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MULTI-SCALE CHARACTERIZATION AND FAILURE IN COMPOSITES UNDER IMPACT: A REVIEW

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Abstract:

This paper reviews recently published research on multi-scale characterization and failure in composites under impact. This article is to understand the characteristics and mechanisms of damage initiation and failure under impact. It is useful to model the processes associated with fracturing encompassing over all the scales. A proper understanding of the micromechanisms of failure is crucial for macroscopic characterization. This paper will provide significant insight into the details of the effects of the complex composite on the material response. It can also be useful for providing insights which can be used in developing more approximate numerical models. This study will open the door to many new angles of research and researchers on multi-scale characterization and failure of composite materials moving forward.

Key Words: Damage Initiation, Micro mechanisms, Numerical Models & Composite Materials

Introduction:

While proper material characterization requires a lot of experiments, often preliminary scoping and design requires only broad statistical bounds of the material parameters. Thus, the presented micromechanical material characterization procedures are not intended to replace experiments, but rather supplement the often expensive and difficult to obtain data required for even the most basic material scoping and initial design processes.The geometrically accurate RVEs use for specific stress concentration and damage initiation and propagation analysis. Finite element modeling of the mesostructure over the distribution of characterizing measurements is automated, and various boundary conditions are applied [1]. Most problems in the natural sciences and engineering involve many different scales. Composite materials are critical for modern technology and have been extensively using in various engineering applications for years. Applications include, though not limited to, space, aerospace, automobile and sports industries [2]. Composite materials may present high stiffness and damping, improved strength and toughness, improved thermal conductivity and improved permeability and unusual physical properties such as negative Poisson’s ratio and negative stiffness inclusions [3]. In which the manufacturing of many products requires low cost, fast cycle time and a wide range of material properties [4]. Fracturing in composite materials is inherently a multi-scale phenomenon, which is often initiated via cracking around micro-scale defects, voids and then manifested as macrocracks and delaminations leading to catastrophic failures. This study is to understand the characteristics and mechanisms of damage initiation and failure under impact; it is useful to model the processes associated with fracturing encompassing over all the scales. A proper understanding of the micromechanisms of failure is crucial for macroscopic characterization. Since micromechanical characterization is available for arbitrary stress/strain states, this technique can be used to determine the complex fault surface. For example, the combined shear and compressive failure are known to have a strong coupling effect. Iterating through various combinations can produce the damaged surface. Most composite materials are multiscale in nature, i.e. the scale of the constituents is of a lower order than the level of the structure. The length scales range from the fiber size whose dimension is measured in microns to the individual plies in laminates whose thicknesses are measured in fractions of millimeters to the laminates themselves whose sizes are measured in millimeters, e.g. 30-40 mm [5]. For most of the linear analyses of composite structures, instead of taking the individual constituent property and geometrical distribution into consideration, homogenized material properties are used [6]. However, when higher accuracy is required, we need to refer directly to the microscopic scale. Then multi-scale modeling is required to couple macroscopic and microscopic models to take advantage of the efficiency of macroscopic models and the accuracy of the microscopic models [3]. The laminates then form parts of composite structures whose sizes are measured in meters. For fiber-reinforced composites, the overall hierarchy of multi-scale analysis is composed of micro-level (fibers and matrix), mesolevel (plies), macro-level (laminated composite) and structural level. Since all damage and failure modes initiate in the micro-level, damage and failure criteria are applied to micro-level stresses and strains [7]. Besides analytical methods, numerical finite element methods were also used to model the composite RVE explicitly by using appropriate periodic boundary conditions [8].

Materials and Method:

This section describes the materials and methods used for processing and characterizing the composites under different investigation. It presents different methods of approach, the details of the tests related to the structural analysis, multi-scale characterization, and failure of various composites prepared for the current research. Multi-scale modeling is a promising analysis for modeling failure in composites. The key characteristic of this study is that damage accumulation is explicitly modeled by directly resolving and numerically evaluating the microstructure response at each material point of a structural simulation [9]. A similitude analysis is used to investigate damage initiation and propagation in layered structures. Tests on plates of varying sizes have shown that scaling procedures can be applied accurately to predict the response of larger or more representative structures.A micro-meso-macro and structural scales combined approach would allow a comprehensive evaluation of material failure responses [10]. These multi-scale methods are addressedin different stages hierarchy analyses shown in the figure below. These steps consist of some detail procedures as follows.

