

Nanomechanics: Aeronautics and Aerospace Prospective

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Nanomechanics are the branch of nanotechnology that studies the behaviour of nanomaterials, nanostructures and nanosystems. The studied subjects includes nanoparticles, nanowires, nanorods, nanotubes, nanoshells, nanomembranes, nanocoatings, nanocomposites, nanofluids, nanomotors, thin films, thin foils, and NanoElectroMechanical Systems (NEMS) etc. In a broader sense, nanomechanics also include nanofabrication, nanometrology and instrumentation for characterization in nanoscale. Without the tools and methods of characterization at nanoscale, it is not possible to gain insight of the properties of nanomaterials, nanostructures and nanosystems and manufacturing processes exert great influence, sometimes, determine the characteristics of the nanoscale materials, structures and systems.

Nanomechanics are of great importance for the development of aeronautics and aerospace industry. In aeronautics and aerospace, the stringent fuel constraints for lifting payloads, the desire for increased functionality, capacity and autonomy compel the seeking for enabling technologies and continues reduction in size, weight and power consumption. Nanomechanics provide solution to the design and manufacturing of high-performance next generation materials and devices for aircrafts, rockets, space stations and planetary exploratory platforms. Actually, aeronautics and aerospace industry is one of the main driving forces of research in nanomechanics. Here, I attempt to give a brief overview of research activities in nanomaterials and nanomanufactures that are of interest to the aeronautic and aerospace applications.

The core of the nanomechanics studies the mechanical behaviour of nanomaterials, nanostructures and nanosystems. It investigates elastic and inelastic behaviour in continuum and uses atomistic/molecular approach at the nanometer scale. Using experimentally collected data and multiscale modeling, nanomechanics establishes mechanisms of deformation and failure of nanostructured materials and nanoscale structures.

Experimental study on nanoparticle's mechanical and thermal properties is very limited. Survey in this field results in a small literature. The reason may be that handling a single nanoparticle is extremely difficult. Moreover, detection of elastic and inelastic deformation at such a small scale is very challenging. On the contrary, much has been done to the direct characterization of a single nanotube and a single nanofiber. As two-dimensional nanomaterials, nanotubes and nanofibers have micron size or even millimeter size on one dimension, which makes the handling of individual nanotubes and nanofibers much easier compared to that of a single nanoparticle. Most of the research work in this direction is carried out with carbon nanotube, motivated by its extraordinarily high strength. The earlier attempts were done by variation excitation. The dynamic response of carbon nanotube used to calculate its Young's modulus. Later, with the advancement in probe-based microscope, conventional bending, tensile and compression tests were carried out at nanoscale to carbon nanotubes and other nanotubes and nanofibers of various materials. Not only Young's modulus but also tensile strength and compression resistance are measured experimentally. Limited by the resolution of probe-based microscope and the complex of the probe-sample interaction, the tested data usually contains large errors

and results from different researchers spread in a wide range. The characterization of mechanical properties of nanocoatings or thin films with nanometer thickness is mostly conducted with nanoindentation test. Fracture and fatigue responses are characterized. The results are usually reliable and consistent. Bulk nanomaterials refer to bulk solids with nanoscale or partially nanoscale microstructures. This category of nanomaterials includes nanocrystalline metals and nanoceramics. They can be manufactured by consolidation of nanoparticles or in the case of nanocrystalline metals from repeated several deformation of conventional metal ingots. At millimeter scale, these samples can be studied using conventional methods used for macro scale samples. Nanoindentation is also used for the characterization of these samples when conventional test is not possible. Comparatively, the mechanical behavior of bulk nanomaterial is well understood.

