A Study on the Effect of Concentric Fiber Layers on the Mechanical Properties of Onyx Reinforced with Continuous Fiberglass

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Abstract: Nylon is a thermoplastic polymer that possesses impressive strength, durability, and low friction properties, making it a commonly used material in engineering applications. The automotive industry utilizes Nylon for manufacturing engine components, brake systems, and fuel tanks. Despite its strength and durability, Nylon may not be suitable for high-load applications that require stronger materials such as metals or composites [1]. However, Onyx, which is Nylon infused with micro carbon fibers, has enhanced strength properties compared to pure Nylon due to its unique micro-carbon reinforcement. Moreover, adding continuous fiber reinforcement to Onyx results in a lightweight and robust material. Fused Deposition Modelling (FDM) technology using a Continuous Fiber Composite 3D Printer can fabricate Onyx components with continuous strand fibers, providing a staggering level of strength [2]. This material combination has the potential to replace metal tooling for aerospace, automotive, and wind energy applications. Nevertheless, the behaviour of these composites under specific loading conditions is not yet fully understood [3]. Therefore, this study employs FDM technology to manufacture components using Onyx with varying content of continuous fiberglass (FG). The study utilized FDM technology to manufacture components made of Onyx, a type of Nylon infused with 20% chopped carbon fiber. The Mark Two™ Continuous Fiber Composite 3D Printer was employed to create tensile samples according to ASTM D638 standard. The samples were printed using concentric fill layers of fiber around the perimeter of the walls with solid infill to strengthen them against deformation. This type of fiber fill is particularly effective in enhancing the strength of the walls, making them highly suitable for use in automotive applications where deformation is a concern. The quantity of fiber reinforcement was varied by modifying the number of concentric fiber layers, which was adjusted from 16 to 24 with the increment of 2 layers. Three samples were printed for each set of layers, resulting in a total of fifteen samples with fiber reinforcement. In addition, one set of three samples was printed using pure Onyx without any reinforcement to allow for accurate comparisons. The mechanical properties of each sample were examined experimentally using a universal tensile testing machine, and the fracture interfaces resulting from tensile testing were analysed using a scanning electron microscope (SEM) S-3000N Hitachi to explain material failure modes and reasons. The Eiger™ images in Fig. 1a and 1b illustrate the geometry of the sample, positioning of FG reinforcement, and Fig.1c shows the physical 3D sample.

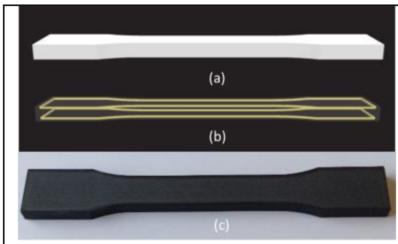


Fig. 1 (a) the Eiger™ images shows the sample geometry, (b) placement of FG reinforcement and (c) the physical 3D sample.

Fig. 2 The sample fractured during the tensile testing.

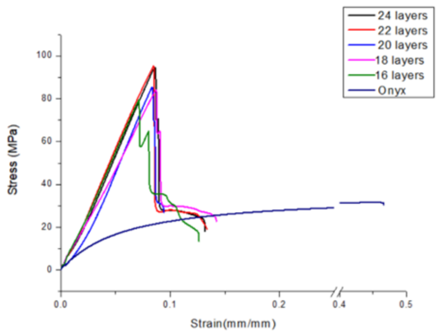
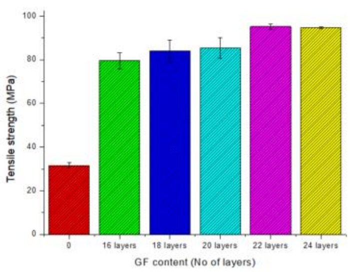
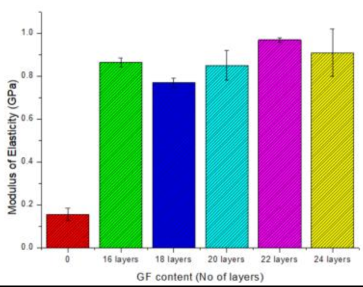


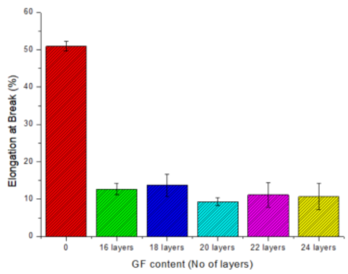
Fig. 3 Stress-Strain curves for Onyx reinforced with continuous FG



