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Tnr Dependent Hot Rolling Microstructure and Texture Development in C-Mn Dual Phase and HSLA Steels

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Abstract. No recrystallization of austenite, Tnr, has an important influence on the transformed phase -fractions and the final crystallographic texture after hot deformation. This paper investigates the evolution of microstructure and texture components during hot-rolling in two austenitic region based on Tnr along with three different cooling trajectory and coiling in dual-phase steels and high strength low alloys steel. The recrystallization of the austenite, the austenite deformation followed by the austenite-to-ferrite transformation influence the final microstructure and texture in dual phase steels, have been examined by means of optical microscopy, X-ray diffraction (XRD) measurements. Recrystallized and deformed austenite have clearly different texture components and, due to the specific lattice correspondence relations between the parent austenite phase and its transformation products, the resulting ferrite textures are different as well.

Introduction

The hot rolled low alloy steels are mainly pearlite and ferrite and arranged in layers. In longitudinal section, this arrangement is visible as a banded structure [1,2]. The hot rolled bands are remains inalterable after cold rolled and continuous annealing of dual phase steels, since during the intercritical heat treatment austenite formation takes place only in the carbon-rich regions featuring pearlite, while the low-carbon regions remains with ferrite [3]. During rapid cooling, martensite or bainite form in the regions previously occupied by pearlite. The banded appearance of the microstructure affects mainly the ductility and the impact energy of the steel, while other microstructural banding is due to the segregation of substitutional alloying elements during dendritic solidification. Several investigations have shown manganese to be the alloying element most responsible for the development of microstructural banding in low alloy steels [4,5]. Moreover, austenitising temperature, austenite grain size, and cooling rate influence the severity of microstructural banding [6]. In the literature effect of Tnr temperature on the microstructural banding along with texture evolution has not been explored. In the paper hot rolling microstructure along with crystallographic texture has been investigated after deformation above and below Tnr along with coiling at different temperatures at the run out table.

Experimental Procedure

Two dual phase steel variants and one high strength low alloy steel (HSLA) with the compositions listed in Table 1 has been used in this study. The dual phase steel alloy DP6 has low carbon and manganese than alloy DP8. The alloy HSLA has low carbon and manganese among the all three alloys. The casted block of these alloys were received from the industry which were pre rolled and later hot rolled according to the hot rolling scheme shown in figure 1.

In order to design the hot rolled experiment scheme shown in figure 2 the Tnr temperature and critical temperatures were determined from the hot torsion tests from the sample of same casted and pre rolled blocks.

The steel blocks were reheated to 1200°C for 1800s subsequently these blocks were hot rolled above Tnr and below Tnr with total reduction of 83% from 37mm to 6mm in the final thickness. After the hot rolling at the run out table these steels were cooled fast 30°C/sec and air-cooled and coiled at different temperature to form different combinations of two-phase material. After hot rolling and coiling at different temperature leads to for three types of two phase microstructures like Ferrite+Martensite, Ferrite+Bainite and Ferrite+Pearlite. These three types of two-phase microstructures had two types of austenite deformation condition depending upon the Tnr. In first case where austenite was deformed above Tnr temperature and subsequently coiled at different temperatures to form three types of two-phase microstructures. On the other hand in the second case austenite was deformed below the Tnr and subsequently coiled at different temperatures to form three two-phase microstructures. These three types of two-phase microstructures for all the three steels are shown in the following sections.

Table 1 - Chemical composition

	C	Mn	Si	Nb	Cr
DP6	0.09	1.63	0.25	< 0.001	0.057
DP8	0.13	2.00	0.25	<0.001	0.055
HSLA	0.06	1.32	<0.008	0.0034	<0.006

