Fundamental Investigation in Manufacturing Formable High-strength Steel Strips with Bimodal Microstructure by Heavy-Reduction Controlled Rolling Process

（大圧下制御圧延による易成形高強度バイモーダル薄鋼板の製造基盤研究）

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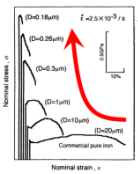
Introduction

The heterogeneous structure (the so-called bimodal structure) having dispersed micron-size grains (1-3 μm) in a matrix of nanosize grains (< 300 nm) in pure Cu produced by multipass equal-channel angular pressing and annealing showed a significantly improved ductility while maintaining its strength [1]. Ductility is significantly enhanced in the bimodal microstructure of hot-extruded plain carbon steel: the manufacture of heterogeneous fine-grained microstructures such as a bimodal structure using a production process similar to that used for steel strips will be an important step toward realizing advanced high-strength steel sheets for lightweight construction. Nonetheless, additional researches are required because the mechanism on formation of the bimodal structure in the steel has not yet been clarified and mass production for steel strips is difficult in this process [2]. The aim of this investigation is to establish a manufacturing process for formable high-strength steel strip sheets with a bimodal microstructure by the heavy-reduction controlled rolling process.

Background

Strong demands for structural metal sheets with improved strength and ductility to enable lightweight construction as a means of reducing environmental impact.

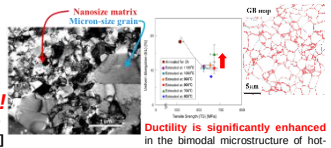
Microstructure control methods
- Solid-solution strengthening
- Precipitation control
- Dispersion strengthening
- Martensite hardening
- **Grain refinement.**



Severe defect!
Deteriorating ductility of nano-sized grains[3]

Strength is considerably improved
(Grain size from Submicron to nanosize)

An innovative method to solve this problem!!
→ Heterogeneous Structure



Ductility is significantly enhanced in the bimodal microstructure of hot-extruded plain carbon steel [2].

The aim of this investigation is to establish a manufacturing process for formable high-strength steel strip sheets with a bimodal microstructure by the heavy-reduction controlled rolling process.

[1] Y. Wang, M. Chen, F. Zhou and E. Ma, *Nature* 419 (2002) 912-915.
[2] K. Nagato, S. Sugiyama, A. Yanagida and J. Yanagimoto, *Mater. Sci. Eng. A* 478 (2008) 376-383.
[3] S. Takaki, K. Kawasaki, Y. Kimura, *J. Mater. Proc. Technol.* 117 (2001) 359-363.

Experimental procedure

1) Material (0.2% carbon steel)
- Initial ferrite grain size : **41μm**
- Rectangle plate : 50×10×300mm³

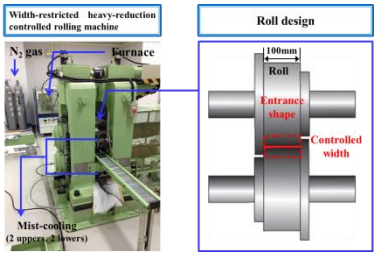
Table. Chemical composition of used steel. (mass%)

C	Si	Mn	P	S	Cr	Ni	Fe
0.213	0.25	0.547	0.005	0.001	0.01	0.02	Bal.

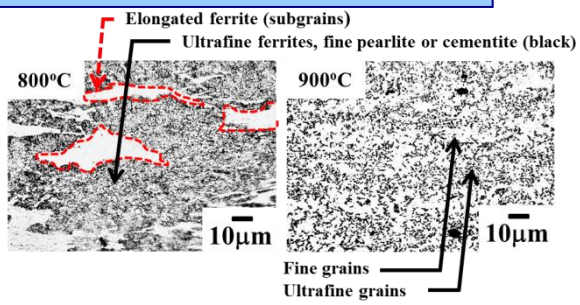
Carbon equivalent(%)＝approx.0.3

2) Heavy-reduction controlled rolling process
(300t, Maximum roll speed 4.2m/min)
- Heating temp. : 700, 800, 900, 1000ºC
- Atmosphere : N_2 Gas
- Grass lubricant
- Rolling speed : 4.2 m/min
- Target reduction ratio : 50, 60, 75%
- Air or Mist cooling

3) Microstructure observation
- Optical microscope : etching (Nital 5%)
- SEM (JSM-5600)

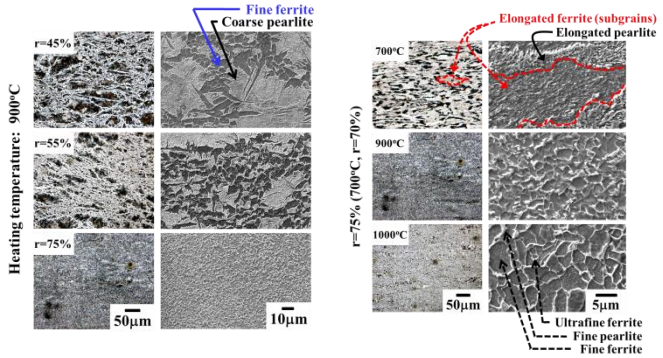


Microstructure with air cooling



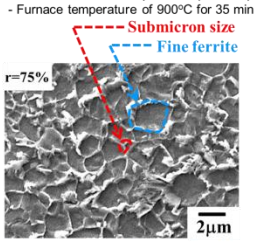
Heterogeneously mixed grains with a size of about 1-3 μm and 4-10 μm in the matrix can be observed, showing **the possibility for producing the bimodal structure at a heating temperature of 900ºC**.

Microstructure with mist cooling

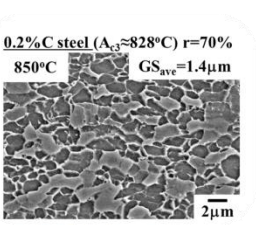


Optimal conditions

Controlled rolling (0.2%C steel)
- Estimated heated temperature (≈ 850ºC)
- Furnace temperature of 900ºC for 35 min

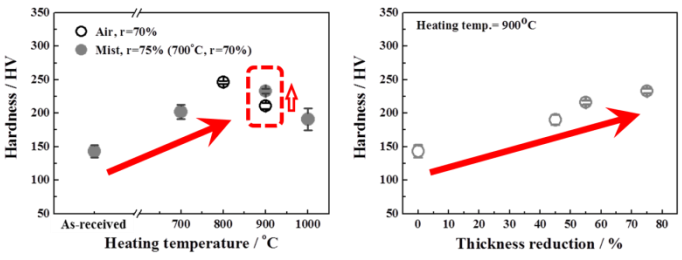


The PSC test (0.2%C steel)
- Deformation at 850ºC



Optimal conditions for producing a bimodal structure in 0.2% carbon steel
- Heating temperature (≈ 900-1000ºC); estimated heated temperature of specimen (≈ 850-950ºC)
- Reduction ratio (≈ 70%); average strain (≈ 1.39)
- Mist cooling

Vickers micro-hardness



Hardness rolled at 900ºC with mist cooling was greater than that rolled at 900ºC with air cooling, indicating **the high performance steel** manufactured by the heavy-reduction single-pass controlled rolling process.