Generation of Superfine Steel by Single-Pass Severe Plastic Deformation

Chair for Hyper-functional Forming
Institute of Industrial Science, The University of Tokyo
Prof. Dr.-Eng. Jun Yanagimoto

Motivation

Bulk steels with fine microstructures have good mechanical characteristics. Severe plastic deformation (SPD), which gives steels a large strain and a high strain ratio, is a recent method for generating ultrafine grains (UFGs). We use extrusion as a single-pass severe plastic deformation (S2PD) process. Extrusion is a continuous process that is useful for generating UFGs because the strain induced by a singlepass can be much larger than that induced by rolling. We describe fine ferrite microstructures generated at approximately $a - g$ transformation temperatures (Ac_3 / Ar_3), and discuss our survey of the superfine material functions of determination of the their UFG steels.

1. Ferrite miniaturization

Strain Up

Extrusion Temperature Down

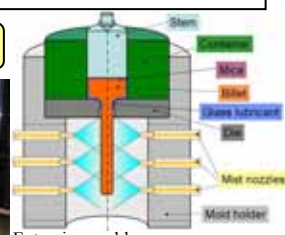
Cooling ratio Up

Transformation driving force Up

Suppress coarsening of Austenite(γ)& Ferrite(α)

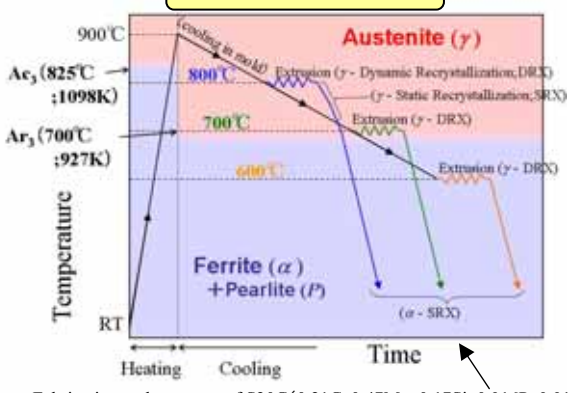
2. Extrusion setup

3000kN hydraulic double acting press
(by AMINO Co.)
Max. ram speed : 50 mm/s



Extrusion mold
・Mold material : SKD61
・Lubrication : Glass lubricant
・Cooling : Water mist
(particle size : 100μm)

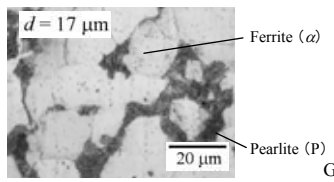
3. Extrusion outline

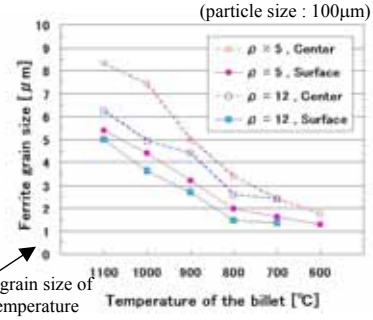


Fabrication and structure of S20C(0.21C-0.47Mn-0.17Si-0.016P-0.014S)

4. Generated fine structures

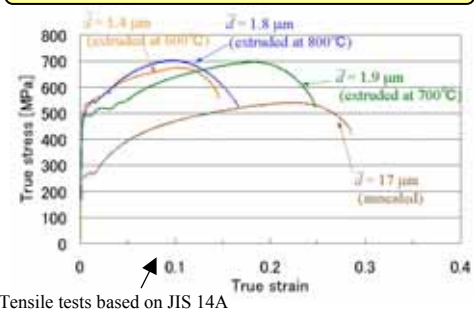
Structure before the extrusion (S20C)





Generated α grain size of extrusion temperature

5. Tensile tests of Extruded UFG steels

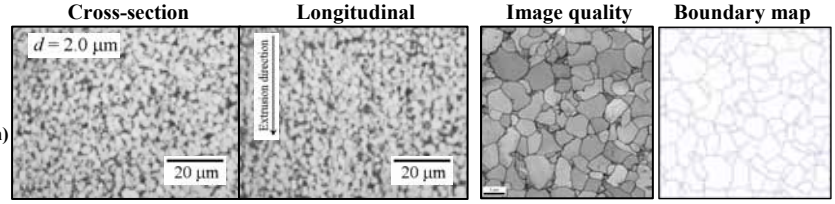


Tensile tests based on JIS 14A
(True stress－True strain)

