Nanocarbon Metals

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Summary

- There is a new class of materials: Covetic
  - Third Millennium Metals, LLC; since 1999
  - Nanocarbon phase, 5-200 nm, > 6 wt. % C
  - Carbon spectra ~ nanotubes, amorphous
- Strongly bound to metal matrix, stable beyond melting point
- Combination of analytic methods needed to measure C
- Nanocarbon raises the melting point
- Nanocarbon has surprisingly little effect on density
- Strength increase possible—depends on processing, %C
- Higher thermal conductivity, but anisotropic
- Higher electrical conductivity

Focus of Talk

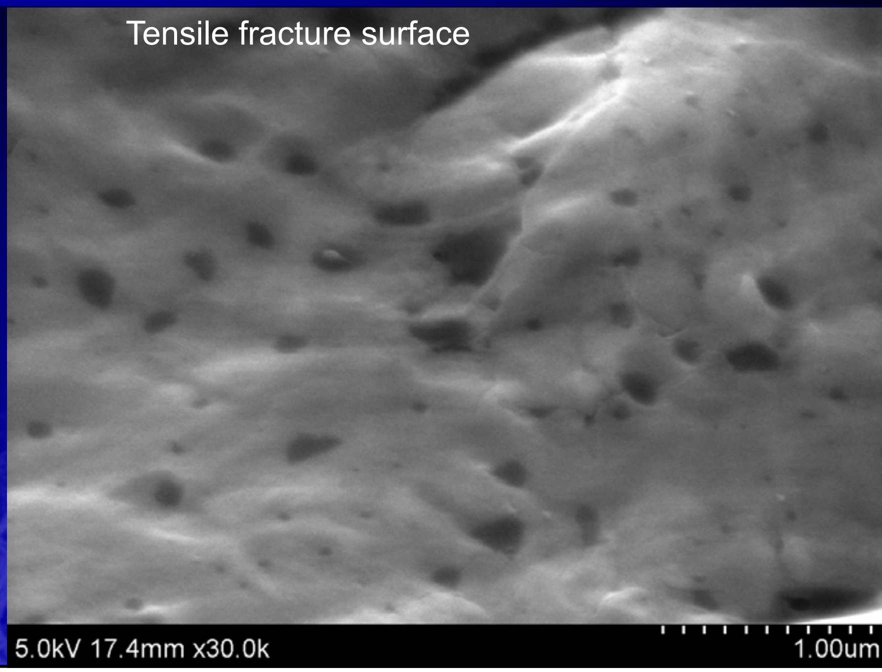
- Background
- Form and distribution of carbon
- Analytical methods
- Melting point
- Density
- Electrical conductivity
- Thermal conductivity
- Tensile properties

Background

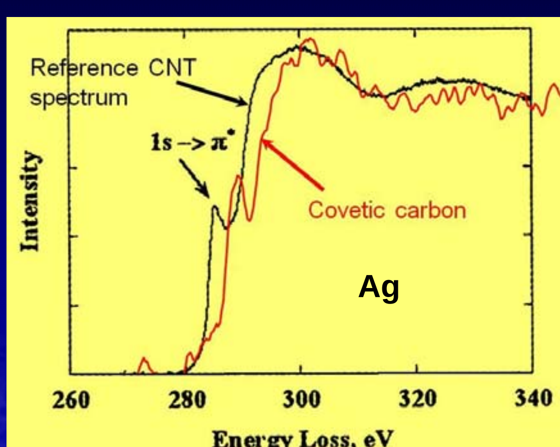
- Third Millennium Metals, LLC
- Proprietary process
- Conversion occurs in melt
  - Al, Cu, Au, Ag, Zn, Sn, Pb, Fe
  - Carbon powder → nanoscale C
  - Applied voltage
- Stable after conversion
- Process development and scale up is ongoing
- Producing research quantities now, ~100 lbs Al, ~300 lbs Cu

