UNIVERSITY OF AUCKLAND
Waipapa Taumata Rau
NEW ZEALAND

Development of High-Performance Ceramic Composites for Hypersonic Vehicle Applications

Project description

This research project aims to develop and characterise advanced ceramic matrix composites (CMCs) capable of withstanding extreme thermal and mechanical stresses encountered in hypersonic flight environments. The study focuses on novel fabrication techniques and material formulations that enhance thermal shock resistance, oxidation tolerance, and structural integrity at temperatures exceeding 2000°C.

The research objectives are:

-To synthesise ultra-high-temperature ceramic composites using silicon carbide and zirconium diboride matrices.
-To evaluate the mechanical and thermal performance of these materials under simulated hypersonic conditions.
-To model the behaviour of these composites in aerospace applications, particularly for thermal protection systems.

Research methods include:

-Materials Synthesis: Spark plasma sintering and chemical vapour infiltration techniques will be used to fabricate the composites.
-Characterisation: Scanning electron microscopy (SEM), X-ray diffraction (XRD), and high-temperature mechanical testing will assess microstructure and performance.
-Simulation: Finite element modelling will simulate thermal gradients and stress distributions during hypersonic flight.

The outcomes of this research include the development of a new class of ceramic composites with superior performance metrics for aerospace defence applications and a validated materials database for use in future hypersonic vehicle design. We expect this research to uncover potential commercial and defence sector collaborations for technology transfer. This research involves dual-use technology with potential military applications, particularly in missile and defence systems. As such, it falls under the New Zealand Strategic Goods List and is subject to Export Controls under MFAT regulations. Any international collaboration, data sharing or physical export of materials will require an export permit.

- Project information

Information about the project, people's roles and responsibilities, and the funding source(s).

Project Identifier

3941234

Keywords

Ceramic Matrix Composites (CMCs)
Hypersonic Vehicles
Defense Applications
Thermal shock resistance
Oxidation tolerance
Materials characterisation
dmp-exemplar

Start date

02/01/2025

End date

01/31/2028

People

Principal Investigator

Title	Name	Email	ORCID
Dr	Sarah Hopkins	s.hopkins@auckland.ac.nz	0000-0002-4705-5362

Project team

Title	Name	Email	Role
Professor	Anna-Lena Richter	anna-lena.richter@ikts.fraunhofer.de	Advisor
	Ben Turley	ben.turley@auckland.ac.nz	Data Manager
	Yvette Wharton	y.wharton@auckland.ac.nz	Research Fellow

Project roles and responsibilities

1. Sarah Hopkins is responsible for oversight and sign-off of all research data management for this project; data collection and analyses.
2. Ben Turley is responsible for implementation of research data management for this project, including storage, access controls and reporting.
3. Yvette Wharton is responsible for data collection and analyses,

Due diligence

Title
Professor

Name
Anna-Lena Richter

Country Collaborator is Based In
Germany

Affiliated Organisation
Fraunhofer Institute for Ceramic Technologies and Systems
(IKTS)

Country of Affiliated Organisation
Germany

Funding

Funding source(s)/scheme
NZ Defence Funding contract

Grant/Contract/Award number(s)
xxx-prop-1234

Financial risk
Professor Richter is not supported financially by the initial research grant, but there are potential financial gains based on any commercialisation of the end product.

Activity type
Strategic basic research

FoR codes
- 401602 - Composite and hybrid materials

SEO codes
- 140199 - Defence not elsewhere classified

Authors
Sarah Hopkins

- Requirements and Considerations

Information about regulatory and contractual obligations, as well as considerations around the ethical and sensitive nature of the research data.

Requirements

Research data security classification

Sensitive
Restricted

Research security assessments

Due diligence and Financial risk
Export Controls
Research Security

Related data policies

The following University of Auckland policies apply to this research project:
- University of Auckland Research Data Management Policy (https://www.auckland.ac.nz/en/about-us/about-the-university/policy-hub/research-innovation/research-data-management/research-data-management-policy.html)
- Research Integrity Policy
- Privacy Policy (and the Privacy Act 2020)
- Intellectual Property Created by Staff and Students Policy

All digital data is subject to the following University of Auckland IT policies and standards:

- Generative AI Usage Standard
- IT Security Policy
- IT Acceptable Use Policy

Considerations

Considerations that apply to this project

Intellectual property (e.g. commercialisation, patent)
Protective security (e.g., International collaboration/export controls)

Data considerations

- All data management procedures are subject to the University of Auckland Research Data Management Policy
- The research data may be subject to a future patent application or other commercialisation opportunities
- The research project is required to maintain post-award research security assessments, documented within this data management plan

Ethics

Ethics approval number

N/A

Ethics type

Ethical considerations and management of data

Export controls

Export controls exemption

New Zealand Strategic Goods List (NZSGL)

Part 2 - Category 2 - Materials Processing
Part 2 - Category 9 - Aerospace and Propulsion
Very Sensitive List of Dual-Use Goods and Technologies

Export permit

An Individual Permit will be obtained prior to any overseas data sharing during the course of this project.

