CHAPTER 6

ESTIMATION OF SOUNDNESS AND WEAR PROPERTIES OF STAINLESS STEEL CLADDINGS

6.1 INTRODUCTION

Claddings are tested to evaluate their soundness, strength and toughness by means of mechanical tests which are destructive in nature. The quality of the claddings in terms of ductility of the clad metal and HAZ are checked by means of a bend tests. Bend test visually shows the influence of welding parameters and welding conditions on the plastic properties of the clad layer and bonding between base metal and clad layer. In this chapter, details about side and face bend tests carried out to evaluate the soundness of the clad and its quality. Also, evaluation of wear resistance of the claddings using dry sliding abrasive wear test is explained.

6.2 EXPERIMENTAL PROCEDURE

6.2.1 Bend test

Four specimens of size 180 x 22 x 19 mm$^3$ were prepared from the cladded structural steel plates produced at different heat input conditions. They are placed across the supports of the die and the side bend test was conducted as per ASTM A-264 procedure to assess the bond integrity and the ductility of the claddings. A load of 10 tonnes was applied using a Universal Testing Machine (UTM) and both the side bend and face bend tests are
performed. Visual inspection was carried out on the bend tested specimens to check the presence of cracks and the nature of the bonding between clad layer and substrate.

### 6.2.2 Wear test

Six specimens of size 30 x 10 x 10 mm$^3$ prepared from the test plate cladded at different heat input and at nitrided conditions are designated and given in Table 6.1.

**Table 6.1 Designation of the wear test specimens**

<table>
<thead>
<tr>
<th>Sl. no</th>
<th>Specimen description</th>
<th>Heat input</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low heat input and nitrided</td>
<td>4.10 KJ/mm</td>
<td>LHN</td>
</tr>
<tr>
<td>2</td>
<td>Medium heat input and nitrided</td>
<td>5.54 KJ/mm</td>
<td>MHN</td>
</tr>
<tr>
<td>3</td>
<td>High heat input and nitrided</td>
<td>6.81 KJ/mm</td>
<td>HHN</td>
</tr>
<tr>
<td>4</td>
<td>Optimum heat input and nitrided</td>
<td>4.61 KJ/mm</td>
<td>OHN</td>
</tr>
<tr>
<td>5</td>
<td>Optimum heat input and non-nitrided</td>
<td>4.61 KJ/mm</td>
<td>ONNN</td>
</tr>
<tr>
<td>6</td>
<td>Base metal (substrate)</td>
<td>-</td>
<td>BM</td>
</tr>
</tbody>
</table>

All the specimens for wear test with their corresponding designations are presented in Figure 6.1.
The wear behaviour of all specimens was tested as per ASTM G-99 procedures to evaluate their wear resistance under dry sliding arrangement of the dry abrasive sliding wear conditions. The arrangement of the wear testing machine is shown in Figure 6.2.

The wear samples were polished to a roughness value less than 0.02 µm by grinding with 1000 grade SiC abrasive paper. The thickness of cladded layer after grinding and polishing was about 3 - 5 mm. The wear behaviour of the specimens were evaluated against a SiC abrasive medium of 240 grade at
a normal load of 20 N for a sliding distance of 2000 meters, as recommended for these specimens (Chatterjee and Pal 2003). The load was applied to the specimen by cantilever technique as found common in the pin on disc machine. The sample was made to slide over the abrasive paper fixed on the rotating wheel. Each test was carried out with a fresh abrasive medium up to a sliding distance of 2000 m. The decrease in height of specimen was found out and the wear rate was calculated by dividing the volume loss by sliding distance using the software available in the computer interfaced with the wear testing machine. Table 6.2 shows the recorded wear and the wear rate of the specimens.