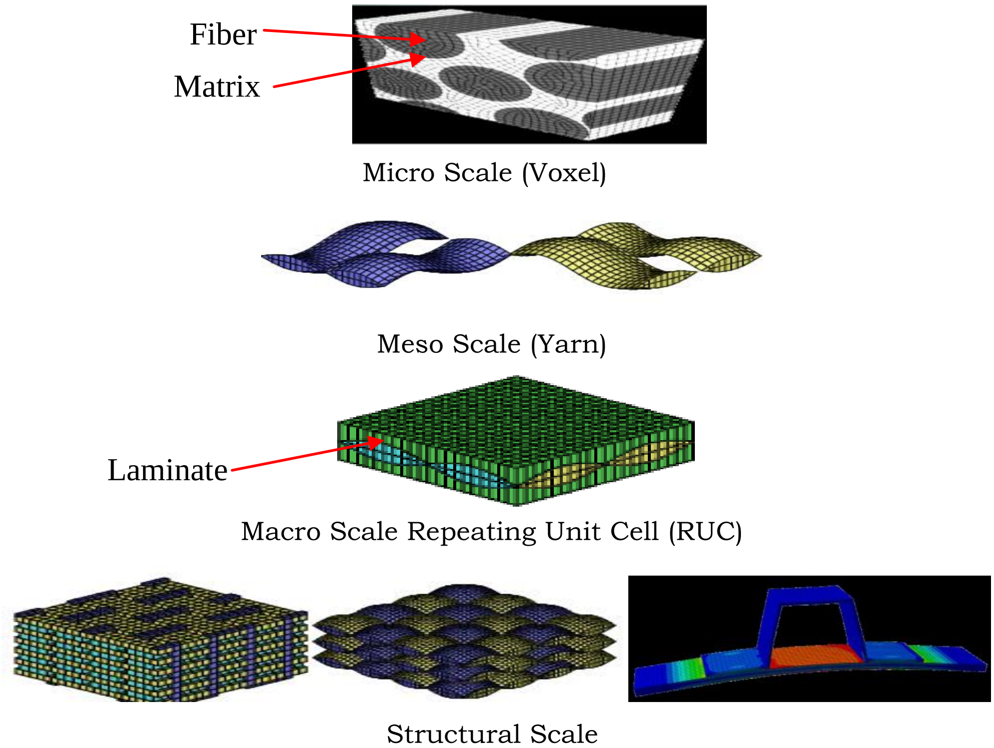

Figure 1: Different stages hierarchy analysis of composites

Micro-Scale Analysis (Micro-Mechanical Analysis): Microscale approaches are applied to predict the transversely isotropic unidirectional laminate properties. Both finite element and analytical models have been developed to predict the elastic and strength properties of composites and their response to different mechanical loadings [3]. To investigate failure mechanisms in composites at the microscopic stage, such as delamination, matrix cracking and fiber breakage, Direct Numerical Simulation (DNS) is applied, which is a numerical approach based on full microscopic modeling of a structure and is solely applied to the region of interest [11]. A representative volume element of the yarn microstructure consists of matrix material and a random arrangement of fibers. The orthotropic elastic-plastic behavior of laminated composites under tension by including separated compliance matrices for the pure resin and fiber-resin combination regions, and accounting for the plastic and strain rate behavior of the resin [12].

Meso-Scale Analysis (Plies): In this approach, the meso level has fiber bundles composed of many micro level composites. The mesoscale simulation is intended to predict the response of each constituent and their contribution to the global behavior. The meso-scale model can help to identify the local stress and strain distribution, and the damage initiation and progression of each constituent. It can also contain features of the complicated internal architecture and give maximum information on geometry. The main feature of meso-scale finite element models is a realistic mesh of the fiber bundle geometry, homogenized local properties of the impregnated tows representing realistic local fiber volume ratios and bundle orientations, as well as the accurate definition of boundary conditions at the coupon level [6,13].

Macro-Scale Analysis (Lamination Analysis): The purpose of macro-scale modeling approaches is to analysis the response of large structures using based on the results obtained from a meso-scale homogenization. Many macro-scale composite models are available in commercial finite element codes [8, 13].

Structural Scale Analysis (Finite Element Analysis): The most common method used for non-trivial geometries is the Finite Element Analysis (FEA). A general background to the FEA will not be detailed here, but it is sufficient to say that it is a method for discretizing a larger structure into smaller elements whose behavior can be modeled using understood logical relationships [14]. The FEM in all its forms has been successfully applied to composite materials. The most general case of the FEA is full 3D analysis, making use of the three-dimensional constitutive relationships. The finite element analysis has no difficulty in allowing for the inherent anisotropy within a lamina.

