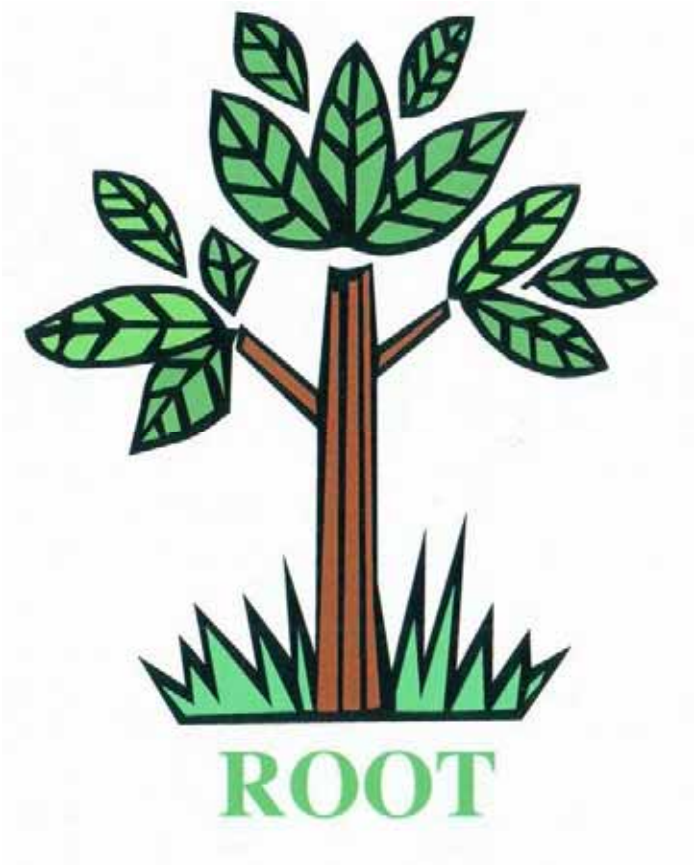
Farghalli A. Mohamed

FAM



FAM

FAMILY

Research Area

Area: Mechanical behavior and correlations with microstructure

Significance: Investigation of mechanical behavior of materials is *vital* for two primary reasons:

- **It contributes to the understanding of deformation mechanisms that are operative under certain conditions of variables (stress, temperature, etc.)**

- **It leads to the development of reliable design criteria.**

Nanograined Materials

Grain size < 100 nm (nm = 10^{-9} m)

Minimum Grain Size in Nanostructured Materials Produced by Cryomilling

Primary among the processing techniques that are available for synthesizing nc-materials (grain size < 100 nm) is ball milling. It has been shown that continuous milling leads to a minimum grain size, d_{min}, which is a characteristic of each metal. The purpose of this study is to develop a model that predicts the dependence of d_{min}, on materials parameters. The concept used in developing the model is the presence of a balance between the hardening rate introduced by dislocation generation and the recovery rate arising from dislocation annihilation and recombination.

Dislocation Model

The rate of grain size decrease $(\delta d/\delta t)^-$: Assumed to be related to the deformation energy provided by milling. This energy is a measure of plastic deformation via dislocation multiplication and motion.

The rate of grain size increases, $(\delta d/\delta t)^+$: Assumed to be proportional to the rate of recovery resulting from dislocations annihilation and recombination to form sub boundaries or low angle boundaries (**Fig. 1**).

Minimum grain size, d_{min}:d_{min} is obtained when $(\delta d/\delta t)^+ = (\delta d/\delta t)^-$.

Rate Eq.: $d_{min}/b = A(e^{-\beta Q/4RT})(D_{po}Gb^2/\nu_0 kT)^{0.25}(\gamma/Gb)^{0.5}(G/H)^{1.25}$

where A is a dimensionless constant, b is Burgers vector, G is the shear modulus, βQ is the activation energy for the recovery process, γ is the stacking fault energy, H is Vickers hardness, T is the absolute temperature, D_{po} is the frequency term for pipe diffusion, R is the gas constant, k is Boltzmann's constant, ν_0 is a constant.

