CEE598: Additive Manufacturing of Structural Materials

1. Contact Information
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2. Office Hours: MW 1-2:30 PM. Students may schedule an appointment outside of the office hours via e-mail. Students may also attend the office hours over Zoom. The link is provided at the end of this document

3. Course Description: This course covers additive manufacturing (AM) techniques for structural materials. This course will provide an overview of the existing AM techniques, materials choice/optimization, manufacturing parameters, properties of the printed parts, post-processing techniques, quality control, and existing and emerging code-based provisions. While additive manufacturing using structural steel and concrete will be emphasized, limited topics in other material systems will be discussed. Lecture. 3 credit hours. 3 contact hours.

4. Enrollment Requirements: CEE graduate students. The course will be made available to aerospace, mechanical, and materials engineering graduate students with instructor approval.

5. Course Objectives

i. Understand the principles and methods of additive manufacturing for structural materials.
ii. Analyze and select appropriate materials for various additive manufacturing processes.
iii. Evaluate the mechanical properties and performance of AM-produced structural components.
iv. Address challenges related to the microstructure, strength, and durability of AM components.

6. Expected Learning Outcomes

Upon completion of this course, students are expected to:

i. Have a strong background in Additive Manufacturing techniques, materials choice, and structural engineering applications.
ii. Understand the impact of AM parameters on strength, fracture/ fatigue and durability of the printed parts.
iii. Employ appropriate post-printing treatments to achieve desirable mechanical properties.
iv. Understand the current codes, quality control techniques, and economic viability of AM for structural engineering applications.

7. Grading policies

Three assessment instruments will be used, as shown in the table below.

3 Term Projects	Pre-approved three term projects (TP). Each student will choose a structural material. For TP-1, all the available AM methods along with the printing and manufacturing parameters will be discussed. TP-2 will focus on the mechanical	25%+25%+25%=75%

	performance and durability of the printed products. TP-3 will discuss the quality control, code provisions, fracture/fatigue, and cost effectiveness issues.	
Bi-weekly assignments	Five reading/problem solving assignments	5×4%=20%
Class Participation	It is expected that students will participate in-class and out-of-class discussions and complete class quizzes	5%

Grading Scale: >= 97.5% A+, 90-97.5% A, 87-90% A-, 83-87% B+, 80-83% B, 77-80% B-, 74-77% C+, 70-74% C, 60-70% D, < 60% E

Note: All the term projects and assignments should be submitted to get a passing grade.

8. Absence and Make-up Policies
Absences: Excused absences related to religious observances/practices that are in accord with ACD 304–04, "Accommodation for Religious Practices". Excused absences related to university-sanctioned events/activities that are in accord with ACD 304–02, "Missed Classes Due to University-Sanctioned Activities". Excused absences related to missed class due to military line-of-duty activities that are in accord with ACD 304–11, "Missed Class Due to Military Line-of-Duty Activities," and SSM 201–18, "Accommodating Active-Duty Military".

Assignments and Projects: Late assignments will incur a 20% per day penalty. The assignments submitted 5 or more days late will automatically receive zero points but should be submitted to get a passing grade. Late project submissions will not be accepted.

9. Faculty Recording of Class Sessions
There will not be a recording of class sessions since this is an in-person class. However, recorded lectures could be posted when the instructor is on travel and cannot teach in-person classes.

10. Lists of any required readings, assignments, examinations, special materials and extracurricular activities: There is no required textbook for the class. The lecture notes will cover the important course topics – theory, concepts, algorithm, and examples. However, it should be noted that the following references will be referred.

Reference Textbooks:

a) Toyserkani, E., Sarker, D., Ibhadode, O. O., Liravi, F., Russo, P., & Taherkhani, K. (2021). Metal additive manufacturing.
b) Joshi, S., Martukanitz, R. P., Nassar, A. R., & Michaleris, P. (2023). *Additive Manufacturing with Metals: Design, Processes, Materials, Quality Assurance, and Applications*. Springer.
c) Abdel-Aal, H. A. (2022). *Additive manufacturing of metals: fundamentals and testing of 3D and 4D printing*. McGraw-Hill Education.

Assignments
There will be approximately 5 assignments. All assignments should be submitted to get a passing grade. It is expected that, on average, students will be spending 5-6 hours reading and reviewing the lecture material and 5-6 hours on the assignments.

Examinations
There will be no examinations on this course.

Course Contents

Applied Metallurgy: 1.1 Phase diagrams and potential diagrams. 1.2 grain size measurement. 1.3 microstructure mechanical properties. .1.4 high-temperature processes and properties of structural steels.

AM Processes for metals: 2.1 Directed energy deposition. 2.2 powder bed fusion. 2.3 Binder jet. 2.4 Ultrasonic vibration assisted process. 2.5 friction stir AM. and 2.6 hybrid AM.

