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

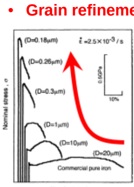
The heterogeneous structure (the so-called bimodal structure) having dispersed micron-size grains (1-3μm) in a matrix of nanosize grains (< 300nm) in pure Cu produced by multipass equal-channel angular pressing and annealing showed a significantly improved ductility while maintaining its strength [1]. 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 still 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

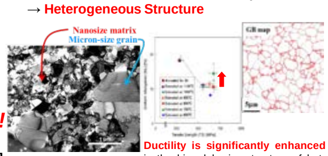
- Solid-solution strengthening
- Precipitation control
- Dispersion strengthening
- Martensite hardening
- **Grain refinement**.



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 : *w*50/80×*t*10×*l*300mm^3

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, 1000°C
- Atmosphere : N_2 Gas
- Grass lubricant
- Rolling speed : 4.2m/min
- Mist cooling

Table. Experimental conditions of rolling test.

Conditions	Reduction ratio, %
700°C (*w*50mm)	70
800°C (*w*80mm)	75
900°C (*w*80mm)	75
1000°C (*w*80mm)	75

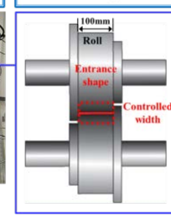
3) Microstructure observation

- Optical microscope : etching (Nital 5%)
- SEM (JSM-5600)
- FE-SEM (JSM-7100F)
- EBSD (TSL, OIM system)

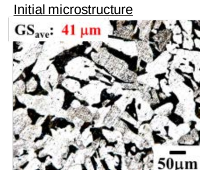
Width-restricted heavy-reduction controlled rolling machine

Maximum load: 3000 kN
Roll diameter: 360 mm
Maximum rolling speed: 4.2 m/min

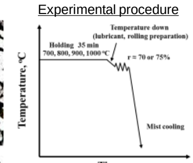
Roll design



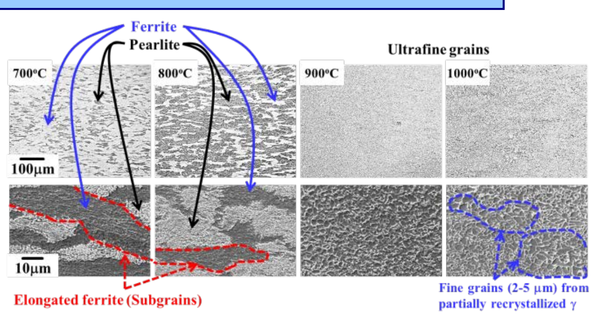
Initial microstructure



Experimental procedure

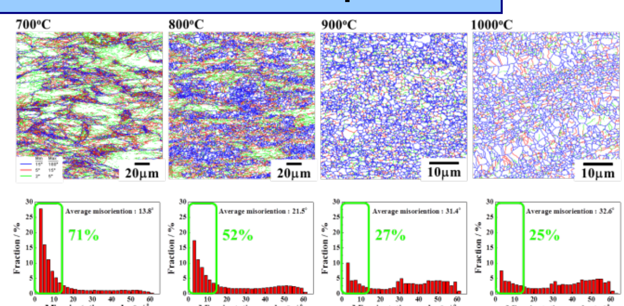


Microstructural evolution



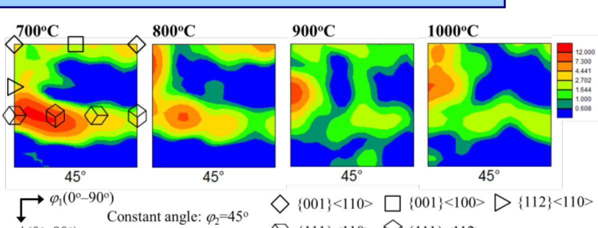
In 700 and 800°C, elongated structures can be mostly observed.
In 900 and 1000°C, **equiaxial ultrafined grains (0.5-1μm) and fine grains (1-4μm) are present with uniformly distributed cementites or fine pearlites throughout the matrix**.

Misorientation maps



Ultrafine grains with HAGBs at heating temperatures of 900°C and 1000°C

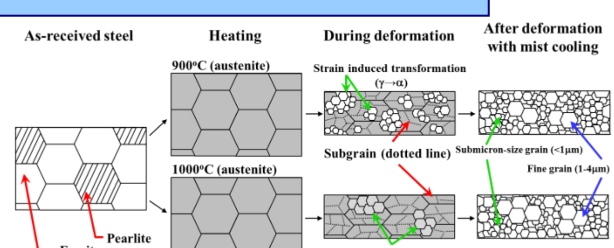
φ_2 = 45° of ODF sections



700°C→ γ-fiber and α-fiber are strongly developed.
800°C
- ✓ Intensity of γ-fiber is decreased and intensity of α-fiber is increased.

900 and 1000°C
- ✓ {113}~{4 4 11}<110> and {332}<113> components are mainly developed by the transformation.
- ✓ **(1000°C)** low intensity of {100}<011> component is present, is developed from recrystallized γ.

Formation of bimodal structure



In 900°C-heated specimen, **much nucleation at grain boundaries occurred, whereas little nucleation took place within the grains upon generating the strain-induced transformation (γ→α),** led to the bimodal structure.
In 1000°C-heated specimen, **partial recrystallization in the austenite took place** in combination with a high deformation temperature and a high imposed strain. Additionally, the recrystallized grains had the formation of a new set of strain-free, **led to the region of fine ferrites (2-5μm)** after the heavy-reduction controlled rolling process.