Fig. 1

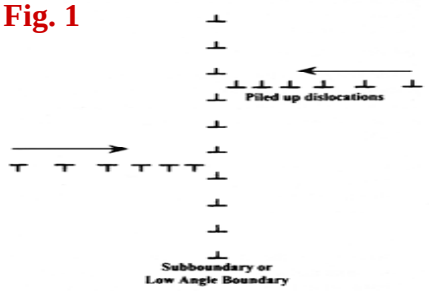


Fig. 1: As milling continues, groups of dislocations approach sub boundaries where they pile-up and enter the walls.

Correlation Between Model Predictions and Expt. Observations

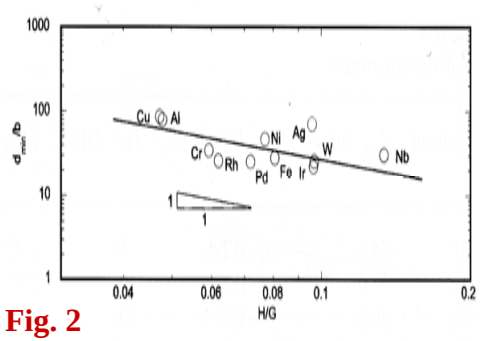


Fig. 2

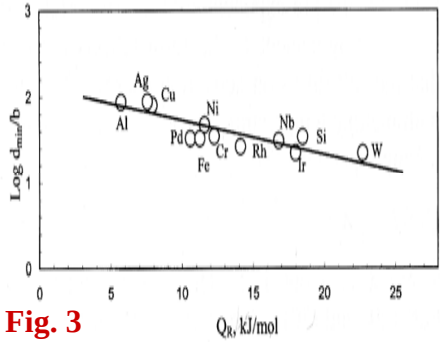


Fig. 3

Fig. 2: Expt. data for FCC and BCC metals are plotted as d_{min} versus the normalized hardness, H/G. As indicated by the figure, tl data can be fitted to a straight line with a slope of about 1 (predicted 1.25). **Fig. 3:** Expt. values of d_{min} are plotted normalized minimum grain size $d$min/b versus the activation energ for recovery, QR. The data fall very close to a straight lin According to the analysis in the model, QR scales with meltir temperature, Tm, and self diffusion activation energy, Q.

The research is significant since a model that provid correlation between d_{min} and materials parameters such hardness and stacking fault energy has been developed for tl first time.

Nature of grain Boundaries in Nanocrystalline Ni

Farghalli A. Mohamed (FAM) and his Research Group,

Introduction. Like ***a house*** consisting of rooms separated by walls, ***a polycrystalline material*** consists of grains separated by grain boundaries. As the number of rooms in a house increases, the number of walls required to divide them also increases and the size of each room can go down. The same is true for a polycrystalline metal: when the number of grains is increased, more grain boundaries are formed between grains and the size of each grain goes down. A metal that has **very small grains** is called a "**nanocrystalline**" materials. The grain size of **nanocrystalline** (nc) materials is given in terms of nanometer. 0ne nanometer is 10^{-9} meter. The grain size of nc materials is less than 200 nm.

The orientations of rooms with respect to each other can make the house attractive in terms of appearance and value. The same is true for a "**polycrystalline**" material: the orientations of grains with respect to each other in a "**polycrystalline**" material can make the metal attractive in terms of properties such as strength. For example, grains in a **polycrystalline** material can be oriented in such way that boundaries exhibit a specific orientation that results in strengthening the material. These boundaries are special boundaries that are referred to as "low sigma coincidence site lattice (CSL) boundaries."

Results. In our resarch program on nanocrystalline metals at UCI, we compared the orientations of the grains in nanocrystalline (nc) Ni with those of large-grained Ni using the technique of **orientation imaging microscopy (OIM**). Figures 1 and 2 show the orientation maps for the nanocrystalline and large-grained Ni, respectively. In the figures, grains exhibit different color due to the difference in orientation. Analysis of the data have indicated that the percentage of CSL boundaries in nanocrystalline Ni is much higher that that of CSL boundaries in large-grained Ni as shown in Fig. 3; in case of nanocrystalline Ni, the percentage is 55.2% while in case of large-grained Ni, the percentage is about 37.3%

Significance. This research is significant since it shows **for the first time** that the percentage of CSL boundaries in nanocrystalline Ni is much higher than that of CSL boundaries in large-grained Ni. This result has far reaching implications in terms of explaining the properties of nanostructured materials and their differences from those characterizing large –grained materials.

