Cracked samples for visual testing

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SUMMARY

Fortum uses visual inspection techniques in in-service inspection of reactor pressure vessel interior and internals. These inspections are performed by Fortum together with Diakont (Russia). In order to assess the performance of the inspections, a set of representative cracked samples were developed and manufactured by Fortum Nuclear Services and Trueflaw Ltd. These samples were inspected by Diakont.

Representative cracked samples with representative surface roughness, oxide layer, crack morphology and different crack openings were successfully manufactured in the project. The inspection of the samples proved challenging due to the surface roughness, crack propagation following the roughness and very small opening of the cracks in the plates inspected.

The inspection indicated, that the visual inspection technology of Diakont, used for the inspection has very high resolution and was able to detect some of the cracks despite the crack opening being below the detection limit given, and despite the inspection challenges described above.

The project was financed by Fortum Nuclear Services.
1 INTRODUCTION

Fortum uses visual inspection techniques in in-service inspection of reactor pressure vessel interior and internals. These inspections are performed by Fortum together with Diakont (Russia). In order to assess the performance of the inspections, a set of representative cracked samples were developed and manufactured by Fortum Nuclear Services and Trueflaw Ltd. Two of these samples were visually inspected by Diakont.

2 SAMPLE MANUFACTURING

Totally five samples were manufactured from stainless steel plate. The sample geometry is presented in Appendix 1. The samples were marked, mounting holes were drilled to them and a scale drawn.

To simulate the rough grinded surface (grinding stone) of reactor pressure vessel inner wall, the samples were treated with manual angle grinding. Grinding tests were performed using different grinding tools (Table 1). The grinding was performed by Fortum Nuclear Services.

Table 1. Grinding test result.

<table>
<thead>
<tr>
<th>Image</th>
<th>Code and Grinding method</th>
</tr>
</thead>
</table>
| ![Grinding 1](image1.png) | Grinding 1  
Lamellar flap disc, 40 grit  
TYROLIT ZA40-B, 27LAM125-22.2 |
| ![Grinding 2](image2.png) | Grinding 2  
Rough grinding wheel  
TYROLIT A30S-BFX, 27E-125*4*22.2 |
| ![Grinding 3](image3.png) | Grinding 3  
Rough grinding wheel  
TYROLIT A30Gu-BF06, 27E0609, 125*7*22.2 |
<table>
<thead>
<tr>
<th>Grinding</th>
<th>Description</th>
</tr>
</thead>
</table>
| 4        | Fiber disc, 24 grit  
          | FESTO, ø115 |
| 5        | Fiber disc, 80 grit  
          | FESTO, ø115 |
| 6        | Grinding stone  
          | ø150*20*ø16 |
| 7        | Laminar flap disc, 80 grit  
          | Klingspor SMT626, ø125-22.2 |
| 8        | Tape grinding, 80 grit |
The rough surface of grinding 6 was selected as the most representative and used for the cracked samples. During grinding, some areas were grinded more heavily to form a slight grinding pit so as to simulate repair grindings on the pressure vessel.

2.1 Flaw manufacturing

Flaws were manufactured by three different techniques. Fortum Nuclear Services welded solidification cracks and weld-implanted fatigue cracks into the samples prior to grinding.

Trueflaw manufactured smaller cracks to the samples by thermal fatigue. These cracks were produced after grinding and followed the grinding scratches on the surface. Consequently, they are considerably more difficult to detect by visual inspection.

After manufacturing, the crack openings of all the flaws were altered by thermal loading by Trueflaw Ltd. The aim was to get representative selection of crack openings to the samples. The resulting crack opening distribution is presented in Figure 1.

Figure 1. Crack opening distribution.

After flaw manufacturing, the samples were oxidized to get a representative black magnetite layer similar to the surface present in the reactor pressure vessel. Finished and oxidized sample is shown in Figure 2.
Due to improper cleaning of the samples prior to oxidizing treatment, some of the cracks were not oxidized properly and the clearly visible artifacts of oxidize-free areas were created during oxidizing. Consequently, some of the samples will need to be re-grinded and oxidized and could not be used within the present study due to tight timetable.

3 VISUAL INSPECTION

Two of the sample plates were lowered into the fuel basket well during the outage 2004 at Loviisa NPP, unit 1. Samples were then inspected visually by Diakont as part of the internal inspection of fuel basket performed during the outage. Currently the two plates are contaminated and will remain at Loviisa power plant.

3.1 Description of the Inspection Method and Equipment

Diakont radiation tolerant STS-K-78P TV inspection system (Figure 3) was used for the inspection. Main features of the system include:
- high speed of inspection up to 150 mm/s;
- guaranteed revealing of defects with opening from 0.1 mm (lower detection limit up to 0.04 mm is possible depending on speed of inspection and transparency of water);
- sizing of objects (length and width) with certified accuracy;
- inspection in areas with dose rate up to $3 \times 10^5$ rads/h;
- digital database of inspected surface images.
TV Inspection System STS-K-78P includes laser holographic probe that enables measuring of defects. The probe was not used for the current inspection as no measurement of defects was required. TV camera of STS-78P system scanned the surface of test sample by means of fuel handling machine mast. Approximate scanning speed was 20 mm/sec. Used picture frame size was 60x45 mm. Each test sample was scanned in 5 horizontal rows with about 10% overlapping.

