Macroscale Mechanics of Single-Crystal Graphene

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'High end' values of Young's modulus (*E*) and particularly, of tensile strength (σ), have been reported for monolayer graphene: but for strength (particularly), only for samples in the few micrometer length scale.[1] The strength of macroscale (centimeter-scale) graphene is relatively unexplored. We are studying the macroscale mechanics of single crystalline adlayer-free monolayer graphene by polymer thin film-assisted tensile testing to 'extract' the values of E and σ for graphene that is adhered to the thin polymer film.[2] In this work, we present the mechanical properties of centimeter-scale single-crystal monolayer graphene (SCG) using 'dog bone' samples with edges aligned along specific crystallographic directions. For SCG samples with zigzag (zz) edges, we measured Young's modulus (*E*) of 1.11 ± 0.04 TPa, tensile strength (σ) of 27.40 ± 4.36 GPa, and failure strain (ε_f) of 6.01 ± 0.92%. Samples with armchair (ac) edges exhibited E = 1.01 ± 0.10 TPa, σ = 20.21 ± 3.22 GPa, and ε_f = 3.69 ± 0.38%, while chiral samples displayed intermediate values: E = 0.75 ± 0.12 TPa, σ = 23.56 ± 3.42 GPa, and ε_f = 4.53 ± 0.40%. The SCG was synthesized using chemical vapor deposition (CVD) on single-crystal Cu(111) foils and tested with a custom-built 'float-on-water' (FOW) tensile system, enabling in situ observation of crack initiation and propagation. Quantized fracture mechanics (QFM) analysis indicated edge defects ranging from several to tens of nanometers, influenced by chirality and notch angle. Weibull statistical analysis further projected that the strength of A4-sized SCG sheets would range between 13.67 and 18.43 GPa, depending on chirality, as failure is primarily initiated at edge defects. These findings highlight the remarkable mechanical performance of macroscale SCG, establishing it as a promising material for a wide range of applications, including aerospace, flexible electronics, and straintronics. *This work is supported by the Institute for Basic Science (IBS-R019-D1).*

References

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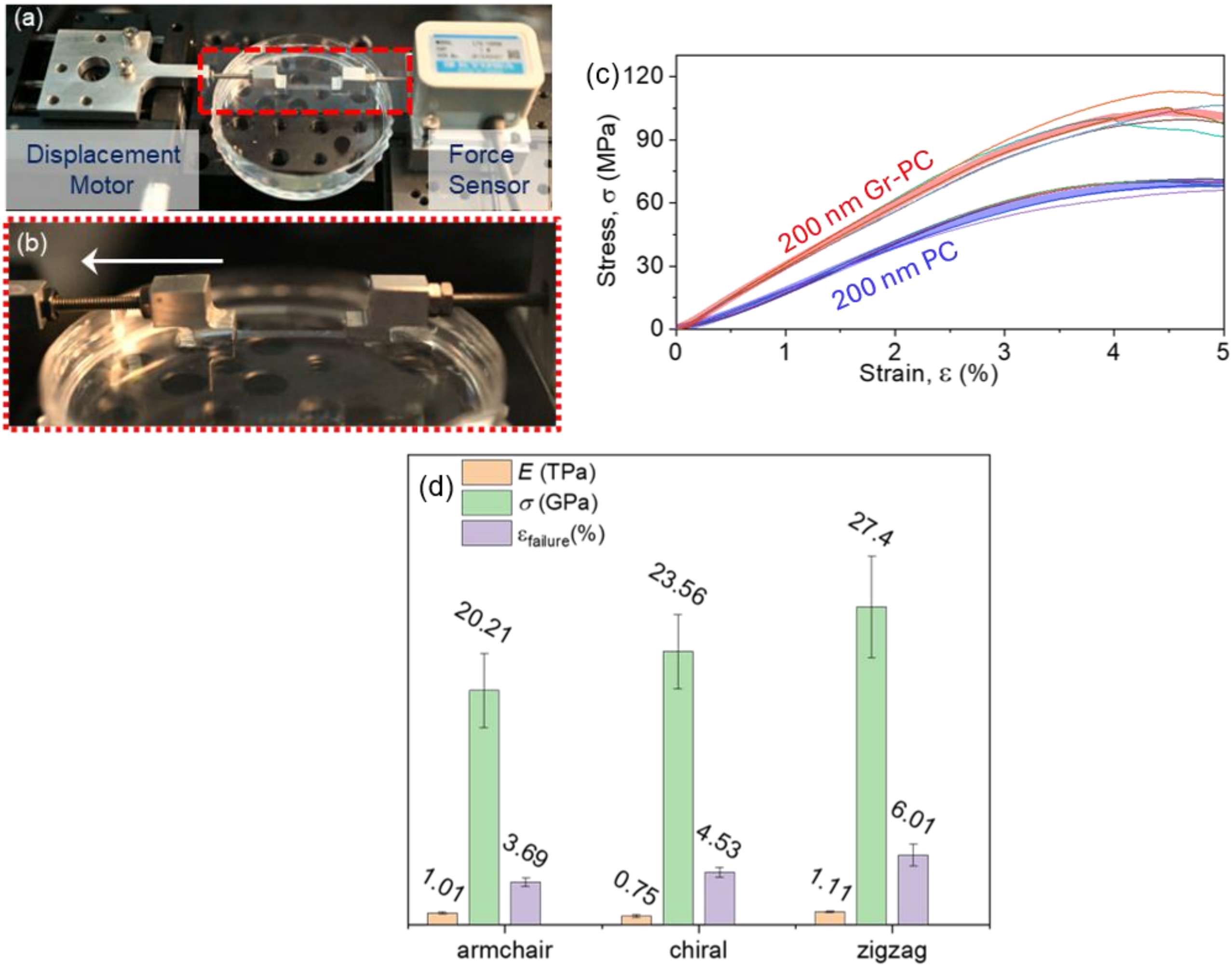

Figure 1: Tensile testing of macroscale single-crystal graphene using a float-on-water (FOW) measurement system. (a,b) An experimental setup illustrating the FOW system with the dogbone-shaped SCG-PC specimen. The white arrow shows the displacement direction. (c) Stress-strain curves of 200 nm PC and 200 nm SCG-PC films with chiral edges, each recorded from five different samples. The red and blue curves present the average stress-strain curves. (d) Comparison of Young's modulus, Tensile strength, strain at maximum stress and Failure strain average values of PC, SCG-PC samples and SLG (extracted from SCG-PC and PC curves).