High Strain Rate Superplastic Behavior of Al-Li-Mg-Cu-Sc Alloy Subjected to Severe Plastic Deformation

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GOAL OF THE WORK

TO STUDY THE SUPERPLASTIC PROPERTIES OF Al-Li-Mg-Cu-Sc ALLOY WITH FINE-GRAINED MICROSTRUCTURE PRODUCED BY DIFFERENT PROCESSING TECHNIQUES

- Production of the fine-grained microstructure by two different processing ways:
  - Equal-channel angular extrusion (ECAE) at 325°C;
  - Hot rolling (HR) at 300°C;
- Study of the superplastic properties of Al-Li-Mg-Cu-Sc alloy subjected to different processing ways at temperatures from 350 to 525°C and strain rates from 1.4×10^{-3} to 1.4×10^{-1} s^{-1};
- Microstructural analysis of deformed samples and study of the cavitation near the fracture zone.

EXPERIMENTAL PROCEDURES

- ALLOY COMPOSITION OF Al-Li-Mg-Cu-Sc ALLOY (1443 Al):

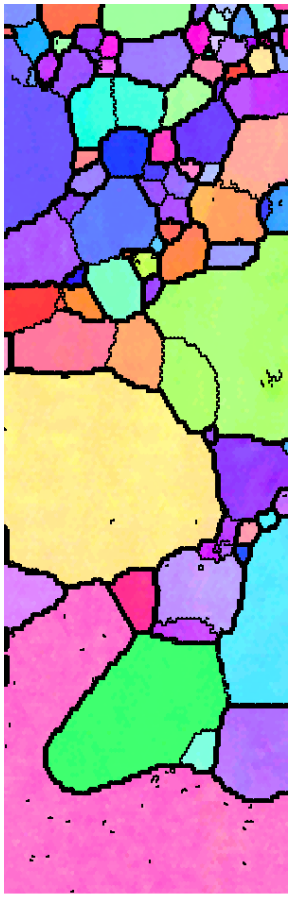
Element	Li	Mg	Cu	Sc	Zr	Fe	Be	Ti	Si	Ni	Al
weight %	1.9	1.0	1.7	0.03	0.08	0.08	0.05	0.04	0.04	0.03	Bal.

- STARTING MATERIAL
  - Direct chill casting;
  - Solution treatment at 530°C for 20 hours followed by water quenching.
- PRODUCTION OF FINE-GRAINED MICROSTRUCTURE
  - ECAE of cylinders ∅20×100 mm^2 at 325°C with a ram speed of ~10 mm/s to the total true strain e≈16 (16 passes) by route Bc;
  - Hot rolling of 60×40×20 mm^3 preforms at 300°C in a duo rolling mill with a strain rate of ~10^{-1} s^{-1} to the total reduction in thickness of 90% (e≈2.3).

EXPERIMENTAL PROCEDURES

- TENSILE TESTS
  - 6x3x2 mm^3 flat polished samples;
  - Shimadzu AG-G testing machine;
  - Temperature range of 350-525°C, Air;
  - Initial strain rates of 1.4×10^{-3}-1.4×10^{-1} s^{-1}.
- MICROSTRUCTURE CHARACTERIZATION
  - Optical microscopy (OM) using Olympus BX-60 Microscope;
  - Transmission electron microscopy (TEM) using Hitachi H-650 Microscope;
  - Orientation imaging microscopy (OIM) using JEOL JXA8100 electron probe micro-analyzer with OIM software provided by TexSEM Lab., Inc.

MICROSTRUCTURE OF 1443 Al BEFORE HOT WORKING

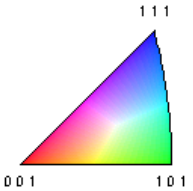


15.00 µm = 15 steps

Gray Scale Map Type: <none>

Color Coded Map Type: Inverse Pole Figure [001]

Aluminum



Boundaries: Rotation Angle

	Min	Max	Fraction
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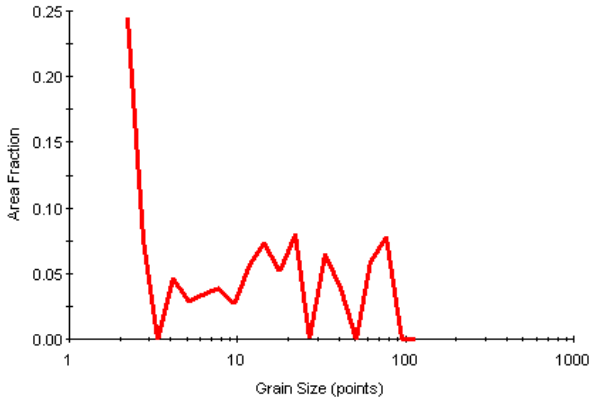
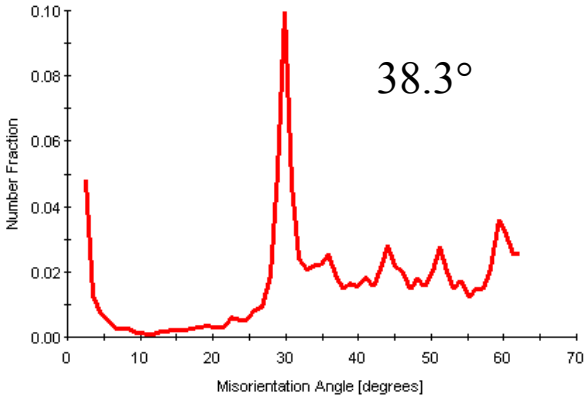
—	15°	62.8°	0.736

*For statistics - any point pair with misorientation exceeding 2° is considered a boundary

