Effects of Shot Peening Using a Circulating Blast Process on Bridge Welded Joints

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Overview

Shot peening is a well-established industrial practice which can enable beneficial compressive stresses to be created in the surfaces of metal parts. Alternative mechanical peening has been shown to improve bridge life and performance by utilizing similarly created compressive stresses particularly in "weld toe" areas of bridge steel. A previous study by Purdue University's School of Materials Engineering gave a preliminary indication that shot peening could be used to create similar stress states in the weld toe area of bridge steel. Circulating Blast Processing is envisioned to produce beneficial compressive stresses in the weld toe areas of bridge steel using a process inherently more amenable for "on-site" treatment of existing bridges than "conventional" shot peening. The overriding objective of this project is to compare welded joints in bridge steel which have been shot peened with a circulating blast process to similarly prepared joints that have not received the blast process peening treatment. Welded carbon steel specimens will be created in conjunction with the testing required to appropriately assess the sample. Four peening conditions are being considered. The key tests to be performed on the various samples are stress measurement and fatigue.

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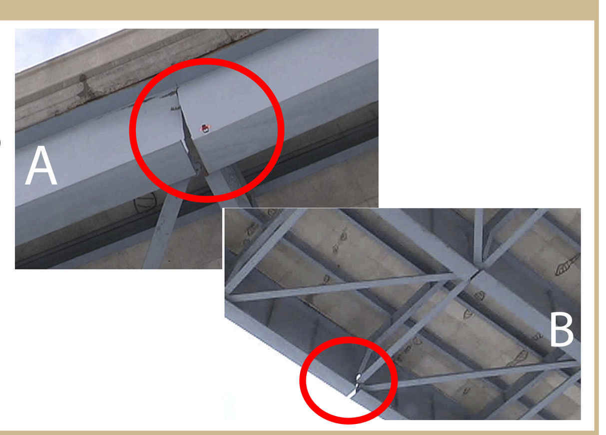
Example of Project Motivation

The Hoan Bridge Collapse- Milwaukee, WI 2000

- Bridge collapse from failure due to high stresses in the welds between the lateral bracing and floor beams
- Cost the city $16 million to demolish and rebuild
- Carried around 36,590 cars per day



Experimental Procedures

Material Choice

The material being used for this project is cold rolled grade 50 ASTM 576 low carbon mild steel. The chemical composition is listed in Table 1. This steel was chosen because it is one of the standard types of low carbon steel that is used in bridge applications, especially where the parts will be welded.

Table 1: Composition of ASTM 570 low carbon steel in addition to the base metal Iron.

Element	C	Mn	P	S	C
Weight %	0.25	0.90	0.04	0.05	0.20

Sample Preparation

Two types of samples were prepared for this project. Tensile/fatigue testing specimens, or "dogbones," and T-joints which are representative of an industrial weld with 8 residual stress measurement locations. The dogbones were machined at Purdue RMS and welded together using TIG welding and the T-joints were created using MIG welding. Due to the requirement of leaving the weld-toe untouched, the dogbones were machined with a channel to prevent grinding on the weld. This created a non-uniform gauge for the dogbone, leading to different stresses during tensile and fatigue loading.

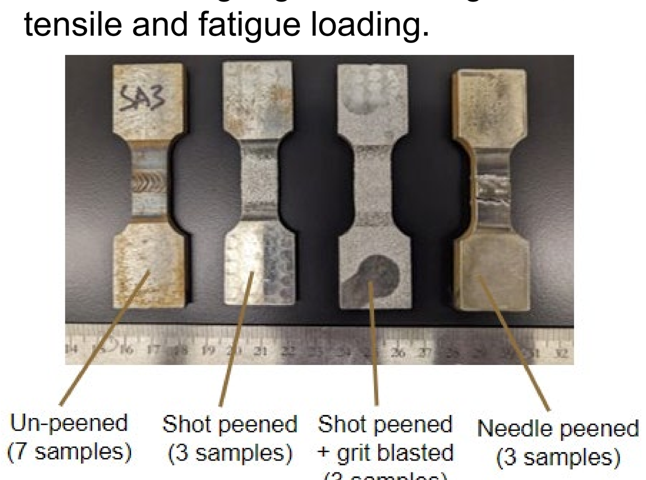


Figure 1: Dogbone sample geometry.

