Efeitos dos laminados a quente e a morno na microestrutura, textura e propriedades de aços baixo carbono

Effects of hot and warm rolling on microstructure, texture and properties of low carbon steel

Roberto Gerardo Bruna
Graduated from the Universidad Tecnológica Nacional of San Nicolás in Metallurgy Engineering and received a master in Siderurgy from Universidad de Buenos Aires in 2004.
In 1992 and currently he works as senior metallurgist for Ternium, Argentina
rbruna@ternium.com.ar

Resumo

É conhecido que variações de processo durante o tratamento termomecânico causam efeito marcante na microestrutura e nas propriedades mecânicas de aços baixo carbono. Vários trabalhos já foram publicados sobre o efeito da composição química, temperatura de reaquecimento, temperatura de laminação de acabamento, temperatura de bobinamento, quantidade de redução durante a laminação a quente e na laminação a frio e temperatura de recozimento nas propriedades mecânicas desses aços. Existem, no entanto, alguns pontos contraditórios na literatura.

Nesse trabalho, são estudados os efeitos da temperatura de término de laminação e a temperatura de bobinamento na microestrutura, recristalização e textura dos aços baixo carbono laminados a quente e a morno em condições industriais. Os efeitos na microestrutura, textura cristalográfica e propriedades são apresentados e discutidos. Adicionalmente, o presente estudo analisa os possíveis mecanismos metalúrgicos responsáveis pelas microestruturas e propriedades mecânicas obtidas.

Palavras-chave: Recristalização, laminado ferritico, textura, aços baixo carbono, energia de defeito de empilhamento (EDE).

Abstract

It is well-known that variations in the thermomechanical processing can have a profound effect on the microstructure and mechanical properties of Low Carbon steels. Numerous studies have been published on the effect of composition, slab reheating temperature (SRT), hot rolling finishing temperature (FRT), coiling temperature after rolling (CT), amount of deformation during hot and cold rolling, and annealing temperature on the mechanical properties of LC steels. There are, however, some disagreements in the results presented in the literature.

In this work the FRT and CT effects on the microstructure, recrystallization behavior and texture of LC steels rolled under hot and warm-rolling industrial conditions were investigated. The results in terms of the microstructure, crystallographic texture and properties are shown and discussed. In addition, this study will present the possible mechanisms responsible for the microstructure and mechanical properties observed.

Keywords: *Recrystallization, textures, ferritic or warm rolling, low carbon steels, stacking fault energy.*

1. Introduction

Conventional hot rolling takes place at temperatures above the austenite to ferrite transformation while warm or ferritic rolling takes place below the two phase (α+γ) region (Messien et al., 1991; Herman et al., 1991). The transition from "hot" to "warm" rolling leads to an important change in metallurgical physics. Austenite restoration differs from ferrite softening mechanisms, being stacking fault energy (SFE) being one of the most important parameters in the competition between recovery and recrystallization mechanisms. In metals of low SFE, such as γ-iron and austenitic steels, in which recovery processes are slow, dynamic recrystallization (DRX) during hot rolling may take place when a critical deformation condition is reached (Sellars, 1986). In metals of high SFE, such as α-iron and ferritic steels, dislocation climb and cross-slip occur readily and due to dynamic recovery is rapid and extensive and is usually the only form of dynamic restoration which that occurs (Langner & Bleck, 1998; Humphreys & Hatherly, 1995; Akbari et al., 1997).

Warm rolling has gained interest as means of cutting down costs and of extending the application range of hot rolled products (Herman & Leroy, 1995). This requires diminishing the temperatures of the whole process from 1250-850°C to approximately 1100-700°C. The possibility of adopting this practice is borne upon the feasibility of insertion into the usual practices of austenitic rolling.

The present work investigates the metallurgical aspects of the process, whose control is not yet completely developed; focusing on the delineation of the necessary conditions to make viable this technique feasible as a "flexible" process for industrial production of low carbon steel.

