Radiography of 140 mm Thick Weld- Multiple Film Technique

S.P. Srivastava, S.P. Pandarkar, K.B. Santhosh, G.P. Sahu and S.B. Jawale
Centre for Design and Manufacture

Abstract
Radiography of 140 mm thick weld joints of Low Alloy Carbon Steel Cruciform Test Specimen was a challenging task due to radiation hazard attributed to large exposure time, high energy and high strength radiation source. High thickness of steel also adds to internal scatter within the specimen, reducing the quality of radiographs. Multiple film technique, which uses more than one film of same or different speed in a single cassette, was developed for panoramic exposure of four weld joints using cobalt 60 source. The technique was able to improve the quality of the radiographs besides reducing the exposure time by one third. This paper presents the detail of multiple film technique and its role in reducing the effect of thickness variation on the image quality.

Introduction
Under the Component Integrity Test Programme, Low Alloy Carbon Steel Cruciform Test Specimen are manufactured at Centre for Design and Manufacture (CDM) for biaxial load testing as a part of studies pertaining to safety aspects of Indian Pressurised Heavy Water Reactor. Specimens are made out of ASTM 508 Low Alloy Carbon Steel (20 MoNi55) in the shape of cruciform having unequal arms each of length 3300 mm and 1900 mm. Four slabs, each 135 mm thick x 300 mm wide, are welded to a symmetrical cross having two equal arms of length 175 mm (Fig. 1). Manufacturing process includes: Cutting of centre block and arms, Machining of centre block and arms for edge preparation, Machining of notches and slots in the centre block, Welding of arms with the centre block, Radiographic testing of weld joints and Post weld heat treatment.

As per the standard practice, symmetrical double V groove was adopted for butt weld joints between arm and centre block, considering very high thickness of 135 mm of the base metal. Further, in order to limit the distortion, heat input was minimized by reducing the volume of weld deposition. This was achieved by machining the weld edge to compound bevel angles, thus making the groove narrower than the conventional groove. Ultrasonic testing (UT) was not feasible because of number of notches adjacent to the weld joint. Since radiographic testing (RT) was the only suitable NDE method for the volumetric examination of the weld, it was employed to detect lack of fusion (LOF) in the side wall, lack of penetration (LOP) at the root, porosity, crack and any other discontinuities existing in the weld. RT of thick specimen has inherent problems such as requirement of high strength source, very high internal scatter, high radiation hazard due to longer exposure time, low sensitivity for the portion away from the film. Any attempt to align the source with weld edge in order to detect lack of side wall fusion gives rise to large thickness variation demanding different exposure time for different shots. At CDM, multiple film technique for panoramic exposure was developed to radiograph all the four weld joints simultaneously. On account of reduced exposure time and less number of shots, this technique offers advantages of less radiation hazard, reduced scatter, high sensitivity and high productivity.
Selection of NDT Method

Welds, with thickness less than 50 mm, are examined by RT due to ease of interpretation and availability of image record. However, in case of RT of thick weld, radiation hazards are more due to high exposure time and high strength of radiation source required for radiography. Therefore, UT with no radiation hazard is considered a better choice for thickness 50 mm and above. Further, UT as compared to RT, gives better sensitivity for planar defects such as lack of fusion and crack. In order to detect lack of side wall fusion, welds are subjected to ultrasonic testing using angle beam technique. Particularly for thick weld, obstacle free large scanning area on both sides of the weld shall be available so that sound beam hits the side wall at zero degree angle of incidence for better detectability of LOF. In this case, due to presence of slots in the scanning area UT was difficult, hence RT was considered suitable NDT method for volumetric examination of the weld.