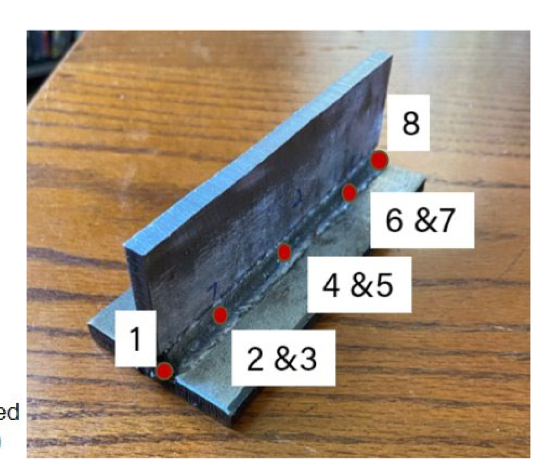


Figure 2: T-joint sample with MIG welding.

Testing Conditions

Due to the non-uniform shape of the dogbones, only the T-joints would be used for residual stress testing and comparison, while the dogbones would undergo tensile and fatigue testing, with the sample types and tests planned shown in Table 2. All dogbones had to be tested using XCT to ensure required homogeneity and minimal porosity in the weld before fatigue testing.

Table 2: Sample testing conditions

Sample	Residual Stress	Fatigue
T-Joint • Unpeened (UP) • Shot Peened (SP) • Shot Peened + Grit Blasted (SP+GB) • Needle Peened (NP)	Yes	No
Dogbone • Unpeened (UP) • Shot Peened (SP) • Shot Peened + Grit Blasted (SP+GB) • Needle Peened (NP)	No	Yes

Residual Stress

Residual stress was measured using a PulsTec μ-X360 residual stress testing machine at the weld toe of the T-joint samples. The residual stress was calculated using x-ray diffraction and comparing with a preset value for the lattice spacing. Bragg's law is shown in figure 3 which is used to calculate the lattice spacing. This test was conducted using the α-ferrite setting with an incident x-ray set at 35º as an entry angle comparing against a lattice parameter of 2.8664 Å along the (211) direction.

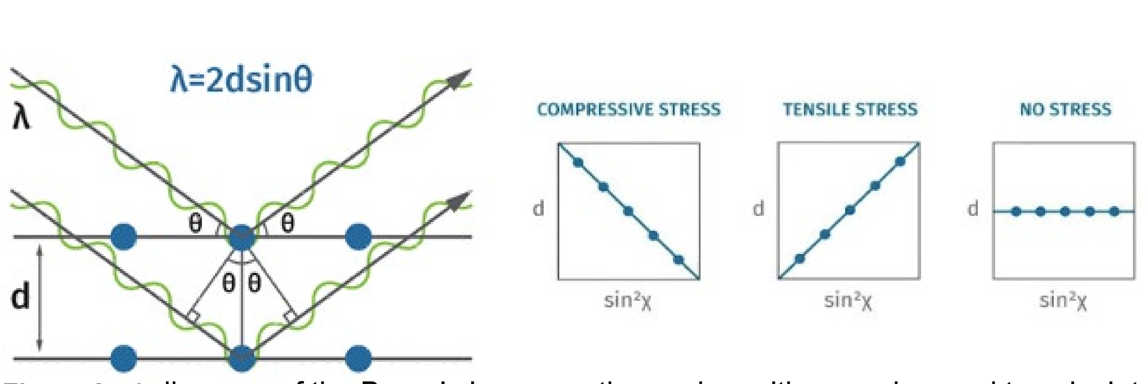


Figure 3: A diagram of the Bragg's Law equation and resulting graphs used to calculate residual stress by the Pulstec μ- X360.

