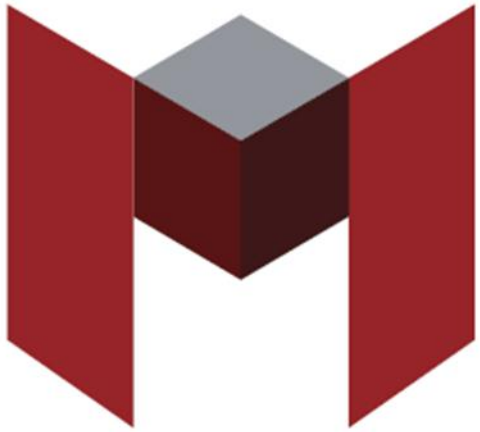
Metal Matrix Composite Optics and Structures

P. Karandikar, M. Watkins, B. Givens, M. Roberts, M. Aghajanian
M Cubed Technologies, Inc. (A II-VI Company)
1 Tralee Industrial Park
Newark, DE 19711

Bill Morgan
II-VI Optical Systems



Mirror Technology Days
November 19, 2014

Outline

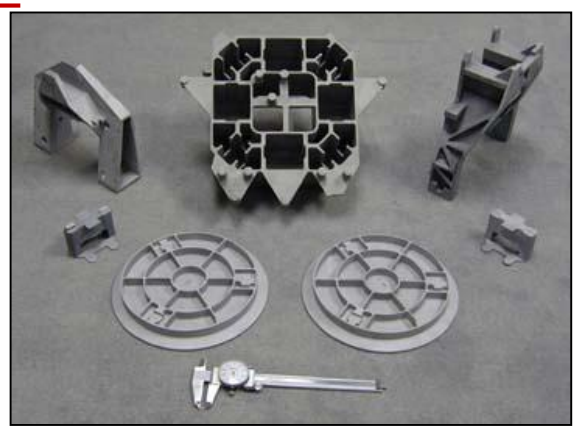
- M Cubed company background and materials technologies
  - Metal Matrix Composites (MMCs) and Reaction Bonded Ceramics
- Material Selection MMCs Vs. Ceramics
  - Comparison of specific properties
  - Advantages of MMCs
- Product Example: Optics and Structures
- Ni-plating development
- Microstructural uniformity
- Thin Ni-plated and preliminary diamond turned MMC optic
- Thick Ni plated components for
  - Diamond turning and
  - Thermal characterization
- Summary

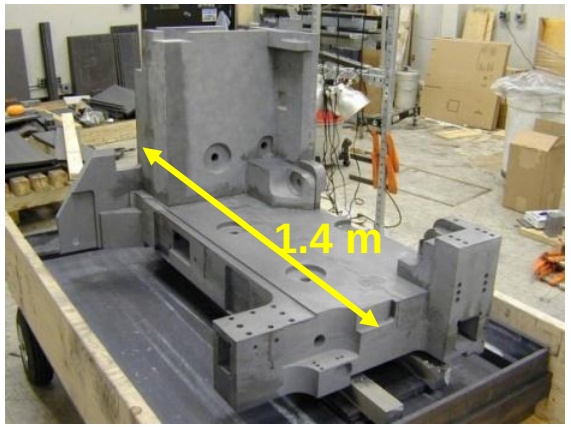
M Cubed Background

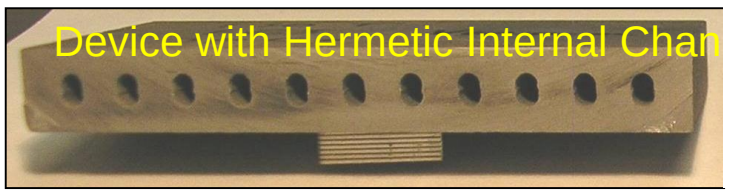
- M Cubed
  - ~200 Employees
  - Three locations: Newark, DE; Monroe, CT; Newtown, CT
  - Small company until October, 2012
- Acquired by II-VI Incorporated in November, 2012
  - II-VI is a conglomerate of advanced materials companies
  - Over 6000 employees world wide
  - OS (EEO + Lightworks Optics) – now a sister company
  - Added capabilities of optics system design, finishing, assembly
- Current Materials/Products/Markets
  - Metal matrix composites, reaction bonded ceramics (SiC, B_4C,…)
  - Semiconductor capital equipment components
  - LCD capital equipment components
  - Wear and thermal management components
  - Armor

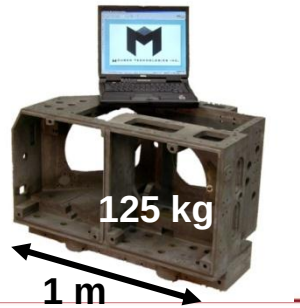
M Cubed Materials Classes

- **Metal Matrix Composites - MMC (Investment cast or Gravity cast): "Super Aluminum"**
  - Properties are metal-like but with higher stiffness, hardness, fatigue resistance and damping capability
  - Al/SiCp, Al/Al_2O_3p; 30% and 55% loading
  - 2.1 m x 2.1 m components routinely produced
  - Machine like metals – with diamond tooling, can drill and tap
  - Can anodize, electroless Ni plate (excellent CTE match)
- **Reaction Bonded (RB) Ceramics**
  - Complex shape and large size capability (2.4 m x 1.7 m)
  - Green to finished <0.5% dimensional change; EDMable
  - Significant tailorability (particle size, Si-alloying, residual Si)
  - SiC, B_4C, C_f/SiC, CNT/SIC, CNT/B_4C
  - Significant lapping and interferometry capacity
  - Patented brazing (7,270,885) bonding technology (6,863,759) for cooled mirrors
  - Directly polishable SiC



