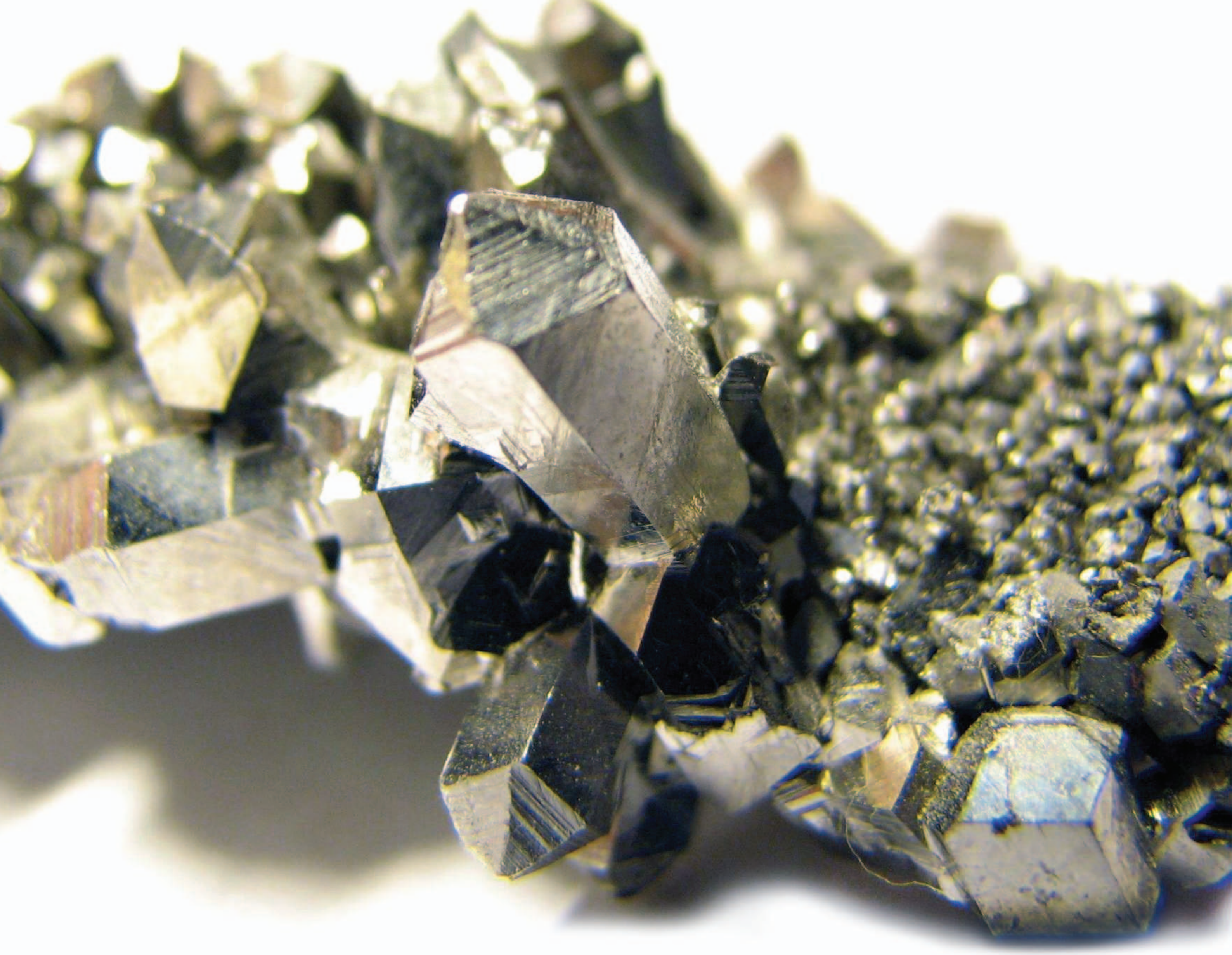

The international Vanadium Award recognises the most outstanding paper in the metallurgy and technology of vanadium and its alloys. Since the inception of this award of the Institute of Materials, Minerals and Mining (IOM^3) in 1982, 27 publications from 10 countries have received this prestigious award. Local steel producers have benefited from this level of support and enjoy high yields on the product.