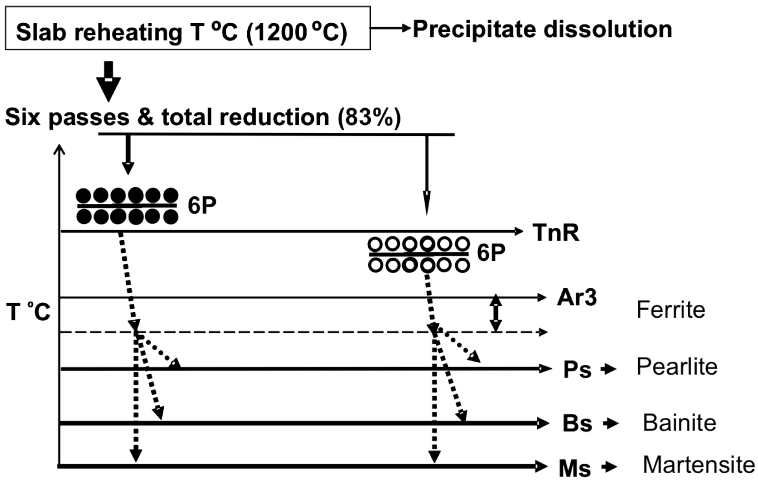

Figure 1 - Schematic of hot rolling schedule

Results

Martensite-ferrite microstructure. Figure 2 shows the two-phase microstructure consisting martensite along with ferrite for the both dual phase steels compositions. The hot rolling deformation induced above Tnr has non banded microstructure while below Tnr gives banded structure with alternate ferrite martensite bands in both the dual phase steels DP6 and DP8 alloys. The amount of second phase martensite is higher in above Tnr hot rolling than below Tnr hot rolling for both the alloys. The grain size is smaller after hot rolling below Tnr compare to above Tnr. The alloy DP6 has slightly more ferrite formation as compare to the alloy DP8. The amount to martensite is high in alloy DP8 in comparison to alloy DP6 in both hot rolling conditions.

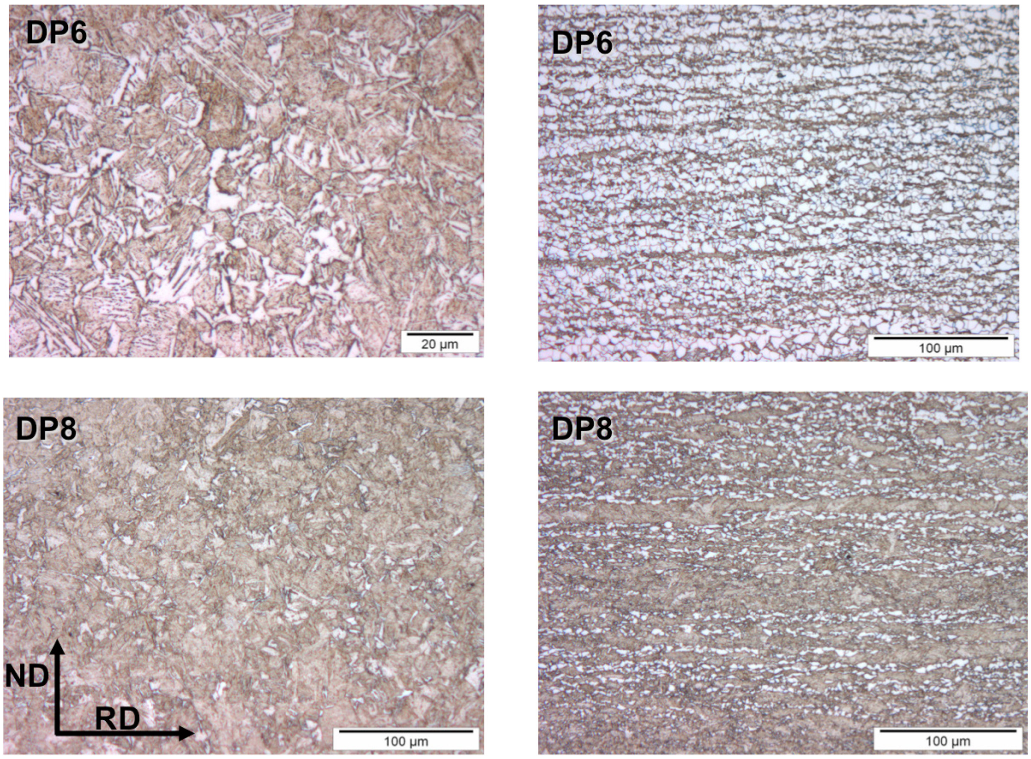

Figure 2 - Martensite-Ferrite microstructure after hot rolling above Tnr (left) and below Tnr (right) with coiling at 350°C

