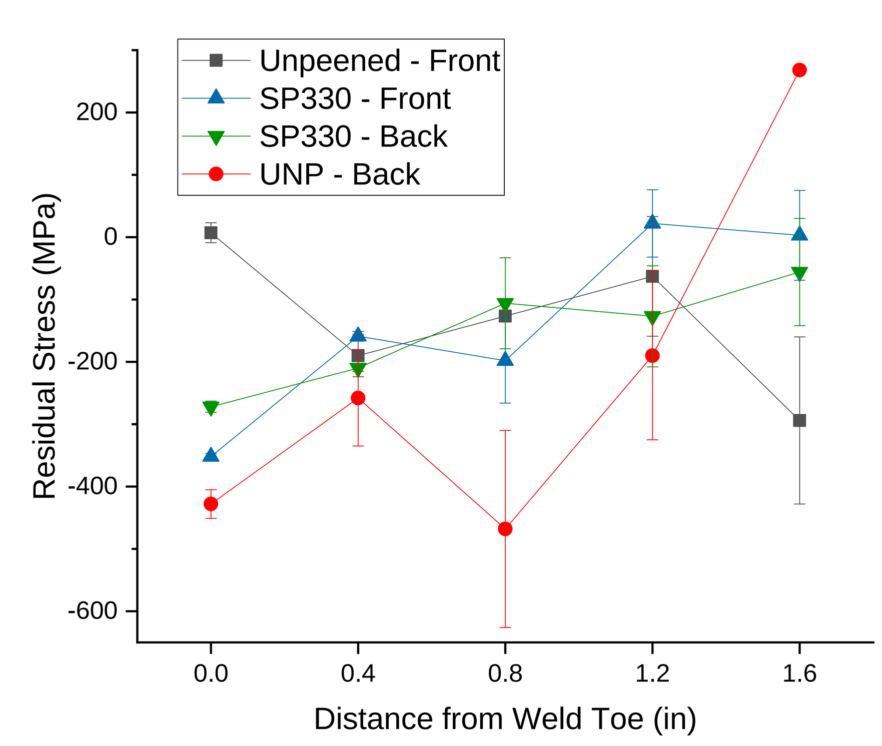

Figure 5: Topographical profile of residual stress for A709.

In our A709 residual stress (RS) results, there is a general trend at the weld toe (0.0 in), where the unpeened samples have RS around 0 MPa, but the shot peened (SP) has a large compressive (represented in the negative direction) stress and the ultrasonic needle peened sample has a greater compressive stress. As the measurements progress away from the weld toe, the standard deviation (error bars) of the measurements increases in the center of the sample, at around 0.8in. This is related to how the residual stress analyzer measures the stress in our samples, as it compares our tested samples to examples of the same material. The samples produced underwent a phase transformation due to the heat treatment around halfway through the sample. Since there are two phases present and the machine relies on a comparison between the same material, the measurements are going to be less accurate with higher standard deviations.

Results and Discussion

AISI 1018

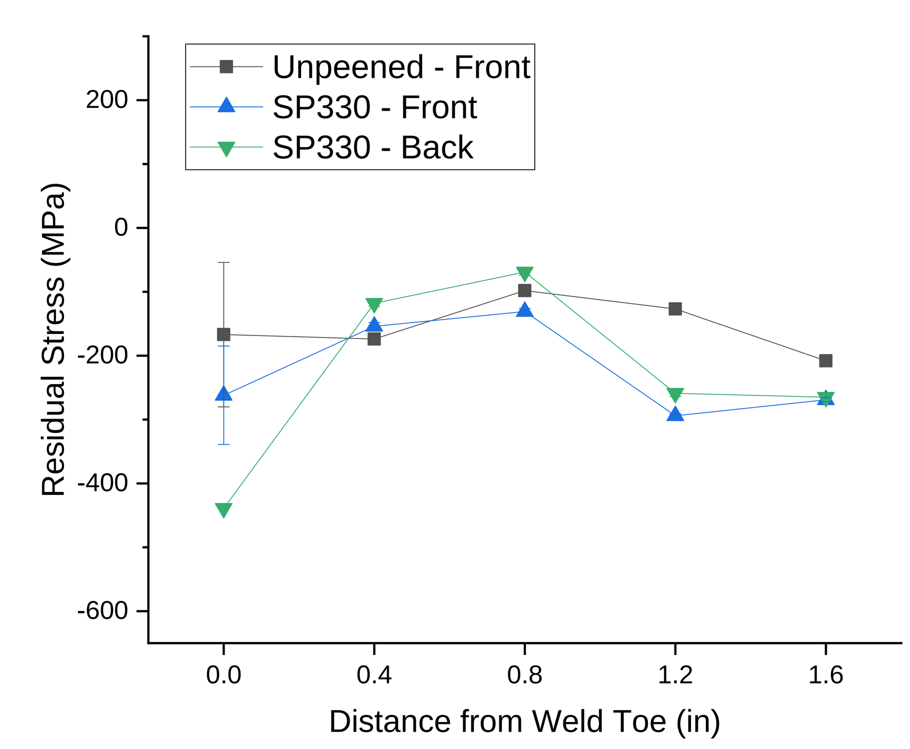

Figure 6: Topographical profile of residual stress for 1018.

In our 1018 residual stress (RS) results, we can see a similar trend of the unpeened samples having a smaller amount of compressive stress (represented in the negative direction) than the shot peened results at the weld toe (0.0in). The magnitude of the compressive stress decreases as the measurements get further from the weld toe. However, at around 1.2in all three samples undergo another increase in compressive stress, this change is independent of the peening treatment as the unpeened sample experiences it as well. This could also be due to the heat treatment the sample underwent, weakening it but not changing the phase.

Conclusions

- At the weld toe, both peening methods induce an average compressive residual stress of -300 to -500 MPa.
- In the 709 samples, the ultrasonic needle peened (UNP) samples had a higher magnitude of compressive stresses than the shot peened samples. This is expected because UNP operates at a higher relative intensity than shot peening.
- As the measurements went further away from the weld toe, the effects of the peening treatments decreased. This is consistent with background research because both peening techniques focus treatment on the weld toe.

Recommendations

- Performing fatigue tests on T-joint samples, pre- and post-treatment would allow for a true comparison on which impact treatment would be the best option for constructing bridges and related infrastructure applications. Test may be financially prohibitive, so a cost-benefit analysis should be considered.
- Additional characterization such as optical microscopy to observe the microstructure and Vickers hardness testing to corroborate the x-ray residual stress data.
- Additional testing on the shot peened S230 samples for further comparison