2. Material and methods

Chemical composition of the experimental steel used in this study is shown in Table 1. Hot and warm rolling trials were carried out by using an industrial six (6) stand hot strip mill (HSM). The industrial trials started from continuously casted 200 mm thick slabs reheated at 1250°C for 2 hours followed by conventional hot rolling in a roughing mill to 31mm. The transfer bars were air cooled to 1040°C for hot rolling and 900°C for warm rolling practices and subsequently rolled in 6 passes to 1.6mm thickness without applying lubrication on the work rolls. The total strain in ferrite region was estimated to be 1.07 considering variations in the rolling forces as an indication of the austenite to ferrite transformation. The FRT was ~ 760°C for the warm rolling, and 850~870°C in case of the hot rolling practice. After rolling the strips were cooled to 500~730°C for coiling. Tensile samples from the hot band material were machined and tested to measure r-values and mechanical properties. Texture measurements were conducted through the strip thickness.

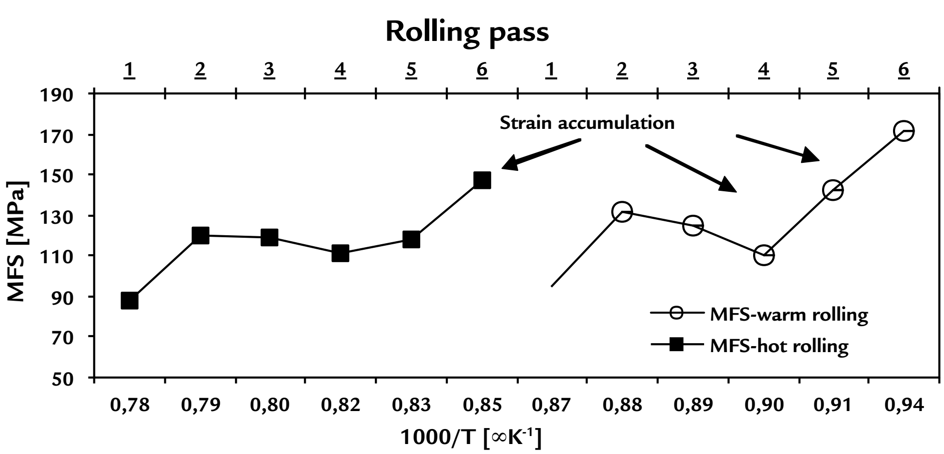
Grade	C	Si	Mn	S	P	Al	N
LC	0.04	0.02	0.20	0.009	0.015	0.043	0.005

Table 1
Chemical composition (wt. %) of the experimental LC steel.

3. Results

Resistance to deformation (mean flow stress)

Figure 1 shows the mean flow stress (MFS) at each stand as a function of the inverse absolute temperature. Values were calculated from the reduction, rolling force and strip width using the Sims approach (Sims, 1954). The corrections for roll flattening, redundant strain, and forward slip between roll and strip were taken into account in these calculations



	Pass	F1	F2	F3	F4	F5	F6
Warm rolling	Strain	1,20	0,84	0,70	0,54	0,33	0,20
	Strain rate [s^{-1}]	10	26	58	105	131	130
Hot rolling	Strain	1,05	0,82	0,65	0,52	0,42	0,27
	Strain rate [s^{-1}]	11	28	58	101	154	172

Figure 1
MFS vs. 1000/T chart for the hot and warm rolling modes.

and have been described by Siciliano et al., 1996.

During warm rolling an abrupt drop in MFS occurs in the fourth pass; this appears to be associated with the start of the austenite-to-ferrite transformation. The temperature in this pass, 840°C, is near the Ar_3 temperature, 855°C, calculated using the equation of Blás et al., 1989.

Microstruture and properties

Figure 2 shows the influence of the FRT on the microstructure. After conventional hot rolling a homogeneous ferrite microstructure with equiaxial fine grains 9-10 ASTM was obtained (a). On the other hand, intercritical rolling showed a heterogeneous microstructure with duplex grain sizes 7-10 ASTM (b). This behavior appears to indicate the occurrence of different softening mechanisms. In sharp contrast to hot rolling, the warm rolling microstructure exhibits bigger grain sizes 5-6 ASTM with irregular shape (c).