Rights holders

Engagement and consultation

Vision Mātauranga

Data sovereignty

Contracts and copyright

Licenses/Agreements/Contracts

Copyright and intellectual property (IP) owners

Joint ownership

Copyright and IP considerations

Copyright and IP ownership rights are shared and stipulated in the funding contract.

- Data

Information about the organisation of the research data across the project life-cycle.

Creation and collection

Data creation/collection

1. Materials Synthesis Data. Process parameters, including temperature, pressure, time, atmosphere (CSV, excel, lab notebooks). ~50-100MB per batch series

2. Microstructural Characterisation Data

- SEM images (TIFF, JPEG) ~500 MB - 2 GB per sample set
- XRD spectra (CSV, TXT) ~500 MB - 1 GB per sample set
- EDS maps (PDF) ~10 - 50 MB

3. Mechanical and Thermal Testing Data. Stress-strain curves, thermal conductivity, oxidation resistance (CSV, excel, MATLAB files) ~100 - 500 MB per test series

4. Simulation and Modeling Data. Finite element models, thermal simulations.

- Input/output files (.inp, .dat., .csv) ~1-5 GB
- Visualisations (PNG, mp4) ~100-500 MB

5. Experimental Logs and Metadata. Lab notes, calibration records, environmental conditions (PDF, docx, txt) ~50-200 MB

6. Regulatory and Compliance Documentation (PDF, docx) ~10-50 MB

Non-digital data/physical artefacts

1. Physical Material Samples used for mechanical, thermal and microstructural testing. Fabricated ceramic matrix composites (CMCs) in various formulations and geometrics. Examples: test coupons, tiles, or rods made from SiC-ZrB2
2. Lab notebooks - primary source documentation for reproducibility and compliance. Includes handwritten or printed records of experimental procedures, observations and results.
3. Test debris and fracture specimens for post-mortem analyses and archiving of failure modes. Broken or deformed samples from mechanical or thermal testing. Examples: fractured tensile bars, oxidised surfaces, delaminated layers.
4. Packaging and Shipping Records for compliance with export control and logistics tracking. Includes labels, customs declarations and physical documentation.
5. Prototypes for the demonstration of application potential. Assessmbled components or mock-ups using the developed materials. Examples: Thermal protection tiles or scaled models for wind tunnel testing.

Data source(s)

Primary

Data source considerations

N/A

Metadata and documentation

All research data will be described using a metadata schema based on the Materials Science Metadata Schema (MSMS), which includes fields for material composition, synthesis method, characterization technique, experimental conditions, and data access restrictions.

A structured metadata template (CSV format) has been developed and will be completed for each dataset and artefact. This template ensures consistent documentation and supports future data reuse and repository submission. The metadata template will be stored alongside datasets and regularly reviewed by the lead researcher.

Discipline-related metadata standard(s) or schema(s)
Metadata for this project will use the Materials Science Metadata Schema (MSMS) that was developed by the International Materials Resource Registries (IMRR) working group of the Research Data Alliance (RDA).

Storage

Size/amount of data
2-4TB

Data storage location(s)
Research Drive (University-approved)
Other

If other, please provide further details:
When available, this project will require a Secure Research Environment (SRE)

Software and Equipment

Software and Equipment used to collect/create the data
1. Equipment for Materials Synthesis
- Spark Plasma Sintering (SPS) system - rapid densification of ceramic powders
- Chemical Vapor Infiltration (CVI) Chamber - composite matrix formation.
- High-Temperature Furnaces - sintering and oxidation testing (up to 2000°C).
- Powder Handling Tools - glove boxes, mixers, and sieves.

2. Equipment for Materials Characterisation
- Scanning Electron Microscope (SEM) - microstructural imaging.
- X-ray Diffraction (XRD) System - phase identification.
- Energy Dispersive X-ray Spectroscopy (EDS) - elemental analysis.
- Thermal Conductivity Analyzer - heat transfer measurements.
- Mechanical Testing Machines - tensile, compression, and flexural testing rigs.

3. Software for Data Acquisition & Analysis
- LabVIEW or National Instruments Software - instrument control and data logging.
- MS Excel for data entry.

