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Implication of Dynamic Materials and Softening Models to the Hot Forging Analysis of SDSS

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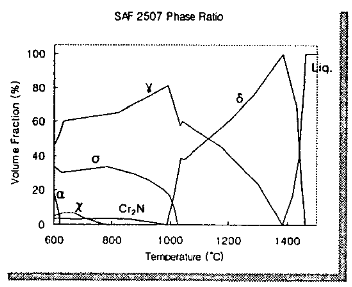
Plastic Forming of SAF 2507

- **High deformation resistance and springback**
  - strictly limited cold forming
- **Degradation by precipitation**
  - Cr_2N, σ : lower impact strength and toughness
  - hot working above 1000 °C recommended



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Research Scopes & Objectives

- **Mechanical test ①**
  - to enhance the design of compression test
- **Flow curve analysis ②**
  - formulation of softening kinetics
  - criteria of dynamic softening behaviors
- **FEM simulation ③**
  - application of improved material database (MDB)
  - implication of dynamic softening effect
- **Solution qualification ④**
  - forming load estimation
  - microstructure profile

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Dynamic Softening during Hot Forging

- **Thermal softening (pseudo-softening)**
  - deformation heating
  - localized adiabatic heating
- **Structrural softening**
  - dynamic recrystallization (DRX)
  - dynamic recovery (DRV)

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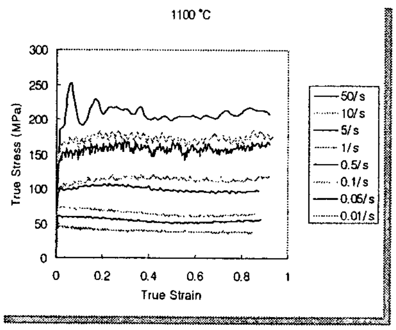
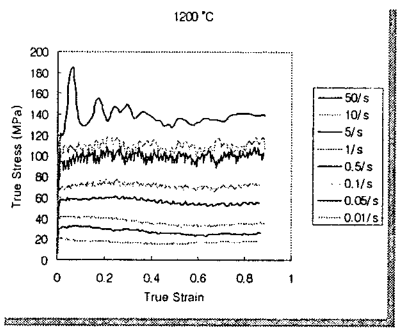
High Temp. Compression Results

- **Weak or no work hardening**
- **Work softening**
- **Stress oscillation**





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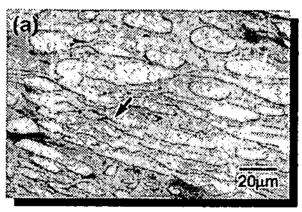
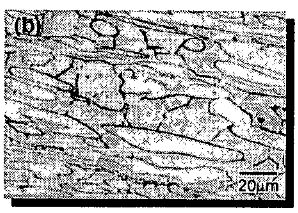
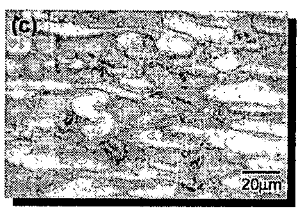
OM of Deformed Structure

- **Shear band formation**
- **Subgrain formation in δ**
- **Serration of phase boundary**







(a) 1000°C, 10/s
(b) 1200°C, 5.0/s
(c) 1250°C, 1.0/s

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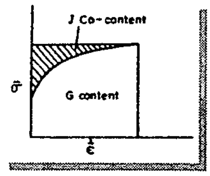
Dynamic Materials Model

- **Power dissipation efficiency**
  - Prasad et al. (1984)
  - amount of energy contributed to structural relaxation



$$\eta = \frac{J}{J_{max}} = \frac{2m}{m+1}$$

- **Stability parameter**
  - Ziegler (1963), Kumar (1987)
  - req'd condition of stable deformation

$$\varsigma = \frac{\partial \ln(m/m+1)}{\partial \ln \dot{\varepsilon}} + m > 0$$