Figure 3 shows the influence of coiling temperature on the microstructure after warm rolling. At the higher coiling temperatures (a), the microstructure consists of very coarse ferrite grains with low hardness. If the coiling is performed at intermediate temperature 650°C), the ferritic microstructure is partially recovered and some recrystallization takes place. In addition elongated (highly deformed) grains in the rolling direction are still present (b). Coiling at low temperature (500°C) leads to a non recrystallized and hardened microstructure. Sawed edges on grains (bulging) indicate an incipient recovery of the microstructure (b, c).

Figure 4 shows the effect of coiling temperature (CT) on yield strength of low carbon steel strip. The lower yield strength of the warm rolled material coiled above

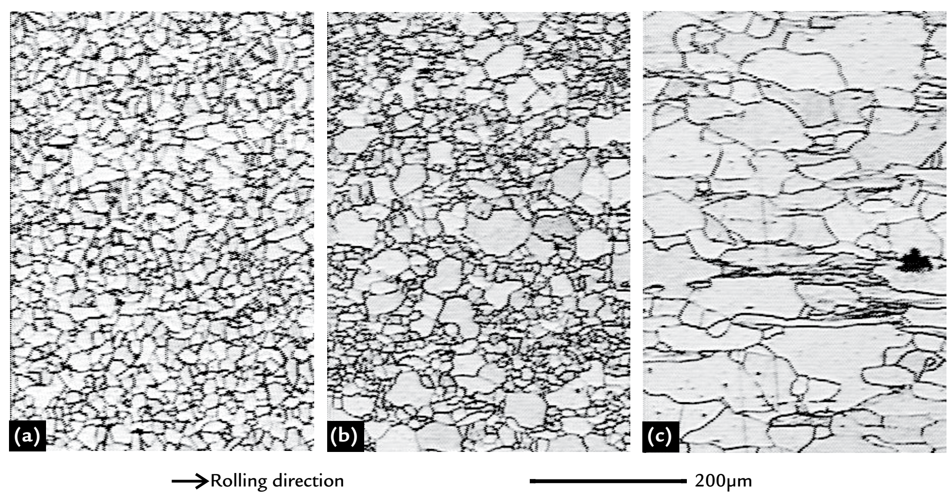


Figure 2
Influence of the final rolling temperature (FRT) on the microstructure of hot-rolled LC steel (t= 1.6 mm) after austenizing at 1250°C: FRT = 870°C (a); FRT = 830°C (b) and FRT = 760°C (c).

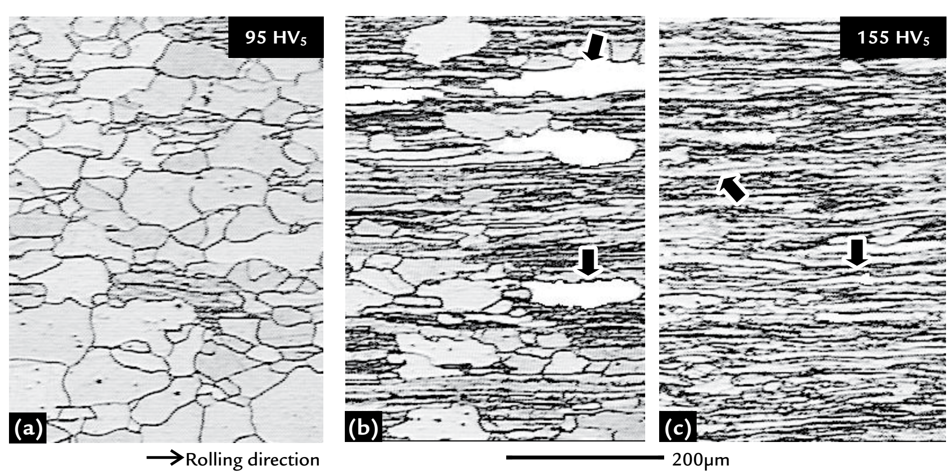


Figure 3
Influence of the coiling temperature (CT) on the microstructure of warm-rolled LC steel after finishing at 760°C (t = 1.6 mm): CT = 700°C (a); CT = 650°C (b), CT = 500°C(c).

