Fatigue Crack Growth Behavior of AISI 409M Grade Ferritic Stainless Steel Welded Joints Using Austenitic, Ferritic and Duplex Stainless Steel Electrodes

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(Received on April 4, 2008; accepted on August 6, 2008)

This paper reveals the fatigue crack growth behaviour of the shielded metal arc welded AISI 409M grade ferritic stainless steel joints fabricated using austenitic stainless steel (ASS), ferritic stainless steel (FSS) and duplex stainless steel (DSS) electrodes. Centre cracked tensile (CCT) specimens were prepared to evaluate fatigue crack growth behaviour. Servo hydraulic controlled fatigue testing machine with a capacity of 100 kN was used to evaluate the fatigue crack growth behaviour of the welded joints. It is found that the joints fabricated by DSS electrode showed superior fatigue crack growth resistance compared to the joints fabricated by ASS and FSS electrodes. Higher yield strength and relatively higher toughness of the weld metal may be the reasons for superior fatigue performance of the joints fabricated by DSS electrode.

KEY WORDS: ferritic stainless steel; shielded metal arc welding; fatigue crack growth behaviour; austenitic stainless steel; duplex stainless steel.

1. Introduction

Ferritic stainless steels (FSS) are used under a less severe corrosive atmosphere for chemical processing equipment, furnace parts, heat exchangers, oil burner parts, petroleum refining equipment, protection tubes, recuperates, storage vessels, electrical appliances, solar water heaters and household appliances.1) Joining of FSS is faced with the problem of grain coarsening in the weld zone and heat affected zone of fusion welds and consequent low toughness and ductility due to the absence of phase transformation during which grain refinement can occur.2) Excessive grain growth can be avoided, of course, by using lower welding heat inputs. It has also been suggested that nitride and carbide formers such as B, Al, V and Zr can be added to FSS to suppress grain growth during welding.3)

Villafuerte and Kerr4) attempted to weld FSS by gas tungsten arc (GTA) welding process and observed that approximately for constant values of heat input per unit distance, the equiaxed fraction increased with welding speed, as long as sufficient titanium and aluminum were present to form nuclease for the second phase. Mohandas et al.5) made a comparative evaluation of gas tungsten and shielded metal arc (SMA) welds of AISI 430 ferritic stainless steel and found that the greater ductility and strength of GTA welds as compared to those of SMA welds can be attributed to the equi-axed morphology of the fusion-zone grains in the GTA welds, and also to inert gas shielding. Meyers and Toit6) investigated the impact properties of 11–12% chromium steels and found that carbon and nitrogen affect the impact properties of the heat-affected zone in these steels. Silva et al.7) investigated the microstructural characteristics of the HAZ in AISI 444 ferritic stainless steel and reported that needle-like Laves phase precipitation occurred in the HAZ, near the partially-melted zone and other secondary phases such as \( \chi \) and \( \sigma \) were also observed, as well as nitride, carbide and carbonitride precipitates.

Most of the reported literature focused on effect of welding processes on fusion zone microstructure, tensile and impact properties. But the published information on fatigue crack growth behaviour of welded FSS joints is very scant.8) Hence, the present investigation was carried out to understand the fatigue crack growth behaviour of SMA welded FSS joints fabricated using three different electrodes such as austenitic, ferritic and duplex stainless steels.

2. Experimental

The rolled plates of 4 mm thickness AISI 409M grade ferritic stainless steel were machined to the required dimension (300×150 mm). The initial joint configuration was obtained by securing the plates in position using tack welding. Single ‘V’ butt joints were fabricated using SMAW process with austenitic stainless steel (ASS), ferritic stainless steel (FSS) and duplex stainless steel (DSS) electrodes. Necessary care was taken to avoid joint distortion and the joints were made with applying clamping devices. The welding conditions and process parameters used to fabricate the joints are given in Table 1. The soundness of welded joints was checked using ultrasonic testing. The chemical compo-
sition of the base metal and weld metals was obtained using a vacuum spectrometer (ARL-Model: 3460). Sparks were ignited at various locations of the samples and their spectrum was analysed for the estimation of alloying elements. The chemical composition of the base metal and weld metals in mass percent are given in Table 2.

