Determination of Hardened Ferrite Grain Distribution due to Carbonitride Precipitation in a Nb-Ti-V Microalloyed Steel

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The High-Strength Low-Alloy (HSLA) steels are produced by controlled thermomechanical processing, where ferrite grain refining and carbonitride precipitation hardening are main responsible to higher yield strength and toughness in these materials. Observations performed in thin foil samples by transmission electron microscopy (TEM) have shown that carbonitride precipitation occurs in the austenite and also during austenite-ferrite (γ-α) phase transformation (interphase precipitation). No carbonitride formation was observed in the supersaturated ferrite. However, TEM analysis suggests that carbonitride precipitation does not present in all ferrite grains, becoming not uniform hardening between grains because there are ones with fine carbonitrides and another without strengthening particles. In the present work some thin foil samples extracted from a 0.137C, 1.38Mn, 0.041Nb, 0.044Ti, 0.031V and 0.008N (wt%) microalloyed steel were investigated by Philips CM120 TEM operated at 120kV. Carbonitride-ferrite orientation relationships were determined by electron diffraction analysis. Metallographic samples were prepared from longitudinal (L), transversal (T) and normal (N) sections of the hot strip rolled steel. Nital 2% etching was carried out on polished surfaces to reveal the ferrite grain boundaries, making it possible to perform instrumented microindentation tests inside them. Measurements of the equivalent Vickers microhardness HV* were determined under standard load of 100mN on 200 different grains in each section at least. Statistical deconvolution of the percentage of ferrite grains with and without precipitation hardening was performed on the obtained frequency distribution from HV* results. Thin foil TEM observations have confirmed that carbonitride formation is not present in all ferrite grains, some of them have showed dislocation arrangements without any significant precipitation. However, carbonitride precipitation in austenite, Fig. 1(a), and interphase precipitation, Fig. 1(b), were usually identified inside different ferrite grains [1]. Both modes of precipitation were observed in a same ferrite grain very rarely. Fig. 2 presents results of microindentation tests carried out in 652 ferrite grains located on L-T-N sections. HV* experimental values have ranged between 310 and 445 and they have shown a good fitting to a Gaussian curve. However, that result was obtained by combination of two populations of ferrite grains, with and without precipitation strengthening whose details are indicated in Table 1. Dispersion observed around average hardness of both types of ferrite grains can be associated to complex changes of behavior of the strengthening mechanisms acting together. The results suggest that minority of ferrite grains (29.7%) likely presents carbonitride precipitation that promotes hardening (404HV*), a estimate lower than earlier reported in literature (~50% of the ferrite grains in ref.[2]).

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References

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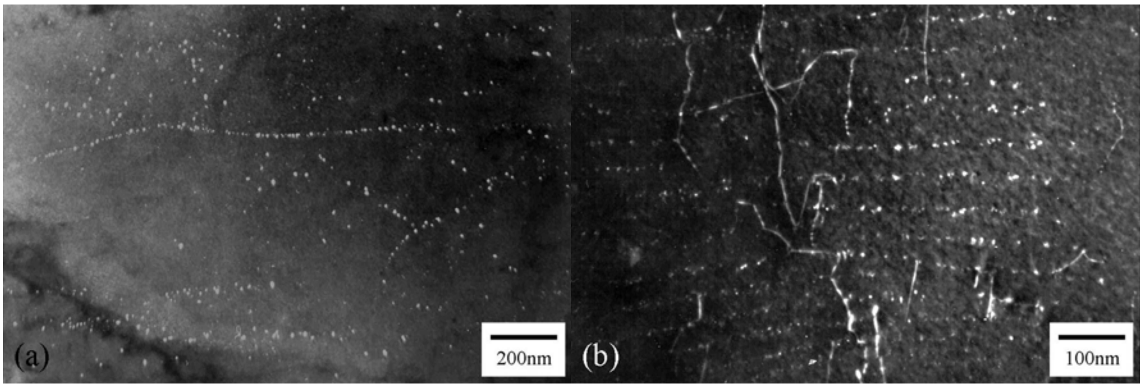

Fig. 1: Dark field TEM micrographs showing typical carbonitride precipitation in austenite (a) under magnification 43500X and rows of fine particles in interphase precipitation (b), magnification 87000X.

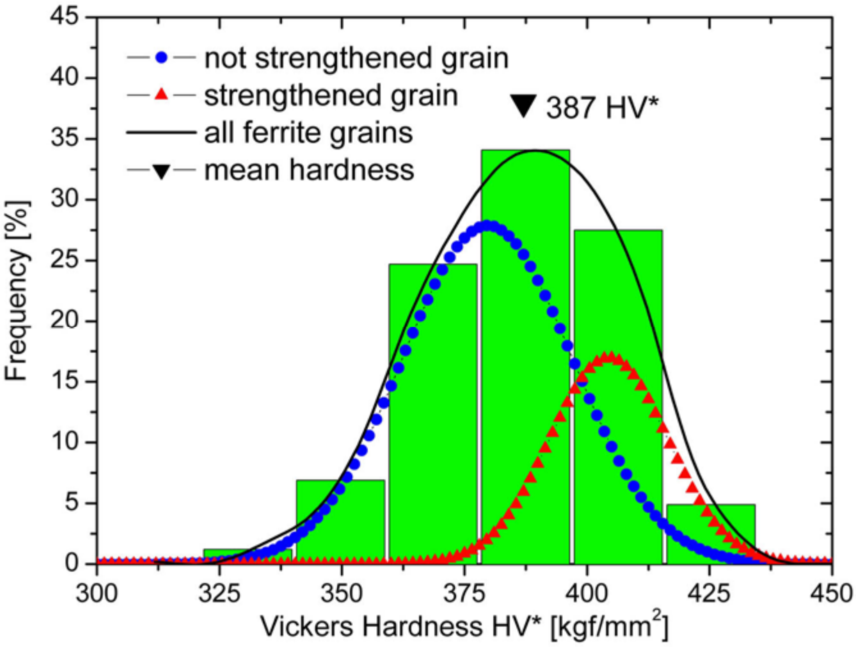

Fig. 2: Deconvolution of precipitation hardening effect on the HV* microhardness distribution. The histogram is related to 652 measurements performed on different ferrite grains.

Table 1: Statistical analysis of HV* frequency distribution showed in Fig. 2.

Strengthening?	amplitude	center	FWHM	% area	# grains
No	27.8	379.7	40.9	70.3	458
Yes	16.9	404.4	28.4	29.7	194
general	-	387	-	-	652