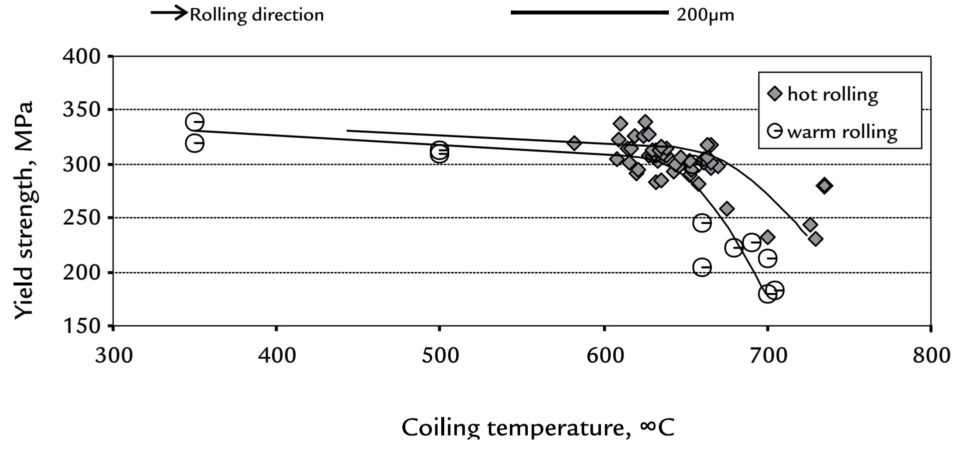


Figure 4
Effect of coiling temperature on yield strength of low carbon steel strips (t=1.6mm).

650°C is due to the larger grain size when compared to hot rolled material.

For low coiling temperatures (approximately < 620°C), yield strength is almost independent of finishing temperature.

Figure 5 presents the r-values of the strips. After rolling in the austenitic range, the LC steel presented r- values near1. Some deleterious effect was observed when the rolling was done in the ferrite region, the warm-rolled LC steel presented more negative values of planar anisotropy (Δr= -0.7) than those obtained with a hot-rolled LC steel (Δr= -0.03).

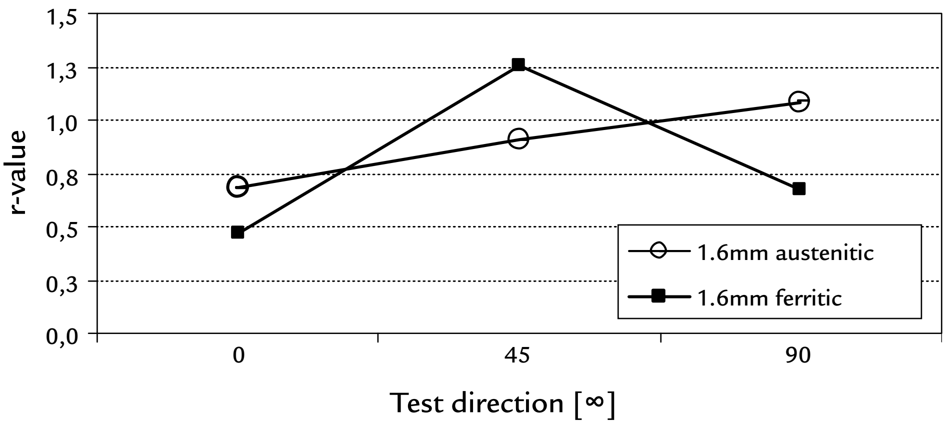


Figure 5
Measured r_m normal anisotropy values for LC steel (t=1.6mm).

