Controlling duplex stainless steel edge cracking

Hot rolling defects are easily formed due to the poor hot workability of duplex stainless steel. At Baosteel, the main hot rolling defect is edge cracking. Research carried out by the stainless steel research center identified the main influencing factors for edge cracking. These included the rolling temperature, phase proportion, σ phase, and micro-alloying elements. The contents of sulfur and oxygen in duplex stainless steel should be reduced as far as possible during the steelmaking process. The starting and finishing rolling temperature, cooling rate, and precipitation of σ phase should be strictly controlled during the rolling process and the proper phase proportion should also be ensured to avoid hot brittleness cracks. Baosteel’s 1780mm hot rolling line isn’t suitable for producing duplex stainless steel, because it doesn’t have an edge heater, the design of the furnace isn’t suitable, and the ability of the rolling mill is too low. All these factors lead to an increase in edge cracking. In order to solve these problems in hot rolling, several effective methods are provided in this paper.

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Duplex stainless steel has both austenitic and ferritic stainless steel features. Compared to ferritic stainless steel, duplex stainless steel has better properties in terms of toughness, inter-granular corrosion resistance and weldability. At the same time it retains some characteristics of ferritic stainless steel, such as the high thermal conductivity, thermal expansion coefficient, magnetic properties, etc. Compared to austenitic stainless steel, duplex stainless steel has higher strength (in particular a significantly improved yield strength), better pitting corrosion resistance, more resistance to stress corrosion cracking, and greater corrosion fatigue performance. Duplex stainless steel is also a resource-saving and high-performance stainless steel product. Moreover it is a high-profit product because of the exclusive fields of application and high threshold of technology. The development and manufacture of duplex stainless steel reflects the technical expertise of stainless steel manufacturers and also creates more economic benefits for the enterprise. Duplex stainless steels form a range of products within the stainless steel family, with 2205 duplex being the most widely used in many fields. This grade now accounts for over 80% of the duplex stainless steel production. For this reason Baosteel focused on 2205 duplex when it first started development of its duplex stainless steel series as early as 2006. Today Baosteel has mastered the key technology of duplex stainless steel production, and in particular the control of edge cracking in hot rolling.

Analysis of crack defects
Micro-cracks were generated at the phase boundary of austenitic and ferritic when thermal deformation occurred, and they extended along the phase boundary. This is mainly because of the differences in crystal structure, the sliding and recovery mechanism between austenitic and ferritic that would lead to the coordination of two-phase deformation, when thermal deformation occurs in duplex stainless steel. The stress concentration occurred easily on the phase boundary, as shown in Figure 1.

Effects of composition on thermal plasticity
Nitrogen content: We composed the duplex stainless steel with different nitrogen contents through tensile testing at an elevated temperature. Results are shown in Figure 2.

Figure 1: (a) Metallographic photo of edge crack along surface, (b) Metallographic photo of edge crack, cross-section.
As we can see from the curves S7 and S8 in Figure 2, both curves have a similar high temperature plasticity when the temperature is raised from 1100º to 1250º. The thermo-plasticity of S8 dropped dramatically from 1050º, while in S7 it started at 950º. We consider that the drop was due to the precipitated phase that affected the hot ductility of steels.

**Sulfur content:** Figure 3 shows that sulfur content has a significant effect on the hot workability of duplex stainless steel. When we define the 70% area reduction as a condition of having good hot workability, the DA (0.0014%S) steel machineable interval is from 950º to 1200º, the S6 (0.006%S) is from 1000º to 1150º, and the S9 (0.011%S) steel machineable interval is from 1050º to 1150º.

**Conclusions:** Increasing the nitrogen content will reduce the hot workability of duplex stainless steel; especially for area reduction when the temperature was below 1000º it had a significant negative effect.

Increasing the sulfur content will reduce the hot workability of duplex stainless steel; especially for area reduction when temperature is above 1150º.

**Single pass compression deformation curve**

Figure 4 illustrates that when duplex stainless steel is deformed at lower strain rates (the strain rate is 0.01s⁻¹ or 0.1s⁻¹) its stress-strain curve displays more obvious dynamic recovery. When duplex was compressed and deformed, hardening first occurred in the ferrite phase. When the deformation happened under high temperature and a low strain rate, fast recovery of ferrite balanced work hardening and softening and the flow stress tended towards a constant value. However when the deformation temperature falls, ferrite soften recovery can’t quickly balance the work hardening, so the work hardening accumulated continuously. This caused dynamic recrystallization of the austenite phase and the flow stress decreased to a constant value again. With the strain rate increased to 5s⁻¹ the softening of duplex was mainly controlled by austenite recrystallization. When work hardening accumulated to a certain extent, dynamic recrystallization took place in the austenite phase, and the flow stress declined rapidly. After softening, caused by dynamic recrystallization, it was replaced by hardening again. At this time, the steady-state was replaced by the stress-strain curve with periodic fluctuations. When the strain rate increased to 30s⁻¹, the period of the stress-strain curve was extended. In addition, it is worth noting that under the same strain rate and strain value,
the increased volume of deformation resistance was uneven when the temperature decreased. It fluctuated significantly when the temperature was between 1000° and 1050°, and between 950° and 1000°.

**Conclusions:** The deformation resistance of duplex stainless steel increased obviously when the temperature dropped from 1000° to 950°, causing the hot rolling load at this temperature to increase significantly. The deformation resistance of duplex stainless steel increased when the strain rate increased while the softening rate was reduced. So we should put the duplex through sufficient dynamic softening and a low deformation rate.

**Controlling edge cracking**

1. Try to maintain the nitrogen and sulfur content in duplex stainless steel at a suitable level.
2. Use all kinds of methods to ensure a rolling temperature of above 1000°.
3. Design the reasonable compression ratio according to the strip thickness.

We can see from figure 5 that the duplex stainless steel edge cracking improved significantly after the above methods were put into action.

**Bibliography**