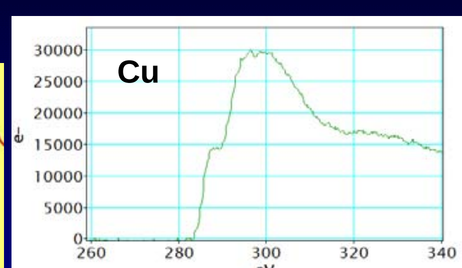
Distribution and Form of Carbon

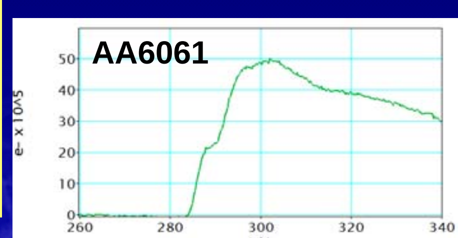
SEM – AA6061 as-extruded, 2.7% nanoC Lourdes Salamanca-Riba



EELS Spectra: Similar to spectrum of SWCNT, but differences between metals





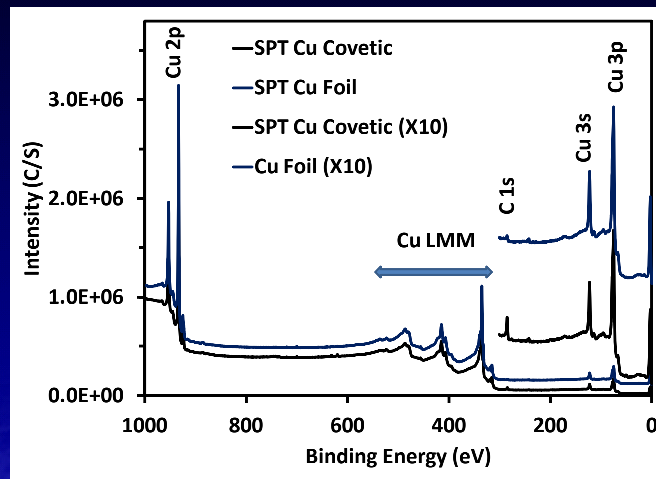


Schlittler, et al., "Single Crystals of Single-Walled Carbon Nanotubes Formed by Self-Assembly," Science, New Series, Vol. 292, No. 5519 (May 11, 2001), pp. 1136-1139

In bulk, Covetic virtually identical to pure Cu

XPS:

- Overall metallic character confirmed
- No difference in electron binding energies
- No evidence for carbide formation



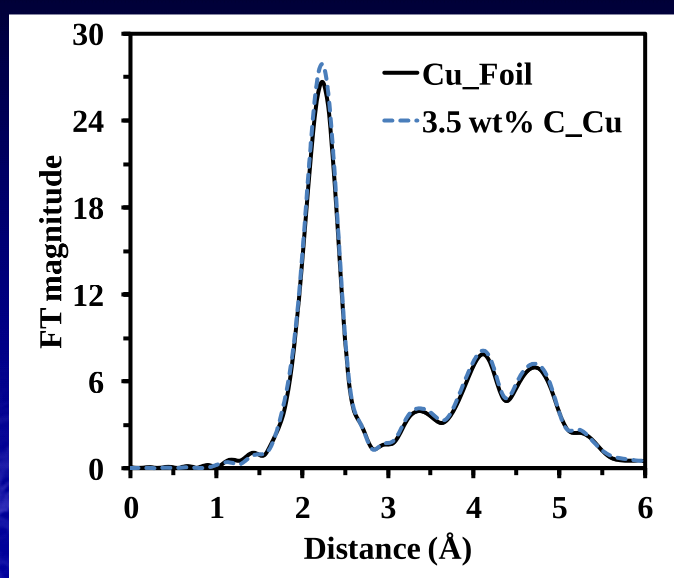
Foil: 0% C

Covetic: 3.5 wt% C

In bulk, Covetic virtually identical to pure Cu

EXAFS/Fourier transforms:

- Overall metallic character confirmed
- FCC structure
- Same structural parameters → no significant difference between atomic spacing of Cu atoms
- No evidence for a solid solution
- No evidence for carbon-Cu bonds except possibly at the interface region