Grain Size

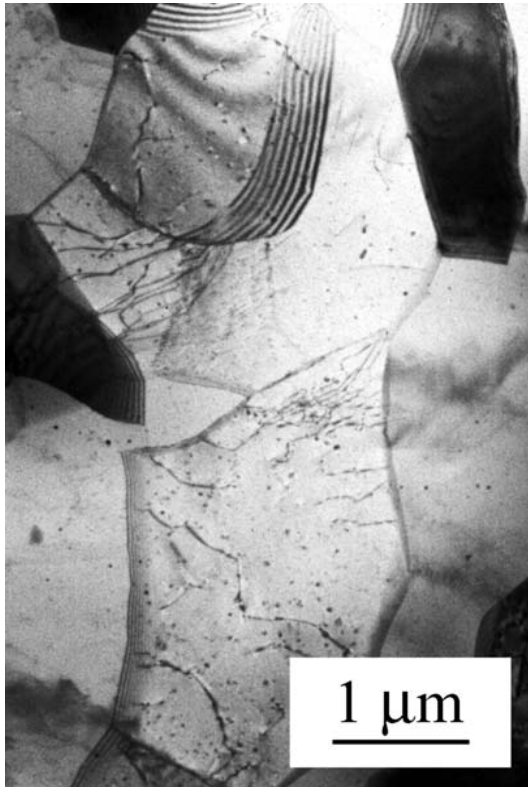


Misorientation Angle

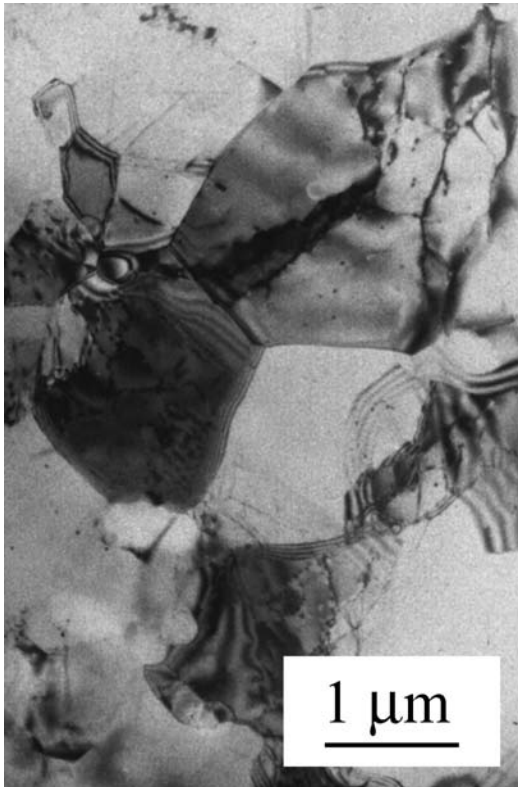


MICROSTRUCTURE OF 1443 Al AFTER HOT WORKING

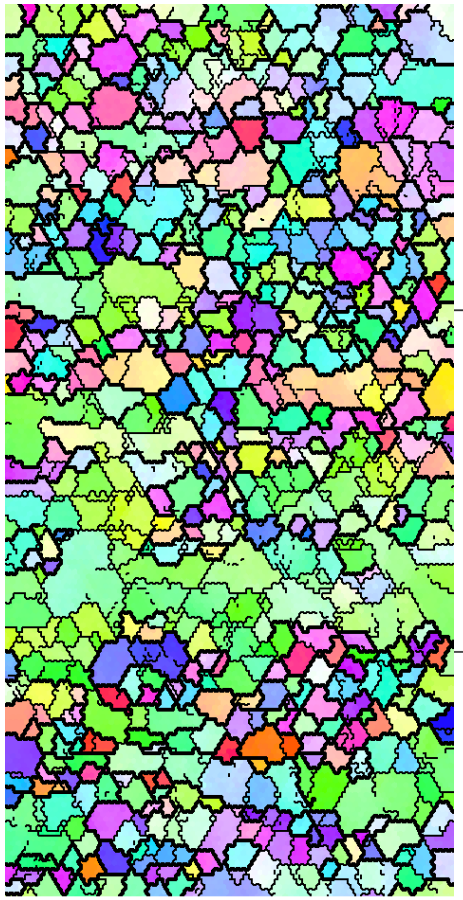
ECAE



Hot Rolling



MICROSTRUCTURE OF 1443 Al AFTER ECAE



Gray Scale Map Type: <none>

Color Coded Map Type: Inverse Pole Figure [001]

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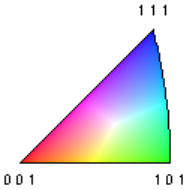


Boundaries: Rotation Angle

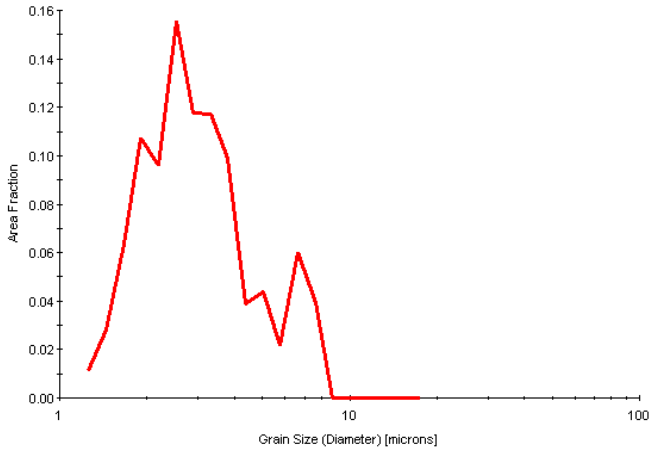
	Min	Max	Fraction
———	2°	15°	0.389
———	15°	62.8°	0.611

*For statistics - any point pair with misorientation exceeding 2° is considered a boundary

7.50 µm = 15 steps

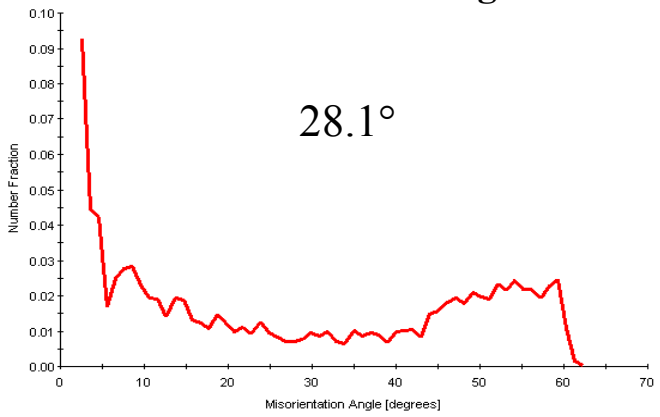
Extrusion Direction

Grain Size

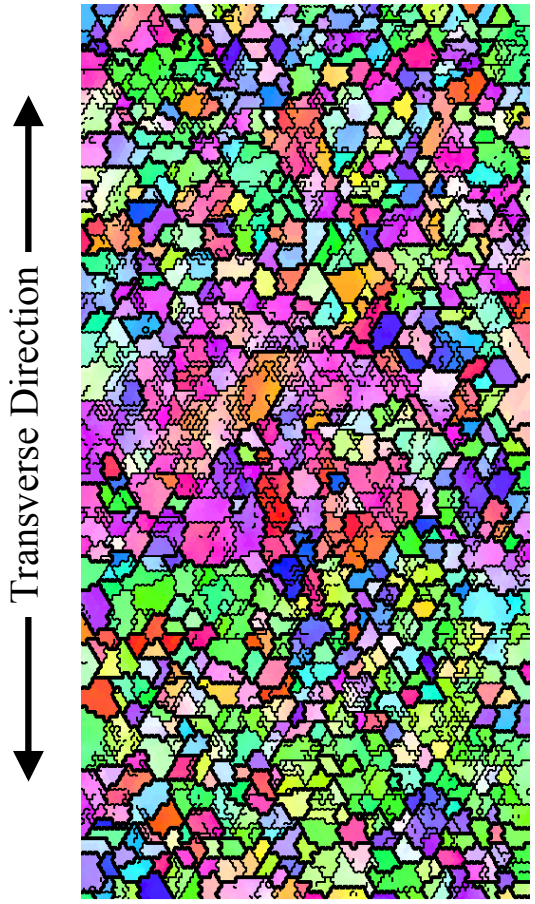


Misorientation Angle

28.1°



MICROSTRUCTURE OF 1443 Al AFTER HOT ROLLING



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Color Coded Map Type: Inverse Pole Figure [001

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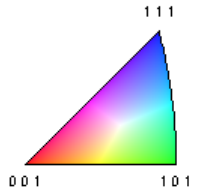

Boundaries: Rotation Angle

	Min	Max	Fraction
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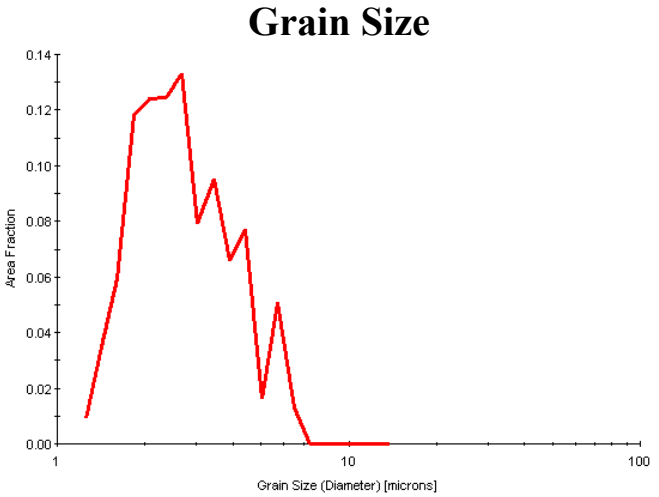
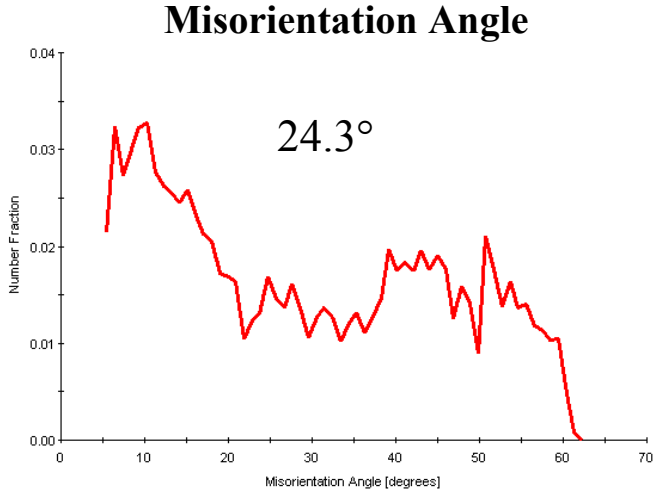
▬	15°	62.8°	0.504