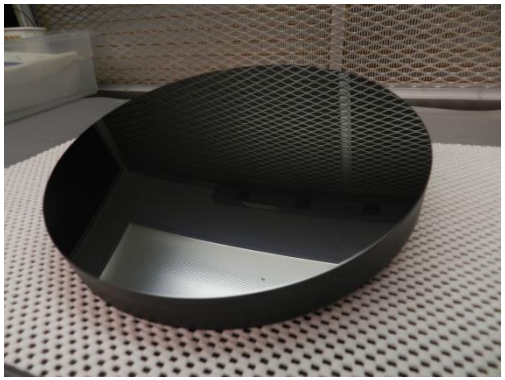






0.25 m Si-SiC Spherical Mirror (Uncoated): Figure & Finish

Directly polishable SiC (RBSC Grade FG)
Eliminates Expensive Cladding
↓ $$

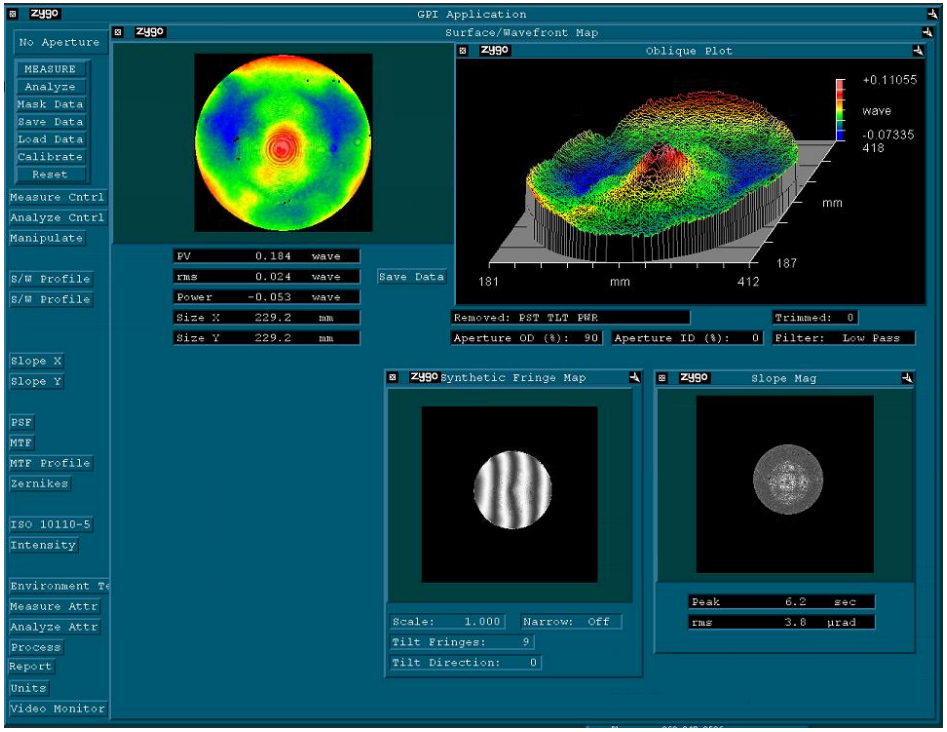


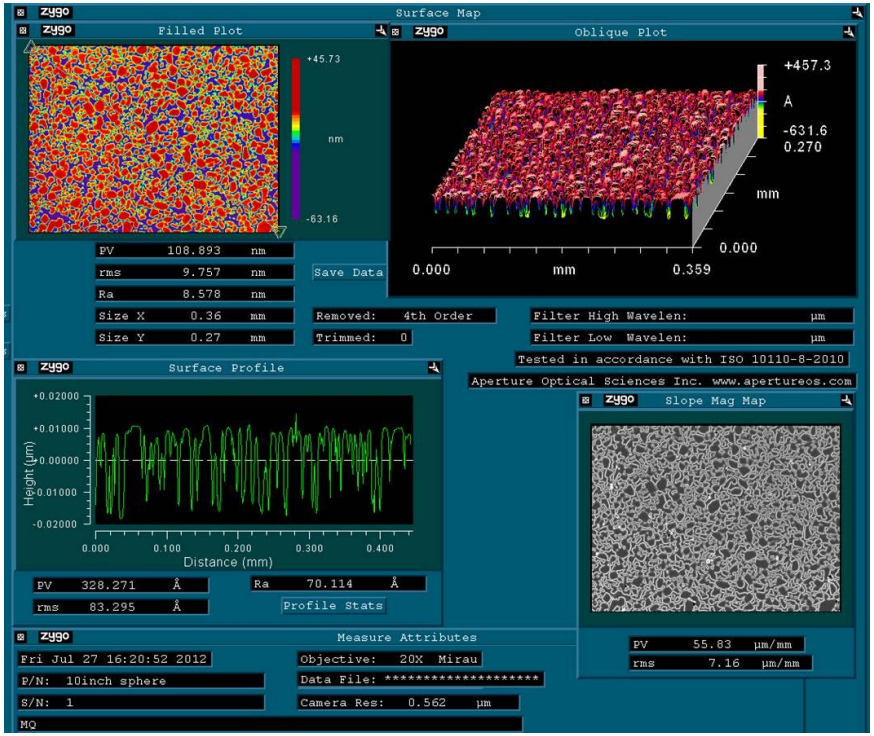
OPTIMUM

2.5m ROC

Figure:
PV – 0.184 λ
RMS – 0.024 λ

Finish:
8.6 nm Ra

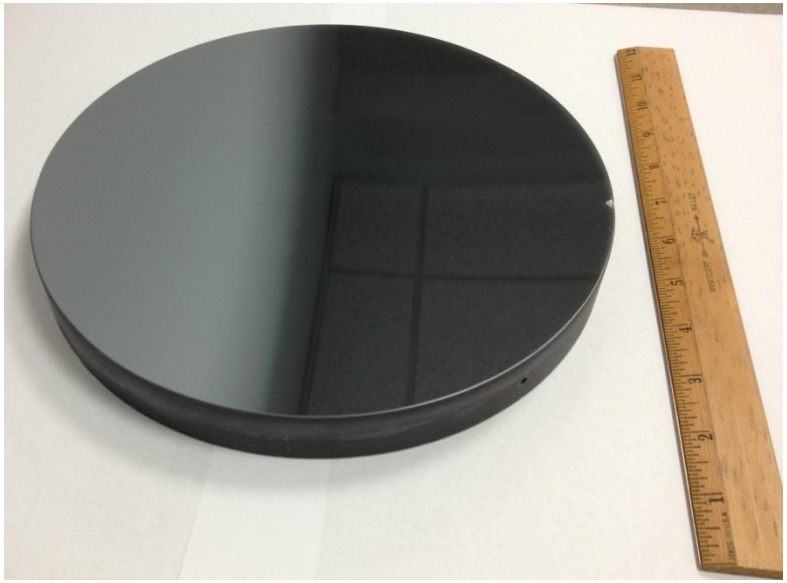




0.25 m SiC/C_f/CNT Spherical Mirror: Figure & Finish

Figure:
PV – 0.186 λ
RMS – 0.029 λ
Finish:
4.6 Å Ra

2.5m ROC



Property Comparison

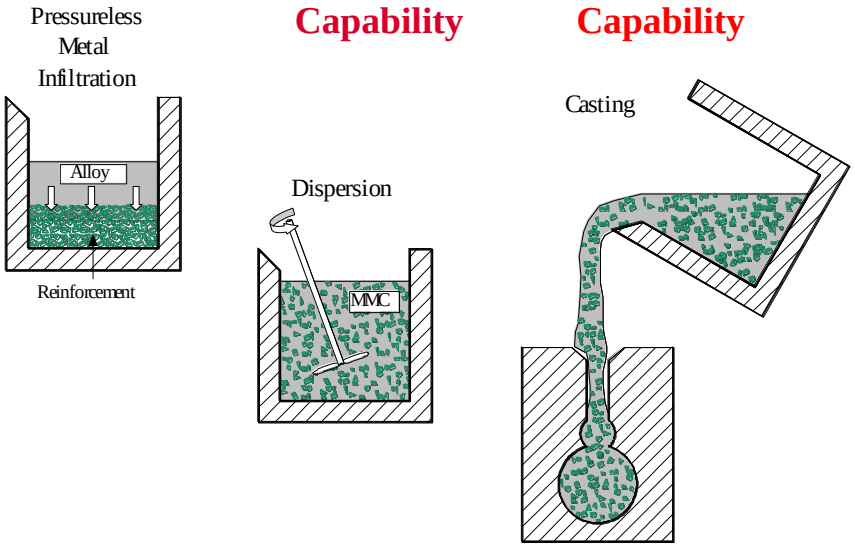
Material	ρ (g/cc)	E (GPa)	UBS (MPa)	UTS (MPa)	K_{IC} (MPa $m^{½}$)	α (ppm/K 25-100C)	K (W/mK)	E/ρ	K/α
6061 Al	2.6	68	--	276	29.0	23.6	175	26.2	7.4
I-70H Be	1.85	287	--	237	11.0	11.3	216	155.1	19.1
Corning ULE	2.2	67	60	--	1.6	0.02	1.3	30.5	65.0
MCT MMC									
Al/SiC_{30p}	2.78	125	--	370	15	14.0	160	45.0	11.4
Al/SiC_{55p}	2.95	200	--	340	11	10.0	180	67.8	18.0
MCT Ceramic									
RB SiC FG	2.94	330	350	--	4	3.0	150	112.2	50.0
CNT/SiC	3.06	374	285	--	6.9	2.7	160	122.2	59.3
Diamond/SiC	3.27	625	--	--	--	2.2	373	191.1	168.0
RB B4C	2.54	370	250	--	4	4.8	52	145.7	10.8
CNT+C_f+B_4C	2.66	397	275	--	4.7	--	--	149.3	--
Diamond/B_4C*	2.92	625	--	--	--	3.3	133	214.0	43.1
Other Ceramics									
CVD SiC	3.21	440	300	--	3.0	2.2	300	137.1	136.4