Analytical Methods for C Determination

- LECO and GDMS do not detect nanoscale C
- XPS best, EDS on polished samples seems to work
- DC-PES may be better with higher carbon levels
- Standardization work needed
- Reference materials needed

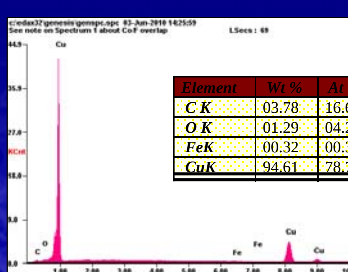
Method	Result (wt. %)
LECO	0.0016
DC-PES*	0.56
GDMS	0.0060
XPS	0.21

* Direct Current Plasma Emission Spectroscopy ASTM E1097 to detect Cu

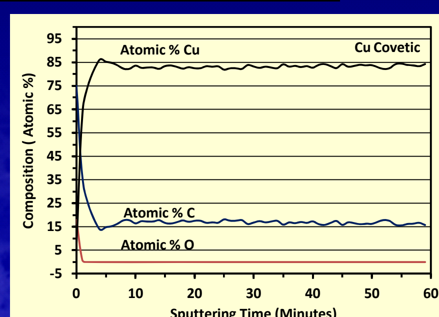
On one sample, good correspondence: XPS and EDS

Copper covetic

Method	Result (wt. %)
Energy Dispersive Spectroscopy	3.8
X-Ray Photoelectron Spectroscopy	3.5



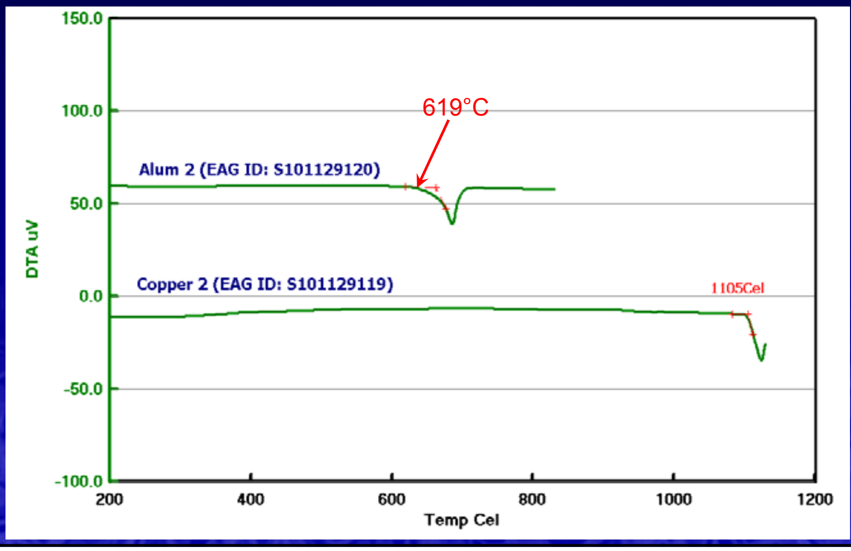
Element	Wt %	At %
C K	03.78	16.65
O K	01.29	04.25
FeK	00.32	00.30
CuK	94.61	78.79



Thermophysical Properties

Increased melting point (DTA)