Feedstocks for AM of Metals: 3.1 Powder feedstock. 3.2 powder production techniques: a) gas atomization, b) water atomization, c) centrifugal atomization, and d) plasma rotating electrode process. 3.3 powder characteristics and their effect on structural components. 3.4 powder recycling. 3.5 wire and sheet feedstock. 3.6 wire and sheet feedstock production. 3.7 effects of wire and sheet characteristics on part quality.

Heat Transfer in Metal AM: 4.1 heat sources. 4.2 heat absorption by feedstock: a) powders and b) wire and sheet. 4.3 heat conduction. 4.4 convective heat. 4.5 flow of liquid metal. Peclet number. 4.6 convective and radiative heat losses.

Microstructure and its control: 5.1 Nucleation, undercooling, solidification and grain growth. 5.2 morphology, spatial inhomogeneity and texture. 5.3 process parameters. 5.4 microstructural features of AM metals, and process dependent microstructure. 5.5 columnar to equiaxed transition. 5.6 texture. 5.7 post-heat treatments. 5.8 microstructure characterization techniques.

Mechanical properties of AM parts: 6.1 strength, ductility, toughness, anisotropy. 6.2 hardness. 6.3 fracture and fatigue. 6.4 creep. 6.5 corrosion resistance. 6.6 effect of heat treatment on mechanical properties.

Common defects and their characterization for Metal AM parts: 7.1 solidification cracking, liquation, and tip cracking. 7.2 voids and pores: gas porosity, keyhole collapse, and lack of fusion. 7.3 surface defects: roughness, balling and surface waviness. 7.4 defect characterization methods: Archimedes' principle, infrared imaging, X-ray tomography, advanced microscopy. 7.5 surface treatments and hot isostatic pressing.

Residual stresses and distortion: 8.1 Origin of residual stresses and distortion, plasticity and material flow, temporal evolution of residual stresses. 8.2 residual stress characterization: hole drilling and curvature methods, diffraction techniques, magnetic and ultrasonic techniques, indentation testing. 8.3 distortion measurement via numerical simulations. 8.4 dependence on AM methods and process parameters. 8.5 buckling, warping and dimensional accuracy. 8.6 controlling residual stresses and distortion.

Safety, sustainability and economic issues of metal AM: 9.1 safety, and health hazards. 9.2 energy consumption, and carbon footprint. 9.3 cost calculations and comparisons. 9.4 sustainable AM methods for metals.

Course Itinerary

Week	Topic	Chapter/topic
1	Applied Metallurgy	1.1, 1.2 and 1.3
2	Applied metallurgy/AM processes	1.4; 2.1, 2.2, 2.3, 2.4, 2.5, and 2.6
3	Metal AM Feedstocks – powder	3.1, 3.2, 3.3 and 3.4
4	Metal AM Feedstocks – wire and sheet	3.5 and 3.6
5	Heat transfer in metal AM	4.1, 4.2 and 4.3
6	Heat transfer in metal AM (contd.)	4.4, 4.5 and 4.6
7	Microstructure and its control	5.1, 5.2 and 5.3
8	Microstructure and its control (Contd.)	5.4, 5.5, and 5.6
9	Microstructure and its control (Contd.)	5.7 and 5.8
10	Mechanical properties of AM parts	6.1, and 6.2
11	Mechanical properties of AM parts (Contd.)	6.3, 6.4, 6.5 and 6.6
12	Common defects and characterization	7.1, 7.2, 7.3, 7.4, and 7.5

13	Residual stresses and distortions	8.1, 8.2, and 8.3
14	Residual stresses and distortions (Contd.)	8.4, 8.5 and 8.6
15	Safety, sustainability and economy and course wrap up	9.1, 9.2, 9.3, and 9.4

11. Policy Regarding Expected Classroom Behavior

Students in this class are expected to acknowledge and embrace the FSE student professionalism expectation located at: https://engineering.asu.edu/professionalism/

(1) Do not show up late for class. You should be seated a few minutes before the start of class. If you are unavoidably late, quietly move to the back row and sit without disturbing the classroom proceedings.

(2) Do not sit in groups and talk during the lecture or while recitation material is being discussed. There is a time and place for group activities.

(3) Ask questions to improve your understanding of the course material.

(4) Course content, including lectures, are copyrighted materials and students may not share outside the class, upload to online websites not approved by the instructor, sell, or distribute course content or notes taken during the conduct of the course (see ACD 304–06, "Commercial Note Taking Services" and ABOR Policy 5-308 F.14 for more information). You may not use recording devices in the classroom without prior permission.

(5) Students, faculty, staff, and other individuals do not have an unqualified right of access to university grounds, property, or services. Interfering with the peaceful conduct of university-related business or activities or remaining on campus grounds after a request to leave may be considered a crime. All incidents and allegations of violent or threatening conduct by an ASU student (whether on- or off-campus) must be reported to the ASU Police Department (ASU PD) and the Office of the Dean of Students.

