NASA-Missouri Space Grant Consortium

Apr 22nd, 8:30 AM - 10:00 AM

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Heskin, Matik S., "Performance Evaluation of Additively Manufactured Carbon/PEEK Composites" (2023). *NASA-Missouri Space Grant Consortium*. 23.
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Performance Evaluation of Additively Manufactured Carbon/PEEK Composites

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Abstract

Carbon/PEEK composites have a broad range of applications due to their combinations of superior creep properties and excellent strength to weight ratios. Like all fiber-based composites they are limited geometrically by their required manufacturing processes. Additively manufactured (AM) materials overcome this issue and can be formed into incredibly complex shapes. By combining these two fields, a material limited in application by geometry can have its shortcomings supported with AM processes.

AM carbon/PEEK composites have already been created but this relatively new material still needs property characterization. Therefore, the objective of this work will be to evaluate the structural performance of additively manufactured carbon/PEEK composites, specifically Young's modulus. The resulting data can be compared to standard carbon/PEEK composites to better understand the change in material property as a result of a different manufacturing process.

Introduction

Fiber based composite structures can be used in a variety of different applications. Found widespread in aerospace, automotive, industrial, and other technical fields, they can be used as a lightweight customizable material for any number of desired parts. Of specific interest is the mixture of carbon fibers and polyetheretherketone (PEEK). While still a thermoplastic, the commercially used PEEK has one of the highest working temperatures and boasts "extraordinary mechanical properties" [1]. To support the properties of PEEK even further the addition of short carbon fibers leads to a significant increase in mechanical properties while retaining PEEK's excellent strength-to-weight and thermal properties.

Traditionally fiber-based composites have been limited by geometric constraints due to the underlying manufacturing techniques needed to create them. Using Impossible Object's unique composite based additive manufacturing machine, shown in Figure 1, short fiber carbon and fiberglass composites can be manufactured in previously infeasible shapes and sizes.

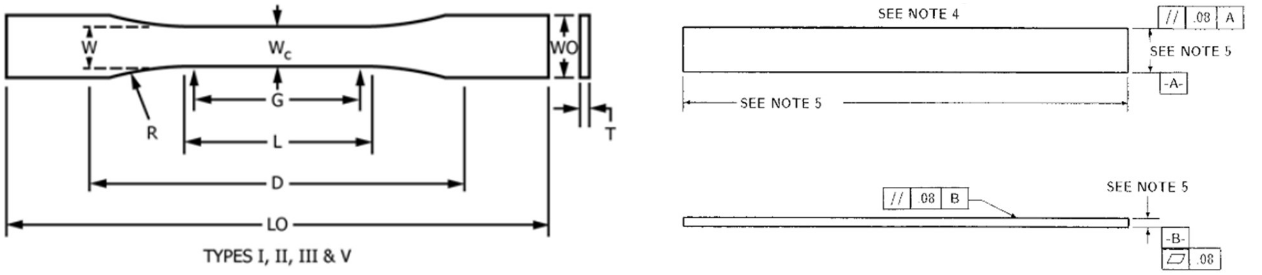
Figure 1. CBAM-2 Printer and Hot Press at Missouri S&T

To better understand how parts made from this new manufacturing technique behave a series of performance evaluations were conducted on Carbon/PEEK composites made using the CBAM-2. After testing was completed a cross-analysis compared traditionally manufactured short fiber Carbon/PEEK composites to that of the CBAM-2 parts.

Specimen Design

Two tensile specimen geometries were tested, a dog-bone and a flat. An example of each is shown in Figure 2. Because the material in question is created from short discontinuous fibers it was unsure which would perform better. The dog-bone and flat specimen are both created using standard testing parameters as described in ASTM D638[2] and D3039[3] respectively. A blanket geometry of both is pictured in Figure 3, specific lengths and radius can be found by consulting the corresponding ASTM.

Figure 2. Dog-bone (top) and Flat (bottom) Tensile Samples



(a.) Dog-bone sample per ASTM D638 **(b.) Flat sample per ASTM D638**

Figure 3. Comparison of Standard Tensile Specimen Geometries

Two silver dots were added one half inch from the center of the specimen. During testing the separation of the dots allows a camera integrated into the test platform to measure percent strain without the need for strain gauges. On either side of a specimen, four total aluminum tabs (two per side) were epoxied on. During testing the clamps apply pressure to the aluminum tabs both distributing load across the grip section of the specimen and preventing the teeth in the clamps from damaging the sample.

Testing

All tensile tests were completed on an the Instron 5985. Figure 4 depicts a flat specimen clamped by its tabs. The red light is from the camera (not pictured) mentioned in Specimen Design. During specimen mounting, care is taken to align the edges of the tabs with the edges of the self-aligning clamps.