Texture

Figures 6 and 7 present the skeleton lines measured at the center of strip(s=0). After hot rolling at 870°C, a weak transformation recrystallization texture is formed which is a consequence of the γ→α transformation from an almost re-

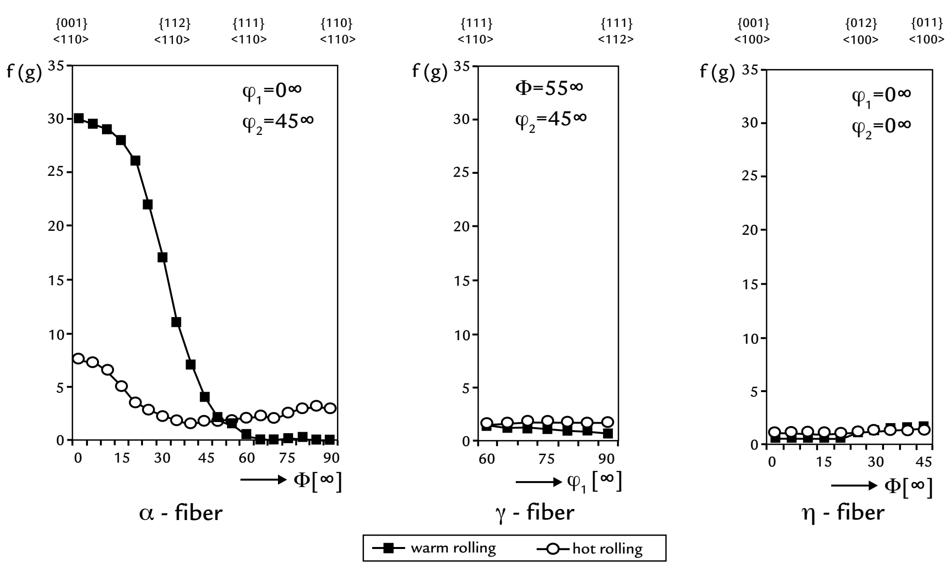


Figure 6
Skeleton lines measured at the center (s=0) of strip.

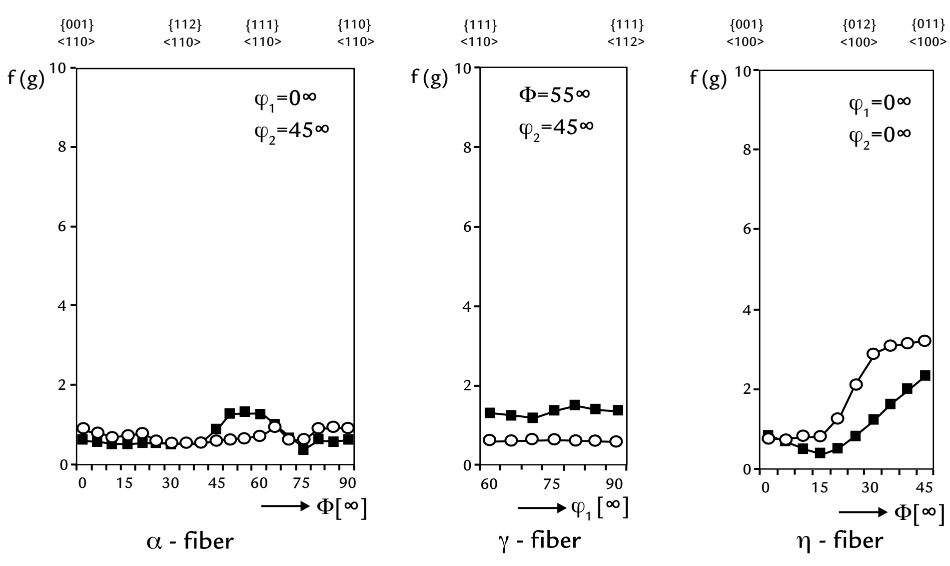


Figure 7
Skeleton lines measured near to the surface (s=0.8) of strip.

crystallized austenite. After warm rolling at 760°C, a characteristic feature is the strongest intensity in the RD α-fibers, extending from {001}<110> to {112}<110> with an intensity of 30 to about 17 times that of a random intensity. There is a slight indication of a shear texture near the surface region (s=0.8) showed as a Goss orientation {011}<100> in the η fiber, which is due to the heavy deformation applied during rolling without lubrication.