Bainite-Ferrite microstructure. Fig.3 shows the two-phase microstructure consisting bainite with ferrite for the dual phase steels compositions and also for high strength low alloy steel composition. The hot rolling deformation induced above Tnr has more bainite then ferrite in both the dual phase steels DP6 and DP8 alloys However, DP6 has slightly more ferrite as compare to DP8. On the other hand hot rolling deformation below Tnr also leads to two phase ferrite-bainite banded microstructure with higher amount of ferrite (80%) than hot rolling above Tnr also bainite volume (80%) is higher in DP8 in comparison to DP6 which has (20%). The bainite-ferrite grain structure is more equi-axed after hot rolling above Tnr in the alloys DP6, DP8 and HSLA however, during hot rolling below Tnr shows bainite-ferrite grains elongated along the rolling direction with fine grain size. The grain size of bainite-ferrite after hot rolling below Tnr is large in HSLA with least amount of carbon and manganese, medium in DP6 with medium amount of carbon and manganese and smallest in DP8 with high amount of carbon and manganese. The alloy DP8 also shows some with very fine grain size bands along the rolling direction after etching.

Ferrite-Pearlite microstructure. Fig. 4 shows the two-phase microstructure consisting of pearlite along with ferrite after hot rolling above Tnr and below Tnr for the DP and HSLA steels. For all the alloys hot rolling above Tnr results in larger grain size of the pearlite-ferrite microstructure than hot rolling below Tnr. In alloys DP6 and DP8 pearlite and ferrite appear in alternate bands for both hot rolling conditions. It is also important to note that the bands are elongated along the rolling direction and are finer after hot rolling below Tnr compared to hot rolling above Tnr. The pearlite phase in HSLA is also organized in narrow bands after hot rolling below Tnr while it is randomly distributed after hot rolling above Tnr.

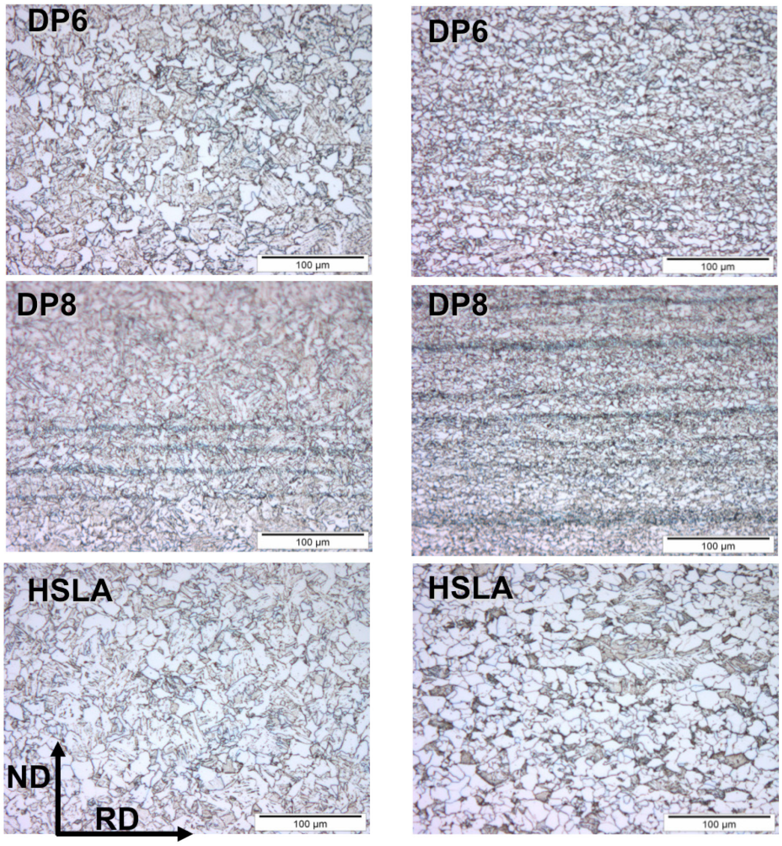

Figure 3 - Ferrite-Bainite microstructure after hot rolling above Tnr (left) and below Tnr (right) along with coiling at 450°C