*For statistics - any point pair with misorientation exceeding 2° is considered a boundary

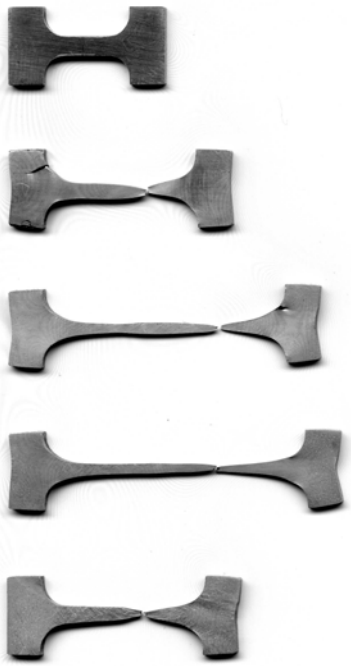




PICTURES OF TENSILE STRAINED SAMPLES

ECAE Condition

$\dot{\varepsilon}=1.4\times10^{-2}\ s^{-1}$



Initial Condition

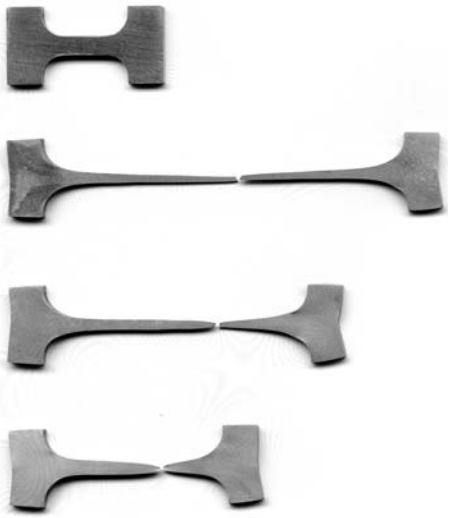
T=350°C; δ=160%

T=400°C; δ=365%

T=450°C; δ=420%

T=500°C; δ=175%

T=450°C



Initial Condition

$\dot{\varepsilon}=1.4\times10^{-3}\ s^{-1}$; δ=650%

$\dot{\varepsilon}=1.4\times10^{-2}\ s^{-1}$; δ=420%

$\dot{\varepsilon}=1.4\times10^{-3}\ s^{-1}$; δ=650%

PICTURES OF TENSILE STRAINED SAMPLES ($\dot{\varepsilon}=1.4\times10^{-2}\ s^{-1}$)

Hot Rolled Condition

Rolling Direction (RD)

Initial Condition

T=400°C; δ=265%

T=450°C; δ=415%

T=500°C; δ=335%

T=525°C; δ=285%

Transverse Direction (TD)

Initial Condition

T=400°C; δ=240%

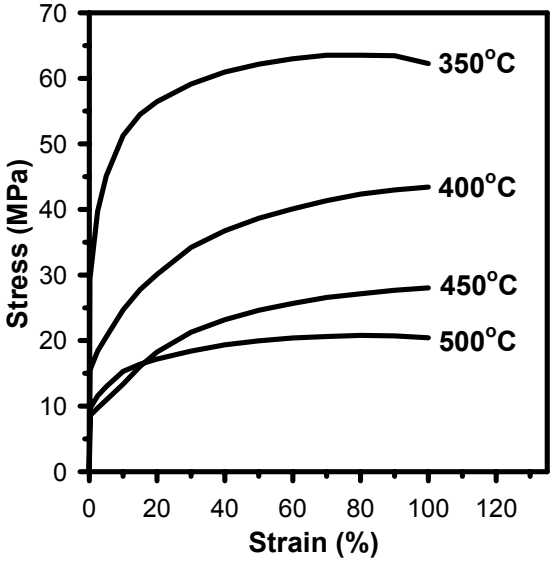
T=450°C; δ=305%

T=500°C; δ=385%

T=525°C; δ=340%

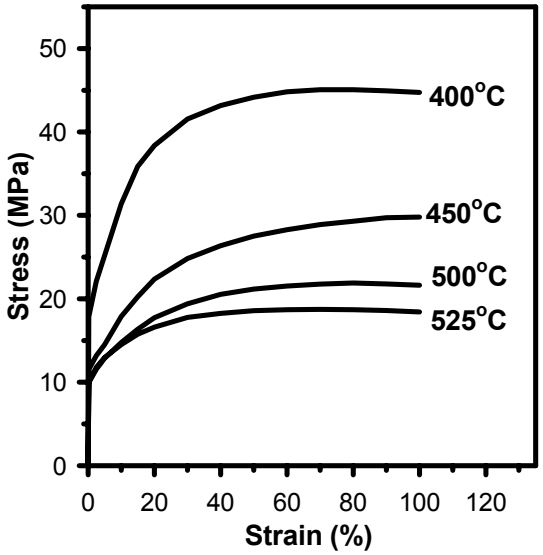
TRUE STRESS-ENGINEERING STRAIN CURVES OF 1443 Al ($\dot{\varepsilon}=1.4\times10^{-2}$ s^{-1})

ECAE Condition

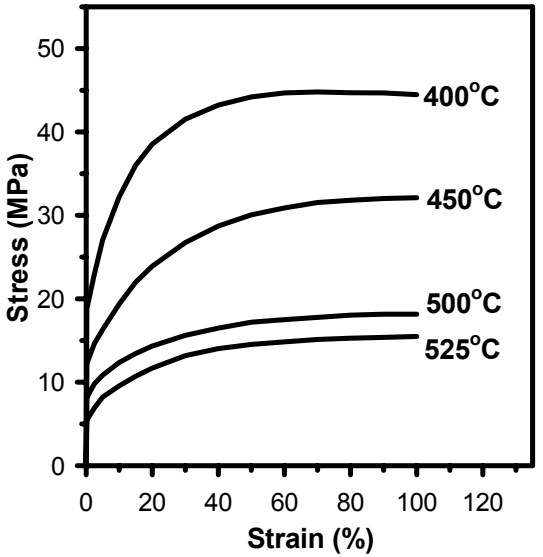


Hot Rolled Condition

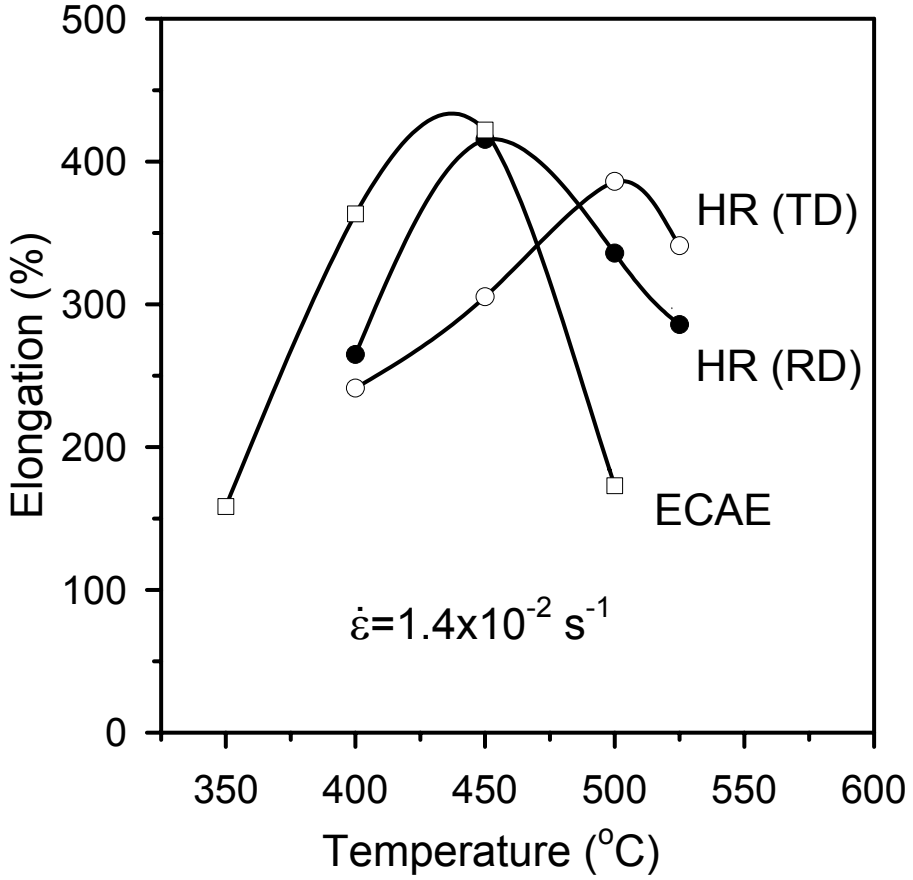
Rolling Direction (RD)