Theoretical Considerations for RT of Thick Weld

In RT, direction of radiation beam with respect to the orientation of the flaw plays an important role for the flaw detectability. If the central beam is aligned with the major dimension of the flaw, the probability of flaw detection is very high. In groove weld, side wall and root are more vulnerable as far as defect is concerned. Radiographic shooting sketch (RSS) for butt weld with double V groove is shown in the Fig. 2. For single V groove weld having
thickness less than 10 mm, even source at S1, aligned with root position can detect LOP in the root and LOF in the side wall as well. However, as the thickness increases, three different shots with source positions S1, S2a and S3a are required in order to detect LOP at root and LOF at each face. Object away from the film produces large geometrical unsharpness and therefore image of the weld groove which is away from the film will not be discernable, if thickness of the weld is more than 80 mm. Hence, beyond 80 mm thickness it is required to take shot from both sides of the weld, if accessible, to limit the unsharpness. Source positions S2a, S3a, S2b, and S3b are suitable for detecting LOF in walls GH, CD, EF and AB respectively. In case of cruciform, since the weld metal thickness including reinforcement was 140 mm similar shooting scheme was adopted for full volumetric examination of the weld.

Multiple Film Technique- Theoretical Aspects

In multiple film technique of radiographic testing, two or more films kept in close contact, are exposed together either to cover the varying thicknesses of the component or to reduce the exposure time. Films in combination may be either of same speed or different speed depending upon the requirement. In case of component of varying thicknesses, to improve the latitude i.e. range of thicknesses covered on the radiograph within acceptable density range of 1.0 to 3.5, combination of fast and slow film is exposed together and each film is viewed separately. Fast film records thicker portion whereas slow film gives the detail of thinner portion.

In the second case, in order to reduce the exposure time, normally applicable for very thick job, two films of the same speed are exposed together which reduces the exposure time by one half. Combination of these films, when viewed separately will not meet density range of 1.0 – 3.5 individually and therefore will not reveal any detail. Such exposed films are viewed together i.e. by super imposing one on another in front of the viewing illuminator. The combined density of two films shall meet the density range of 1.3-4.0. In the technique developed at CDM in total two pairs of film were used, as explained in the subsequent paragraph, to get the advantage of both improved latitude and reduced exposure time.

Radiographic Testing of Weld Joints of Cruciform

Weld groove for butt joint in 300x135 mm cross section consists of symmetrical double V with 2 mm root land. Each V groove, includes two bevel angles; first one 75° starting from root up to 20 mm height and second one 24° starting from 20 mm up to 47.5 mm height (Fig. 3). Qualified welding procedure specification (WPS) and qualified welders were used for welding. All weld edges were checked for presence of any lamination by liquid penetrant test (PT). Root was fused by GTAW, and remaining weld was deposited by SMAW process. Pre-heating, with inter pass weld temperature control was done to avoid the formation of martensite and to prevent hydrogen induced cracks. Post weld heat treatment

Fig. 2: RSS of double V butt weld in plate having thickness 80 mm or more

Fig. 3: Weld groove configuration
was adopted basically for stress relieving. Root pass welding and inter stage welding were subjected to RT and PT to detect any gross defect whose elimination after final pass requires lot of material removal by grinding process.

In order to detect lack of fusion in the side wall each weld joint in each arm requires at least five shots- one straight and four inclined shoots, two from each face. Though thickness penetrated in straight shot is 140 mm, interpretation is carried out only for half the thickness i.e. 70 mm of the weld which is closer to the film. Straight shot (SS) in which source and film are kept at SS1 and F1 respectively (Fig. 4), the total volume covered, is $ABCD \times 300 \text{ mm}^3$ (Fig. 3). In this shot, because of its diverging nature, penetrating radiation is more or less parallel to faces AB and CD which are inclined at 12° with the vertical. Therefore, these shots are suitable for detecting any LOF in faces AB & CD and LOP at the root CO. Similarly by keeping source at SS2 volume MNOPQ can be examined with high degree of confidence for detecting LOP in faces MN and PQ.

