Effects of Shot Peening on Residual Stresses in Gear Surfaces

PURDUE MATERIALS ENGINEERING

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The ZF TRW Lafayette branch produces power steering systems for the heavy duty trucking industry. To meet safety and performance standards for their customers, ZF TRW uses shot peening to increase the fatigue life of their products. They need to understand how the shot peening process affects the resulting microstructure of the rack piston for the THP60 power steering pump and the impact on mechanical properties. Our goal is to provide guidance on which parameters are the most important in the shot peening process and how modifying these parameters affects the microstructure, residual stress, and hardness.

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Project Background

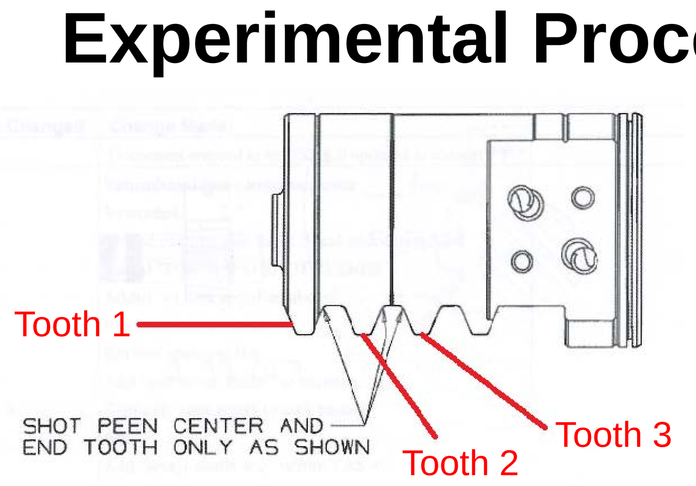
We set out to tell TRW how much room they have in their peening process to change parameters without negatively affecting the performance of their THP60 rack pistons. There are 3 concepts that are fundamental to this project: shot peening, residual stress, and fatigue.

Shot peening is a cold work process performed on metals to improve fatigue life, reduce corrosion, and prevent hydrogen embrittlement, among other benefits. Modern shot peening involves inundating the surface of a metal component with glass, ceramic, or metal shot at a high velocity. This creates a thin layer of residual stress on the surface of the component.

X-ray diffraction (XRD) is a technique to determine residual stress present in a shot peened sample. It uses the distance between planes in the crystal structure as a strain gage. Its deformation causes changes in the spacing of the lattice parameter from its stress free value to a new value which corresponds to the magnitude of the residual stress.

Fatigue is the condition of repeatedly stressing a material below its yield stress, culminating in structural changes such as cracks or fracture after a significant number of repetitions. Fatigue cracks are most likely to initiate on the surface of a part where there is no material to constrain deformation. One of the main functions of shot peening is to induce compressive residual stresses on the surface, inhibiting tensile stresses that tend to pull the material apart, thus extending the fatigue life.

