

Vanadium Microalloyed Forging Steels

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1. Introduction

Many applications for structures, machine and vehicle parts require high strength and good fatigue resistance. Traditionally, steels for these applications have been produced by forging and then heat treating to produce martensitic microstructures. The hardened microstructures are then tempered, at low temperatures, if ultrahigh strengths and moderate toughness are required, or are tempered at high temperatures, if moderate high strength and high toughness are required.^{1,2)} For moderate high strength products, vanadium microalloyed steels are now widely used.³⁻⁵⁾ For example, Table I, from papers given in an international symposium, lists applications for which microalloyed forging steels were used in 1987.⁴⁾ The moderate high strengths of vanadium microalloyed steels are produced during cooling after forging and as described below, no further heat treatment is required. The microstructures, in contrast to the martensite of quenched and tempered steels, consist of ferrite and pearlite precipitation strengthened by vanadium carbonitride precipitate dispersions.³⁻⁵⁾

The Use of microalloying in steels is based on the addition of small amounts of vanadium, niobium and/or titanium,⁵⁾ typically on the order of 0.1 to 0.2 mass pct or less. Other elements, such as aluminium for grain size refinement and boron for hardenability, and elements residual from steelmaking, may of course also present in steels in small amounts, but such elements and their effects are generally considered to be outside of microalloying technology.

Microalloying was first applied, in the 1960s and 1970s, to flat-rolled, low-carbon steel for higher strengths, in which low-temperature controlled rolling and niobium additions combined to prevent austenite recrystallisation, and thereby promoted very fine ferrite grain sizes with excellent combinations of strength, between 300 and 500 MPa, and toughness.⁶⁾ The need for higher strengths, combined with forging and higher carbon contents, however, produced a much different set of conditions for microalloying in forging steels. As a result microalloying in forging steels developed widely only in the 1980s. Vanadium became the primary microalloying element, and microstructures consisting largely of pearlite strengthened by vanadium precipitates replaced the largely ferritic structures of low-carbon sheet and plate products in which niobium was the primary microalloying element.

This paper describes in detail the processing, microstructure and properties of medium-carbon, vanadium-containing forging steels.

2. Processing Considerations

Forging steel technology is based on thermomechanical forming of bar steels. Today the bar steels are almost universally produced by electric arc furnace melting of scrap steel, ladle