Effects of Shot Peening on Residual Stresses in Gear Surfaces

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 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 gauge. 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.

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.

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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.

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

<table>
<thead>
<tr>
<th>Current Unpeened</th>
<th>Current Peened</th>
<th>40-30</th>
<th>40-75</th>
<th>70-30</th>
<th>70-75</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.85</td>
<td>2.50</td>
<td>1.87</td>
<td>1.28</td>
<td>1.79</td>
<td>1.79</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>40-30</th>
<th>40-75</th>
<th>70-30</th>
<th>70-75</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.10</td>
<td>0.27</td>
<td>0.25</td>
<td>0.33</td>
</tr>
</tbody>
</table>

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 unmovimg. Because we measured 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 shallower than in any other sample. Because the other measurements align so closely, it seems likely that for true peak compressive residual stress was missed as it occurred between the second and third measurement depths.

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 the 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


MSE 430-440: Materials Processing and Design