Multi-Scale Modeling of 2D and 3D Carbon/Carbon Composites: A Review

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ABSTRACT

In the present scenario composite materials have found wide verity of applications in the field of aerospace. There are many different types of composite which are used for different applications. Carbon fiber carbon matrix composites are used in high temperature applications. C/C composites can withstand a temperature of up to 2500K It is also very important to know mechanical properties of these C/C composites. In this work, different papers have been studied to understand the different modeling methods for finding the mechanical properties of 2D and 3D C/C composites. 2D C/C composites have good properties in only two directions such as x and y directions but not in z-direction, whereas 3D composites possess good properties in all the three directions. In this paper importance has been given to strength and stiffness of C/C composites. Finally it is found out that there are lots of papers which talk about elastic properties and damage modeling of 2D and 3D orthogonal composites. There are very limited papers available for analysis of mechanical properties and damage modeling of 3D woven composites.

Keywords: Carbon-Carbon composites, elastic properties, multi-scale modeling

INTRODUCTION:

Now a day's carbon fiber carbon matrix composites are widely used in aerospace industries because of its high corrosion resistance, superior mechanical properties, low coefficient of thermal expansion and also better frictional performance. There has been lot of research to know the microstructural characteristics and mechanical properties of 2D and 3D C/C composites. 2D C/C composites possess good properties only in in-plane stress field but not in out of plane stress field, whereas 3D C/C composites possess good properties in both the types. In this literature main concentration is given to 3D C/C composites but also on some of the 2D C/C composites which concentrate on out of plane properties.

DISCUSSION:

Shigang et al. [1] developed the numerical simulation based on uniaxial tensile test, and showed that manufacturing defect such as voids in the fiber yarn has greater influence on the performance of 3D orthogonal C/C composites. Further Shigang et al. [2] developed the multi scale model to analyse the damage behavior 3D orthogonal C/C composites and predicted the strength and stiffness with variation of temperature up to 2500K. His results shows that, young's modulus of C/C composite started decreasing after 1500K, in-plane tensile strength started decreasing sharply after 1900 K.

Drach et al. [3] proposed the numerical modeling of C/C composites with Nano textured matrix and 3D pores of irregular shape, and by approximating 3D pores shape into ellipsoidal shape found out the effect of pores on the properties of C/C composites. Rajaneesh et al. [4] estimated Elastic modulus of 3D C/C composites using image based finite element simulations and experiment by considering defects such as big voids cross section distortions and misalignment in bundles.

Liu et al. [5] used 3D pixel method for developing damage model based on post failure shear behavior of 3D weave C/C composites fasteners under several load angles. Results show that strength of the specimen decreases with increase in load angle and damage of X and Z tows are major concern in shear loading.

Wen Shyong Kuo et al. [6] examined the failure behavior of 3D woven C/C composites and reported from compression test that failure occurs due to bending fracture of axial yarn and when loaded in the transverse shear, the induced failure is position-dependent.

Dian et al. [7] studied the high temperature compression properties and failure mechanism of 3D needled C/C composites and concluded that composite shows non-linear and plastic failure feature after 6000 C. The major damage patterns are tearing of 900 oriented fibers and shear failure of 00 oriented fibers. Further Dian et al. [8] stated that modulus and bend strength of 3D needled C/C composites decrease significantly with increasing temperature due to severe carbon oxidation. Below 5000 C, damage of the composite is in the form of matrix cracking, 900 fiber/matrix debonding and 00 fiber fracture, whereas above 5000 C due to oxidation of carbon, interfacial bonding between fiber and matrix is decreased significantly.

Yingjie et al. [9] developed 2D needled C/C composite which is based upon analysis of RVE models of hierarchical microstructure of composites. The laminate consists of z direction needles with lamina of randomly oriented short fibers, unidirectional lamina in x and y direction. Further concluded that increasing the thickness ratio of short-chopped fiber felt to unidirectional fiber ply can slightly improve the shear modulus G12 but elastic modulus E11 and shear modulus G23 are both decreased.

Meng et al. [10] proposed the hierarchical scheme based 3D needled C/C composite meso model for prediction of effective elastic properties. Results showed that increasing the short fiber aspect ratio improves the composite properties and larger needling density is advantageous for out of plane properties but not for in plane properties.

Hassan et al. [11] made comparison study damage and fracture resistance of 2D and 3D composites and concluded that 3D C/C composites possess lower shear strength, higher ultimate deformation in shear, much higher fracture resistance and weak interface characteristics compared to 2D C/C composites. Hatta et al. [12] compared the fracture behavior between 2D and 3D C/C composites and concluded that tensile strength of 3D C/C composites is much lower than that of the 2D C/C composites. Further also predicted that interfacial bonding of 3D C/C composites was much weaker compared to 2D C/C composites.

Venkat Rao et al. [13] studied effect of different architecture such as 3D orthogonal, 3D plain woven and 4D in plane types on mechanical properties of C/C composites. According to the studies different architecture had major effect on the effective properties and also consideration of defects such as debonding and voids played major role in knowing the mechanical properties.

A Sudhir et al. [14] developed multi scale simulation strategy based on numerical homogenization method to find effective properties of 8 harness satin weave C/C composites. Further stated that numerical homogenization method is suitable any traditional architecture with very little modification to the modeling technique.