Impact Damages in Composite Materials:

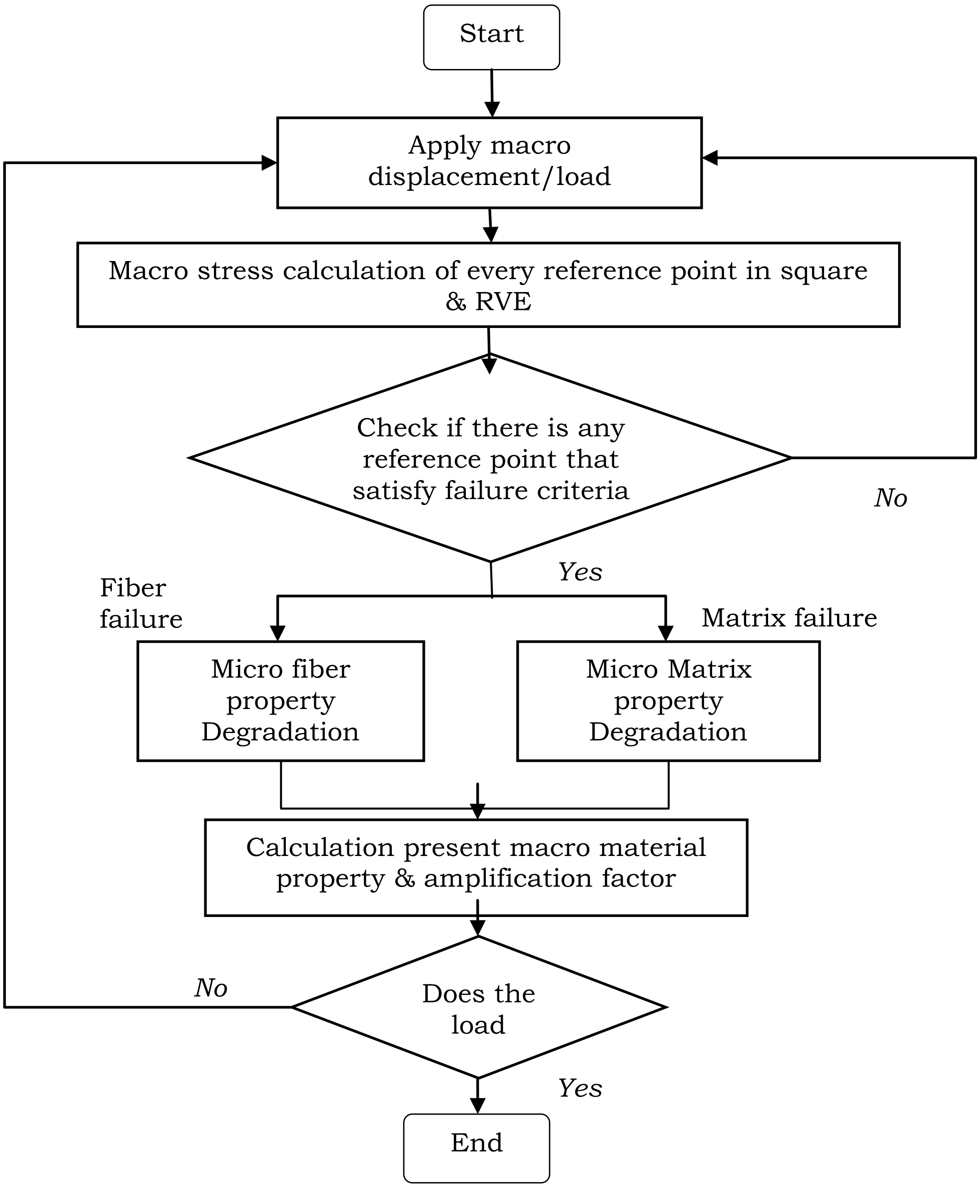

Figure 2: Flowchart for damage determination and evolution process

Damage take place only on principal material planes of many composite materials. Therefore, the damage parameters can be limited to those affecting the normal and transverse principal material directions. In the case of unidirectional composites, the coupling of shear and normal damage is caused due to micro-cracks, fiber breaks and fiber-matrix deboning as in the above formulation. Damage modeling is done by using failure criteria for every single failure mode. These failure criteria can be distinguished into three groups, failure criteria based on strength-based failure criteria, damage mechanics and failure criteria based on fracture mechanics [15]. Some materials may not experience a linear coupling between the two damages. Therefore, weave plane composites under shear experience stiffness reduction due to matrix cracking and fiber-matrix deboning with little to no fiber breakage resulting in only a small amount of reduction stiffness in the fiber directions. Micromechanics can be used to isolate the damage evolution in the constituents (fiber and matrix) [1]. The statistical shows that the accurate stress and strain concentration tensors, constituent damage can be predicted using the methodology in [16]. Damages in the composite are different from those in metals. Composite failure is a progressive accumulation of damage, including complex failure mechanisms and multiple damage modes. The impact on the structure has a dynamic nature, and it is necessary to take into account the effects arising from inertia and spreading