AA6061 solidus: 582°C → 619°C
Copper: 1085°C → 1105°C



Density remains unusually high Naval Academy, CAPT Lloyd Brown

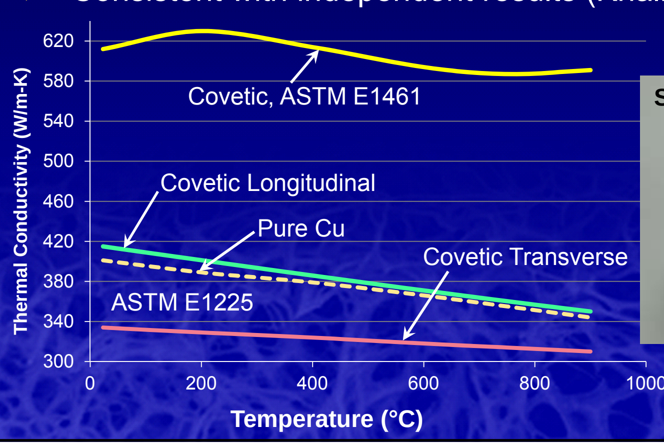
3.8 wt % Cu Covetic

- Compressed 50% in Gleeble to consolidate any porosity
- Ultrapycnometer 1000
- Before compression = 8.7894 g/cm^3
- After compression = 8.8777 g/cm^3
- Compared with ρ_{Cu} = 8.94 g/cm^3
- Only 0.7% reduction in density with 3.8 wt % C vs. 10% expected

Thermal conductivity: Anisotropic and rate-dependent

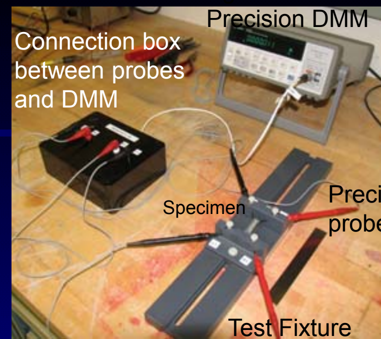
As-extruded Cu Covetic (0.057 wt % C)

- Steady state longitudinal → increased with nanocarbon
- Steady state transverse → decreased with nanocarbon
- Transient longitudinal → 50% increase with nanocarbon
- Consistent with independent results (Khalid Lafdi, U. Dayton)