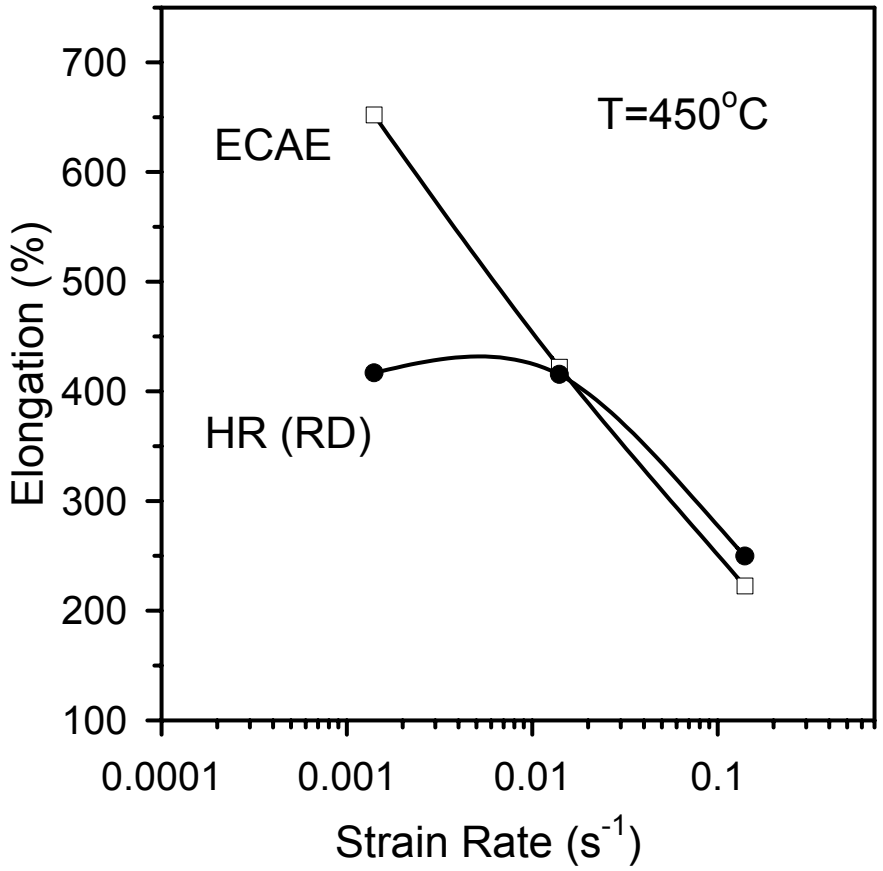
Transverse Direction (TD)



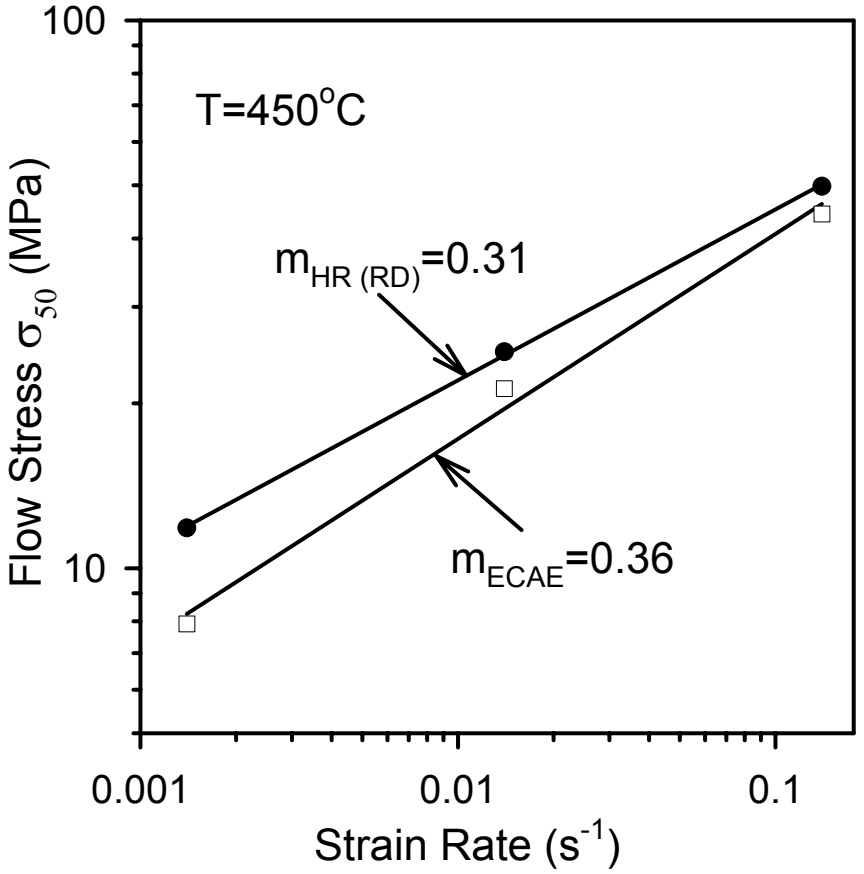
TEMPERATURE DEPENDENCE OF THE TOTAL ELONGATION



STRAIN RATE DEPENDENCE OF THE TOTAL ELONGATION

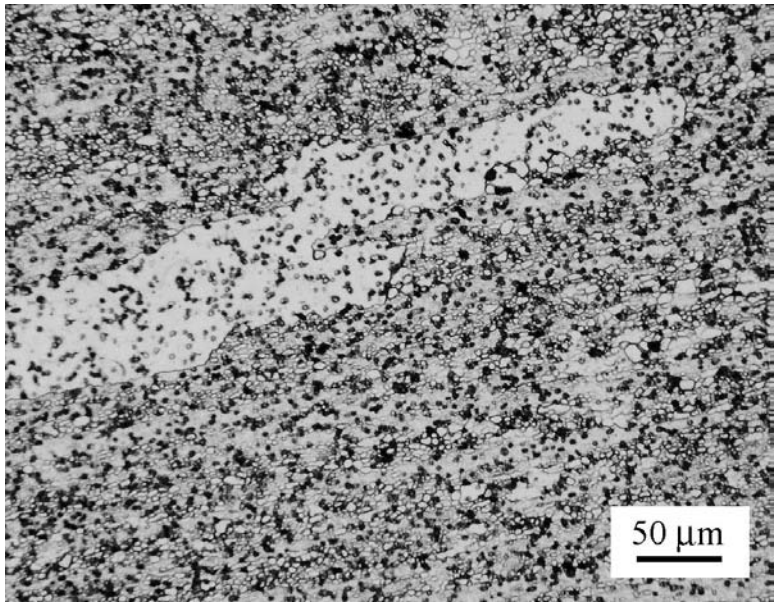


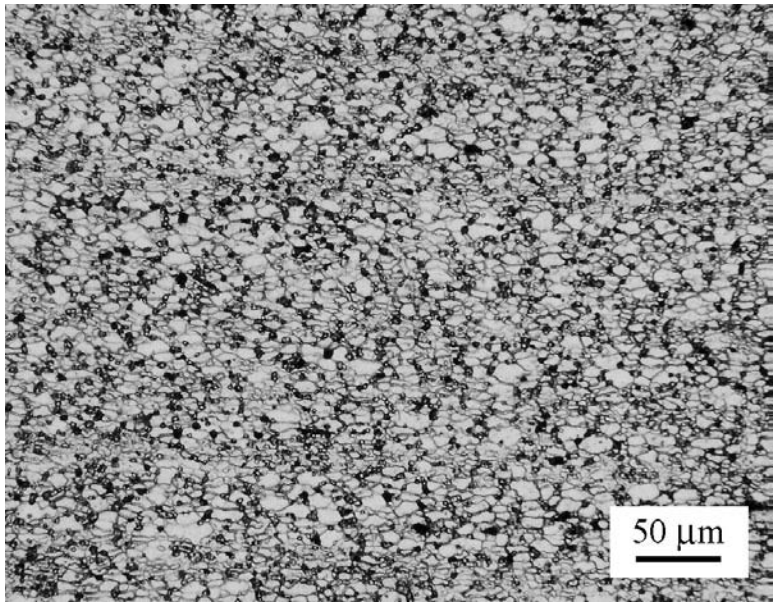
STRAIN RATE SENSITIVITY OF 1443 Al



MICROSTRUCTURES AFTER SUPERPLASTIC DEFORMATION

ECAE Condition (T=450°C; $\dot{\varepsilon}=1.4\times10^{-2}$ s^{-1}; $\delta=420\%$)





