IEA Annexes on Materials for Transportation Applications

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PM9098 & PM9134

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IEA Annexes on Materials for Transportation Applications

The following is a combined and sequential overview of R&D on two IEA Annexes involving coating evaluation (PM9098) and rolling contact fatigue (PM9134)

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Motivation (Behind Both Annexes)

- **Considerable effort has been directed towards increasing fuel efficiency and lowering emissions in diesel engines because of rising fuel prices and their environmental impact (NOx and particulates).**
- **New materials technologies *(e.g, alloys, coatings, ceramics)* for fuel systems, exhaust after-treatment, valve train, air handling, structural and insulating materials are required to meet these objectives.**
- **However, the integration of new technologies into the diesel engine community first requires:**
  - **Research that validates the applicability of these technologies to improve performance (i.e., surface durability and functionality) while lowering or maintaining acceptable life-cycle costs.**
  - **Commercialization of new materials technologies that have undergone thorough interrogation, test standardization, and component design.**

PM 9098 (Coating Evaluation)

M. K. Ferber (ORNL)

IEA Annex on Materials for Transportation Applications

21CTP Technical Goal: Develop and demonstrate an emissions compliant engine system for Class 7-8 highway trucks that improves the engine system efficiency from ~42% today to 50% by 2010.

Project Objectives

Promote commercialization of new materials technologies by developing standard testing and characterization methods in conjunction with national and international standards communities.

FY 2005 Focus

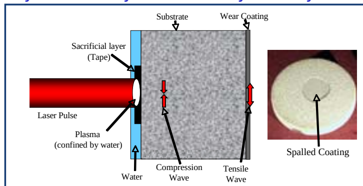
Completed preliminary investigation of characterization techniques for assessment of contact damage and quantitative adherence measurements for ceramic coatings for wear and thermal management.

Planned Duration

October 2001 to September 2006

DOE Funding/Industry Cost Share

FY04: $200K; FY05: $190K



Laser Shock Method Provides for Quantitative Assessment of Coating Adherence

Principal Investigator(s)

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Accomplishments

Demonstrated capability of laser shock method to initiate debonding and spallation in both metallic and ceramic coatings

Significant Future Milestones

Develop model to predict tensile stress magnitude generated in thin coatings due to the laser shock process-June 2006

Project ID/Agreement ID	Program Structure	Sub-Program Element	R&D Phase	Date
PM_9098	Materials Technology	HV Propulsion Materials	Applied Research	8-12-05

Objectives

- **Promote commercialization of new materials technologies by developing standard testing and characterization methods in conjunction with national and international standards communities.**
- **Project Currently Addresses Standardized *Adherence* Test Methods for Ceramic Coatings in Vehicular Engines**

Project motivated by recent assessment, "Standardized Test Methods for Ceramic Coatings in Vehicular and Stationary Power Engines- A Survey of Needs and Opportunities", Gateway Materials Technology

Approach

- Stresses are generated using commercial laser shock peening (LSP) equipment
- Application of laser pulse to rear face of coated specimen generated planer compressive stress wave
- On reflection of the free surface of the coating, the stress in this wave becomes tensile

Relevance to 21 CT Goals

21CTP Technology Goal: Develop and demonstrate an emissions compliant engine system for Class 7-8 highway trucks that improves the engine system efficiency from ~42% today to 50% by 2010.

- **Coatings for thermal protection can enable waste heat recovery**
  Advanced Materials for Thermal Control (*)

  Develop advanced materials to enable the control of inlet and exhaust gas temperatures, critical component temperatures, and energy loss to the engine coolant

- **Coatings for wear resistance improve durability & reduce friction**
  1. **Improve durability of underlying metallic component** ***Improved Materials for Fuel Systems: Scuff and Wear-Resistant Materials (*)***

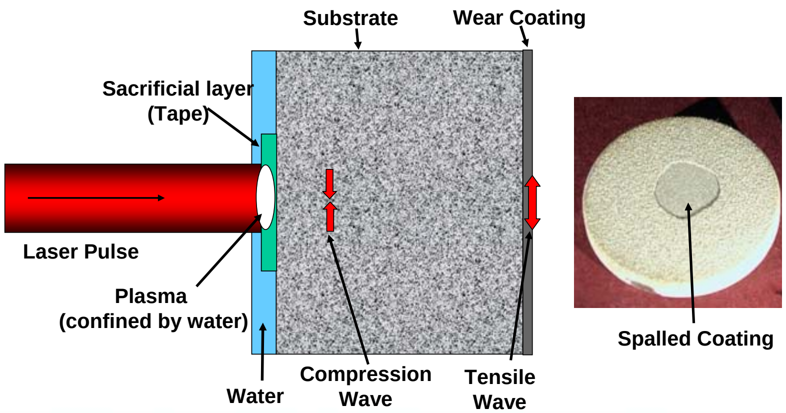
     Develop advanced wear and scuff-resistant materials for applications in heavy-duty diesel fuel injection systems

