Additive Manufacturing of Braided Structures for Composite Reinforcement

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Braided patterns are often used to provide structural reinforcement in other materials. However, traditional methods of fabricating these braided structures are limited in their abilities. These techniques typically involve intertwining spools of material around a mandrel to create a cylindrical braid (Adanur, 1995). However, 3D printing, a form of additive manufacturing, continues to develop and offer many new possibilities in the realm of manufacturing. This can be credited to its process of depositing material in thin layers to gradually build the design from bottom to top (Dai & Hong, 2014). This allows for creating designs that would otherwise be impossible or incredibly difficult to realize.

The objective of this project is to test the abilities of 3D printing technology as it applies to the manufacturing of braided patterns in multidimensional space. Five differently patterned braided cylinders (diamond, regular, Hercules, tri-axial, and bifurcated) have been designed in SolidWorks and 3D printed from polylactic acid (PLA). The diamond, regular, and Hercules patterns have also been printed from thermoplastic polyurethane (TPU) at a 50% scale in size. PLA is a rigid plastic, while TPU is much more flexible (Brancewicz-Steinmetz, Sawicki, & Byczkowska, 2021). To compare the abilities of these structures, a combination of compression and tensile tests has been performed to gain knowledge of a few of their mechanical properties. Results have provided data concerning modulus of elasticity, force at yield, displacement at yield, and other measurements for each of the differently patterned structures and materials. The PLA prints underwent compression tests of the whole structures and tensile tests on separated, individual strands from the diamond, regular, and tri-axial braids. The force vs. displacement plots represent these tests in Fig. 1 and Fig. 2, respectively. Tests performed on the TPU prints were of equally portioned strips of the diamond, regular, and Hercules patterns undergoing tensile force at a constant rate, represented by the force vs. displacement plot in Fig 3. The resulting data provides insight into the capacities of both the materials and designs used for experimentation.

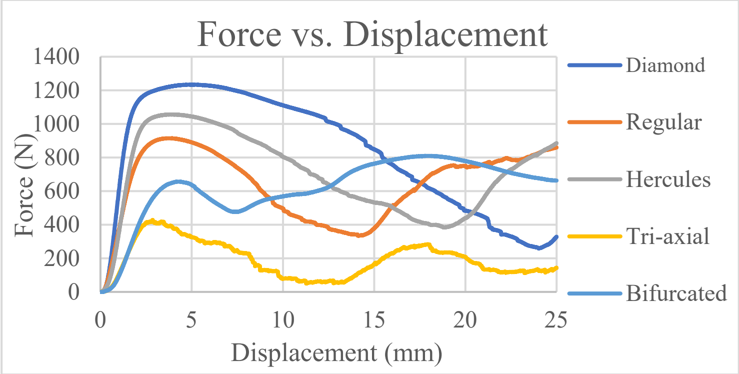

Fig. 1 PLA Compression Tests Force vs. Displacement Graph.

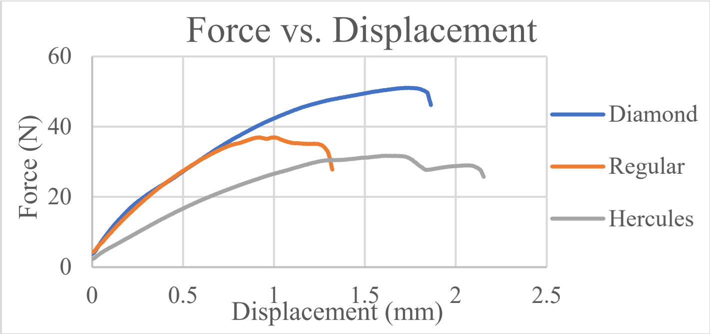

Fig. 2 PLA Tensile Tests Force vs. Displacement Graph.

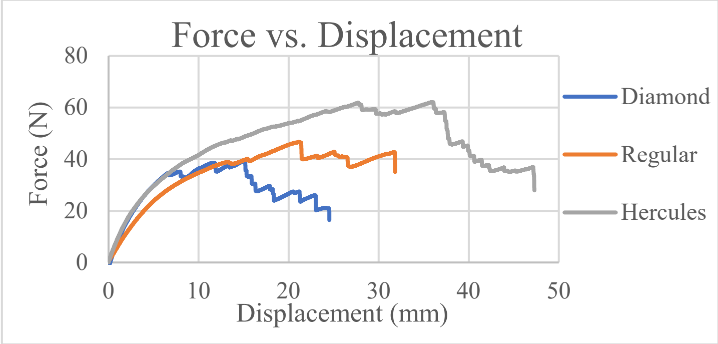

Fig. 3 TPU Tensile Tests Force vs. Displacement Graph.

