INTERNATIONAL MOLYBDENUM ASSOCIATION
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Hot forming and heat treatment of duplex stainless steels

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.

Temperature uniformity is important in successful hot forming of duplex stainless steel. If the shape of the work piece is not compact, the edges may be significantly cooler than the bulk, and there is a risk of cracking in these cooler regions. To avoid this cracking, it is necessary to reheat the piece when these local regions are in danger of cooling below the minimum hot working temperature. The lower end of the suggested hot forming temperature range may be extended somewhat, but only if the temperature uniformity within the work piece, especially the edges or thinner sections, is maintained.

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

Grade	UNS No.	EN No.	Hot forming temperature range		Minimum soaking temperature	
			°C	°F	°C	°F
	S32101	1.4162	1100–900	2000–1650	950	1750
2304	S32304	1.4362	1150–950	2100–1740	980	1800
2205	S32205	1.4462	1230–950	2250–1740	1040	1900
2507	S32750	1.4410	1230–1025	2250–1875	1050	1920
	S32520	1.4507	1230–1000	2250–1830	1080	1975
	S32760	1.4501	1230–1000	2250–1830	1100	2010
304	S30400	1.4301	1205–925	2200–1700	1040	1900
316	S31600	1.4401	1205–925	2200–1700	1040	1900

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

Grade	UNS No.	Minimum annealing temperature	
		°C	°F
2304	S32304	980	1800
	S32003	1010	1850
	S32001	1040	1900
	S32101	1020	1870
	S32202	980	1800
	S82011	1010	1850
2205	S32205	1040	1900
	S32506	1020–1120	1870–2050
	S32520	1080–1120	1975–2050
255	S32550	1040	1900
2507	S32750	1025–1125	1880–2060
	S32760	1100	2010
	S32707	1080–1120	1975–2050

Source: Producer data sheets and ASTM A 480

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