

Significant influence of carbon and niobium on the precipitation behavior and microstructural evolution and their consequent impact on mechanical properties in microalloyed steels

S. Liu^a, V.S.A. Challa^a, V.V. Natarajan^a, R.D.K. Misra^{a,*}, D.M. Sidorenko^b, M.D. Mulholland^b, M. Manohar^b, J.E. Hartmann^b

^a Laboratory for Excellence in Advanced Steel Research, Materials Science and Engineering Program, Department of Metallurgical, Materials and Biomedical Engineering, University of Texas at El Paso, 500 W. University Avenue, El Paso, TX 79968, USA

^b ArcelorMittal Global R & D Center, 3001 East Columbus Drive, East Chicago, IN 46312, USA

ARTICLE INFO

Keywords:

Microalloyed steel
Precipitation
Martensite/austenite island
(Nb, Ti)(C, N) precipitate

Carbon and niobium (Nb) play an important role in influencing the ultimate microstructure and mechanical properties. In this regard, we elucidate here the impact of carbon and Nb on the microstructural evolution and precipitation behavior during continuous cooling of industrially processed microalloyed steels with varying carbon and Nb-content. The microstructure and precipitation evolution was studied via electron microscopy and related to the outcome of thermodynamic simulation. The increase of carbon content in steel increased the precipitation temperature of (Nb, Ti)(C, N), which led to relatively larger size (Nb, Ti)(C, N) precipitates. Furthermore, high carbon content contributed to stabilization of austenite and delayed the transformation of ferrite and bainite, such that martensite/austenite content (M/A) was obtained. The M/A islands in high carbon-containing steel contributed to highest strength and intermediate elongation. The high degree of (Nb, Ti)(C, N) precipitation in steel contributed to refinement of prior austenite grain size and strain accumulation, which increased ferrite and bainite start transformation temperature, resulting in higher volume fraction of polygonal ferrite. Polygonal ferrite in steel with high Nb-content was responsible for relatively low strength in comparison with steels with higher carbon or intermediate carbon-Nb contents. Granular bainite and lath bainite in steel with intermediate C and Nb-contents was characterized by best combination of strength and elongation. The outcomes of the thermodynamic simulations were consistent with the experimentally observed microstructure.

1. Introduction

High strength low-alloy (HSLA) steels are widely used for pipelines, buildings, bridges, and ships because of their potential to obtain high strength-toughness combination [1]. Desired mechanical properties can be obtained through optimization of alloy design and thermo-mechanical controlled processing (TMCP) [2–5], involving grain refinement in conjunction with microstructural control and precipitation strengthening. The microalloying elements, Ti and Nb, enable grain refinement and also contribute to precipitation hardening. Ti is beneficial because it combines with nitrogen at relatively high temperatures and restricts grain growth, while, Nb effectively retards recrystallization during the hot rolling process leading to grain refinement. Moreover, both Ti and Nb, can precipitate as carbides from the supersaturated ferrite solid solution during austenite-to-ferrite trans-

formation, increasing strength. However, the relative contribution of microalloying elements on strength is governed by the impact that carbon-content may have on the precipitation behavior and transformation products.

In the present study, we underscore the effect of carbon and niobium on the precipitation behavior and microstructural evolution and their consequent impact on mechanical properties. The microstructural evolution as a function of carbon and niobium content was theoretically simulated and compared with the experimental findings.

2. Experimental procedure

The nominal composition of steels in weight percentage is listed in Table 1 and were industrially processed. Nb and Ti were added for precipitation strengthening and grain refinement.

* Corresponding author.

E-mail address: dmisra2@utep.edu (R.D.K. Misra).

Table 1

The chemical composition of experimental steels (wt%).

Samples	C	Mn	Si	Cr	Nb	Ti	N
Base Steel (A)	0.046	1.87	0.35	0.4	0.042	0.120	0.004
High C- low Nb Steel (B)	0.096	1.91	0.37	0.39	0.048	0.126	0.004
C- high Nb Steel (C)	0.049	1.942	0.37	0.396	0.063	0.11	0.004

Table 2

The tensile properties of experimental steels.

Samples	Yield strength (ksi) (MPa)	Tensile strength (ksi) (MPa)	Total elongation (%)
Base steel (A)	122 (841)	130 (896)	24.3
High C- low Nb steel (B)	137 (945)	143 (986)	18.4
C- high Nb steel (C)	112 (772)	124 (855)	11.2

Standard tensile tests were conducted at room temperature (RT) on longitudinal specimens machined according to ASTM E8 specification (dimensions 225 mm×12.5 mm×3 mm, gage length 50 mm) using computerized tensile test system.

