Low-Cost, MesoScale Parts Fabricated from Nanocrystalline Metals

LDRD
LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Sandia National Laboratories

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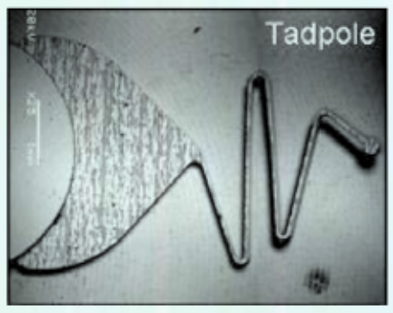
University Partners • Srinivasan Chandrasekar – Purdue University – Nanostructured Powder and Foil Production (Chris Saldana - graduate student)
Naresh N. Thadhani – Georgia Tech – Shock Wave Consolidation Mold Design and Modeling Analysis (Anthony Fredenberg – graduate student)

Project Overview

- Goal: To develop methods for creating and utilizing bulk nanocrystalline metals in mesoscale NW-like parts (especially surety mechanisms).
- Motivation: Nanocrystalline metals exhibit very high strength and hardness, characteristics providing designers with a new suite of "super" materials for ever-smaller mesoscale surety components.

METHODOLOGY

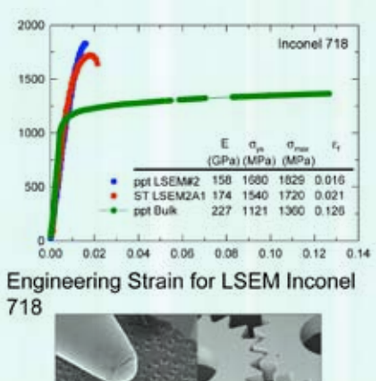
- The team will study 3 methods of creating nanocrystalline material:
  - Cold Spray Consolidation
  - Shock Wave Compaction
  - Large Strain Extrusion Machining (LSEM

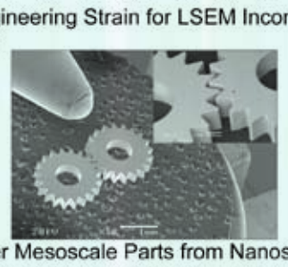


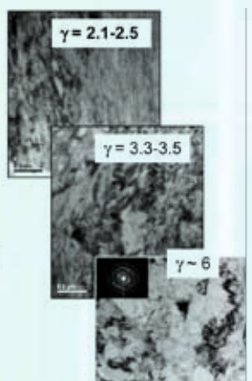
Nanocrystalline Part

Large Strain Extrusion MachiningNanostructured Material from Machining Chips!


Large Strain Extrusion Machining (LSEM)



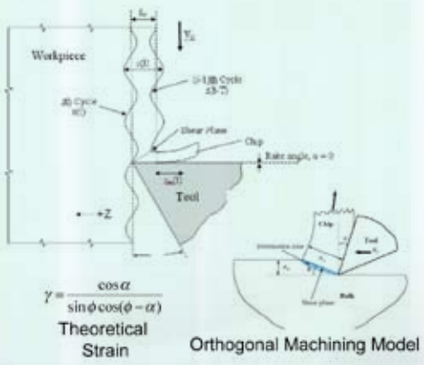




Strain Affects Grain Morphology

First-Ever Mesoscale Parts from Nanostructured Material (shown with ball point pen tip)

Creating Nanostructured MaterialsModulation Assisted Machining (MAM) Powder



Theoretical Strain

Orthogonal Machining Model

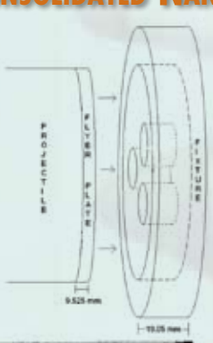
Table 1. Morphology and microstructure of MAM Al 6061T6 particles

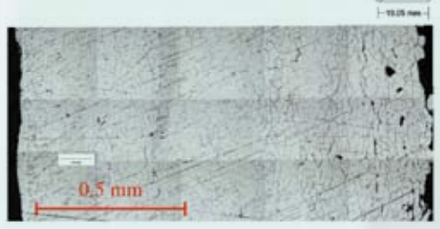
Particle Morphology	Microstructure	Size and Texture
Equiaxed		• Equiaxed grains • Crystalline size: 100 to 300 nm • Texture: {111} and {220}
Needle		•Elongated grains •Layer thickness: 100 to 200 nm •Texture: {200} and {220}
Platelet		•Laminar structure •Layer thickness: 50-200 nm •Texture: {111} and {220}

Powder Characterization

- Machining Parameters Determine Particle Morphology
- Grain Morphology Follows Particle Morphology
- Utilized SNL's Unique Capability for FIB Preparation of TEM
- Discovered ultra-fine grains (100-300nm) at surface grading to um grains in interior