The crossheads are orientated such that the specimen is perpendicular to the camera. Using the Instron software the initial gauge length is set; the camera then takes a snapshot of the sample unloaded. If the dots of the specimen don't fall within the camera's frame, it is during this step that the entire camera is lowered or raised so the gauge is centered. After the camera has taken its first snapshot testing can begin. The ASTM's don't specifically recommend load rates, so using historical norms, the dog-bone was loaded at a rate of 2 mm/min while the flat specimen was loaded at 5 mm/min. Crosshead displacement continues until complete specimen failure.

In all tested cases, dog-bone and flat, the specimens failed in two places near-simultaneously. It is not known whether the samples initially failed in one location followed very closely by the other or if they failed at the same time. With the addition of a slow-motion camera it's possible this could be determined during future work.

Figure 4. Flat Tensile Specimen Mounted on Instron

(a) Post-test Flat Specimens **(b) Post-test Dog-bone Specimens**

Figure 5. Failed Specimens, Flat (a) and Dog-bone (b)

Currently it is theorized the sample fails in one location and the release of energy causes the remnant to “spring” back, snapping the specimen at the second location. This is supported somewhat by how forcefully the specimens failed in all cases, it was not uncommon for the failed center remnant to eject itself, both fracturing in multiple spots either in air or during impact with the ground near the Instron.

Figure 5 shows all recovered specimens along with the corresponding fragments of the specimen that were found. Additionally, it should be noted that the dog-bone samples weren’t necessarily predisposed to break in their gage length as they were designed to do. It is unclear why these samples so frequently failed in the larger cross sections, but it does cause concern with how well this geometry type represents this material. With this in mind tensile properties calculated from both specimens were different, though not substantially.

Results

Compared to the dog-bone specimens, the flat samples predicted higher mechanical properties with respect to ultimate tensile strength and Young’s modulus, 206.35 MPa and 17.49 GPa respectively. These values predict a 6.6% and 10.4% higher tensile strength and Young’s modulus than the dog-bone. On the other hand, the flat showed a consistently lower elongation at break 1.16 as opposed to 1.25. On all tabulated properties deviation was small. This does ease the concern that the specimens failing in multiple locations/out of their gage lengths may not be as significant of a concern. All predicted tensile properties for both geometries can be seen in Figure 6.

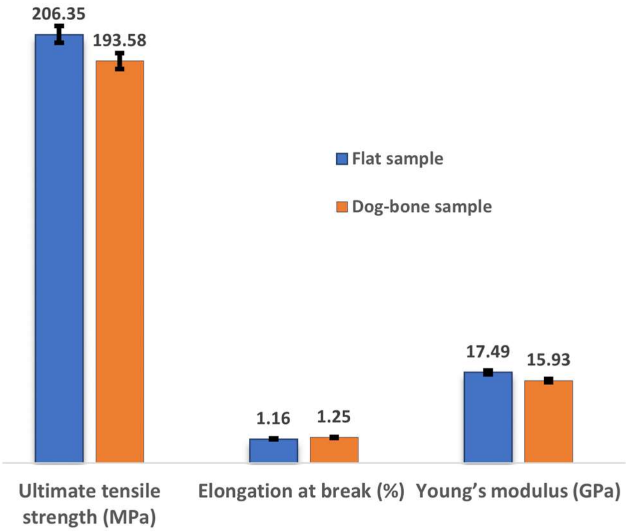


Figure 6. Tensile Properties of Carbon/PEEK Flat and Dog-bone Geometries

For the benefit of comparison between different manufacturing methods, total carbon fiber content is the largest single variable that predicts tensile properties[4]. This holds true across most composites including short fiber Carbon/PEEK. This isn't to say failure begins in the fiber, on the contrary, but it can be shown that a higher fiber content means a lower matrix content. In the case of the CBAM-2's manufactured Carbon/PEEK panels, carbon content is 18.6% of the total composition.

Comparison

To most accurately compare the mechanical properties of the CBAM-2's Carbon/PEEK and a traditionally manufactured material, carbon content was of primary concern. Additionally, for it to be a proper comparison the comparison material would also need to be a short fiber reinforced composite (SFRC). The closest SFRC found was that of carbon fiber content of 15%, any closer in carbon content would likely require a custom material to be made. The material in question is specifically RTP 2282, with parts created using injection molding. While the RTP company does not disclose fiber length, due to manufacturing constraints of injection molding it is a very good assumption that they would be shorter than the carbon fibers utilized in the CBAM-2.

