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

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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 750⁰C 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 ≤ 740⁰C. 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 α’>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 (~4 MPa/%α’) 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:

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Figure 1: a) Thin foil BF STEM image of the Ref+V alloy after annealing at 740⁰C / 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 750°C / 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 (α1) which have grown into austenite (regions α2) 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 750°C / 180 s showing clustering of very small V(C,N) particles. b) V map. c) N map.

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