Results & Discussion

Microstructure

The first round of dogbones had issues of porosity. For the fatigue and tensile test data to be usable, the dogbones had to have minimal porosity and a homogenized weld structure. Shown in Figure 4 (a) is an unusable weld structure with major porosity, Figure 4 (b) shows the structure and porosity required for fatigue testing.

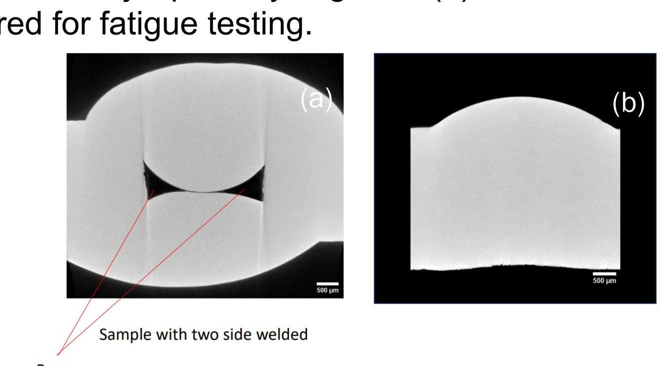


Figure 4: (a) porous and non-homogenized weld structure which is unusable. (b) required homogeneity and porosity of the weld structure for fatigue and tensile testing.

Residual Stress

Residual stress was measured using the 8-point scheme showed in Figure 2 on the T-joints. Points 1 and 8 were neglected since the edge effects that would be nonexistent in a real bridge weld. Figure 5 shows the residual stresses measured for all points for all peening conditions measured. Of these points, point 3 and point 7 were the most representative for the residual stress profile at the weld. Only points 3 and 7 were measured for NP since the original residual stress data had to be redone.

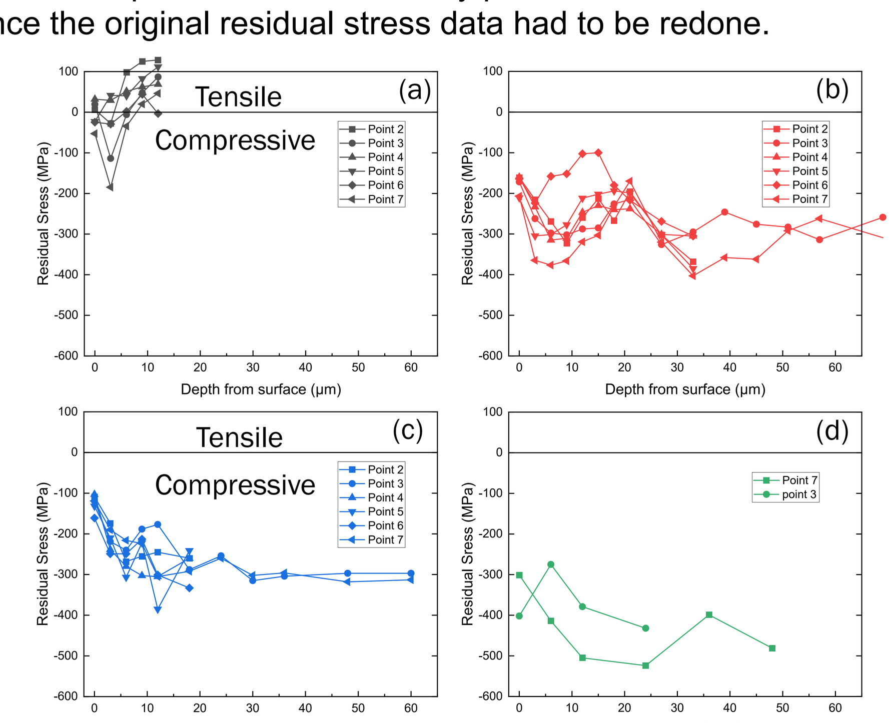


Figure 5: Residual stress measurements for points 2-7 for the (a) unpeened (UP), (b) shot-peened (SP), (c) shot-peened + grit blasted (SP+GB), and (d) needle-peened (NP).

