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MOTORCYCLE SERIES

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Performance Rotors

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Rotor Deployment Challenges

Challenges	Solutions
Maximize Brakes' Maximum Operating Temp (MOT)	NASA Fiber formulation
Selectively Reinforced Braking Surface	Functional Reinforced Gradient (FRG) Technology
Employ cost-effective machining technology	Diamond Tooling and advanced machining procedures

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‘Rocket Science’

Cutting edge hybrid composite material utilizing technology developed for NASA

Composite Constituents

- Aluminum alloy
- NASA fiber
- SiC Particles
- Nano Technology

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What is a MMC?

Metal Matrix Composites (MMCs) are a mixture of metal (i.e. aluminum) and ceramic (i.e. SiC) to produce a lightweight material with tailored mechanical properties: i.e. high stiffness, good wear resistance, low coefficient of thermal expansion, high thermal conductivity

Composite Property = **Matrix Contribution** + **Reinforcement Contribution**

Matrix Contribution

- Strength
- Volume fraction
- Dislocation density
- Work hardening
- Grain size
- Porosity
- Phase reactions
- Precipitates
- Heat treatment
- Alloying elements
- Etc.

Reinforcement Contribution

- Strength
- Volume fraction
- Particle size
- Particle type
- Aspect ratio
- Interfacial characteristics
- Particle reactions
- Distribution
- Etc.

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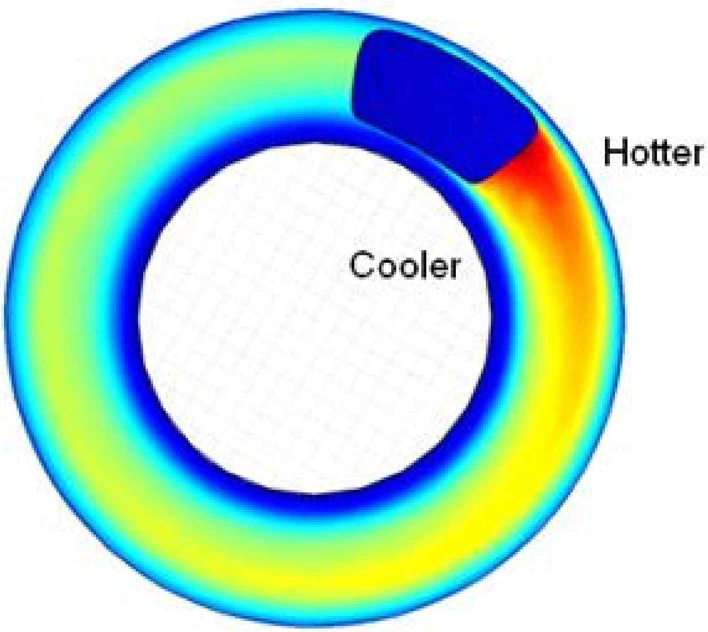
Basic Physics of a Braking Event

Thermal Stresses are a result of heating/cooling due to the Transient nature of breaking **and** the velocity gradient across the braking interface.