(a) Tensile strength

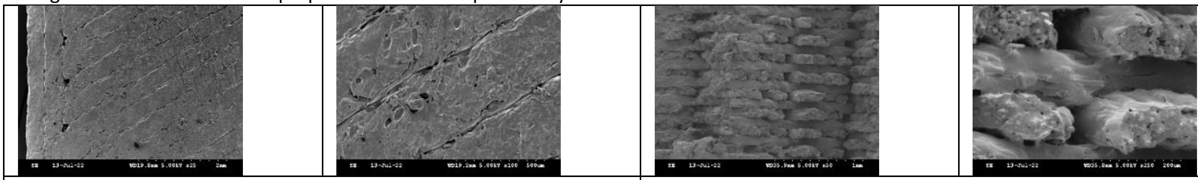


(b) Modulus of Elasticity



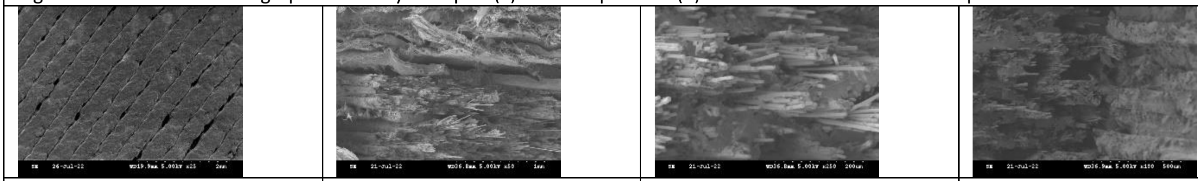
(c) Percentage of Elongation

Fig. 4: Illustrates the tensile properties for the samples of onyx reinforced with continuous FG.



a | b

Fig. 5: shows the SEM micrograph of the onyx samples (a) outter top suface (b) fractured interface of tensile specimens



(a) | (b) | (c) | (d)

Fig. 6: shows the SEM micrograph of the onyx with continuous GF samples (a) outter top suface (b to d) fractured interface of tensile specimens

Fig. 2 shows the fractured surface during the tensile test. The results of a tensile test designed to assess the effect of various quantities of continuous FG on the tensile properties of onyx components, such as ultimate strength, modulus of elasticity, and elongation at break, are presented in Fig. 3 and Fig. 4. Results indicate that samples printed without continuous fiber demonstrated the lowest tensile strength (32 MPa) and highest percentage of elongation at break (51%) compared to all other samples. In contrast, samples with 16 layers of FG exhibited a remarkable improvement in tensile strength (80 MPa), which represents a 150% increase compared to pure onyx samples, these results are align with the other published data [1]. Similarly, modulus of elasticity showed significant improvement in the same samples. However, the percentage of elongation decreased. The data also demonstrate that increasing the content of continuous FG enhances tensile strength and modulus of elasticity but reduces the percentage of elongation that can be attributed to the load being transferred onto the continuous fibers, leading to their predominant failure during testing. The tensile properties of samples with 16 to 24 layers of continuous fibers improved by 19% for tensile strength and 11% for modulus of elasticity, while the percentage of elongation decreased by 15%. The graph presented in Fig. 1 illustrates the stress-strain curves for the composite samples that were printed using Onyx and varying number of layers of continuous FG. The samples experienced failure through delamination of adjacent layers starting from the outer edge before exploding, with the final failure occurring near the sample grip. The stress values for pure onyx samples were low and the curve almost flat, in contrast to the reinforced samples. Samples printed with Onyx with FG reinforcement exhibited sharp stress peaks, with higher peaks observed as the number of GF layers increased. The stress peaks for samples with 22 and 24 layers were the highest among all the samples. Fig. 5 and Fig. 6 present scanning electron microscope (SEM) images of two types of samples: pure onyx and onyx reinforced with FG. The images Fig. 5a and Fig. 6a show the outer top surfaces as well as the fractured interfaces, revealing various defects. The defects include openings, voids, and air gaps, which are visible on both the outer and fractured surfaces. Fig. 6b displays chopped carbon fibers that were pulled out from the matrix during fracture. In Fig. 6c and 6d, the fibers are clearly visible as they were pulled out and gradually broke, leading to failure. Figure 2f highlights openings that formed after the FG filament was completely pulled out.

Conclusion: Overall, the findings suggest that continuous FG played a vital role in enhancing the tensile strength for onyx components. The microstructural defects observed on the outer and fractured interfaces, such as air gaps and voids, are directly related to the tensile strength results. Therefore, it is crucial to address these printing problems and defects to enhance the strength and accuracy of the samples. Moreover, the poor bonding between the matrix and fibers, as evidenced by the fibers being pulled out during the test, needs improvement to enhance overall strength.

Acknowledgments: This work was carried out at the University of Sunderland. The author would like to thank the University of Sunderland for providing funding to support this research. I would like to thank Mr Carl Gregg and Miss Kayleigh Ironside to provide support for 3D printing and SEM work.

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