Production of Nano-based Light Alloys and Composites for Aerospace Applications

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Nanostructured materials offer the potential for significant improvements in materials properties.

California Nanotechnologies Inc. (Cal Nano), Cerritos, Calif., manufactures and supplies ultrafine, near-nano and nanostructured materials and products for use in aerospace, space, energy, oil and gas, sports and recreation, and many other industries (Fig. 1).

Materials property benefits

The company's efforts in ultrafine, near-nano and nanostructured materials in the aerospace industry include projects with industry and government (e.g., U.S. Department of Defense). Industry activities include projects with Pratt & Whitney/Rocketdyne, Boeing Research and Development (formerly Boeing Phantom Works), and other aerospace industry leaders [1-3]. This includes manufacturing parts made of light alloys (aluminum, magnesium, and titanium), superalloys (Ni- and Co-base), metal-matrix composites, and carbides for use in commercial aerospace and space industries in applications ranging from airframes to propulsion. Nanostructured materials offer the potential for significant improvements in materials properties resulting from grain size reduction effects in pure metals and metal alloys, from nano-particulate reinforcements formed in situ (e.g., AlN), and from nano-particulate reinforcements blended into the matrix (e.g., Al_2O_3) in composites.

In terms of grain size reduction effects, improvements in mechanical properties from near-nano and nanostructured materials are predicted by the *Hall-Petch* relationship [4]. The yield strength and hardness properties are expressed as:

$$\sigma_y = \sigma_0 + \mathbf{k}d^{-1/2}$$

$$H = H_0 + \mathbf{k}'d^{-1/2}$$

where σ_y and H refer to the yield strength and hardness of the material, respectively, d is the grain diameter, and **k** and **k**′ are constants unique to each material. These properties increase with a decrease in grain size of the material.

Fig. 1 — *Cal Nano conducted research and development with Pratt & Whitney/Rocketdyne for Space Shuttle applications.*

Fig. 2 — *Omni-Lite Industries production facility; Omni-Lite is a co-founder and shareholder of California Nanotechnologies.*

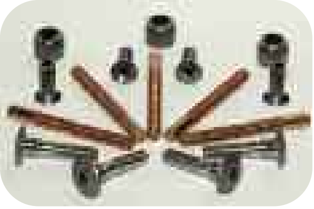

Fig. 3 — *Cold-forged parts produced from various standard materials.*

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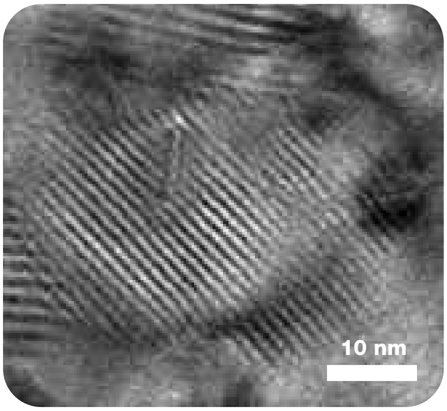

Fig. 4 — *Microstructure of nano-composite showing nano-particulate reinforcement in aluminum alloy matrix.*

Fig. 5 — *View inside of a cryomill.*

Current development programs

California Nanotechnologies Inc.'s recent programs include working with nano metal-matrix composites (NMMCs) using 6000 and 7000 series aluminum and cryomilled aluminum-magnesium-SiC, and metals/metal alloys. NMMCs and cryomilled metals, including titanium, have been produced into 0.20-in. (5 mm) diameter wire/rod from large consolidated billets for subsequent cold forging operations (Fig. 2). Wire and rod produced from billet enable high production rates in cold forging parts including fasteners, pins, caps and many other components. Production rates for cold-forging parts commonly reach thousands of parts per minute. Figure 3 illustrates several aerospace components in cold-forging operations produced from standard wire feedstock.

Improved parts performance

Components produced from these nanostructured alloys and composites show considerable improvement over conventional materials. Figure 4 shows such nano-particulate reinforcement in an aluminum matrix imaged using transmission electron microscopy. The table shows an example of the type of mechanical property improvements realized from nanosize grains and/or nanoparticulate reinforcements. The ultimate tensile strength is reported from test specimens machined from a bulk sample of the consolidated ultrafine, near-nano and nanomaterials.

Cryomilling

To obtain cryomilled metals and alloys, nanomaterials are produced by milling conventional feedstock in a cryo-

TENSILE STRENGTH OF NANO-BASED ALLOYS AND COMPOSITES

Material	Ultimate tensile strength, MPa (ksi)
Ti-6Al-4V, as received	982.1 (142.2)
Ti-6Al-4V, cryomilled, argon	1151.8 (167.0)
Al 7075, conventional	517.1 (75.0)
Al 7075/Al2O3, nano-composite	710.2 (103.0)
Al-7Mg-SiC, cryomilled, nitrogen	758.4 (110.0)

genic environment consisting of either argon or nitrogen. Figure 5 shows the inside of a milling vessel containing a mixing arm, milling media, and charge (e.g., aluminum or titanium powder) in the cryogenic environment. After milling, degassing is normally performed before cryomilled powders are consolidated into a billet. The nano-based powders may be consolidated to form a billet using a variety of techniques including hot and cold isostatic pressing (HIP or CIP) and sintering processes (e.g., vacuum sintering and spark plasma sintering). Wire and rod for cold heading and other production operations are produced from nano-consolidated materials using techniques commonly used to produce wire from billets (e.g., direct, indirect, and hydrostatic extrusion methods).

Summary

Aerospace components in production volumes can be produced using nano-based materials. Nano-based components can be produced in high-volume operations by providing the material in wire and/or rod form for use in production cold and hot forging operations. For these production operations, the nano-based materials are consolidated into billets and produced into wire using traditional wire forming operations. Components produced from these nano-based light alloys and composites enable use in higher performance applications compared to conventional materials.

References

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