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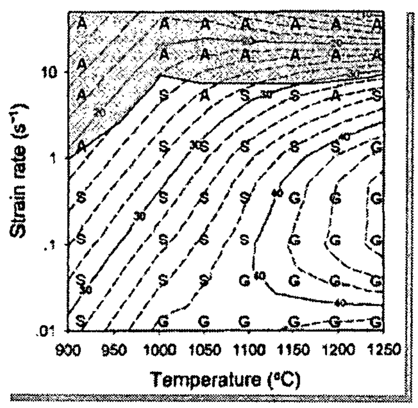
Construction of Deformation Maps

- **Dynamic materials model**
  - stability criterion
  - power dissip. efficiency



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Flow Behavior vs. Microstructure

- **ASB: instability / SG: DRV / GBSR: DRX**

		900°C	1000°C	1050°C	1100°C	1150°C	1200°C	1250°C
	0.01	SG	GBSR	GBSR	GBSR	GBSR	GBSR	GBSR
	0.05	SG	SG	SG	GBSR	GBSR	GBSR	GBSR
	0.1	SG	SG	SG	GBSR	GBSR	GBSR	GBSR
$\dot{\varepsilon}$	*0.5*	SG	SG	SG	SG	GBSR	GBSR	GBSR
(s^{-1})	*1.0*	ASB	SG	SG	SG	SG	SG	GBSR
	5.0	ASB	SG	ASB	SG	SG	ASB	SG
	10	ASB	ASB	ASB	ASB	ASB	ASB	ASB
	50	ASB	ASB	ASB	ASB	ASB	ASB	ASB

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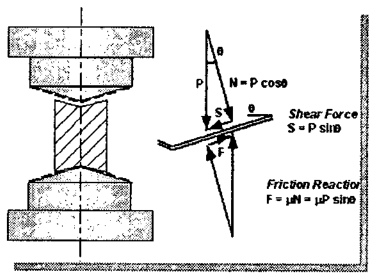
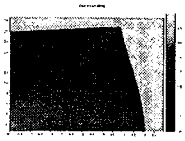
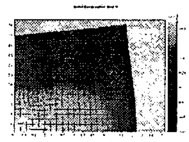
Seibel Type Compression Test

- **Self-compensation of friction**
  - **Yoshijawa et al. (1994)**
  - **cup & cone design**

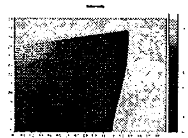




tan θ < μ



tan θ = μ



tan θ > μ

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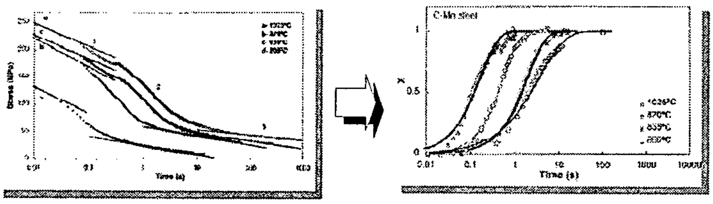
Load Relaxation w/DRX

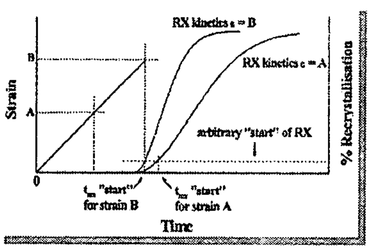
- **Gradual transition to steady state**
  - **structural relaxation by DRX**
  - **Jonas (1988), Karjalainen (1995), Mateo (2001)**

$$\sigma = (1 - X)\sigma_1 + X\sigma_3$$
$$= (1 - X)(\sigma_{o1} - \alpha_1 \log t) + X(\sigma_{o3} - \alpha_3 \log t)$$



Study of DRX based on SRX Kinetics - I

- **Unified approach of recrystallization**
  - **DRX = SRX fast enough to be observed in the time scale of deformation (*Hodgson et al.*)**