Adding vanadium to improve the ductility[1] of niobium-containing steels

Dr Kevin Banks, Dr Alison Tuling and Prof Barrie Mintz

Dr Kevin Banks and Dr Alison Tuling from the University of Pretoria's Department of Materials Science and Metallurgical Engineering, in collaboration with Prof Barrie Mintz of the City University, London, are the most recent recipients of the International Vanadium Award for their research into high-strength low alloy (HSLA) steels.

Their work, documented in a research paper entitled 'Influence of V and Ti on hot ductility of Nb-containing steels of peritectic C contents', dealt with the widely reported issue that the presence of niobium (Nb) reduces hot ductility in some steels, which can result in transverse cracking of slabs during straightening at the end of the continuous casting operation. This work demonstrated (in laboratory simulations) that the addition of vanadium (V) to a titanium-niobium (Ti-Nb) microalloyed steel can help increase the ductility in the critical temperature range at which straightening takes place. This was confirmed under full-scale steel production.

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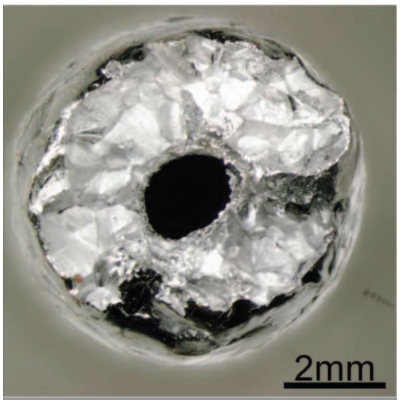
[1] Ductility is the ability of a material to undergo permanent deformation through elongation without fracturing.

Adding V to the Ti-Nb-containing steels resulted in significantly improved ductility with reduction in area values at 800 °C in excess of 45%.

Since the early semi-industrial pilot plants that were developed after World War II, continuous casting has become the route to follow in large-scale steel production. Over 90% of the steel produced in the Western world is now produced in this way. The molten steel (see Figure 1) is poured into a vertical, water-cooled copper mould. The steel is removed from the bottom of the mould in a continuous slab. On exit, the steel must be bent and unbent to orientate the slab in the horizontal for ease of handling (cutting, transport, etc). In the unbending/straightening zone (750–1 000 °C), the steel is particularly vulnerable to cracking, as a number of important metallurgical interactions occur.

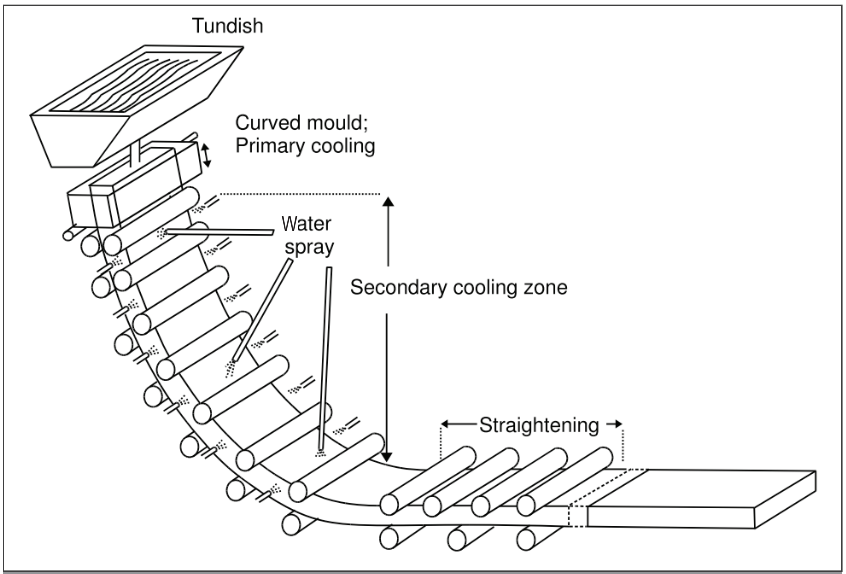
The transverse cracking that occurs is detrimental to downstream quality, as these cracks result in either poor surface quality or poor edge quality after further processing and must be mitigated by scarfing or trimming. This contributes to the cost of production and loss of yield.

The cracking mechanism can be studied in the laboratory using thermomechanical simulation. The 'hot ductility test' has been established to predict transverse cracking.