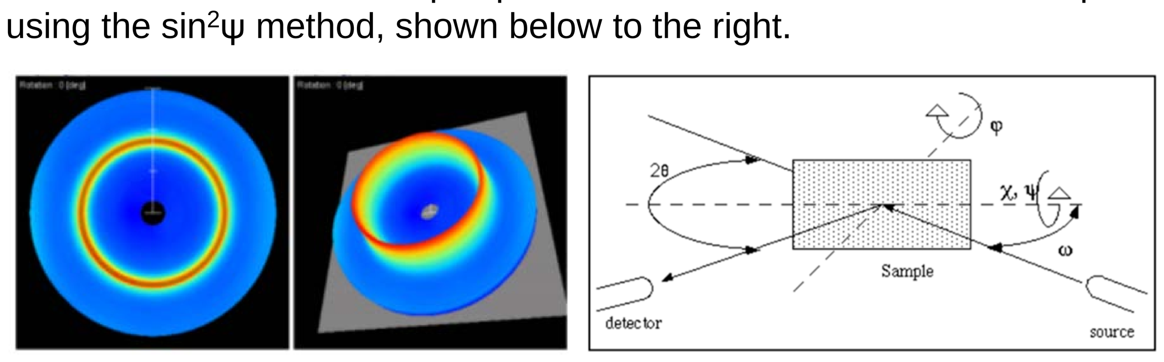
Experimental Procedure



The schematic and actual picture of the as-received rack piston are shown above. The sample preparation procedure followed the ASTM standards. Synthetic chemotextile hard napless polishing cloth and glass filled epoxy powder were used to improve edge retention. The etchant was nital which contained 2% nitric acid and 98% ethanol. Parts for the Design of Experiments were named with a two-number convention. The first number is the peening air pressure, and the second number is the percentage of the normal peening time that was used.

Residual Stress Measurement by XRD

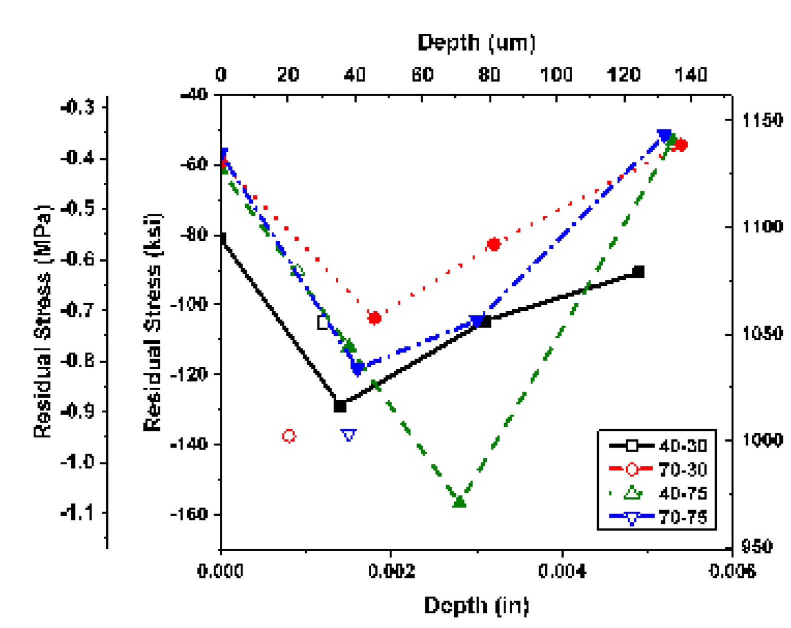
To measure the residual stress at the surface of the parts from the current process, we used the Debye-Scherrer Ring method, shown below on the left. The depth profiles were created for the other parts using the $\sin^2\psi$ method, shown below to the right.