The welded joints were sliced using power hacksaw and then machined to the required dimensions for preparing tensile, impact and fatigue test specimens as shown in Fig. 1. Tensile test was conducted in 100 kN, electro-mechanical controlled Universal Testing Machine (Make: FIE-BLUE STAR, India; Model: UNITEK-94100). ASTM E8M-04 guidelines were followed for preparing and testing the tensile specimens. Since the plate thickness is small, subsize impact specimens were prepared. Impact test was conducted at room temperature using pendulum type impact testing machine (Make: ENKA Y, India) with a maximum capacity of 30 J. ASTM E23-04 specifications were followed for preparing and testing the specimens.

Vickers microhardness testing machine (Make: Shimadzu, Japan and Model: HMV-2T) was employed for measuring the hardness of the weld with 0.5 kg load. Microstructural examination was carried out using a light optical microscope (Make: MEJI, Japan; Model: MIL-7100) incorporated with an image analyzing software (Metal vision). The specimens for metallographic examination were sectioned to the required size from the joint comprising fusion zone region and were polished using different grades of emery papers. Final polishing was done using the diamond compound (1 μm particle size) in the disc polishing machine. The specimens were etched with 5 mL hydrochloric acid, 1 g picric acid and 100 mL methanol applied for 10–15 s.

For centre cracked tensile (CCT) specimen, the sharp notch (5 mm length and 0.05 mm tip radius) was machined in the middle of the fusion zone region using the wire-cut electric-discharge machining (WEDM) process. Procedures prescribed by the ASTM E647-04 (ASTM, 2004) standard were followed for the preparation of the specimens. Fatigue crack growth experiment was conducted using a servo hydraulic, 100 kN universal testing machine. A frequency of 20 Hz under constant amplitude loading (R = 0) was used for all fatigue tests. Before loading, the specimen surface near the notch was polished to facilitate fatigue crack growth measurement. A traveling microscope with an accuracy of 0.01 mm was used to monitor the crack length. The specimen was loaded at a particular stress level (range), and following crack initiation from the tip of the machined notch, its subsequent propagation into the weld metal was recorded from initiation to the complete failure of the specimen. Similar crack growth experiments were conducted on a number of specimens at various stress levels, and the experimental data were recorded. The fractured surface of the fatigue tested specimens was analysed using scanning electron microscope (Make: JEOL, Japan; Model: 6410LV) at higher magnification to study the fracture morphology to establish the nature of the fracture.

### 3. Results

#### 3.1. Tensile and Impact Properties

Transverse tensile properties such as yield strength, tensile strength and percentage of elongation of the joints were evaluated. In each condition, three specimens were tested, and the average of three results is presented in Table 3. Of the three joints, SMADSS (fabricated by DSS electrode) joint exhibited higher strength values, and the enhancement in strength value is approximately 14% compared to SMAASS (fabricated by ASS electrode) joint and 6% compared to SMAFSS (fabricated by FSS electrode) joint. Charpy impact toughness values of all the joints were evaluated and they are presented in Table 3. Of the three joints, the SMAASS joint exhibited higher impact toughness val-

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### Table 1. Welding conditions and process parameters.

<table>
<thead>
<tr>
<th>Material</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>Ti</th>
<th>Mo</th>
<th>Cu</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Metal</td>
<td>0.028</td>
<td>1.10</td>
<td>0.030</td>
<td>0.010</td>
<td>0.40</td>
<td>10.90</td>
<td>0.39</td>
<td>0.004</td>
<td>--</td>
<td>Bal.</td>
</tr>
<tr>
<td>SMAASS</td>
<td>0.035</td>
<td>0.82</td>
<td>0.018</td>
<td>0.015</td>
<td>0.67</td>
<td>19.00</td>
<td>11.00</td>
<td>--</td>
<td>0.01</td>
<td>0.1</td>
</tr>
<tr>
<td>SMAFSS</td>
<td>0.075</td>
<td>0.70</td>
<td>0.017</td>
<td>0.014</td>
<td>0.60</td>
<td>17.00</td>
<td>0.40</td>
<td>--</td>
<td>--</td>
<td>Bal.</td>
</tr>
<tr>
<td>SMADSS</td>
<td>0.030</td>
<td>0.80</td>
<td>0.018</td>
<td>0.016</td>
<td>0.80</td>
<td>22.00</td>
<td>9.00</td>
<td>--</td>
<td>3.00</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

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### Table 2. Chemical composition of base metal and weld metals.

