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A REVIEW OF PROGRESSIVE DAMAGE ANALYSIS AND FATIGUE LIFE PREDICTION FOR DEGRADED E-GLASS FRP MATERIAL

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***Abstract**— A detailed review of different types of numerical analysis and experimentations of the degraded E-glass FRP material with considering various parameters for progressive damage analysis (PDA) and fatigue life of material-model to ensure about how long maintain its properties. The environmental parameters affect the material properties during its use. Even though degraded material have remaining useful life after degradation during service conditions. The analysis presented by different researchers is useful to predict fatigue life of degraded material and to save the cost of material. During the analysis of degraded material various properties of material other than parent material has been selected using area separation method in FE model. Various researcher are presented fatigue life simulation with the help of sudden and gradual material properties.*

***Keywords**— Material degradation, Damage parameters, Life prediction, Fatigue, Finite element analysis*

I. INTRODUCTION

This Paper is introducing about composite materials analysis and experimental methods. Composite materials are widely used in engineering and most preferable, because of their light weight and some mechanical properties. A combination of more than two materials is known as composite materials. Composites are design materials with properties better than those of predictable materials (metals, ceramics, or polymers).

In now days, fatigue failure is most associated with failure mechanism in composite materials during the service condition, due to their limited life or some environment effect and some chemical reaction there are some degradation is extent to the materials. The literature contains the notable review on composite material and some degradation arises during the service condition.

M.Naderi and A.R. Malingo developed a 3D model and applied in ABAQUS through hashin failure criteria and material degradation rule for testing a fatigue life of carbon-epoxy and validated with experiment data. shokrieh and lessard also developed a 3D model of finite element method to pretend the experiment data of progressive damage model and also proven energy criteria rule to predict that fatigue life of layup.

A statically model is developed to predict the unidirectional composite laminate exposed to multiaxial loading based on generalized residual material degradation rule Diao, L.B. Lessard, and M.M. Shokrieh [12]. Papanikos & Tserpes [17, 18] is suggested to fatigue damage model in numerical way for carbon epoxy FRP material for stress analysis, fatigue analysis and degradation rule. Many researcher have investigated on stress analysis, fatigue analysis and fatigue life prediction on composite materials. Ever J. Barbero, Mehdi Shahbazi [35] also indicated that progressive damage analysis in ANSYS APDL. An algorithm is set for GFRP materials under cyclic loading and also provide algorithm for PDV simulation under cyclic loading and FE implementation and model validation describe Eliopoulos, E.N. and T.P. Philippidis [34]. To understand the progressive damage analysis for fatigue life and degradation rule for degraded FRP material the researcher has developed the numerical analysis and experimental model. The main objective of the present study is to review of the fatigue life prediction and progressive damage analysis for FRP material.

II. PROGRESSIVE DAMAGE MODELLING

In a Progressive damage modelling the damage has been started initially and slowly damage take place in materials. In PDA fatigue analysis and material degradation, these two steps are more important with damage initiation. Ever J. Barberoa, Mehdi Shahbazi [35] is perform PDA, the user needs two important steps: properties of the different material and material model. These two steps are describe in damage initiation and damage evolution law. With the help of Hashin criteria, Progressive damage analysis includes four nodes for damage initiation like fiber tension, fiber compression, matrix tension, matrix compression. For a laminate sheet lay-up static strength is less than its cyclic loading. Progressive damage initiation means as the number of cycle passes the material properties is gradually deteriorated. There are some material failure criteria and there's rule are indicate in table [15]. Tsai-Hill et al. and hashin have suggested that Static failure criterion for composite laminated failure have planned to model composite laminated failure. Fatigue failure criterion can be obtain from static strength and fatigue strength static criteria.Fig.1 show a different strength and fatigue ratio at composite lays up. Wei Lian, Yao, Weixing [13] is presented that fatigue have different characteristic longitudinal, transverse, and in shear by FEA (Finite Element Analysis) method and pretend the fatigue damage evolution and predict the fatigue life of different composite lay-up. Damage evolution law describe that how material can be degraded at each cycle passes. There are two types evolution in ANSYS: (1) stiffness reduction & (2) continuum mechanics. When the failure criteria has been satisfied then stiffness reduction is applied neither continuum mechanics are used, these uses only the PDA methods not only information about damage evolution.