(6) The usage of any electronic device in the classroom for purposes unrelated to the ongoing classroom activities is strongly discouraged.

12. Generative AI

Note: Use of Generative AI Permitted Under Some Circumstances or With Explicit Permission

Some assignments in this course may include or allow use of Artificial Intelligence (AI), including ChatGPT or related tools for the creation of text, images, computer code, audio, or other media. The instructor will inform you when, where and how you may use these tools, and provide guidance for attribution. Use of generative AI tools in any other context in this course will be considered a violation of the ASU Academic Integrity Policy, and students may be sanctioned for confirmed, non-allowable use. If at any point you have questions about what is permitted, contact the instructor to discuss *before* submitting work.

13. Academic Integrity

All engineering students are expected to adhere to the ASU Student Honor Code and the ASU academic integrity policy, which can be found at https://provost.asu.edu/academic-integrity/policy). Students are responsible for reviewing this policy and understanding each of the areas in which academic dishonesty can occur. If you have taken this course before, you may not reuse or submit any part of your previous assignments without the express written permission from the instructor.

All student academic integrity violations are reported to the Fulton Schools of Engineering Academic Integrity Office (AIO). Withdrawing from this course will not absolve you of responsibility for an academic integrity violation and any sanctions that are applied. The AIO maintains a record of all violations and has access to academic integrity violations committed in all other ASU college/schools.

14. Student Copyright Responsibilities

You must refrain from uploading to any course shell, discussion board, or website used by the course instructor or other course forum, material that is not the student's original work, unless the student first complies with all applicable copyright laws; faculty members reserve the right to delete materials on the grounds of suspected copyright infringement.

The contents of this course, including lectures and other instructional materials, are copyrighted materials. Students may not share outside the class, including uploading, selling or distributing course content or notes taken during the conduct of the course. Any recording of class sessions by students is prohibited, except as part of an accommodation approved by the Disability Resource Center. (see ACD 304–06, "Commercial Note Taking Services" and ABOR Policy 5-308 F.14 for more information).

15. Policy against threatening behavior, per the Student Services Manual, SSM 104–02

Students, faculty, staff, and other individuals do not have an unqualified right of access to university grounds, property, or services (see SSM 104-02). Interfering with the peaceful conduct of university-related business or activities or remaining on campus grounds after a request to leave may be considered a crime. All incidents and allegations of violent or threatening conduct by an ASU student (whether on- or off-campus) must be reported to the ASU Police Department (ASU PD) and the Office of the Dean of Students.

16. Warning of Offensive Class Materials
Efforts will be made to present the course contents in an objective manner. The students can communicate directly with the instructor if they have any objections.

17. Disability Accommodations
Suitable accommodations are made for students having disabilities. Students needing accommodations must register with the ASU Disabilities Resource Center and provide documentation of that registration to the instructor. Students should communicate the need for an accommodation in enough time for it to be properly arranged. See ACD 304- 08 Classroom and Testing Accommodations for Students with Disabilities.

18. Harassment and Sexual Discrimination
Arizona State University is committed to providing an environment free of discrimination, harassment, or retaliation for the entire university community, including all students, faculty members, staff employees, and guests. ASU expressly prohibits discrimination, harassment, and retaliation by employees, students, contractors, or agents of the university based on any protected status: race, color, religion, sex, national origin, age, disability, veteran status, sexual orientation, gender identity, and genetic information.

Title IX is a federal law that provides that no person be excluded on the basis of sex from participation in, be denied benefits of, or be subjected to discrimination under any education program or activity. Both Title IX and university policy make clear that sexual violence and harassment based on sex is prohibited. An individual who believes they have been subjected to sexual violence or harassed on the basis of sex can seek support, including counseling and academic support, from the university. If you or someone you know has been harassed on the basis of sex or sexually assaulted, you can find information and resources at

https://sexualviolenceprevention.asu.edu/faqs. As a mandated reporter, I am obligated to report any information I become aware of regarding alleged acts of sexual discrimination, including sexual violence and dating violence. ASU Counseling Services, https://eoss.asu.edu/counseling is available if you wish to discuss any concerns confidentially and privately. ASU online students may access 360 Life Services, https://goto.asuonline.asu.edu/success/online-resources.html.
Note: certain aspects/ policies of this course could evolve/ change as the semester progresses. Such changes will be announced in the class and the students will be given time to adjust and adapt.

19. Photo requirement

Arizona State University requires each enrolled student and university employee to have on file with ASU a current photo that meets ASU's requirements (your "Photo"). ASU uses your Photo to identify you, as necessary, to provide you educational and related services as an enrolled student at ASU. If you do not have an acceptable Photo on file with ASU, or if you do not consent to the use of your photo, access to ASU resources, including access to course material or grades (online or in person) may be negatively affected, withheld or denied.