EFFECT OF CONTROLLED ROLLING PARAMETERS ON THE AGEING RESPONSE OF AN HSLA-80 STEEL

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ABSTRACT

Microalloyed steels containing copper in order to promote precipitation hardening are one of the approaches adopted to develop new materials with high mechanical strength but minimized carbon content to assure good weldability. Besides that, the thermomechanical processing of such alloys can eliminate the subsequent quench and tempering heat treatments required by conventional steels. The effects of controlled rolling parameters over the ageing response of an HSLA-80 microalloyed steel with 1.10% copper were studied in this work. The relatively weak influence over the ageing response verified when the reheating temperature was elevated from 1100°C to 1200°C indicated that copper precipitation is the main mechanism behind the hardening promoted by the ageing treatment; niobium had a secondary role. The strain degree applied during the roughing phase increased the ageing response of the alloy, but a increase in the strain degree applied during the finishing phase had no effect over this aspect. Also a finishing temperature variation did not affect significantly the ageing response of the HSLA-80 steel.

KEYWORDS: HSLA-80 Steel, Precipitation Hardening, Copper, Controlled Rolling

1. INTRODUCTION

The minimization of carbon content in structural steels has became a true obsession for steel metallurgists during the last decades, as this alloy element significantly degrades the weldability of such materials. On the other hand, carbon has a vital participation in the hardening mechanisms applied in conventional steel alloy design. This situation motivated the development of several alternative alloys to produce plates with equivalent mechanical strength but minimized carbon content. In the specific case of steel plates one can mention, for example, the hardening through copper precipitation in ferrite of HSLA-80 steel [1].

Copper precipitation in ferrite can contribute significantly to steel strength. This alloy element does not form intermetallic compounds with iron; the atomic diameter of both are quite similar. The maximum solubility of copper in austenite is 2.4% at 840°C [2]. The age hardening of copper steels, generally performed under temperatures from 500 to 600°C, promotes the precipitation of copper-rich ε particles, with diameter from 2 to 45 nm. This phase preferentially nucleates inside dislocations inside ferrite grains, as well their boundaries and sub-boundaries [1]. Electronic diffraction patterns showed that ε precipitation is mostly constituted of copper, with a lattice parameter slightly higher that that pure metal [2] and can contain up to 4% iron [3]. In commercial microalloyed steels there is in practice a simultaneous copper and niobium precipitation, as the temperature range normally used favors this occurrence [4]. One must remember that precipitation hardening decreases toughness, so this hardening mechanism must be judiciously applied [1].

Although copper precipitation hardened microalloyed steels are already being used since 30 years ago, relatively few studies were developed about the effect of controlled rolling parameters over the age hardening response of such material. For example, it is known that the use of accelerated cooling immediately after hot rolling enhances this response, as there is less time available for an undesired copper precipitation in austenite during plate cooling [5]. It was also determined that, if hot rolling finishing temperature is lower than the alloy Ar_3 temperature, age hardening response of the as-rolled material is much lower than if it is reaustenitized after hot rolling. In some cases this response can be virtually null. The reason for this decrease in hardening effect could be a possible ε dynamic precipitation in the metaestable austenite under temperatures below Ar_3 point [6].

This work will show the results got about the effects of some controlled rolling process parameters over the age hardening response of a microalloyed HSLA-80 structural steel.

2. EXPERIMENTAL PROCEDURE

The HSLA-80 steel studied in this work was melted in a laboratory vacuum induction furnace and poured in a cast iron mould. The ingot had weight of about 85 kg, 100 mm x 130 mm rectangular section and 850 mm of length. Its chemical analysis was 0.044% C, 0.65% Mn, 0.32% Si, 0.005% P, 0.011% S, 0.013 Al_{sol}, 0.87% Ni, 0.77% Cr, 1.12% Cu, 0.23% Mo, 0.077% Nb and 0.0030% N. The ingot was rough rolled to break and homogenize the as-cast structure. The specimens for the hot rolling tests were machined from these as-rough rolled rectangular bars, with 50 x 42 mm section. The dimensions of the hot rolling specimens were 42 mm x 50 mm x 100 mm.

Two series of tests were carried out to study the effect of controlled rolling parameters over age hardening response of HSLA-80 steel. The first one aimed to verify the effect of the strain degree applied to the specimen, while the other was performed in order to study the effect of finishing temperature. Specific details about the trials can be seen in Table 1. Finishing temperature in the first series of tests was kept constant at 750°C, while this parameter was equal to 700°C or 800°C in the second series.