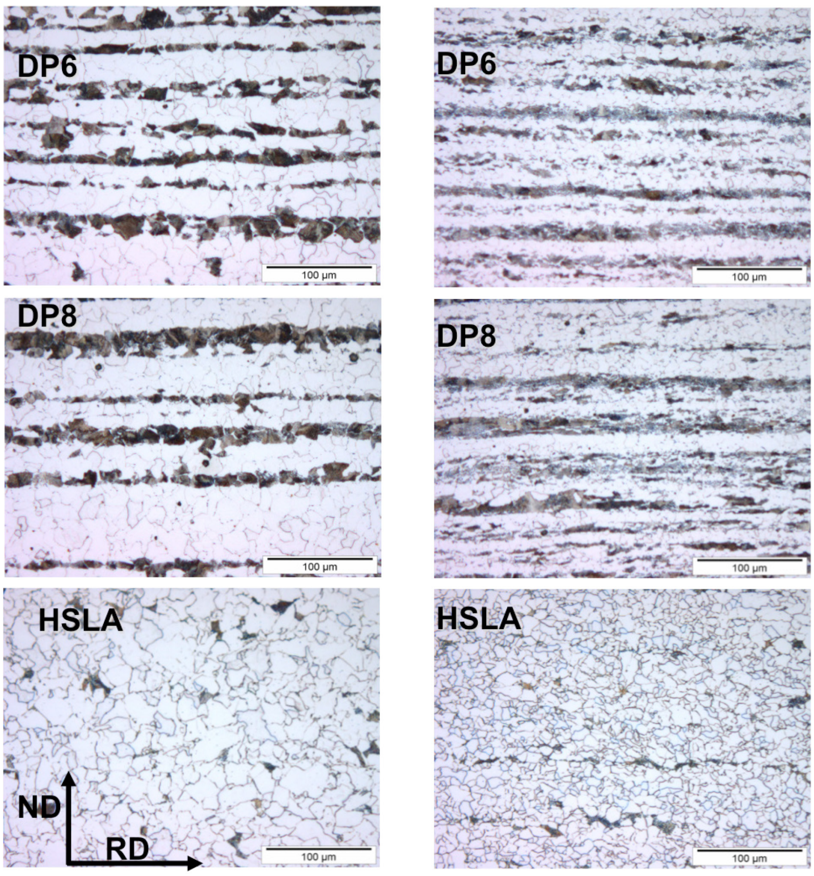

Figure 4 - Ferrite-Pearlite microstructure after hot rolling above Tnr (left) and below Tnr (right) with coiling at 600°C

Texture evolution. The intensity of alpha fibre, {554}<225> and {110}<001> (Goss) orientations was extracted from the ODFs and is shown in figure 5. The alpha fibre intensity has been plotted as a function of the angle Φ. The orientation at Φ=0° is the rotated cube. For all conditions, the maximum texture intensity is located at the rotated cube orientation or, in a few cases, close to it along the alpha fibre. The rotated cube orientation intensities after hot rolling above and below Tnr are usually similar except for the HSLA alloy with bainite-ferrite microstructure and for the DP8 with martensite-ferrite and pearlite-ferrite microstructures. In general, the texture intensity in the partial alpha fibre range (Φ=0 - 55°) after hot rolling below Tnr is higher or equal to the one after hot rolling above Tnr, except for the HSLA alloy with a bainite-ferrite microstructure.

The orientation at Φ=90° along the alpha fibre is the Rotated Goss and corresponds to a local maximum after hot rolling above Tnr, except for DP8 alloy with pearlite-ferrite microstructure. The intensity of the Rotated Goss orientation is always higher or equal after hot rolling performed above Tnr in comparison to hot rolling performed below Tnr. Similarly the intensity of the Goss orientation obtained after hot rolling above Tnr is also higher or equal to the one after hot rolling below Tnr, except for the HSLA alloy with a bainite-ferrite microstructure. These differences are the most visible for the two DP alloys with bainite-ferrite microstructure. In all cases except for the HSLA alloy with a bainite-ferrite microstructure the intensity of the {554}<225> orientation is higher after hot rolling below Tnr than after hot rolling above Tnr.

