# Hardenabilities of Vanadium-Modified 4330 Low Alloy Constructional Steels

P. L. MANGONON

*The substitutability of vanadium for molybdenum in a 4330 low alloy steel grade was investigated. In particular, the influence on hardenabiltiy of three factors, 1) composition (partial and total substitution), 2) austenitizing temperature and 3) small additions of titanium were determined. Critical hardenable diameters,* $D_I$, *based on 50 pct martensite hardness and austenitic grain sizes reveal very significant information. At normal commercial heat treating temperatures, the results show that a one-for-two vanadium-for-molybdenum substitution by weight attains equivalent hardenabilities. The data suggest that as much as 0.24 pct V is dissolved in austenite at 871 °C (1600 °F) and that the austenitic grains in vanadium steels coarsen easier than those in molybdenum steels. These refute older concepts about insolubility of vanadium carbides and finer austenitic grain sizes for vanadium steels.*

An examination of the list of current AISI and SAE constructional low alloy steel compositions designed for quenched and tempered applications reveals that the 6100 alloys are the only steels containing vanadium. In addition, vanadium containing steels account for only a small percentage of the total low alloy steels produced in the United States. Historically, however, vanadium containing low alloy steels accounted for a major portion of the total low alloy steel produced in the early 1900s as shown in Fig. 1.[1] This figure shows the usage of vanadium steels peaking in 1920 to about 34 pct of the total alloy production and then curtailed drastically from then to only about 4 pct of total low alloy production in 1978.[2] During the same period, Figure 1 portrays also the steady dramatic decline in production of nickel steels.

There is no doubt that the shifts in usage from one alloy system to another are technically sound. History suggests, however, that the overriding factors for steel producers as well as customers in these shifts are the availability and economics of the alloying elements. This was the case in the late sixties and early seventies for nickel in stainless and low alloy steels. The cost and availability of nickel forced producers to substitute manganese for nickel.[3] In the case of vanadium, it demonstrates the development of molybdenum usage in alloy steels. As discussed in a 1921 paper[4] and quoted by Robinson,[1] McKnight[4] pointed out: "at this time the Ford car was built for the most part of steel which was ordered to conform to the analysis, 0.23 to 0.28 pct carbon, 1 pct chromium, 0.18 pct vanadium and 0.70 to 0.90 pct manganese. This analysis was so written that the steelmaker would average 7 pct of his heats on the low side and 15 pct on the high side (of the carbon range). The low carbon heats were used for case hardened parts and the high carbon ones for oil quenching

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P. L. MANGONON, Manager, Steel Research and Development, Foote Mineral Company, Route 100, Exton, PA 19341.

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