M. Naderi, A.R. Maligno [15] states that generally, in material properties degradation rule, it has two types

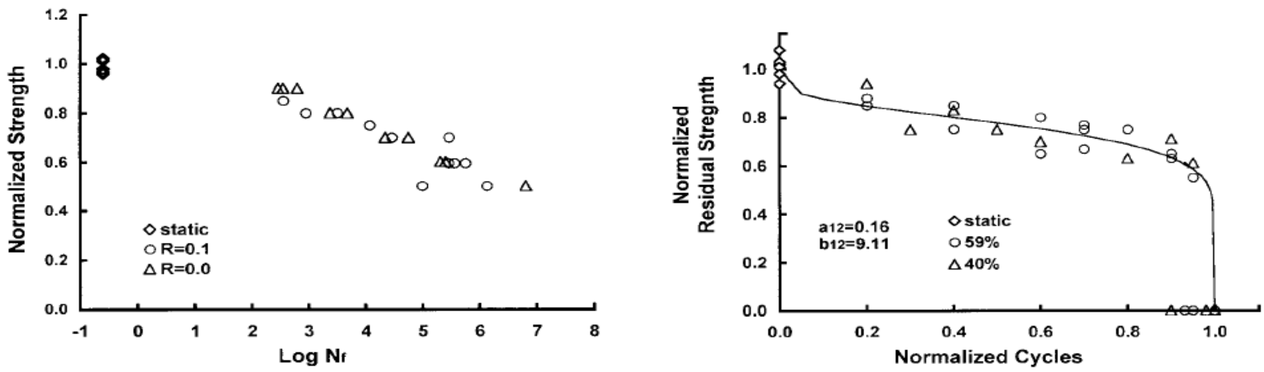

Figure 1 Experimental data of static strength and fatigue life of lamina under in-plane shear loading with deferent stress ratios [12, 14]

(1) Sudden degradation, (2) gradual degradation. When component fails under the failure criteria and its property shortly decreases and disables to carry a load and cracks initiate it called sudden degradation. When a component carry a load and did not withstand a load during cyclic loading and cracks are initiate slowly till the final breakage take place, it's called gradual degradation. As the no. of cycle increases component can be degraded on each cycle. Sudden degradation rules are condensing in table 1 [15]. The residual strength and stiffness of unidirectional ply below random stress ratio's equations to obtain fatigue life [15].

$$\frac{R(n,\sigma,r)-\sigma}{Rs-\sigma} = \left[1-\left(\frac{\log(n)-\log(0.25)}{log(N_f)-\log(0.25)}\right)^{\beta}\right]^{\frac{1}{\alpha}}$$

$$\frac{E(n,\sigma,r)-\frac{\sigma}{\varepsilon f}}{Es-\frac{\sigma}{\varepsilon f}} = \left[1-\left(\frac{\log(n)-\log(0.25)}{\log(N_f)-\log(0.25)}\right)^{\alpha}\right]^{\frac{1}{\gamma}}$$

If the material fails under fiber tension and compression loading the catastrophic failure take place and materials breakage and all properties is "virtual" zero value [14,15]. Due to the some precaution zero value cannot be used [20]. In gradual degradation rule the material properties like strength and stiffness are gradually degraded due to the repeatedly applied load on cyclic loading. In this study, for the fatigue life the generalized material properties degradation technique are proven by Shokrieh, M.M. and L.B. Lessard [15, 16]. Progressive fatigue damage model can be executed with the help of mathematical code and combination experiment data of static and fatigue loading. The problem is declared and numerical coding is done through the commercial software ABAQUS & ANSYS APDL and also generated the result as the experiment data shows [20, 35].