Images were recorded in dynamic mode of inspection on the archiving computer of the STS-K-78P system and were viewed on the viewing computer at the same time. Diakont inspector viewed the images and identified defects. After recording and viewing the images, the camera returned to few positions of estimated defects in static mode of inspection. Optical and electronic zoom were used. Frame sizes were 24x18 mm and 12x9 mm.

Diakont TV inspection system STS-K-78P completely meets the requirements of valid Russian regulations on visual inspection, including RD-EO 0079-97 "TV inspection at nuclear power plants. General requirement", approved by Russian Federal Nuclear Regulatory Service (GAN RF).

3.2 Results

The inspection revealed caverns (cavities), discontinuity flaw on grindings and suspicion upon cracks. The rough surface grinding made the visual inspection rather difficult.

The results of the inspection are presented in Table 2. Frames showing the identified suspicion upon cracks are shown in Figures 4 – 5.

Table 2. Grinding test result.

<table>
<thead>
<tr>
<th>Frame Number</th>
<th>Operator information</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>131449</td>
<td>TRF 1 sample, 1st row</td>
<td>Caverns 1.32x0.44 mm and diameter of 0.4 mm on grinding</td>
</tr>
<tr>
<td>131317</td>
<td>TRF 1 sample, 2nd row</td>
<td>Defect 0.2x2 mm on grinding</td>
</tr>
<tr>
<td>Frame Number</td>
<td>Sample Type</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>131343</td>
<td>TRF 1 sample, 2nd row</td>
<td>Defect 0.25x2.95 mm on grinding</td>
</tr>
<tr>
<td>131397</td>
<td>TRF 1 sample, 4th row</td>
<td><strong>Suspicion upon crack 0.16x6.6 mm</strong></td>
</tr>
<tr>
<td>131459</td>
<td>TRF 1 sample, 4th row</td>
<td>Caverns 2x2.6 mm and 2.5x1.4 mm</td>
</tr>
<tr>
<td>131435</td>
<td>TRF 1 sample, 5th row</td>
<td>Caverns 1.8x3 mm and 1.2x2.4 mm</td>
</tr>
<tr>
<td>131063</td>
<td>TRF 2 sample, 2nd row</td>
<td>Cavern 1.26x2.35 mm</td>
</tr>
<tr>
<td>131136</td>
<td>TRF 2 sample, 3rd row</td>
<td><strong>Suspicion upon crack 0.17x3.6 mm on grinding</strong></td>
</tr>
<tr>
<td>131462</td>
<td>TRF 2 sample, 5th row</td>
<td>Cavern with diameter of 1.0 mm</td>
</tr>
<tr>
<td>131267</td>
<td>TRF 2 sample, 5th row</td>
<td>Cavern with diameter of 0.6 mm</td>
</tr>
<tr>
<td>131273</td>
<td>TRF 2 sample, 5th row</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. Frame 131459 showing crack in TRF 1.

Figure 5. Frame 131462 showing crack in TRF 2.
3.3 Diakont Comments Regarding TRF1 and TRF2 samples

The manufactured samples and flaws fully represent the true wall of reactor pressure vessel after grinding during repair works. Due to the roughness of surface, it is very difficult to reveal defects that appear after grinding. The black oxide layer on the samples is very similar to the true surface of reactor pressure vessels.

However, the real wall without mechanical treatment is much less rough, especially the reactor wall with corrosion resistant cladding. Besides, not only single cracks, but also grids of cracks may appear on the reactor vessel walls with corrosion resistant cladding according to experience of inspections of such reactors. However, cracks revealed are very similar to the cracks Diakont inspectors met in practice.

4 DISCUSSION

The inspected samples with the rough grinded surface and very tight flaws following the grinding scratches presented a very challenging inspection target. The rough surface was chosen to simulate actual grinding marks on reactor pressure vessel. These rough grindings present a preferred initiation site for the service induced cracks postulated, and thus the choice of surface roughness is well grounded.

An other factor contributing considerably to the detectability of the cracks was the fact, that the cracks initiated from and followed the grinding markings. This is also the expected behavior of the postulated service induced cracks and the behavior can be considered representative.

The crack openings in the samples inspected are below the detection limit reported by Diakont. Thus the crack openings can be considered too small for proper assessment of the inspection capabilities.

The crack distribution present in the samples TRF 1 and TRF 2 inspected by Diakont is presented in Figure 6. The crack openings present in the samples are lower than the detection limit of 0.1 mm given by Diakont. However, Diakont was able to detect two of the cracks in the samples. Considering the small opening and other factors discussed, this can be considered to be quite good achievement and shows the very high capability of the Diakont inspection technology. It should be noted, however, that both of the detected cracks were located at grinding pits described above. These areas had slightly lower surface roughness and the direction of the grinding markings is different. Consequently these areas may have drawn more attention than the rest of the sample and the detection of the cracks may be easier.
5 CONCLUSIONS

The following conclusions can be drawn from the study:

• Representative cracked samples with representative surface roughness, oxide layer, crack morphology and different crack openings were successfully manufactured.

• The inspection of the samples proved challenging due to the representative surface roughness, cracks following the roughness and very small opening on the cracks.

• The inspection confirmed that the visual inspection technology of Diakont used for the inspection has very high resolution and was able to detect some of the cracks despite the crack opening being below the detection limit given and despite the inspection challenges described above.
APPENDIX 1. SAMPLE GEOMETRY

[Diagram of a rectangle with dimensions 300x200 and notations OL TRF n O Z]