# Flammability Study of 3D Printed Continuous Fiber Reinforced Thermoplastic Composites for Space Application

Jadyn Parker[1], Yu-Chao Shih[1], Yan Yongzhe[1], and Haibin Ning[1]

[1]Department of Mechanical and Materials Engineering, University of Alabama at Birmingham – Birmingham, AL

## Abstract

Carbon fiber reinforced thermoplastic composites have been extensively used in aerospace and their flame resistance is of great interest and needs to be thoroughly investigated. In this work, continuous carbon fiber reinforced nylon matrix composites with different fiber orientations were fabricated using a fused deposition modeling method and their flame resistance was studied by performing ASTM D635. The burning rate of the composite was measured and the effect of the fiber orientation on the burning rate was determined. This study will provide great understanding of the flammability of the additively manufactured continuous carbon fiber reinforced thermoplastic composites.

## Introduction

Continuous carbon fiber thermoplastic composites (CCF-TC) are typically strong, stiff, lightweight, and exhibit very low thermal expansion and have been used in various application including aerospace. With new advancements in additively manufacturing, high-quality fiber reinforced thermoplastic composites can be easily customized and produced. In this experiment, nylon is used for the matrix and carbon fiber is used for the reinforcement because they exhibit good mechanical properties and pair well with fusion deposition molding (FDM). Prior research has been conducted on the flammability of 3D printed composites with varying fiber content, but minimal research has been conducted on their flame resistance and the effect of fiber orientation on their flame resistance.

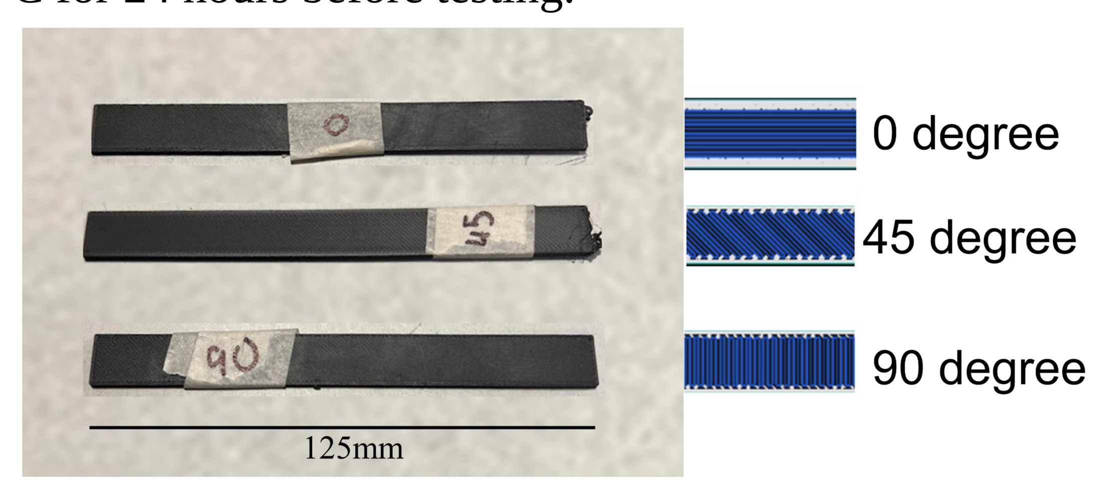
Markforged MarkTwo 3D Printer for Sample Printing

## Objectives

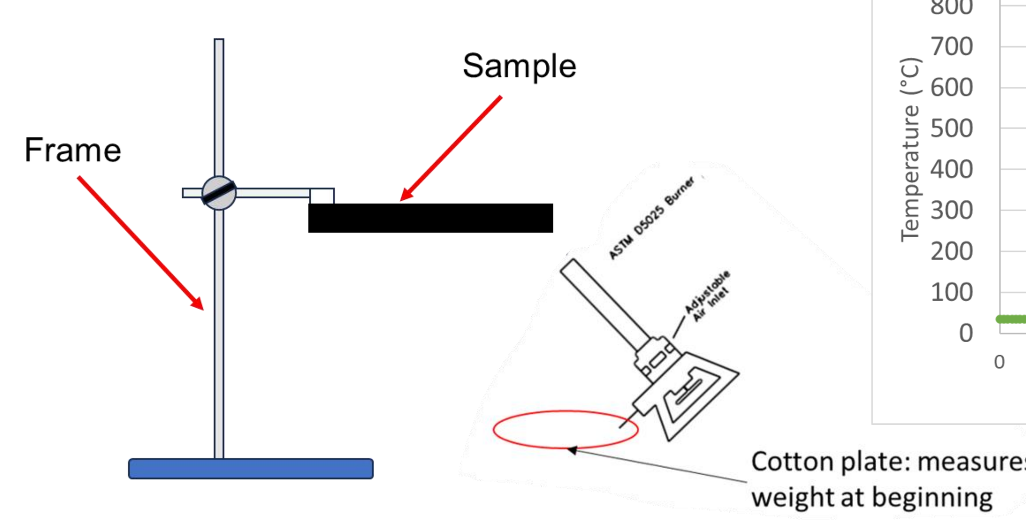
- Conduct fire testing on 3D printed carbon fiber thermoplastic composites.
- Determine the relationship between fiber orientation and flammability.
- Identify a relationship between thermal conductivity and burn rate of continuous fiber.