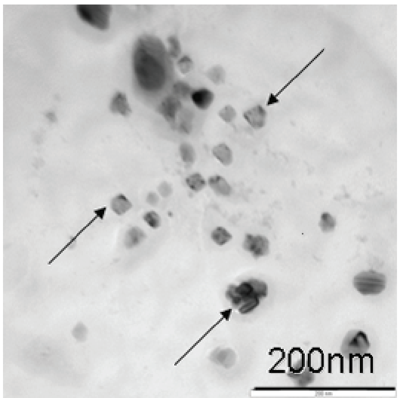


→ *Figure 2a. Rock candy failure in a hot ductility specimen.*

The authors used a sophisticated thermal profile in the hot ductility technique to study peritectic carbon steels with varying levels of the microallying elements Ti, Nb and V, as well as considering the effect of nitrogen levels.



→ *Figure 1: Schematic representation of a continuous casting machine.*



→ *Figure 2b. Vanadium-free steel showed copious carbonitride precipitation (15–23 nm) at the γ-grain boundaries, as well as some finer precipitation within the grains, which causes such failures (Ti-Nb steel).*

Peritectic carbon (C) steels are difficult to cast, even without microalloy additions, as the grain size during unbending is inevitably large and causes a weakening of the steel, making it more vulnerable to cracking during the strain applied during unbending. The addition of the microalloys adds complexity to the casting of these steels. If these elements form fine carbonitride precipitates, they strengthen the steel so as to force the unbending strain to a small region adjacent to the grain boundaries, where the plasticity is quickly exhausted and fails in a rock candy-like fashion (see Figure 2a).

However, what the present work showed is that certain combinations of the microalloys produce differing amounts and sizes of precipitation and thus the additions strongly influence the propensity for transverse cracking (see Figure 2b).

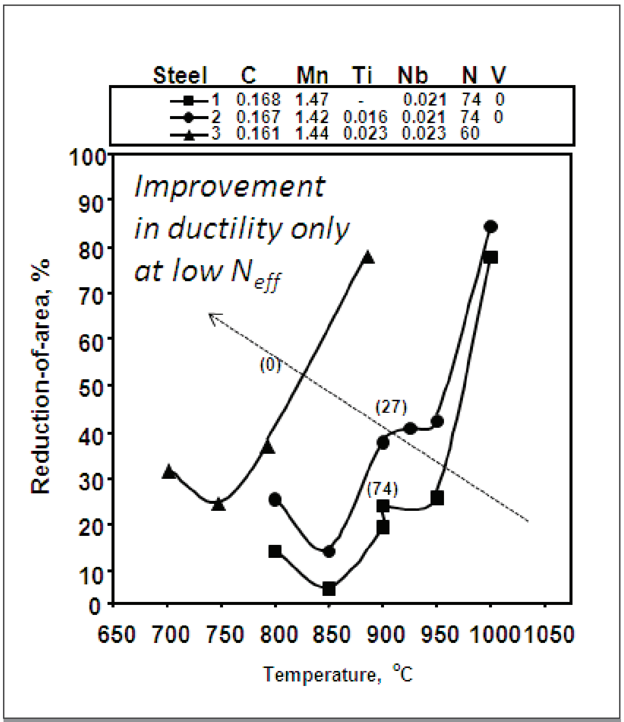


Figure 3: The influence of Ti on the hot ductility of 0.165% C- and 0.02% Nb-containing steels. The numbers in parenthesis are the N_{eff} x 10–4 values (the N available in the solution after the Ti has combined with the N).