Since faces BC (or CD) and NO (or OP) are inclined at 37° with the vertical and job thickness is more than 80 mm, to increase the probability for detecting LOF, it is necessary to take another radiograph with source in offset position, such that radiation beam is parallel to these walls. This requires two inclined shots with source at an angle with respect to weld axis WW’. Considering the symmetricity of all the welds in each arm with respect to central axis XX’, it was decided to use panoramic shot (PS) to radiograph the four weld joints simultaneously in one shot, in order to reduce the total exposure time. In this set up, source is required to be positioned either at PS1 or PS2 on the central axis XX’ of the cruciform such that the source to film distance (SFD) remains same for all the four weld joints with beam parallel to the walls inclined at 37° with the vertical.

**Use of Multiple Film Technique for RT of Cruciform**

**Straight Shot:** For straight shot with source at SS1 and film at F1 (Fig. 4), multiple film technique was used in which two films of same speed loaded in the same cassette were exposed to half the exposure time required for single film. Such exposed films were viewed together i.e. by superimposing one on another in front of the viewing illuminator. Since penetrantometer was kept on full thickness, minimum SFD obtained by Equation 1 (Table 1) for $T = 140 \text{ mm}, u_g = 1.7 \text{ mm}$ and $\varphi = 7.5 \text{ mm}$ was 950 mm. During radiography, actual SFD was increased to 1100mm to minimize the divergence of the beam with respect to the face AB or DE. Exposure time for D7 single film using 40 curie cobalt source was estimated to 6 hour.

**Inclined and Panoramic Exposure:** Thickness across the weld cross section, seen by the radiation beam is different, because of the inclination and therefore it becomes essential to use multiple film to accommodate variation of optical density within acceptable limit. Radiographic setup for the panoramic exposure is shown in the Fig. 5. With its entire arm in horizontal plane, cruciform was kept above the source to take advantage of the shielding during panoramic exposure.

Ray diagram, using AutoCAD was prepared to know the source position, source to film distance and thickness variation for a set up which will give
adequate coverage of the weld with central beam parallel to face BC. Values of geometrical unsharpness were calculated using Equation 1 for three SFDs and thicknesses as shown in the Fig. 6. From the results of several iterations, with varying SFD and thickness, it was observed that for source at 600 mm, gamma ray from a point source was parallel to the face BC within 6° and geometrical unsharpness was within the limit.

For source at 600 mm below the top surface of the cruciform on vertical axis XX', thickness, angle, and SFD with exposure time for each combination, are tabulated in Table 2. Exposure time were calculated using Equation 2, which is basically applicable to narrow beam geometry and is meant only as a guide for knowing approximate exposure time. Actual exposure time is established by trials rather than formula as it depends on the accuracies of many variables such as source size and its strength, SFD, film processing time/condition, scatter radiation etc. For very thick specimen actual exposure time is less than the calculated one, due to internal scatter contributed by the specimen itself. During trial shot, using fast film Agfa D7, it was observed that even with low exposure time, film density for the thickness

![Fig. 6: Ray diagram for panoramic exposure using multiple film](image)

### Table 1: Formula

<table>
<thead>
<tr>
<th>Calculation of SFD, based on ( \eta_g )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( SFD = T \left(1 + \frac{T}{\eta_g}\right) ) --- (Equation 1)</td>
</tr>
</tbody>
</table>

- \( SFD \) – Source to film distance,
- \( T \) – Thickness penetrated,
- \( \eta_g \) – Geometrical unsharpness
  - < 1.7 mm, for \( T < 100 \) mm
- \( \eta_p \) – Effective source size
  - \( = \sqrt{d^2 + l^2} \)
- \( d \) and \( l \) are diameter and length of a cylindrical source.