<table>
<thead>
<tr>
<th>Material</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>Ti</th>
<th>Mo</th>
<th>Cu</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Metal</td>
<td>0.022</td>
<td>1.10</td>
<td>0.030</td>
<td>0.010</td>
<td>0.40</td>
<td>10.90</td>
<td>0.39</td>
<td>0.004</td>
<td>--</td>
<td>Bal.</td>
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<tr>
<td>SMAASS</td>
<td>0.035</td>
<td>0.82</td>
<td>0.018</td>
<td>0.015</td>
<td>0.67</td>
<td>19.00</td>
<td>11.00</td>
<td>--</td>
<td>0.01</td>
<td>0.1</td>
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<td>17.00</td>
<td>0.40</td>
<td>--</td>
<td>--</td>
<td>Bal.</td>
</tr>
<tr>
<td>SMADSS</td>
<td>0.030</td>
<td>0.80</td>
<td>0.018</td>
<td>0.016</td>
<td>0.80</td>
<td>22.00</td>
<td>9.00</td>
<td>--</td>
<td>3.00</td>
<td>Bal.</td>
</tr>
</tbody>
</table>
ues, and the enhancement in toughness value is approximately 25% compared to SMADSS joint and 75% compared to SMAFSS joint.

3.2. Hardness and Microstructure

Vickers microhardness measured at the weld metal region of the joints is presented in Table 3. The hardness of the SMAASS and SMAFSS joints in the weld metal region are 260 VHN and 324 VHN respectively. However, the hardness of the SMADSS joints in the weld metal region is 375 VHN, which is relatively higher compared to SMAASS and SMAFSS joints. Optical micrographs taken at weld metal (WM) region are displayed in Fig. 2. The joints fabricated by ASS electrode primarily contain solidified dendritic structure of austenite (Fig. 2(b)) and the joints fabricated by FSS electrode contain solidified ferritic grains (Fig. 2(c)). Whereas, the joints fabricated by DSS electrode contain solidified austenitic structure in the ferrite matrix (Fig. 2(d)).

3.3. Fatigue Crack Growth Behaviour

The fatigue crack growth experiment was conducted at five different stress levels ($\Delta \sigma$) of 75, 100, 125, 150 and 175 MPa under constant amplitude loading conditions ($R=0$). The measured variation in crack length ($2a$) and the corresponding number of cycles ($N$) endured under the action of particular applied stress range are plotted as shown in Fig. 3 for all the joints. The fracture mechanics based Paris Power Eq. (1), given below, was used to analyse the experimental results.

$$\frac{da}{dN} = C \times (\Delta K)^m$$ (1)

Where $da/dN$, crack growth rate; $\Delta K$, stress intensity factor (SIF) range; ‘$C$’ and ‘$m$’ are constants. The SIF value was calculated for different values of growing fatigue crack length ‘$2a$’ using the following expression (2)

$$\Delta K = \phi \times (\Delta \sigma) \times \sqrt{2a}$$ (2)

However, the geometry factor for the CCT specimen was calculated using the expression given below Eq. (3)

$$\phi = F(\alpha) = \sec \left( \frac{\alpha}{2} \right)$$ (3)

Where, ‘$a$’ is the crack length, ‘$W$’ is the width of the CCT specimen, ‘$\alpha$’ is a geometric factor which is equal to ($a/W$) and ‘$\phi$’ is a function of ‘$\alpha$’.

<table>
<thead>
<tr>
<th>Joint</th>
<th>Yield strength (MPa)</th>
<th>Tensile strength (MPa)</th>
<th>Elongation (%)</th>
<th>Hardness (VHN)</th>
<th>Impact toughness J</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base metal</td>
<td>360</td>
<td>480</td>
<td>12.0</td>
<td>330</td>
<td>22</td>
</tr>
<tr>
<td>SMAASS</td>
<td>205</td>
<td>280</td>
<td>10.55</td>
<td>260</td>
<td>24</td>
</tr>
<tr>
<td>SMAFSS</td>
<td>220</td>
<td>305</td>
<td>6.76</td>
<td>324</td>
<td>6</td>
</tr>
<tr>
<td>SMADSS</td>
<td>230</td>
<td>325</td>
<td>8.35</td>
<td>375</td>
<td>18</td>
</tr>
</tbody>
</table>

Table 3. Tensile, hardness and impact properties of base metal and welded joints.
The crack growth rate, $da/dN$ for the propagation stage was calculated for the steady state growth regime, at different intervals of crack length increment, against the associated number of cycles to propagation. The relationship between SIF range and the corresponding crack growth rate in terms of best fit lines is shown in Fig. 4 for all the joints.

