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Influence of Cr, Mn and Mo Addition on Structure and Properties of V Microalloyed Medium Carbon Steels

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The effect of austenitizing temperature and Cr, Mo and Mn addition on microstructure and mechanical properties of V microalloyed medium carbon steel has been studied by means of metallography and mechanical testing. The addition of Cr, Mn and Mo leads to a decrease in yield strength (YS) by approximate 100 MPa in comparison to the base steel. It is assumed that Mn and Mo increase hardenability by promoting the formation of bainitic sheaves (BS), *i.e.* by suppressing the formation of ferrite-pearlite and acicular ferrite (FP-AF). Cr at the level used in this work is not that effective. Presence and packet size of bainitic sheaves decrease the Charpy V-notch impact energy at 20 °C (CVN20) in comparison to ferrite-pearlite and acicular ferrite microstructures.

KEY WORDS: Medium-carbon steels; Chromium; Molybdenum; Manganese addition; Bainite; Acicular ferrite

1. Introduction

The demand for economical steels has increased over past decades. Steels are expected to have a lean chemistry and to be easier to fabricate. At the same time they are expected to have properties at least equal to steels which are being substituted. These demands have been, at least in part, met by V microalloyed medium carbon forging steels in order to substitute traditional quenched and tempered (Q+T) steels; their main advantage is that they save energy by eliminating the heat treatment from the production route, in spite of some lower toughness.

The main alloying element in microalloyed medium carbon forging steels is V. It is assumed that V promotes strengthening by precipitation of V(C,N) particles which precipitate during and/or after austenite-ferrite transformation[1]. At the same time, an increase in toughness is provided by intragranular nucleation of acicular ferrite, dominantly on VN particles[1–3]. Also, small amount of titanium is usually added in order to prevent the grain growth at high temperatures[4]. Bainite and/or acicular ferrite are frequently encountered structures[1–4] in the medium carbon V-microalloyed steel. Both microstructures are formed in the same temperature range; the only difference is the nucleation sites, *i.e.* while bainites nucleates at the austenite grain boundaries (intergranularly), acicular ferrite nucleates on the particles within the grains (intragranularly)[5,6]. Therefore, final microstructure is determined by the effectiveness of nucleation sites.

Some of the alloying elements, primarily Cr and Mo are not originally added to the V-microalloyed medium carbon forging steels; their small addition is usually introduced by negligence in recycling process. However, the effect of these elements, including Mn, on the transformation behavior is of the particular interest in this steel grades. They have very strong influence on the formation of proeutectoid ferrite. If the proeutectoid ferrite is formed during transformation, it decorates the prior austenite grains disabling them from their role as nucleation sites for bainite formation. Therefore, in the presence of proeutectoid ferrite, acicular ferrite intragranular nucleation is the

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Table 1 Chemical compositions of experimental steels (wt%)

Steel	C	Si	Mn	P	S	Cr	Ni	Mo	V	Ti	Al	N
Base-steel	0.26	0.30	1.48	0.0080	0.0080	0.29	0.16	0.03	0.12	0.010	0.02	0.0166
L-7Cr	0.26	0.32	1.57	0.0080	0.0050	0.57	0.16	0.03	0.12	0.010	0.03	0.0159
L-9Mo	0.27	0.32	1.58	0.0080	0.0060	0.29	0.17	0.21	0.10	0.010	0.02	0.0138
L-22Mn	0.26	0.31	1.75	0.0100	0.0100	0.37	0.18	0.04	0.17	0.010	0.03	0.0021