Software and equipment used to manipulate/analyse the data
1. Software for Data Analysis
- OriginLab or MATLAB - plotting, curve fitting, and statistical analysis.
- Excel - basic analysis.

2. Software for Simulation & Modeling
- ANSYS or COMSOL Multiphysics - finite element modeling (FEM) of thermal and mechanical behavior.
- Abaqus - advanced structural simulations.
- Thermo-Calc - thermodynamic modeling of ceramic systems

3. Software for Image & Spectra Processing
- ImageJ for SEM image analysis
- Bruker or PANalytical Software for XRD data processing
- Adobe Illustrator for preparing figures and diagrams.

- Research Security Assessment

Assessment of Digital Data Management

This section is concerned primarily with digital and physical security – specifically the loss of, or unauthorised access to digital information, including Intellectual Property (IP), research data, personal information, and sensitive/dual-use data.

Breach of Personally Identifiable Information (PII)

Potential for risk

Not applicable

Inherent Risk Rating (before controls)

Suggested or implemented controls

Residual Risk Rating (after controls)

Data access or disclosure to participants or uninvolved internal parties

Potential for risk

-Research data and technologies are highly sensitive.
-Accidental disclosure of research data to other members of the organisation could lead to loss of IP.
-Loss of research data and/or materials would likely result in abandonment of the research and loss of government contracts.

Inherent Risk Rating (before controls)

High

Suggested or implemented controls

-Secure research storage location on Research Drive would likely prevent accidental or deliberate information loss or unauthorised use (Medium level residual risk)
-Future use of secure research environment (or other separate secure storage location with additional access controls) would result in implementation of best practice controls (low residual risk).

Residual Risk Rating (after controls)

Medium

Data access or disclosure to external parties

Potential for risk

-Accidental disclosure could lead to loss of IP, potential government investigations/fines, loss of government contracts, and breach of international sanctions.

-Potential for end outcomes of research to be weaponized if in the wrong hands.

Inherent Risk Rating (before controls)

High

Suggested or implemented controls

-Onsite access only
-Collaborator will be vetted and a data sharing agreement in place
-Likely that security requirements imposed by collaborators host organisation (and requirements as a German national) are more stringent that NZ requirements.

Residual Risk Rating (after controls)

Low

Data modification or manipulation

Potential for risk

-Loss of viability of the research
-Risk to future IP and commercial and defense applications
-Risk to safety of any future application or use of new material

Inherent Risk Rating (before controls)

High

Suggested or implemented controls

-Access to trusted partners and vetted researchers only
-Highly sensitive data only accessible by onsite, security-vetted project team

Residual Risk Rating (after controls)

Medium

Data deletion

Potential for risk

-Loss of viability of the research
-Risk to future IP and commercial and defense applications

Inherent Risk Rating (before controls)

High

Suggested or implemented controls

-Access to trusted partners and vetted researchers only
-Highly sensitive data only accessible by onsite, security-vetted project team

Residual Risk Rating (after controls)

Medium

Assessment of Physical Access Management

This section is concerned with unauthorised access by research collaborators or other third parties to physical spaces in which sensitive/restricted information and technologies are kept, physical record containment and disposal, and appropriate access to sensitive/restricted technologies.

Inherent Risk Assessment

Yes (Inherent Risk: Extreme)

What controls are in place to ensure the operating environment is secure?

-The lab is locked down with swipe card access to known and approved individuals
-Access only to researchers working on the project (security-vetted)
-Lab space and materials are not visible to the outside
-Logs of entry are obtainable from security personnel

What controls are in place to ensure physical records are kept secure?

-Physical materials and research data are locked down in a safe in a locked lab
-All materials are clearly labelled to ensure they are not mistaken or misplaced

What controls are in place to ensure sensitive technologies cannotbe accessed or operated by individuals without authorization?

-Access controls to lab
-Personnel vetting
-All research staff and project team members need to complete safety training

Residual Risk Rating (after controls)

Medium (Within appetite, no further action needed)

- Sharing and access

Information about management of and access to the data, now and in the future.

The primary Data Owner is:
Sarah Hopkins

The primary Data Custodian is:
Ben Turley

During the project

Data access and sharing during the project
Only security-vetted project team members will have access to the digital data and physical materials for this project.

After the project

Data access and sharing after the project
Only security-vetted project team members will have access to the digital data and physical materials for this project.

Applicable minimum retention period
[20 years] Registered patents, retention period from the date of filing

Data retention and deletion
Data will be securely retained and deleted as per contract requirement

- Publish and report

Plans to publish research data arising from this project, including considerations related to Open Access and licensing.

Data accessibility N/A

Data publication(s) N/A

Creative Commons and other licencing