Hot forming

Duplex stainless steels show excellent hot formability with relatively low forming loads up to at least 1230°C (2250°F). However, if hot forming takes place at too low a temperature, deformation accumulates in the weaker but less ductile ferrite, which can result in cracking of the ferrite in the deformed region. Additionally, a large amount of sigma phase can be precipitated when the hot working temperature drops too low.

Most producers recommend a maximum hot forming temperature between 1100°C (2000°F) and 1150°C (2100°F). This upper temperature limit is suggested because of the effect of high temperatures on the dimensional stability of a part and the increased tendency to scale formation with increasing temperature. At high temperatures, duplex stainless steel becomes soft and fabricated pieces such as vessel heads or piping warp or sag in the furnace if they are not supported. At these temperatures the steel may also become too soft for certain hot forming operations.

Table 1 summarizes the suggested temperature ranges for hot forming and the minimum soaking temperatures. It is not necessary or always advisable, to start hot working at the highest temperature in the range. However, the steel should reach at least the minimum soaking temperature before hot working. The furnace should be charged hot, to avoid slow heating through the temperature range where sigma phase is formed.

Table 1: Hot forming temperature range and minimum soaking temperature for duplex stainless steels (common austenitic grades are included for comparison).

<table>
<thead>
<tr>
<th>Grade</th>
<th>UNS No.</th>
<th>EN No.</th>
<th>Hot forming temperature range</th>
<th>Minimum soaking temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>°C</td>
<td>°F</td>
</tr>
<tr>
<td>2304</td>
<td>S32101</td>
<td>1.4162</td>
<td>1100–900</td>
<td>2000–1650</td>
</tr>
<tr>
<td>2205</td>
<td>S32304</td>
<td>1.4362</td>
<td>1150–950</td>
<td>2100–1740</td>
</tr>
<tr>
<td>2507</td>
<td>S32205</td>
<td>1.4462</td>
<td>1230–950</td>
<td>2250–1740</td>
</tr>
<tr>
<td>304</td>
<td>S32750</td>
<td>1.4410</td>
<td>1230–1025</td>
<td>2250–1875</td>
</tr>
<tr>
<td>316</td>
<td>S32520</td>
<td>1.4507</td>
<td>1230–1000</td>
<td>2250–1830</td>
</tr>
<tr>
<td>316</td>
<td>S32760</td>
<td>1.4501</td>
<td>1230–1000</td>
<td>2250–1830</td>
</tr>
<tr>
<td>304</td>
<td>S30400</td>
<td>1.4301</td>
<td>1205–925</td>
<td>2200–1700</td>
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<tr>
<td>316</td>
<td>S31600</td>
<td>1.4401</td>
<td>1205–925</td>
<td>2200–1700</td>
</tr>
</tbody>
</table>

Source: Producer data sheets
Heat treatment

After hot forming, it is necessary to perform a full solution anneal followed by a rapid quench to fully restore the mechanical properties and corrosion resistance. The work piece should be brought above the minimum solution annealing temperature and held long enough to dissolve any intermetallic precipitates. A conservative guideline is that the holding time at temperature should be comparable to the total time that the piece was held in the 650–980°C (1200–1800°F) temperature range subsequent to the previous full anneal. The part should be water quenched from the solution annealing temperature. It should not be allowed to spend several minutes in the 700–1000°C (1300–1830°F) range while being transferred to the quench location after this final anneal. Minimum solution annealing temperatures for duplex stainless steels are summarized in Table 2.

At solution annealing temperatures, duplex stainless steels are quite soft, and warping and distortion are likely if the work piece is not adequately supported. This can be a significant problem in tubular products, especially those with large diameters and thin walls. Re-forming or straightening warped duplex products is more difficult than austenitic stainless steels because of the high ambient temperature strength of duplex stainless steels. Attempts to minimize this distortion by short annealing times, slow heating into the annealing temperature range, or the use of a lower than recommended annealing temperature may not dissolve intermetallic phases or may cause the formation of additional amounts of intermetallic phases. This will lower corrosion resistance and reduce toughness.

The use of stress relief treatments to reduce the cold work from forming or straightening operations is not advisable. The duplex stainless steels inherently have very good chloride stress corrosion cracking resistance and this can be only marginally improved by reducing residual cold work. There is no satisfactory temperature below the solution annealing temperature at which stress relief can be employed without the danger of formation of intermetallic phases, which will lower corrosion resistance and reduce toughness.

Table 2: Minimum solution annealing temperatures for duplex stainless steels

<table>
<thead>
<tr>
<th>Grade</th>
<th>UNS No.</th>
<th>Minimum annealing temperature °C</th>
<th>°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>2304</td>
<td>S32304</td>
<td>980</td>
<td>1800</td>
</tr>
<tr>
<td>2205</td>
<td>S32205</td>
<td>1040</td>
<td>1900</td>
</tr>
<tr>
<td>255</td>
<td>S32550</td>
<td>1040</td>
<td>1900</td>
</tr>
<tr>
<td>2507</td>
<td>S32750</td>
<td>1025–1125</td>
<td>1880–2060</td>
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<tr>
<td></td>
<td>S32760</td>
<td>1100</td>
<td>1975–2050</td>
</tr>
<tr>
<td></td>
<td>S32707</td>
<td>1080–1120</td>
<td>1975–2050</td>
</tr>
</tbody>
</table>

Source: Producer data sheets and ASTM A 480