The data points plotted in the graph mostly correspond to the second stage of Paris sigmoidal relationship ($10^{-6}$ to $10^{-3}$ mm/cycle). The exponent $'m'$, which is the slope of the line on log–log plot and the intercept $'C'$ of the line, were determined and they are presented in Table 4.

When the crack growth rate was around $10^{-3}$ mm/cycle, the corresponding $D_K$ value was taken as critical SIF ($D_K_{cr}$). Similarly, when the crack growth was around $10^{-6}$ mm/cycle, the corresponding $D_K$ value was taken as threshold SIF ($D_K_{th}$). The values of $D_K_{cr}$ and $D_K_{th}$ for all joints were evaluated and are presented in Table 4. Normally, in the case of steels, the threshold value is obtained for a crack growth rate of $10^{-8}$ mm/cycle. Due to the specimen configuration and loading conditions, crack propagation rates in the region of $10^{-8}$ mm/cycle could not be obtained. The fatigue crack growth (fracture mechanics) parameters of all the joints are compared in Table 4.

It is also advantageous to plot the standard $S$–$N$ curves for the test conditions, which will indicate the trend and also be useful for design purposes. Fig. 5 shows the relationship between stress range ($S$) and the number of cycles to failure ($N$) on a log–log plot for all the joints. Each endurance line can be represented by a Basquin type equation, in general form, as expressed below:

$$N_i = A \times (\Delta \sigma)^{-n} \quad \text{............... (4)}$$

Where $'A'$ and $'n'$ are constants ($'n'$ is slope of the line and $'A'$ is intercept of the line) and their values are evaluated and presented in Table 4.

### Table 4: Fatigue properties of ferritic stainless steel joints.

<table>
<thead>
<tr>
<th>Joints</th>
<th>$m$</th>
<th>$C$</th>
<th>$n$</th>
<th>$A$</th>
<th>$\Delta K_{th}$</th>
<th>$\Delta K_{cr}$</th>
<th>$\Delta \sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMAASS</td>
<td>4.92</td>
<td>1.69x10^-10</td>
<td>2.67</td>
<td>1.8x10^-11</td>
<td>5.5</td>
<td>20</td>
<td>65</td>
</tr>
<tr>
<td>SAFSS</td>
<td>5.62</td>
<td>6.3x10^-11</td>
<td>3.04</td>
<td>2.2x10^-12</td>
<td>5.0</td>
<td>18</td>
<td>55</td>
</tr>
<tr>
<td>SMADSS</td>
<td>4.65</td>
<td>1.2x10^-10</td>
<td>2.46</td>
<td>1.2x10^-11</td>
<td>6.0</td>
<td>25</td>
<td>75</td>
</tr>
</tbody>
</table>

### 3.4. Fracture Surface

The fatigue fracture surface appearance corresponding to crack initiation, crack propagation and the final failure regions of the joints (100 MPa alone), as observed under the scanning electron microscope (SEM) is displayed in Fig. 7. The fatigue crack initiation region (FCI) is corresponding to 1 mm from the tip of the machined notch; fatigue crack propagation (FCP) region is referred to 1 to 6 mm; final failure (FF) region is referred to 6 mm away from the crack length from its original (initial) length, at the earlier crack growth stage under particular stress level. This is because at this stage, the crack is expected to attain more regular and stable front shape. Similar criteria were adopted by other investigators also. $^{10,11}$ Fig. 6 shows the relationship exists between applied stress range ($S$) and the crack initiation life $(N_i)$ for all the joints. Each endurance line can be represented by a Basquin type equation, in general form, as expressed below:

$$N_i = A \times (\Delta \sigma)^{-n} \quad \text{............... (4)}$$

Where $'A'$ and $'n'$ are constants ($'n'$ is slope of the line and $'A'$ is intercept of the line) and their values are evaluated and presented in Table 4.
The cracks initiated in FCI region are clearly seen in SEM fractographs (Fig. 7). The length of cracks is relatively longer in the SMAFSS joint (Fig. 7(b)) compared to SMAASS (Fig. 7(a)) and SMADSS (Fig. 7(c)) joints. Invariably in FCP regions (where steady state crack growth occurs), the micro-level striations were observed and the spacing between the striations varies in each joints. The spacing between micro-level striations is much wider in SMAFSS (Fig. 8(b)) joint compared to SMAASS (Fig. 8(a)) and SMADSS (Fig. 8(c)) joints and it is evident form the FCP regions of SEM fractographs.

