The formation of non-transformation products and grinder burn on heat-treated steel gears is a serious problem for John Deere. These defects reduce hardness, residual compressive stresses and fatigue life, increasing scrap costs. John Deere has suggested shot peening as a possible way to restore mechanical properties. Shot peening induces compressive residual stress into the gears, potentially undoing the damage caused by grinder burn. Residual stress, metallography and microhardness measurements were conducted on gear samples provided by John Deere in order to recommend whether or not John Deere should pursue the shot peening approach.

Project Background

This work provides an analysis and evaluation of the non-transformation products, internal products, and grinder burn issues that John Deere is experiencing as a result of current heat treatment and finish machining. A carburizing heat treatment is applied to the 8620 steel gears in order to create a hard outer martensitic surface while retaining a tough pearlitic core (Fig. 1). Quenching after carburization produces a compressive residual stress profile that improves fatigue life and minimizes crack propagation.

During the carburization heat treatment process, softer non-transformation products (NTP) are sometimes formed on the gear surface. This NTP layer is thought to result from de-alloying during carburization. If any NTP affected zone measures deeper than 25 \( \mu m \), the part is scrapped.

Grinder burn occurs during finish grinding and can over-temper or re-harden the surface, depending on severity. This results in an inhomogeneous surface with hard and soft spots, making the tooth vulnerable to failure in bending. Burned areas are detected using an acid etching process and present themselves as black streaks. The darker that a streak comes through, the more intense is the burn. John Deere uses a gradient scale to pass or reject burned gears.

Shot peening is being implemented in an attempt to rectify lost residual stress and surface hardness. Shot peening imparts compressive residual stress into the parts by plastically deforming the surface via the shot media impacts.

Experimental Procedure

Gears affected by NTP development and grinder burn were sectioned and prepared for X-ray diffraction testing, optical microscopy, and Vickers hardness measurements.

An audit part with previous residual stress measurement history was used to verify XRD machine capability. A surface profile along the length of the grinder burn (red line in Fig. 12) was created on both the base grinded part and the subsequently shot peened part. A depth profile was also taken from 0-200 \( \mu m \) depth at the middle of the burn.

Vickers hardness and optical microscopy were used to verify levels of NTP and grinder burn. Cross-sections were cut to measure the depth and hardness of each area. Surface hardness was also measured along the surface of the burn part.

Non-Transformation Products

Optical microscopy and residual stress and hardness measurements were performed on a set of shot peened and non-shot peened poor microstructure gears. As shown in Fig. 8, the greatest amount of NTP was found near the 30\(^\circ\) offset location (Fig. 7).

Table: Non-Transformation Products

<table>
<thead>
<tr>
<th>Gear Type</th>
<th>Non-Peened</th>
<th>Peened</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness (HRC)</td>
<td>21</td>
<td>35</td>
</tr>
<tr>
<td>Peen Depth (( \mu m ))</td>
<td>15</td>
<td>25</td>
</tr>
</tbody>
</table>

Results & Discussion

Application of shot peening was able to improve the internal stress state and recover some of its hardness lost due to NTP layer formation at the surface. The application of shot peening introduced up to 1400 MPa of compressive residual stress into the surface of the gear. The effect of shot peening on residual stress and hardness decreases as depth increases, and is negligible beyond a depth of 220 \( \mu m \).

Grinder Burn

A severe grinder burn region was selected by visual inspection and measurements were taken along the burned area. The average surface hardness of a shot peened tooth was shown to be higher than a non-shot peened. Figure 13 shows a clear surface hardness difference between shot peened and non-shot peened teeth. The greatest post-peen hardness difference presented itself in the burned zone. This shows that shot peening cannot fully recover lost surface hardness in the grinder burn region.

After grinder burn, it was expect to see high tensile stress in non-shot peened and compressive stress in shot peened. In Fig. 14, the non-shot peened part still has lower compressive stress. Surface residual stress of the shot peened part shows significantly higher residual stress compared to non-shot peened. It shows application of shot peening was able to recover a large amount of lost compressive residual stress on the grinder burn surface.

Non-peened grinder burn shows that it lost significant residual stress after being burned but it still keeps lower compressive stress and does not go up to tensile stress. Residual stress profiles (Fig. 15) show development of tensile stress near surface after grinder burn. It shows how the application of shot peening is able to recover the residual stress lost from burning.

Recommendations

Our team recommends that John Deere further pursue shot peening as a countermeasure to offset the negative effects of excessive surface NTP and grinder burn. Additionally, we suggest more testing to be done to establish a correlation between residual stress recovery and a non-destructive testing method such as Barkhausen Noise.

Future Work

Further work should be performed to verify the efficacy of shot peening in residual stress recovery. An increased and varied sample volume in XRD residual stress testing and subsequent fatigue testing should be performed to verify applicability of results to all products subject to remediation. Analysis can be used to provide in-line quality assurance.