The residual stress measurements from points 3 [Figure 6 (a)] and 7 [Figure 6 (b)] that were most representative show a much greater compressive (negative) residual stress in the surface of the peened samples compared to the unpeened sample. This greater residual stress correlates to a higher fatigue life as it prevents crack growth and propagation through dislocation pinning and crack closure.

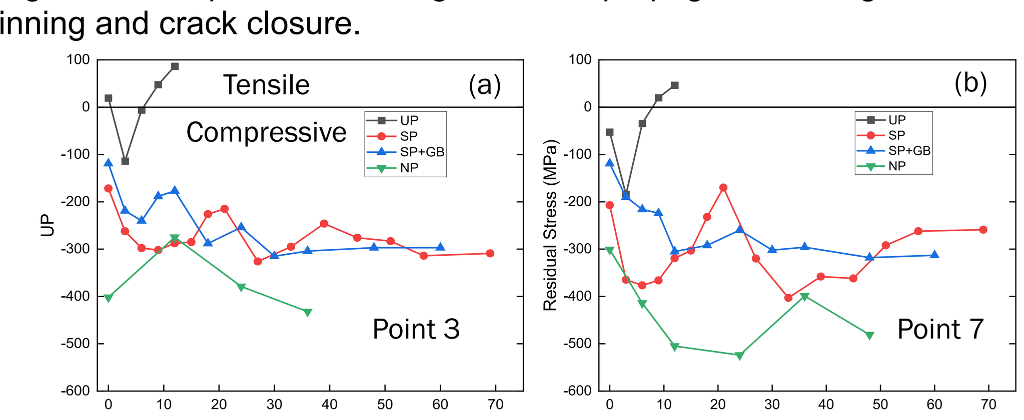


Figure 6: Residual stress measurements of all peening conditions at the most representative points measured at point 3 (a) and point 7 (b).

Tensile Testing

Tensile testing was done to determine the yield and ultimate tensile strength (UTS) of the dogbones as welding affects the mechanical properties. The tensile testing yielded typical stress-strain curves for carbon steel at the weld section shown in Figure 7 with slightly higher yield strength and UTS found in the shot-peened samples over the unpeened samples shown in Table 3. The needle-peened samples were not tensile tested due to low sample number.

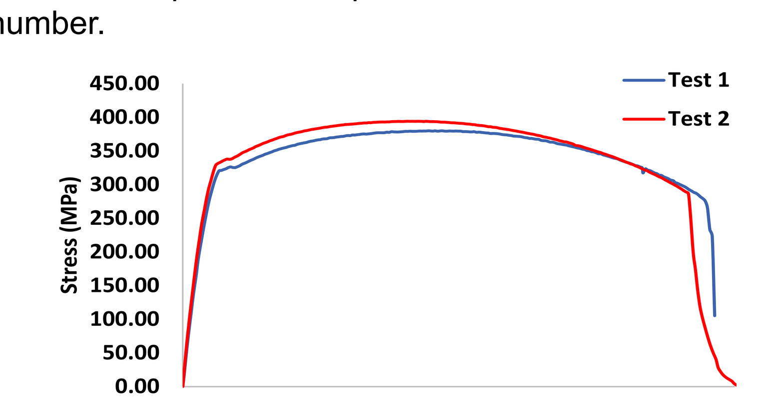


Figure 7: Stress vs displacement chart for UP dogbone at the weld section

Table 3: Measured yield strength and UTS for the UP, SP, and SP+GB samples at weld.

	Un-Peened	Shot-Peened	Shot Peened + GB
Yield Strength (MPa)	325	360	355
UTS (MPa)	380	415	409

Fatigue Testing

Fatigue testing found that the SP and SP+GB samples had nearly 3 times the fatigue life of UP with NP nearly double, shown in Figure 8. It is hypothesized that the NP is lower due to less surface area covered by the needle peening process. It seems the SP residual stresses and fatigue life are not affected by the grit blasting process.