Extrusion Direction
Tensile Axis

Grip Zone

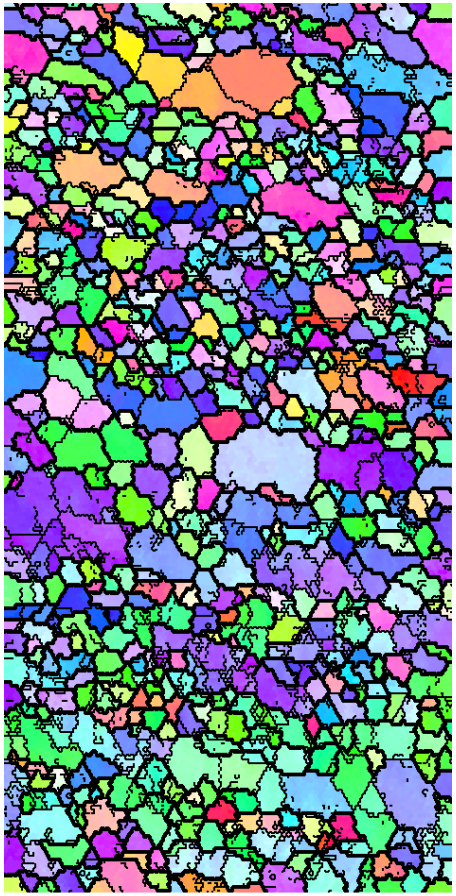
d_{REC}=4.5 µm
V_{NR}=20%

Gauge Section

d_{REC}=6.5 µm
V_{NR}=0.5%

MICROSTRUCTURES AFTER SUPERPLASTIC DEFORMATION

ECAE Condition, Grip Zone (T=450°C; $\dot{\varepsilon}=1.4\times10^{-2}$ s^{-1}; δ=420%)

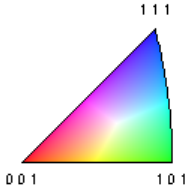


12.50 µm = 25 steps

Gray Scale Map Type: <none>

Color Coded Map Type: Inverse Pole Figure [001]

Aluminum

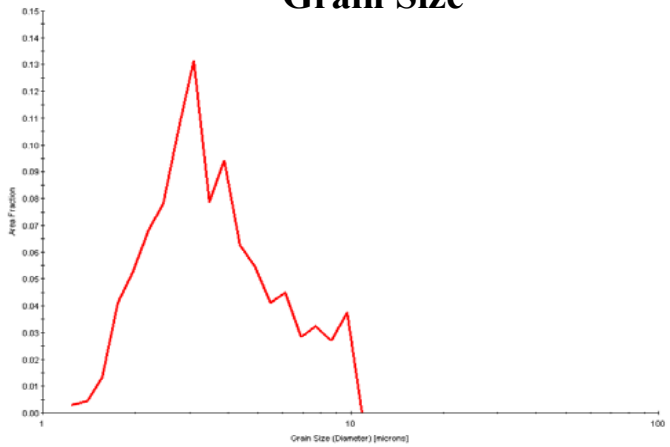


Boundaries: Rotation Angle

	Min	Max	Fraction
—	2°	15°	0.360
—	15°	62.8°	0.640

*For statistics - any point pair with misorientation exceeding 2° is considered a boundary

Grain Size

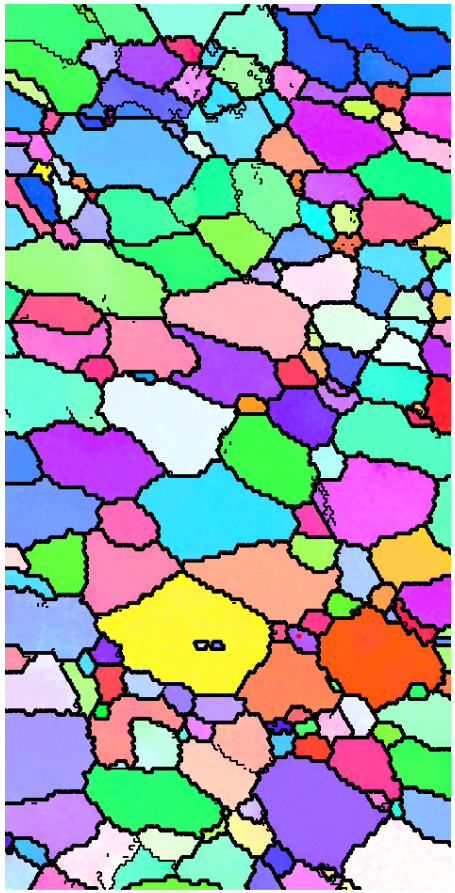


Misorientation Angle

27.4°

MICROSTRUCTURES AFTER SUPERPLASTIC DEFORMATION

ECAE Condition, Gauge Section ($T=450°C$; $\dot{\varepsilon}=1.4\times10^{-2}\ s^{-1}$; $\delta=420\%$)

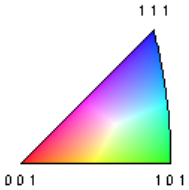


12.50 µm = 25 steps

Gray Scale Map Type: <none>

Color Coded Map Type: Inverse Pole Figure [001]

Aluminum

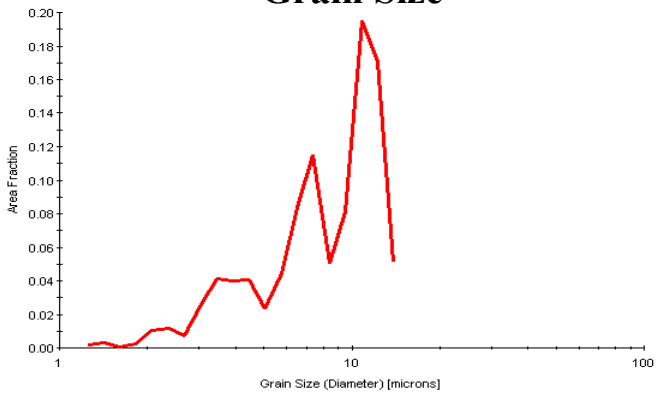


Boundaries: Rotation Angle

	Min	Max	Fraction
—	2°	15°	0.113
▬	15°	62.8°	0.887

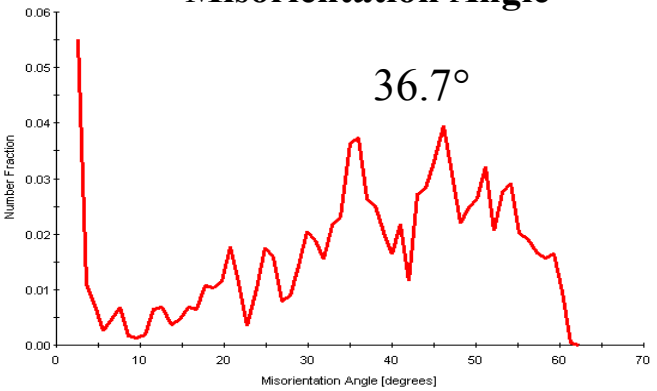
*For statistics - any point pair with misorientation exceeding 2° is considered a boundary