Parameters		A		B		C		D	
Reheating Temperature [°C]		1200	1200	1200	1200	1100	1100	1100	1100
Roughing Strain	Real	0.36	0.36	0.69	0.69	0.36	0.36	0.69	0.69
	Nominal [%]	30	30	50	50	30	30	50	50
Finishing Strain	Real	0.51	1.10	0.51	1.10	0.51	1.10	0.51	1.10
	Nominal [%]	40	67	40	67	40	67	40	67
Total Strain	Real	0.86	1.46	1.20	1.79	0.86	1.46	1.20	1.79
	Nominal [%]	58	77	70	83	58	77	70	83
Final Thickness [mm]		17.6	9.8	12.6	7.0	17.6	9.8	12.6	7.0

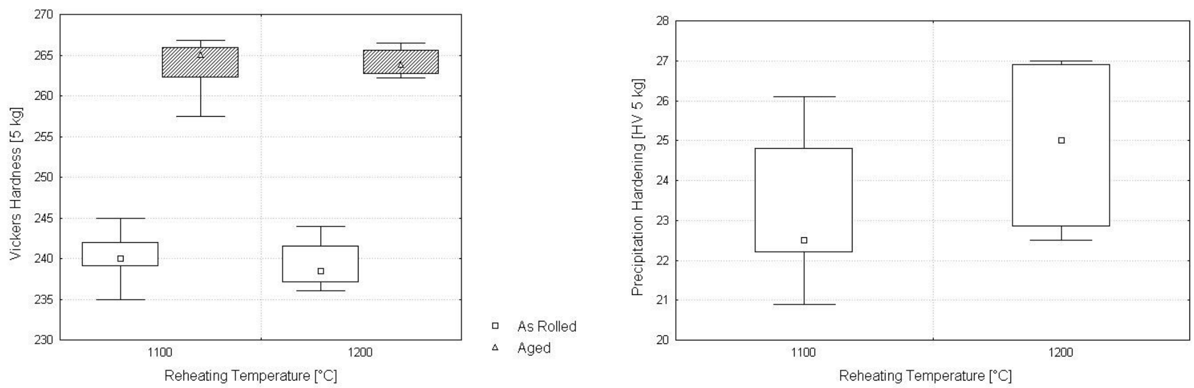
Table 1: Experimental parameters applied in the controlled rolling tests performed in this work.

The hardness of as-rolled specimens was measured along their transversal sections using the Vickers scale with 5 kg load. All surfaces were ground and polished previously to the hardness measurements. Ten hardness values were measured along the diagonal of the major face. This was done aiming to minimize the influence of eventual segregations and/or orientations present in the samples.

After that the as-rolled samples were aged at 600°C during one hour. These conditions were previously determined aiming an optimization regarding mechanical strength and toughness for the final plate [7]. Hardness measurements were also performed in the aged specimens, according to the same conditions described before. The response to ageing corresponds to the hardness difference between as-rolled and aged samples.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 1a shows the effect of reheating temperature applied during hot rolling tests over the hardness values of as-rolled and aged specimens; for its turn, Figure 1b shows the precipitation hardening got for this samples. The results indicate that a increase of reheating temperature from 1100°C to 1200°C did not promoted greater final hardness in the as-rolled samples – by the way, these values even decreased; the same fact was observed for the aged samples. The authors also verified this weak effect over yield and tensile strength of the aged HSLA-80 samples [8]. However, precipitation hardness was clearly greater for the samples reheated at 1200°C, probably indicating a slightly greater effect of a increased amount of solute niobium, but much lower than that observed for copper.



(a) (b)

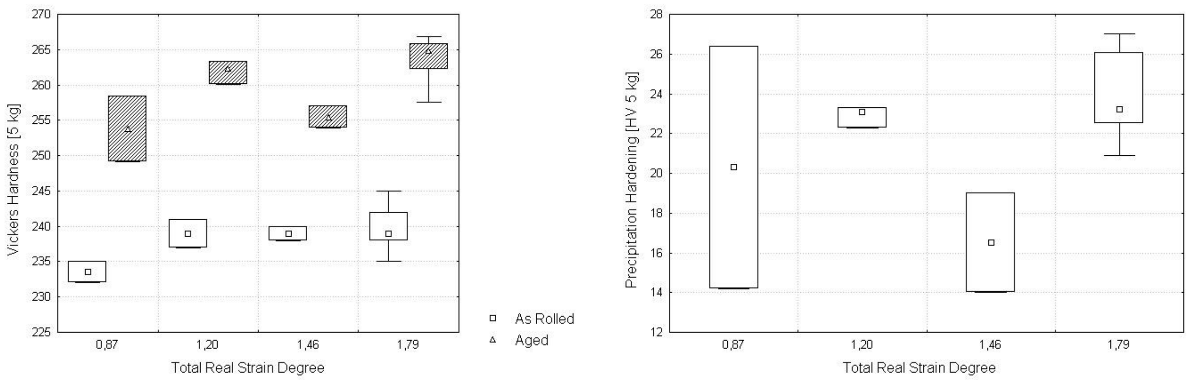
Figure 1: Reheating temperature effect over a) as-rolled and aged hardness and b) precipitation hardening.