Section of Cu extrusion

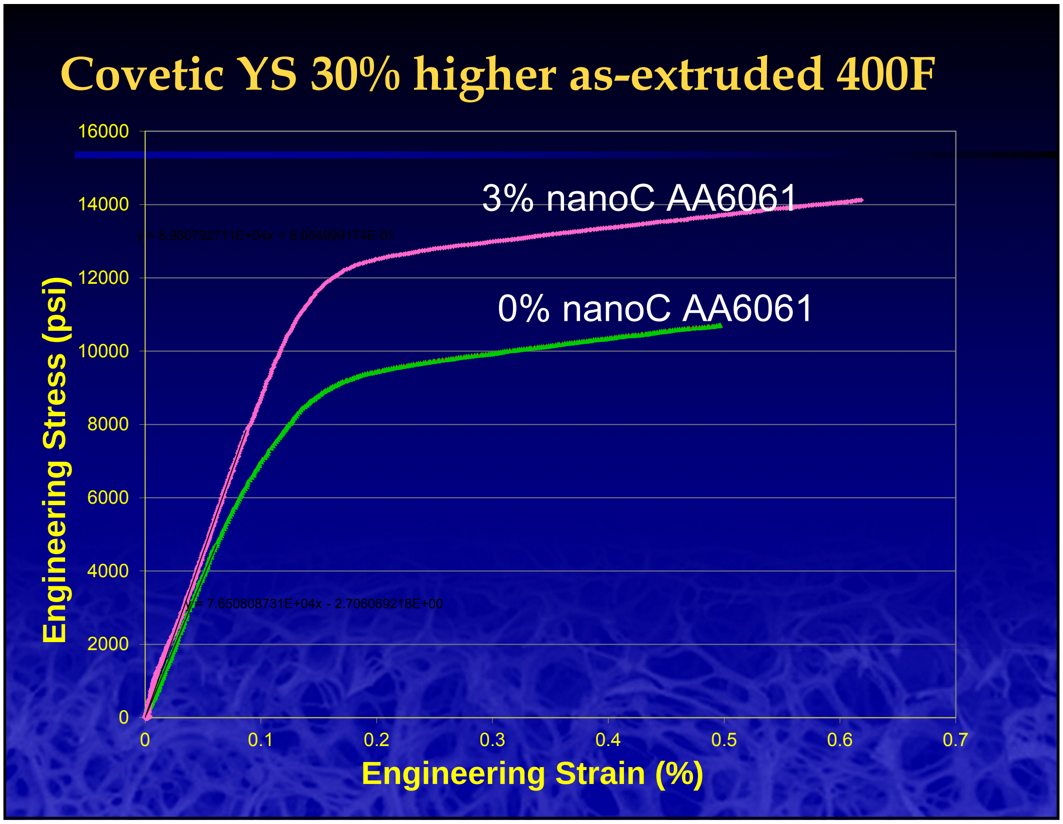
Electrical Conductivity of Al increased

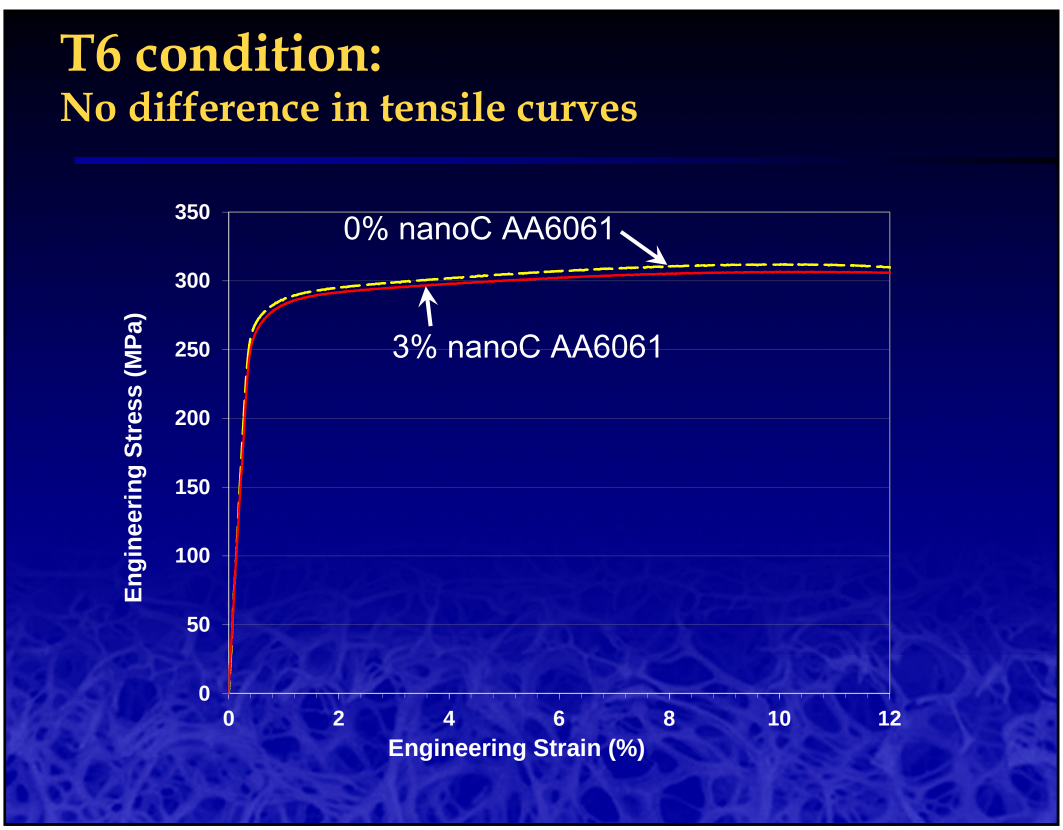


- High conductivities seem possible
- Causes of variability require further study