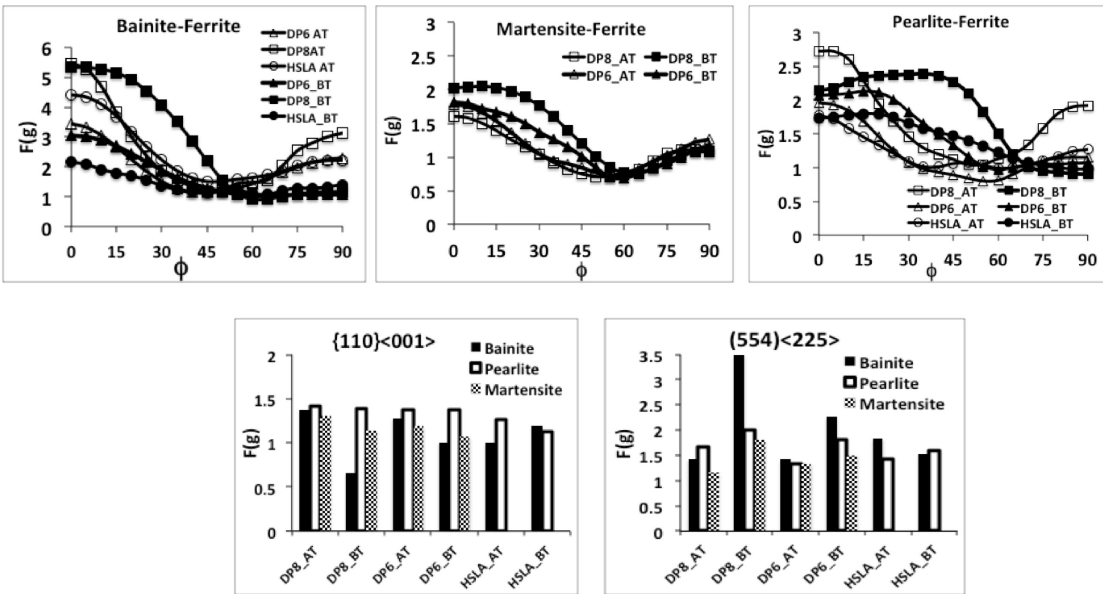

Figure 5 - Alpha fibre (top) and {110}<001> and {554}<225> orientations (bottom) for Bainite, Pearlite and Martensite phases

Discussion

The effect of hot rolling temperature in austenite followed by different cooling rate upto different coiling temperature has been has been varied in the present study to investigate the banded nature of the two- phase microstructures. The banding severity has been summarized for all the three alloys with different experimental conditions in the figure 6.

During the hot rolling in above Tnr austenite region followed by slow cooling up to 600 C coiling the ferrite-pearlite microstructure formed in alternate band of ferrite and pearlite. Which is similar to the typical hot rolling microstructure reported in literature [8,9] for low carbon steels. Which was reported as the term microstructural banding and used to describe a microstructure consisting of alternating bands of pro-eutectoid ferrite and pearlite. This banding mainly depends on three factors: the micro segregation of alloying elements, the cooling rate (or in general the imposed temperature profile) during the transformation, and the austenite grain size. Offerman et al [9] have confirmed that the ferrite/ pearlite bands are strongly related to the micro segregation of alloying elements like manganese and chromium. When cooling was fast with lower coiling temperatures 450 and 350 induces large undercooling which results in non-banded microstructure that formed almost full bainite and martensite microstructure. In a similar composition 0.15 mass% C, 1.40 mass% Mn Thompson and Howell [7] investigated microstructural banding and concluded that increasing the cooling rate from the austenitic condition reduces the intensity of banding because it reduces the Ar3 temperature differences of the segregated bands. In the case of alloy HSLA with low manganese and chromium does not show banding.

