Materials Science & Engineering A 714 (2018) 25–35

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Modeling the viscoplastic behavior and grain size in a hot worked Nb-bearing high-Mn steel

G.R. Ebrahimi[a], A. Momeni[b], H.R. Ezatpour[c,*]

[a] Department of Materials and Polymer Engineering, Hakim Sabzevari University, Sabzevar, Iran
[b] Department of Materials Science and Engineering, Hamedan University of Technology, Hamedan, Iran
[c] Faculty of Engineering, Sabzevar University of New Technology, Sabzevar, Iran

ARTICLE INFO

Keywords:
TWIP steel
TRIP steel
Dynamic recrystallization
EBSD
Hot deformation

ABSTRACT

In this study, hot compression tests were performed on a Nb-containing high-Mn steel at temperatures in range of 850–1150 °C and strain rates of 0.001–1 s^{-1}. The stacking fault energy of the material at different conditions, i.e. without Nb, with Nb and C in solution and with Nb and C as NbC, was calculated by JMat Pro software as 10.9, 10.15 and 10 mJ/m^2. The software predicted that the stacking fault energy reaches 200–250 mJ/m^2 as temperature rises to the deformation range. A new model with interactive effects of temperature, strain and strain rate was constructed on the basis of Johnson-Cook equation to predict the experimental flow curves satisfactorily. Optical microscopy and SEM-EBSD observations showed that strain-induced boundary migration (SIBM) is the major mechanism of dynamic recrystallization giving rise to a necklace structure at the early stages of recrystallization. It was found that very fine layers of lath martensite form within the large austenitic grains during post-deformation quenching. However, the martensite layers were less discernible in the small DRX grains. The dynamically recrystallized grain size decreased with increase in strain rate or decrease in temperature. The model developed based on Bate and Hutchinton approach showed that the recrystallized grain size has an indirect relationship with the flow stress level.

1. Introduction

High manganese twinning/transformation induced plasticity (TRIP/TWIP) steels are promising groups of advanced high strength steels. They obtain their high strength, ductility and fracture toughness by martensitic transformation or mechanical twins during plastic deformation [1,2]. These unique properties have introduced them as alternative materials to common high strength steels in automotive industries [3,4]. The stacking fault energy (SFE) plays a crucial role in imparting the mentioned attributes to high-Mn steels [5,6]. Indeed, twinning is the dominant deformation mechanism when the chemical composition is carefully designed by adding 15–30% Mn along with appropriate amounts of Al, Si and C to maintain SFE in range of 20–40 mJ/m^2 [7–9]. When SFE lies below the mentioned range, martensitic transformation is the prevailing deformation mechanism and when SFE exceeds the range conventional dislocation glide conveys the plastic deformation [5,6]. Therefore, any change in the chemical composition of these steels has a crucial effect on SFE and therefore on the mechanism of plastic deformation.

Even though the austenitic structure of these steels ensures high ductility, the low intrinsic strength is the great drawback which has challenged the researchers [10]. Some modifications in the chemical composition of steels have been tried to make them appropriate for high-strength car components [10]. In the recent tries, microalloyed high-Mn steels have been introduced as a new generation in which a combination of precipitation hardening and twinning provides higher strength levels [11,12]. It has been approved that micro-additions of V, Ti or B can significantly increase the yield strength of austenitic matrix through the interaction of microalloyed carbides with the matrix dislocations, low and high angle grain boundaries (GBs) and twin boundaries [13]. However, some other issues such as the effects of microalloying elements on SFE, their interaction with GBs as solute atoms or precipitates during hot working still needs further investigation. The interaction between microalloyed carbonitrides and restoration mechanisms (dynamic or static recrstallizations, DRX or SRX) in common microalloyed steels have been well investigated [14–19]. The focus of previous works has been on the precipitation regimes and the interaction between precipitation and restoration mechanisms [20–23]. In high-Mn steels, the influence of processing parameters, i.e. strain rate and temperature, and micro-alloy additions on the solute drag,

* Corresponding author.
E-mail address: H.R.Ezatpour@gmail.com (H.R. Ezatpour).

https://doi.org/10.1016/j.msea.2017.12.094
Received 17 September 2017; Received in revised form 25 December 2017; Accepted 26 December 2017
Available online 27 December 2017
0921-5093/

Table 1
Chemical composition of Nb-bearing high-Mn steel used in the present investigation.