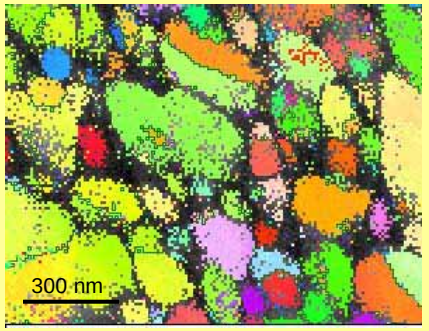


Fig. 1. Orientation map for nano-crystalline (nc) Ni.

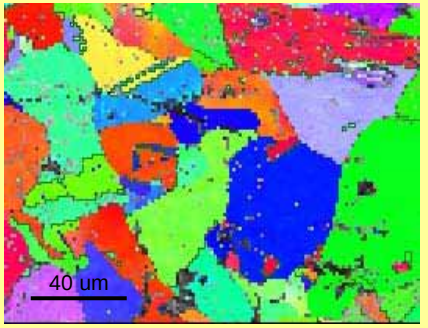


Fig. 2. Orientation map for large-grained Ni.

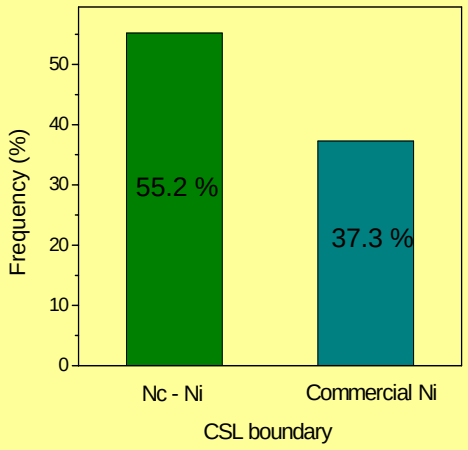


Fig. 3. The percentage of CSL boundaries in Nanocrystalliine (nc) Ni and large-grained Ni.

Correlation Between a Deformation Model Based on Boundary sliding and Experimental Data On Nanocrystalline Ni

Farghalli A. Mohamed (FAM)

Introduction:

Like ***a house*** consisting of rooms separated by walls, ***a polycrystalline metal*** consists of grains separated by grain boundaries. As the number of rooms in a house increases, the number of walls required to divide them also increases and the size of each room can go down. The same is true for a polycrystalline metal: when the number of grains is increased, more grain boundaries are formed between grains and the size of each grain goes down. A metal that has **very small grains** is called a "**nanocrystalline**" or "nanostructured" metal.

When **enough stress** is applied to a **nanostructured metal** at a **certain temperature**, the grains slide past each other and the metal changes shape or deforms, a phenomenon known as "**boundary sliding**." Scientists try to develop an equation that relates the outside stress applied to the metal to the rate at which this sliding happens at different temperatures. This equation reflects a deformation process that controls the mechanical behavior of the "nanocrystalline" metal. Developing this equation is important because it allows us to predict how these materials will behave under a variety of conditions.

Development of Rate Equation:

In our research program on nanocrystalline metals at UCI, a rate equation that describes the deformation behavior of "nanocrystalline" metal has very recently been developed. The equation reflects the following sequence of events (see Fig. 1)

(1) As a result of sliding of a group of grains in a nanostructured metal, the applied stress becomes concentrated at a triple junction (a point at which three grains meet) that obstructs the group's motion

(2) The stress concentration at the triple junction generates a crystal imperfection known as a "dislocation" that moves like a zipper to the opposite boundary where it is absorbed, allowing the sliding process to continue.

The rate equation is given by:

$$\dot{\gamma} = 9\left(\frac{b}{d}\right)^3\left(\frac{D_{gbo}}{b^2}\right)\exp\left(\frac{-Q_{gb}}{RT}\right)\left[\exp\left(\frac{2M\tau b^3}{kT}\right)-1\right] \quad (1)$$

Where $\dot{\gamma}$ is the rate of sliding, b is the Burgers vector, d is the grain size, D_{gbo} is the frequency factor for grain boundary diffusion, R is the gas constant, Q_{gb} is the activation energy for grain boundary diffusion, M is a stress concentration factor, τ, is the applied shear stress, T is the absolute temperature and k is Boltzmann's constant.

