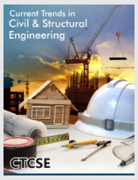

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Review on Hot and Control Rolling of HSLA Steel

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Abstract

The superior properties offered by HSLA steel over the former C-Mn steels make them popular in a variety of industrial applications. An overview of the main characteristics of these steels and details of their types and their main strengthening mechanisms is illustrated in this paper.

Characteristics of HSLA Steel

The motivation to develop HSLA steel has been attributed to the following [1]:

1. The production cost of HSLA steel is relatively low.
2. Weight reduction requirements; especially for the automotive industry. The higher strength of HSLA steel makes it possible to reduce the thickness of steel plates used in vehicle production.
3. In the past, higher ultimate tensile strengths in steel could be produced by increasing the carbon content but these steels were difficult to weld, which limited their use in many engineering applications, such as pipeline which requires both a high yield-strength steel and good weldability. The lower carbon content of HSLA steel facilitates the welding process using the current and basic welding procedures.
4. Microstructure and mechanical properties can be controlled easily and cheaply; strength can be enhanced through vanadium and niobium additions as both elements do not oxidise during the steel melt processing. These elements can combine with C and N forming nitrides and carbides which can strengthen the steel by grain refinement and precipitation hardening.

Types

HSLA steel can be classified into six main categories based on chemical composition, microstructure and properties [2,3]:

1. Ferrite-pearlite steels which contain small amounts of nitride, carbide and carbonitride forming elements, ≤0.1wt.per. cent, for precipitation hardening and grain refinement.
2. Pearlitic steels which contain higher contents of carbon to increase the volume fraction of pearlite in the microstructure, and so improve the strength and wear resistance.
3. Acicular ferrite steels containing small amounts of carbon, ≤0.05%. The steel offers high yield strength, ~700MPa, good toughness, weldability and formability.
4. Weathering steels, containing small additions of specific alloying elements, such as phosphorus and copper to enhance atmospheric corrosion resistance and solid- solution hardening.
5. Dual-phase steel; the name indicates their mixed microstructures, which consists of martensite dispersed in a ferritic matrix. The steel has an excellent combination of high tensile strength due to the presence of martensite and good ductility due to the presence of ferrite in the microstructure.
6. Inclusion-shape-controlled steels, containing small amounts of the rare-earth elements or titanium, zirconium and calcium in order to control the shape of the sulphide inclusions. The process aims to change sulphide inclusions shape from elongated stringers to small, dispersed, almost spherical globules to improve ductility and toughness.

Strengthening mechanisms

The strengthening mechanisms of HSLA steels can be classified into the following categories [1,2,4]:

1. Solid solution strengthening dislocation movement during loading is impaired by the presence of interstitial and substitutional solute atoms in a crystal lattice. The resistance to dislocation movement depends on the solubility of the solute atoms of the alloying elements in the steel.

2. Grain-boundary strengthening grain boundaries are effective in obstructing dislocation movement. This leads to higher strengths and the finer grain size limits crack propagation, improving the impact behaviour. Therefore, a finer grain size will increase strength and toughness, simultaneously.

3. Dislocation strengthening: the dislocation density on deformation increases as the load increases. Due to the high volume of dislocations induced during loading, dislocation movement is obstructed by other dislocations moving in the opposite direction. The efficiency of this mechanism is governed by the degree of saturation of the structure with dislocations.

4. Precipitation strengthening: the high additions of carbide, nitride and sulphide forming elements leads to super-saturation of the solutes at high temperature. Consequently, second-phase particles precipitate out of solution on cooling to room temperature and form at the matrix and grain boundary. The efficiency of these particles in improving strength depends on their characteristics, such as identity, size, location and volume fraction. However, precipitation must be carefully controlled so that the toughness is not impaired too much.

5. Phase-transformation strengthening steel passes through various phases during heating and cooling. The presence and amount of phases depends on the temperature and alloying composition. Each phase has its own properties. In case of equilibrium cooling of steel, the main phases present are austenite, ferrite and pearlite. The strengthening mechanism depends on the nature of the phases present and their volume fraction.

Rolling of HSLA Steel

Many flat products are produced by rolling, meeting both requirements of reliability and cost effectiveness [5,6]. A typical rolling facility consists of a reheat furnace, sizing press, roughing mill, finishing mill for plate steel and for strip steel, used mainly for car bodies a run-out table and coiler [7] (Figure 1).

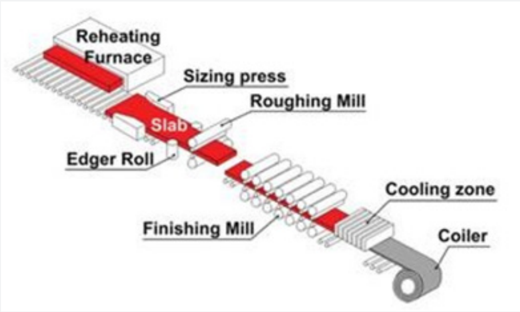

Figure 1: Schematic illustration of traditional hot rolling process [7].

