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Control of Recrystallization Temperature via VC Formation on TiN Nanoparticles in Novel Ultra Low Carbon (ULC) Automotive Strip Steels

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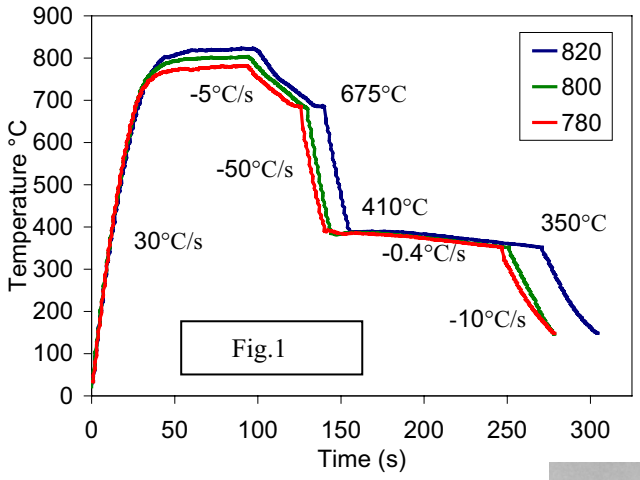
Ultra Low Carbon (ULC) strip steels are a particular family of high formable automotive steel grades with typical applications in every automotive vehicle, such as the spare wheel well and the front and rear door inner. The production route of ULC strip steel grades requires the control of carbon and nitrogen additions to parts per million content, and even these small carbon and nitrogen additions must be stabilizedby titanium, niobium or mixed micro alloying element additions. It is reported [1], that V additions in ULC strip steels lower the recrystallization temperature.

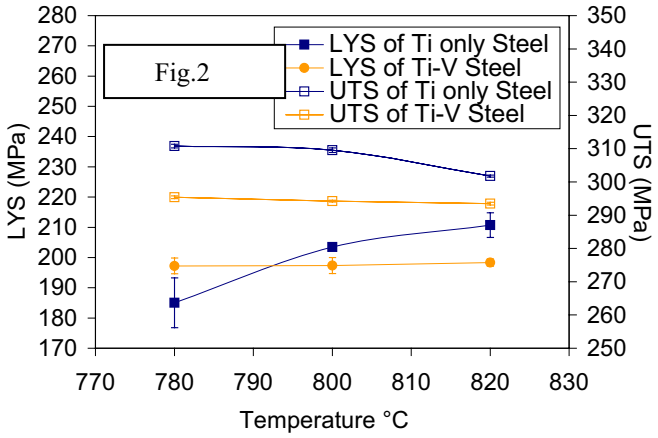
While the effect on the mechanical properties and the processing parameters of V additions in ULC strip steels is broadly documented [2], the nature of the precipitation sequences, that take place in V alloyed ULC strip steels is not well understood. The present study was carried out, using a variety of continuous annealing processing conditions (within the temperature region of 780^{o}C-820^{o}C, Fig 1), followed by a detailed electron microscopy examination of obtained samples, to help clarify the role of the various nanosized precipitate species, as well as the various stages of their formation. Initial mechanical property data (Fig 2) and MT-DATA modeling sequences (Fig 3) have highlighted the advantages of V additions in the obtained yield and tensile strength values, as well as the complex nature of precipitate sequences that could take place during the later stages of steel processing and especially during coiling.

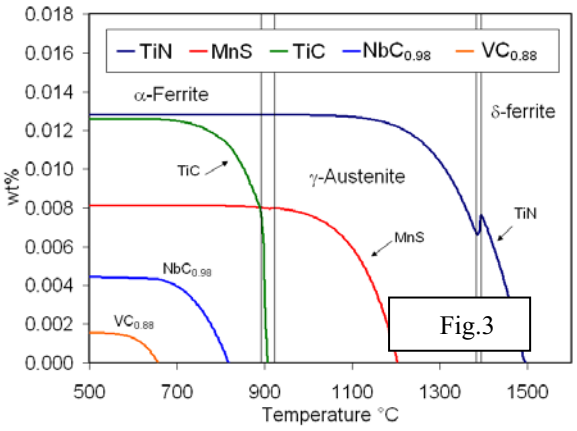
SEM examination coupled with EDX microanalysis, both on the Ti only and on the Ti-V ULC strip steels samples, only revealed the presence of primarily ferritic microstructures with limited presence of coarse MnS, TiMnS, or TiN particles. However, the fine details of the microstructure were revealed using TEM microscopy coupled with EDS microanalysis, which highlighted the presence of complex epitaxial growth of VC particles on nanometer sized TiN particles, at intermediate annealing temperatures, ie 800^{o}C (Fig. 4) or $Ti_4C_2S_2$ particles again on TiN, especially at the higher annealing temperatures (820^{o}C), Fig 5. The intensity of VC epitaxial formation on TiN nanoparticles, is governed by vanadium supersaturation in the steel. VC formation is expected to take place during the coiling stages of the strip steel. The activation energy of VC formation is expected to be reduced given that a low energy coherent or semicoherent interface is established by VC and TiN, a result of the good crystallographic match (both are FCC particles), having a calculated lattice parameter misfit of only 1.9%. Vanadium additions are responsible for stabilizing carbon, which has a detrimental effect on formality during the hot rolling sequences and thus facilitate the production of ferritic matrix which is Interstitially Free. This epitaxial formation would not retard the recovery and recrystallization processes during continuous annealing in Ti-V ULC strip steels, compared with the effect of TiC in Ti only ULC strip steels. Hence, a profound reduction in recrystallization temperature is manifested in V ULC steels.