□ No band ☰ Weak band ▤ Strong band

	>(Tnr)		(Tnr>)	
$\alpha + \alpha_P$	DP6	▤	DP6	▤
	DP8	▤	DP8	▤
	HSLA	□	HSLA	☰
$\alpha + \alpha_B$	DP6	□	DP6	☰
	DP8	□	DP8	☰
	HSLA	□	HSLA	☰
$\alpha + \alpha_M$	DP6	□	DP6	▤
	DP8	□	DP8	▤

Figure 6 - Microstructural characters evolution in C-Mn steels

The fig. 6 also summaries the banding observed after hot rolling in below Tnr austenite region followed by cooling up to different coiling temperature. During slow cooling up to 600 C coiling the fine grain ferrite-pearlite microstructure formed in closer alternate bands of ferrite and pearlite that are different than the bands appear above Tnr. During hot rolling below Tnr leads to high stored energy in pancaked austenite and leads to large nucleation sites of ferrite during phase transformation. Similarly, when pancaked austenite was cooled fast and low coiling temperatures leads to formation of fine alternate band of ferrite-martensite and weakly banded bainite. .

The thermo-mechanical process like hot rolling where austenite undergoes straining depending upon the Tnr get recrystallization or non-recrystllisation microstructure normally changes the texture evolution. The recrystallized austenite and non-recrystallised austenite undergo transformation to ferrite, which leads to evolution of different texture components as shown in schematic figure 7. It can be seen that, at temperatures above the Tnr, the deformed austenite grains (containing fcc deformation textures) are regularly converted into equiaxed grains (containing the "cube" or fcc recrystallization texture. Once recrystallization takes place, the rolling components are largely replaced by the recrystallization or cube component, which is identified as the {001}<010>. The physical mechanisms involved in the formation of the cube texture are discussed in [11] and are also reviewed briefly below. The principal component present in recrystallized fcc materials, such as austenite, is the cube or {001}<010> orientation. During transformation, although in fact 24 K-S (or 12 N-W) products are formed, their locations can be readily represented by their "averages," that is, by the three Bain products of the cube parent. Given that 45°<100> rotations are involved, inspection of Fig. 5 indicates that these are the Goss {110}<001>, the rotated Goss {110}<110>, and the rotated cube {001}<110>. Thus, the presence of the first two of these orientations in transformed steels (i.e., in ferrite) is a sign that the austenite was recrystallized prior to transformation. As the rotated cube can also be formed from the Br (i.e., from deformed austenite), see below, its presence is not an infallible sign of prior austenite recrystallization.

The intensity of the cube component generally increases (and that of the retained rolling component decreases) with the accumulated strain prior to recrystallization. As indicated in figure 7 the principal component present in recrystallised austenite is cube orientation. During γ-α transformation, cube transforms to rotated cube, Goss and rotated Goss. Because cube replaced three components, the intensity of each is about one-third of that original cube. This is a general feature of transformation textures, in that product textures are usually much less intense than parent textures. In the present result the intensity of rotated cube, Goss and rotated Goss shows weak changes in the intensity for the different phases bainite, martensite and in pearlite with hot rolling above Tnr to Hot rolling below Tnr. However, these changes are similar as expected theoretically expected for single-phase ferritic steels after transformation in similar conditions.

