Fatigue Prediction of Unidirectional Composite Materials with Different Fiber Angles

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***Abstract*— Fibrous Composites are finding more and more applications in aerospace, automotive and naval industries, because of their particular strength. Investigating mechanical behavior under dynamic loads to replace these materials is very important. In the present paper, Study Fatigue properties of Composite material by investigating fatigue behavior of its components. So, to achieve this purpose, firstly, modeling and Fatigue Analysis of glass fiber (E) and matrix (epoxy) in separate case by using Finite Element Software (Ansys). After that, can approach S-N curve of unidirectional fibrous composite under axial tension loading with stress ratio R=0.1. Finally, comparisons of the finite element results of Ansys and the experimental data based on fatigue testing that results are satisfactorily in good agreement with each other. Thus, extend S-N Curve of composite based on three point bending fatigue and obtain fatigue damage diagrams and study effect of fiber angle on the fatigue damage of unidirectional fibrous composite materials.**

Keywords- Fatigue; Fiber Angle; Fatigue Damage; S-N Curve.

I. INTRODUCTION

Composites material to weight ratio have high strength and hardness in corresponding fatigue life. Composite materials are non-homogeneous and anisotropic, so their behavior compared to homogeneous materials such as metals and isotropic in much more complex. Because of this complexity is that different types of damages, interaction between them and the different growth rates of these damages can occur in composite materials. Most important modes of failure are [1]:

1. Fiber Failure
2. Matrix Cracking
3. Gaps in the matrix
4. Fiber buckling
5. The connection failure between fiber and matrix
6. Separation Layers

In order to use more efficient of composite materials, damage model and the fatigue life prediction methods need to be improved constantly.

According to the classified of fatigue damage criteria, damage models and fatigue life prediction methods can be divided into four general categories:

Macroscopic scale of fatigue strength criteria, Criteria based on residual strength, Criteria based on residual stiffness and Criteria based on the actual damage mechanisms [2].

Most of the residual stiffness models presented is not valid at all three stages of stiffness degradation, especially, if it is related to the ultimate failure [3]. In approximation of the residual stiffness, fatigue failure occurs when the module reaches its critical level that it is defined differently by many researchers. Therefore, to simulate the ultimate failure, tensile properties of matter must be involved. On the other hand, destructive testing to determine the remaining strength of each layer should be done. Thus, many samples must be tested in a number of loading cycles. Since the samples are not completely the same, must be used the distribution in the result tests and determine destructive behavior of residual strength. Therefore, the statistical parameters are very important and necessary to obtain S-N curves [4].

Experimental Studies effects of adhesion of fiber and matrix on the fatigue behavior of carbon fiber and composite material of epoxy / glass are represented that fatigue performance is improved by increasing the surface characteristics and also, Quality of adhesion between fiber and matrix influence on the fatigue behavior of reinforcing both brittle polyester and plastic polypropylene [5].

II. FATIGUE PROPERTIES OF COMPOSITE COMPONENTS

A. Fatigue properties of matrix under tensional loading with R=0.1

Mechanical properties of resin and matrix in this article are according to the table 1.

Table1. Mechanical properties of used matrix [6]

Environment conditions		Process	Weight ratio
Moisture	temperature		
48%	24	15h at T60	100:34

Experimental specimen fatigue testing of matrix is shown in Fig. 1.

Fig. 1 Experimental specimen [7]

According to testing conditions and axial loading, after simulated specimen with define loading in finite element analysis of Ansys, attained S-N curve by using critical node data of results file. Comparing to available experimental results that shown in Fig. 2 [6, 8, 9].

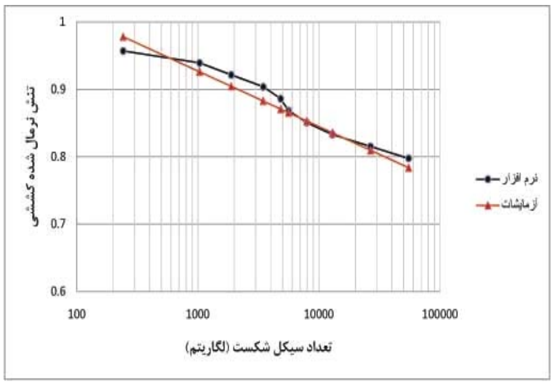

Fig. 2 S-N curve of matrix under tension loading with R=0.1

B. Fatigue properties of fiber under tensional loading with R=0.1

Mechanical properties of fiber are almost equal in steps of before and after combination composites, so in this article used E-glass of unidirectional with 92145 standard of manufacture's company named Cs-inter glass that details are written in Table2.