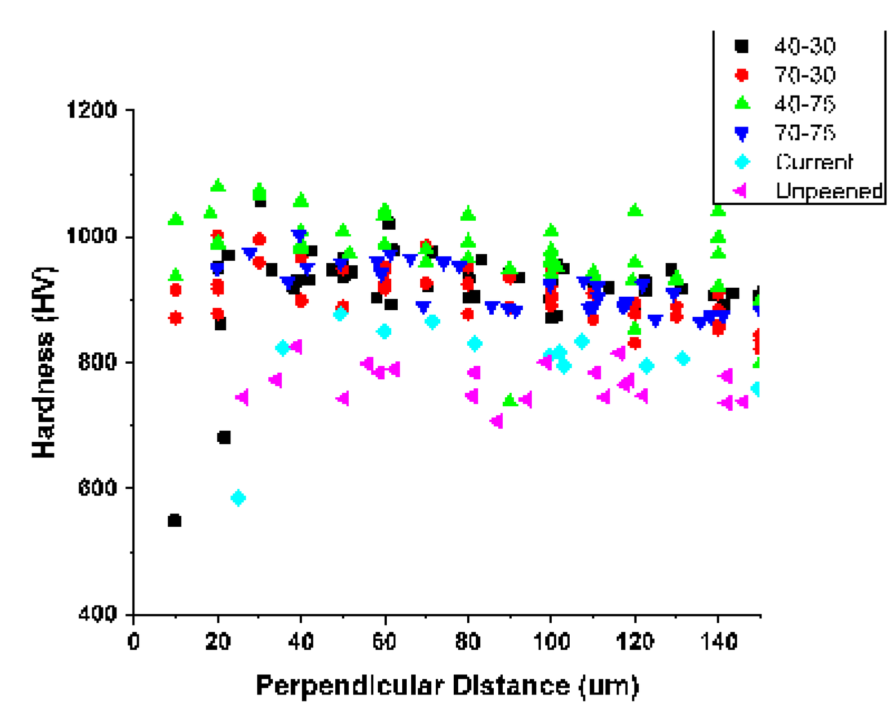
Since austenite had a different crystal structure from martensite and other phases of iron, the resulting diffraction pattern would be different. Thus, we could estimate the amount of retained austenite by comparing the intensities of diffraction peaks arising from each of the phases. In the absence of significant undissolved carbides and preferred orientation, there was a correlation between the intensity ratio and the volume fraction of retained austenite. Two standards (ASTM E975 and SAE SP-453) for austenite measurements were used. Both assumed that the material had a nearly random orientation and had few carbides.

Results

Residual Stress & Hardness



The residual stress profiles and the maximum hardness value and location for the four experimental samples. 40-75 shows the greatest residual stress at the deepest location, along with the highest hardness value.



Hardness values near the surface for the four experimental samples, the current process, and an unpeened region. The 40-75 sample showed the highest average hardness and the unpeened sample showed the lowest average.

Presence of Cementite

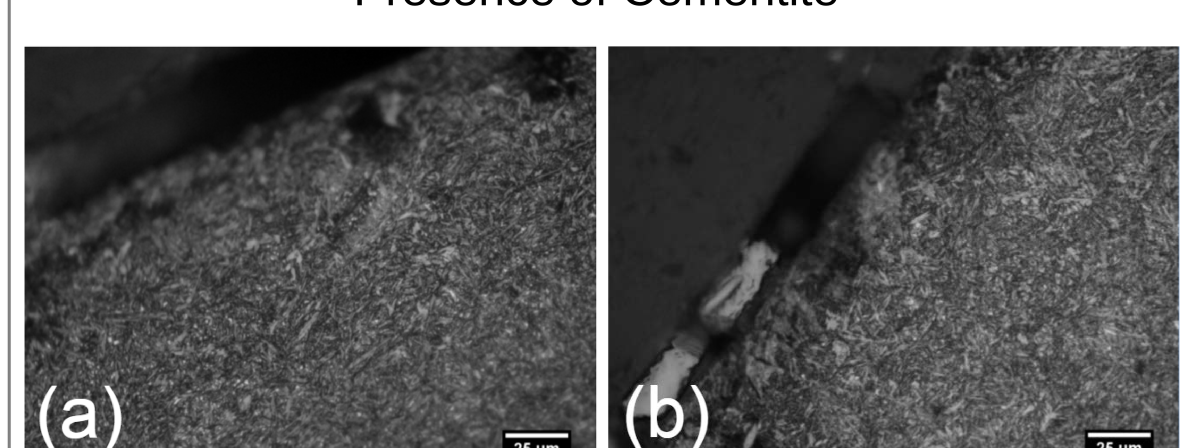


Image (a) shows the microstructure near the surface of the peened region for 40-30. Image (b) shows the same region for 40-75. All samples had microstructures comprised of tempered lath martensite. Small, semi-circular, white areas reveal the presence of cementite, more heavily present in Image (a) than in Image (b).