voltage wavesof the material. Often the material response is highly nonlinear, and large deformations occur [17]. Understanding damage processes in the composite media is essential to analyze mechanical characteristics only found in the failure modes of composite structures, i.e. material degradation. In the damage process, firstly, we have to define an efficient continuum damage mechanics model considering the concept of multi-scaled components. Types of failure mechanisms

- ✓ Ply cracking/splitting
- ✓ Delamination
- ✓ Sublaminate buckling
- ✓ Crushing
- ✓ Kink band formation
- ✓ Localization of failure
- ✓ Interactions between mechanisms

Results and Discussion:

The energy absorbed during impact process is often very large. This energy is mainly dissipated by a combination of matrix damage, fiber fracture and fibre-matrix debonding. These facts lead to the significant reductions in the load-carrying different capabilities in such structures [18]. Modeling various yarn architectures confirm a better structural reinforcement to resist impact loads. The addition of designed yarn architectures or formations; weaves and braids, to the structures has significantly improved the impact damage resistance or the damage tolerance of textile composites. In the multi-scale modeling, a multi-scale aspect often arises because most of the general impact damage occurred in the local region. Damage composites exist at the microscale level, while impact loads are applied at the structural level. Because it needs to consider a multiscale approach for that kind of problem.

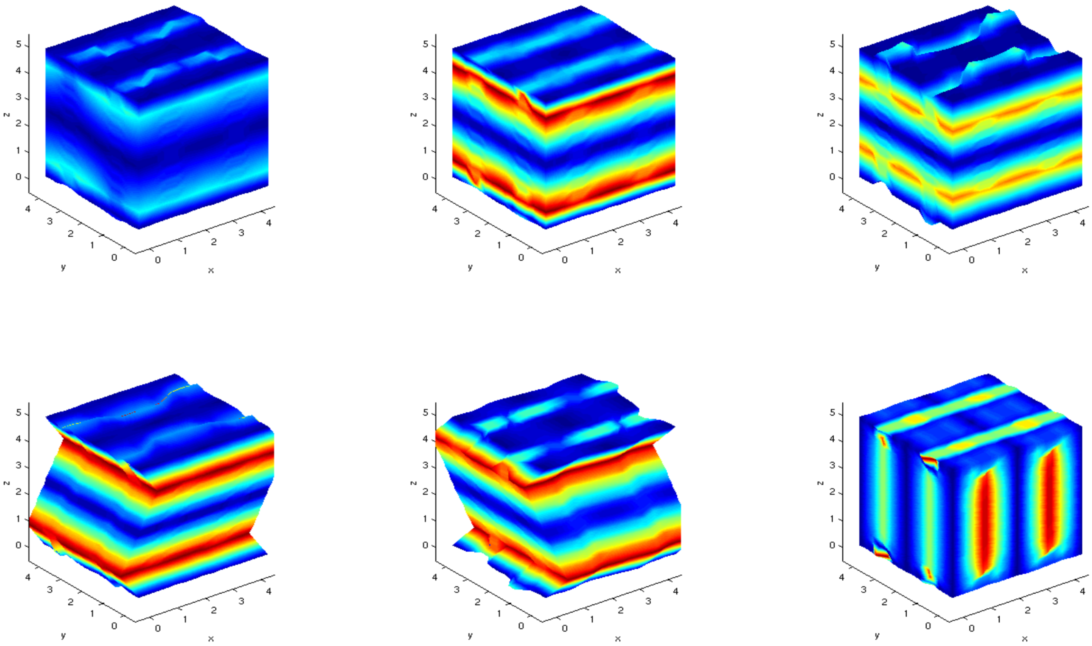

Figure 3: Characteristic of displacements for the unit cell [19].

