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The effect of chemical composition on grain structure and texture evolution of hot rough rolled carbon steels

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Combination of thin slab casting and direct hot rolling to obtain thin steel plate products is an energy efficient process in commercial steel plants. Generally, cracking near the surface is the most serious problem especially during rough rolling of as cast thin slabs. Therefore, it is highly recommended that the microstructure near the surface should be controlled to have enough ductility to withstand the strain. In this study the effect of chemical composition on microstructure evolution and texture has been investigated for the steel plates rough rolled from 70 to 25 mm at a commercial plant. In low carbon content of 0.05 wt%, the micrograph was seen to comprise mainly ferrites with minor pearlite islands which changed to ferrite–pearlite structure with increasing carbon to 0.17 wt%. A detailed investigation was carried out to examine the behavior of the grain structure formed in rough rolled steels, using high resolution SEM microscope fitted with EBSD camera. In all investigated steel plates, a fine grain structure was observed in the plate top surface due to development of rapid static recrystallization after rough rolling which gradually coarsened in mid-section region. Investigation was carried out to understand the effect of alloying elements such as Mn on the texture. Mainly fiber textures of both ND and RD directions were observed after transformation showing inhomogeneity with increasing distance from the plate surface towards the depth. Massive ferrite (bcc) grains transforming from austenite (fcc) has been detected during the rough rolling process. Therefore, tensile test was carried out at 600 °C in order to investigate the failure mechanism of ferrite as the work roll chilling has a significant effect on temperature reduction in the plate surface which may lead to lower ductility of massive ferrites and thus formation of crack at the surface during rough rolling process.

1. Introduction

The feature of the world flat-rolled steel industry has been significantly changed since 1980s by thin slab casting technology [1,2]. In comparison with the conventional slab casting, there are several metallurgical significances in the course of processing including, refinement of dendritic structures leading to greater homogeneity due to rapid solidification, reducing energy consumption during rough/hot rolling and minimizing the tendency of forming crack in the bending region [3]. The 4th generation of thin slab casting in Korea (South) offers 6.5 m/min casting speed for alloyed steel which can even be increased to 7.5 m/min for ultra/low carbon steels [4]. Nowadays, target is determined to hit ~10 m/min which is at least a theme to approach a more energy efficient and greener production technology.

The basic principle of the thermomechanical processing of metals is controlling the condition in order to maximize the grain boundary area per unit volume in the austenite phase to increase the density of nucleation sites for austenite to ferrite transformation [5]. The processing of the steel up to rough rolling stage is involved with different certain sets of texture evolution mechanisms including austenite deformation (during rolling) and austenite recrystallization (during and after rolling). The process of austenite (fcc) to massive ferrite (bcc) transformation (during rolling) can also be carried out [6] leading to failure because of a sudden severe drop in temperature (> 250 °C) due to work roll chilling [7] causing a lower ductility and thus surface cracking at the surface [8].

In early 1980s, it was suggested that γ (fcc) to α (bcc) transformation is carried out during deformation at high temperature referred to as Strain Induced Transformation (SITF) [9]. The process of transformation was also known as Deformation Induced Ferrite Transformation (DIFT) [10–12] which has been recently quoted as Dynamic Transformation (DT) from austenite to ferrite receiving interest over the past years [6]. The possibility of the

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transformation was studied not only above normal equilibrium transformation but also below Ae_3 i.e. during quenching or cooling to room temperature [13]. It was shown that dynamic transformation of ferrite could be performed above paraequilibrium Ae_3 in plain low carbon steel. The volume fraction of ferrite can be increased with increasing the strain during the rolling process [14]. However, the process did not appear below the critical strain level. It was suggested that the stored energy in deformed austenite provides a driving force for this transformation. Because of short time transformation accompanied with high density of dislocations, this process can be called as massive transformation which may contain cementite particles as well as cementite films along the ferrite grains [14]. However, massive transformation can also be performed by a large undercooling [15].

The austenite hot rolling texture has been extensively investigated showing the main components of copper, brass and goss in austenite phase [16]. In transformation from austenite to ferrite, it was seen that the cube orientation can be transformed into goss, rotated goss and rotated cube [17]. Formation of goss and rotated goss orientation can also be indicative of austenite recrystallization prior to transformation of gamma (fcc) to alpha (bcc). However, formation of rotated cube from brass component is not an infallible sign of prior austenite recrystallization [16,17]. Transformation from deformed austenite is found to be complex due to the occurrence of variant selection and existence of high number of parent orientations rather than cube component [16] discussed above. It was shown that the copper texture {112} ⟨111⟩ can be replaced by transformed copper {113} ⟨110⟩ orientation which consequently reforms to {112} ⟨110⟩ and then {223} ⟨110⟩ at lower temperature [16,18]. Furthermore, during the gamma (fcc) transformation to alpha (bcc) the brass component was seen to transform to {332} ⟨113⟩ anisotropy and then {554} ⟨225⟩ with decreasing time [19]. In addition to the effect of temperature, chemical composition can be effective on the texture formation. For instance, an increase in manganese content up to 2.48 wt% results in stronger {332} ⟨113⟩ and {113} ⟨110⟩ orientations as well as {001} ⟨110⟩ component [16]. Addition of manganese may increase the deep-drawability during the hot rolling process [20].

