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

（幅拘束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

Micron-sized grains (1~3μm) were introduced into the nano-sized matrix by annealing after fabricating pure Cu with nano-sized grains (<300nm) by multi-pass ECAP, resulting in ductility increased sharply with bimodal structures (submicron-sized grains in a matrix of nanometer-sized grains) reported from Y. Wang et. al..[1] K. Nagato and J. Yanagimoto [2] also reported that bimodal structure in S20C was generated through hot extrusion and its ductility was significantly improved. However, a bit of achievements concerning bimodal structure and its characteristics in steels has been reported, and a lot of problems still remain to be solved such as large amount of power consumption and cost as well as manufacturing time, due to multi-processing and further processing etc. This study was conducted to collect preliminary data for formation and mechanical property of bimodal structure in low carbon steel through the plain strain compression test realizing large-reduction single-pass rolling.

[1] Y. Wang, M. Chen, F. Zhou and E. Ma, Nature, Vol. 419, (2002), 912-915.
[2] K. Nagato, S. Sugiyama, A. Yanagida and J. Yanagimoto, Materials Science and Engineering A, Vol. 478, (2008), 376-383.

Background

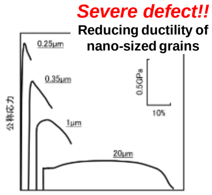
High demands for fabricating formable high-strength materials to realizing light-weight of vehicles, aircrafts and structural materials.

Microstructure control methods

- Precipitation control
- Elements addition
- **Grain refining**, etc.

Severe defect!!

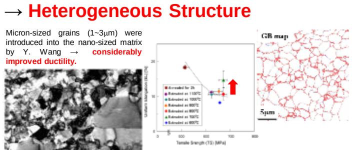
Reducing ductility of nano-sized grains



Significantly increasing strength
(Submicro and nano size)

New method to solve this defect!!
→ Heterogeneous Structure

Micron-sized grains (1~3μm) were introduced into the nano-sized matrix by Y. Wang → **considerably improved ductility.**



Bimodal structure in S20C was generated through hot extrusion and **its ductility was significantly improved** from K. Nagato and J. Yanagimoto.

Purpose of this study is **to establish the manufacturing base of bimodal steel strips with formable high-strength by width-restricted heavy-reduction controlled rolling process.**

Experimental procedure

1) Material (S20C)

- Initial ferrite grain size : **22μm**
- Rectangle specimen : 10×50×20mm

Table. Chemical composition of S20C. (mass%)

C	Si	Mn	P	S	Cr	Ni	Fe
0.20	0.19	0.53	0.024	0.014	0.02	0.01	Bal.

Carbon equivalent(%)＝approx.0.3

2) Plain-strain compression test
(15ton, Maximum ram speed 4m/s)

- Ram speed : 10mm/s
- Target reduction ratio : 70%
- Atmosphere : N_2 Gas
- Deformation temp. : 700, 750, 800, 850°C
- Mist cooling temp. : 20～30°C /s

3) Microstructure observation

- Optical microscope : etching (Nital 5%)
- FE-SEM (JSM-6330F)
- EBSD (EDAX/TSL, OIM system)
- Image analyze (grain size, $D = \sqrt{4A/\pi}$)
  A : area of each grain

4) Tensile test (Shimazu AG-50kN)

- Temperature : room temp.
- Strain rate : 1×10^{-3}/s
- Extensometer : Shimazu SG10-100
  (Unavailable type by fracture)

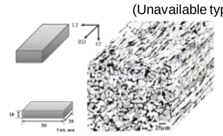


Fig. Orthogonal views of as-received S20C steel. Rolling (RD), long transverse (LT) and short transverse (ST) directions indicated.

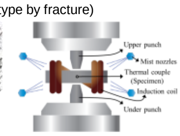


Fig. Schematic illustration of plane-strain compression test.

Fig. Photo for tensile equipment with an extensometer.

