Effective Elastic Property of Randomly Damaged Composite Laminates

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Introduction

The production of composite laminates is subjected to large variability because of unavoidable fabricating imperfections, operational factors, inaccurate experimental data etc. [1, 2]. In the conventional deterministic analysis of structures, the variations in the system parameters are neglected and mean values of system parameters are used in the analysis with some factor of safety. During operational period matrix cracking is one of the predominant modes and early stage of damage in composite laminates. To account for the effect of such damage, normally effective elastic properties are calculated and thereby it is used to calculate global structural response such as natural frequencies, deflection etc. We have developed an analytical framework to analyse the effect of spatially random matrix cracking damage in composite laminates [1].

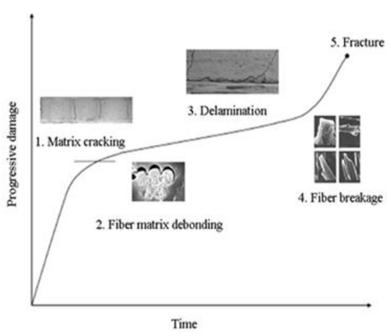

Figure: Occurrence of progressive damage in composites

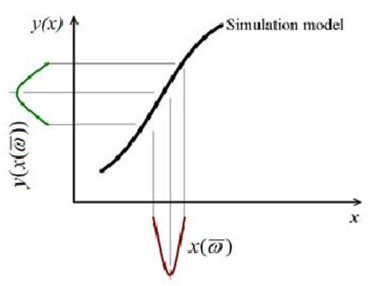

Figure: Description of the system showing stochastic input parameters and output response

Key Idea

A novel concept of stochastic representative volume element (SRVE) has been proposed to account for the spatially random variation of material properties and crack density. In this approach, each representative unit (structural elements) of the structure are considered as stochastic, instead of considering homogenized properties of a conventional representative volume element throughout the entire domain. In traditional approach, typically a single RVE is considered, wherein one RVE represents the entire analysis domain. In the present approach we ensure to account for all the information pertaining to randomly varying matrix cracking damage and stochastic material properties in the analysis.

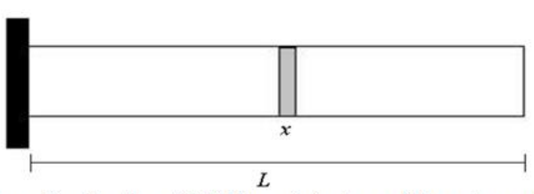

Figure: Consideration of SRVE for analyzing the spatially random system (Cantilever beam with varying structural attributes along the length)

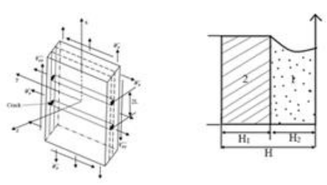

Figure: (a) Laminated composite containing cracked ply (b) One quarter of laminated composite unit-cell

Results and discussion

Results are presented for stochasticity in micro-mechanical and macro-mechanical properties, separately. From the probability density function plots, it can be noticed that response bound is more for micro-mechanical analysis compared to macro-mechanical analysis while same degree of stochasticity is considered in both the cases. This observation can be explained by the cascading effect showing that consideration of stochasticity in more elementary level of the multi-scale hierarchy increases the response bound of output parameters at the global level.

