Shear and dynamic effects on hot deformation of Fe-25Mn-5Al-0.7C lightweight steel

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FeMnAlC lightweight steel has a narrow hot-working window. In industrial rolling, shear stress and dynamic parameter variations are inevitable and may cause defects. This study compares uniaxial and shear-compression tests on Fe-25Mn-5Al-0.7C steel at $950-1100$ ℃ and $0.01-10\ s^{-1}$, including sudden temperature/strain-rate changes. Results show that shear stress significantly enlarges the instability region on processing maps, narrowing the safe window to $\mathrm{T}>1075$ ℃ and $\dot{\varepsilon}<0.015\ s^{-1}$. Shear stress is confirmed as the primary cause of banded structures and flow localization. Increasing temperature or strain rate eliminates these defects, while a sudden strain-rate rise promotes DRX nucleation and improves uniformity. A temperature-modified DRX model accurately predicts the microstructural evolution.

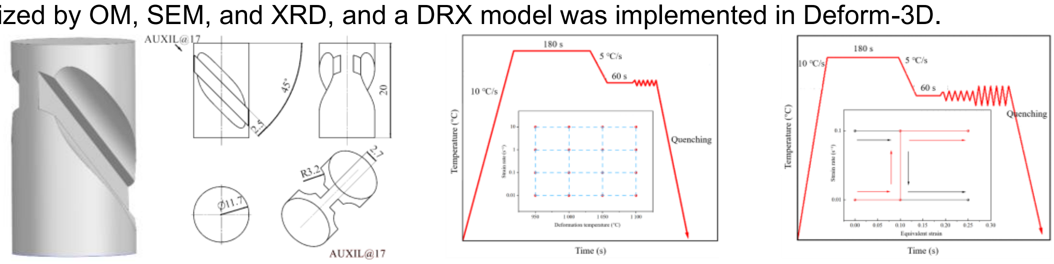
KEYWORDS: LIGHTWEIGHT STEEL – MULTI-AXIAL STRESS – SHEAR-COMPRESSION SPECIMEN – DYNAMICALLY VARYING PARAMETERS – DYNAMIC RECRYSTALLIZATION

Introduction

FeMnAlC lightweight steel has a narrow hot-working window. In rolling, shear stress and dynamic temperature/strain-rate variations are unavoidable and cause defects [1]. Yet most studies focus on uniaxial steady-state conditions, ignoring the coupled effects of shear and transients. This work compares uniaxial and shear-compression tests with sudden changes to clarify the roles of shear and transient conditions in deformation instability and microstructure evolution, guiding process optimization.

Experimental Methods

The experimental material was Fe-25Mn-5Al-0.7C lightweight steel, prepared by vacuum melting, forging, and wire-cutting. Shear-compression specimens (Fig.1a) were used to impose shear stress on Fe-25Mn-5Al-0.7C steel [2]. Hot compression tests were performed at $950-1100$ ℃ and $0.01-10\ s^{-1}$ under steady-state (Fig.1b) and sudden temperature/strain-rate change (Fig.1c) conditions [3]. Microstructures were characterized by OM, SEM, and XRD, and a DRX model was implemented in Deform-3D.



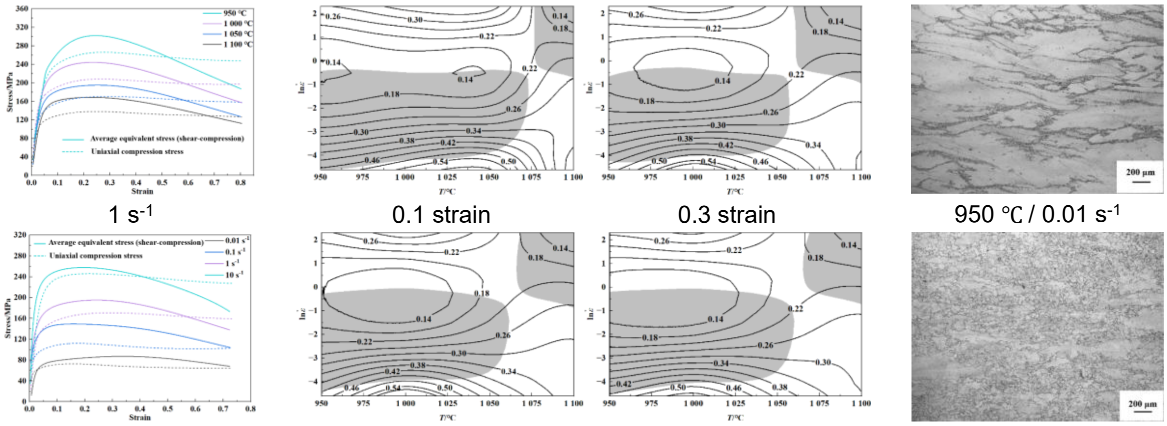
(a) Specimen (b) Steady-state (c) Sudden change