Computational models have been developed at the atomic level to address the fundamental issue of deformation at nanoscale under mechanical loading. The most studied materials are nanocrystalline metals and carbon nanotubes. In both cases, large-scale molecular dynamics (MD) is the most commonly used simulation method. Molecular dynamics (MD) provides atomic level structural information on grain boundaries of nanocrystalline metals. Simulations are commonly performed in uniaxial tension under high load and high strain rate conditions. Processes that may occur during plastic deformation of nanocrystalline metal have been proposed, including dislocation nucleation and twins at boundaries grain boundary slide, diffusion along grain boundary and triple junction, grain boundary rotation. These numerical analyses provide insight into the failure mechanism of nanocrystalline metals and are used to explain their distinct characteristics of mechanical properties. For carbon nanotubes, bonding potentials used to describe bonding and non-bonding atomic interaction of single walled carbon nanotube (SWCNT) and interlayer potentials are used to describe layer to layer interaction of multiple walled carbon nanotube (MWCNT). The failure of CNT is commonly explained by Stone-Wales defect gliding on the CNT wall. The Elasticity and tensile strength of SWCNT and MWCNT are calculated. However, the results spread in a very wide range, just like the results from experiments attempted to characterize an individual CNT.

The properties of nanomaterials, structures and systems are closely related to the manufacturing processes that produce them. Research in nanomanufacture not only deals with scaled-up, reliable, and cost-effective manufacturing of nanoscale materials, structures, devices, and systems, but also understands the mechanism of the processes and their

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influence on the materials and system responses under various loading conditions.

There are two approaches to nanomanufacture: top-down or bottom-up. Top-down fabrication reduces large pieces of materials down to the nanoscale, whereas, the bottom-up creates products by assembling atomic- and molecular-scale components. Top-down approaches allow us to use existing micro manufacturing techniques and extend its ability to produce nanoscale products. Examples include high energy ball milling and nanolithography. These techniques were developed from industrial manufacturing techniques. Bottom-up approach works on new concepts of placing certain molecular-scale components together that will spontaneously “self-assemble,” into ordered structures while bottom-up is more capable of building complex nanoscale structures and devices, it is also a time consuming process.

In the aeronautics and aerospace field, much of the research efforts in nanomanufacture is devoted to the development of nanocomposites. Nanocomposites are used to develop light weight structural materials, protective coatings, materials, high strength fire retardants, multifunctional materials and materials that of special properties and withstand extreme environment.

Like conventional composites, nanocomposites can be categorized by matrix materials: polymer matrix nanocomposites, metal matrix nanocomposites, and ceramic matrix nanocomposites. Polymer matrix nanocomposites are the most researched one, due to low cost of nanoclay (reinforcement material) and the excellent mechanical and thermal properties of polymer matrix nanocomposites. Polymer nanocomposites are also the first to be used in commercial products. For instance, nanoclay reinforced polymers are used in GM produced vans as step assist. Carbon nanotube-infused polymer composite

is now used in Zivex Matrine LRV-17 Long Range Vessel and F-35 Lightning II Joint Strike Fighter. Many methods have been described for the manufacturing of polymer matrix nanocomposites. The most popular ones includes: intercalation of the polymer or pre-polymer from solution, in-situ intercalative polymerization, melt intercalation, direct mixture of polymer and particulates, template synthesis, in-situ polymerization and sol-gel process.

The research in manufacturing of metal matrix nanocomposites and ceramic matrix nanocomposites are mainly drive by the desire of high performance structural materials required by aerospace application. Metal matrix nanocomposites and ceramic nanocomposites is much more expansive compared to their polymer counterpart. Therefore, the production of such can only by justified by the high cost of aerospace products and defense applications. Methods used for the fabrication of ceramic matrix nanocomposites include high energy ball milling, polymer precursor process, and sol-gel process. Metal matrix nanocomposites can be processed with spray pyrolysis, melt spin, electroplating, sol-gel, ultrasonic assisted rapid solidification and liquid filtration.

Carbon nanotubes are desired reinforcement materials due to its outstanding strength and elasticity. It holds promises not only for high strength light weight structural material but also for multifunction structural materials, enabled by its unique electronic and optical properties. Many attempts have been conducted to incorporate carbon nanotube into polymer, metal and ceramic matrices. Homogeneous disperse of carbon nanotube into matrix material is very challenging. Therefore, there are processes that developed especially to manufacture CNT reinforced composite. These processes include hot processing, solve thermal process, catalytic decomposition and template growth of CNT, just to name a few.