Using data sheets from the RTP company[5], Young's modulus is reported as 15.2 GPa, ultimate tensile strength is 207 MPa, and elongation at break is reported broadly as 1-2%. Initial analysis shows an almost perfect match to the flat specimens ultimate tensile strength. When looking at Young's modulus, the CBAM-2's flat specimen modulus was reportedly 15.1% higher.

The material data sheets provided claim that ASTM D638 (dog-bone) was used, in this case a better comparison is the CBAM-2's dog-bone material properties. Comparing this geometry, RTP reports an ultimate tensile strength 6.9% higher, but a Young's modulus of 4.5% lower. Figure 6 compares both material properties between all three specimens.

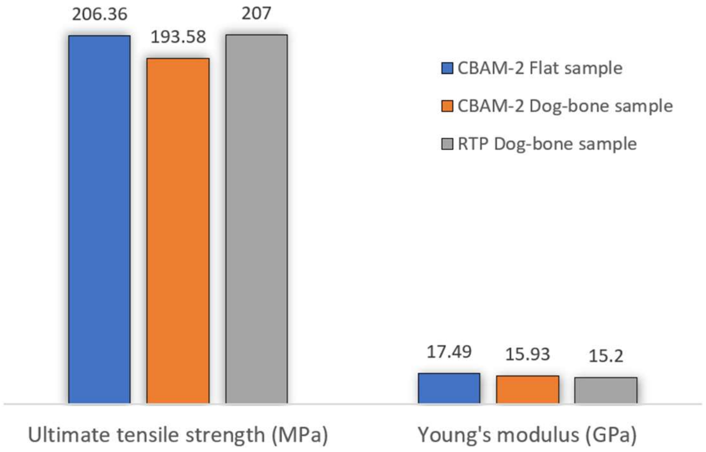


Figure 7. Tensile Properties of CBAM and RTP Carbon/PEEK

Considering both, it can be concluded that the different manufacturing techniques do not lend themselves to significantly higher or lower tensile properties.

Summary

This project completed tensile testing on two specimen geometries created using the CBAM-2 to understand which is more apt for measuring ultimate tensile strength and Young's modulus. After tensile properties were found a comparison to a traditionally manufactured like-material was completed to verify that the manufacturing process did not hinder expected material performance. As the project continues additional mechanical properties such as flexural modulus, compression strength, and impact resistance will be determined. It is important as testing continues to understand the nature of the manufacturing process of the CBAM such that a chosen specimen geometry does not compromise results found from otherwise standard ASTM testing procedures. Comparison between like materials can be continued as other material properties are found. To address the issue of specimens failing in multiple locations, it is advised moving forward that a high-speed camera is utilized to better understand how tensile specimens are failing, allowing researchers to determine if it is a cause for concern or not.

Acknowledgments

The author would like to thank the NASA-Missouri Space Grant Consortium Grant Award number 80NSSC20M0100, which sponsored this work. The author would also like to thank his advisor, Dr. K Chandrashekhara, without whose guidance and support this would not be possible. Support from Impossible Objects through the Center for Aerospace Manufacturing Technologies (CAMT) at Missouri University of Science and Technology is gratefully acknowledged. Finally, the author would like to thank N. Pundhir, K. Dasari, and M. Rangapuram for their support, insight, and experience throughout this project.

Biography

Matik S. Heskin is from Weston, Missouri, and is 4th year Aerospace Engineering student at the Missouri University of Science and Technology. In the past four years he has held three different leadership positions on the Miner Aviation Student Design Team at Missouri S&T. He has served as a Research and Development Intern at Spirit AeroSystems. After his undergraduate he plans to intern at Spirit AeroSystems once more before returning to Missouri S&T to begin his PhD in Mechanical Engineering.

References

[1] McKeen, L. W., "High-temperature polymers," The Effect of Creep and Other Time Related Factors on Plastics and Elastomers (Second Edition) https://doi.org/10.1016/B978-0-8155-1585-2.50012-1.

[2] "Standard Test Method for Tensile Properties of Plastics", *American Society for Testing and Materials*, 2015, DOI: 10.1520/D0638-14

[3] "Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials", *American Society for Testing and Materials*, 2008, DOI: 10.1520/D3039_D3039M-08.

[4] Huang, Z. M., Guo, W. J., Huang, H. B., & Zhang, C. C. (2021). Tensile Strength Prediction of Short Fiber Reinforced Composites. Materials (Basel, Switzerland), 14(11), 2708. https://doi.org/10.3390/ma14112708

[5] RTP company RTP 2282 HF TFE 15 polyetheretherketone (PEEK), carbon fiber reinforced - PTFE lubricated Available: https://www.matweb.com/search/datasheet.aspx?matguid=d2d3cd0d0a3945e58a2367bf5c50ed1a.