Grain Size



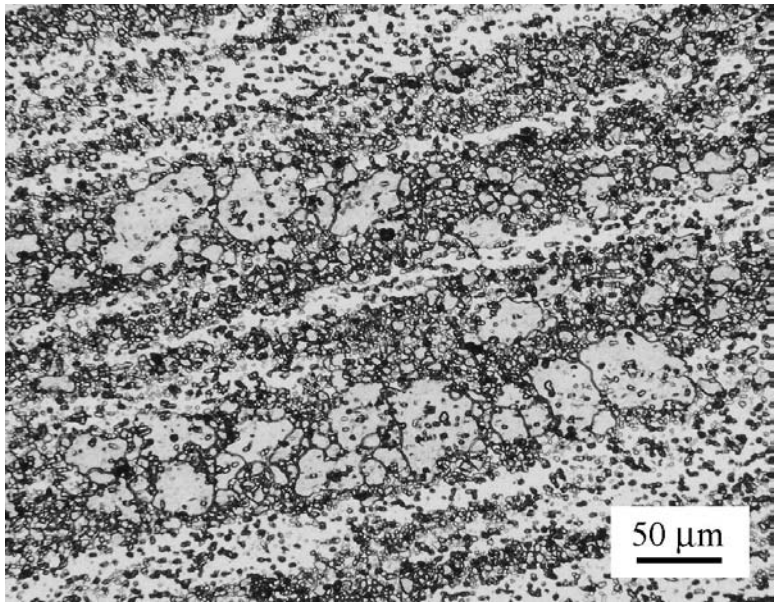
Misorientation Angle

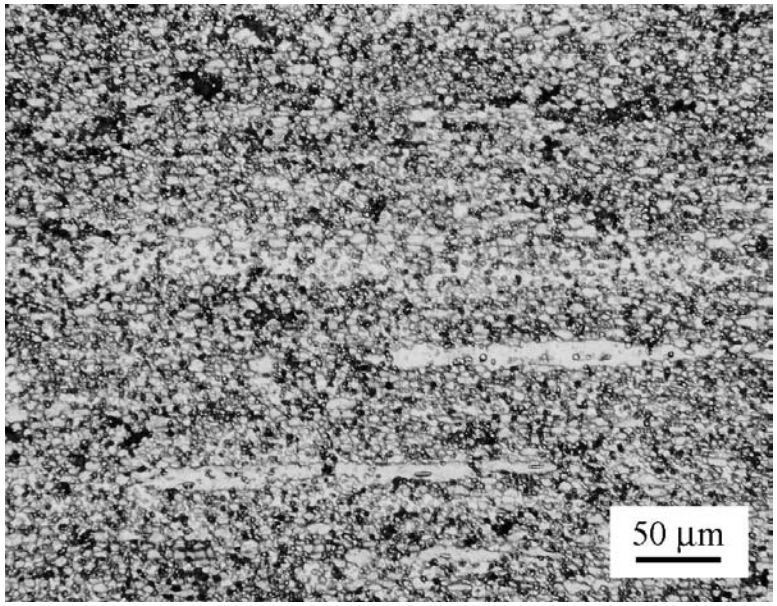
36.7°



MICROSTRUCTURES AFTER SUPERPLASTIC DEFORMATION

Hot Rolled (RD) Condition ($T=450°C$; $\dot{\varepsilon}=1.4\times10^{-2}\ s^{-1}$; $\delta=415\%$)





Rolling Direction
Tensile Axis

Grip Zone

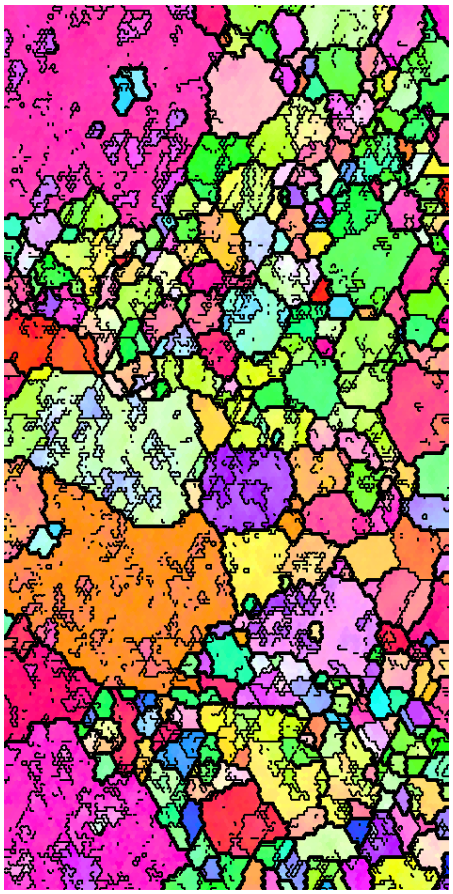
$d_{REC}=5.0\ \mu m$
$V_{NR}=30\%$

Gauge Section

$d_{REC}=4.5\ \mu m$
$V_{NR}=5\%$

MICROSTRUCTURES AFTER SUPERPLASTIC DEFORMATION

Hot Rolled (RD) Condition, Grip Zone (T=450°C; $\dot{\varepsilon}=1.4\times10^{-2}$ s^{-1}; δ=415%)

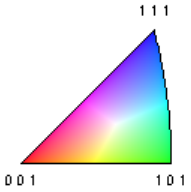


12.50 µm = 25 steps

Gray Scale Map Type: <none>

Color Coded Map Type: Inverse Pole Figure [001]

Aluminum



Boundaries: Rotation Angle

	Min	Max	Fraction
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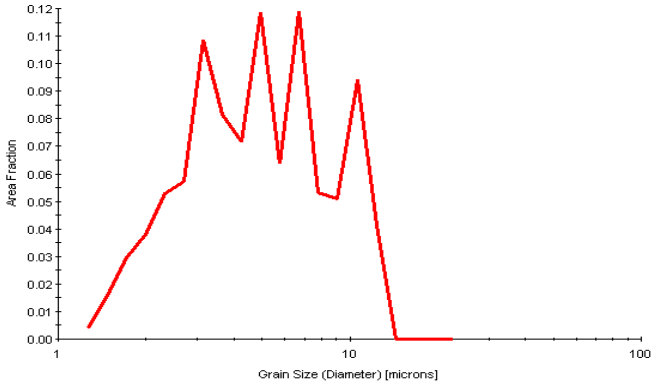
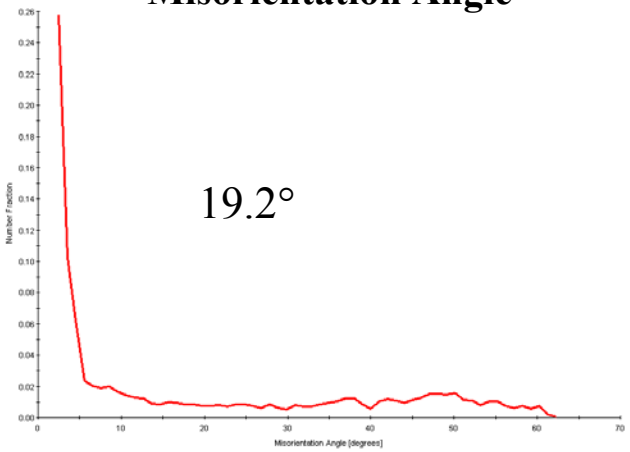
—	15°	62.8°	0.424

*For statistics - any point pair with misorientation exceeding 2° is considered a boundary

Grain Size



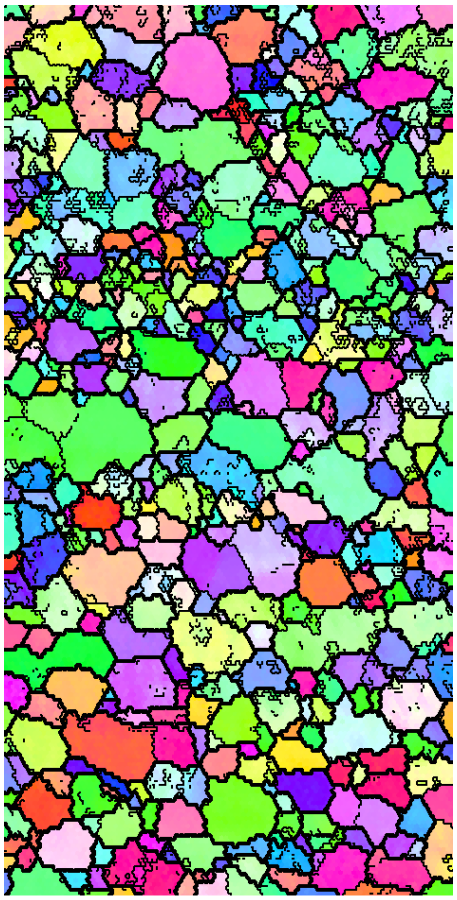
Misorientation Angle



19.2°

MICROSTRUCTURES AFTER SUPERPLASTIC DEFORMATION

Hot Rolled (RD) Condition, Gauge Section (T=450°C; $\dot{\varepsilon}=1.4\times10^{-2}$ s^{-1}; δ=415%)