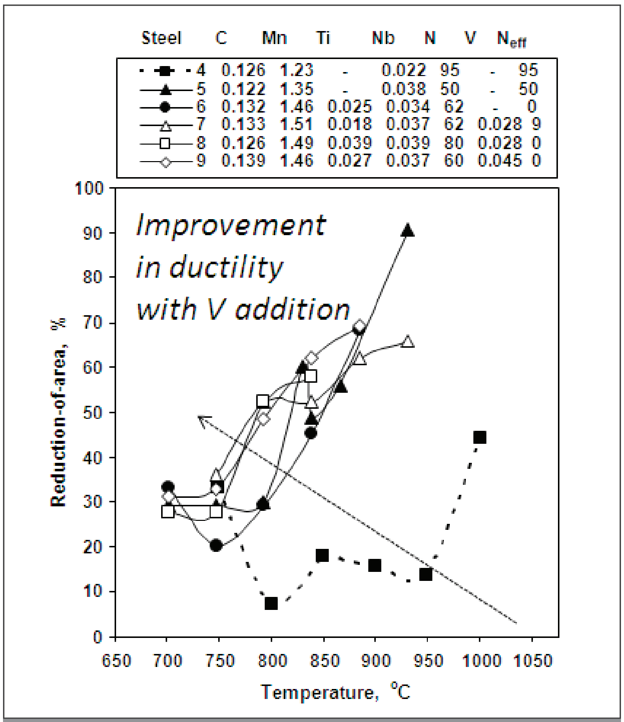


Figure 4: Influence of V on the hot ductility of Nb-containing Ti steels. Open symbols are for the V-containing steels and closed symbols are for the V-free steels. The ductility improves with the addition of vanadium.

Influence of Ti on Nb-containing steels within the peritectic C level

Nb-containing steels are notoriously difficult to cast so that the likely increased precipitation from both Nb and Ti might be expected to produce even worse ductility. If all nitrogen (N) is combined as Ti-rich compounds, then precipitation of Nb can only take place at temperatures below those used for normal straightening. It is then likely that the N left in solution, after combining with the Ti, will dictate the hot ductility. This nitrogen, N_{eff} (the N available in the solution after the Ti has combined with the N), is then able to precipitate out as carbonitride in a fine detrimental form on deformation and so control ductility. The less N available for forming Nb (carbon or nitrogen), in other words, the higher the Ti-Nb ratio, the better the ductility will be.

> This improvement was due to a decrease in the fraction of fine particles, and in accordance with this better ductility, transverse cracking of industrial slabs was avoided.

Figure 3 indicates that as the N_{eff} value decreases from 0.0074% to 0, the ductility improves. However, in some industrial processes where high N is unavoidable, Ti additions are not sufficient to avoid transverse cracking.

Influence of V on the hot ductility of Nb/Ti-containing steels within the peritectic carbon range

When V, Nb and Ti steels were examined (see Figure 4), it was shown that the V-Nb combination (open symbols) gave better ductility than the V-free steels, 4–6 (solid symbols).

The cause of the improvement was shown to be the few coarser precipitates observed in the V-containing steel and lack of

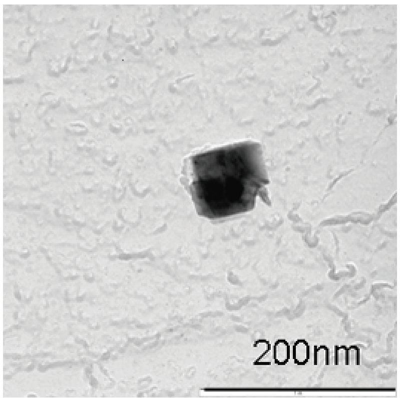


Figure 5: Isolated coarse precipitates found in the V-containing steel, steel 9, after testing at 800 °C.

fine V-containing precipitates, as indicated in Figure 5, which provides a comparison to the copious Ti-Nb precipitation (15–23nm) in the Ti-Nb steel (Figure 2).

In the present instance, no V-containing precipitates were observed, presumably because of the presence of Ti, all the N being combined with the Ti or as Ti-Ti precipitates. All the V is therefore probably in solution and able to retard the precipitation of Nb, resulting in the absence of the finer detrimental carbonitride precipitation that occurs in the V-free Ti-Nb-containing steel leaving only the coarser Ti-Nb precipitates that are formed with the slow cooling prior to deformation.

The winners of the International Vanadium Award (from left): Prof Barrie Mintz, Dr Kevin Banks and Dr Alison Tuling.

This result is in accordance with previous work where stress relaxation tests confirmed that the Nb addition to the V steels delays the onset of Nb-V carbonitride precipitation, which is in accordance with the work of Akben et al, published in *Acta Metallurgy*.

The V addition therefore behaves in a very similar, beneficial manner as the steel would behave, whether it contains Ti or not. Finally, something that is very important from a commercial point of view is that whereas transverse cracking was observed in the Ti-Nb steels in this C range, the addition of V was found to eliminate this problem.

For titanium-containing steels, an under-cooling cycle needs to be introduced in order to use the hot ductility results to predict transverse cracking behaviour.

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