From the fractographs of final failure (FF) region, it is observed that the tear dimples are elongated along the loading direction and this is mainly because of the limit load condition at the time of final fracture. Even though unstable crack growth occurs in the final failure region, the final fracture is still in the ductile mode and it is evident from the presence of dimples. But the shape and size of the dimples are different in all the joints and it is influenced by the grain size of the fusion zone region. The size of the dimples is much larger (coarse dimples) in the SMAFSS (Fig. 9(b)) joint compared to SMAASS (Fig. 9(a)) and SMADSS (Fig. 9(c)) joints and it is evident from the FF regions of SEM fractographs.

4. Discussion

The fatigue crack initiation behaviour, fatigue crack propagation behaviour and fatigue life of ferritic stainless steel joints are influenced by the filler metals used. Of the three joints, SMADSS joints are offering higher fatigue resistance than SMAASS and SMAFSS joints. In the CCT specimen, the notch is machined in the weld metal (WM) region of the joints by WEDM process to evaluate the crack growth behaviour of the welded joints under fatigue loading. The fatigue crack initiates from the tip of the machined notch and it grows in the weld metal region until final failure takes place. Hence, the weld metal properties such as tensile strength, impact toughness, hardness and microstructure will definitely influence the fatigue performance of the joints. The effect of these weld metal properties on fatigue performance is analysed in detail in the following paragraphs.
The tensile properties (yield strength, tensile strength and elongation) of SMADSS joints are superior as compared to their counterparts (Table 3). The variations in tensile, impact and hardness properties of FSS joints are caused by the two important characteristics of weld metal. They are: (i) chemical composition of the weld metal (ii) microstructure of the weld metal. Chromium is the most important alloying element in stainless steels. Chromium promotes the formation of ferritic structure. It is also strong carbide former and hence increases the hardness and strength of the stainless steels.12) Of the three joints, SMADSS joint contains higher amount of chromium (2% higher than SMAASS joints and 5% higher than the SMAFSS joints). This may be one of the reasons for the formation of ferritic structure in the weld metal region of SMADSS joint (Fig. 2(d)).

Similarly, nickel is another important alloying element in stainless steels. Nickel promotes the formation of austenitic structure and hence increases ductility and toughness of the stainless steels.13) Of the three joints, SMAASS joint contains higher amount of nickel (2% higher than SMADSS and 10.6% higher than SMAFSS). This may be the one of the reasons for the formations of austenitic structure in the weld metal region of SMAASS joint (Fig. 2(b)). Higher amount of chromium and very less amount of nickel in SMAFSS joint led to the formation of ferritic structure in the weld metal region.

Molybdenum is also another important alloying element, which strongly promotes the formation of ferritic structure in stainless steel. It is also carbide former and hence increases the strength and hardness of the stainless steels.14) Of the three joints, SMADSS joint contains higher amount of molybdenum (3% higher than SMAASS and SMAFSS joints). Though the amount of chromium and nickel in weld metal region of SMAASS and SMADSS joints are approximately equal, the presence of higher amount of molybdenum in SMADSS made all the difference. Higher amount of molybdenum suppressed the formation of austenitic structure and promoted the formation of ferritic structure in SMADSS joint and it acted as a balancing element.

Though the carbon content in weld metal region is very low compared to Cr, Ni, Mo, it also plays an important role in the formation of microstructure. Carbon is a strong austenite former and strongly promotes an austenite structure in stainless steels. It also has strong affinity towards Cr and Mo to form carbides and hence it subsequently increases the strength and hardness of the stainless steels.15) Of the three joints, SMAFSS joints contain higher amount of carbon (0.04% higher than SMAASS joint and 0.045% higher than SMADSS joint). However, the presence of higher percentage of carbon will enhance the brittleness of the weld metal and also will lead to the formation of higher volume fraction of chromium carbides in the weld metal region. Though the carbon is an austenite former, very less amount of nickel and higher amount of chromium suppressed the formation of austenitic structure in the weld metal region of SMAFSS joint.