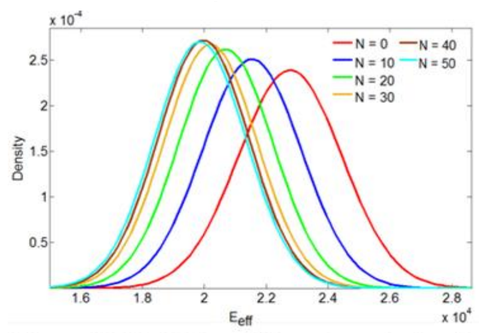

Figure: PDF plot for different crack density

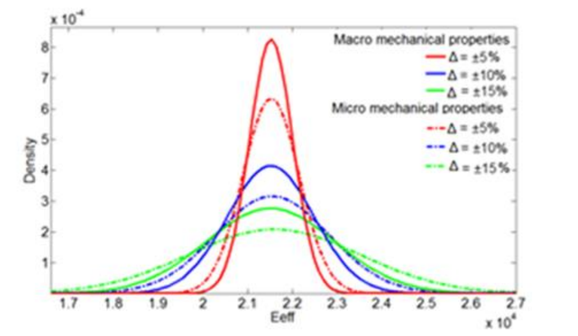

Figure: PDF for different degree of stochasticity

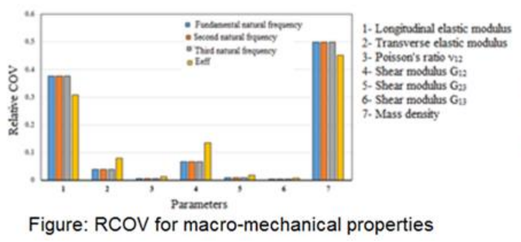

Figure: RCOV for macro-mechanical properties

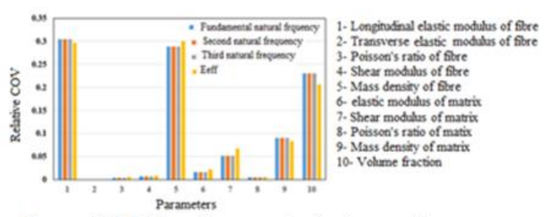

Figure: RCOV for micro-mechanical properties

Sensitivity of different micro and macro-mechanical properties are shown above using the measure of relative coefficient of variation (RCOV). Such analysis is crucial to determine the relative influence of different input parameters to the output quantity of interest. The effective elastic property of damaged composite laminate can be used to characterize different global responses [1] of the structure as shown below.

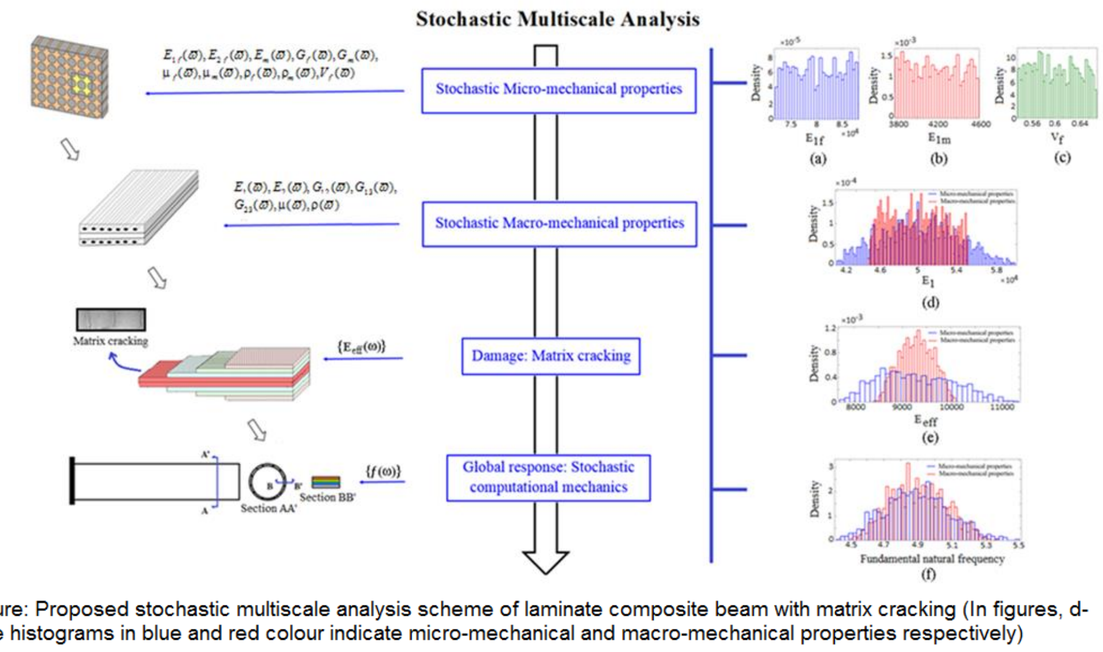

Figure: Proposed stochastic multiscale analysis scheme of laminate composite beam with matrix cracking (In figures, d-f the histograms in blue and red colour indicate micro-mechanical and macro-mechanical properties respectively)

Conclusion

This investigation deals with developing an analytical framework for effective elastic properties of damaged composite laminates including the effect of spatially varying material properties. Such effective elastic properties can be used in efficiently characterizing different global responses of the structure (such as natural frequency, deflection etc.). Sensitivity analysis is carried out to quantify the relative importance of different input parameters. Future research will be carried out to quantify the influence of such spatially varying damages and material property distribution in the global dynamic responses of structure based on the proposed SRVE based approach.

References

[1] **Naskar, S.**, Mukhopadhyay, T., Sriramula, S. & Adhikari, S. (2017). Stochastic natural frequency analysis of damaged thin-walled laminated composite beams with uncertainty in micromechanical properties. *Composite Structures*,160 312 – 334

[2] Dey S**.**, **Naskar S**.**,** Mukhopadhyay T., Gohs U., Spickenheuer A., Bittrich L., Sriramula S., Adhikari S., Heinrich G. (2016) Uncertain natural frequency analysis of composite plates including effect of noise – A polynomial neural network approach, *Composite Structures*, 143 130–142