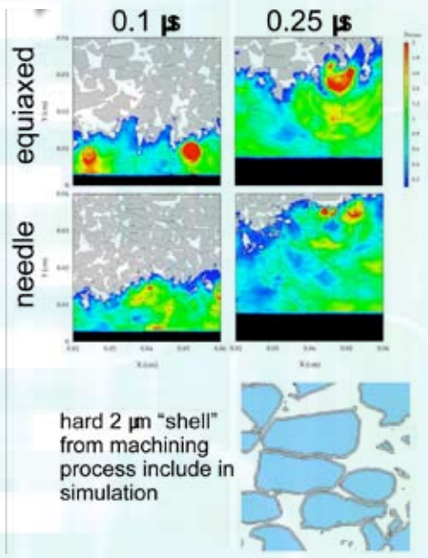
Shockwave Consolidated Nanostructured Metals





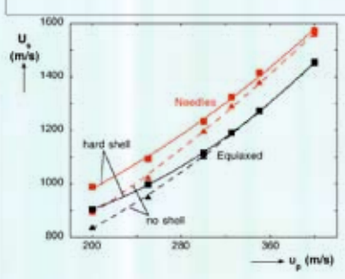
- steel capsule in Al holder
- 69% initial density
- complete compaction estimated for 650 m/s based on static data
- 98% density achieved for needles; hardness maintained
- incomplete compaction and porosity toward rear face

Shockwave Consolidation Modeling

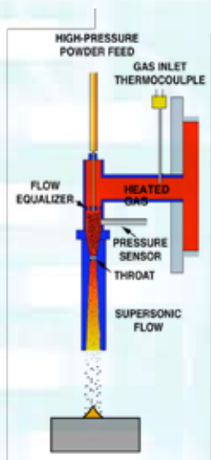


hard 2 μm "shell" from machining process include in simulation

- experimental microstructures imported into CTH
- examine complex nature of wave through real powder structure
- determine effects of morphology on compaction
  – final density (to guide experiments)
  – deformation characteristics (improve bonding and prevent grain growth)

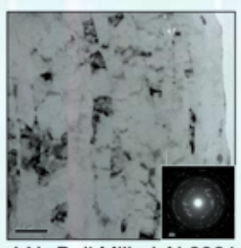


Cold Spray Consolidation of Nanostructured Metal



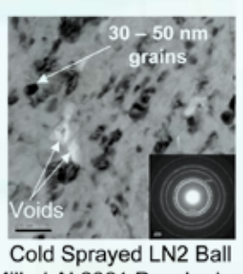
Schematic of the cold spray process


LN_2 Ball Milled, Nanostructured Powder


LN_2 Ball Milled Al 6061 Powder Has 250-300nm grains,lath-like structure w/ intra-grain porosity and no texture

Cold Spray Process


Cold Sprayed Al Sample



Cold Sprayed LN2 Ball Milled Al 6061 Powder has 30-50nm grains and small regions of porosity

Why are there nano-voids in the nanocrystalline material?

- Minimum grain size for Aluminum is ~ 20 nm
- Dislocations are unstable in Aluminum grains smaller than 18nm
- Plastic deformation is responsible for grain refinement in LN2 ball milled and cold sprayed aluminum
- Both cold sprayed samples show grain sizes between 20 and 50 nm.
- Grain refinement through plastic deformation will not create Al grains less than ~ 20 nm in size.

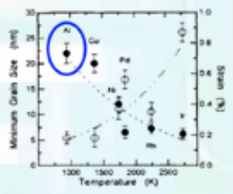


Figure 1. Minimum average grain size (filled symbols) and atomic-level strain (open symbols) for ball-milled fcc metals versus melting temperature.

J. Eckert, Relationships Governing the Grain Size of Nanocrystalline Metals and Alloys, *NanoStructured Materials*, 1995, 6(1-4), p 431-416

Heterogeneous void nucleation is the likely cause:

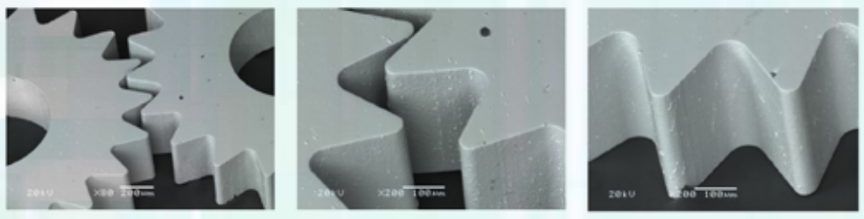
- Within precipitates
- At interfaces
- At grain boundary triple points

Both 5083 & 6061 contain precipitate forming elements
Aluminum nitrates are known to form in LN2 ball milled aluminum.

Bulk Nanocrystalline Al Was Created Using Cold Spray!!

Conclusions

- Nanostructured Material Created by Several New Methods Has Been Analyzed
- Bulk Nanostructured Material Has Been Created Using Cold Spray and Shock Compaction
- Cold Spray Nanocrystalline Material Has Reached the Lower Limits of Grain Size!
- Mesoscale Parts Were Created Using LSEM Chips



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