**Table 6.2 Wear properties of claddings**

<table>
<thead>
<tr>
<th>Sl no</th>
<th>Specimen designation</th>
<th>Wear properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Wear, ( \mu m )</td>
</tr>
<tr>
<td>1</td>
<td>LHN</td>
<td>116</td>
</tr>
<tr>
<td>2</td>
<td>MHN</td>
<td>187</td>
</tr>
<tr>
<td>3</td>
<td>HHN</td>
<td>284</td>
</tr>
<tr>
<td>4</td>
<td>OHN</td>
<td>52</td>
</tr>
<tr>
<td>5</td>
<td>ONNN</td>
<td>382</td>
</tr>
<tr>
<td>6</td>
<td>BM</td>
<td>542</td>
</tr>
</tbody>
</table>

The wear tracks of samples after the completion of wear tests were studied by a Scanning Electron Microscope to understand the wear tracks under abrasive wear conditions.
6.3 RESULTS AND DISCUSSION

6.3.1 Bend test

The visual inspection of the specimen was carried out to detect crack, undulations or any other form of physical damages and irregularities present after the bend tests. The photograph of side bend test specimens is given in Figure 6.3. It is evident from Figure 6.3 that the specimens are found to be satisfactory and without any cracks or undulations indicating the good ductility of the stainless steel cladding.

![Figure 6.3 Side bend test specimens](image)

LOW HEAT INPUT SPECIMEN, (1.10 KJ/mm)

MEDIUM HEAT INPUT SPECIMEN (5.54 KJ/mm)

HIGH HEAT INPUT SPECIMEN (6.81 KJ/mm)

OPTIMUM HEAT INPUT SPECIMEN (4.61 KJ/mm)
The photograph of face bend test specimens is given in Figure 6.4. It is evident from Figure 6.4 that all the face bend test specimens are found without any cracks, undulations and material pullouts. This confirms the soundness of the joint and the good quality of bonding of the weld clad layer with the base metal.

![Figure 6.4 Face bend test specimens](image)

6.3.2 Wear of nitrided specimens cladded at different heat input conditions

The wear of nitrided specimens along with the base metal is presented in Figure 6.5. From the figure it is found that the wear of the nitrided specimen cladded at optimum heat input condition is found to be very lower than that of other specimens nitrided and cladded at different heat input conditions. The liquid nitriding contributed to the improvement of wear
resistance and the nitrided layer exhibited approximately 5-6 times increase in wear resistance. The wear of the base metal (carbon steel substrate) is found to be very high.

Figure 6.5  
Comparison of wear rates of nitrided specimens cladded at different heat input conditions

6.3.3 Wear rate of nitrided specimens cladded with different heat inputs

The wear rate of the nitrided specimens cladded with different heat input conditions along with the base metal is shown in Figure 6.6. From the figure, it is found that the wear rate of the nitrided specimen cladded at optimum heat input condition is found to be very lower than the other specimens nitrided and cladded at different heat input conditions. The wear of the base metal (carbon steel substrate) is also shown for comparison.
Figure 6.6  Comparison of wear resistance of nitrided specimens cladded at different heat input conditions

6.4 SCANNING ELECTRON MICROSCOPIC (SEM) IMAGES OF SPECIMENS CLADDED AT DIFFERENT HEAT INPUTS

It is understood that the presence of deep groove on the worn out surface of the sample indicates higher wear. The depth of abrasion scoring marks is found to be more on the wear surfaces of nitrided specimens cladded at high heat input conditions than that of specimens cladded at low and optimum heat input conditions as shown in Figure 6.7. This increased wear could be due to the higher dilution present in the high heat input overlay.
Figure 6.7 Scanning electron micrographs showing worn surfaces

Also, the scanning electron micrograph of the severely worn out surface of the low carbon steel substrate is shown in Figure 6.8 to visualise the heavy material pullout on the surface of the base material without cladding and nitriding.
LOW CARBON STEEL SUBSTRATE 
(UN CLADDED AND NON-NITRIDED) 

Figure 6.8 Scanning Electron Micrograph showing worn surface of base metal

6.5 SUMMARY

The claddings produced at optimum heat input conditions possessed good ductility compared to the other claddings. Also, the face and bend tests confirm the soundness of the joint in the cladding and their quality of bonding with the base metal.

The liquid nitrided specimen showed a substantial wear reduction during the dry sliding wear conditions. It was found that cladding produced at optimised PTAW process and nitrided conditions had improved wear resistance.