* - calculated

MMC Casting and Advantages

Complex Shape Capability

Large Size Capability

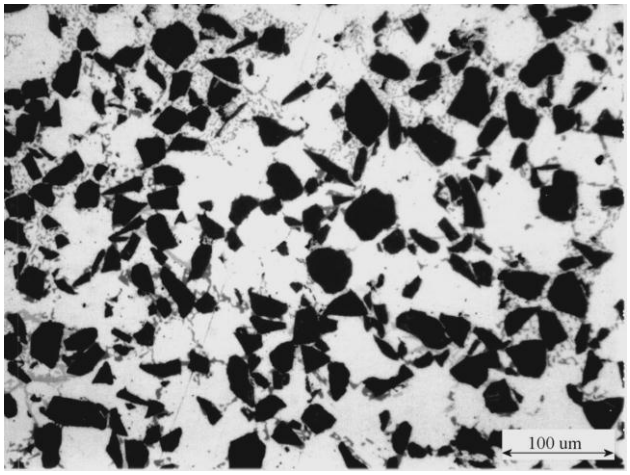


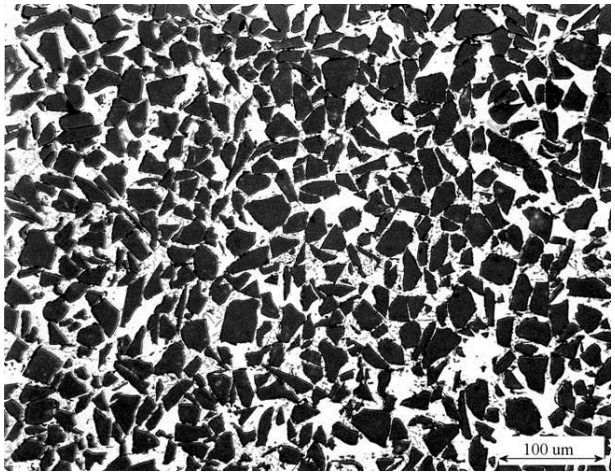
- Net and near-net shape fabrication with investment and sand casting
- Production technology (TRL, MRL > 6)
- Fully machinable, including direct threading
- CTE match with Ni plating, minimizing thermal distortion
- Mirror finishing of Ni plating with conventional diamond turning and polishing
- Casting capability in excess of 2 m x 2 m and 500 kg
- Greatly enhanced mechanical and thermal stability relative to traditional metals
- High damping capacity
- High toughness relative to ceramics

Material Property Data & Microstructures

	Metal Matrix Composites (MMCs)		
Property	**Al/SiC_{30p}**	**Al/SiC_{55p}**	**6061Al**
Ceramic (vol. %)	30	55	0
ρ (g/cc)	2.78	2.96	2.6
E(GPa)	120	202	68
UTS (MPa)	317	340	276
K_{IC} (MPa $m^{1/2}$)	15	11	29
α, 20-100°C (ppm/K)	14	10	23.6
K (W/m-K)	148	160	150