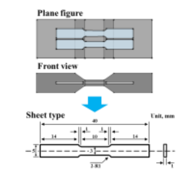
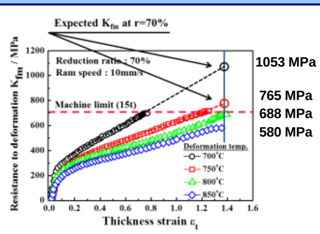


Fig. Schematic diagram of tensile test specimen.

Compression behavior



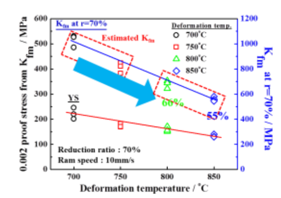
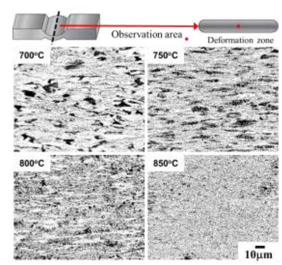


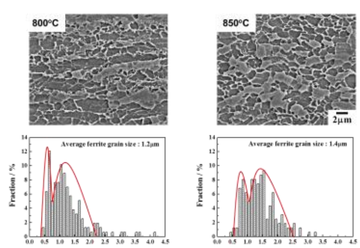
Table. Values for each conditions after compression test.

Conditions	Reduction ratio, %	Strain, ε	Strain rate, $\dot{\varepsilon}$
700°C	48	0.65	0.71
750°C	67	1.10	1.04
800°C	70	1.22	1.20
850°C	69	1.17	1.34

1. Y.S and K_{fm} reduced linearly with increasing deformation temperature from 700 to 850°C.
2. Specimen at deformation temp. of 850°C is formable with about a half of K_{fm} at deformation temp. of 700°C.

Microstructural evolution





The possibility to form the bimodal structure in S20C

$800℃ \leq expected\ Ac3(828℃) \leq 850℃$

EBSD results

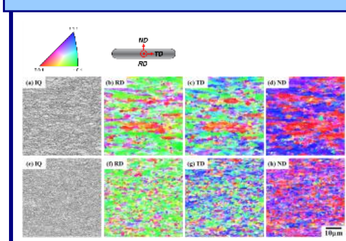


Fig. EBSD analysis of deformation zone of compressed samples; (a)-(d) compressed at 750°C, (e)-(h) compressed at 850°C, (a) and (e) IQ maps, (b) and (f) RD maps, (c) and (g) TD maps, and (d) and (h) ND maps.

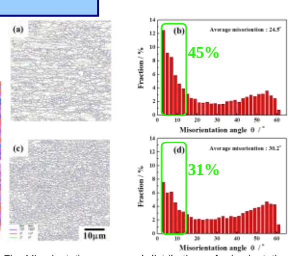
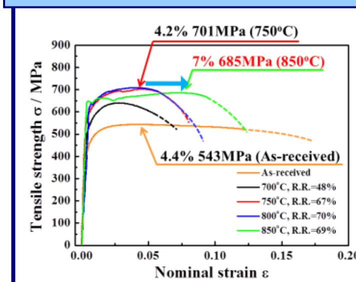
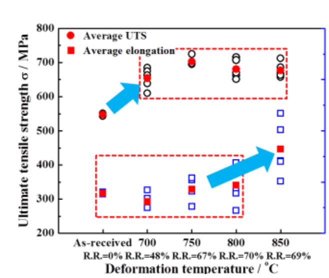


Fig. Misorientation maps and distributions of misorientation angles in the compression test; (a), (b) compressed at 750°C, $f_{LAGB}(2 \leq \theta < 15)$=45%, θave=24.5° and (c), (d) compressed at 850°C, $f_{LAGB}(2 \leq \theta < 15)$=31%, θave=30.2°

1 Texture at deformation temperature of 850°C was weaker than that of the other.
2. The fraction of LAGBs decreased 14% with changing deformation temperature from 750 to 850°C.

Mechanical property





Uniform elongation deformed at 850°C increased around 4% than that of others with holding high strength after deforming.