12.50 µm = 25 steps

Gray Scale Map Type: <none>

Color Coded Map Type: Inverse Pole Figure [001]

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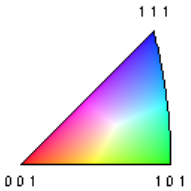
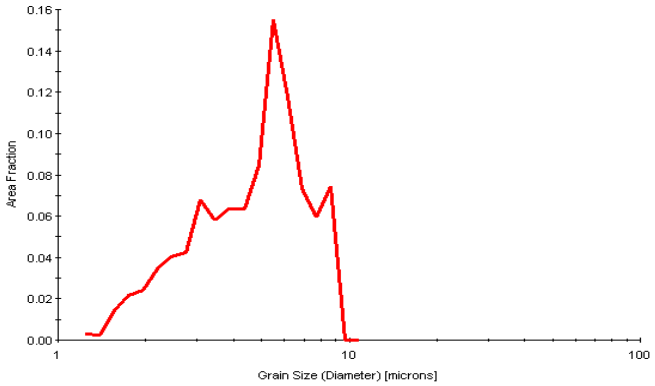


Boundaries: Rotation Angle

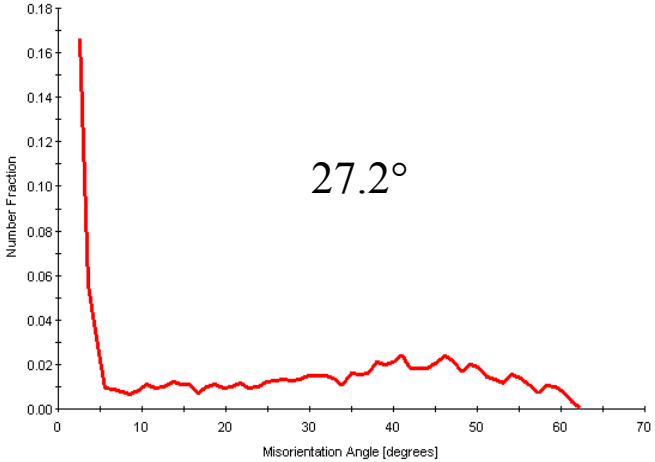
	Min	Max	Fraction
—	2°	15°	0.347
▬	15°	62.8°	0.653

*For statistics - any point pair with misorientation exceeding 2° is considered a boundary

Grain Size



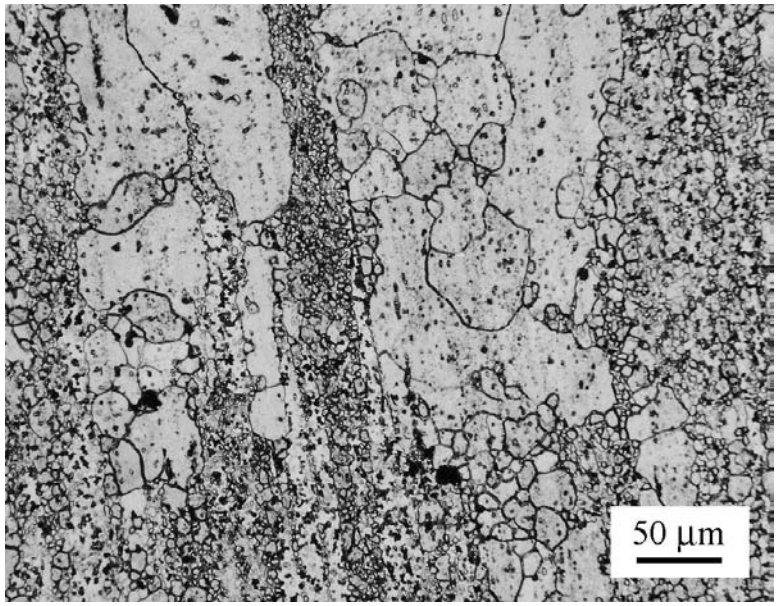
Misorientation Angle

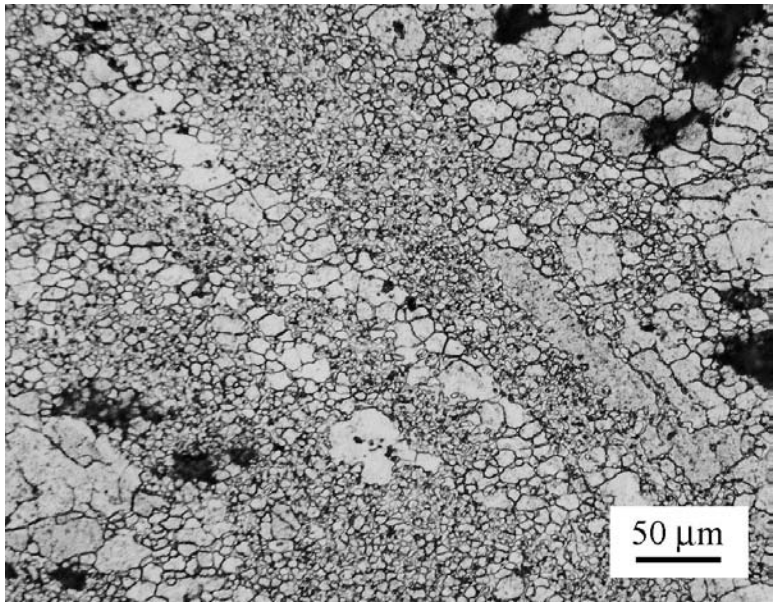


27.2°

MICROSTRUCTURES AFTER SUPERPLASTIC DEFORMATION

Hot Rolled (TD) Condition ($T=500°C$; $\dot{\varepsilon}=1.4\times10^{-2}\ s^{-1}$; $\delta=385\%$)





Transverse Direction
Tensile Axis

Grip Zone

$d_{REC}=6.0\ \mu m$
$V_{NR}=40\%$

Gauge Section

$d_{REC}=6.0\ \mu m$
$V_{NR}=20\%$

MICROSTRUCTURES AFTER SUPERPLASTIC DEFORMATION

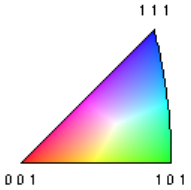
Hot Rolled (TD) Condition, Grip Zone (T=500°C; $\dot{\varepsilon}=1.4\times10^{-2}$ s^{-1}; δ=385%)

12.50 µm = 25 steps

Gray Scale Map Type: <none>

Color Coded Map Type: Inverse Pole Figure [001]

Aluminum

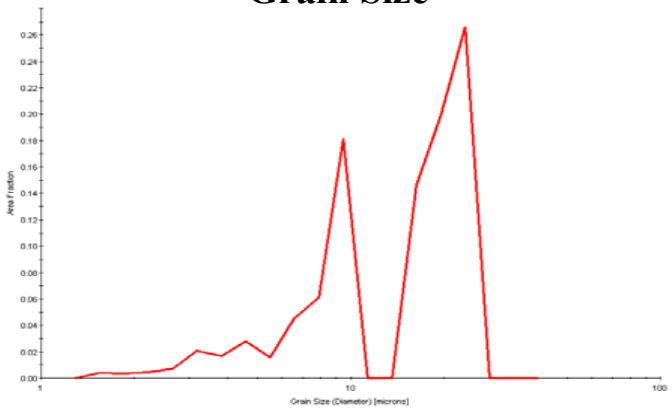


Boundaries: Rotation Angle

	Min	Max	Fraction
	2°	15°	0.226
	15°	62.8°	0.774

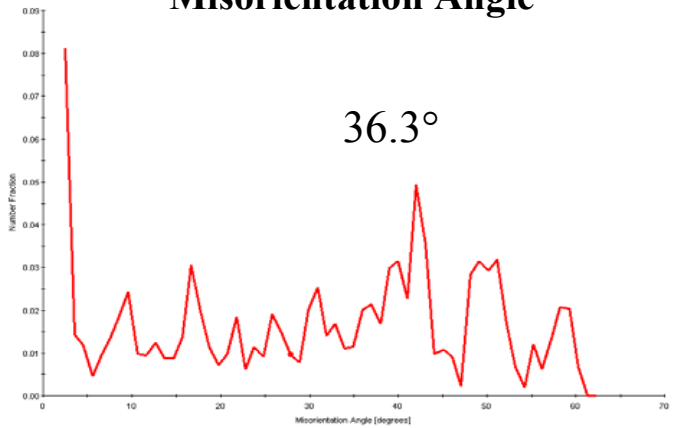
*For statistics - any point pair with misorientation exceeding 2° is considered a boundary

