Ceramic Applications in the Automotive Industry

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Ceramics components in automotive applications

- fuel injectors
- high pressure pump
- electronic device
- filter, catalyst carrier

Functional Ceramics
- spark and glow plugs
- oxygen sensor
- knocking sensor
- parking distance control
- PTC heaters
- fuel injection systems
Ceramics components in automotive applications

- Fuel injectors
- High pressure pump
- Electronic device
- Filter, catalyst carrier
- PTC heater
- Structural Ceramics
  - Pump components (sealings), brake discs, catalyst support, particulate filter,
• Liquid fuels will still significantly contribute to up-coming energy demands
• Combustion engines are necessary in the next decades
• Individual transport: long range distance, trucks, hybrids

Quelle: World Energy Council WEC
European Fuel-Economy Goal up to 2025

Goal can only be obtained by more efficient combustion engines → Downsizing concept (smaller, but more efficient engines)

US Goal: 100 g/km

- 37,3 mpg
- 42 mpg
- 57,4 mpg
- 78,4 mpg

President Barack Obama's administration altered its proposal for a 2025 U.S. fuel-economy average to 54.5 miles per gallon to make allowances for light trucks, people familiar with the negotiations said.
Downsizing is based on the principle of a reduction in engine size in order to reduce consumption without affecting power.

**Measures:**
- Reduction of number of cylinders
- Supercharging (use compressed air)
- Direct injection systems

**Challenges and Needs:**
- Injection control system
- High pressure fuel pump
- High thermal and mechanical loading

Downsizing can reduce the CO₂ emissions between 5% for diesel models and 40% for gasoline models by 2020. These engines should be able to remain dominant for a long time in the car market.
Downsizing is already reality in the present US market.
• High pressure pump systems for gasoline engines
• Spark plugs
• Porous ceramics for local reinforcement of metal matrix composites
• Piezoelectric injection systems
• PTC heating elements
• General conclusions
Piezoelectric Driven Common Rail Fuel Injection Technology

Piezo technology increases efficiency and reduces emission → already used in Diesel systems, but with a high potential for gasoline systems

courtesy: Robert Bosch GmbH
High fuel injection pressure is needed to reduce droplet size (-40%), → decrease of fuel consumption and pollutant emissions (-80%).
Fuel evaporation in combustion chamber

30 MPa, 1.6 ms ASOI

50 MPa, 1.6 ms ASOI

30 MPa, 3.2 ms ASOI

50 MPa, 3.2 ms ASOI

source: Spicher, KIT-IFKM
3-Piston High Pressure Pump for Gasoline Engines

Cam/sliding-shoe contact is tribological highly loaded due to an insufficient lubrication of petrol with increasing pressure → ceramic components can be a solution
Silicon carbide and SiAlONs indicate a similar behaviour with a very low friction coefficients at a system pressure of 50 MPa
The texture significantly improves the performance of self-mated silicon carbide at low speed or low contact force.
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An ignitable mixture for low and high loads is only formed in a very narrow spatial zone

Source: KIT / IFKM, Spicher
Future trends for spark plugs in fuel-efficient engines

Microstructure with a glassy phase and pores

Challenges
- Distance between electrodes will increase
- Higher voltage will be applied
  → longer spark
- Pressure increase in combustion chamber
  → higher thermal and mechanical loading
- Reduction in size
Strength distribution and typical failure mechanisms of commercial spark plugs

Strength distribution reflects also the electric breakthrough behaviour → Most current commercial materials do not match the requirements

compaction defects
Future trends for spark plugs in fuel-efficient engines

Challenges:
• smaller diameter → higher thermal and mechanical loading
  → strength must be increased by enhanced processing conditions
• adjustable resistance
• high voltage → increase in electrical breakthrough
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Inhomogeneous cooling causes thermal stresses that can be minimized by a local reinforcement with ceramics (preform concept).
Local reinforcement of pressure die-casted Al-MMCs

![Diagram of the die-casting process with local reinforcement (ceramic preform)]
Preparation of Porous Ceramic Preforms

Pore filler concept
Porosity: up to 75%
Pore size and shape depend on filler

Freeze casting
Porosity: 20-85%
Ice crystals form final pores

Ceramic foams
Porosity: 85-95%
cell size depends on polymer foam

Different types of ceramic preforms can be manufactured by using powder technology processes.

Mattern et al., JECS (2004).
Preparation of freeze-casted Al-MMCs

Waschkies et al., JACS (2009)

Estimation of failure probability for different perform types

Freeze casted preforms can be used for pressure casting, while preforms with pore fillers and bottle neck pores will break.

Mattern et al., JECS (2004).
Outline

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Mechanisms of high field strain in ferroelectric ceramics

Strain behaviour

Piezoelectric effect (intrinsic)

Domain switchung (extrinsic)

→ High strain materials rely on both intrinsic and extrinsic effect
Typical strain of a donor-doped Pb(Zr,Ti)O₃ ceramic (PZT): 0.15 - 0.2 % at 20-30 kV/cm

→ Multilayer device
Piezoelectric Driven Common Rail Fuel Injection Technology

courtesy: Robert Bosch GmbH

→ typical driving voltage: 100 V, total strain 20-30 µm
Requirements for piezoelectric actuators for fuel injection systems

- cofiring with internal electrodes (multilayer device)
- high strain
- operating temperatures from -40 to 150 °C
- small temperature dependence of strain
- high reproducibility (mass production)
- “low cost“
- challenge: replacement of PZT by lead free ferroelectrics
Comparison of Pb(Zr,Ti)O₃ and a lead-free ceramic

Lead-free ceramics show a lower strain for a similar electric field strength and exhibit a much stronger temperature dependence of strain.
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The increasing efficiency of fuel saving cars requires a supplementary heat system based on functional ceramics showing a positive temperature coefficient resistance (PTCR) effect.
PTC effect in donor-doped BaTiO$_3$-based ceramics

- PTC-effect is based on the temperature depended potential barrier at the grain boundary → high electrical resistance above $T_C$
- The ferroelectric phase equals the charge of the potential barrier below $T_C$ → low electrical resistance
BaTiO$_3$-based PTC heating elements

Highly efficient cars do not produce enough „waste energy“ for heating

source: eberspächer catem, Germany
PTC effect in donor-doped BaTiO$_3$-based ceramics

Seat heater for convertibles

OEMs favour different local heating elements to reduce total energy consumption
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Requirements and Challenges for Materials Research

Complexity of requirement profiles for the system

- Reliability
- Quality
- Costs
- Weight...

Complexity in materials preparation

- Structural Properties
- Functional Properties
- Multifunctional Properties
- Composites
- Multimaterial Composites
- Powder Technology
- Thermomechanical Treatment
Requirements and Challenges for Product Development

→ Reduction of product development time due to shorter product life cycles

Support through modeling and simulation and better coordination

Reduction of product development time

Reduction of product life cycle
Modeling and simulation across the whole length scale

- Ab-initio calculations
  - MD- simulation
  - New materials

- Phase field or vertex dynamic simulation
  - Microstrutural design

- FE-methods for calculation of coupled loading conditions
  - Design optimization

courtesy: P.F. Becher
“This could be the discovery of the century. Depending, of course, on how far down it goes.”

source: Kienbaum, Bullinger