C	Si	Al	Mn	Cr	S	P	Nb	Ni	V	Cu	Fe
0.29	0.01	0.009	20.29	0.19	0.005	0.011	0.202	0.04	0.01	0.07	Balance

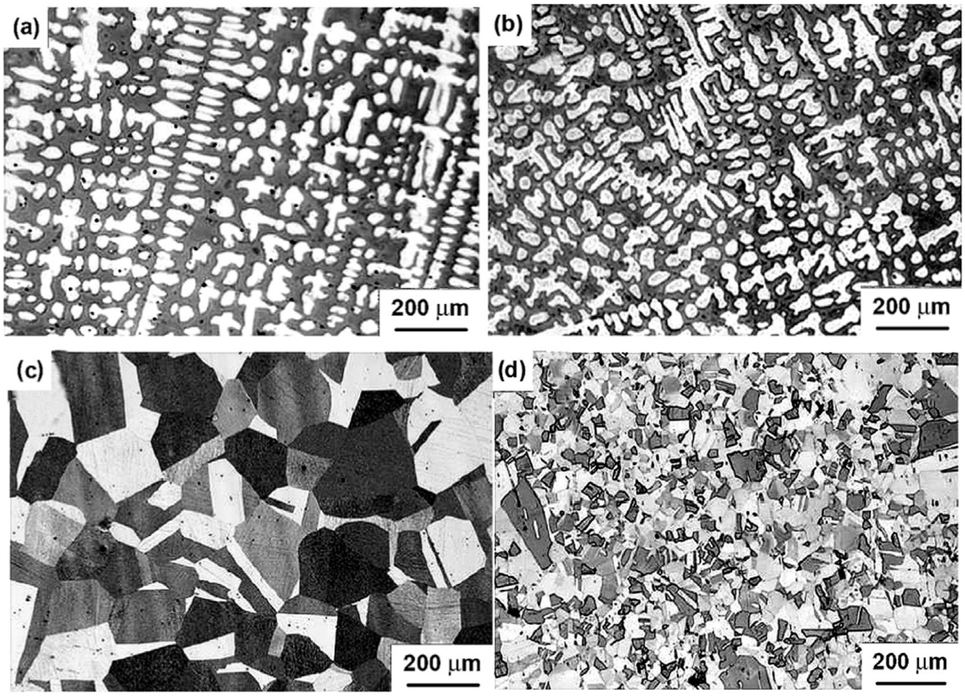

Fig. 1. (a, b) Cast and (c, d) hot rolled and homogenized microstructures of (a, c) Nb-free high-Mn steel and (b, d) Nb-bearing high-Mn steel.

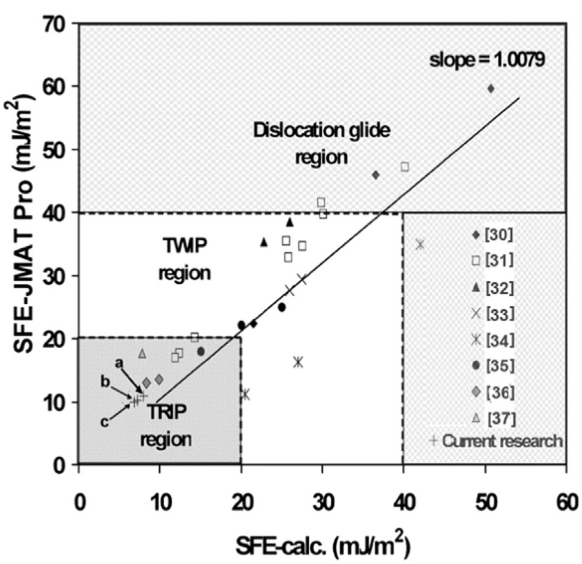

Fig. 2. Comparison of stacking fault energy values calculated by the JMAt pro software with those reported in the literature.

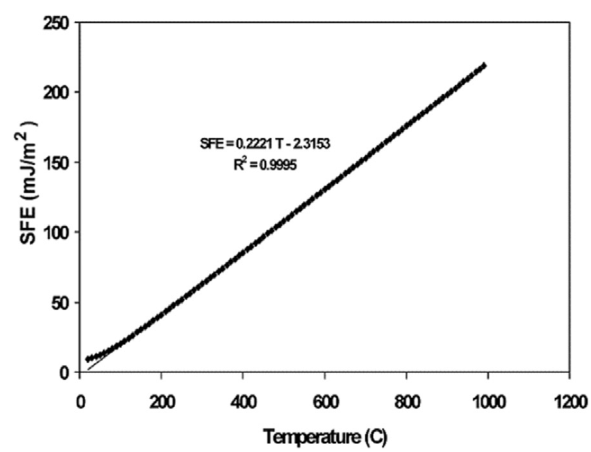

Fig. 3. Variations of the stacking fault energy for the studied material with deformation temperature.

precipitation behavior and softening mechanisms have not received as it merits [13]. If during hot working carbon and microalloying elements are in solution, they exert solute drag forces on the GBs and postpone DRX or SRX [24]. However, when dynamic precipitation occurs, submicron particles may effectively pin the GBs and inhibit recrystallization [25]. Unlike to the submicron particles, large ones (often larger than 1 μm) may stimulate DRX or SRX by the mechanism so called "particle stimulation of nucleation" (PSN) [26]. In addition to the above complex scenario, the microalloying elements affect SFE and necessitate careful consideration to avoid any composition deviation from the required ranges. Hence, the present investigation has aimed at shedding light on the effect of microalloying with Nb on SFE, dynamic recrystallization behavior and modeling the flow curves and grain size of a Nb-bearing high-Mn steel.

2. Experimental procedures

2.1. Nb-bearing high-Mn steel preparation

The chemical composition of the Nb-bearing high-Mn steel used in this investigation is presented in Table 1.

The material was melted in a vacuum induction melting (VIM)