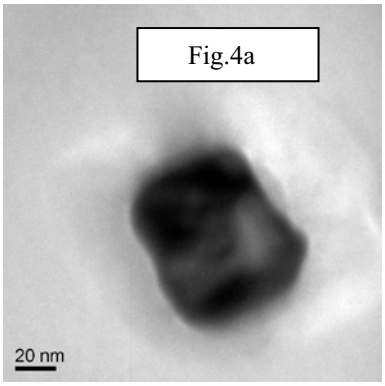
References:

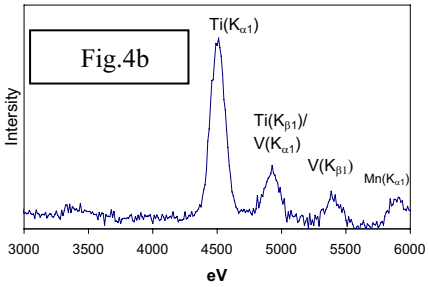
[1] PS Mitchell *et al*, 39th Mechanical Working and Steel Processing Conference Proc. (1997) p. 37.
[2] SW Ooi and G. Fourlaris, Materials Characterization, 56 (2006), p.214.

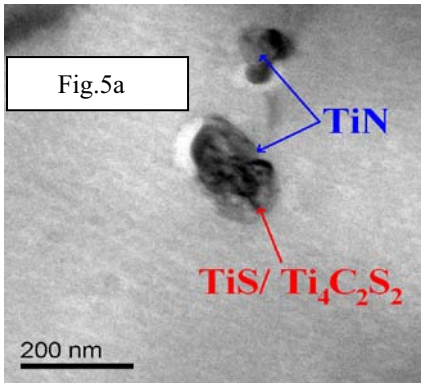












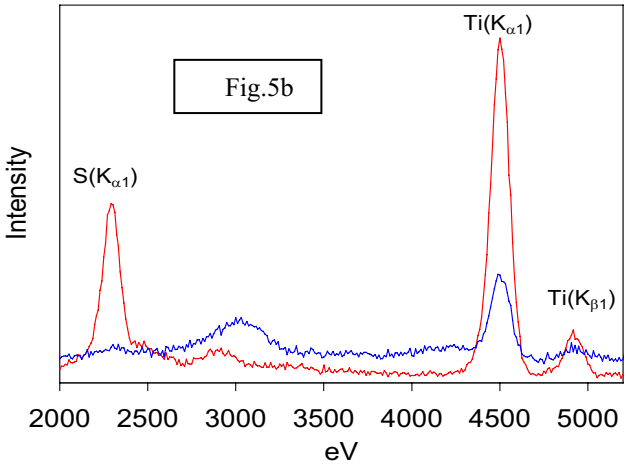


Figure 1. Continuous annealing heat treatment cycles employed.
Figure 2. Effect of annealing temperature on the lower yield stress (LYS) and tensile strength (UTS).
Figure 3. Weight percent of precipitate species present in Ti-V ULC strip steel.
Figure 4. (a) Bright field TEM micrograph of a coarse TiN and VC precipitates present in the Ti-V ULC steel continuously annealed at 800ºC,(b) The corresponding EDS traces.
Figure 5. (a) Bright field TEM micrograph of the TiN and TiS (or $Ti_4C_2S_2$) co-precipitates on TiN present in the Ti only ULC for a sample continuously annealed at 820ºC, (b) Associated EDS microanalysis traces taken from the particles in (a).

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