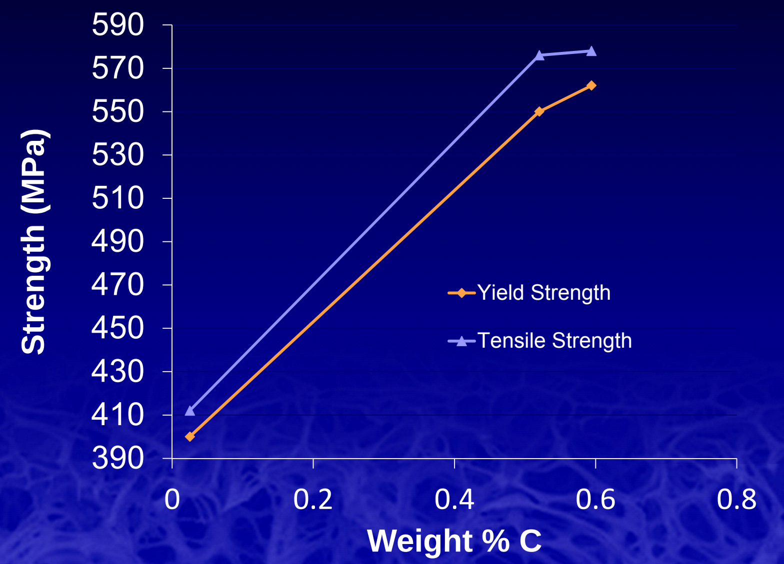
Type of Material	Condition	%IACS	Test Lab
0%C 6061	Conventional 6061, T6[1]	47	USNA
3%C 6061	Covetic T6 ground	48	USNA
3%C 6061	Covetic T6 turned surface	56	USNA
3%C 6061	Covetic As-Extruded	66 ± 17	USNA
EC-1350	Electrical grade Al	61.8	**Literature**

Mechanical Properties

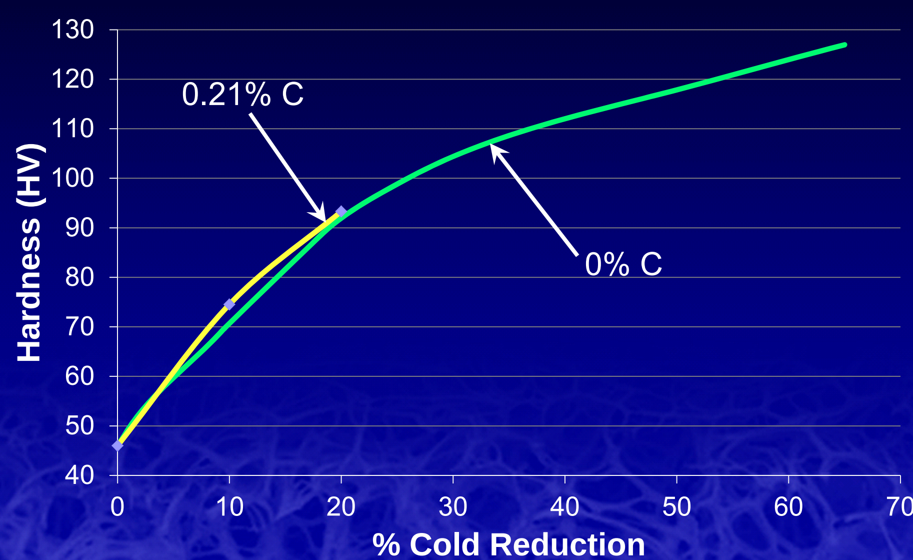

Covetic YS 30% higher as-extruded 400F
3% nanoC AA6061
0% nanoC AA6061
y = 8.980792711E+04x + 8.054999174E-01
y = 7.650808731E+04x - 2.706069218E+00
Engineering Stress (psi)
Engineering Strain (%)
16000
14000
12000
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7


T6 condition:
No difference in tensile curves
0% nanoC AA6061
3% nanoC AA6061
Engineering Stress (MPa)
Engineering Strain (%)
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12

Effect of carbon level on 7075 strength
Warm Rolled



Work Hardening of Cu: No difference Cold Rolling at 0.21% C



Applications

- Anisotropic, high thermal conductivity Cu
  - Heat exchangers
  - Microelectronics
  - Electrodes and electrical contacts
- High electrical conductivity aluminum
  - High tension lines
  - Wiring
  - Electrodes and contacts
- Currently evaluating AA5083 covetic for naval structural applications

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- Strength increase possible—depends on processing, %C
- Higher thermal conductivity, but anisotropic
- Higher electrical conductivity, questions about variability