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Fracture and Deformation of Materials Under Extreme Conditions

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RCEU 2023 Project Proposal

Project Title

Fracture and Deformation of Materials Under Extreme Conditions

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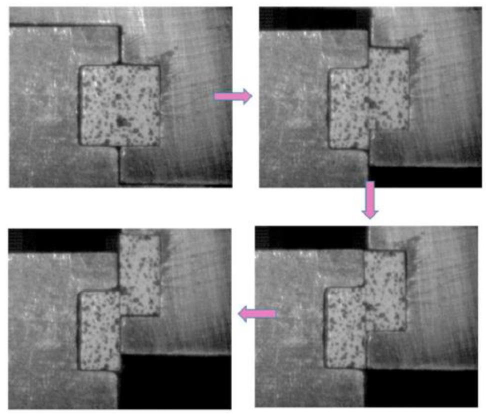
I. Project Description

Many engineered devices and the materials they are constructed from are subjected to extreme loading conditions. In particular armor, projectiles, explosive ordnance containment devices, and aerospace vehicle structural components are subjected to high-speed impacts and shock loading. Fiber-reinforced composites (FRCs) are a material of interest for these applications due to their excellent strength-to-weight ratio.

In order to accurately design such devices using FRCs, it is necessary to experimentally determine how FRCs deform and fracture at high strain rates. However the high anisotropy and non-homogenous material structure of FRCs makes this challenging. It is particularly difficult to accurately test FRCs under high strain rate shear loading. Many existing experimental methods such as Iosipescu shear, double-notched shear, and torsional shear tests are unable to consistently induce shear fracture at high strain rates.

For this project, the student will design and perform high strain rate shear tests using square block FRC shear specimens. The tests will be performed on a split-Hopkinson pressure bar (SHB) high strain rate testing apparatus. The student will then analyze the experimental data to determine if the tests successfully loaded the specimens and caused fracture under shear conditions.



Square block FRC shear test (F. Weng et al., 2021)

II. Student Duties, Contributions, and Outcomes

a. *Specific Student Duties* - The student will read literature on FRC materials and high strain rate shear testing. They will utilize CAD software to design fixtures to mount the specimen to the SHB testing apparatus. They will then oversee the fabrication of the fixtures as well as the fabrication of the FRC square block shear test specimens. The student will then perform the high rate shear experiments and analyze the experimental data using experimental techniques such as elastic wave analysis, high speed imaging, and Digital Image Correlation (DIC). The student will assess whether the test specimens were successfully loaded in shear, and if so they will determine the stress versus strain response and strain at fracture of the FRC material. If there is sufficient time and interest, the student may also be introduced to the basics of finite element analysis (FEA) using the commercial software LS-DYNA with the goal of simulating the experiments.

b. *Tangible Contributions by the Student to the Project* – The shear test fixtures designed by the student will continue to be used for high rate testing of FRCs after the completion of this particular project. The student's analysis of how successfully the fixtures are able to load the FRC specimens in shear will be useful for designing future improved high rate shear tests. The student's research efforts will also contribute towards potential publications related to this work.

c. *Specific Outcomes Provided by the Project to the Student* – This project will give the student the opportunity to experience the full engineering process of design, fabrication, assembly, and troubleshooting as they create and use the new SHB shear mounting fixtures. The student will also gain hands-on experience with testing of material mechanical behavior, as well as develop an understanding of experimental measurement techniques such as strain gages, elastic wave analysis, Digital Image Correlation, and the split-Hopkinson bar test technique. Through these experiments, the literature review, and the mentorship process the student will gain a deeper understanding of material deformation and fracture beyond what is found in a typical undergraduate Mechanics of Materials course. Specifically the student will learn how material stress-strain and fracture behavior differs between high and low loading rates, as well as be introduced to material wave dynamics due to high rate shock and impact loading. In addition they will be introduced to the FRC class of materials and understand how FRCs are manufactured, the structural properties of FRCs, and the advantages/disadvantages of FRCs compared to other types of materials.

III. Student Selection Criteria

This project is open to students of all ranks who are pursuing an Engineering degree.

IV. Project Mentorship

The student will be mentored on the topics and skills needed to complete the specific project, as well as on more general topics relevant to success as an engineer and conducting research. Specific mentorship topics include: conducting literature reviews and literature research, presenting technical information, the engineering design process (component design, ease of manufacture and assembly, material selection), the basics of deformation and fracture, how material behavior differs across different classes of materials and at different loading rates, and how to critically analyze experimental data to assess its accuracy and reliability.

An initial meeting between the student and faculty mentor will cover the project timeline and major milestones. Regular weekly meetings will be held to discuss the student’s progress, challenges, plans for the next week and how best to proceed. In addition to the formally scheduled meetings, the faculty mentor will expect to meet with the student informally several times each week as necessary. At the end of the summer the student will prepare a final presentation to the research group summarizing what they have learned and their research findings.