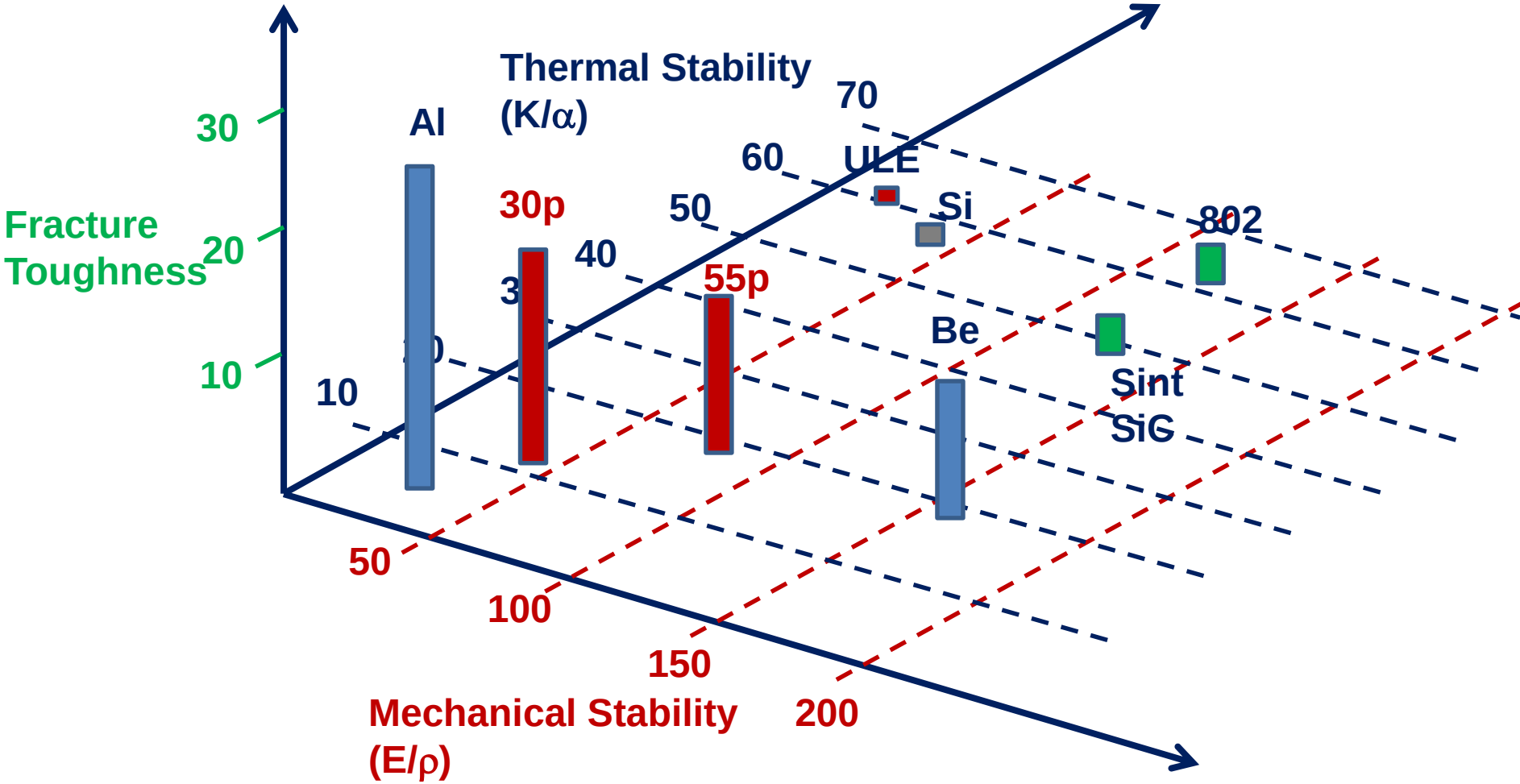
Al/SiC_{30p}



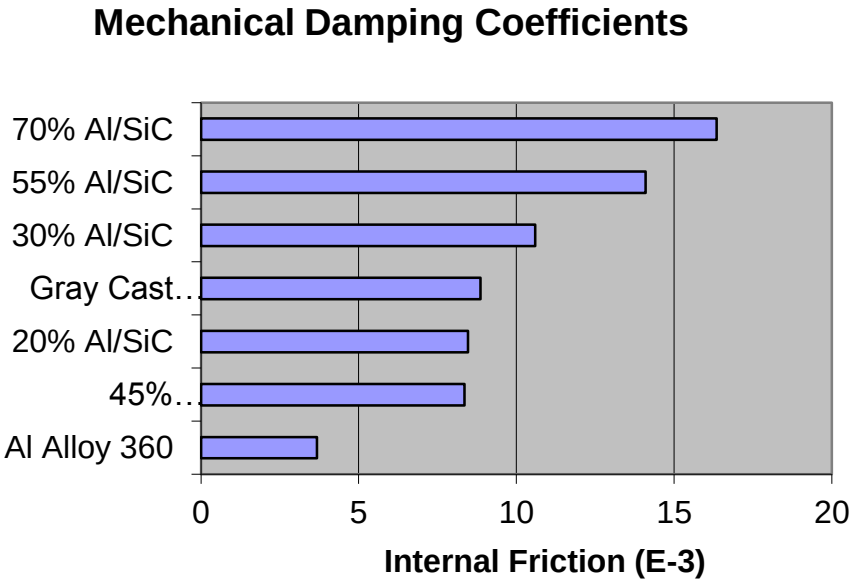


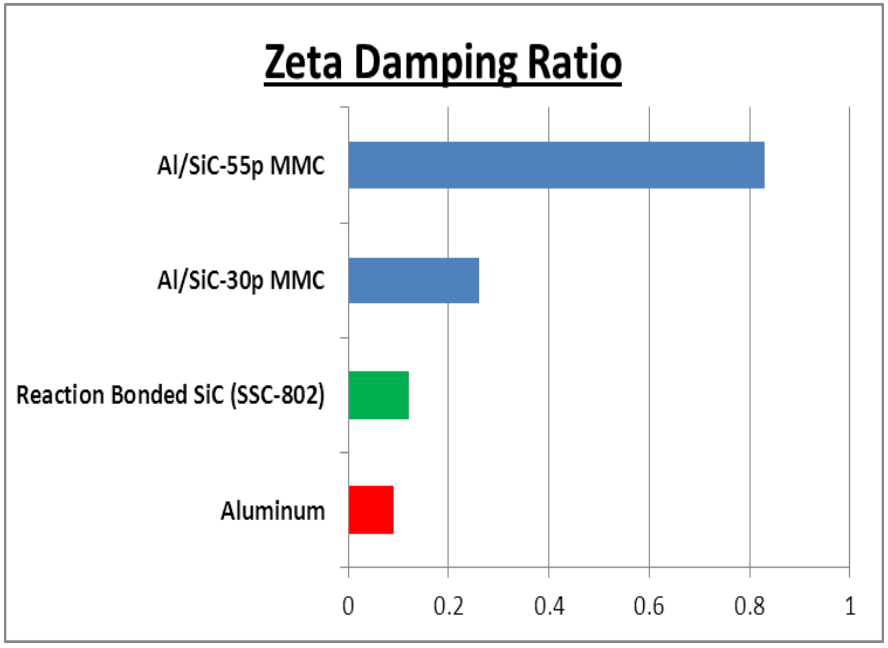
Al/SiC_{55p}

Property Comparison 3D Plot

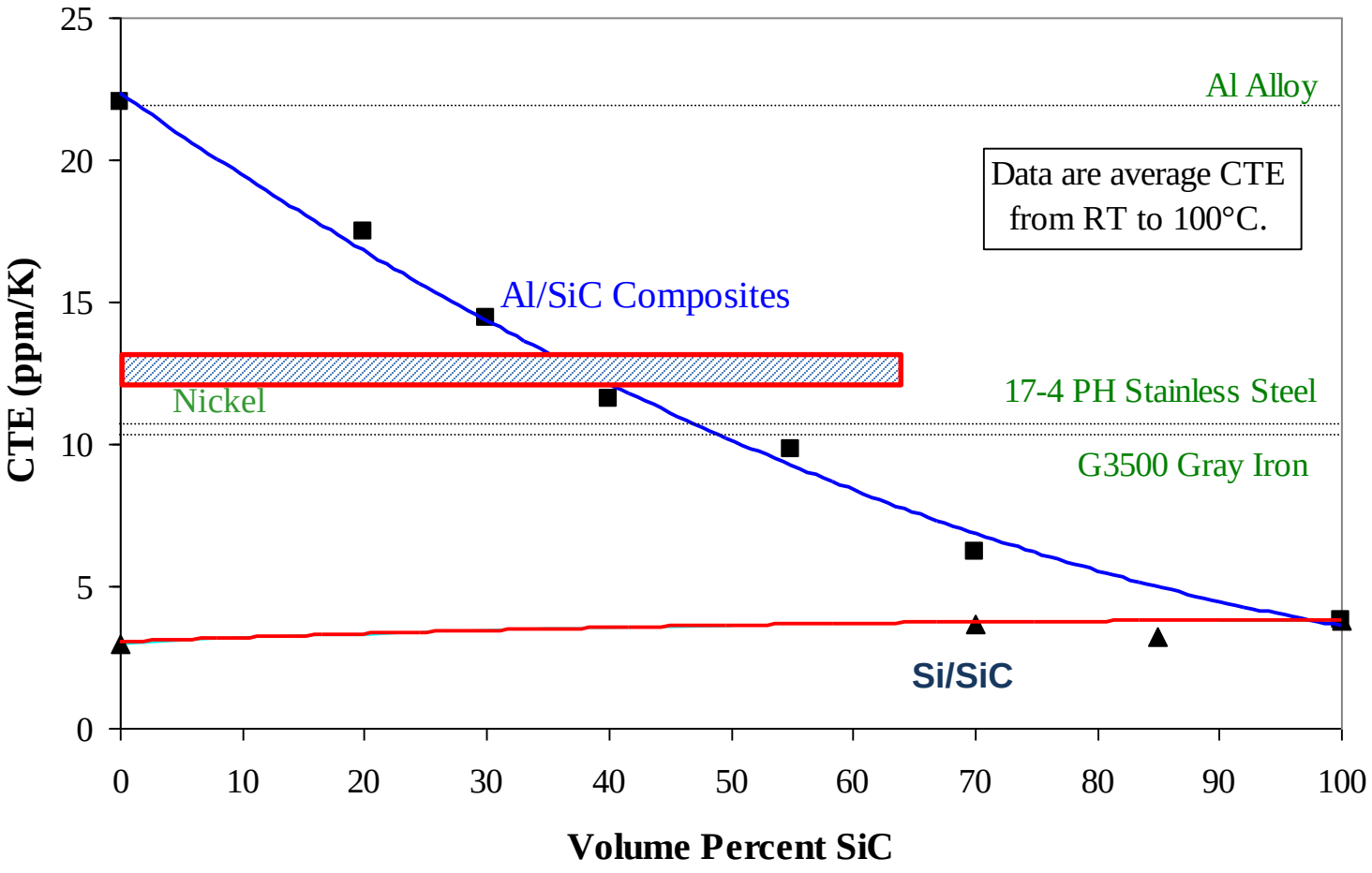


Damping Ability of MMCs



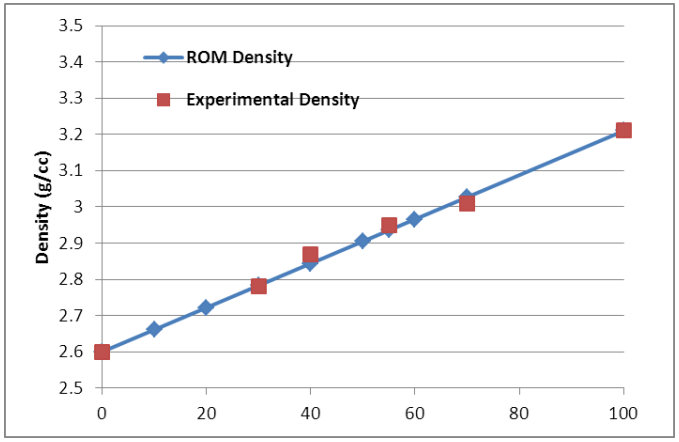


CTE Tailoring and Matching