The formation of austenitic structure will enhance the ductility (percentage of elongation) and subsequently increases the impact toughness values.16) However, the formation of ferritic structure will enhance the tensile strength.17) The formation of carbides such as chromium carbide, molybdenum carbide will also be beneficial to enhance the strength and hardness of stainless steels to some extent. But higher volume fraction of these carbides will lead to reduction in ductility, strength and impact toughness.18)

Hence, the formation of fully austenitic structure in the weld metal region of SMAASS joint due to the presence of higher percentage of nickel content led to the enhancement in ductility and impact toughness properties. On the other hand, the formation of fully ferritic structure and possible formation of large volume fraction of carbides in the weld metal region of SMAFSS joint due to the presence of higher percentage of chromium and carbon (very less percentage of nickel) content led to the reduction in ductility and impact toughness properties. However, the formation of combined ferritic and austenitic structure in the weld metal region of SMADSS joint due to the presence of balanced percentage of chromium, nickel and molybdenum content led to the higher strength and hardness properties.

Higher yield strength and tensile strength of the SMADSS joint is greatly used to enhance the endurance limit of the joints and hence the fatigue crack initiation is delayed. The combined effect of higher yield strength, and relatively higher toughness compared to base metal of the SMADSS joint offers enhanced resistance to crack initiation and crack propagation and hence the fatigue performance of the joints is superior as compared to their counterparts.

The crack growth exponent ‘m’ is an important parameter to evaluate the fatigue crack growth behaviour of materials since it decides the fatigue crack propagation life of the materials. This exponent is obtained from the slope of the curve drawn between da/dN and SIF range. If this exponent is lower, then slope of the curve is lower and that indicates the resistance offered by the material to the growing fatigue crack is higher and hence the fatigue life will be longer. If this exponent is larger, then slope of the curve is higher and that explains the resistance offered by the material to the growing fatigue crack is lower and hence the fatigue life will be shorter.19) The crack growth exponent ‘m’ for SMADSS joint is lower compared to SMAFSS and SMAASS joints (Table 4) and this indicates that the SMADSS joint offer higher resistance to fatigue crack growth compared to SMAFSS and SMAASS joints.

In the lower ductility and toughness weld metal, as in the case of SMAFSS joints, since the deformation and the yielding are mainly concentrated in the weld metal region, the extension of the plastic zone is limited within the fusion zone. As soon as the plastic zone reaches the weld metal, plasticity keeps on developing along the interface between the base metal and weld metal region.20) The triaxial state of stress is high in WM region and the relaxation of this stress is poor. The crack driving force needed for crack extension is small. So, the fracture toughness of the lower ductility weld metal is not high. On the other hand, if strength of the weld metal is higher, the plastic zone can easily extend into the parent material because the deformation and yielding occur in both weld metal and the base metal. The stress relaxation can easily take place in the crack tip region. So more crack driving force is needed for crack extension and the fracture resistance of the higher
strength weld metal region is greater than the lower strength weld metal region.\textsuperscript{21} This is also one of the reasons for better fatigue resistance of the SMADSS joints.

5. Conclusions

From this investigation, following important conclusions are derived:

(1) The fatigue crack initiation behaviour, fatigue crack propagation behaviour and fatigue life of ferritic stainless steel joints fabricated using duplex stainless steel electrode are superior compared to the joints fabricated using austenitic stainless steel and ferritic stainless steel electrodes.

(2) SMADSS joints endured 15\% higher number of cycles compared to SMAASS joints and 40\% higher number of cycles compared to SMAFSS joints.

(3) The combined effect of higher yield strength and relatively higher toughness of the SMADSS weld metal offers enhanced resistance to crack initiation and crack propagation and hence the fatigue performance of the joints is superior as compared to their counterparts.

Acknowledgements

The authors are very grateful to Dr. G. Madhusudhan Reddy, Scientist-F, Defence Metallurgical Research Laboratory (DMRL), Hyderabad for his valuable suggestions, guidance and discussion.

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