4. Discussion

Recovery and recrystallization

Analysis of the mean flow stress (MFS in Figure 1) can be helpful in understanding the microstructural events that occur during hot rolling. The MFS naturally increases as the temperature decreases. Therefore, a change of slope between two consecutives rolling passes could point to the beginning of DRX. In the hot rolling mode, according to the present MFS variations, DRX occurs in passes 2 and 3 because the strain rates and temperatures are quite high, and the strain rates are lower. The analysis indicates that some strain accumulation (partial recrystallization) can occur in the later pass due to the relatively low temperatures involved. In ferrite region the MFS values increased more rapidly than for the austenitic hot rolling when deformation temperature decreased. The higher increase of MFS is the consequence of the sensitivity of dynamical strain aging (DSA) by a high solute carbon content at the strain deformation (Dadras, 1978; Bergstrom & Roberts, 1971).

Warm rolling schedule exhibited ferrite grains strongly elongated after coiling at low temperature. Saw edges on grains (Figures 2, b-c) indicate a certain recovery of the ferritic structure during rolling. This could be associated to the crystallographic nature of ferrite (high SFE), which gives a higher mobility to partial dislocations during deformation, mainly during the initial rolling steps in ferrite where temperature is higher. This fact, together with the verification of the existence of an intense partial RD//<110> α fiber, with a peak of H component, and a weaker ND//<111> γ fiber, allow us to infer that the recrystallization of ferrite could be developed through a low stored energy mechanism known as SIBM (strain induced boundary migration). The mechanism involves the bulging or migration of part of a pre-existing grain boundary to the interior of a more deformed grain, leaving behind a region virtually free of dislocations (Beck & Sperry, 1950). This mechanism may be responsible for the exaggerated grain growth observed when the material is coiled at high temperature (Figure 2, a). The present results are in agreement with the work of Bleck (Bleck et al.,1993) who also found a similar dependence with the temperature at industrial production.

Properties and rolling textures

Yield strength is almost independent of finishing temperature if low coiling temperatures are applied, Figure 4. In spite of the differences in grain size and recrystallization degree, yield strength could be mainly governed by nitrogen and carbon contents. Both elements will contribute to ageing; nitrogen depending on the amount of AlN precipitation, carbon on carbide distribution. If nitrogen is fixed by high coiling temperature or due to incomplete dissolution lower yield strength levels can be obtained. Larger grains at higher coiling temperatures after ferrite rolling further contribute to low yield strength values, as those obtained in this work.

The measured negative planar anisotropy (Δr= -0.7) for warm rolled strip indicates a tendency to ear formation. Estimations from texture modeling by Ray (Ray et al., 1994) indicate the {112}<110> deformation texture component as the most responsible for ear formation. This texture component with an intensity of 17-random was found in the present work.

On the other hand DePaepe et al., 1997 demonstrated that the intensity of the unfavorable {100} and {110} orientations in the recrystallization texture increases with increasing solute C-content in the ferrite region during the rolling and subsequent recrystallization. Therefore, the lack of alloying elements to combine with the C in the applied LC steel is expected to lead to a final texture not suitable to produce deep drawable grades, i.e. low r-values.

5. Conclusions

During warm rolling, dynamic recovery of ferrite occurs due to its high SFE, thus leading to a strained and non-recrystallized ferrite structure after coiling at low temperature. On the contrary, an exaggerated grain growth occurs if the coiling temperature is high enough. This abnormal grain growth would take place by the occurrence of SIBM.

Mechanical properties are determined by the degree of recrystallization and recovery, grain size and AlN precipitation. Low yield strength grades can be obtained after warm rolling, however, its remarkable negative planar anisotropy indicates a tendency to ear formation.

