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Improvement in toughness of welded constructional steels through titanium additions*

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We are currently investigating the effect of various alloying additions in the weld deposit and base material on the precipitate dispersion and stability, the microstructure and toughness of microalloyed constructional steels, in both the as-welded as well as welded and stress-relieved conditions. Materials investigated include welded AlTi, AlTiV, AlTiNb and AlV steels with the use of electrodes either with or without Mo additions. This paper is an interim report of the work.

It has been found that in all the weld deposits studied the presence of 0.2 % Mo (by mass) has the effect of increasing the strength and lowering the transition temperature (27 J Charpy V-notch shelf energy). On the other hand, stress-relieving heat treatments of 540–640 °C for various times causes the $T_{27\,\mathrm{J}}$ to decrease in alloys not containing Mo, but increase slightly in the steels containing Mo. Thus, although Mo additions are on the whole beneficial, their positive effect is minimized after stress relieving treatments. Steels containing V were found to exhibit secondary hardening on reheating. Mo is well known for refining the as-welded microstructure, although our transmission electron microscopy (t.e.m.) studies have also revealed a tendency for Mo to decrease the amount of grain boundary carbides in the weld deposit.

The presence of small additions of Ti in constructional steels brings about a fine dispersion of TiN precipitate which remains stable even under high heat-input welding cycles, thereby preventing significant grain growth and loss of toughness in the h.a.z. We have studied the stability of these precipitates in steels containing various amounts of Ti (0.01–0.04 %, by mass), as well as in a 0.01Ti0.06V steel, by using a weld simulator to simulate the electro-slag and submerged arc weld thermal cycles (T = 1400 °C, $\Delta t_{800\rightarrow 500}$ = 300 s; T = 1350 °C, Δt = 100 s). The transition temperatures, austenitic grain sizes and size distribution of TiN precipitates (with the use of extraction replicas) were all measured and found to vary in a consistent way. The particle size in the steels before thermal cycling was found to be *ca.* 5–10 nm. The 1400 °C cycle, however, brought about considerable coarsening, causing the coherent cube-shaped precipitates to elongate. The TiV steel exhibited a 40 °C higher $T_{27\,\mathrm{J}}$ than the straight Ti-steel and t.e.m. revealed that dislocation locking by particles was more common in the V steel. S.t.e.m. based energy dispersive X-ray spectroscopy microanalysis of individual precipitates also showed that in some cases the TiN compound was modified to (TiV) (N), the amount of V being about 10 %. On this basis it appears that the nitrides in the TiV steel are less stable at higher temperatures than in the Ti steel, and the larger grain sizes and coarser precipitate dispersions measured in the TiV steel tend to confirm this assumption.

* Extended abstract; the full paper has been accepted for publication in *Metals Technology*.