Lateral buckling and mosaic formation in simply-supported monolayer graphene

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Abstract

Graphene is believed to exhibit the highest stiffness and strength ever recorded and a very high strain to failure. This assertion is mainly based on the findings of bending experiments performed on flakes suspended on circular holes [1], which rely on certain assumptions regarding the bending stiffness of graphene and the expected non-linear form of the derived stress-strain curve. Extensive research in this field has revealed the substantial complexity of the mechanical behaviour of graphene [2]. For instance, mechanical response of graphene may be affected by the occurrence of out-plane phenomena which arise in various ways depending on whether the flake is freely suspended in air or whether it interacts with an underlying substrate or a surrounding matrix. In this regard, the performance and reliability of graphene-based devices are often limited by the interfacial properties between graphene and substrate materials. In order to investigate the morphological changes of simply-supported graphenes under mechanical loading, we have performed in-situ uniaxial tensile test combined with Atomic Force Microscopy (AFM). We have demonstrated that –beyond a certain critical load- wrinkles in the form of delaminated folds originate parallel to the loading direction due to Poisson's contraction exerted laterally by the polymer substrate. Most notably, the critical strain for the generation of these wrinkles in both tension and compression is less than 1%. Moreover, by implementing a procedure with which lateral wrinkling is induced by applying tension, followed by an unloading stage that effectively applies uniaxial compression and results in Euler buckling, we managed to create a mosaic pattern in exfoliated graphene. We show that these patterns can be used as channels for trapping or administering fluids at interstitial space between graphene and its support. Insight on the formation of these wrinkles, morphometrics, and dependence on graphene/polymer interaction strength, is offered through analytical modelling and atomistic simulations. Furthermore, high-resolution AFM images have shown the brittle fracture of graphene at strain levels considerably lower than those predicted on the bases of nanoindentation tests [1].

References

[1] C. Lee et al., Science 321 (2008), 385-388 (2008)

[2] C. Galiotis et al., Annu. Rev. Chem. Biomol. Eng. 6 (2015) 6.1–6.20

Figures

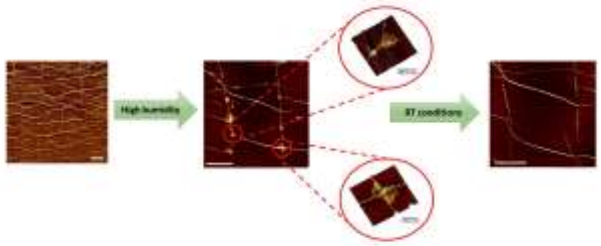

Figure 1: A self-assembled wrinkle networks for trapping or administering fluids