The process starts by heating the ingot up to a high temperature in a furnace in order to dissolve all the alloying elements. The ingot is then transferred to the roughing mill which shapes the ingot into a conveniently shaped slab which can then be easily progressively hot rolled to the desired thickness. Due to the reactivity of steel with oxygen during rolling, an oxide scale usually forms on the outer surface of the steel. The rolled plate after cooling down to room temperature has the scale removed. The cooling rate to room temperature after hot rolling can be optimised to achieve the desired microstructure. Hot rolling is a simple process and it offers lower production cost in comparison with control rolling. However, microstructure, including grain growth and precipitation morphology, cannot be controlled during this rolling process. After casting the grain size is very coarse and the high finishing temperature approx. 950-1000°C ensures that the grain size remains coarse leading to poor strength and impact behaviour. Intergranular fracture is enhanced in coarse grained structures leading to hot surface cracking of slabs in some HSLA steels and subsequent difficulties when it comes to hot rolling them [8-10]. Because the finishing temperature is so high on hot rolling the resultant grain size is coarse and as such the mechanical properties are poor and this can also be accompanied by an in-complete breakdown of the as cast microstructure Thus, controlling grain growth behaviour during processing is essential to achieve good hot ductility and the optimum mechanical properties. This can be achieved by control rolling where the finishing temperature can be in the range 800-900°C but not by hot rolling. However, control rolling although more economical requires more complex, advanced equipment and smaller companies cannot afford the initial outlay.

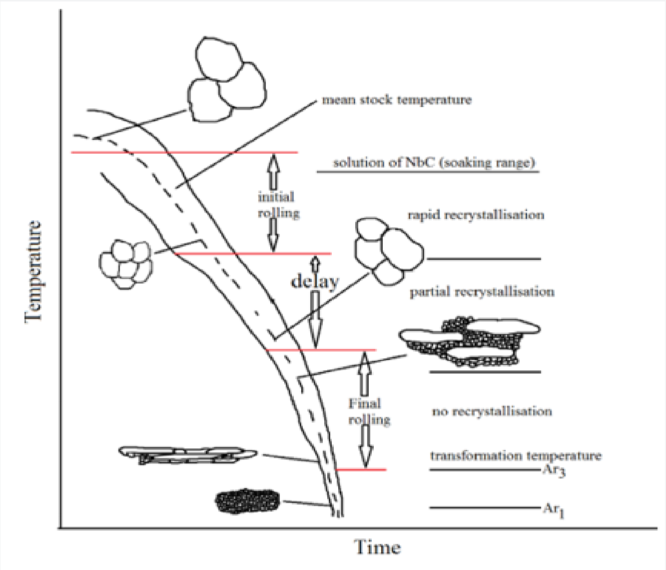

Figure 2: Schematic representation of various processes taking place during control rolling of C-Mn-Nb steels [19].

Globally, most small steelmakers still operate on the basis of traditional hot rolling and as already stated with this process, controlling microstructural evolutions during rolling is not possible resulting in poor mechanical properties [11,12]. In the most advanced control rolling technology, temperature during rolling is continuously controlled such that the austenite grain size is refined and the rolling is interrupted with a hold to allow the plate to attain a lower temperature during the rolling process Moreover, phase transformation and its consequences such as precipitation behaviour are optimised during cooling of the slab [13,14]. The

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refinement of the austenite grain size gives higher area fraction of boundaries, which in turn increases the number of nucleation sites for ferrite grains during transformation. Consequently, the mechanical behaviour is enhanced due to the beneficial effect of the finer ferrite grains [15-18]. A typical schematic representation of various processes taking place during control rolling of C-Mn-Nb steels is illustrated in Figure 2.

Control rolling normally ends at a temperature slightly higher than Ar3 (the temperature at which austenite begins to transform to ferrite during cooling) or higher than Ar1 (the temperature at which transformation of austenite to ferrite or to ferrite and cementite is completed during cooling) but lower than the austenite recrystallisation temperature, TR. The degree of grain refinement depends on the amount of dislocations and slip bands (localized dislocation slipping in an individual grain) in non-recrystallized austenite [1,3,20]. A higher dislocation density and a greater number of slip bands results in an increase in the nucleation sites during the austenite to ferrite transformation, leading to finer ferrite grain structure [1,3,20]. More advanced control rolling techniques have been developed to better control the recrystallisation process. This is known as dynamic recrystallisation control rolling. In this process, the overall strain is higher than with finish rolling while the deformation from pass to pass is accumulated. As a result, the critical strain required to induce dynamic recrystallisation is exceeded and hence a very fine grain size is obtained. Cooling rate in control rolling process generally depends on the desired microstructure. Air cooling is normally used after rolling to obtain ferrite-pearlite structures. However, accelerated rolling is utilized to refine the ferrite grain size and to enrich the rest of the matrix with non-equilibrium phases martensite and/or bainite [1,3,20].

Acknowledgment

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Conflict of Interest

No conflict of interest.

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