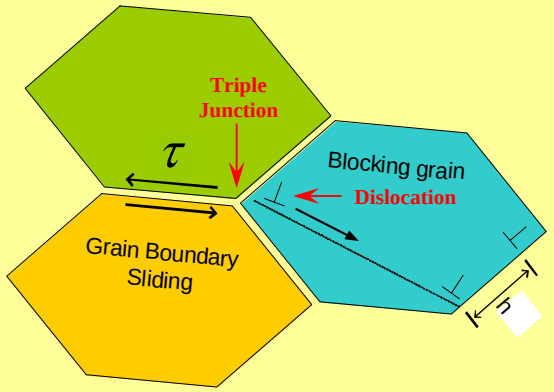


Fig 1: Schematic diagram for the proposed model, showing that as a result of boundary sliding, dislocations are generated at a triple junction and then traverse the grain to the opposite grain boundary where they are absorbed.

Correlation with Data:

Fig. 2 shows that the deformation rates as a function of stress for nanocrystalline-Ni agree reasonably well with the predictions of Equation 1.

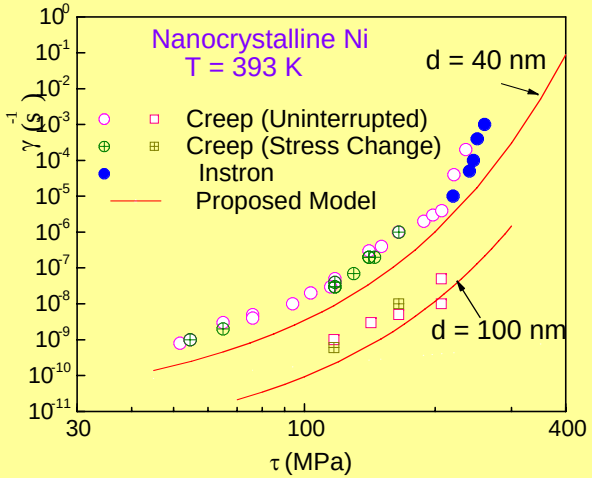


Fig 2: Sliding rate, $\dot{\gamma}$, is plotted as a function of shear stress, τ, on a double logarithmic scale for 40 and 100 nm nc-Ni at 393 K. The figure also shows the prediction of the proposed model.

Significance:

This research is significant since it shows that the prediction made by a recently developed model based on boundary sliding agree with the positions and trend of the experimental data of nanocrystalline Ni

Ultrafine-grained Materials

Grain size in the range 200 nm -500 nm

Measurement of Boundary Sliding in ultra fine-grained materials

Farghalli A. Mohamed (FAM) and his Research Group

Introduction. Like ***a house*** consisting of rooms separated by walls, ***a polycrystalline material*** consists of grains separated by grain boundaries. When the number of grains is increased, more grain boundaries are formed between grains and the size of each grain goes down. A metal that has **very small grains** is called a "**nanocrystalline**" material. The grain size of **nanocrystalline** (nc) materials is expressed in nanometer. 0ne nanometer is 10^{-9} meter. The grain size of nc materials is less than 200 nm.

When **enough stress** is applied to a polycrystalline material, the grains slide past each other and the metal changes shape or deforms, a phenomenon known as "**boundary sliding**." As a result of boundary sliding, steps (offsets) are produced on the surface of a flat specimen as shown in Figure 1. Detection of these steps provides evidence for the occurrence of boundary sliding, a process that may lead to the formation of voids and cavities in the material. The formation of voids in turn results in premature failure of the material.

While computer simulations indicate the occurrence of boundary sliding in nanocrystalline materials, there is no experimental evidence to support this indication. The reason is that traditional techniques that are available for detecting sliding in large-grained materials are not suitable for nanocrystalline materials because these techniques do not have sufficient resolution.

In future rsearch, we plan to use the novel technique of Atomic force microscopy (AFM) (Figure 2) to study sliding in nc-materials due to exciting preliminary results we have just obtained. The AFM works by scanning a fine ceramic or semiconductor tip over a surface. The tip is positioned at the cantilever beam shaped much like a diving board. As the tip is repelled by or attracted to the surface, the cantilever beam deflects. The magnitude of the deflection is detected by a laser that reflects at an oblique angle from the very end of the cantilever. A plot of the laser deflection vs. tip position on the sample surface provides the resolution of the hills and valleys that constitute the topography of the surface.