Texture after gamma (fcc) to alpha (bcc) transformation is derived from a complexity of high temperature, deformation, recrystallization and phase transformation [16]. It was seen that deformation mode changes towards the plate thickness of the steel during the hot rolling process and therefore leads to significant change in the texture [21]. This inhomogeneity in texture attributes to inhomogeneous and redundant shear strains performed by friction between the sheet surface and the rollers [22].

Currently, only a few works have been published on the effect of chemical composition and deformation on the grain structure and texture evolution of rough rolled steels [23,24]. In the present work, investigation was carried out in order to understand the effect of chemical composition on mechanical properties, phase transformation, dynamic recrystallization, grain structure, and texture evolution performed during and after rough rolling process. Effort was also made to introduce potential factors contributing to surface cracking.

Table 1
Chemical composition of the steel grades.

Type	C%	Si%	Mn%	P%	S%	Al (T/S)%
A	0.05	0.014	0.173	0.009	0.002	0.02/0.01
B	0.17	0.025	0.171	0.013	0.002	0.02/0.02
C	0.17	0.021	0.913	0.015	0.002	0.02/0.01

2. Experimental

The samples in the form of industrial plates were provided from POSCO in order to investigate the deformation evolution during rough rolling process and phase transformation after cooling. Table 1 shows the chemical composition of examined steels. In the process of thin slab casting (see the scheme in Fig. 1), solidification in the liquid steel with a superheat of 20–40 °C was started in copper mold converting to a semi-finished solid state material due to removal of superheat and latent heat consequently from the melt at the solidification front forming solid shells. Thickness reduction in semi-solid state was applied by supporting

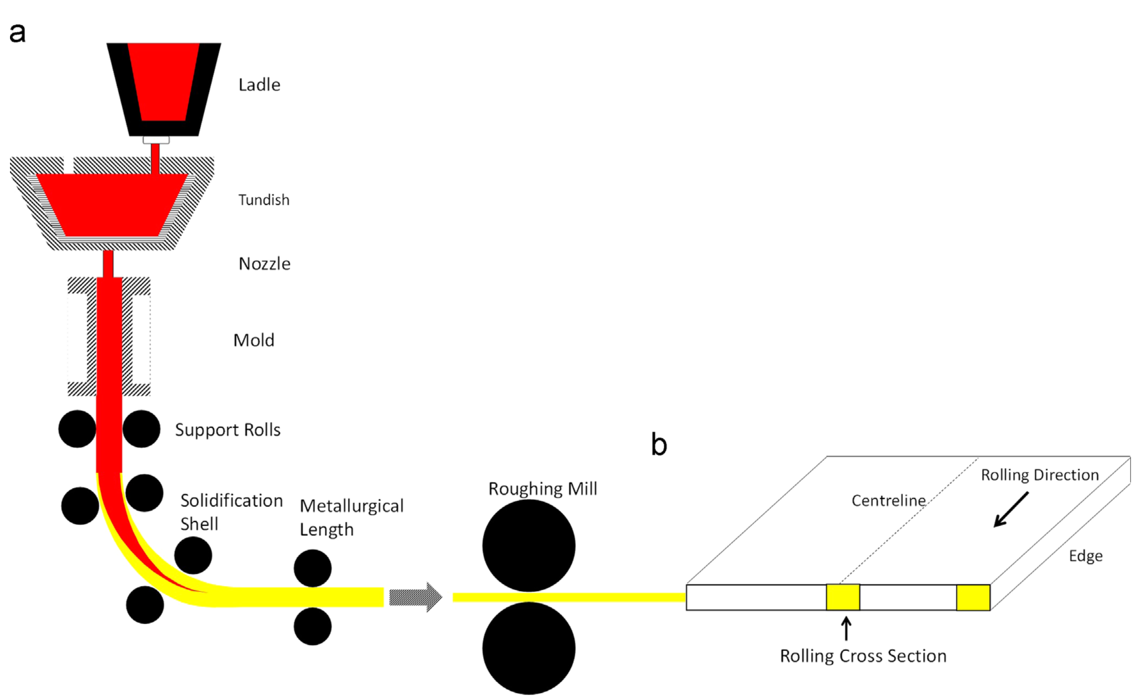

Fig. 1. Schematic demonstration of (a) continuous thin slab casting followed by rough rolling and (b) investigated regions in a rough rolling thin slab.