MULTISCALE, MULTIDISPLINARY MODELING

FOR DAMAGE TOLERANCE DESIGN OF FIBER REINFORCED COMPOSITES

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Abstract -- The use of fiber reinforce composites (FRCs), both polymer matrix based (PMCs) and ceramics matrix based (CMCs), in replace of metals has been considerably expanded in military and civil applications over the last several decades. The most recent evidence is Boeing's decision to use up to 50% (by weight) composite materials in its newest civil airplane -- Boeing 787. FRCs have long been advocated as excellent alternatives to metals that can offer major weight-savings (efficiency), better damage tolerance (longer service time with less maintenance), stronger resistance to environmental attacks (endurance), and more flexibility in component design. However, despite a huge body of literature on composite studies some key issues remain unresolved, of which the most critical ones are 1) lack of proven test methodologies, 2) no reliable durability assessment techniques, and 3) no established certification procedures to satisfy governmental regulation authorities. The primary cause is the lack of understanding of the interplay among the multiple damage processes (matrix cracking, matrix/fiber shear splitting, delamination, local fiber rupture or kinking, etc.) that co-evolve in response to environmental changes and external loading. These damage modes occur in various materials scales at different load levels and are strongly coupled to each other -- it is this nonlinearly coupled damage evolution that dominates the macroscopic composite properties. Individual mode can be and has been treated using various continuum damage mechanics (CDM) or fracture models, but progressive damage evolution including multiple modes operating against each other remains a huge challenge yet to be solved. Traditional continuum mechanics based composite theories are not likely to meet the challenge because they do not have internal material-based length scales that are critically related to damage initiation and propagation. Micro-mechanics based models (or unit-cells) have little chance to succeed by themselves either –they are too "local" to adequately respond to those damage or failure mechanisms driven by global stress field (a delamination crack in a laminated textile composite is a good example). Furthermore, in many modern composites, especially 3D integrally woven composites, there can be simply no repeating units, or even if they exist, their dimension is not much smaller than the entire composite component.

Recent development of high-resolution materials characterization methods such as TEM, SEM and AFB has enabled much improved understanding of fundamental mechanisms operating in engineering materials at various length scales ranging from nanoscale to microscale and to macroscale. The necessity of multi-scale, multi-disciplinary approaches for composite materials design is increasingly appreciated within the composite research community, evidenced by the fact that funding agencies have for recent years insisted on interdisciplinary approach to solving materials problems. The hierarchy of structural scales and their associated damage modes immediately calls for multi-scale approaches that consist of discrete methods of analysis ranging from micro-mechanical modeling to the continuum levels of mathematical prediction to complete the design process. From mechanics point of view the key issue is, how to connect results at the different length scales, and of particular interest is how damage transfers from a lower level scale to a higher one. In this study, a formulation of multiscale multi-disciplinary approach will be

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introduced and researching findings using this approach for composite damage tolerance design, as well as further improvement of this approach will be summarized.