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The results of the PLA compression tests offer data regarding the mechanical properties of the structures, such as force at yield, displacement at yield, and the initial slope of the force vs. displacement relation. The forces at yield from highest to lowest are as follows: diamond at 1234.62 N, Hercules at 1056.88 N, regular at 915.16 N, bifurcated at 658.76 N, and tri-axial at 440.21 N. The displacements at yield from highest to lowest are as follows: diamond at 5.04 mm, bifurcated at 4.39 mm, Hercules at 3.89 mm, regular at 3.75 mm, and tri-axial at 3.05 mm. It should be noted that the bifurcated prints began with a larger height than the other prints. The ranking from highest to lowest measured initial slope of the force vs. displacement curve is as follows: diamond at 949.18 N/mm, Hercules at 696.57 N/mm, regular at 525.27 N/mm, bifurcated at 292.76 N/mm, and tri-axial at 259. 17 N/mm.

The tensile tests of individual strands of the PLA prints provide data of the maximum force, displacement at maximum force, tensile stress at maximum force, and Young's modulus for diamond, regular, and Hercules patterned braids. The following measurements are averages of the samples tested for each braid pattern. The maximum forces from highest to lowest are as follows: diamond at 52.34 N, Hercules at 47.28 N, and regular at 41.63 N. The displacements at maximum force from highest to lowest are as follows: Hercules at 2.425 mm, diamond at 1.74 mm, and regular at 1.24 mm. The highest to lowest measured tensile stresses at maximum forces are as follows: diamond at 16.66 MPa, Hercules at 15.05 MPa, and regular at 13.25 MPa. The ranking from highest to lowest measured Young's modulus is as follows: diamond at .31 GPa, regular at .30 GPa, and Hercules at .15 GPa.

The tensile tests for the TPU prints provide data of the maximum force, displacement at maximum force, tensile stress at maximum force, and Young's modulus for diamond, regular, and Hercules patterned braids. The maximum forces from highest to lowest are as follows: Hercules at 64.47 N, regular at 44.08 N, and diamond at 40.63 N. The displacements at maximum force from highest to lowest are as follows: Hercules at 33.8 mm, regular at 20.07 mm, and diamond at 13.89 mm. The tensile stresses at maximum force from highest to lowest are as follows: Hercules at 1.08 MPa, regular at 0.88 MPa, and diamond at 0.82 MPa. The ranking from highest to lowest measured Young's modulus is as follows: diamond at 1.17 MPa, Hercules at 0.87 MPa, and regular at 0.68 MPa.

Statement of Research Advisor

Ms. Katherine Griffin investigated the design and 3D additive manufacturing of braided structures. First, she used SolidWorks to design various structures such as plain, regular, Hercules, triaxial, and bifurcated braids. Then, using a 3D printing machine, she produced several samples with PLA and TPU. These samples were tested in the lab for tensile strength. The results are very valuable for the advancement of 3D printing of flexible fibrous structures, which has not been done yet.
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Authors Biography

Katherine Griffin is a junior-year student pursuing a B.S. degree in Mechanical Engineering at Auburn University. She has studied the design and manufacturing of braided patterns and structures using 3D modeling software and additive manufacturing technology.

Ajay Jayswal completed his BS in Mechanical Engineering from Tribhuvan University, Nepal, in 2017 and his M.S. in Mechanical Engineering from Auburn University in 2021. Currently, he is a Ph.D. Student at Auburn University. He has published 5 peer reviewed journal articles, and 1 peer reviewed conference article. His research interests include additive manufacturing of polymers, computer design of textile-based structures, polymer processing and composites, viscoelasticity, and finite element modeling.

Dr. Adanur is a professor in the Mechanical Engineering Department. He has a BS in Mechanical Engineering, a M.S. in Textile Engineering and Science, and a Ph.D. in Fiber and Polymer Science. His research interests include dynamics of machinery, fibrous structures, composites, nanomaterials, and additive manufacturing of polymeric materials. He has published his research results in numerous books, articles, and conferences.