Fig.1 - schematic of the Gleeble thermal simulation experimental scheme

Results and Discussion

Flow Stress and Processing Maps

Shear-compression tests (Fig.2a) showed that peak stress decreases with temperature and increases with strain rate, with rapid post-peak softening attributed to shear banding. Processing maps (Fig.2b) revealed that shear stress enlarges the instability domain, narrowing the safe window to $\mathrm{T}>1075$ ℃ and $\dot{\varepsilon}<0.015\ s^{-1}$. Unstable microstructures showed coarse banded structures (Fig.2c), while safe ones exhibited uniform equiaxed grains, confirming shear stress as the primary cause of rolling defects.



1 s^{-1} | 0.1 strain | 0.3 strain | 950 ℃ / 0.01 s^{-1}

1050 ℃ | 0.5 strain | 0.7 strain | 1100 ℃ / 0.01 s^{-1}

(a) Flow stress curve | (b) Processing Map | (c) Microstructure

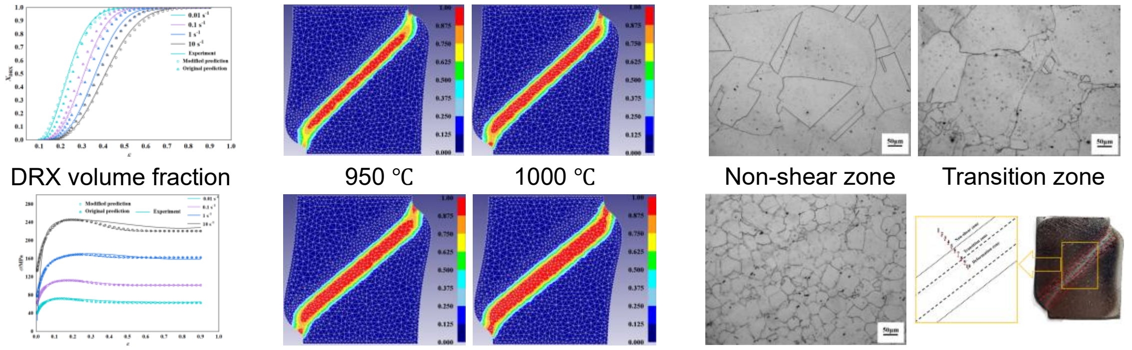
Fig.2 - results of Gleeble thermal simulation experiments and metallographic tests

DRX Kinetic Model and Numerical Simulation

A DRX kinetic model was established based on uniaxial compression data:

$$X_{\mathrm{DRX}} = 1 - \exp\left[-b_0\left(\frac{\varepsilon-\varepsilon_c}{\varepsilon_p}\right)^{k_0}\right] \qquad [1]$$

where X_{DRX} is the DRX volume fraction, ε_c the critical strain, and ε_p the peak strain. Parameters were fitted via the Zener–Hollomon parameter and temperature-corrected. Embedded into Deform-3D, the model predicted DRX predominantly in the shear zone, increasing toward the center, in good agreement with experiments.



DRX volume fraction | 950 ℃ | 1000 ℃ | Non-shear zone | Transition zone

Flow stress curve | 1050 ℃ | 1100 ℃ | Deformation zone | Zoning schematic

(a) Comparison | (b) DRX fraction contours (1 s^{-1}) | (c) Micrographs of hot-deformation zones

Fig.3 - DRX prediction model and Deform-based numerical simulation with secondary development

Conclusions

1. Shear stress markedly narrows the safe hot-processing window of Fe-25Mn-5Al-0.7C steel to $\mathrm{T} > 1075$ ℃ and $\dot{\varepsilon} < 0.015$ s^{-1}.
2. Shear stress is the direct cause of banded structures and flow localization. Increasing temperature or strain rate effectively eliminates such defects; a dynamic temperature rise also improves uniformity.
3. The temperature-modified DRX model, validated by Deform-3D simulations, can reliably predict the DRX distribution under multi-axial stress, offering a useful tool for industrial rolling schedule design.

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