Cementite Volume Percentages

Current Unpeened	Current Peened	40-30	40-75	70-30	70-75
4.85	2.30	1.87	1.28	1.79	1.79

Surface Retained Austenite

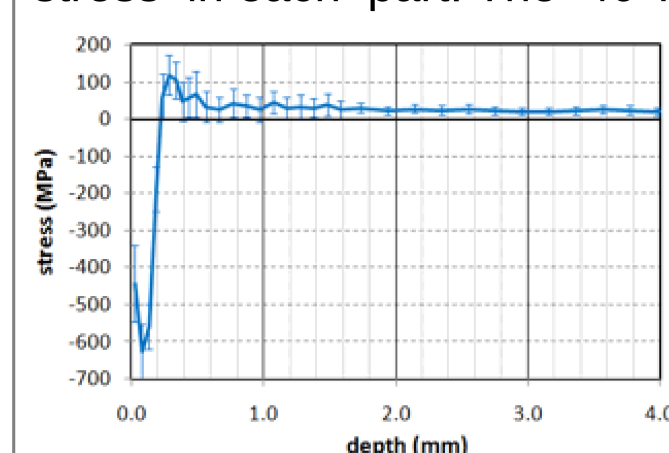
Three of the samples had similar levels of retained austenite, around 0.3 percent. The 40-30 sample had a higher level of retained austenite but was still relatively low at only 1.10 percent. This could cause a slight effect in the observed hardness and residual stress.

Retained Austenite Volume Percentages

40-30	40-75	70-30	70-75
1.10	0.27	0.25	0.33

Discussion

The below figure shows a typical residual stress depth profile for a shot peened metal. The maximum compressive stress is reached within 100 μm and then drops until a tensile residual stress is reached deeper in the part, a necessary force balance as the part is unmoving. Because we took measurements at four discrete depths, it is possible we did not accurately capture the peak compressive residual stress in each part. The 40-75 part had the largest compressive residual stress and the deepest maximum, but its third measurement was taken more shallowly than in any other sample. Because the other measurements align so closely, it seems likely that for the other three samples, the true peak compressive residual stress was missed as it occurred between the second and third measurement depths.



Residual stress depth profile for shot peened Ti-6Al-4V. Retrieved from Los Alamos National Laboratory.

The 40-30 sample had the greatest compressive residual stress at the surface at roughly -80 ksi while the other three samples were all around -60 ksi. The 40-30 sample also had a much greater compressive residual stress deeper into the part. At 0.005 inches from the surface, the residual stress in the 40-30 sample was -91 ksi while the other three samples showed residual stresses at this depth of only about -52 ksi. The 70-30 sample exhibited lower residual stress readings in two locations than any other sample. Collectively, the results demonstrate that peening with a greater velocity induced less residual stress into the part.

Near the surface, the 40-75 sample showed slightly higher hardness values overall. The 40-75 sample exhibited the least cementite at 1.28%. Its retained austenite measurements were similar to both the 70-30 and the 70-75 samples. Hardness would be expected to be lower with more cementite and more retained austenite since these are softer phases. However, there is no correlation between retained austenite and hardness supported by the data. The unpeened tooth showed on average lower hardness values than all of the other samples, demonstrating that the shot peening process does affect hardness.

Conclusions

Peening at a lower velocity produced a deeper and greater residual stress field. Our results showed it is possible to peen the part at too high a velocity, causing a negative effect on the imparted residual stress. The residual stress curves showed no peening time effect, indicating that the current process runs longer than is necessary to reach the saturation point where no additional benefit is achieved. All of the peened parts were harder than the unpeened parts, but all peened parts were not significantly different in hardness from each other.

Reference

1. Anderoglu, O. (2005). Residual stress measurement using x-ray diffraction. Master's thesis. Texas A&M University.
2. Shot peening residual stresses in Ti-6Al-4V. (n.d.). Retrieved April 20, 2016, from http://www.lanl.gov/residual/peen_ti.shtml