A weak texture was obtained in this unalloyed LC steel, thus, rolling would have been carried out in the recrystallization mode both for hot and warm rolling. The slight indication of a shear texture near the surface region is due to the heavy deformation applied during rolling without lubrication.

6. Acknowledgements

The author is indebted to Prof. Dr. Wolfgang Bleck from Aächen University for conducting the texture measurements and his important contribution for the metallurgical discussion. Special thanks to Dr. Fulvio Siciliano Jr. for his help with the analysis of the mill log data.

7. References

AKBARI, G.H., SELLARS, C.M., WHITEMAN, J.A. Microestructural development during warm rolling. ***Acta Mater.*** v. 45, p. 5047-5058, 1997.

BECK, P.A., SPERRY, P.R. Strain induced grain boundary migration in high purity aluminum. ***Journal of Applied Physics***, v.21, p. 150-152, 1950.

BERGSTROM, Y., ROBERTS, W. The application of a dislocation model to dynamical strain ageing in a-iron containing interstitial atoms. ***Acta Metallurgica***, v.19, p.815-823, 1971.

BLÁS, J.G. et al. Influência da composição química e da velocidade de resfriamento sobre o ponto Ar3 em aços de baixo C microligados ao Nb. In: CONGRESSO ANUAL DA ASSOCIAÇÃO BRASILEIRA DE METAIS, ABM. ***Anais...*** São Paulo, 1989. v. 1, p. 11-29.

BLECK, W. et al. Effect of temperature sequence during hot strip rolling on structure and properties of mild steels. ***Steel Research***, v.64, n.8/9, p.399-400, 1993.

DADRAS, P. Activation energy for the strain aging of mild steel. ***Trans. JIM***, v.19, p.230-232, 1978.

DE PAEPE, A., HERMAN, J. C., LEROY, V. Deep drawable ultra low carbon Ti-If steel hot rolled in the ferrite region. ***Steel Research***, v.68, n.11, p. 479-486, 1997.

MESSIEN, P. et al. Laminage ferritique de bandes à chaud minces en acier doux. ***La Revue de Métallurgie-CIT***, p. 433-442, 1991.

HERMAN, J.C., CANTINIEAUX, P., LANGLAIS, J.M. Future prospects of ferritic hot-rolled thin strip steel a new low cost approach for steel sheet production. ***Steel World***, p. 48.54, 1991.

HERMAN, J.C., LEROY, V. Ferritic hot rolling and the potential for hot rolled and cold rolled products. In: ***The Future of Flat Rolled Steel Production***, Chicago, 1995. p. 1-10.

HUMPHREYS F.J., HATHERLY, M. ***Recrystallization and related annealing phenomena***, Pergamon, 1995. 617p. cap.6, p.169-221.

LANGNER, H., BLECK, W. Fundamentals of Softening Processes during Ferrite Hot Rolling. In: ***Proceedings of 40th MWSP Conference***, ISS, Warrendale, 1998. V.35, p.345.

RAY, R. K., JONAS, J. J., BUTRON-GUILLEN, M. P., SAVOIE, J. Transformation Textures in Steels. ***ISIJ International***, v.34, n.12, p. 927-942, 1994.

SELLARS, C.M. Modeling of structural evolution during hot working process. ***Annealing processes-recovery, recrystallization and grain growth.*** HANSEN, JENSEN, LEFFERS, RALPH. (Ed.). p.167-184, 1986.

SIMS, R.B. The calculation of roll force and torque in hot rolling mills. In: ***Proceedings of the Institute of Mechanical Engineers***, Professional Engineering Publishing, 1954. V. 168, p.191-200.

SICILIANO Jr, F. et al. Mathematical modeling of the mean flow stress, fractional softening and grain size during the hot strip rolling of C-Mn steels. ***ISIJ International***, v.36, n.12, p. 1500-1506, 1996.

Artigo recebido em 24 de outubro de 2008. Aprovado em 11 de outubro de 2010.