Table2. Mechanical properties of fiber [6]

X(MPa)	ν_{12}	G_{12}(GPa)	E_{22} (GPa)	E_{11}(GPa)
2400	0.25	29.2	73	73

According to testing conditions and axial loading, after simulated specimen (cylinder shape) with define loading in finite element analysis of Ansys, attained S-N curve. To develop S-N curves and results realization, compare it to available experimental results that shown in Fig. 3 [6, 8, 9].

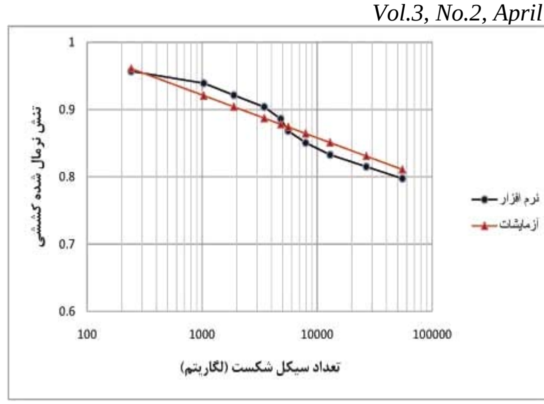

Fig. 3 S-N curve of fiber under tension loading with R=0.1

III. Fatigue Properties of Composite Materials

To determine critical nodes, should be performed static analysis with a minimum of two loading before fatigue analysis.

This is obviously that discussed two different kinds of subject in relation to composite components and its connections.

1. Stress concentration factor: because the fibers in matrix caused to stress concentration in all direction but with different value.

2. Adhesion between matrix and fiber quality: assumed that adhesion between matrix and fiber is perfectly in this research to obtain reliable results and very close approximation to actually results [9].

A. Fatigue properties of composite material under tensional loading with R=0.1

The measures recommend in the standard and compliance with dimensional requirements, part of geometry as is described in Table.3 and shown in Fig.4.

Table3. The dimensions of experimental samples [13]

$T_{(tab)}$	$t_{(Specimen)}$	Lay Up	Θ	W	L_{tab}	L_T
5	1.9	$[0]_8$	90	12.7	90	350

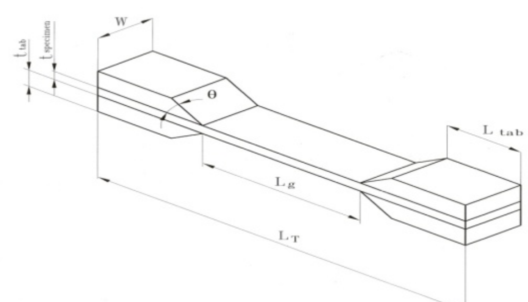

Fig.4 Experimental geometry of the longitudinal properties of composite [13]

According to the testing conditions and axial loading, after simulated specimen with define load in the finite element analysis of Ansys, attained S-N curve by using critical node data of results file that shown in Fig.5 and in order to compare the results, available experimental data as shown in Fig.6 [10-12]

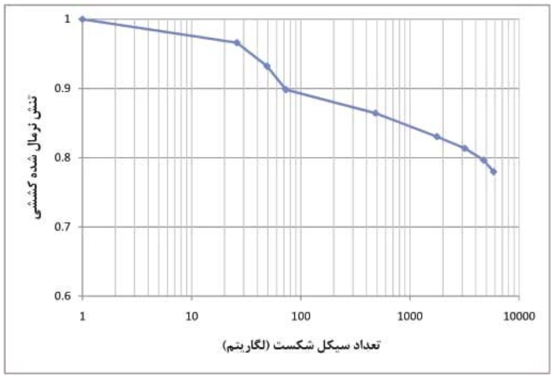

Fig.5 S-N curve of composite material under tension loading with R=0.1 based on Finite element analysis