III. *NUMERICAL PROCEDURE FOR MODEL DEVELOPMENT*

Numerical procedure is the set of algorithm for solving a problem well posed mathematical problems. Stress analysis and increase fatigue life prediction FE model the geometry using commercial software like ABAQUS and ANSYS. To set an algorithm for a progressive damage model and fatigue life prediction, write a subroutine or programing language are accessible in commercial software. In subroutine random material properties are required for continue an algorithm, the researcher may have work on Gaussian distribution function and it's distinct in ABAQUS which define initial solution independent state variable to implement for materials Ever J. Barberoa, M Nadnderi [20, 35].

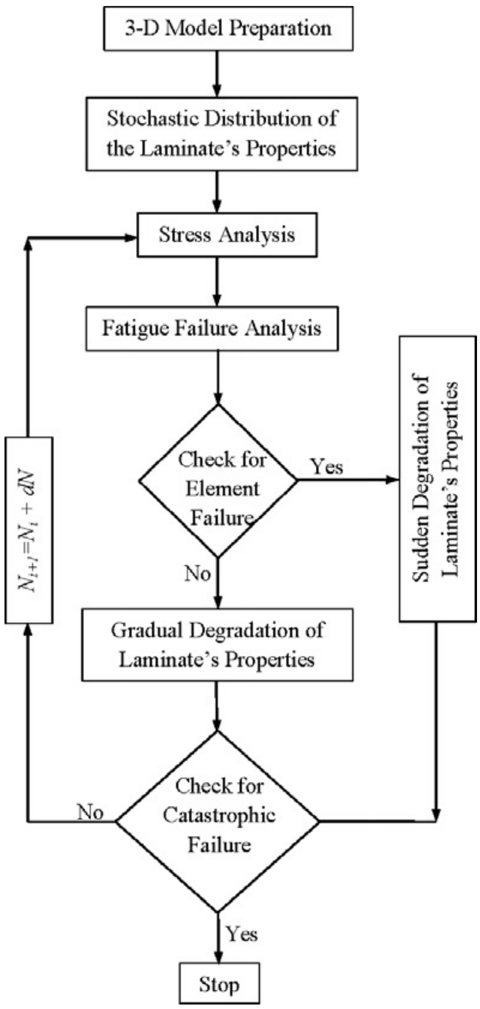

Figure 2 Flow chart of PDA damage model [20]

The progressive damage modelling is applied through commercial software ABAQUS and ANSYS. Above figure shows flow chart for the PDA damage model for composite material. UMAT is define for the subroutine programme for analysis and in programing all material control points define material properties and there characteristics. Jacobian matrix are used for the stress and solution dependent variables values which is increase at the end of the increment and other subroutine USDFLD it state that material filed variable and it depends on material point of element for which material definition is includes by Ever J. Barberoa, M Nadnderi [20,35]. W.Van paepegem, J.Degrieck, P.De Baets [27] presents damage analysis of carbon fibers and matrix fiber reinforced exposed to static tension loading with numerica analysis. I. Koch, M. Zscheyge [10] developed a method for used prediction and visualization of degraded behaviour of composite laminate under tension fatigue loading. The result are define on a 3D behaviour of stiffness reduction and damage evolution of the element. Xiaoxue Diao, Larry B. Lessard [12, 14] is presented the fatigue life prediction of composite laminate imperilled to multi-axial loading. This model is also used un-axial loading to experiment data for fatigue behaviour. Nenad Stojkovic, Radomir Folic [24] also research on use of single parameter on a numerical model to find a stiffness degradation of the element on various load level and therefore, reduce the effort of the experiment for the purpose of each parameter independently. Vahid Ghaffari Mejlej [19] has to be work on remaining to predict the fatigue life and material property degradation of randomly oriented under laminate at various stress ratio. Various energy are used for finding the material behaviour via VUMAT in subroutine. For obtain high prediction value it's depend upon stiffness and strength reduction on the basis of stress method. In these method to see the result used of tiny model because of the more collectively and consistency in predicting fatigue life. J. Bienias, H.De̜bski [3] present a numerical analysis of damage composite materials with matrix reinforced and carbon fiber on a static tension loading. To validated numerical analysis, experiment are conducted for the strength test and stiffness reduction.

