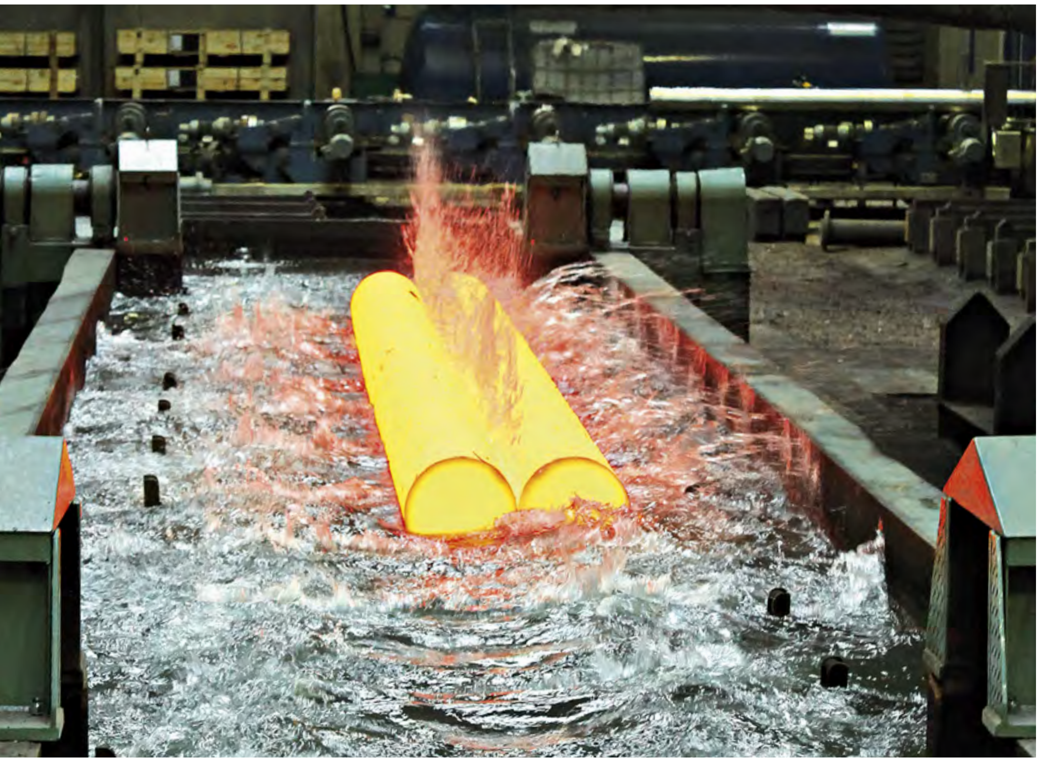

Duplex stainless steel has to be water quenched immediately after solution annealing.

The driving force for sigma phase formation increases with increasing molybdenum and chromium content. The more highly alloyed grades, from 2205 on up are therefore most affected. Precipitates tend to form quicker with increasing alloy content as shown in Figure 4 where the start curve for 2507 is to the left (shorter time) of the one for 2205. Lean duplex grades such as 2304 do not readily form intermetallic phases and nitride precipitation is more likely as shown in Figure 4.

The presence of sigma phase decreases the pitting resistance of duplex stainless steels, due to the depletion of chromium and molybdenum in surrounding areas. This depletion leads to a local reduction of the corrosion resistance next to the precipitates. Toughness and ductility are also sharply reduced when intermetallic phase precipitation occurs.

Chromium nitride precipitation can for some grades start in only 1–2 minutes at the critical temperature. It can occur in the grain or phase boundaries as a result of too slow cooling through the temperature range of 600–900°C (1100–1650˚F). Nitride formation is not very common in most duplex grades, but it can be an issue with some lean duplex stainless steels, due to relatively high nitrogen content and reduced nitrogen solubility compared to higher alloyed grades. Similar to sigma phase, it can largely be avoided in the steel mill by water quenching from an adequate solution annealing temperature.

Chromium nitride can, however, also precipitate in the HAZ and weld metal in welded fabrications. A high ferrite content in the vicinity of the fusion line, due to very rapid cooling in this area, can lead to nitrogen oversaturation. Ferrite in general has very low solubility for nitrogen which decreases further as the temperature decreases. So if nitrogen is 'caught' in the ferrite phase it might precipitate as chromium nitride upon cooling. A slower cooling rate will result in a competition between nitride precipitation and an increase of austenite re-transformation. More austenite allows more nitrogen to dissolve in the austenite grains, reducing the nitrogen oversaturation of the ferritic grains and the amount of chromium nitride. The precipitation of chromium nitrides in welds can therefore be decreased by increasing the austenite level through higher heat input (slower cooling) or through additions of austenite-promoting elements such as nickel in the weld metal or nitrogen in the shielding gas.

If formed in large volume, chromium nitrides may adversely affect corrosion resistance and toughness properties.

Alpha prime can form in the ferrite phase of duplex stainless steels below about 525°C (950°F). It takes significantly longer to form than the other phases discussed above and is first noticed as an increase in hardness and only later as a loss in toughness (Figure 4).

In ferritic stainless steels alpha prime causes the loss of ambient temperature toughness after extended exposure to temperatures around 475°C (885°F); this behavior is known as 475°C/885°F embrittlement. Fortunately, because duplex stainless steels contain 50% austenite, this hardening and embrittling effect is not nearly as detrimental as it is in fully ferritic steels. It does affect all duplex stainless steel grades, but is most pronounced in the molybdenum-containing grades and much less in the lean duplex grades.

Alpha prime embrittlement is rarely a concern during fabrication because of the long times required for embrittlement to occur. One exception, which has to be carefully evaluated, is stress relief treatment of duplex-clad carbon steel constructions. Any heat treatment in the critical temperature range for alpha prime formation of 300–525°C (575–980°F) (or for intermetallic phase formation of 700–950°C (1300–2515°F), for 2205) has to be avoided. If a stress relief treatment is required, it is best to consult the clad plate producer for advice.

However, the upper temperature limit for duplex stainless steel service is controlled by alpha prime formation. Pressure vessel design codes have therefore established upper temperature limits for the maximum allowable design stresses. The German TüV code distinguishes between welded and unwelded constructions and is more conservative in its upper temperature limits than the ASME Boiler and Pressure Vessel Code. The temperature limits for these pressure vessel design codes for various duplex stainless steels are summarized in **Table 2**.

The second generation duplex stainless steels are produced with very low carbon content so that **carbide** formation to a detrimental extent is typically not a concern.

Table 3 summarizes a number of important precipitation reactions and temperature limitations for duplex stainless steels.

Table 2: Upper temperature limits for duplex stainless steel for maximum allowable stress values in pressure vessel design codes

Grade	Condition	ASME		TüV	
		°C	°F	°C	°F
2304	Unwelded	315	600	300	570
2304	Welded, matching filler	315	600	300	570
2304	Welded with 2205/2209	315	600	250	480
2205	Unwelded	315	600	280	535
2205	Welded	315	600	250	480
2507	Seamless tubes	315	600	250	480
Alloy 255	Welded or unwelded	315	600		

Table 3: Typical temperatures for precipitation reactions and other characteristic reactions in duplex stainless steels

	2205		2507	
	°C	°F	°C	°F
Solidification range	1470–1380	2680–2515	1450–1350	2640–2460
Scaling temperature in air	1000	1830	1000	1830
Sigma phase formation	700–950	1300–1740	700–1000	1300–1830
Nitride, carbide precipitation	450–800	840–1470	450–800	840–1470
475°C/885°F embrittlement	300–525	575–980	300–525	575–980