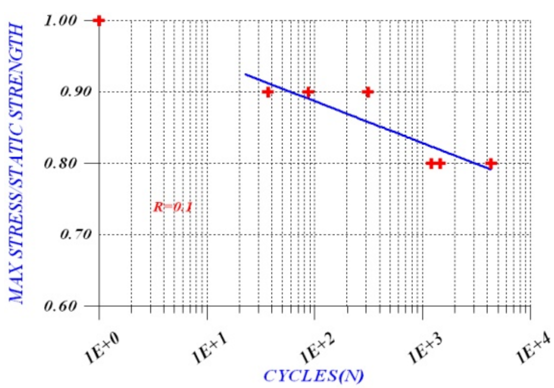

Fig.6 S-N curve of composite material under tension loading with R=0.1 based on experimental data [6]

B. FATIGUE PROPERTIES OF COMPOSITE MATERIAL UNDER TENSIONAL LOADING IN THE TRANSVERSE DIRECTION WITH R=0.1

Spectrum of characteristics is in the Table.4 for the tensile test. The results of this section are extracted, as you can see S-N curve in Fig.7.

Table4. The dimensions of experimental samples [6]

$t_{(tab)}$	$t_{(Specimen)}$	Lay Up	θ	W	L_{tab}	L_T
5	1.9	$[90]_8$	90	25.4	35	200

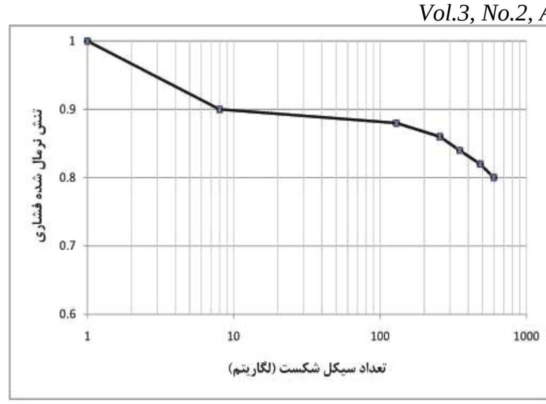

Fig.7 S-N curve of composite material under tension loading in the transverse direction with R=0.1 based on Finite element analysis

IV. SIMULATION OF THREE POINT BENDING FATIGUE TEST

Loading is one major input to the finite element based fatigue analysis. Loading information can be obtained by using a number of different methods such as three points bending that used in this investigation are one of the most popular fatigue tests. The dimensions of samples and configuration of three point bending fatigue test are presented in Table 5 and Figure 8, respectively.

Table5. The dimensions of experimental samples

$t_{(Specimen)}$	Lay Up	W	L_T
1.9	$[0]_8$	50	300

Fig.8 Three points bending testing fatigue machine [14-15]

In according Fig. 8 the boundary conditions for the system are obviously that simply supported at the both ends of piece and the load attached at the center of piece.

A. RESULTS AND DISCUSSION

Maximum's displacements are in the middling of specimen amount of 16.7 mm and two free ends of specimen upward in the same size. Static analyzed in finite element model in the same conditions and stress contour show in Fig.9 based on Von Misses Criterion.

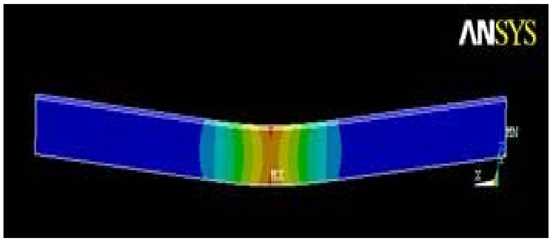

Fig.9 Stress contour based on Von Misses criterion [10, 13]

By several analyzed in finite element codes (APDL) can draw force variations in terms of displacement (Fig.10)

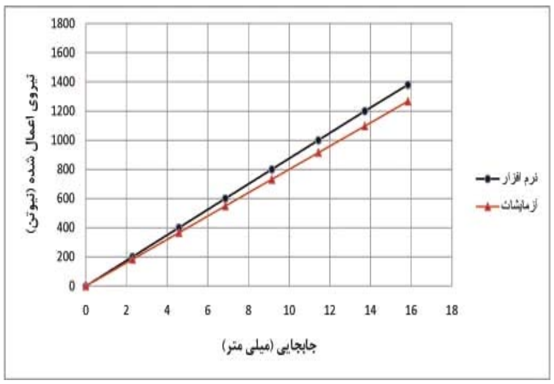

Fig.10 Force variations in terms of displacement

B. 4-2 Fatigue Properties of model under 3 point bending load

Simulate all of conditions in Ansys software and obtained S-N Curve of Composite materials by writing a new macro to fatigue analysis in P method that shown in Figure 11 [15-17]

