The Effect of Vanadium and Niobium on the Properties and Microstructure of the Intercritically Reheated Coarse Grained Heat Affected Zone in Low Carbon Microalloyed Steels

Y. LI, D. N. CROWTHER,[1] M. J. W. GREEN,[1] P. S. MITCHELL[2] and T. N. BAKER

Metallurgy and Engineering Materials Group, Department of Mechanical Engineering, University of Strathclyde, Glasgow, G1 1XJ, UK. 1) Corus Group, Swinden Technology Centre, Moorgate, Rotherham, S60 3AR, UK.
2) Vanitec, Winterton House, High Street, Westerham, Kent, TN16 1AJ, UK.

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Four steels, C–Mn–0.05V, C–Mn–0.11V, C–Mn and C–Mn–0.03Nb, all essentially boron-free were subjected to processing to simulate the microstructure of a coarse grained heat affected zone (GC HAZ) and an intercritically reheated coarse grained HAZ (IC GC HAZ). This involved reheating to 1350°C, rapid cooling ($\Delta t_{8/5}$=24 s) to room temperature and then reheating to either 750°C or 800°C. The toughness of the simulated GC HAZ and IC GC HAZ was assessed using both Charpy and CTOD tests and the hardness of both zones was also measured. A detailed assessment of the size and area fraction of martensite–austenite (M-A) phase in the IC GC HAZ in the steels was obtained from a combination of Scanning Electron Microscopy (SEM) and Image Analysis of the resultant SEM micrographs. In addition, the distribution of the M-A phase was examined by observing 250 fields at a magnification of 2500 times in the SEM for each of the steels.

It is clear that the alloying addition has a significant effect on the amount and size of the M-A phase. The addition of 0.05% V to the C-Mn steel resulted in the lowest IC GC HAZ Charpy 50J impact transition temperature and the 0.1 mm CTOD transition temperature. The corresponding size and area fraction of the M-A phase were the smallest of the four steels. Raising the level of vanadium to 0.11% caused a deterioration in IC GC HAZ toughness, which was reflected in a greater area fraction of M-A phase, larger mean and maximum sizes of M-A particles and significantly more fields containing M-A phase. The addition of 0.03%Nb produced poorer IC GC HAZ toughness data than C–Mn–V and C–Mn steels and this was related to the large size and area fraction of M-A phase quantified in the Nb steel. The presence of M-A phase is considered to be the dominant factor in determining the toughness of IC GC HAZ.

KEY WORDS: V-microalloyed steel; Nb-microalloyed steel; coarse grained heat affected zone; intercritically reheated coarse grained heat affected zone; martensite–austenite phase; heat affected zone toughness; welding.

1. Introduction

The balance of high strength and good toughness in HSLA steels can be upset by the thermal cycles experienced during welding, producing poor toughness in the heat affected zone (HAZ). Historically, the lowest toughness was expected in the grain coarsened heat affected zone (GC HAZ), which is the part of the HAZ immediately adjacent to the weld fusion line.[1] During welding, the GC HAZ experiences peak temperatures up to the melting point, followed by rapid cooling. The high temperatures can lead to significant austenite grain coarsening, and the combination of a coarse austenite grain size and rapid cooling promotes brittle microstructures, which contain high proportions of ferrite side-plates and bainite. In recent years, it has been found that the most degraded part in the HAZ is the intercritically reheated coarse grained HAZ (IC GC HAZ), which is the region of the GC HAZ heated to temperatures between the Ac_1 and Ac_3 by subsequent welding passes.[2,3] During the intercritical thermal cycle, partial transformation to austenite occurs, particularly where austenite stabilisers, such as carbon or manganese, are segregated in the initial microstructure. These areas include pearlite/bainite colonies.[4] On cooling, these high carbon regions transform to pearlite/bainite or martensite-austenite (M-A) constituents, depending on the hardenbility of the austenite and cooling rate. The presence of M-A phase is generally regarded as the major factor which reduces the HAZ toughness.[5,6] However, it is also reported that the loss in toughness is not solely due to the presence of M-A phase, but is related to the distribution and morphology of the M-A constituent, and the matrix microstructure.[7]

Niobium is added to enhance the strength of HSLA steels. However, under welding conditions, niobium has an