The colours represent the magnitude of the displacements under the application of a unit macrostrain, with blue representing zero displacements, and red representing maximum displacement.

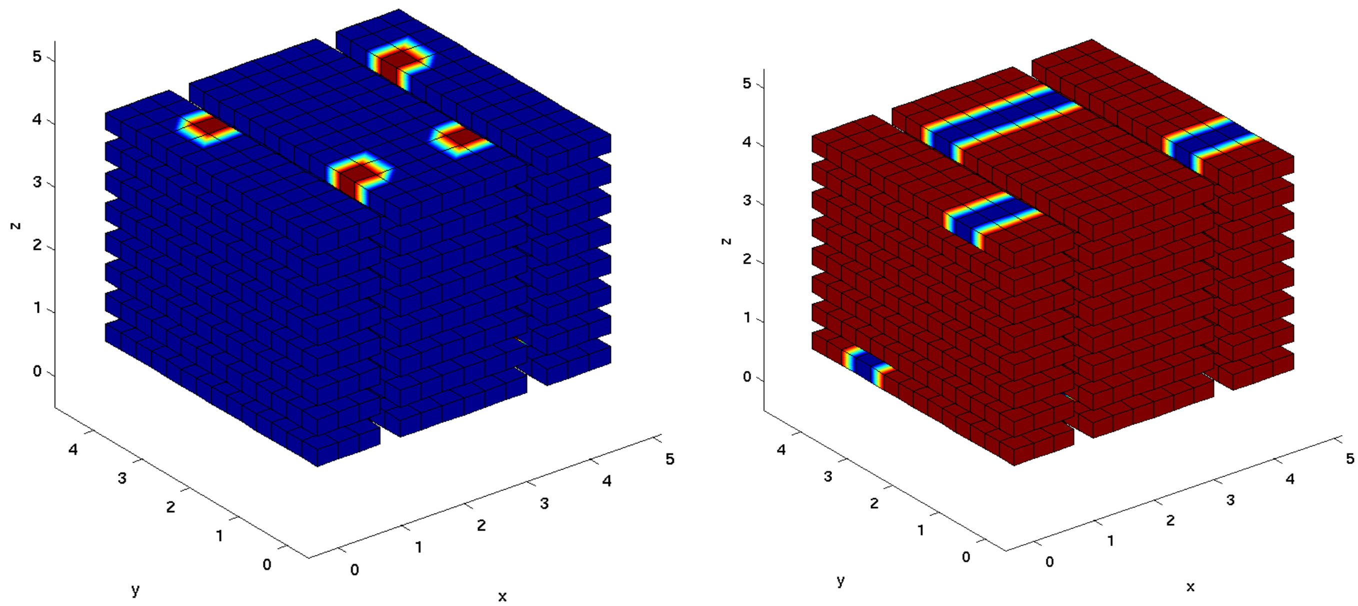

Figure 4: Distribution of damage during tensile loading (at macro-scale load 210-220MPa) [19].

To understand how the damage is affecting the unit cell, the damage distribution contour plot, Figure 4, shows us that at a load of 220MPa, the location of the damage is concentrated in the parts of the weft tow that not directly under the binder tow. This failure mode results in the failure of a localized region of the tow, but in such a way that reduces the ability of the tow to transfer load from one side of the unit cell to the other [19]. The model uses a finite element representation of a repeating unit cell and uses the asymptotic homogenization method to both localize the macro-scale loads and to determine averaged properties over the unit cell. The damage is modeled using a continuum damage model resulting in stiffness degradation. In the tow, the damage is modeled as orthotropic, using independent failure criteria in orthogonal directions. In the matrix, the damage is modeled as isotropic, using the von Mises failure criteria. This model is capable of making useful and accurate predictions on the behavior of the composite with knowledge of the weave and is an efficient method of gathering micro-scale damage response information to be homogenized and used in macro-scale finite element modeling [20].

Conclusion:

This paper reviews recently published research on multi-scale characterization and failure in composites under impact. In the first problem, the dynamic characteristics of fabric structures are analyzed by the concept of impact damage resistance or impact damage tolerance considering the geometrical shapes. Damage composites normally exist at the micro-scale level, while impact loads are applied at the structural level. Because it needs to consider a multi-scale approach for that kind of problem. The newly proposed multi-scale failure criterion achieves the whole processes of damage identification, determination, and evolution, which helps in understanding the failure mechanism of composites further. This study will open the door to many new angles of research and researchers on multi-scale characterization and failure of composite materials moving forward.