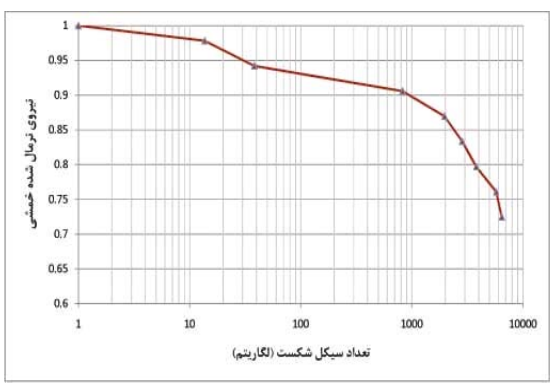

Fig.11 S-N curve of composite material under three point bending fatigue

V. Effects of different fiber angles on the fatigue life of composite

In this case, obtained S-N Curve of unidirectional composite with different fiber angles (zero, 30, 45, 60 and 90 °) as shown below under the two kinds of loading such as axial tension and comparison load and reported the results.

A. Fatigue properties of composite material with different fiber angles under axial tension loading

It is obviously that by increasing fiber angles caused to decrease fatigue life of composite material based on Fig.12. Thus, the highest fatigue life is associated composite with zero degrees of fiber angle and the lowest is associated with 90 degrees of fiber angle in the same working conditions.

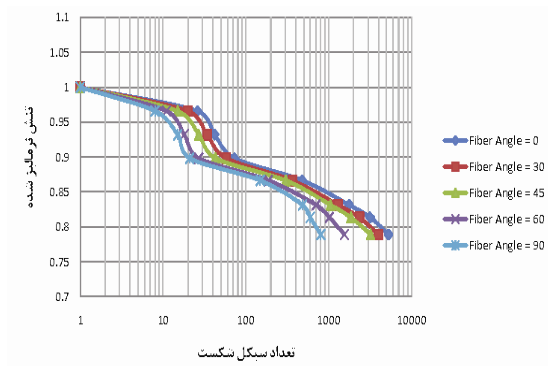

Fig.12 S-N curve of unidirectional composite with different fiber angles under axial tension loading

B. Fatigue properties of composite material with different fiber angles under axial compression loading

It is obviously that by decreasing fiber angles caused to increase fatigue life of composite material based on Fig.13. Thus, the highest fatigue life is associated composite with 90 degrees of fiber angle and the lowest is related to zero degrees of fiber angle in the same working conditions.

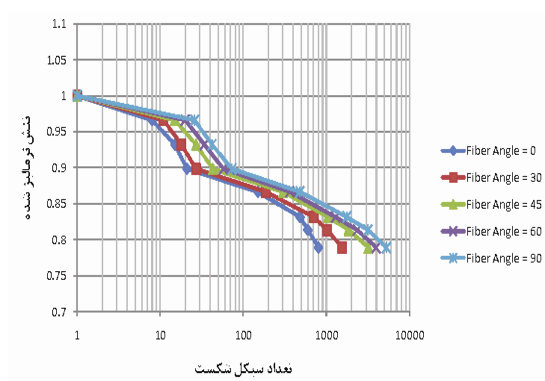

Fig.13 curve of unidirectional composite with different fiber angles under axial compression loading

VI. Fatigue Damage for Composite Materials Based on Model Results

At this stage, after modeling and simulate real conditions based on environmental laboratory. Use workbench software to fatigue Analysis and with respect to the fatigue life contour of model, by assuming fatigue durability factor $K_f = 0.92$ and used Goodman's theory and S-N method was predicted that show critical node of maximum damage on the contour [18-19].