Optical micrograph (100μm below the surface)

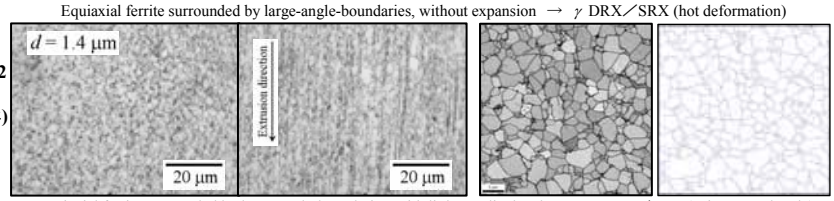
Cross-section	Longitudinal	EBSP results(at ϕ/4, Cross-section) Image quality	Boundary map

800℃, ρ=12 (Hot extrusion) (Ac_3 : 825℃)



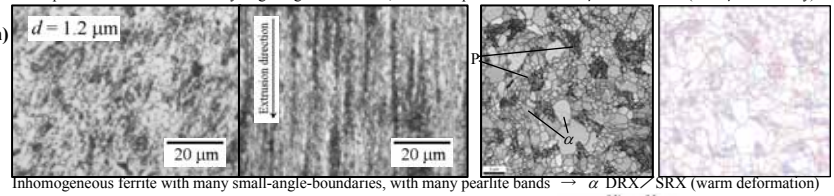
Equiaxial ferrite surrounded by large-angle-boundaries, without expansion → γ DRX／SRX (hot deformation)

700℃, ρ=12 (on Ar_3) (Ar_3 : 700℃)



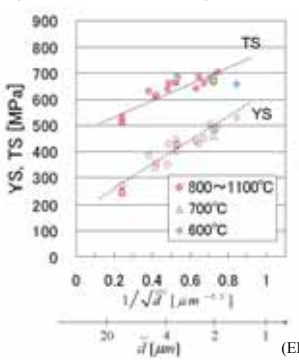
Equiaxial ferrite surrounded by large-angle-boundaries, with little pearlite bands → γ DRX／SRX (exist γ state barely)

600℃, ρ=5 (Warm extrusion)

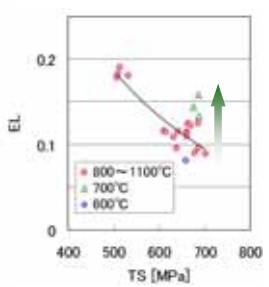


Inhomogeneous ferrite with many small-angle-boundaries, with many pearlite bands → α DRX／SRX (warm deformation)

	Min	Max	
	15°	180°	・・・High-angle-boundary
	5°	15°	・・・Low-angle-boundary



Relationships between α size to the -1/2 power and TS(Tensile strength)/ YS(Yield strength) (Result of the test piece extruded at 600℃ is below the Hall- Petch line)



Elongation increase of 700℃ extrusion
(EL : Uniform elongation, TS : Tensile strength)
Value of EL×TS : Max. over 10,000
・Pearlite grains are located discretely.
・Deformation texture is included.

6. Summary

We miniaturized α grains of ferrite S20C by extrusion using a S2PD process, and surveyed the variation in UFG structures and mechanical characteristics by changing extrusion temperature from 800℃ (hot deformation) to 600℃ (warm deformation). The results are shown below. (1) The UFGs extruded at 700 ℃ were hot-deformation structures with γ recrystallization, and those extruded at 600℃ were warm-deformation structures with α recrystallization. (2) From the comparison of the tensile test results of UFG steels extruded at 800 700 and 600℃ (1073 973 and 873 K), the average ferrite grain size range was 1～2 μm. The UFG steel extruded at 700℃ maintained a tensile strength of 700 MPa step increased its percentage uniform elongation to 15%, 5% greater than that of the UFG steel extruded at 800℃. The UFG steel extruded at 600℃ decreased both its tensile strength and uniform elongation.