Significance. This research is significant since we can really see "**Grain boundary sliding**" from Atomic force microscopy as a evidence of a process that lead to the formation of voids and cavities in the material.

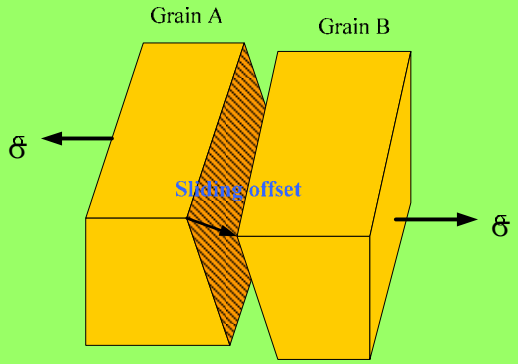


Fig. 1. Grain boundary Sliding between two grains.

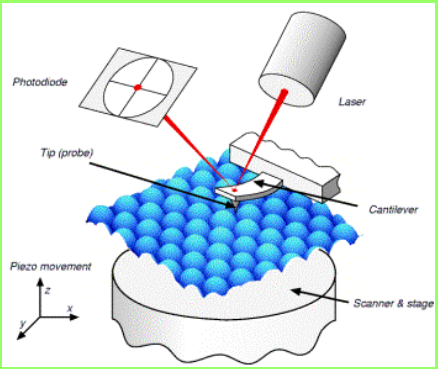


Fig. 2. The illustration shows how Atomic force microscopy (AFM) works.

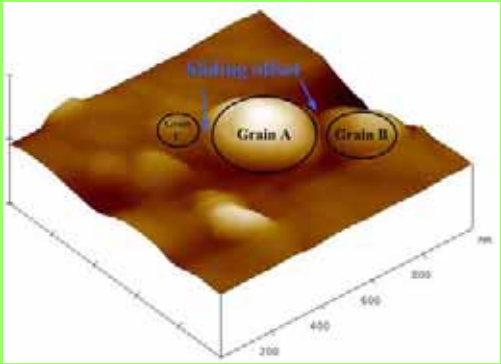


Fig. 3. AFM picture shows grain boundary sliding between two grains.

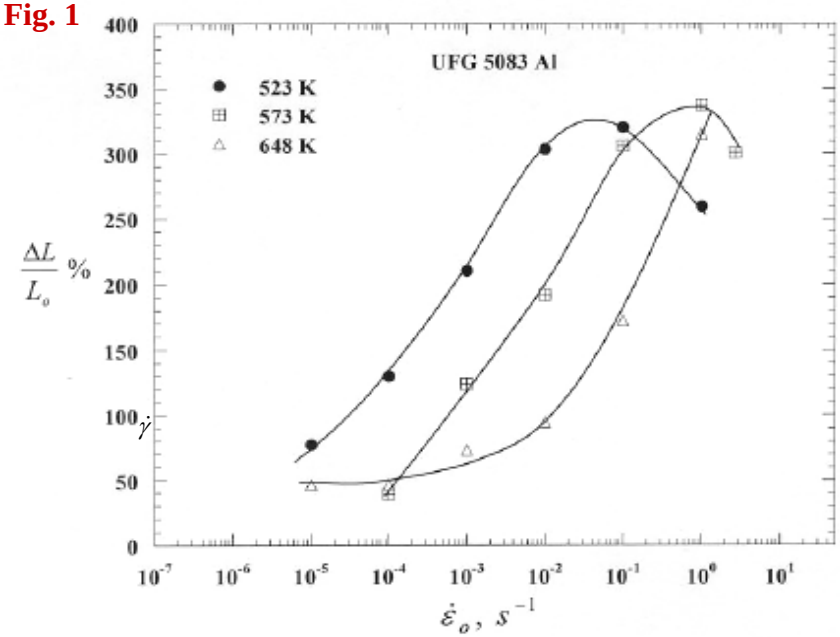
High Strain Rate Superplasticity in Bulk Ultrafine Grained 5083 Al

Objective: To investigate the creep behavior of ultrafine grained 5083 Al alloy (d ~ 300 nm) that was prepared by cryomilling and consolidation, and that has the potential for use in engineering applications at high temperatures

Results: Results reveal the occurrence of high strain rate superplasticity (HSRS) as described herein.