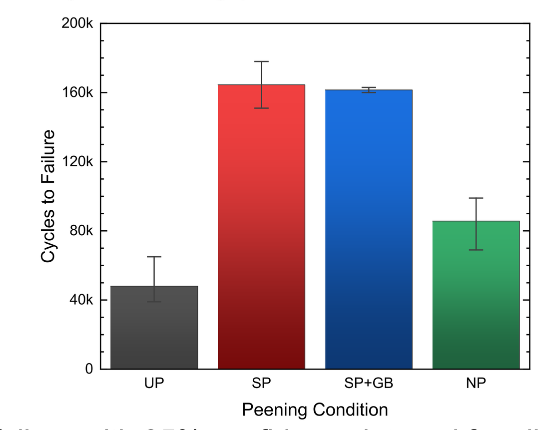


Figure 8: Cycles to failure with 95% confidence interval for all peening conditions.

Figure 9 shows the fatigue fracture locations for all peen conditions. Peening the dogbones causes the fracture location to begin further away from the weld with the furthest being SP and SP+GB. NP is not as far likely due to the lower surface area coverage from the peen line.

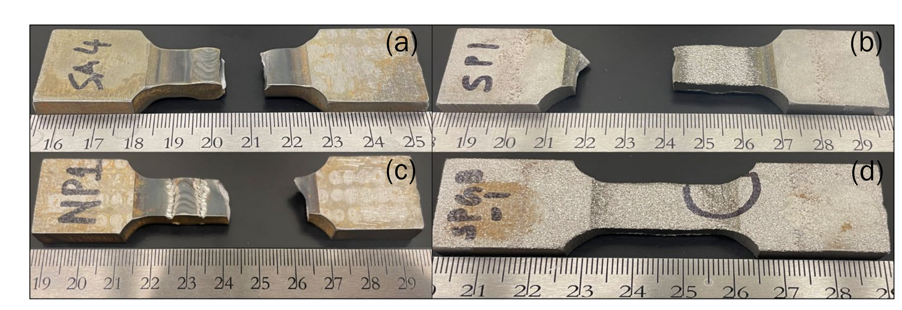


Figure 9: Fracture location of representative fatigue tested (a) UP, (b) SP, (c) NP, and (d) SP+GB dogbone samples.

Conclusions

- Shot and needle peening increase compressive residual stresses in the weld area.
- Increased compressive residual stress increases fatigue life.
- Needle peening has greater compressive residual stress but not as long of a fatigue life as shot peening due to lower surface area covered by the needle peen line
- Improved fatigue life allows longer lasting bridges which saves money.

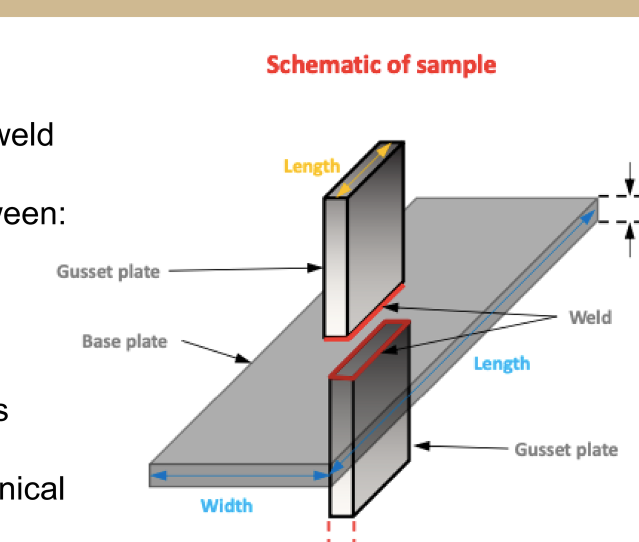
Future Work

Gusset Plate

- Fatigue Test new geometry
- Closer to real world bridge weld than dogbone samples
- Comparing differences between:
  - Gusset plate length
  - Distance of weld
  - Base plate length

Fatigue and Tensile Testing

- Increase number of samples tensile and fatigue tested to prove correlations in mechanical properties



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Acknowledgements

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