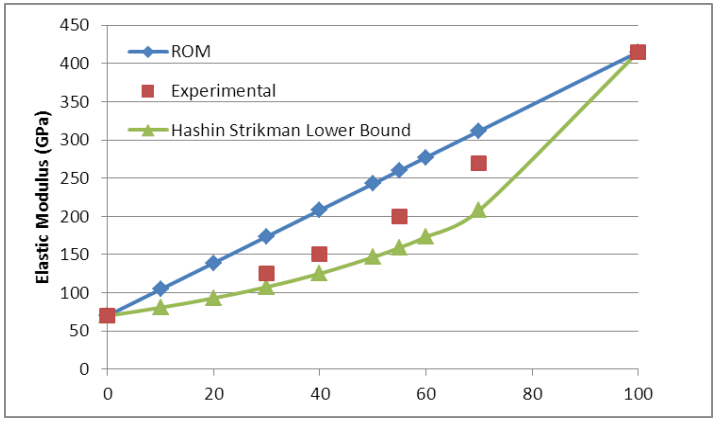


Al/SiC MMC Comparison of Properties with Theoretical Predictions

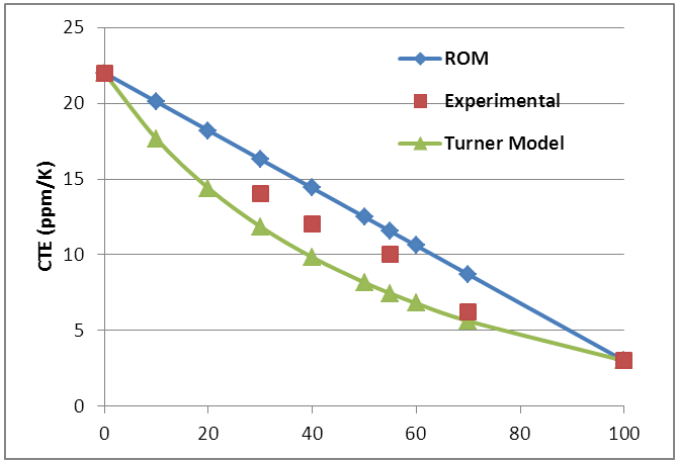
Density: ROM



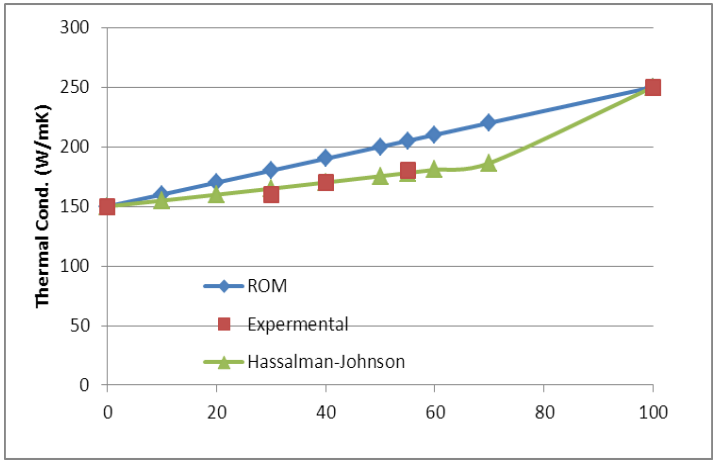
E: Hashin Strikman LB



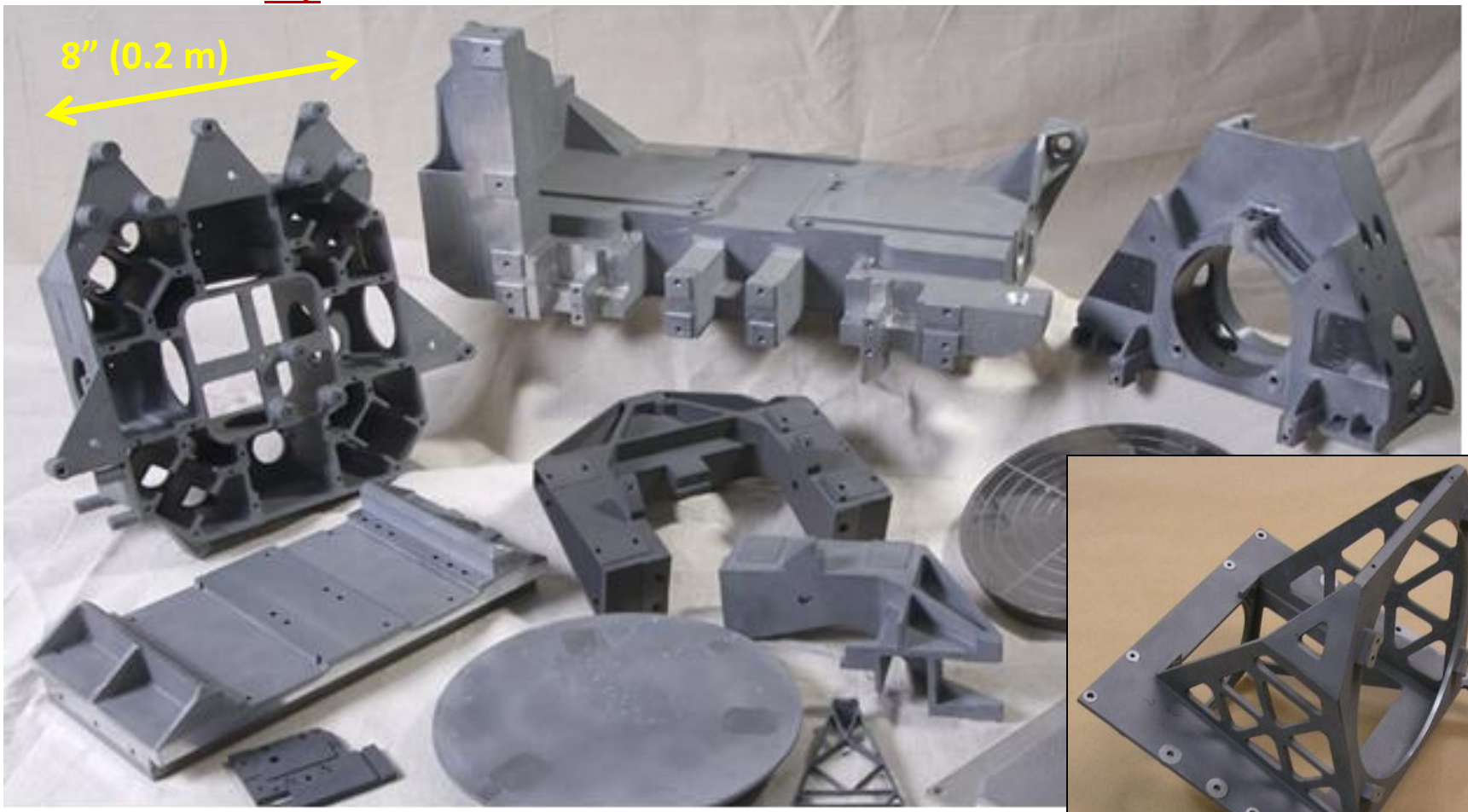
α: Turner Model