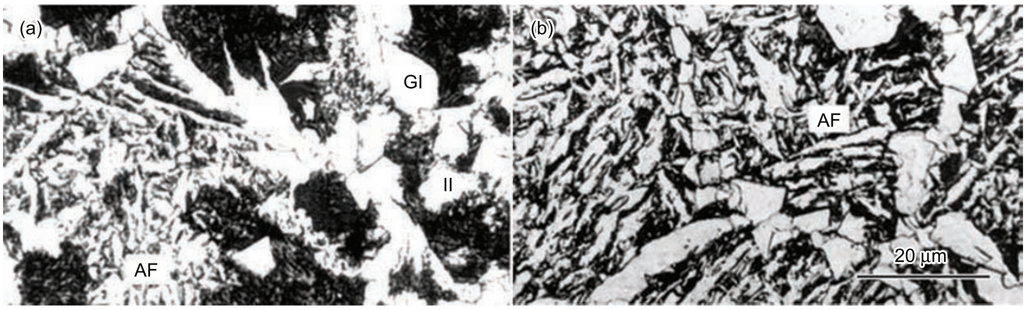

Fig. 1 Microstructure of high-N steel air-cooled from austenitization temperature of: (a) 950 °C, (b) 1300 °C (GI–grain boundary ferrite idiomorphs; II–intragranular idiomorphs; AF–acicular ferrite)

dominant mechanism for austenite decomposition. Generally, Cr, Mn and Mo raise the hardenability of the steel, defined as their ability to prevent formation of proeutectoid ferrite and pearlite during hardening[1,5]. These elements promote the formation of hard phases such as bainite and martensite[5]. The influence of V and nitrogen was reported in numerous papers[1,2,5], while the results reporting the influence of Cr, Mo and Mn on the acicular ferrite formation in V microalloyed medium carbon forging steels are limited[3,7,8].

Therefore, the aim of this work is to clarify the influence of Cr, Mo and Mn on the formation of bainite and acicular ferrite during continuous cooling of V microalloyed medium-carbon steels and its influence on mechanical properties.

2. Experimental

Four different medium-carbon steels, containing various content of Cr, Mo and Mn, were vacuum melted, casted into ingots, press forged and hot rolled to 22 mm diameter rods. The chemical compositions of tested steels are given in Table 1. The 180 mm long test pieces which were reheated to different austenitizing temperatures, ranging from 950 °C to 1300 °C for 30 min, and cooled in still air. The still air-cooling rate was estimated to be between 1.15 and 1.35 °C/s, depending upon the reheating temperature. The test pieces were then mechanically polished and etched in 2% nital to observe the microstructures by optical microscopy. Tensile test pieces with round shape (L_0=40 mm, d_0=8 mm) and Charpy V-notch impact test pieces, were taken from the center of the bar.

3. Results

3.1 Microstructure

Four steels (base steel and steels L-7, L-9 and L-22 with enhanced content of Cr, Mo and Mn, respectively) were prepared to investigate the effect of alloying elements on the transformation behavior of the air cooled medium carbon V-microalloyed steels. Prior austenite grain size was 21–90 μm in the temperature range of 950–1250 °C.

The microstructure of the base steel austenitized at 950–1050 °C consists of polygonal ferrite idiomorphs, nucleated at austenite grain boundaries or within the former austenite grains, surrounded by pearlite and some acicular ferrite, Fig. 1(a). With increasing austenitization temperature to 1150–1300 °C, the fraction of acicular ferrite increases and becomes dominant morphology, Fig. 1(b).

The microstructure of the Mo steel (L-9) reheated to 950–1150 °C is characterized as bainitic sheaves and some acicular ferrite (Fig. 2(a)), and as the absence of primary grain boundary ferrite. Microstructure obtained after cooling from high austenitizing temperature (1250 °C) consists of bainitic sheaves and some acicular ferrite (Fig. 2(b)).

The microstructure of the L-7 (Cr steel) air cooled from 950–1050 °C (Fig. 3(a)) consists of intragranularly nucleated polygonal ferrite, grain boundary idiomorphs and allotriomorphs. With increasing austenitization temperature to 1150–1300 °C, the acicular ferrite becomes dominant morphology, alongside with grain boundary idiomorphs (Fig. 3(b)).

The microstructure obtained in the Mn steel after air cooling from both the low austenitization temperature (950 °C) and the high austenitization temperature (1300 °C) consists of bainitic sheaves. The microstructure is free of grain boundary ferrites (Figs. 4(a) and 4(b)).

The bainitic sheaves, their packet size, in Mo and Mn added steels depend on the reheating temperature. Air cooling from higher reheating temperature