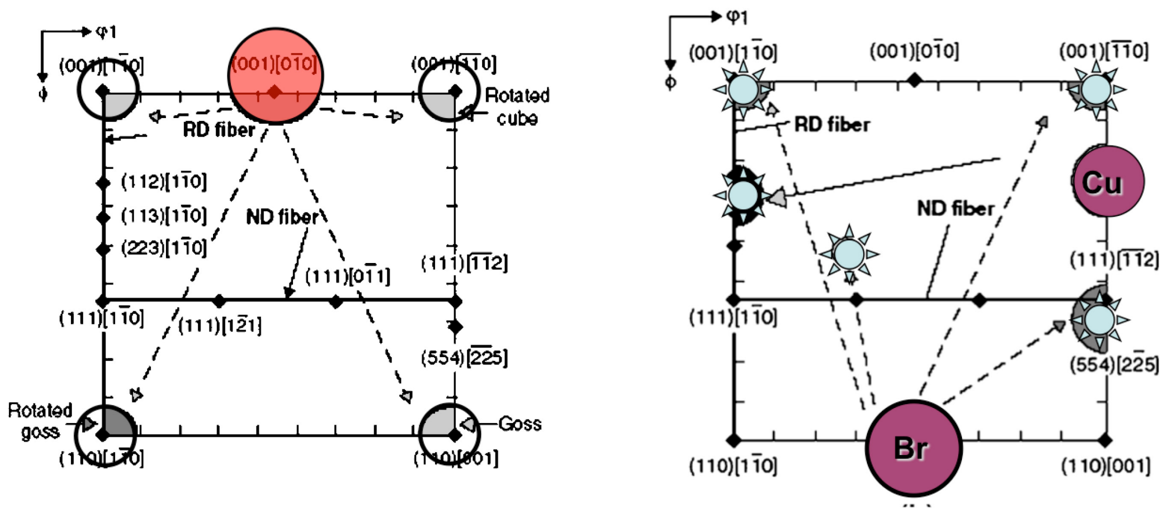

Figure 7 - φ2-45° section of Euler space showing bcc texture components formed from recrystallised austenite (left) and non-recrystallised austenite (right)[12]

The transformation behavior of deformed austenite is considerably more complex for two reasons. One is that many more parent orientations are present than the single cube considered previously. Each of these can be expected to be responsible for a number of products. The other is the occurrence of variant selection, which is discussed below. Because of these complications, it has been a considerable challenge to unravel the physical events occurring during the transformation and therefore to predict the texture of such materials in a reliable way [12]. The principal features of the texture changes taking place during transformation after austenite deformation below Tnr are summarized in Fig. 7 right. Here, the dominant Cu, Br, and Goss components of the parent rolling texture can be readily identified in the φ2=45° cross section. The components between Cu and Br, including the S, cannot be seen in this section as they are out of the plane of the diagram. The figure shows how the Cu is replaced by what is known as the “transformed Cu” or {113}<110> to {112}<110> on the LH side of the diagram. The Br transforms into the following components, which are also identified in the illustration: the “transformed Br” or {554}<225> to {332}<113> on the RH side.

It is understood from the above literature summary of single phase ferrite transformation texture components it can be concluded that appearance/change in intensities of alpha fibre, (554)<225>, cube, Goss and R-Goss components clearly reflects the type of austenite it transforms. The transformation texture results for the two phases are presented in figure 5, which shows the overall comparison of the intensities of important aforesaid components for different product phases of the all the alloys DP6, DP8 and HSLA. The overall intensities of all two phase product texture components are in general weak except in bainite. The weak intensity is expected after transformation after hot rolling [12]. The austenite deformed above Tnr shows the major appearance/maximum intensity of rotated cube, Goss and rotated Goss texture components for the second phase pearlite, bainite and martensite along with first phase ferrite of DP6, DP8 and HSLA. As reported in pervious studies the austenite deformation above Tnr temperature produces have cube orientation and it transform to ferrite with rotated cube, Goss and rotated Goss orientation in ferritic steels. Similar observations are observed also in two-phase product phases with little variation in texture intensities. The austenite deformed below Tnr shows relatively increased intensity in alpha fibre and {554}<225> orientation along with weak intensity of rotated cube, Goss and rotated Goss texture components for the second phase pearlite, bainite and martensite along with first phase ferrite of DP6, DP8 and HSLA. These results are similar to the reported earlier that austenite deformation below Tnr leads to beta fibre components after transformation in ferritic and bainitic steels [13]. Also compositional difference in steels does not affect the product texture and it is similar to single phase IF steels however, intensities are different for different product phases.

Conclusions

The Tnr of austenite is an effective parameter of hot deformation for controlling the texture and microstructure during hot rolling followed by run out table in steels.

The deformation of austenite above Tnr followed by fast cooling at run out table, which forms Marteniste, and Bainite with ferrite does not does not show microstructural banding. However below Tnr reveals banding in martensite but not in bainite but in both phases have fine grain size. Pearlite with ferrite shows banding either case but the banding width is smaller along with fine grain size.

The texture after austenite deformation above Tnr reveals rotated cube, Goss and rotated Goss after γ-α transformation for all two-phase microstructures of the alloys DP6, DP8 and HSLA. The texture after austenite deformation below Tnr reveals transformed Cu and Transformed Br after transformation for all two-phase microstructures of the alloys DP6, DP8 and HSLA. These texture changes are similar to the simulated texture after transformation in single-phase ferritic steels.

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