  2. **Minimize losses due to friction**
     Advanced Materials for Hot Section Components (*)

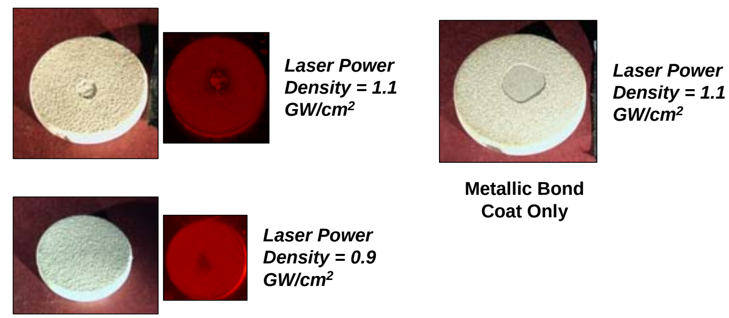
     Evaluate the tribological characteristics of hot-section components in order to reduce frictional losses

(*) Heavy Vehicle Propulsion Materials Multi-Year Program Plan, 2006-2012

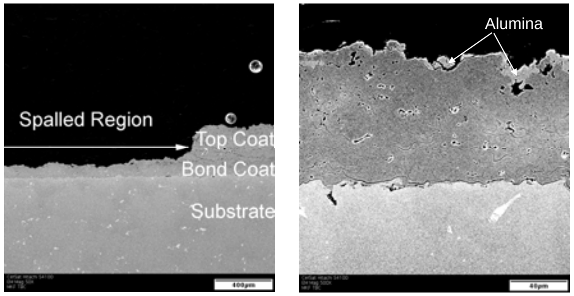
Laser Shock Principle



Technique was Capable of Generating Controlled Failures in Both Ceramic and Metallic Coatings



The Primary Crack at the Highest Power Density Formed at the Top Coat / Bond Coat Interface



Technology Transfer

- **The hardware required for these tests is already located at a commercial site (LSP Technologies, Columbus, OH)**
- **Vendor has expressed interest in applying this methodology in their commercial practice**

Future Work

- Sensitivity and reproducibility of the technique must be evaluated
  - Tests in progress - to be completed in June 2006
- A model for predicting stress magnitude must be developed
  - Current activities focus on adaptation of available computer codes for shock physics
  - Validation of model will be completed September 2006

PM 9134 (Rolling Contact Fatigue)

A. A. Wereszczak (ORNL)

IEA – Evaluate Rolling Contact Fatigue

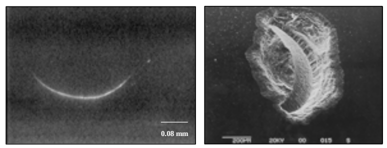
21CTP Technical Goal: Develop and demonstrate an emissions compliant engine system for Class 7-8 highway trucks that improves the engine system efficiency from ~42% today to 50% by 2010.

Project Objectives
- Enable greater use of next generation ceramic and coated-metal roller elements for diesel engines.
- Correlate RCF test methods that are used internationally.

FY 2005 Focus
- Evaluate the coupled effects of machining-induced sub-surface damage & ceramic microstructure on RCF.

Planned Duration
October 2003 to September 2006

DOE Funding/Industry Cost Share
FY04: $180K; FY05: $150K



Examples of surface c-cracking (left) and spallation (right) in Si_3N_4 ball bearings caused by rolling contact fatigue (RCF).

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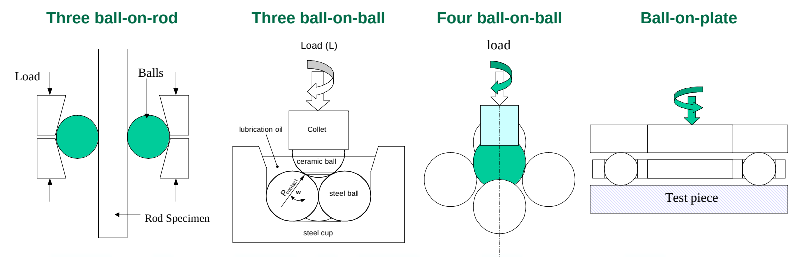
Accomplishments
- RCF test facility established at ORNL.
- Summary report completed on RCF test methods and result interpretations used in Germany, Japan, UK, & USA.
- Method developed to evaluate and discriminate the elastic properties of ball bearings in-situ using resonance ultrasound spectroscopy.

