Heavy Vehicle Propulsion Materials

Engineered Surfaces for Diesel Engine Components

Project (PM_9123)

Principle Investigator: M. Brad Beardsley

CATERPILLAR®

September 13-15, 2005

This presentation does not contain any proprietary or confidential information

Engineered Surfaces for Diesel Engine Components

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.**

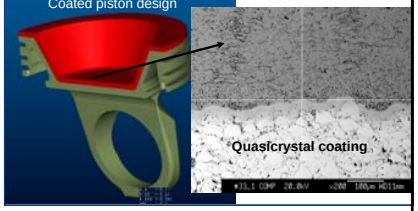
Project Objectives
Develop high density, low thermal conductivity metallic coatings based on amorphous steels and quasicrystal materials for use as thermal barrier coatings in HCCI engine designs.

FY 2005 Focus
Develop coating properties and spray parameters for coating of engine components

Planned Duration
October 2003 to September 2005

DOE Funding/Industry Cost Share
FY04: $40K/$40K; FY05: $75K/$75K

Coated piston design



Principal Investigator(s)
M. Brad Beardsley, Caterpillar Inc.
(309) 578-8514, (Beardsley_M_Brad@cat.com)

Technology Development Manager
Sid Diamond, DOE/OFCVT
(202) 586-8032; sid.diamond@ee.doe.gov

Accomplishments
1) Initial diffusion study of quasicrystal coatings shows capability to operate at expected engine temperatures.
2) Thermal conductivity of amorphous steel coating shown to be stable at expected engine temperatures.
3) Spray parameters to coat initial piston design for single cylinder engine test has been completed.

Significant Future Milestones
Demonstration of initial engine durability of amorphous steel coating to be completed by end of FY 2005

Project ID/Agreement ID	Program Structure	Sub-Program Element	R&D Phase	Date
PM_9123	Materials Technology	HV Propulsion Materials	Applied Research	8-12-05

Engineered Surfaces for Diesel Engine Components

Objectives

- **Develop high density, low thermal conductivity metallic coatings based on amorphous steels and quasicrystal materials for use as thermal barrier coatings in HCCI engine designs.**
  - **Develop high velocity oxygen-fuel (HVOF) processing method for coating deposition to minimize as-deposited coating porosity and eliminate need for sealing of porosity**
- **Develop coating properties and spray parameters for coating of engine components**
  - **Determine benefit of HVOF processing on coating durability as related to adherence and coating strength**
  - **Determine effect of long term exposure to engine operating temperature on coating properties**

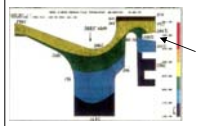
Engineered Surfaces for Diesel Engine Components

Relevance to 21CT Goals

- **High density (sealed) TBCs can reduce fuel consumption**

		Water Cooled Baseline	Unsealed TTBC	Sealed TTBC
Recip BMEP	KPa	1427	1411	1406
Air Flow	Kg/hr	274	288	249
Vol Efficiency	%	85.5	81.3	80.3
Air/Fuel Ratio		30.4	30.3	29.5
Peak Cyl Press.	MPa	16.0	16.0	16.0
Recip SFC	G/kW-hr	217.1	231.7 (+6.7%)	206.5 (-4.9%)
Recip SHR	KW/KW	0.479	0.499	0.399

- **Temperature reduction needed for HCCI engine components**



Piston ring groove
318°C w/o TBC
286°C with TBC
(example from prior TBC engine work, not HCCI component)

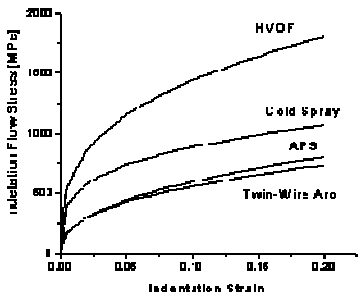
Technology Transfer

- **Powders commercially available from The NanoSteel Company (amorphous steel) and Saint-Gobain (quasicrystals)**
- **Piston manufacturing issues reviewed with Mahle and no major hurdles identified**
- **Caterpillar currently implementing two production HVOF applications for wear and chrome plate replacement**
  - **Similar investment for piston/head coatings feasible**

Engineered Surfaces for Diesel Engine Components

Approach

- New metallic base amorphous steels and quasicrystalline materials with low thermal conductivity allow for HVOF processing with lower porosity and higher durability than ceramic plasma sprayed TBCs
- Effects of long term high temperature exposure of the new TBC materials to be evaluated
- FEA analysis of coated components using measured coating properties to be verified by engine coating testing

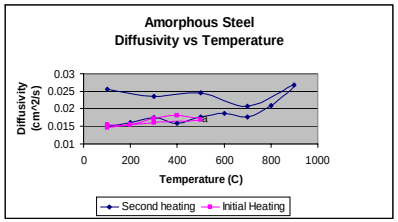


HVOF coating strength is typically 2X to 3X higher than plasma sprayed (APS) coatings which leads to significantly higher coating durability

Engineered Surfaces for Diesel Engine Components

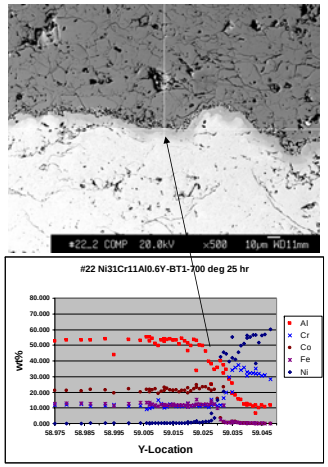
Technical Accomplishments/ Progress/Results

- Initial thermal diffusivity measurements for the amorphous steel coatings show detrimental effect of temperature exposures above the glass transition temperature of the material which is approximately 700°C
- FEA analysis indicates the surface temperature of HCCI engine piston with 3.5 mm thick amorphous steel coating will be less than 700°C



Exposure to temperatures above glass transition temperature (700°C) causes an increase in thermal diffusivity of amorphous steel

Technical Accomplishments/ Progress/Results



- **Diffusion couple studies of the quasicrystalline (QC) coatings show that the reactivity of the aluminum based QC coatings with metallic substrates or bond coatings is high at temperatures above 500°C. Stability of the QC material is good up to 1000°C.**
- **FEA analysis of indicates the coating/substrate temperature of HCCI engine piston with 3.5 mm thick amorphous steel coating will be less than 400°C, therefore the QC material.**

Engineered Surfaces for Diesel Engine Components

Future Work

- **Initial engine test of HVOF amorphous coating to be completed by end of 2005**
  - Non-optimized coating process to be used to gain initial understanding if HVOF coating process benefits will be realized
  - Optimized coating process to be used for second piston coating in FY2006
- **Develop optimized HVOF spray parameters to coat piston and head geometry for engine test in FY2006**
  - Higher temperature of HVOF process creates additional issues for piston coating
  - Piston geometry presents challenge to coat uniformly with highest quality coating
- **Complete characterization of the coating properties and effect of long term exposure to engine operating environments**
  - Mechanical property behavior of HVOF coatings
  - Determine effect of oxidation and high temperature exposure on mechanical properties