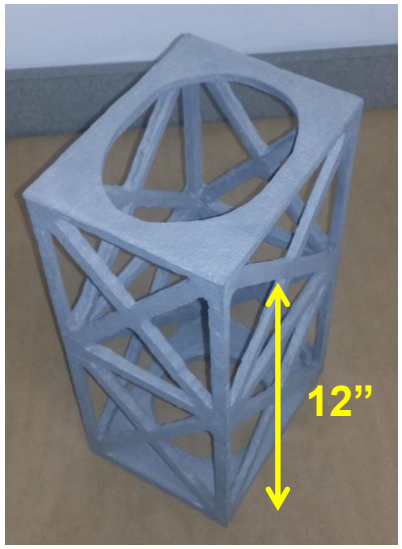
K: Hasselman-Johnson



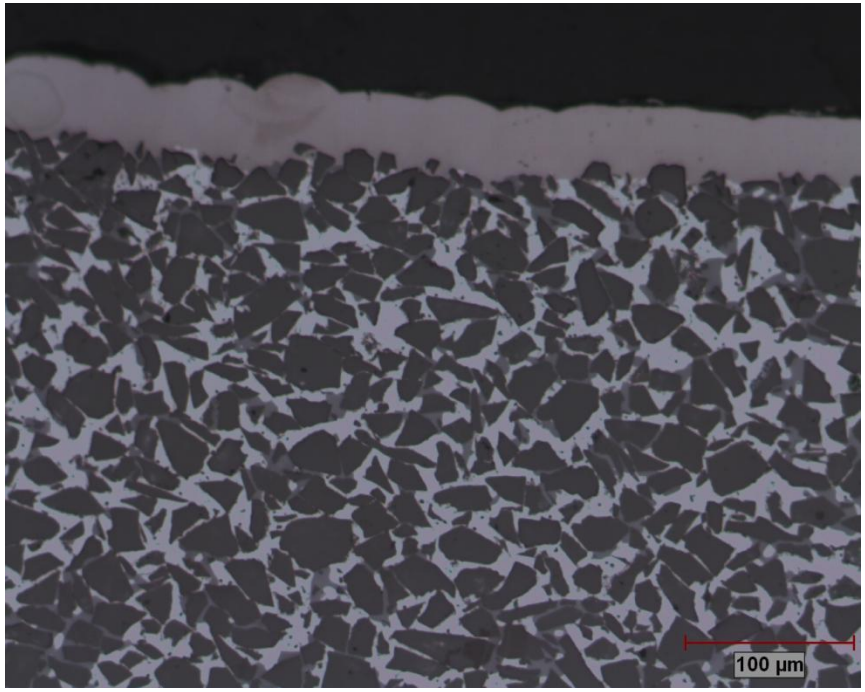
Al/SiC_{30p} Cast and Selectively Precision Finished Components

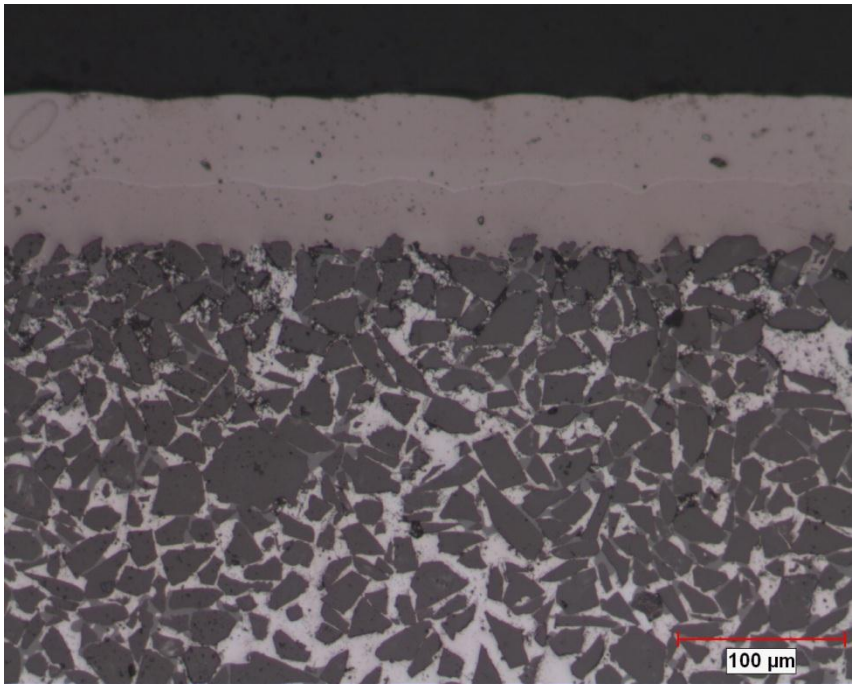


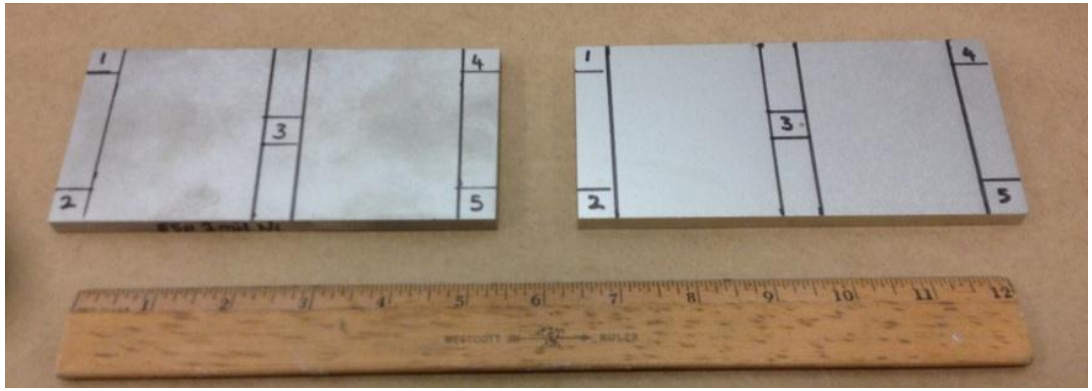
Al/SiC $_{55p}$ Cast and Slectively Precision Machined Components