1. Ductility curves exhibit maximum elongations of more than 300% at strain rates higher than 10^{-2} s^{-1} (**Fig. 1**).

Fig. 1



2. The stress exponent inferred from the plot of the normalized strain rate against the normalized effective stress (**Fig. 2**) on a logarithmic scale is 2, which characterize superplastic flow.

3. The true activation energy is equal to that for boundary diffusion.

Fig. 2

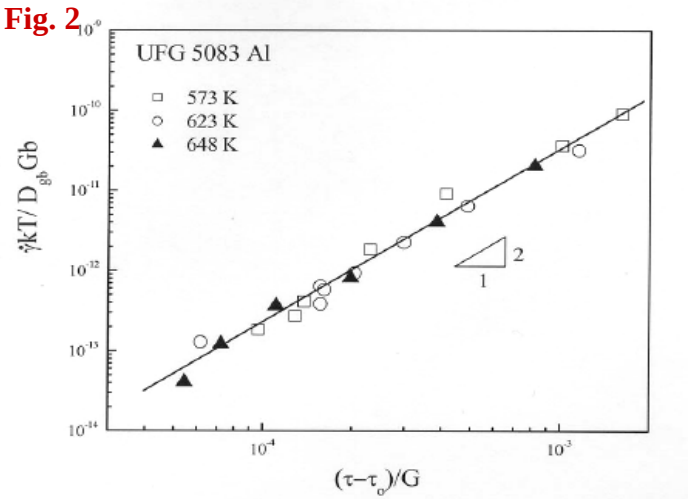
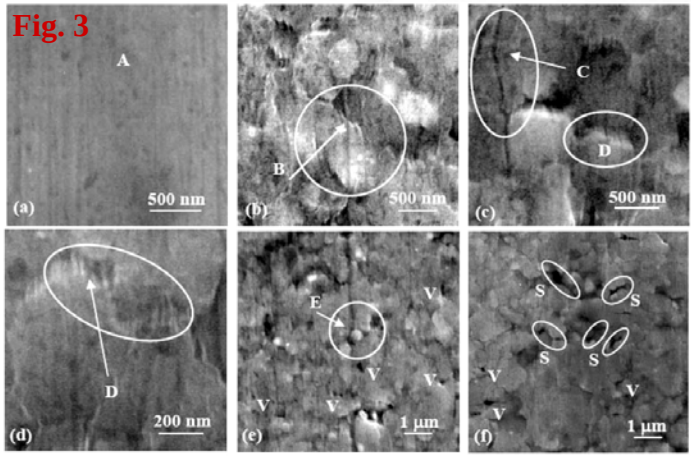


Fig. 3



4. Evidence of the occurrence of boundary sliding and its features such as offsets ("B"), rotation of grains ("C"), striated bands ("D"), emergence of new grains ("E"), voids ("V"), and grain separation ("S") (**Fig. 3**); 'A' represents microstructure of an untested sample.

The results are notable since the occurrence of HSRS in UFG 5083 Al will facilitate forming the alloy for commercial applications.

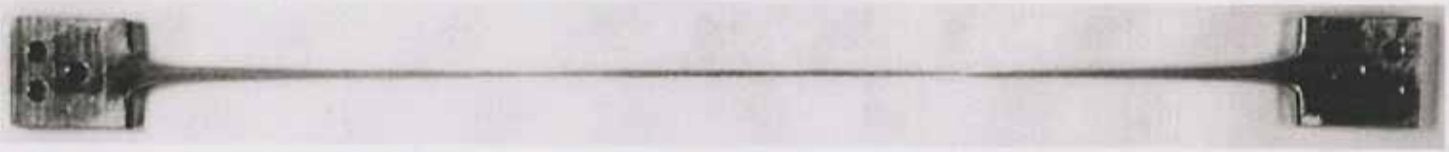
Micrograined Materials

Grain size in the range 1 μm – 10 μm (μm = 10^{-6} m)

Superplasticity

(a)

(b)