## Methodology

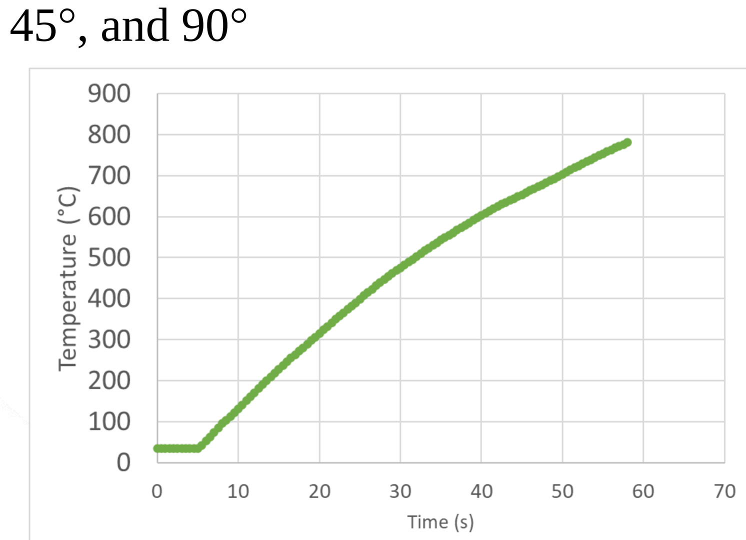
CCF-TC samples with dimensions of 125 x 13 x 2 mm and 100% infill are additively manufactured using a Markforged MarkTwo, MA, U.S. 3D-printer. Samples printed using Onyx consisted of various fiber angles including 0°, 90°, 45°, and quasi-isotropic. ASTM D635 was performed and burn rate was calculated and the thermal conductivity was analytically determined. All samples were conditioned in a dryer at ~68 °C for 24 hours before testing.