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References:

1. Shawn E, A Brown, T Briggs. (2013). A Micro to Macro Approach to Polymer Matrix Composites Damage Modeling: Final LDRD Report.SAND2013-10666, 1-38.
2. Savvas Triantafyllou, Structural Mechanics, ETH.Zurich, https://www.ethz.ch/content/specialinterest/baug/institute-ibk/structural-mechanics/en/people/former-staff/savvas-triantafyllou.html (Accessed July30, 2016).
3. Xiwen Jia, Zihui Xia, Bohong Gu, (2015). Nonlinear numerical predictions of three-dimensional orthogonal woven composite under low-cycle tension using multiscale repeating unit cells.International Journal of Damage Mechanics. 24(3) 338-362.
4. Abdu Y A. (2016). Implementation of Lean Manufacturing: A Case Study at ASK Automotive Private Limited (India), Int. J. Adv. Res. Sci. Technol. 5(1), 556-562.
5. Barbero EJ. Finite Element Analysis of Composite Materials. Boca Raton, FL: CRC Press; 2008.
6. C. C. Mei, and B. Vernescu. “Homogenization Methods for Multiscale Mechanics,” World Scientific, New Jersey, 2010.
7. Voyiadjis, G., Pekmezi, G., and Deliktas, B. (2010). "Nonlocal gradient-dependent modeling of plasticity with anisotropic hardening." International Journal of Plasticity, doi:10.1016/j.ijplas.2010.01.015, 1335-1356.
8. Chen, S., and Feng, B. (2011). Size effect in microscale cantilever beam bending." Acta Mechanical, doi: 10.1007/s00707-011-0461-7, 291-307.
9. https://www.deepdyve.com/lp/elsevier/experimental-and-computational-investigation-of-progressive-damage-txltOihd4O (Accessed June 28, 2016).
10. Johnston, J. and Chattopadhyay, A. (2015). Effect of Material Variability on Multiscale Modeling of Rate-Dependent Composite Materials. Journal of Aerospace Engineering, doi:10.1061/(ASCE)AS.1943-5525.0000488, 04015003.
11. C.A. Buizer, (2010). Low-velocity impact analysis of composite plates with a buffer-zone interface between micro- and macro-modeling. Master external internship MT 10.04, Seoul National University.
12. http://www.eng.ox.ac.uk/solidmech/research/micromechanics-and-materials-modelling. (Accessed January 18, 2016)
13. Hosseini-Toudeshky, H., Farrokhabadi, A., and Mohammadi, B. (2012). "Implementation of a micro-meso approach for progressive damage analysis of composite laminates." Structural Engineering and Mechanics, doi:10.12989/sem.2012.43.5.657, 657-678.
14. O. C. Zienkiewicz, R. L. Taylor, and J. Z. Zhu. The Finite Element Method: Its Basis and Fundamentals. Elsevier Butterworth-Heinemann, 6th edition, 2005. ISBN 978-075066320-5.
15. S. Zheng and C.T. Sun. (1995). A double-plate finite element model for the impact-induced

delamination problem. Compos. Sci. Technol., 53:111, 8.
16. E. Barbero, G. Abdelal, and A. Caceres, (2004). A micromechanical approach for damage modeling of polymer matrix composites. Comp. Struct., 67,427-436.
17. Kreculj, D.; Rasuo, B. (2009). Impact Problem on Aircraft Constructions from Composite Materials. Technics, Mechanical Engineering, Belgrade, 6, 1-8.
18. D Kreculj, B Rašuo, (2013). Review of Impact Damages Modelling in Laminated Composite Aircraft Structures.Tehnički vjesnik 20(3), 485-495.
19. Amit Visrolia, (2013). Damage tolerance and multi-scale simulation of novel 3D composites, A thesis submitted for the degree of Doctor of Philosophy, University of Bath.
20. Nilsson, E. (2005). Residual Strength Prediction of Composite Laminates Containing Impact Damage, Master Thesis, Linköping University.
21. Y Abdulfatah Abdu, T M Shafi'i, S U Musa, U Shamsu, H Alhassan, U. K. Gupta (2015). Use of Polymer Matrix Composites for Conventional Steel Drive Shafts: A Study, ELK Asian Pacific Journals. ISBN: 978-81-930411-4-7, 1(30):179-186.