Thin and Thick Ni Plating- Bonding and Microstructure



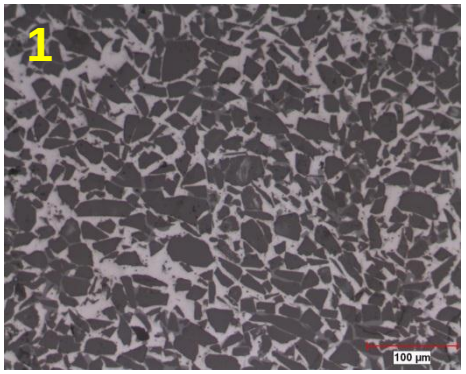


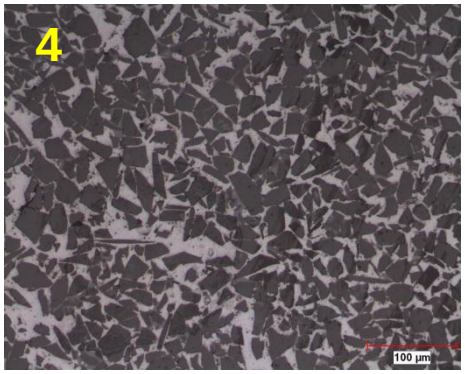


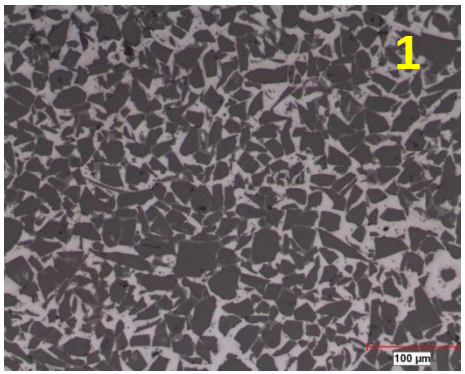
Detailed CTE measurements planned

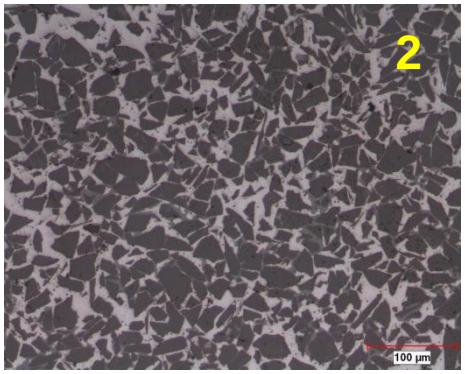
- **Over operational temperature range**
- **MMC**
- **Ni**
- **Plated MMC**

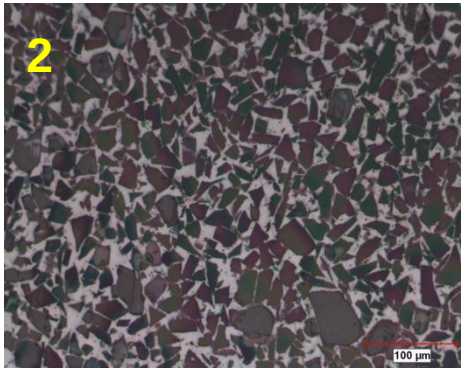
Microstructural Uniformity











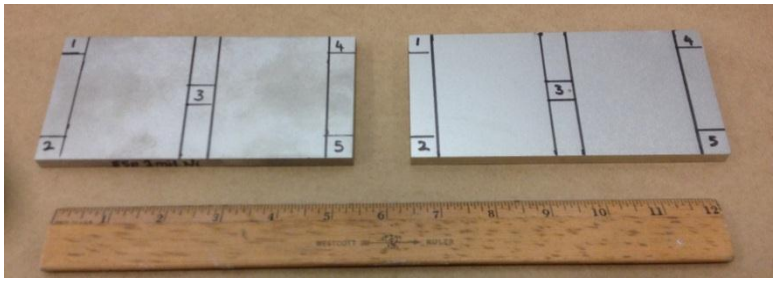
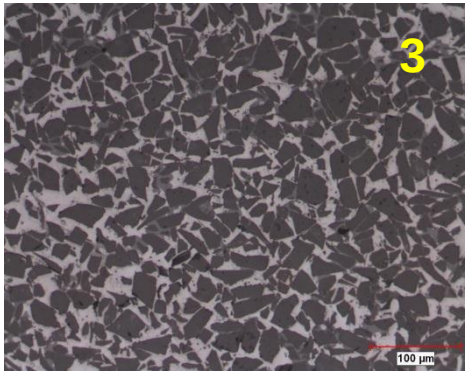
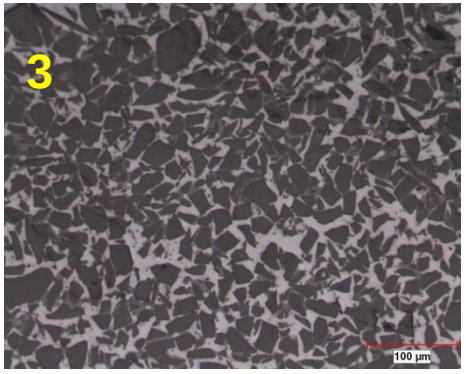
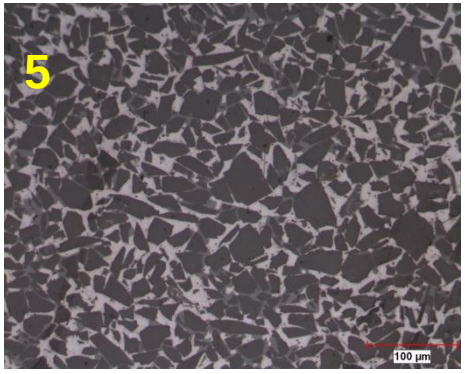
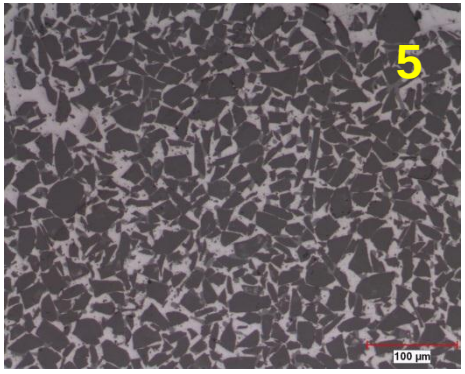


