Nanoscale Solutions to Tailor Fiber Architectures for Realizing Composites with Triumvirate Properties

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Biography

I completed my Bachelors in Mechanical and Automation Engineering from Amity University, India in 2013. I joined Clemson University for my Masters in Mechanical Engineering in 2014 with an aim to constantly challenge myself to do the best. Under guidance of Dr.Huijuan Zhao and Dr.Srikanth Pilla, I started my research in Fall 2015 with a focus on development of new material architectures with tailored properties to suit targeted applications.

Overview:

Polymer composites are fast becoming the mainstay of various industries in the light of their superior mechanical properties, low density, high corrosion resistance and faster assembly. The design flexibility offered by polymer composites in terms of achieving high specific properties and light weighting is almost limitless. This freedom of tailoring material properties is what has made polymer composites the most sought out option in industries like automobile, aerospace and construction.

Motivation

Mechanical stiffness of the polymer is defined as the resistance offered to the mobility of molecular chains. Thus, higher the resistance offered (through the introduction of reinforcements), superior would be the mechanical stiffness. On the other hand, strength is the inherent property of the polymer to withstand the external stress. In case of a composite, although the reinforcements poses enhanced load bearing capability, it is the effective stress transfer at the interfacial region of the matrix and reinforcement that dictates the active strength of a composite. Conversely, toughness is defined as the ability of a polymer/composite to withstand the sudden, impact load. These triumvirate properties provide complimentary and contrasting characteristics for composites thereby leveraging them for wide variety of applications. My research aims at providing nanoscale solutions to tailor fiber surface architecture that when impregnated in polymeric matrices will yield composites with superior triumvirate properties that can be tailored according to one's application needs.

State of the Art

With the release of the Boeing 787, which is about 50 percent advanced composites, namely carbon fiber, discussion has ensued around the changes it will bring in the aviation industry [1].The use of carbon fiber reinforced epoxy by BMW to manufacture nearly 70% of their exterior frame in the i3 has translated into enormous savings in terms of light-weighting, use of less expensive water treatments and no requirement for expensive anticorrosive treatments [2,3].These examples are a testimony of the wide application base of the composites. Among the properties that composites possess, it is the stiffness, strength and toughness that most applications mandate. Hence, it is critical to design composites with superior performance in these attributes.

Intellectual Merit

The distinguishing feature of composite materials is the ability to tailor material properties to specific applications. This requires applicants to have a basic understanding of the potential sources of variability introduced by utilizing composite materials. Controlling the morphology of fibers system including nanofibers, plays a critical role in achieving the desired purpose of composite solutions with superior strength, stiffness and toughness. We propose a new material morphology called 'RODING ARCHITECTURE' that has the potential to satisfy/enhance the properties like strength, stiffness and toughness simultaneously. *What is 'Roding' architecture?* Nanomaterials possess variety of morphologies or shapes such as nanospheres, nanotubes, nanofibers, nanoboxes, nanoclusters, nanoreefs, platelets, etc. Each of these morphologies has specific purpose that they help to serve. In order to achieve superior strength and stiffness we propose addition of **'Rod'** like fibers that have the morphology similar to a rod element but possess high strength and elastic modulus. Although fibers at various scales may be considered to test our hypothesis, the most challenging length scale is the one at nanoscale which will be the focus of the research. Here we consider carbon nanotubes as 'Rod' like nanofillers since they not only have higher reinforcing efficiency but also serve plethora of additional purposes. Design of composite materials with enhanced toughening is more complex and challenging. Toughening can be induced by copolymerization [4], blending with tough polymers, plasticization or by adding special toughened additives. These methods are often a long and costly, making them less viable options when considering large scale applications. Incorporating special additives is a facile means to enhance the toughness both from property and economic points of view. All of these options aim at varying the morphology of the composite by adding an additional element, termed dampening element, which has the capability to absorb impact energy. This '**Dampening**' element plays an important role in enhancing the toughness of the composite. We propose hyperbranched polymers as a plausible option to significantly increase toughness at relatively low loading level because of their unique highly branched morphology that have the capacity to absorb energy.

Broader Impact

The goal of the research is to elucidate the concept that one can design his own composite to fit targeted application by controlling the morphology and composition of the composite materials. This concept is proved by taking one-application namely automotive body structures and by developing composite material solutions that are capable of satisfying all the requirements of the same. Just by considering one application, we have developed many viable options by controlling the material morphology. This concept when translated into large scale has the potential to transform the transportation and material industry and act as a portal of possibilities and challenges for material customization.

Research Approach

The main steps in designing composite morphologies are: design the application, finalize the application requirement categories, list different available and potential compositions and morphologies to suit the requirements, modify the morphology and composition of the composite material according to the application requirements, and perform testing to confirm the success of the material morphology. According to the above-mentioned steps, first, we chose an application that has a huge impact on the world economy as well as everyday lives of people: automotive body structures. Next, the three main categories of structural requirements were studied in detail, namely stiffness, strength and energy absorption (toughness) [5]. Available composite options and plausible morphologies have been studied in detail. Finally, samples prepared by using composites consisting of 'Roding architecture 'will be tested to perceive the influence and efficiency of 'Roding architecture' in altering the properties to suit the chosen application. In order to better understand the impact of altering the morphology of the composite material (via the introduction of 'Roding' nanofillers) on the performance of the structure, chemical, experimental and molecular dynamics simulation techniques are being employed.

Findings to Date

Nanofillers with 'Roding' architecture have been synthesized and have been introduced in epoxy through covalent bonding. Characterization techniques like Raman spectroscopy; FTIR and SEM were used to prove the altered morphology of the nanofillers. The success of nanofillers with 'Roding' architecture in changing the overall composite properties and morphology is being investigated using DSC, TGA, and Gel fraction percentage calculations. The influence of the synthesized nanofillers on mechanical properties of epoxy is being confirmed using tensile and 3-point bending tests.

Conclusions

Nanofillers with 'Roding' architecture are expected to influence the mechanical properties of any matrix into which they are incorporated. Though in this initial attempt 'Roding' architecture was proven via realizing the architecture at a nanoscale, the same can be translated into micro and macro scale to suit the mass production needs of the transportation industry. They have the potential to make the composite tougher, stronger and stiffer. The level of improvement in stiffness, strength and toughness is related to the percentage of the 'Roding' architecture present in the composite. The catch here is not to restrict ourselves to a particular morphology but to explore the opportunity to customize the composite morphology, which has the potential to revolutionize the very basics of engineering and materials, as we know them.

References

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