A. Fatigue Damage of Model Under Axial Tension Loading in the Fiber Direction

The maximum fatigue life of model under certain loading is about 1220 cycles and the minimum is about 253.1 cycles that presented in the contour by red color at Fig.14 and Fig.15

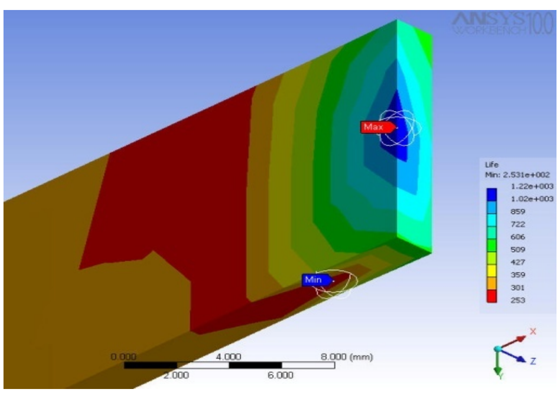

Fig.14 Fatigue life contour of composite under axial tension load in the fiber direction

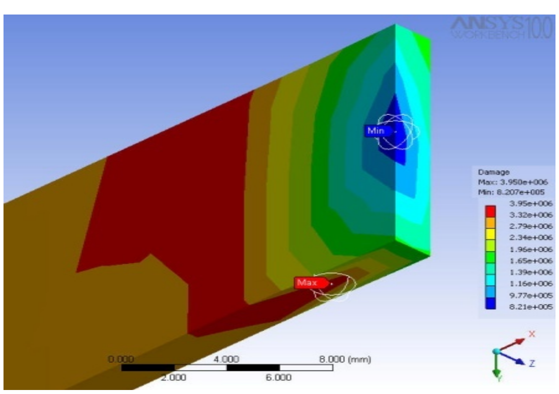

Fig.15 Fatigue damage contour of composite under axial tension loading in the fiber direction

B. 6-2 Fatigue Damage of Model Under Axial Tension Loading in the Transverse Direction

The maximum fatigue life of model under define loading is 856 cycles and the minimum is 70.4 cycles that presented in the contour by red color at Fig.16 and Fig.17

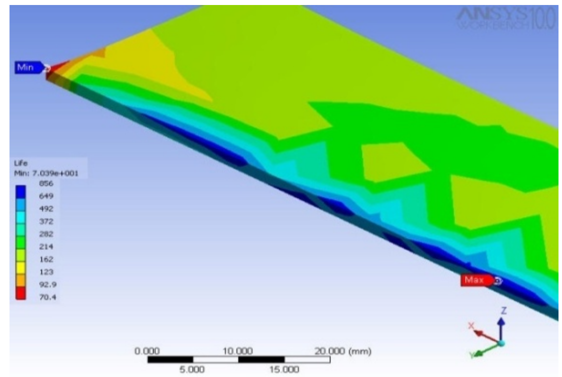

Fig.16 Fatigue life contour of composite under axial tension load in the transverse direction

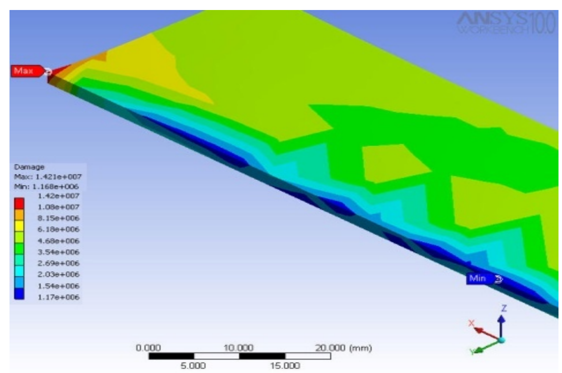

Fig.17 Fatigue damage contour of composite under axial tension load in the transverse direction

VII. Conclusion

Increasing fiber angle cause to decrease tensile and increase compressive ultimate strength in unidirectional composite materials. On the other hand, under axial tensile loading during fatigue life of composite materials with fiber angle of zero degrees is highest and is lowest with fiber angle of 90 degrees. Therefore, under axial compressive loading during fatigue life of composite materials with fiber angle of zero degrees is lowest and is highest with fiber angle of 90 degrees. However, using of unidirectional composite with fiber angle of 45 degrees under combination loading involve of tensile and compressive axial loading is most optimal choice.

To increase efficient in different conditions such as Environmental, working and …. , use of layered composite with fiber angle of zero and 90 degrees is better than unidirectional composite with fiber angle of 45 degrees. In this case, number of layers, thickness and …. are effective parameters on the fatigue life of materials.

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