  - **invalid for extended recovery processes (ex. cDRX)**

Study of DRX based on SRX Kinetics - II

- **SRX Kinetics**
  - additivity rule for on-set time of straining

$$X = 1 - \exp\left[-\ln 2 \left(\frac{\int_0^t dt}{t_{50}} \right)^n \right]$$

  - empirical formula $t_{50} = A\varepsilon^a$
- **Formulation of DRX**
  - Avrami's relation

$$X = 1 - \exp\left[-\ln 2 \left(\frac{\varepsilon^{1-a}}{A(1-a)\dot{\varepsilon}} \right)^n \right]$$

  - "arbitrary" initiation of DRX (1%)

$$\varepsilon_c = \left[A(1-a)\dot{\varepsilon}(0.0145)^{1/n} \right]^{1/1-a}$$

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Compensation of Dynamic Softening

- **Dynamic recovery**

$$\sigma = \sigma_{DRV} = \sigma_0 + B[1 - \exp(-C\varepsilon)]^m$$

- **Dynamic recrystallization**

$$\rho = \rho_0(1 - X) \qquad \sigma = \alpha\mu b\sqrt{\rho}$$

$$\Rightarrow \quad \sigma = \sigma_{DRV} \qquad \varepsilon < \varepsilon_c$$

$$\sigma = \sigma_{DRV} - \Delta\sigma_{DRX} = \sigma_{DRV} - B\sqrt{X} \qquad \varepsilon \geq \varepsilon_c$$

- **Localized adiabatic thermal softening**

$$\sigma = \sigma_{DRV} \cdot S_{ASB} = \left\{ \sigma_0 + B[1 - \exp(-C\varepsilon)]^m \right\} \cdot \left[1 - \left(\frac{T - T_0}{T_m - T_0} \right)^p \right]$$

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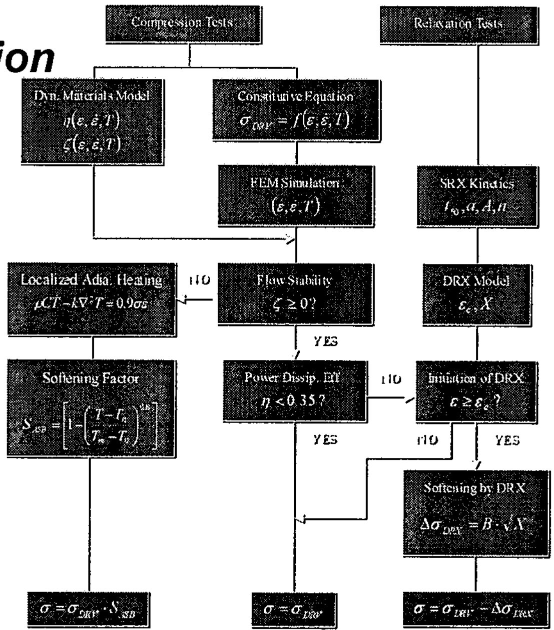
Schematics of Stress Calculation

- **Adiabatic heating**
  - **stability parameter**
- **DRV / DRX**
  - **Power dissip. eff.**



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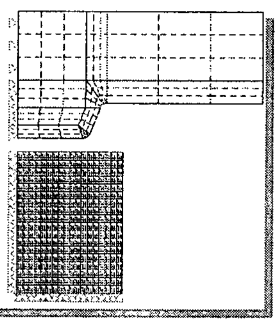
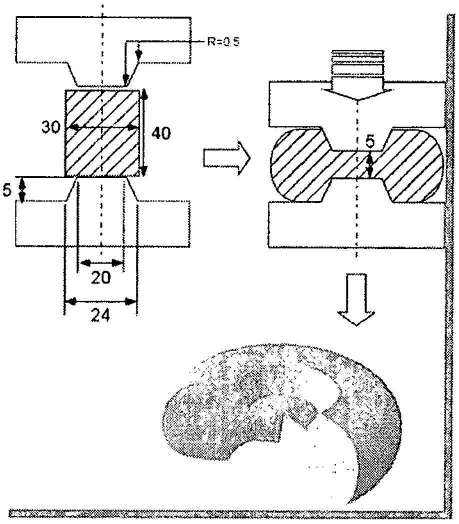
Process Selection