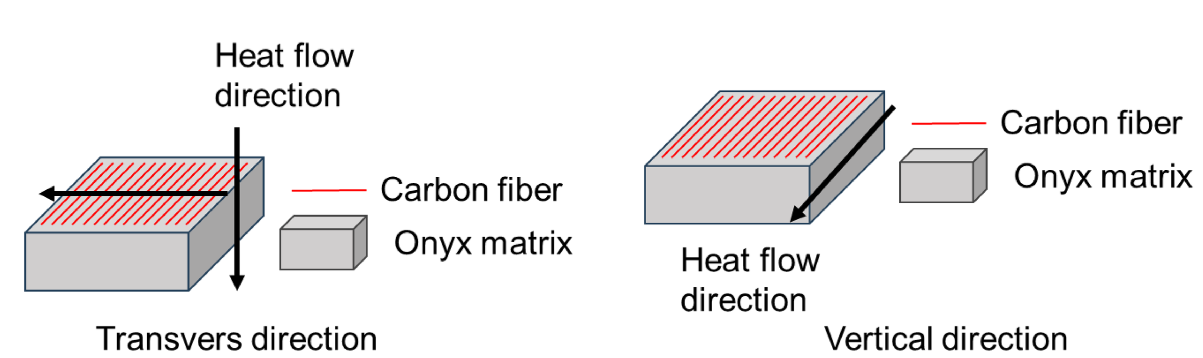

Samples with fiber angles 0°, 45°, and 90°




ASTM D635 Test Setup




Flame Calibration Graph




Heat Flow Direction in 0- and 90-Degree Samples

Thermal Conductivity Calculation

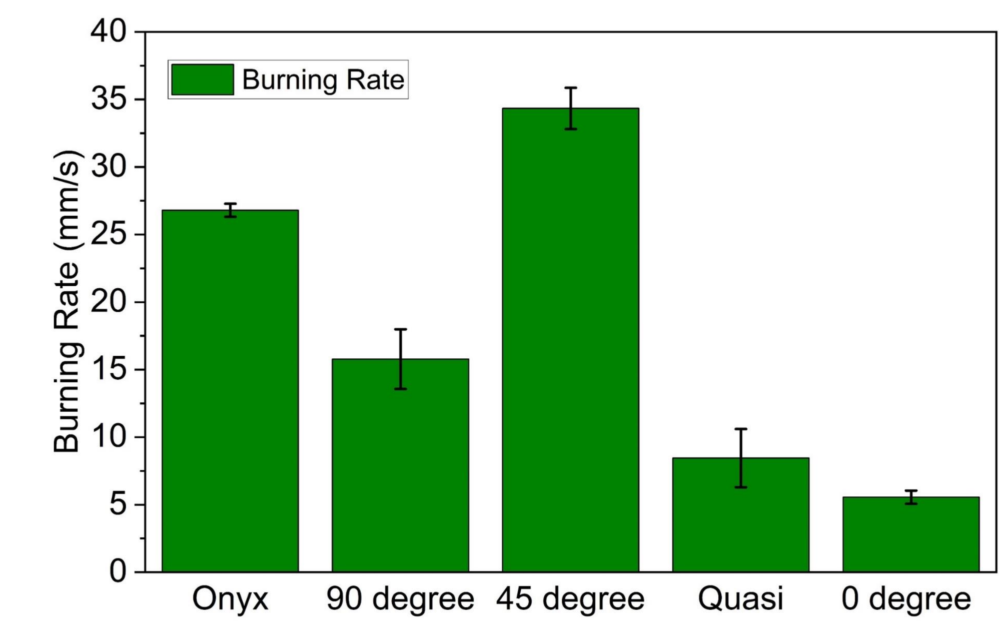
$$k_{cT} = \left(\frac{1 - v_f}{k_m} + \frac{v_f}{k_f}\right) \quad \text{Transverse direction}$$

$$\frac{1}{k_{cV}} = k_m\left(1 - v_f\right) + k_f v_f \quad \text{Longitudinal direction}$$

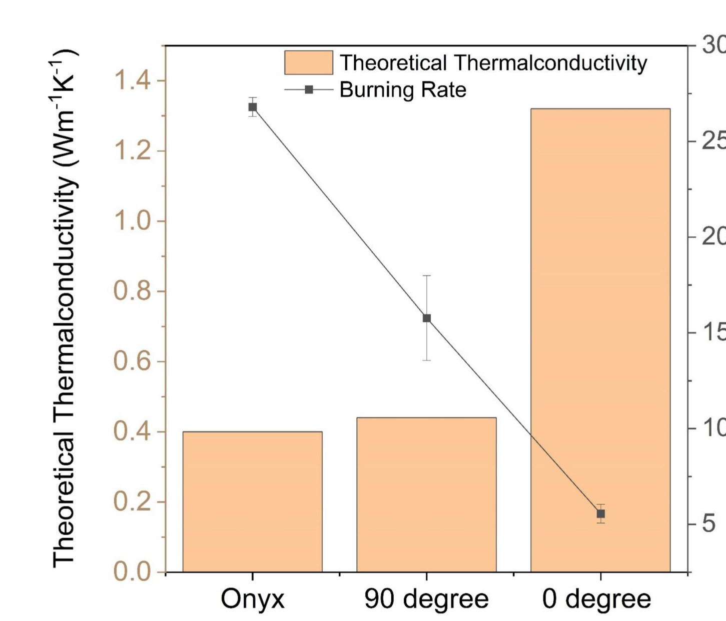
## Results and Discussion

- Only carbon fibers were present after the burn testing of the composite samples.
- Nylon matrix in the composites burns while the carbon fibers do not burn. The composites with different orientations have different behavior in burn test in spite of their exactly the same composition (carbon fiber content and matrix content).
- Thermal conductivity was theoretically determined based on equations in existing literature. Higher thermal conductivity reduces the burn rate and improves the flame resistance.

A Composite Sample during Burn Test




Average Burning Rate of Samples




Theoretical Thermal Conductivity


0° Specimens After Fire Testing

## Conclusions

- 0° and quasi-isotropic samples have the lowest burn rate.
- The 45° sample has the highest burn rate.
- The burning rate of fiber reinforced thermoplastic composites is a function of fiber orientation.
- The 0° and quasi-isotropic fibers significantly reduce flammability of the matrix. Burning rate decreases with increasing 0° carbon fibers. The possible reason is that a fiber angle perpendicular to a flame slows flame propagation by improved heat conduction.
- Composite design can achieve better flame resistance by integrating more 0° fibers in the flame propagation direction.

## Acknowledgements

Support provided by National Science Foundation (Grant # DMR-2148897 – Research Experiences for Undergraduates (REU) awarded to UAB.