

Structure-properties relationship of ultra-fine grained V-microalloyed dual phase steels

Babak Shalchi Amirkhiz¹, Colin Scott¹, Fateh Fazeli¹

1. CanmetMATERIALS / Natural Resources Canada, Hamilton, Canada

The effect of vanadium microalloying on ultra-high strength dual phase (DP) ferrite-martensite steel microstructure and was studied using TEM. It was found that the addition of 0.14% wt V to a Fe-0.18C-1.5Mn-0.3Si-0.008N reference alloy introduced very significant ferrite grain size refinement in the cold rolled and annealed state. Image analysis of TEM foils and direct and indirect extraction replicas after cold rolling and intercritical annealing at 750°C intense showed V(C,N) precipitates (mean radius 3.7 nm) were abundant in the ferrite phase whereas precipitates were scarce in martensite (austenite) and much larger (mean radius 6.7 nm) as seen in Figs 1-3. Another effect of V was to strongly delay the formation of austenite during heating and isothermal holding and to promote the reverse transformation to ferrite during cooling (Fig. 2d) while at the same time retarding/suppressing the pearlite and bainite transformations i.e. it provides an overall increase in hardenability. Undissolved cementite was observed at intercritical annealing temperatures $\leq 740^{\circ}\text{C}$. Because of high solubility of Mn (up to 10at%), cementite was distinguishable in Mn EDS maps (Fig. 1b). The vanadium alloy was much stronger than the reference steel at low martensite fractions due to grain refinement and selective strengthening of the ferrite phase. The contribution of V(C,N) precipitates to strength were measured using a model described in [1]. For $\alpha' > 45\%$ the V-added steel became softer than the reference steel. The net result was that the vanadium alloy showed a much lower sensitivity to martensite content ($\sim 4 \text{ MPa}/\% \alpha'$) where the YS, UTS and work hardening rate became lower than the reference, primarily due to martensite softening. The latter was attributed to the fixing of solute carbon by V(C,N).

References:

- [1] S.Allain, O.Bouaziz, I.Pushkareva, C.P.Scott, MSEA A 637, (2015) p 222-234.
- [2] The authors acknowledge funding from Vanitec and ArcelorMittal Dofasco.

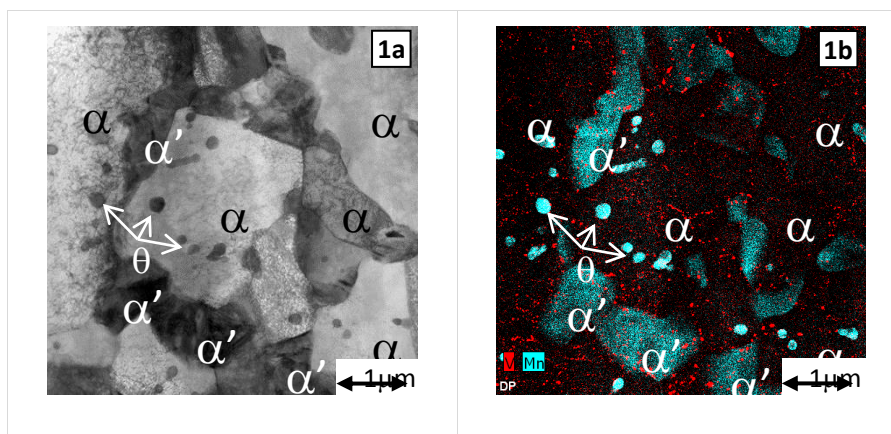


Figure 1: a) Thin foil BF STEM image of the Ref+V alloy after annealing at 740°C / 120s and die quenching. b) Composite EDX chemical map of the same region showing Mn (blue) and V (red).