Functional Reinforcement Gradient-FRG



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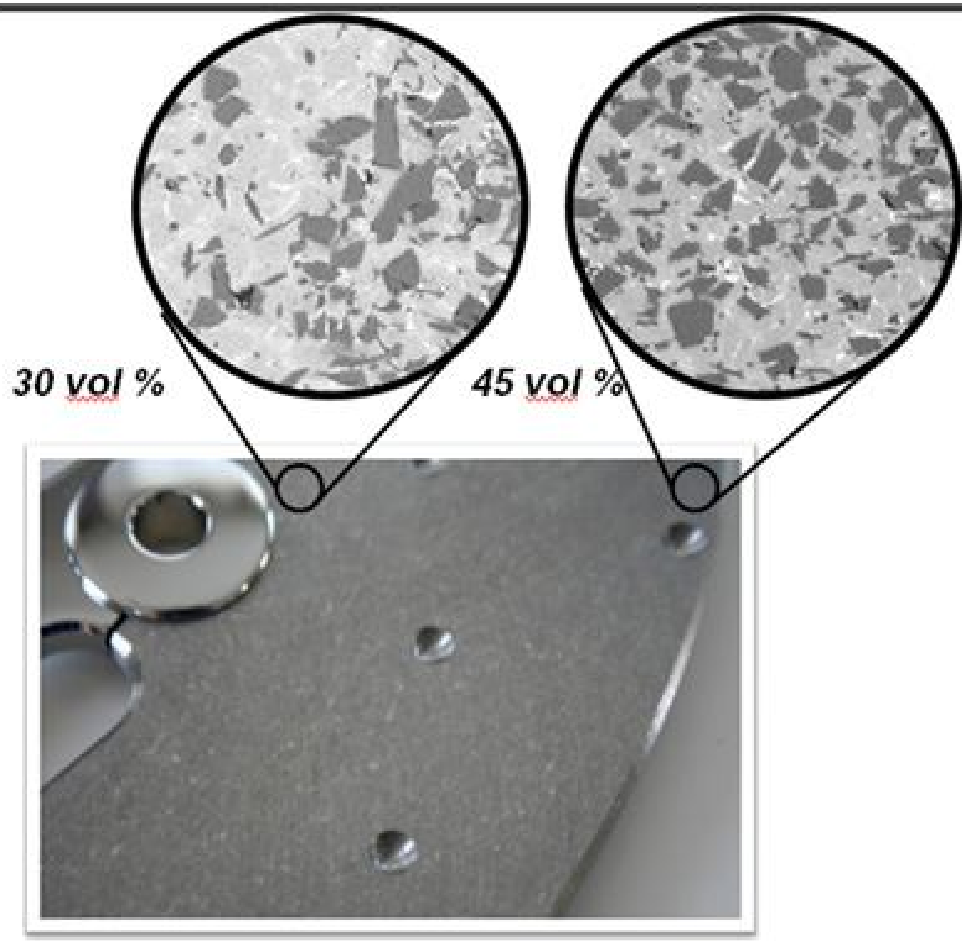
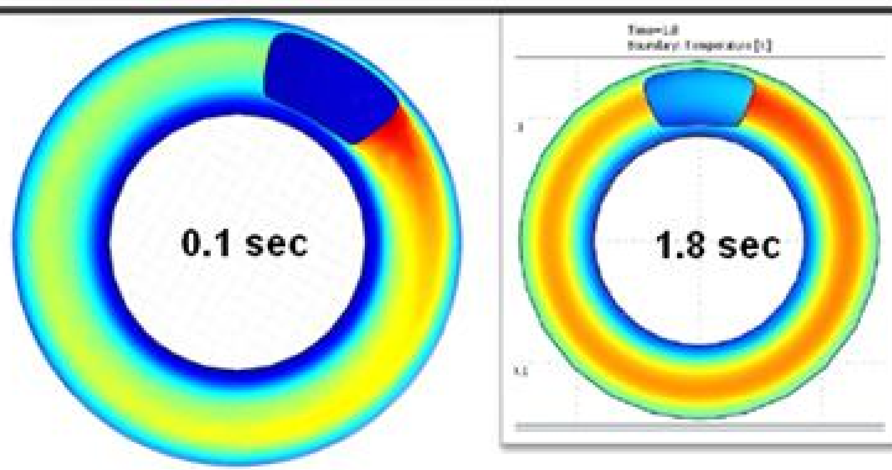
FRG Technology

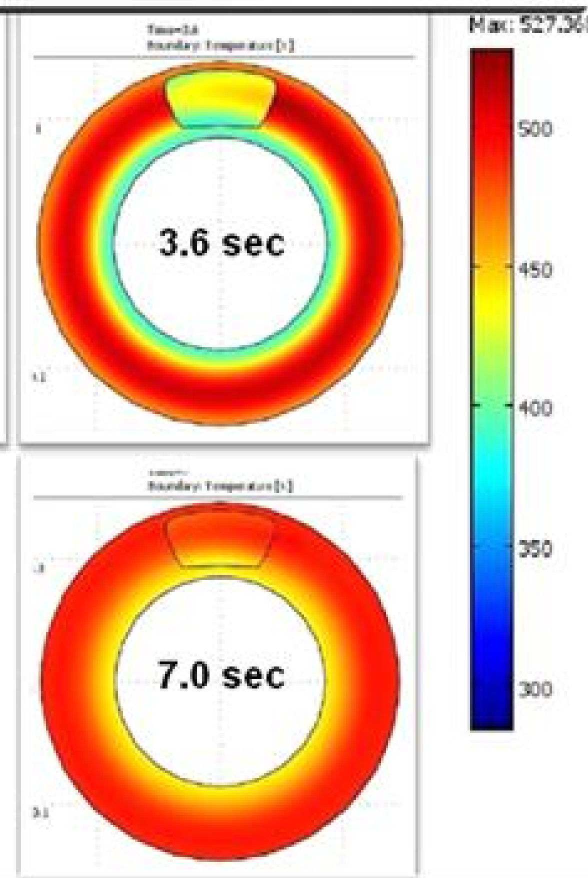


Functional Reinforced Gradient (FRG) reduces the thermal stresses induced by the braking event