A increase in reheating temperature can promote contradictory effects over the age hardening response of the HSLA-80 steel. For one hand, greater austenitizing temperatures increase the amount of solute niobium, that is, greater precipitation potential during ageing treatment. As a matter of fact, the forecast value of solute niobium after a 1200°C reheating is over twice the calculated value considering a 1100°C reheating: 0.032% versus 0.015%, respectively [9]. On the other hand, lower reheating temperatures promote finer austenitic grain size, as shown in Table 2 [10]. Evidence in the literature [1,11] reports that a finer grain size leads to a finer copper precipitation, increasing its hardening effect. So, the final result from a variation in the reheating temperature over age hardening response will be function of the net result between these contradictory tendencies.

The effects of the total strain degree over hardness values of the as-rolled and aged samples, as well over ageing response, were very weak, as Figure 2 shows. A comparison between samples submitted to extreme levels of strain degree (that is, 0.87 and 1.79) shows a discrete higher hardness for the samples with greatest strain degree. However, this effect is ambiguous for the other cases.

T_{reheat} [°C]	Grain Size after Reheating [µm]	Grain Size After Roughing [µm]	
		$\varepsilon_{esb} = 0.36$	$\varepsilon_{esb} = 0.69$
1100	82±4	64±3	24±1
1200	102±4	52±2	32±1

Table 2: Effect of reheating temperature and strain degree over austenite mean grain size after reheating and roughing stage during controlled rolling of the same HSLA-80 steel studied in this work [10].



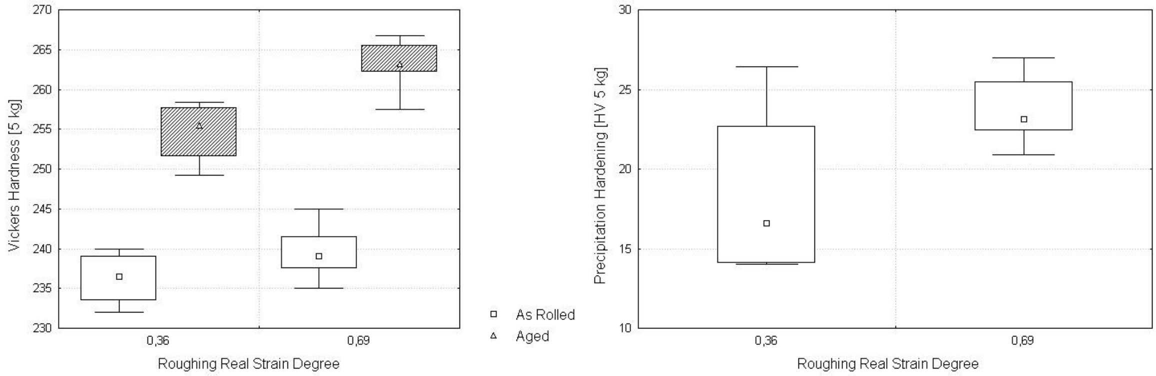
(a) (b)

Figure 2: Total hot rolling strain degree effect over a) as-rolled and aged hardness and b) precipitation hardening.

For its turn, the effect of the strain degree applied during the roughing phase have interesting aspects, as Figure 3 shows. This effect was not very intense in the case of the as-rolled samples, but much more significant in the aged ones. The precipitation hardening results confirmed this tendency. This explains the apparently ambiguous results shown in Figure 2b, where samples submitted to a total strain degree of 1.20 showed a greater precipitation hardening than those submitted to a higher value of 1.46. As indicated in Table 1, in the first case strain degree applied in the roughing phase was equal to 0.69, while in the second this value was equal to 0.36. The enhanced effect in the ageing response promoted by a increase in the strain degree during the roughing stage can be explained due to the greater grain refining effect verified under these conditions, as shown in Table 2 [10].

