The Use of Vanadium in Reinforcing Bar Steels

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In Europe, high strength reinforcing bars for concrete structures are largely joined by welding and in order to achieve good joints without pre–heat and cracking, the steels have a low carbon content of about 0.25%. At this carbon level the strength is reduced and has to be restored by the addition of micro alloys, or by in–line heat treatment. The addition of vanadium to the steels is the most commonly used method of restoring the strength, and the most universally acceptable, taking account of the varying conditions of manufacture which exist in mills making these bars. This report describes the production of these steels, and compares the production and properties, with those of bars produced by other alloys or methods.

Strength

The addition of vanadium to a 0.25% carbon steel can increase the yield strength from 350 N/mm^2 to over 600 N/mm^2, depending on the carbon content, vanadium addition, manganese content and bar diameter.

The vanadium in creases the yield strength through precipitation of vanadium carbonitrides in the ferrite, largely by interphase precipitation and to a small extent by grain refinement. The precipitation strengthening results from precipitates forming during and after rolling, and is largely independent of the rolling conditions. The precipitates tend to be coarser and less effective in larger diameter bars. The strengthening effect from a given vanadium addition therefore, is less as bar diameter increases. The larger diameter bars may also have a slightly coarser grain size. The effect of vanadium content and bar diameter for a series of laboratory steels are given in Fig 1.

Increasing the nitrogen content can also increase the yield strength of the bar, as can be seen in Fig 2.

Dendability

In many applications, reinforcing bars are bent through a radius of 180 °, and in many specifications a rebend test is incorporated to ensure that the bars can be bent in this manner. If free nitrogen is present in the steels, the bars may crack during this test due to the strain ageing effect of the free nitrogen in solution. This however, rarely happens with vanadium steels because the nitrogen forms vanadium carbonitride with the vanadium, and so the nitrogen is removed from solution and is present as harmless precipitate. It is however, important that the ratio of vanadium to nitrogen is above a certain limit, to ensure that there is no free nitrogen in solution.

Weldability

Vanadium steel reinforcing bars are welded by manual metal arc processes, and by using welded joints considerable savings in steel are achieved, with the result that lower cost reinforced concrete bridges, tunnels etc. can be constructed.

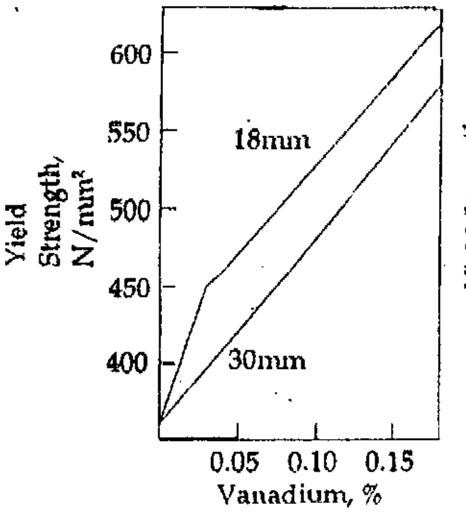
Typical steel compositions and structures are shown in Table 1.

Advantages of Vanadium over other HSLA Rebar

The fact that vanadium steel rebars achieve their strength mainly through precipitation means that they can be made under a wide range of production conditions, involving a wide variation in temperature of reheating, rolling, pass reductions and finishing temperature. They can be produced on old mills which roll slowly and give finishing temperatures which are low, or on modern high speed mills where heavy reductions and high finishing temperatures are involved.

Steels strengthened by niobium additions on the other hand, depend for their strength primarily on grain size, and a low finishing temperature. Although these conditions can be met in older slower mills where finishing temperatures are low, such temperatures cannot be achieved on fast mills, at least not without loss in production. When rolling niobium steel bars, unlike vanadium steels, it is essential to use a high reheating temperature and reasonably long soaking time, to ensure that the niobium goes into solution. Accelerated cooling of reinforcing bar has also been used to provide an increase in strength, but in order to do this, special equipment has to be installed, and it is often not possible to do this on existing mills without unwarranted expense.

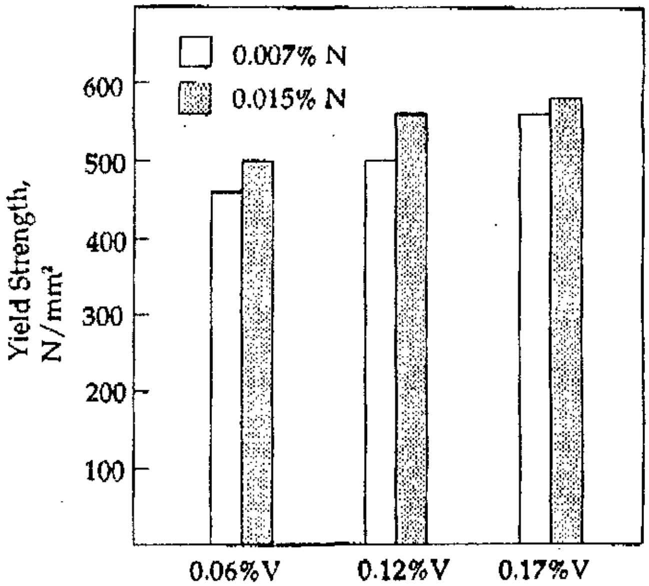
Bars which are strengthened by accelerated cooling have a hard tempered martensite structure on the outside, which carries the load and a soft ferrite pearlite structure in the core. In applications where the surface is machined to provide a screw thread for joining or other purpose, the accelerated cooling process is not suitable.



Base Composition, %

C	Mn	Si	N	Al
0.24	1.25	0.45	0.007	0.01

Fig.1 Effect of Vanadium on Yield Strength



Base Composition, %

C	Mn	Si	Al
0.24	1.25	0.45	0.01

Fig.2 Effect of Nitrogen with Vanadium on Yield Strength

Table Ⅰ Composition and Properties of some Typical Weldable grade High–strength Reinforcing Bar Steels

Composition,%				Diameler		Yield Strength		U.T.S.		Elongation
C	Mn	Si	V	mm	guage	N / mm²	Ib / in² × 1000	N / mm²	Ib / in² × 1000	%
0.24	1.3	0.40	0.09	40	14 (1.57in)	506	73.4	715	103.7	16
0.25	1.4	0.30	0.07	32	10	517	75.0	707	102.5	23
0.21	0.9	0.40	0.05	40	14 (1.57in)	441	64.8	617	89.5	21
0.21	1.0	0.25	0.04	32	10	434	63.0	600	87.0	21