-Patent Pending
-Cost Effectively Manufactured

Braking Event w/ MMC Rotor





- Temperature variation in rotor during braking event is managed by FRG

- High thermal conductivity of MMC makes the rotor a uniform temperature quickly, reducing warping propensity

Ceramics Processing Equipment

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Automated ceramic processing equipment

Automated Kilns of Preform Processing

Designed and built 4 automated electric kilns for production processing of ceramic preforms

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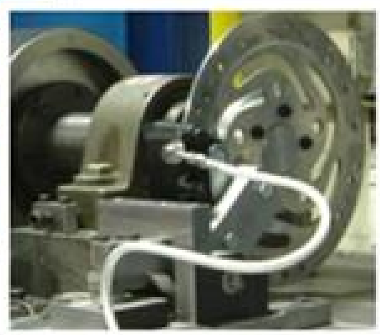
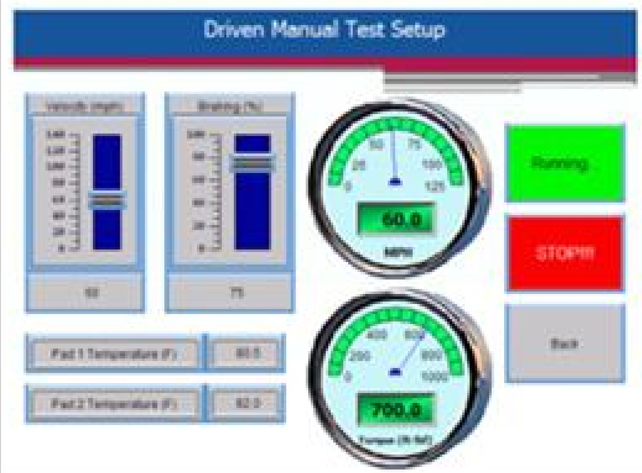
Dyno Equipment Design/Build

REL Brake Rotor Dynamometer



User Interface



Brake Rotor Dynamometer – Designed and Built in house for testing of rotors

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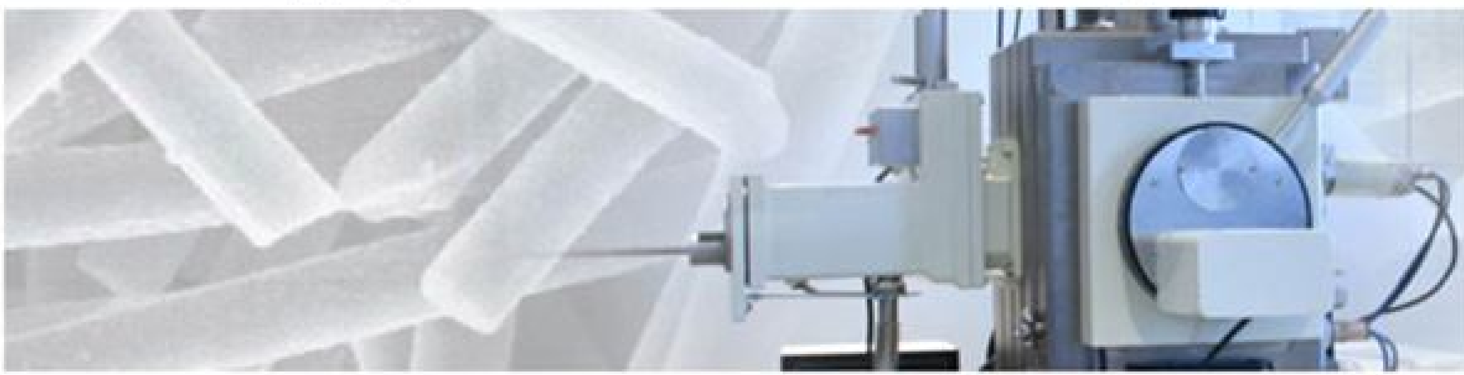
Quality Control - Scanning Electron Microscope

Understanding the bonding between the reinforcement and the aluminum matrix is paramount to be able to optimize material strength for optimum performance and repeatability

JEOL JSM-820 SEM with (1) **Digital Imaging system** and (2) **Energy dispersive x-ray spectrometer** (EDS).