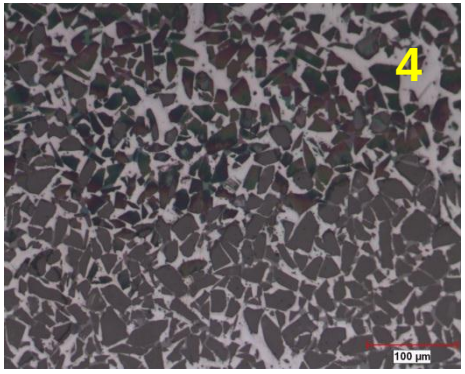
Image analysis: SiC content ±2%







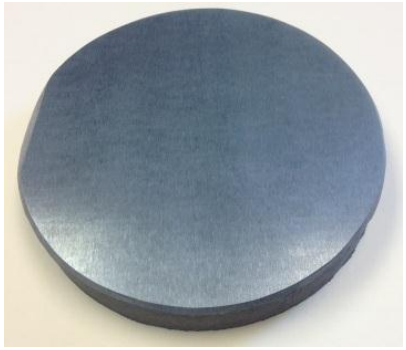


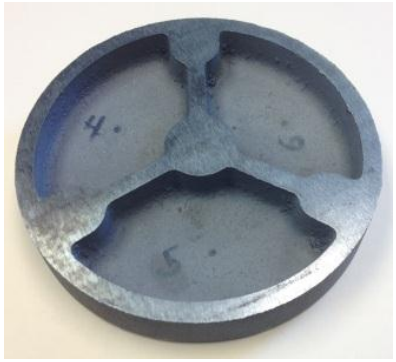


Thin Ni-Plated Al/SiC_{55p} MMC Optic

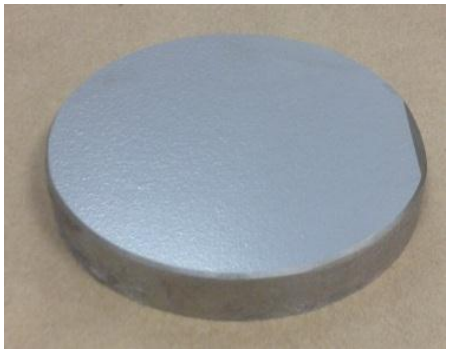
As cast

Surface Generated

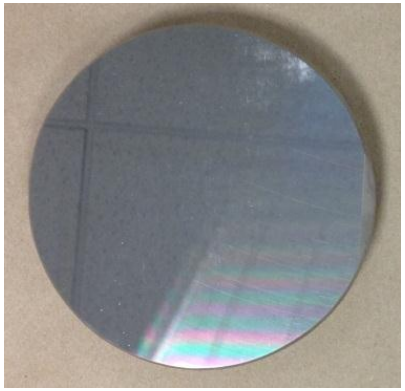




Ni-plated



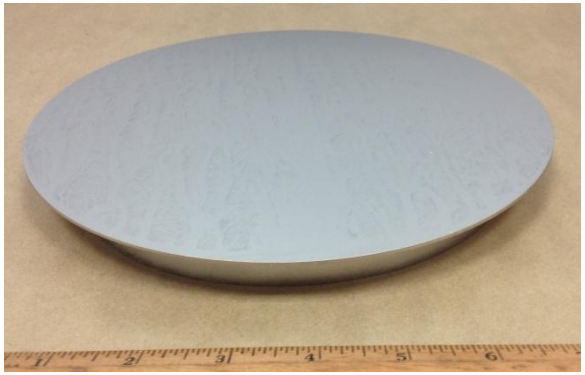
Diamond Fly cut

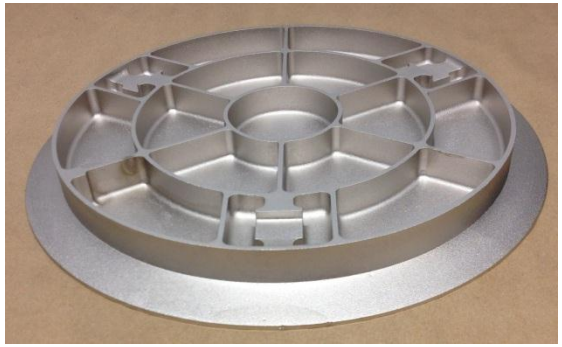


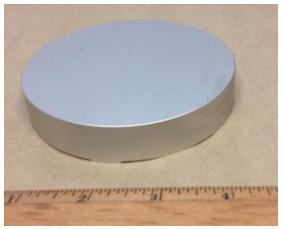
- **Finishing was limited due to the low thickness of Ni.**

Thick Ni-plated MMC Components: Finishing and Characterization Plan

Al/SiC$_{30p}$







Al/SiC$_{55p}$

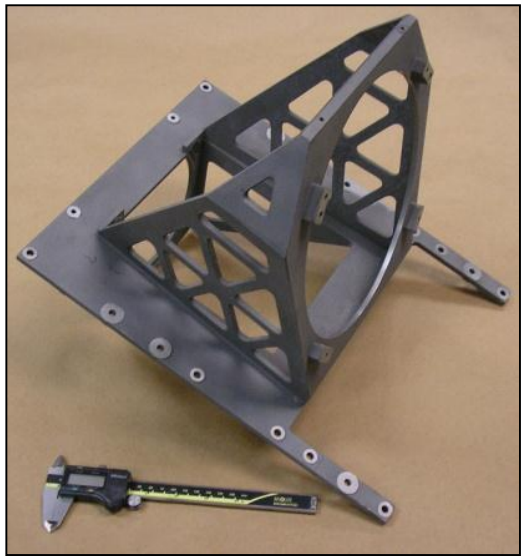
Al/SiC$_{30p}$

- Several components made
- Stabilized
- Surface generated
- Ni-plated
- Ready for diamond turning
- Finish polish
- Measure
- Thermal stability

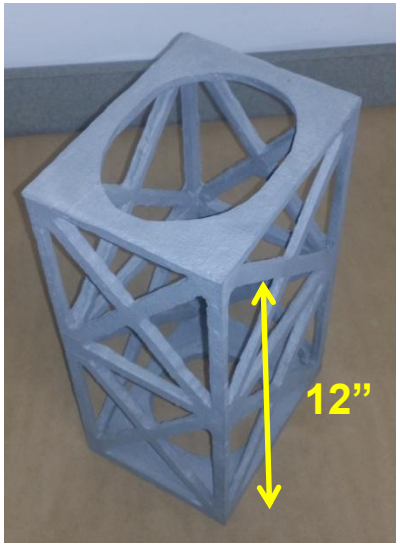
Summary

- Metal matrix composites offer a viable high-toughness, high specific stiffness, high thermal stability alternative for optics and structures
  - Enable an athermal design
- Microstructural uniformity of Al/SiC55p evaluated and SiC volume fraction was found to be within ±2%
- Several MMC components were fabricated, surface generation was completed, stress relieving was completed, and parts were Ni plated.
- Strongly adherent, uniform Ni plating was demonstrated
- Preliminary feasibility of diamond turning was demonstrated
- Further diamond turning and finishing of plano, spherical, and off-axis parabolic mirrors is underway
- Thermal stability testing (80°C to -60°C) of diamond turned optics is underway
- Ability to fabricated and finish MMC structures/optics housings was demonstrated
- Current production capacity for MMC optics and housings is 2.1m x 2.1m (this size components are made currently for stage applications)

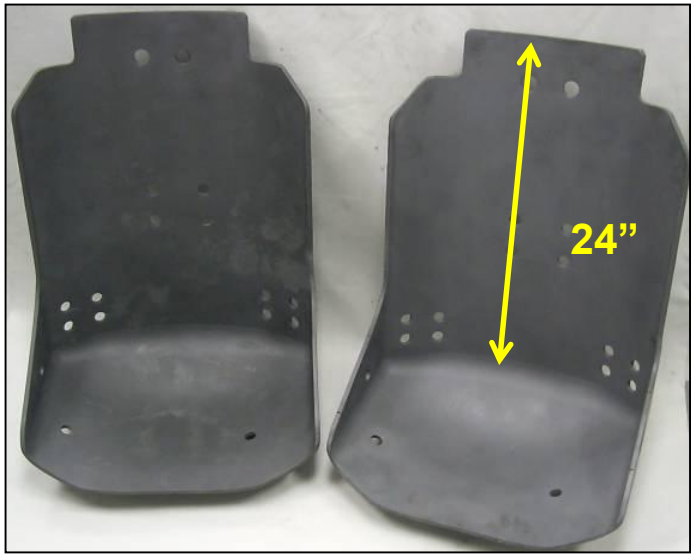
Cast Al/SiC-30p Optics Housing



Cast Al/SiC-55p Optics Housing



Reaction Bonded B_4C Helicopter Seat Tiles



Al/SiC55p MMC Large Structure

Thank You
Any Questions?

300 mm SiC Wafer Chuck

Reaction Bonded SiC 450 mm Mirror