

Effect of vanadium, nitrogen, and aluminium on the mechanical properties of reinforcing bar steels

A systematic study has been made of the effects of vanadium, nitrogen, and aluminium on the properties of 18 and 30 mm rolled bars, having a base composition of 0.24% C-1.25% Mn-0.475% Si, as used for high-strength reinforcing bars. It has been shown that additions of vanadium up to 0.18% can increase the yield strength by 207-256 N/mm², depending on the diameter and the level of other elements, without impairing the bend and rebend properties. The effect of vanadium on a 0.13C-1.5Mn-0.45Si steel has also been studied. Variations in finish-rolling temperature had very little effect on the properties. The weldability of a limited number of steels was shown to be equal to that of C-Mn steels. The properties of a number of commercial steel reinforcing bars having similar compositions are also included for comparison.

MT/301

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Until a few years ago, most reinforcing bars supplied in the hot-rolled condition, were made from carbon-manganese steels containing about 0.3% carbon and 0.8% manganese. These steels had a yield strength of the order of 250 N/mm² and gave an elongation of about 20-25%. In the past decade there has been an increasing demand for higher-strength reinforcing bars, and 410 N/mm² is quite common for the minimum yield strengths required in many national specifications. This high yield strength was first achieved by raising the carbon, manganese, and/or silicon contents and Braaten¹ has described typical high-strength steels of this type which were produced in Norway in 1967. Different steel compositions have been developed in other countries, and typical compositions of steels in current production are given in Table 1.

In the past few years there has been an increasing demand for larger-diameter bars which are required to have similar strength, elongation, and bendability to the small bars. There is also an increasing demand for steels which can be welded in the shop or on site, but the high carbon and silicon contents of the steels mentioned above make them unsuitable.

Vanadium has been added to reinforcing bar steels to produce yield strengths of 410 N/mm² and 450 N/mm² minimum yield strength for many years, but no systematic work has been published on the effect of variation in vanadium content, or other elements. Braaten¹ described the average compositions of weldable steels, produced in Norway, which contain microalloy additions to meet certain specifications, but he did not specifically mention vanadium and gave no indication of the relationship between the quantity of microalloy added and the yield strength, or of the effect of other elements.

In order to achieve the desired weldability, it is probably necessary to limit the carbon content to a maximum of 0.25% with a manganese content of not more than about 1.3%. A steel of this composition has a yield strength of about 350 N/mm² but, by the addition of a microalloying

element, the strength can be increased to over 450 N/mm².

For several reasons, vanadium is the most convenient microalloying element to use: it forms a nitride which leads to a fine ferrite grain size, and precipitates as a carbide or carbonitride in ferrite. The formation of these compounds is affected by nitrogen content and, to a lesser degree, by aluminium because of its affinity for nitrogen. The work described in this paper was therefore designed to study the effect of variations in vanadium, nitrogen, and aluminium on the tensile and bend properties of a steel having the following base composition (wt-%):

C	Mn	Si
0.24	1.2	0.45

In view of the growing importance of weldability, a limited study was also made of the effect of vanadium on the properties of a steel of the following base composition (wt-%):

C	Mn	Si
0.15	1.4	0.45

Most of the results were obtained from 70 kg melts rolled on a laboratory mill, but it has also been possible to include results on bars produced from full-scale heats made in an 80 t electric furnace and rolled on a production mill. These heats included bars of larger diameter than was possible with laboratory heats.

Experimental procedures and results

A series of 70 kg melts of steel was made in an induction furnace and cast into 76 mm square ingots. Swedish iron was used as the base material, and the manganese, vanadium, and nitrogen were added as ferroalloys. The compositions of all the steels are given in Table 2. In some cases duplicate steels were made. The ingots were reheated to 1250°C and rolled in a laboratory mill to bars of 30 and 18 mm dia, using 10 and 14 passes respectively, with a finishing temperature of 1050°C; the average reduction per pass was 25%. Some of the steels were also rolled in accordance with a modified schedule involving 11 and 16 passes respectively, and a finishing temperature of 850°C. Tensile tests were carried out on the unmachined rolled bars, and the results from the bars finished at 1050°C are given in Table 3a and b. All the steels were subjected to bend tests as specified in BS 4449. In this test the bars were bent through 180° at 20°C, around a radius of 3d, where d is the diameter of the bar. Several of the steels were subjected to a rebend test

Table 1 Typical composition and properties of commercial C-Mn reinforcing bar steels

Composition, wt-%			Bar dia., mm	Yield strength (min.) N/mm ²
C	Mn	Si		
0.4	1.2	0.35	35	455
0.40	0.80	0.45	16	433