Significant Future Milestones
- Develop the C-sphere test coupon and the ability to exploit the characterization of sub-surface damage in finished ceramic balls and link that damage to RCF performance. [Sep2006]

Project ID/Agreement ID	Program Structure	Sub-Program Element	R&D Phase	Date
PM_9134	Materials Technology	HV Propulsion Materials	Applied Research	7-05

Objectives

- **Enable greater use of next generation (i.e., longer lasting, more durable, lower losses due to friction) ceramic and coated metal roller elements for diesel engines**
- **Correlate rolling contact fatigue (RCF) test methods used internationally**



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Approach

- Vary the machining of Si_3N_4 ceramic balls to study its ultimate effect on RCF performance
- Develop a test coupon that can readily exploit the evaluation of RCF-limiting flaws in ceramic balls
- Collaborate with international partners and correlate RCF test methods
- Work with domestic suppliers of Si_3N_4 ball compositions to ultimately improve RCF performance

Relevance to 21 CT Goals

21CTP Technology Goal: Develop and demonstrate an emissions compliant engine system for Class 7-8 highway trucks that improves the engine system efficiency from ~42% today to 50% by 2010.

The substituted use of ceramic roller elements in diesel engines enables

- Higher thermal efficiency
- Longer characteristic life
- Reduction in parasitic losses
- Reduced weight

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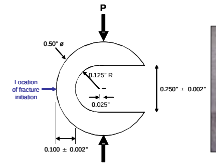
Accomplishments

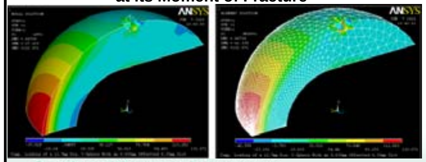
- **RCF test facility established at ORNL**
- **Testing plan and new test specimen conceived and testing initiated to study subsurface damage effects on RCF performance (satisfied FY05 milestone)**
- **Method developed to evaluate and discriminate the elastic properties of ball bearings in-situ using resonance ultrasound spectroscopy (RUS)**
- **Summary report completed on RCF test methods and result interpretations used in Germany, Japan, UK, and USA**

"C-Sphere" Specimen Developed to Study Surface Flaws and Their Ultimate Influence on RCF

C-Sphere Specimen is Made By Machining a Groove in a Sphere and then Diametrally Loaded to Failure



Stress State in a C-Sphere Specimen at its Moment of Fracture

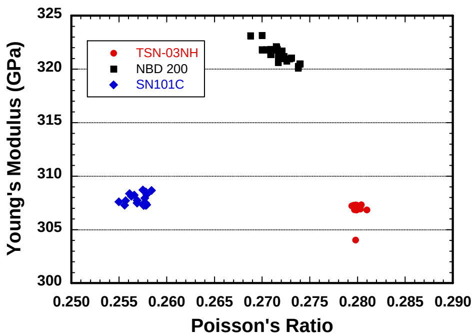


The Effects of Four Machining Conditions on RCF Performance are Being Explored

Diameter & Finish	Step	Wheel	Removal	Removal per pass
12.7 mm / 0.500" Coarse	1 (roughing) 2 (induce damage) 3 (finishing)	accepted practice 100 grit 600 grit	0.004" 0.0005"	0.001" 0.001" 0.0001"
13.2 mm / 0.520" Coarse	1 (roughing) 2 (induce damage) 3 (finishing)	accepted practice 100 grit 600 grit	0.004" 0.0005"	0.001" 0.001" 0.0001"
12.7 mm / 0.500" Fine	1 (roughing) 2 (induce damage) 3 (finishing)	accepted practice 180 grit 600 grit	0.004" 0.0005"	0.001" 0.001" 0.0001"
12.7 mm / 0.500" RCF-Conventional	"Accepted" practice for RCF test bar finishing			

RUS Was Used To Quantify and Discriminate Elastic Properties of Spheres

Variability in Properties for Three Si_3N_4 Ball Grades



RUS Setup for Ball Analysis

Technology Transfer

- **C-Sphere test specimen has potential to enable materials developers to readily and inexpensive assess RCF performance.**
- **RUS can both quantify elastic properties and discriminate variability in ceramic balls**
- **Domestic Si_3N_4 ball manufacturers (Saint-Gobain & Ceradyne) have expressed interest in both of the above. The RUS method has the potential to be easily automated.**

Future Work

- Continue to correlate RCF performance with identified flaw population & subsurface damage in Si_3N_4 balls
- Assess if RUS can non-destructively identify RCF-limiting flaws
- Participate in international RCF round robin study with Germany, Japan, and the UK
- Begin RCF interrogation of tribologically-coated metal specimens

Publications, Presentations, Patents

Publications

- W. Wang, Y. Wang, A. A. Wereszczak, M. Hadfield, and W. Kanematsu, "Rolling Contact Fatigue of Ceramics," in internal review, to be published as DOE/ORNL Technical Report, 2005.
- A. A. Wereszczak, W. Wang, and O. Jadaan, "Strength of a C-Sphere Specimen," to be published in *Engineering & Science Proceedings*, 2006.