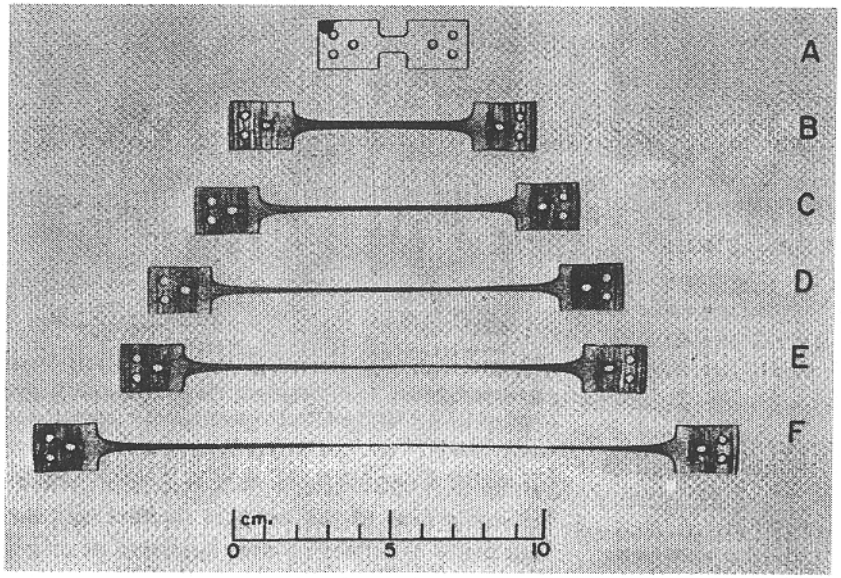
2.5 cm

- Superplasticity refers to the ability of fine-grained materials to exhibit extensive elongations during elevated temperature forming.
- Advantages:
  - Use of very small loads in forming processes such as forging and extrusion
  - The production of complex engineering shapes with fine details
- Superplastic materials, such as Al alloys, are widely utilized in various industrial applications related to the manufacturing of automotive and aerospace components.

Micrograin Superplasticity

- Manifestation
  - Extremely large uniform elongations under tension.

Zn-22%Al tested in tension at $1.33 \times 10^{-2} s^{-1}$ for different times



•Deformation is quasi uniform
•Necking is diffuse not localized
•Specimens gradually pull out to a fine point

- Requirements
  - $T > 0.5\ T_m$.
  - Fine, stable and equiaxed grain size ($d < 10\ \mu$m).
  - Mobile, high-angled boundaries which resist tensile separation.

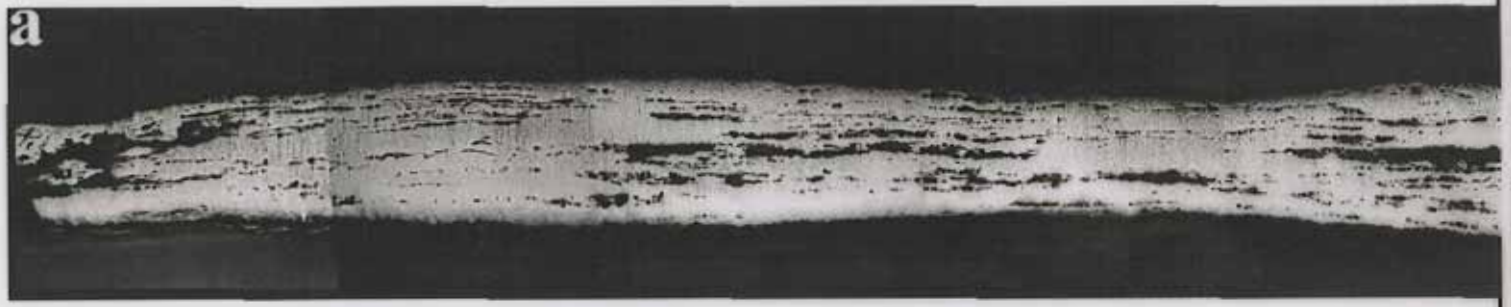
Cavity Stringers

- Cavity stringers have been reported to develop during high temperature deformation of numerous superplastic alloys.
- Cavity stringers were observed to be aligned parallel to the tensile axis in most studies, regardless of whether the materials used in the investigations were microduplex or quasi-single phase alloys, and whether or not particles existed.

Zn-22%Al, 0.5 mm

Al-33%Cu, 1 mm

Controlling Elongation by Modifying the Microstructure



Impurities ⇒ Cavitation ⇒ Elongation = 500%

No impurities ⇒ No cavitation ⇒ Elongation = 3000%