Transmission electron microscopy (TEM) was carried out on thin foils and carbon extraction replicas. Thin foils were prepared by cutting thin wafers from the steel samples and grinding to ~35 µm in thickness. Three millimeters disks were punched from the wafers and electropolished using 10% perchloric acid in ethanol. Electron transparent foils were examined by Hitachi H9500 TEM operated at 200 kV. Energy-dispersive X-ray spectroscopy (EDS) was carried out to study the composition of precipitates.

JMatPro software was used to calculate CCT curves of experimental steels. The CCT diagrams of steels were calculated based on the chemical composition, finish rolling temperature of 910 °C and the prior austenite grain size of 30 µm.

3. Results

3.1. Tensile properties

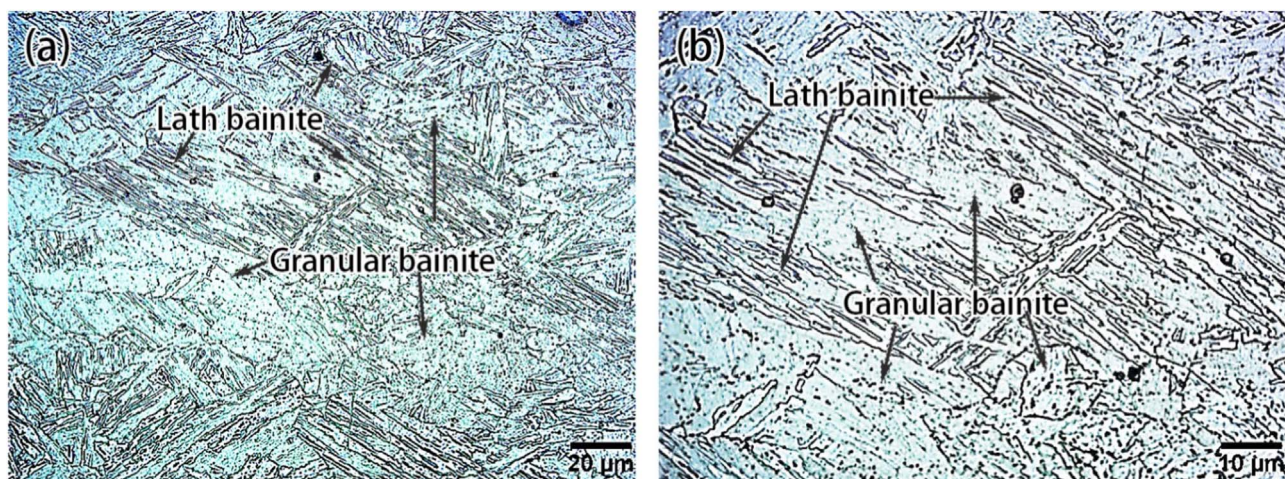
The tensile test results of the three experimental steels are summarized in Table 2. The increase in yield and tensile strength followed the sequence: steel B (YS: 137 ksi (945 MPa), TS: 143 ksi

(986 MPa)) > steel A (YS: 122 ksi (841 MPa), TS: 130 ksi (896 MPa)) > steel C (YS: 112 ksi (772 MPa), TS: 124 ksi (855 MPa)). While the ductility followed the sequence: steel A (24.3%) > steel B (18.4%) > steel C (11.2%). Thus, steel B had the highest strength, followed by steel A and C. The elongation was highest for steel A, followed by steels B and C.

3.2. Microstructure

Light micrographs of base steel A are presented in Fig. 1. As marked in Fig. 1, the matrix of steel A consisted of ~40% lath bainite and ~60% granular bainite with lath bainite being the predominant constituent. Granular bainite was located between the bainite laths. Polygonal ferrite was not observed. The morphology of lath bainite and granular bainite as imaged via SEM are illustrated in Fig. 2. Fig. 2 did not indicate the presence of cementite either in granular bainite or lath bainite. Both types of bainite were cementite-free and are attributed to relatively low carbon-content in steel A. The lath-like bainitic ferrite and granular bainite both contained high density of dislocations (Fig. 3). Precipitates of size less than 10 nm were observed in granular bainite, pinned by dislocations (Fig. 3(c)).

The microstructure of steel B with higher C-content consisted of ~85% granular bainite, ~10% lath bainite and ~5% martensite/austenite (M/A) island. As illustrated in Fig. 4, majority of bainite in

**Fig. 1.** Light micrographs of base steel A.

Download English Version:

<https://daneshyari.com/en/article/5456084>

Download Persian Version:

<https://daneshyari.com/article/5456084>

[Daneshyari.com](https://daneshyari.com)