J Xie et al. [15] proposed an anisotropic elasto-plastic damage constitutive model for 3D needled C/C-SiC composites by considering innovative plastic potential function containing variable parameters to consider anisotropy of plastic deformation in each material direction. Further stiffness degradation was characterized by considering exponential damage state function based on the Weibull statistical distribution of the material strength. Further J Xie et al. [16] established a methodology to predict the scattered mechanical properties of the 3D needles C/C composites in which random distribution, uncertainty, density and size effect of needles where considered.

Pailhes et al. [17] developed constitutive damage model which lies within the frame work of continuum damage mechanics to describe the mechanical behavior of 3D C/C composites. Effective compliance tensor increment was used to describe the various process involved in nonlinear behavior under compressive loading.

Tsukrov et al. [18] presented the procedure to consider irregular shaped pores present in the carbon-carbon composites formed during infiltration treatment. The pores where analyzed using numerical method and effect of the pores was considered to calculate the effective properties of c/c composites.

Xujiang et al. [19] presented a strategy for generating RVE by considering microstructures of randomly distributed pores in c/c composites by combining the modified random sequential adsorption algorithms and the microstructure information obtained from substantial PLM images. FEM based on numerical homogenization method has been used to understand the effect of volume fraction and aspect ratio of pore inclusion on effective elastic properties of c/c composites.

Hong bin et al. [20] presented RVE of c/c composites with fibers oriented in four different directions to discuss the effect of graphitization on residual stresses generated. Based on computational meso mechanics model, thermal residual stress distribution of the material was obtained for different graphitization temperature, cooling rate and interface stiffness using a FEM.

W.H Xie et al. [21] proposed a new constitutive model named general weighted flexibility matrix (GWFMM) material model for the analysis of structures made of bi-modulus orthotropic material in complex 3D stress state. According to the paper maximum tension stress of bi-modulus model increases by 81% when compared with single modulus model. Further maximum relative errors of of GWFMM model is 12.3% with most of the relative errors are within 5%.

Rajaneesh et al. [22] used the X-ray tomography to construct the microstructure of 4D in-plane C/C composites and constructed the finite element mesh including the defects such as distortions in bundles and voids. Effective elastic properties have been estimated using asymptomatic homogenization method by considering periodic boundary conditions. Further matrix cracking was modeled by degrading the properties of matrix and also modeled the interface damage by introducing frictional cohesive surface and concluded that contribution of fiber reinforcement in damage is very less due to interfacial debonding.

Xinxing Han et al. [23] carried out multi scale computational homogenization of 2d c/c woven composites from micro scale to mesoscale using data-driven self-consistent clustering analysis using different solvers for different scales and verified the results by comparing with FEA and experimental results

Golovin et al. [24] developed a phenomenological model for c/c composite deformation by considering homogeneity, high anisotropy of mechanical characteristics and different ways of resistance to extension and compression.

Xin Liu et al. [25] Developed two step homogenization method using Mechanics of Structure Genome (MSG), to find the effective properties of woven composites. MSG is used to obtain point wise anisotropy due to woven microstructure.

Song Yu et al. [26] conducted numerical analysis for calculating macro-mechanical properties of 3D woven orthogonal composites using Voxel based FEM and compared it with multi scale FEM and which is on the basis of surface and interior RVE and digital image correction test.

Bassam Said et al. [27] developed iterative multiscale modeling approach for nonlinear mechanical analysis of 3D woven composites by considering domain decomposition. Generally material loses its periodicity during manufacturing, which has been considered while developing this model.

Sohail Ahmad et al. [28] developed the analytical model based on volume averaging method to predict the elastic and strength properties of 3D woven hybrid and non-hybrid composites on the basis of two different geometric models.

Gang Liu et al. [29] proposed the multi scale progressive failure simulation model of 3D woven composite, using modified Puck criteria for fibre yarn and parabolic yield criteria for matrix. Effective elastic properties, failure strength and damage evaluation process are predicted and compared with the experimental results.

Yang Liu et al. [30] used X-ray micro tomology images to reconstruct representative volume cells of 3D orthogonal woven composites by considering local details of yarn geometry. In comparison with the idealized model, reconstructed model showed better agreement of strength and stiffness results when compared with experimental results.

Dai S et al. [31] used two different models namely unit cell finite element meso model and mosaic macro model to conduct numerical analysis of 3D woven composites to predict the elastic properties and damage progression behavior of two weave types namely orthogonal and angle interlock.

Trenton Rick et al. [32] compared three different methods of modeling strategies for predicting effective properties of 3D woven composites, which contained two FE models namely triply periodic boundary condition (TP) and in-plane periodic boundary condition (IPP) model and Multi-scale Generalized Method of Cells (MSGMC). All the three model showed almost similar results in in-plane properties, but only TP and MSGMC methods predicted the out of plane properties, and there was some deviation in the results when compared to each other.

CONCLUSION:

In most of the papers analysis of composites is done using multi scale modeling since to know the behavior of 2D and 3D composites, detailing is required in both micro and meso-modeling. There are many papers on finding the mechanical properties and damage modeling of 2D and 3D orthogonal (without locking of x and y direction fibers) C/C composites. But there are very limited papers which talk about strength and stiffness of 3D woven C/C composites in which z-direction fiber is considered to lock x and y direction fibers.

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