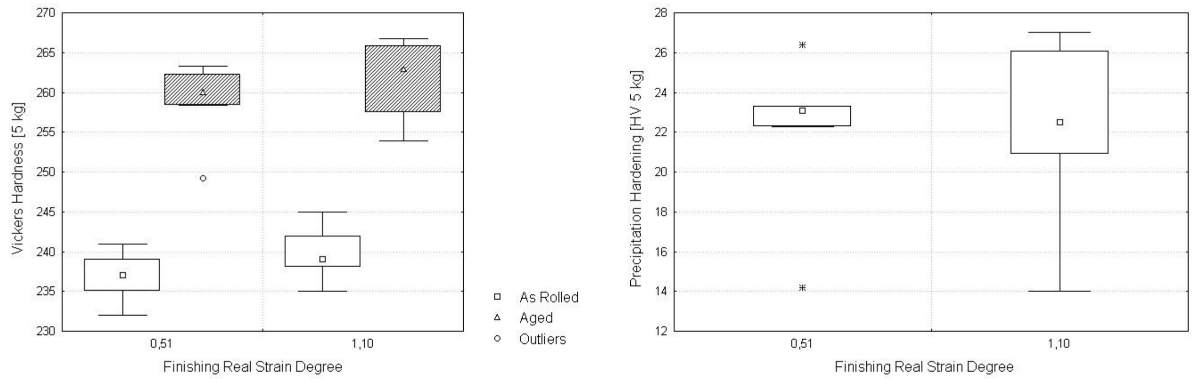
Strain degree applied during the finishing stage had a very modest effect in the hardness of both as-rolled and aged samples, and practically no effect in the ageing response, as shown in Figure 4. In this last case it was observed only a wider dispersion in the results got for the greatest strain degree applied during finishing stage.

Theoretically speaking, an increase in the strain degree applied during the finishing stage of controlled rolling would lead to an even greater age hardening response, as there is no more austenite recrystallization under these relatively lower rolling temperatures. The resulting strain hardening would promote a greater grain refining effect than that verified when deformation is applied in the high temperature range, where austenite recristallizes quickly. But this did not happened here. According to literature [6], this loss in the age hardening response can be associated to copper precipitation in the strain hardened metastable austenite, at temperatures lower than the Ar_3 point, which did not promotes hardening. The increase in the strain hardening degree of austenite, associated to greater strain degrees applied during the finishing stage, would enhance this kind of precipitation, counterbalancing the possible effects that grain refining could have over ageing response.



(a) (b)

Figure 3: Roughing strain degree effect over a) as-rolled and aged hardness and b) precipitation hardening.



(a) (b)

Figure 4: Finishing strain degree effect over a) as-rolled and aged hardness and b) precipitation hardening.

Lower finishing temperatures did not produce significant effects over hardness values got in the as-rolled nor in the aged specimens, as Figure 5 shows. Apparently the ageing response would be slightly greater in the case of the lowest finishing temperature – that is, 700°C – but this conclusion is not statistically supported due to the wide data dispersion. So, as it was previously seen [8], a finishing temperature variation in the 700°C to 800°C range did not influence significantly the mechanical properties of the HSLA-80 steel.

Finally, it must be considered that the ageing conditions applied here – one hour at 600°C – aimed a balance between mechanical strength and toughness, and not a maximum ageing response [7,8]. The slight over-ageing applied to the samples of this work could have contributed to mask some of the relationships between process parameters and ageing response.

4. CONCLUSIONS

The results of this work show that the effect of process parameters of controlled rolling over the ageing response of an age hardenable HSLA-80 microalloyed steel was not very significant for the parameter value ranges applied. Apparently most of the hardening effect is due do copper precipitation, with niobium having a discrete role, as demonstrated the weak effect associated with the increase in the reheating temperature from 1100°C to 1200°C. The increase in the strain degree applied during the roughing phase intensified the ageing response, but no significant effects were detected by greater values of finishing strain degree, as well by a finishing temperature variation between 700°C and 800°C.

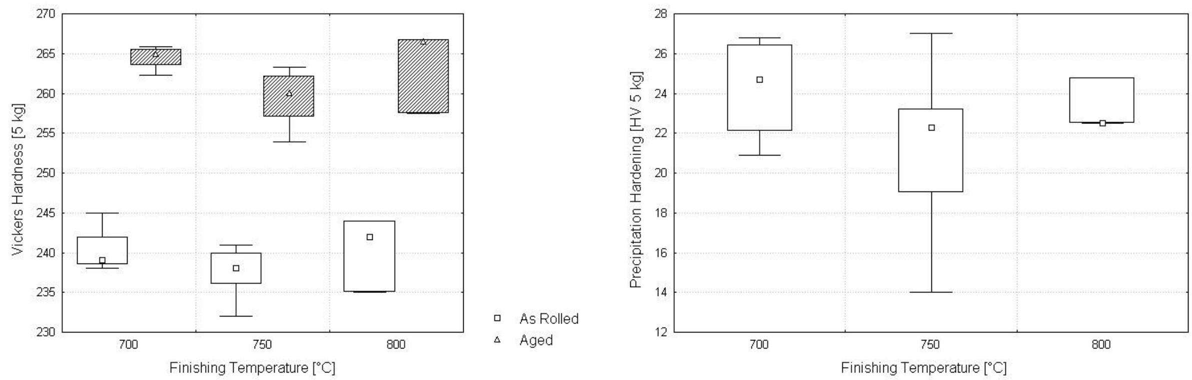


Figure 5: Finishing temperature effect over a) as-rolled and aged hardness and b) precipitation hardening.

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