IV. *EXPERIMENTAL PROCEDURE*

M. M. Shokrieh, Xiaoxue Diao [12] has developed the fatigue life prediction model for cross fiber laminate at different angle on a component under cyclic tension loading condition.it also adding damage model in this study, difference to traditional damage rule palmgren and miner's rule are sensitive to the loading history and capable of distinguishing between high–low and low–high loading sequences. E. Pach I. and J.P. Ipin [22] developed experiment model to find the fatigue life of the composite material under continuous load cycle and various loading condition on his presented work. Due to higher cost of the testing component the testing a material is much more expansive, therefore they developed a fatigue machine for the composite at a low expanse and easy to manufacture. Its major feature are law cost, dependability and small dimension. R.J.Huston [8] work on repeated tension fatigue test on unidirectional carbon epoxy and test result achieved from strength and stiffness model. They carried out fatigue test on a range loading so that result could be matched with damage predicted by the strength model. Mehdi Nikforooz, John Montesanob [21] has to be work on fatigue test under different angle ply laminate at area temperature and also stiffness degradation was investigated and compare with the glass epoxy. M. Abo-Elkhier Hamada, AA El-Deen [1] developed an experiment model analysis and it was conducted experiment on fatigue loading to define the parameter and the material are used for the experiment was GFRP laminate. The experiment result shows the parameter providing the fatigue behaviour of composite laminate. M.A. Badie, E. Mahdi, A.M.S. Hamou [33] was work on a both experiment and analysis on stiffness of the composite material drive shaft. They investigated on various angle ply and assembling sequence of shaft. Different design method are used for the FE analysis to finding the mechanical behaviour of their shaft. These experiment I only studied on assembling sequence, stiffness, and fiber angles. W.R. Broughton, M.R.L. Gower, M.J. Lodeiro [4] evaluate experiment studied on different measurement technique with digital image correlation and multi fiber Bragg grating sensor for this measurement. These study aim Constant amplitude of GFRP and fatigue loading condition on open hole tension fatigue behaviour of GFRP laminate and amplitude loading. Constant amplitude ratio conducted on r max/r min and test ratio for two more stress level. Xiaoxue Diao, Larry B. Lessard [12, 14] was work on experimental work of fatigue behaviour and also used uniaxial fatigue loading for testing the material. Residual material property degradation are define the fatigue behaviour of composite materials and also studied on stress ratio and fatigue failure of FRP material. Priscilla Rocha Vieira, Eliane Maria Lopes Carvalho [40] was achieve a satic test and evaluate the modulus of elasticity. They considered glass fiber which are used in building or construction work and finding the fatigue behaviour. Jayantha A. Epaarachchi, Philip D. Clausen [6,7] is presents and debate fatigue damage model of GFRP under step loading. They expressed work on constant amplitude and step loading developed by the previous authors. The model was tested on each single data and that experiment data are good agreement with result.

V. CONCLUSIONS

From the review of the literature it has been observed that the progressive damage analysis and experimental study of the degraded E-Glass/epoxy composite materials, the fatigue life has been increase if the environmental effect and some other factor like chemical reaction, due to loss of significant properties in service condition is decreases. From the present study it can be identified that degraded sheet can be used further time in service condition and it also uses failure criteria and material degradation rule in the subroutine programmed in ANSYS APDL or ABAQUS subroutine can be measure the progressive damage of the FRP sheet for damage initiation. Different types of laminates sheet [90°, 45°, 30° 0°] can be measure from the numerical study and Experimental procedures, it can showing that 0° plies have better stiffness, strength, and fatigue life. PDA can be predicting the stiffness reduction and process damage parameter to do, but it can’t be predicting the crack density.

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