Grain Size



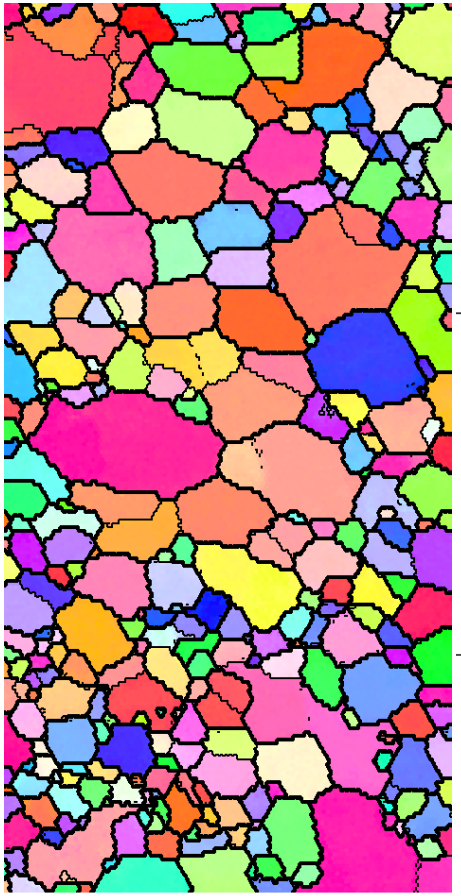
Misorientation Angle

36.3°



MICROSTRUCTURES AFTER SUPERPLASTIC DEFORMATION

Hot Rolled (TD) Condition, Gauge Section (T=500°C; $\dot{\varepsilon}=1.4\times10^{-2}$ s^{-1}; δ=385%)

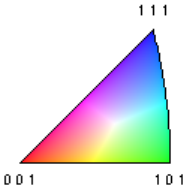


12.50 µm = 25 steps

Gray Scale Map Type: <none>

Color Coded Map Type: Inverse Pole Figure [001]

Aluminum

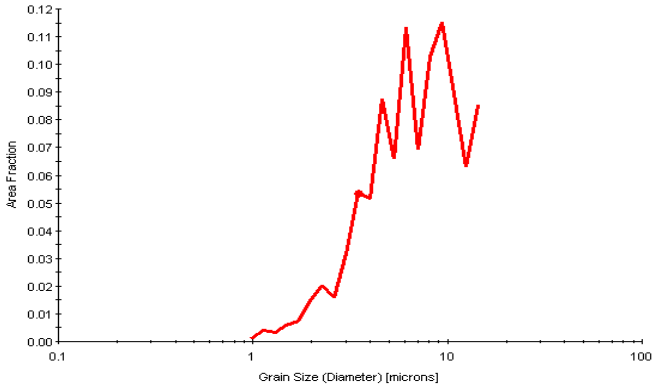


Boundaries: Rotation Angle

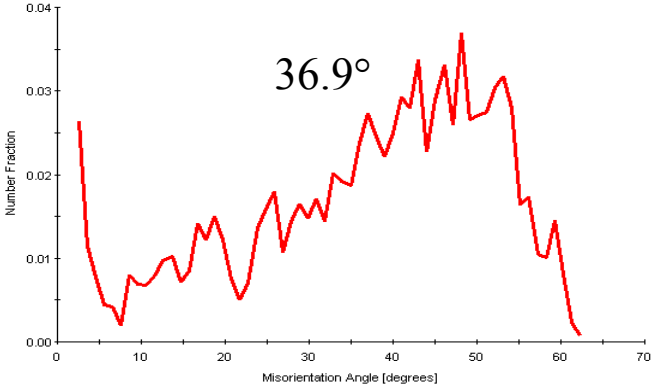
	Min	Max	Fraction
	2°	15°	0.109
	15°	62.8°	0.891

*For statistics - any point pair with misorientation exceeding 2° is considered a boundary

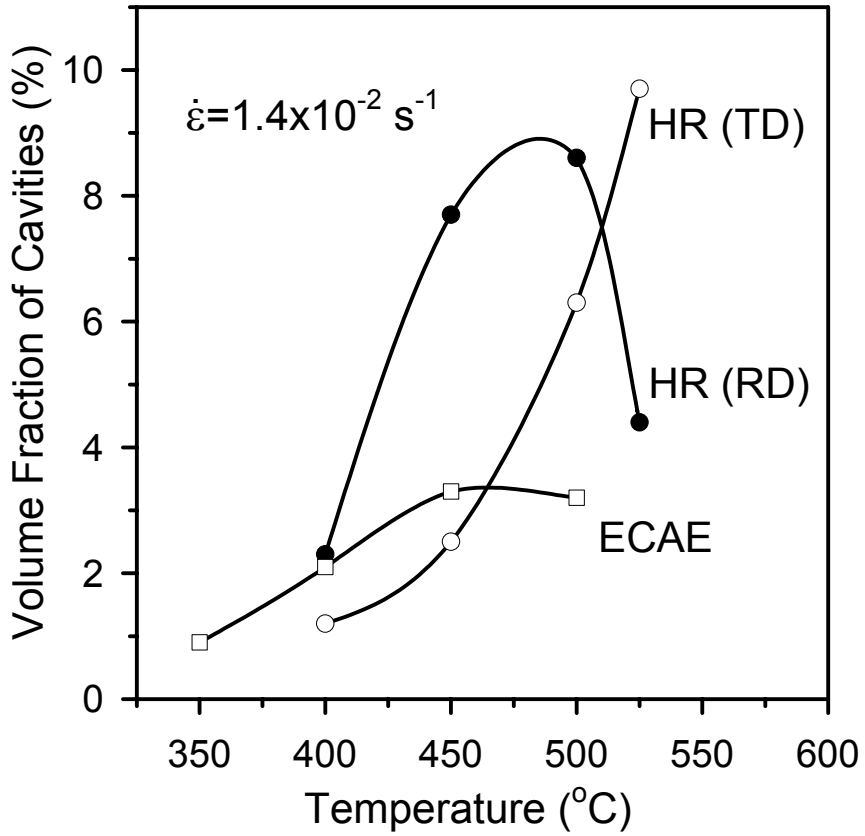
Grain Size



Misorientation Angle



CAVITATION DURING SUPERPLASTIC DEFORMATION



CONCLUSIONS

- Both ECAE at 325°C and hot rolling at 300°C resulted in formation in the 1443 Al of partially recrystallized (about 70%) microcrystalline structure with the mean size of recrystallized grains of 3 μm.
- Superplastic properties of the 1443 Al were studied in the temperature range of 350-525°C and at strain rates of 1.4×10^{-3}-1.4×10^{-1} s^{-1}. In both conditions the total elongations of about 400% were obtained at 450°C and a strain rate of 1.4×10^{-2} s^{-1} indicating a high strain rate superplasticity.

CONCLUSIONS

- The higher homogeneity of microstructure in the ECAE condition resulted in higher elongations and lower cavitation during superplastic deformation as compared to the hot rolled 1443 Al. In the ECAE condition the maximum elongation of 650% was obtained at 450°C and a strain rate of 1.4×10^{-3} s^{-1}. While after hot rolling material possessed lower elongations (up to 415%) and even at higher temperatures (up to 500°C). Besides, some anisotropy of in-plane mechanical properties of the sheet was observed.

- Superplastic deformation resulted in considerable improvement of microstructure homogeneity. After deformation under the optimum superplastic conditions, the volume fraction of unrecrystallized areas decreased to as low as 0.5% in the ECAE condition and to 5% in the hot rolled condition.