# Purdue University
# School of Materials Engineering

## MSE 597-HS: Ceramics for Hypersonic Applications

**LECTURE**: TTH 1:30 – 2:45, via Zoom (lectures recorded and will be posted on Brightspace)
Location: https://purdue-edu.zoom.us/j/3310261656
We may or may not observe the Purdue Reading Days.
*It is expected that you will have your camera on during lecture*

**LECTURER**: Prof. Rod Trice, ARMS 2227, rtrice@purdue.edu

Trice Office Hours: After class on Tuesday 3-4

**PREREQUISITES:** The course will be offered to junior and senior level engineering or science undergraduates, graduate students, and/or by instructor's permission.

**APPROACH:** Prof. Trice will develop and deliver a 15-week course from the open literature and other sources with a focus on ceramics for hypersonic flight. The course objective will be to learn about the history of hypersonic flight and design, the operating conditions during flight, and aspects of ceramic applications to include structure, coatings, and windows. We will develop the fundamentals, and then apply those to the hypersonic application.

**TEXTBOOK:** There is currently no comprehensive book on this topic; thus, this course will be developed from literature and individual book chapters.

**LECTURE**: Course will be taught using Zoom on T/Th at 1:30-2:45. Lecture will also be recorded and posted on Brightspace. On most days, Powerpoint notes will be developed and delivered to students prior to lecture. These notes will be sketches of the content and the student must still virtually attend the course.

**WEBSITE**: Homework problems and solutions, and links to other resources such as your lecture videos and the course notes, will be available on Brightspace. Your grades will also be posted there as well. We will use Gradescope to submit assignments.

**Examination Dates and Further Instructions**

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|---|---|
| Exam 1: | February 25 |
| Exam 2: | April 1 |
| Final Exam: | |

All examinations are closed-book but you may use up to 1 sheet of HANDWRITTEN notes (8.5" x 11", two sides). Besides this crib sheet, the only other things allowed for the exams are writing implements, eraser, straight edge (ruler), and a calculator. *You cannot use your phone as a calculator but please bring your phone to the exams to upload your exam to gradescope. I reserve the right to give either open note or take home exams.*

**All** students will upload their exams to Gradescope just after the exam. See further instructions below. Exams will be conducted during class using Zoom.

## Grading

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|---|---|
| Exam I | 30% |
| Exam II | 30% |
| Final Exam | 30% |
| Homework/Paper | 10% |

Every semester I receive multiple emails asking if there is a way to obtain extra credit in the class. There is not. Your course grade will come from these the three exams and homework/paper.

**Make-up exams** will be given only for the following verifiable reasons: serious illness, family emergencies, direct conflict with another scheduled exam (must inform instructor no later than two weeks prior), or official university absence.

**Grading appeals** will be considered up to 5 days after an exam is returned to you. Exam regrade requests will be handled through Gradescope (see below); provide a brief, logical explanation of the basis in your appeal. I do make mistakes grading and am happy to take a look, but please no whining; just present your case.

### Campus Emergency Policy

In the event of a major campus emergency, course requirements, deadlines and grading percentages are subject to changes that may be necessitated by a revised semester calendar or other circumstances. Any such changes will be posted to the course website.

**In case of emergency**, e-mail Prof. Trice at rtrice@purdue.edu as soon as possible.

### Academic Dishonesty

Purdue University Regulations, Part 5, Section III-B-2-a describes the formal policies governing academic dishonesty. A guide providing specific examples, tips, and consequences is available from the Office of the Dean of Students at http://www.purdue.edu/ODOS/osrr/integrity.htm.

### Gradescope Overview and Practice Quiz

**All students** will be uploading their exams on gradescope.com to facilitate my efficiency at getting you feedback on your performance. Thus, you will not be submitting any "paper" copies to Prof. Trice/TA this semester. Your registration information for the class has been linked from Brightspace to gradescope.com. More details to follow.

### CLASS OUTLINE:

*Week 1/History of hypersonic flight and design*: It will be important to discuss the history of hypersonic flight, beginning with RTV-G-4 Bumper missile, which flew at 5,150 mph, but charred upon re-entry. Prof. Trice will discuss various programs, such as NASA's X43A, the development of propulsion systems to include scramjets, etc., to provide a complete picture of efforts to achieve

hypersonic flight. These lectures will be presented in a historically sequential order so that students can understand how the technology has developed over the last ~70 yrs.

*Week 2/Hypersonic aerothermodynamics:* This part of the course will consider the environmental conditions on the leading edges and other structure of the aircraft, focusing on the heat flow into and out of critical components. Establishing the local temperature, composition of the gaseous environment, and pressure from a thermodynamics viewpoint will help the students understand the materials requirements and be strong motivation to focus on ceramics and other high temperature materials as solutions.

*Week 3-4/Ultrahigh temperature ceramics and sintering*: Many of the proposed solutions for the extreme operating conditions focus on the development of ceramic materials. One class of these materials, identified as Ultrahigh Temperature Ceramics or UHTCs, will be covered extensively in this class. These materials include $ZrB_2$, $HfB_2$, and HfC. Prof. Trice has worked extensively with these materials in past and is familiar with the literature describing how to sinter these materials into useful shapes.

*Week 5-6/Thermal properties of ceramics*: Thermal properties of ceramics are important as they determine heat conduction into the hot regions of the aircraft. Understanding thermal conductivity and how it is influenced by alloying/impurities and microstructural defects (such as porosity) is key. Starting with the fundamental origins of specific heat will be important.

*Week 7-8 Composites including carbon/carbon and ceramic matrix composites*: This part of the course will focus on the properties, processing, and mechanical properties of composites, focusing on carbon/carbon and ceramic matrix composites. Of interest will be to discuss the densification techniques use for the matrix materials, and the influence on properties. SiC/SiC composites will also be discussed, focusing on crack deflection and high temperature strength.

*Week 9-10/Manufacturing of ceramics and ceramic composites*. It is important to connect the materials being considered for hypersonic structure to their manufacture. Of interest here will be discussion of new additive manufacturing methods to make aircraft part, along with more established methods such as “hand” layup ply-by-ply of composite structure.

*Week 11-12/High temperature coatings*: Most solutions to the high temperature requirements for hypersonic flight will require a thermal protection system; this part of the course will focus on high temperature coatings. Prof. Trice will draw upon his 20+ years’ experience in the thermal-spray field to discuss methods for applying coatings and how properties can be engineered for specific applications.

*Week 13-14/Materials for RF and IR performance*: Development of the key materials properties for RF and IR windows will be discussed. Prof. Trice will develop lectures to help the students understand the current state of the art, along with the requirements for windows used in hypersonic applications.

*Week 15/High Impact Opportunities for Hypersonic Materials*: Prof. Trice will finish the class with lectures that discuss critical research areas in materials for hypersonic flight.