- **Disk upsetting**
  - **simple axisymmetric forging process**





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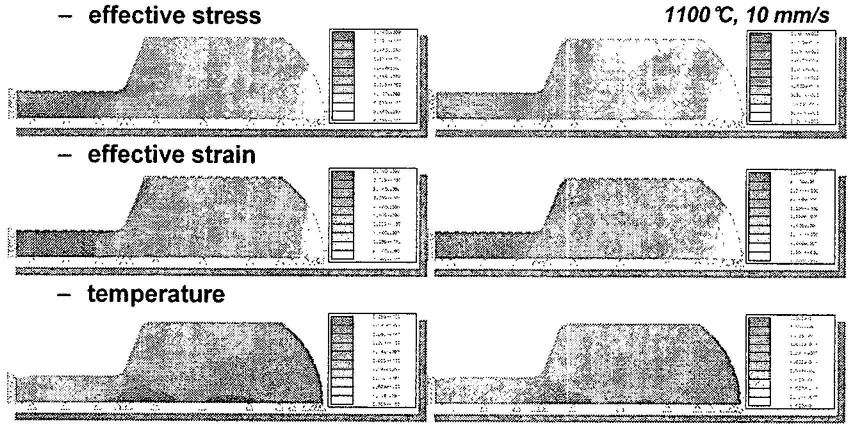
Effect of Stress Calculation Methods

- **Direct input of Num. Data**
- **Compensation by formula**

– effective stress *1100℃, 10 mm/s*

– effective strain

– temperature



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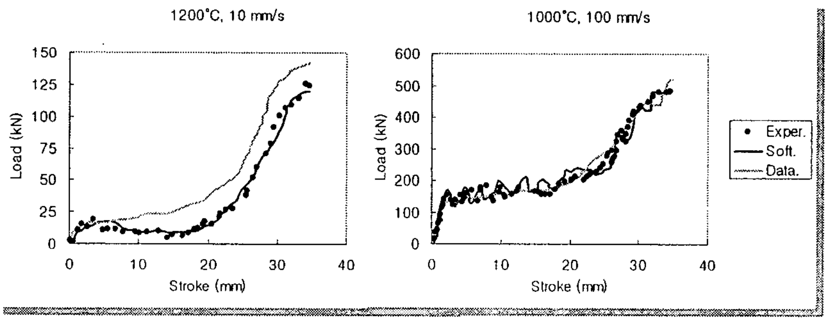
Forming Load Prediction

- **High T, medium stroke speed**
  - **higher load level predicted by num. input MDB**
- **Load oscillation at fast strokes**
  - **cannot be predicted by numerical flow data**



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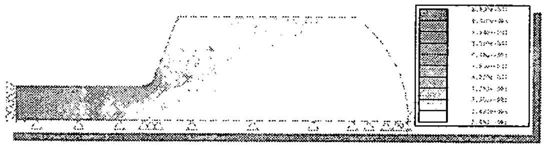
Microstructure Profile of Forged Part

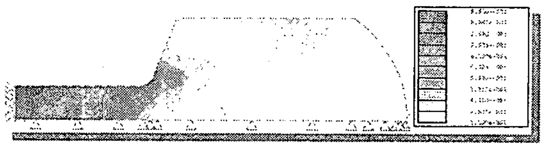
- **Distribution of DRX volume fraction**

1200℃, 10 mm/s

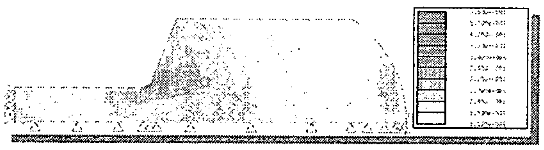
  - measured by QI



  - compensation by formula



  - num. data input



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Summary & Conclusions

- **Formulation of gDRX kinetics**
  - framework of SRX kinetics determined by load relaxation
- **Prediction of softening behavior**
  - criteria based on dynamic materials model
- **FEM with softening compensation**
  - improve in forming load prediction & microstructure

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