### Table 2: Exposure Time

<table>
<thead>
<tr>
<th>SFD (mm)</th>
<th>Thickness (mm)</th>
<th>Angle with vertical</th>
<th>Time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFD=671</td>
<td>T=151</td>
<td>0°, 26.5°</td>
<td>t=3.9</td>
</tr>
<tr>
<td>SFD=702</td>
<td>T=158</td>
<td>0°, 31.4°</td>
<td>t=5.6</td>
</tr>
<tr>
<td>SFD=714</td>
<td>T=161</td>
<td>0°, 32.8°</td>
<td>t=6.2</td>
</tr>
</tbody>
</table>

![Fig. 5: Set up for panoramic exposure](image)
Ta and SFDa, was on higher side and therefore to offset this, slow film Agfa D4 was considered a better option as compared to Agfa D7 film.

To reduce the exposure time, combination of fast (D7) and slow (D4) films was found suitable for lower thickness region ‘Ta’, whereas combination of two fast films (D7) were adequate for higher thickness regions ‘Tb’ and ‘Tc’. To take care of the continuous variation in the thickness and for the continuity of the weld image, one large size D7 film, overlapping the total thickness range was used. All the three films with their relative positions, were loaded in a single cassette. Film were exposed for 3 hours 30 minutes, which is approximately one half the maximum exposure time Tb = 6 hours 12 minutes and greater than the half of the minimum exposure time i.e. 3.9/2 hours.

Tungsten arrow markers were placed on the film as well source side to show the coverage of the weld width and projection of the source side weld image on the film. In total three image quality indicators (IQI), two for source side and one for film side were placed to check the adequacy of the image quality.

**Interpretation of Multiple Films**

During interpretation of radiographs, two D7 films were viewed together for thicknesses ‘Tb’ and ‘Tc’. For thickness ‘Ta’, because of adequate density only one film either D7 or D4 can be viewed individually, however, if D7 and D4 are viewed together, better perception of the IQI image is obtained. As per the ASME requirements, image of the 4T hole in 60 number plate type IQI was seen when both the films were viewed together. In addition to plate type IQI, wire type IQI No.1 ISO 7 (DIN) was also used, for which 5th wire image was seen. Weld at intermediate stage having thickness of 110mm was radiographed using two films of same speed at half the exposure time required for single film. Fig. 7 and Fig. 8 are radiographic images of single film and superimposed double film respectively. On single film, with optical density 1.63, even image of the fourth wire of a wire type penetrameter is not seen clearly, whereas two films superimposed and viewed together is able to reveal well defined image of the fifth wire and slightly faint indication of the sixth wire. Besides wire, images of letter B and J4 are clearly seen in Fig. 8.

**Table 3: Comparison between single and multiple film technique**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Exposure Type</th>
<th>Source Position</th>
<th>Shots per arm</th>
<th>Time per shot (hour)</th>
<th>Shots for four arms</th>
<th>Total Time (hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SS1 &amp; SS2</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>48</td>
</tr>
<tr>
<td>1.</td>
<td>Directional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>2.</td>
<td>Directional</td>
<td>PS1 &amp; PS2</td>
<td>2</td>
<td>6.2</td>
<td>8</td>
<td>49.6</td>
</tr>
<tr>
<td>3.8</td>
<td>Panoramicr</td>
<td>PS1 &amp; PS2</td>
<td>2</td>
<td>6.2</td>
<td>2</td>
<td>12.4</td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.2</td>
</tr>
</tbody>
</table>
Conclusions

Radiography of thick weld requires proper planning to take care of flaw detectability, scatter radiation, high exposure time, large value of unsharpness, shielding to reduce the radiation hazard, IQI sensitivity etc. At CDM, multiple film technique was developed to address these problems. Review of exposure time (Table 3) indicates that total exposure time for four welds of a cruciform is 97 hour when single film is used with directional exposure. Whereas time for panoramic exposure combined with multiple film technique is only 30.2 hour, which is approximately one third (31%) of the total time.

Multiple film technique with panoramic exposure not only reduced the exposure time but also minimized the density variation along the composite film from one end to another end.

References