Neutron diffraction studies of residual stresses around gouges and gouged dents
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The residual stress pattern surrounding gouges and gouged dents in oil and gas transmission pipelines is complex and difficult to model. Measurement of these residual stress distributions provides useful data for evaluating fitness for service and also model validation. Neutron diffraction (ND) is the only experimental method capable of directly evaluating residual strain throughout the entire thickness of a pipe wall, in and around dented or gouged regions. In a previous work at Chalk River NRU reactor\(^1\), ND residual strain measurements were made on GdF Suez pipe sections BEA154, BEA159 and BEA179 as part of a comprehensive collaborative project co-funded by the US Department of Transportation Pipeline Hazardous Materials Safety Administration (US DOT PHMSA) and the Pipeline Research Council International (PRCI). The present work is in continuation to the previous work and includes three vintage pipe sections, BEA214, BEA215, and BEA211. A description of the defects on these pipe sections along with the steel grade is included in Table 1. The samples BEA214 and BEA215 are sections from X63 grade pipe of diameter 24 inch and the sample BEA211 is from X52 grade pipe of diameter 26 inch. The sample BEA214 was created under “high impact” dynamic conditions, using the GdF Suez Pipeline Aggression Rig\(^1\) (PAR), whereas the samples BEA215 and BEA211 were created under slow dynamic condition with the PAR pressing a gouging tool into the surface and dragging it axially along the pipe wall. Due to limitation of time, only the samples BEA214 and BEA215 were investigated at CNBC; the sample BEA211 was sent to NIST, US.

Measurements were taken at a number of locations corresponding to the red dots (see Figures 1 and 2 for BEA214 and BEA215 gouged sections respectively). At each location stresses were determined at five different depths from the outer surface. From these measurements numerous residual stress plots were constructed, such as the axial and hoop stress variation along the gouge centerline, as seen in the lower two plots of Figure 1 and 2. For BEA214 defect, both the axial and hoop stresses depict almost similar variations along the centerline. They are mainly tensile in the top layers and compressive in the bottom layers. The highly deformed region near the left end of the gouge has complex stress pattern. The nature of stresses is, however, different for BEA215, which is a more severe defect than BEA214. In this case, the stresses are mainly compressive except for the thin layer near the surface.

In summary, the previous as well as the current work on gouges reveals that the moderate gouges have similar residual stress patterns – moderate tensile outer wall, high compression inner wall. The pipe grade affects the magnitude of the stresses. The severe gouge is different, however – one type of stresses may dominate the other through the thickness.

\(^1\) http://cins.ca/docs/exp_rep/CNBC-2012-MS-1.pdf
Table 1: A summary of the gouge defects examined

<table>
<thead>
<tr>
<th>Defect</th>
<th>Pipe grade</th>
<th>Gouge type (% depth)</th>
<th>Dent type (% depth)</th>
<th>Defect production method</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEA214</td>
<td>Vintage X63</td>
<td>23% medium</td>
<td>1% shallow</td>
<td>Dynamic</td>
<td>Length 380 mm, diameter 24 inch. Done at CNBC.</td>
</tr>
<tr>
<td>BEA215</td>
<td>Vintage X63</td>
<td>18% small to medium</td>
<td>5.1% severe</td>
<td>Slow dynamic</td>
<td>Length 560 mm, diameter 24 inch. Done at CNBC.</td>
</tr>
<tr>
<td>BEA211</td>
<td>Vintage X52</td>
<td>23% medium</td>
<td>5.1% severe</td>
<td>Slow dynamic</td>
<td>Length 520 mm, diameter 26 inch. Sent to NIST.</td>
</tr>
</tbody>
</table>
Figure 1: BEA214 gouge on X63 vintage pipeline section (top); Axial stresses along the center line for (hoop = 0 mm) at five different depths (middle); Hoop stresses at the same locations as above (bottom).
Figure 2: BEA215 gouge on X63 vintage pipeline section (top); Axial stresses along the center line for (hoop = 0 mm) at five different depths (middle); Hoop stresses at the same locations as above (bottom).