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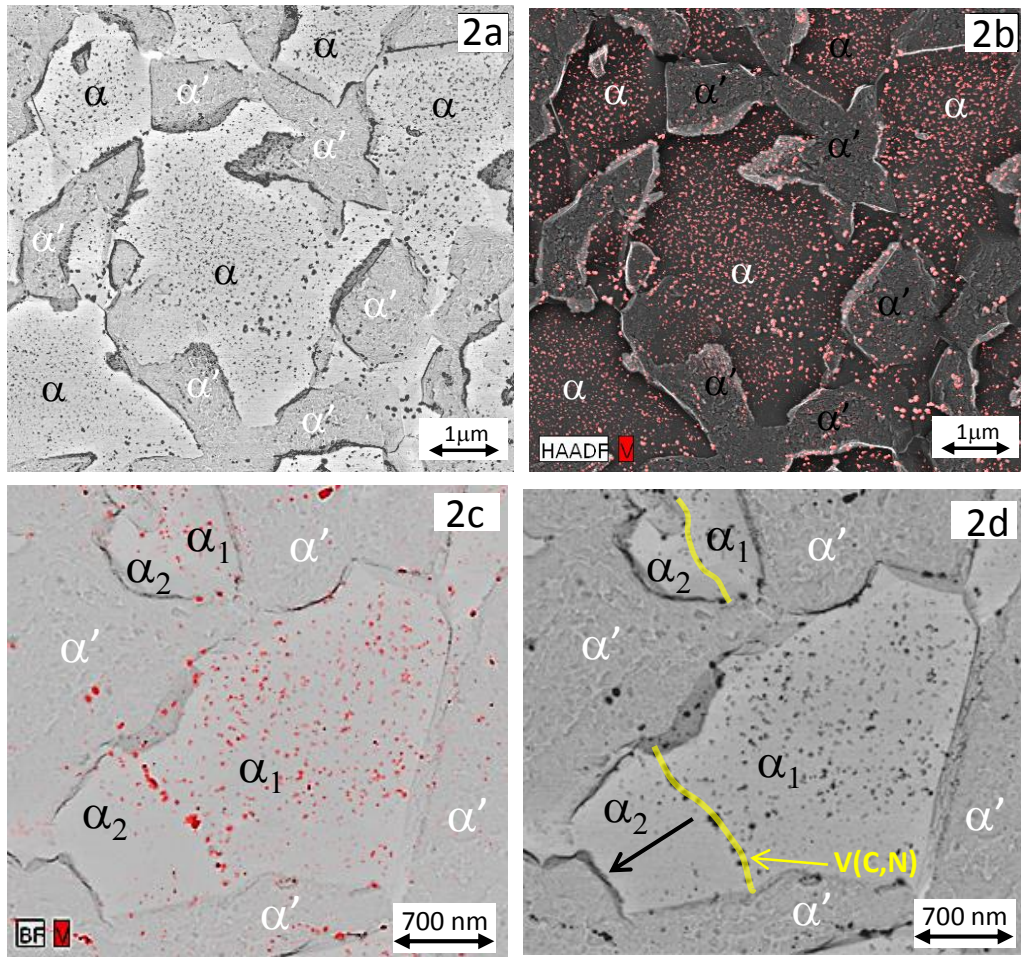


Figure 2: a) BF STEM image of a direct extraction replica (Ref+V alloy annealed at 750⁰C / 180 s and die quenched), b) EDX chemical map superimposed on the HAADF image of a) (note reversed contrast) showing the localization of V precipitates (red) in ferrite. c) BF STEM image showing primary (untransformed) ferrite islands (α_1) which have grown into austenite (regions α_2) by reverse transformation during air cooling before quenching. d) EDX chemical map showing the V distribution in c).

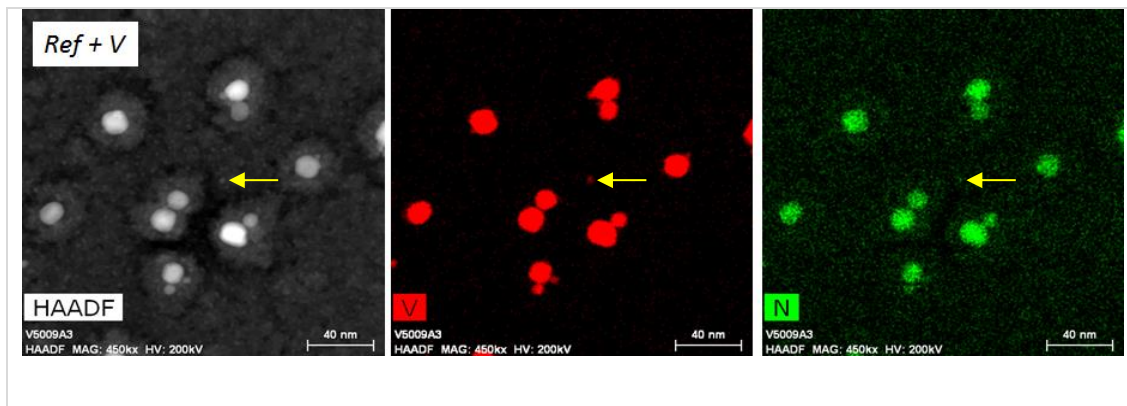


Figure 3 a) HAADF STEM image of a direct extraction replica from the Ref+V alloy after annealing at 750⁰C / 180 s showing clustering of very small V(C,N) particles. b) V map. c) N map.

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