- *-Microstructural observations*
- *-Element mapping*
- *-Bonding efficacy in composites*
- *-Identification of phases*



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Quality - Rotor Traceability

Matrix Rotor carry a lifetime warranty, therefore each rotor is given a individualized serial number that allows for part tracking throughout the manufacturing process to insure only high quality products reach the end consumer.

Rotors are traced from: preform manufacture → casting → heat treatment → final machining and grinding

NSF
ISO9001:2008
Certified

Matrix Rotor Advantages

- Improved Bike Handling due to Rotor Weight Reduction
- Superior Wear Resistance
- Rotor Warp Elimination
- Brake Noise Elimination
- Minimal “Fade”
- Aesthetically Pleasing with double disc ground surface

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Rotor Property Comparisons

Material Property/ Characteristic	Cast Iron	Al MMC	Remark
Density (g/cc)	7.3	2.9	60% lighter
Thermal Conductivity (W/m-K)	55	240	higher, more effective conductor
Thermal Shock Resistance (W/m)	6,800	44,000	7x higher, less prone to cracking due to thermal cycles
Bending Strength (MPa)	200	300	higher strength, carries higher clamping loads and braking torque
Wear & Friction	Good	Excellent	better braking response, minimal fade
Damping Capacity	Fair	Excellent	offers low NVH
Corrosion Resistance	Poor	Excellent	better corrosion resistance
Life Expectancy (km)	60,000	200,000	almost requires no replacement

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Rotor Property Comparisons

Material Property/ Characteristic	Cast Iron	Al MMC	Remark
Young's Modulus (GPa)	110	130	take higher clamping load
Elongation (%)	0.5	0.45	similar ductility/toughness
Coefficient of thermal expansion (10^-6)	12	12	same, stabile dimensions as temperature increases
Maximum Operating Temperature (ºC)	700	520-550	Lower MOT offset by higher heat dissipation
Brake Rotor Application	Yes	Yes	FRG handles temp loading in front brake applications
Machining Cost	Acceptable	Acceptable	MMCs require diamond tooling

Matrix Brakes vs. Conventional Brakes

From Property Tables

- 60% Lighter
- Quieter Braking
- Higher Resistance to Wear, Warp, and Corrosion

Overall

- Customizable Appearance
- Protected Technology
- Cost Effective MMC Brakes
- Passed DOT (Greening) and OEM Testing

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Recent Publications /Conferences

1. A. Loukus, J. Loukus, H. Zhang, J. Dreyer, S. Berg, Application of functional gradient Al-Metal Matrix composites as a brake rotor FEA, SAE Paper, submitted March, 2009.
2. A. Loukus, J. Loukus, The effect of heat treatment on the Structural properties of Al Metal matrix composites, submitted March, 2009, IJMC
3. Hongwen Zhang, Josh Loukus, Adam Loukus,, Improvement of the bonding interface in hybrid fiber/particle reinforced Al matrix composite, Material Letters 63 (2009) 310-312.
4. Hathaway, R; Loukus, A; Loukus, J; et. al "Manufacturing Process Influence on Microstructural Features of Selectively Reinforces Magnesium MMCs", *TMS Proceedings*, San Antonio, TX. 2006.
5. Loukus, J.E., Loukus, A., Halonen, A., The Effects of Processing Methods on the Mech Prop. of Cast Mg MMCs. AFS Int. Conf. on High Integrity Light Metal Castings. Oct. 31 – Nov. 1, 2005. Indianapolis, IN.
6. J.E. Loukus and G. Subhash, *Experimental Modeling of High Speed Grinding,* 2004
7. G. Subhash, J.E. Loukus, W. Zhang and A. Chandra, *Experimental and Numerical Modeling of Material Removal During High Speed Grinding process,* Proc. SEM IX International Congress on Exp. Mech., June 5-8, Orlando, Florida, pp. 127-130 (2000).
8. A.R. Loukus, G. Subhash, M. Imaninejad, Mechanical Properties and Microstructural Characterization of Extrusion Welds in AA6082-T4, *J. of Mat. Sci.*, 39 (2004) pp 6561-6569
9. A.R. Loukus, G. Subhash, M. Imaninejad, Optimization of Material Properties and Process Parameters for Tube Hydroforming of Aluminum Extrusions, *J. of Eng. Mat. Tech.* (2006)

Invited Speaker – Global Motorsports Congress, Cologne, Germany, October 2007, Advanced Materials

Invited Panel Speaker– TMS Conference San Antonio Texas, April 2006, Current and Future Trends in Micro and Nano MMCs

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